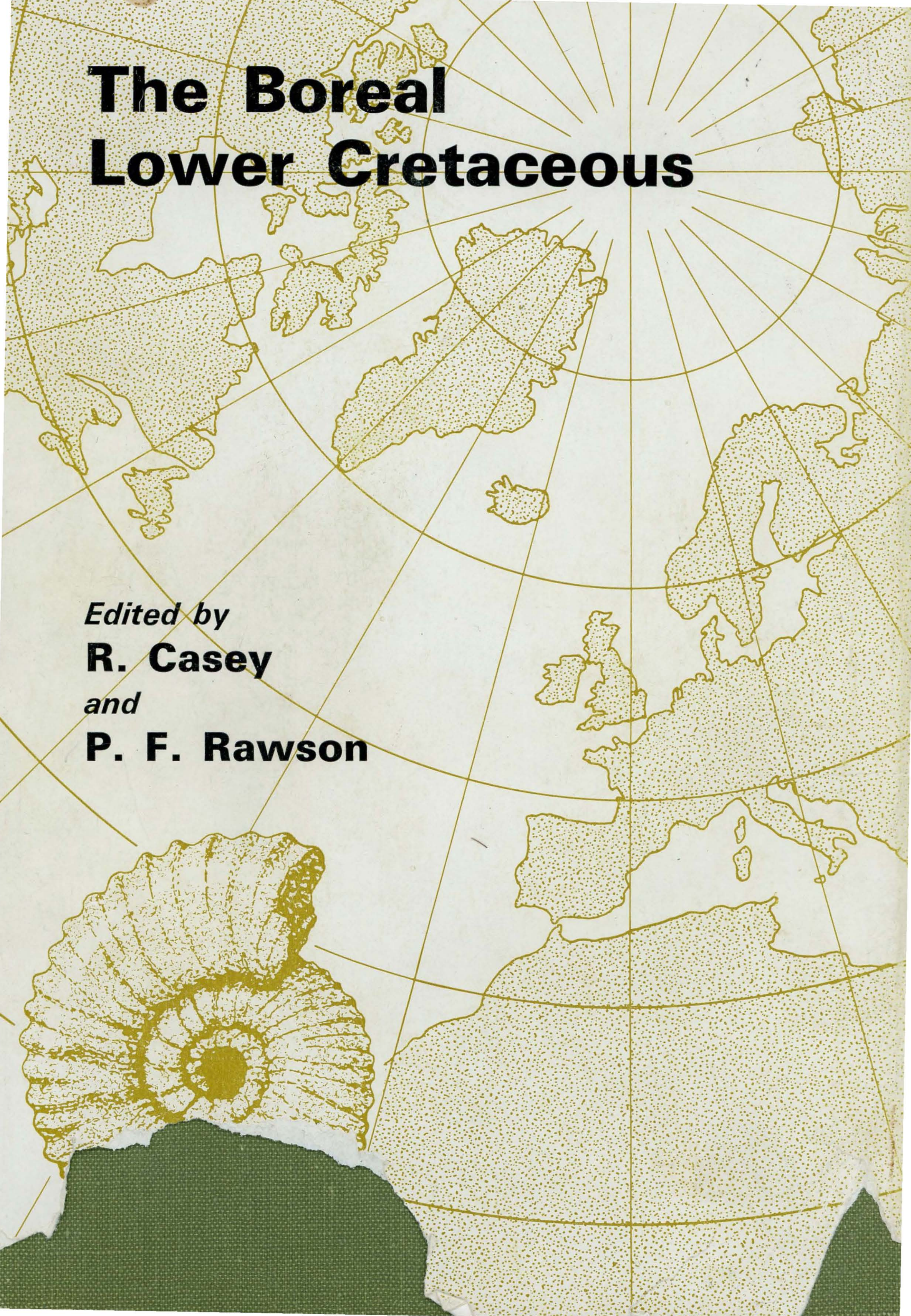
The Boreal Lower Cretaceous

Edited by

R. Casey

and

P. F. Rawson



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The Boreal Lower Cretaceous

The proceedings of an International Symposium
organised by Queen Mary College (University of London)
and the Institute of Geological Sciences,
17-30 September 1972

Edited by
R. Casey
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Preface

Preface

This volume brings together a selection of papers read or presented in abstract at the International Symposium on the Boreal Lower Cretaceous organised by the Department of Geology, Queen Mary College (University of London) and the Institute of Geological Sciences (Natural Environment Research Council), 17-30 September, 1972. The symposium focused interest on problems common to the Lower Cretaceous in many parts of the northern hemisphere, notably in the realms of biostratigraphy and time-correlation. It also gave opportunity for field work in some of the best-known areas of the English Lower Cretaceous.

As befits its location near one of the classic regions of the European Mesozoic, Queen Mary College maintains a strong tradition of research in the Lower Cretaceous. In joining the College as hosts to the symposium, the Institute of Geological Sciences embarked on a new venture, one that strengthens the links between the Institute and the Universities and that reflects the Institute's broadening interests and responsibilities in the international field.

The organising committee consisted of: R. Casey, F.R.S. (Chairman), P. F. Rawson (Secretary), Beris Cox (I.G.S.), S. R. A. Kelly (Q.M.C.), G. Pinckney (Q.M.C.) and E. P. Smith (I.G.S.). The committee acknowledges its gratitude to Sir Kingsley Dunham F.R.S., Director of the Institute of Geological Sciences, Sir Harry Melville F.R.S., Principal of Queen Mary College and Professor J. F. Kirkaldy, head of the Department of Geology at Queen Mary College, for providing the facilities for holding the symposium; Dr. B. N. Fletcher (I.G.S., Leeds), Dr. F. A. Middlemiss (Queen Mary College), Dr. J. W. Neale (University of Hull), Dr. H. G. Owen (British Museum, Natural History) and Mr. C. J. Wood (I.G.S., London) for assisting in conducting field excursions; and Dr. H. W. Ball (British Museum, Natural History), Mr. N. F. Hughes and Dr. C. Forbes (Sedgwick

Museum, Cambridge) and Dr. J. W. Neale (University of Hull) for making available palaeontological collections in their respective institutes.

In the production of this volume the editors thank Seel House Press, especially Mr. G. Wilding, for their ready co-operation, Mrs. Jean Fyffe (Queen Mary College) for drawing many of the figures, and Dr. E. Kemper (Hanover) and Dr. J. P. Thieuloy (Grenoble) for translating the summaries. Messrs E. P. Smith, G. Pinckney and S. R. A. Kelly assisted with proof-reading, and Susan Rawson helped to compile the indices. Lastly, we thank those colleagues who acted as referees of papers submitted for publication.

R. Casey
1 September 1973
P. F. Rawson

Structural elements and biostratigraphical framework of Lower Cretaceous rocks in southern Alaska

David L. Jones

Lower Cretaceous sedimentary rocks in southern Alaska are included in three structural belts that nearly parallel the present arcuate coastline. Several thousand metres of sediment occur in each belt, but the sediments of the central belt are generally more fossiliferous than coeval rocks of the other two belts. Hence it is from this belt that most of our knowledge of the Cretaceous biostratigraphy has been obtained. Fossils of Berriasian, Valanginian, Hauterivian, Barremian and Albian age occur in southern Alaska: the faunas contain representatives of both the Boreal and North Pacific Faunal Provinces.

In Südalaska gehören Gesteine der Unterkreide drei Strukturzügen an, die etwa parallel zum heutigen gebogenen Verlauf der Küste angeordnet sind. Die Mächtigkeit der Unterkreide erreicht in jedem dieser Gürtel mehrere tausend Meter. Die Fossilführung ist im mittleren Gürtel jedoch am reichsten, so daß die Kenntnisse über die Biostratigraphie der Unterkreide von Südalaska im wesentlichen auf diesen zentralen Gürtel zurückgehen. Fossilien aus dem Berrias, Valangin, Hauterive, Barrême und Alb sind aus Südalaska bekannt geworden. Die Faunen enthalten sowohl Vertreter der borealen als auch der nordpazifischen Faunenprovinz.

Le Crétacé inférieur sédimentaire de l'Alaska méridional est représenté dans trois zones structurales qui s'étendent à peu près parallèlement à la courbure de l'actuel rivage. Plusieurs milliers de mètres de sédiments doivent lui être attribués dans chacune de ces zones, mais les sédiments de la zone médiane sont généralement plus fossilifères que les roches contemporaines des deux autres zones. Jusqu'alors, c'est de cette zone que provient l'essentiel de nos connaissances sur la biostratigraphie du Crétacé. Des fossiles berriasiens, valanginiens, hauteriviens, barrémiens et albiens ont été recueillis dans le Sud de l'Alaska: ces faunes sont un mélange de représentants de la province faunique boréale et de celle du Pacifique-Nord.

1. Introduction

Lower Cretaceous rocks in southern Alaska are of interest because they provide critical data pertaining to the geological and biological evolution of the northern Pacific rim. Their faunas, in some instances, comprise mingled elements of northern and southern forms and thus permit correlation of the North Pacific Province with the North American Boreal Province. Comparison of Lower Cretaceous faunas of southern Alaska with those to the south, particularly in California, together with a limited amount of oxygen isotopic data, permit speculation as to late Mesozoic marine temperature regimes along the Pacific Coast of North America. Finally, analysis of Lower Cretaceous tectonostratigraphic elements permits tentative reconstruction of plate-tectonic activities involving interaction between the North American plate and an ancestral Pacific (=Kula?) plate.

Unfortunately, Lower Cretaceous rocks in southern Alaska are still poorly known. This is a function of their great structural complexity in some areas and their relative inaccessibility in others. Hence, this summary must be regarded as preliminary and subject to possible major revision as new data and concepts are elucidated.

2. Major structural elements

Lower Cretaceous sedimentary rocks in southern Alaska are included in three belts that nearly parallel the present arcuate coastline. Each belt comprises very different lithological suites, and each has had a different geological history; their faunas, however, are similar. Berg, Jones, and Richter (1972) have informally named these belts the Chugach terrane, the Matanuska-Wrangell terrane, and the Gravina-Nutzotin belt (Fig. 1).

In plate-tectonic theory, these three belts correspond, respectively, to (1) trench deposits formed in part on oceanic crust at the continental margin; (2) arc-trench gap deposits formed on an unstable continental shelf; and (3) a magmatic, or volcano-plutonic, arc formed as a result of the subduction of an oceanic plate beneath the continent. Most of our biostratigraphical knowledge is derived from the arc-trench gap deposits.

2a. Chugach terrane

Upper Mesozoic rocks of the Chugach terrane comprise several thousand metres of flysch-like graywacke, argillite, volcanic rocks, and melanges, all highly deformed and regionally metamorphosed. Fossils are remarkably scarce, and Lower Cretaceous forms are known only from two places (see Fig. 2). These fossils are *Buchia okensis* (Pavlow) of Berriasian age. Both Upper Cretaceous and Jurassic fossils are also known from the Chugach rocks, but the internal stratigraphy has not been determined because of complex folding, thrust faulting, and a lack of marker beds.

Rocks of the Chugach terrane accumulated in a deep marine environment (Burk 1965; Moore 1969; Plafker and MacNeil 1966; Berg *et al.* 1972), probably near the edge of the continent and perhaps in an oceanic trench (Moore 1972). A deep-water environment is further suggested by analysis of sedimentary structures (Moore 1972) and by the scarcity or lack of shallow-water faunas.

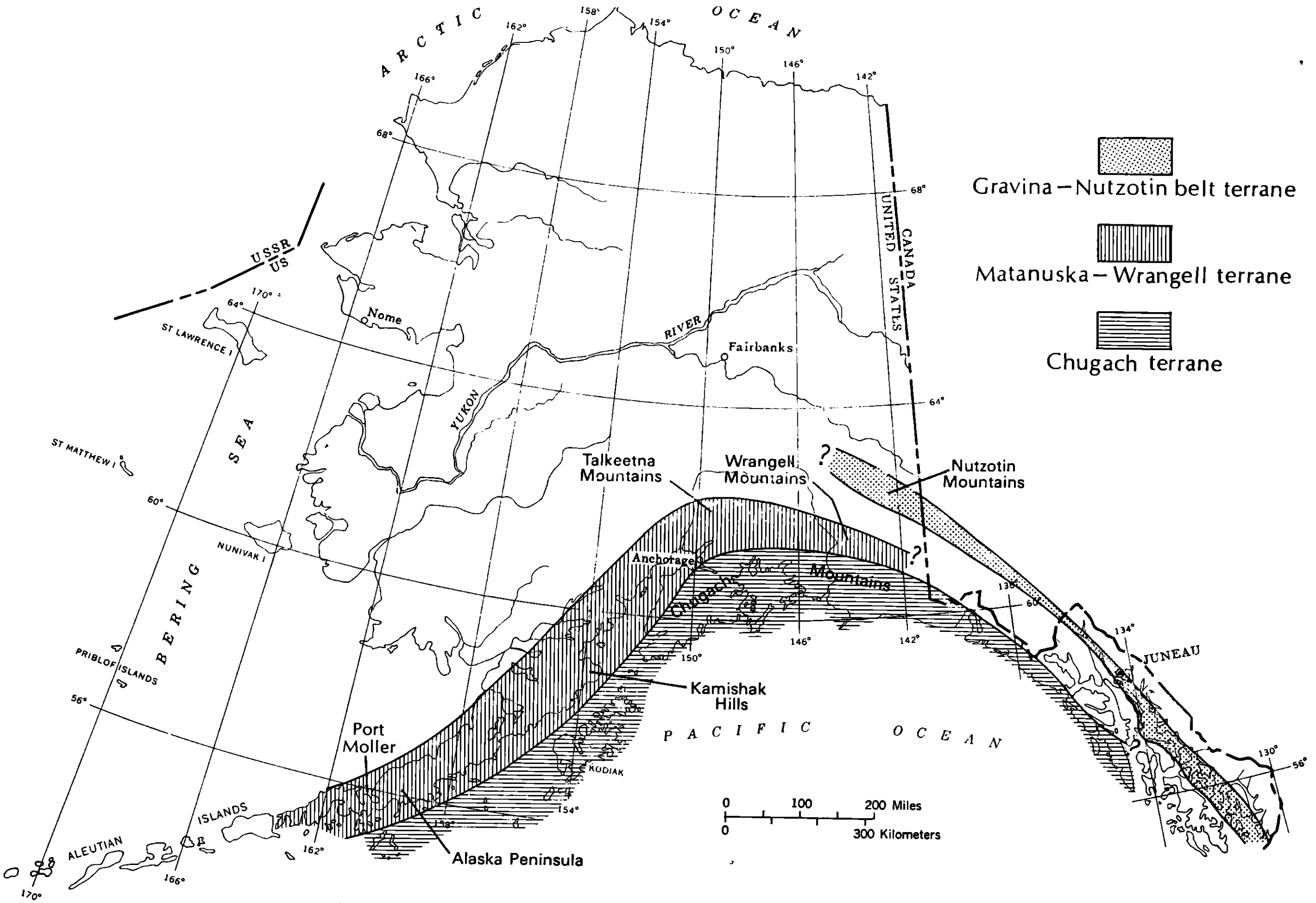

Fig. 1. Distribution of major late Mesozoic tectonic elements in southern Alaska.

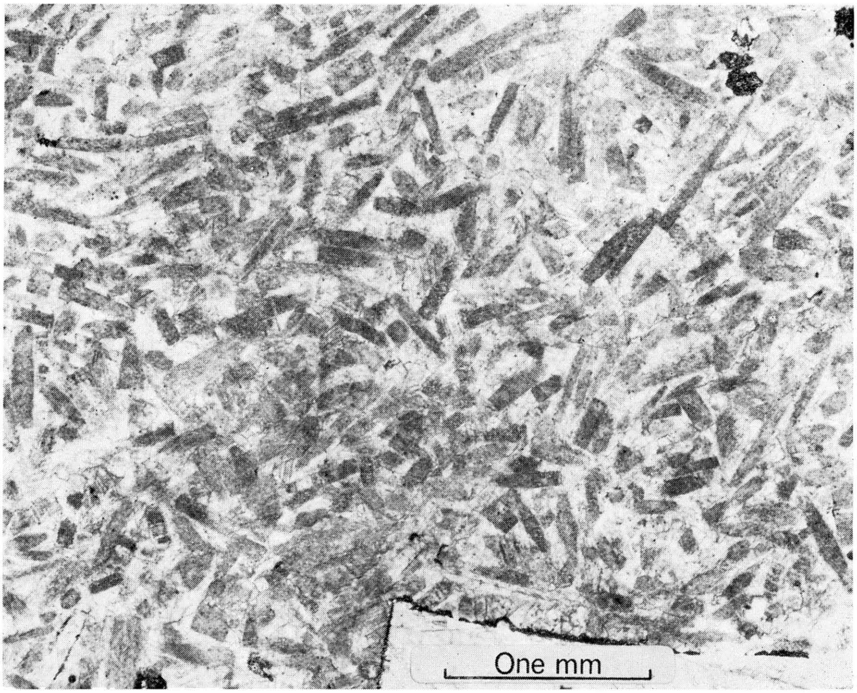

Plate 1

Photomicrograph of Nelchina Limestone.

2b. Matanuska-Wrangell terrane

Lower Cretaceous rocks of the Matanuska-Wrangell terrane are part of a thick sequence of shallow-water, mainly clastic deposits that range in age from Middle Jurassic to Upper Cretaceous (Maestrichtian). They are underlain by Lower Jurassic sedimentary and volcanic rocks; Triassic shale, limestone, and amygdaloidal basalt; and Permian andesite, limestone, and argillite. The Permian andesite apparently was formerly an old island arc formed on oceanic crust that was accreted to the North American continent in early Mesozoic time (Richter and Jones 1973). The Lower Cretaceous rocks were deposited on an unstable continental shelf, which received sediment mainly from the north. Rapid changes in facies and thickness and many local unconformities characterize these rocks along strike, and limited data suggest a change to deeper water conditions southward normal to the regional strike. The deep-water rocks of the Chugach terrane, however, are everywhere separated from the shallow-water rocks of the Matanuska-Wrangell terrane by a major thrust fault (E. M. MacKevett, personal communication, 1972).

Upper Mesozoic rocks of the Matanuska-Wrangell terrane are structurally much simpler and generally more fossiliferous than coeval rocks of the other two belts. Hence, much of our knowledge of Cretaceous biostratigraphical sequences in southern Alaska has been obtained from this terrane.

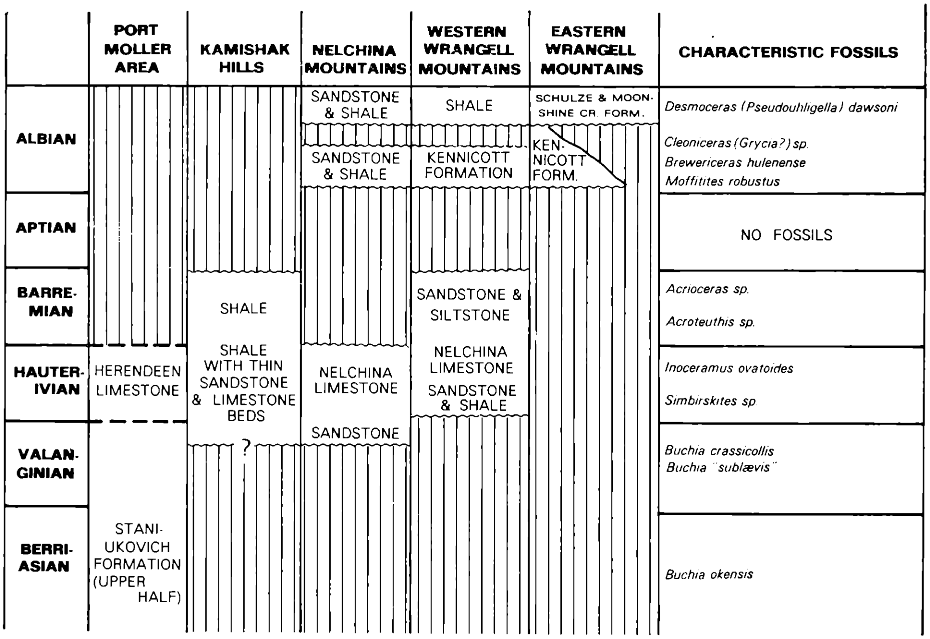

Fig. 2. Simplified correlation chart of Lower Cretaceous rocks of the Matanuska-Wrangell terrane, southern Alaska.

The oldest Lower Cretaceous rocks of the Matanuska-Wrangell terrane are far out on the Alaska Peninsula in the Port Moller area (Fig. 3). There, rare specimens of *Buchia okensis* occur in the upper half of the Staniukovich Formation of Burk (1965). East of this locality, the age of the basal Lower Cretaceous beds becomes progressively younger, so that in the eastern Wrangell Mountains, rocks of Albian age rest directly on the pre-Cretaceous basement (Fig. 2).

The Lower Cretaceous stratigraphical units are lithologically rather monotonous, consisting mainly of interbedded medium- to fine-grained sandstone, siltstone, shale, and minor conglomerate. A conspicuous, thick-bedded light-gray to nearly white limestone unit, which occurs in scattered patches from Port Moller to the western Wrangells, is unusual in that it is composed dominantly of calcite prisms derived from fragmentation of *Inoceramus* valves (Plate 1). This unit is named the Herenden Limestone to the west and the Nelchina Limestone to the east. Formation of this distinctive unit involved establishment of optimum ecological conditions for massive production of *Inoceramus* shells in a high-energy environment. Identifiable shells are rare, but most are *I. ovatoides.*

The following brief account summarizes stage-by-stage the salient features of Lower Cretaceous strata in the Matanuska-Wrangell terrane (see Figs 3–6).

Berriasian. Arkosic sandstone of the upper half of the Staniukovich Formation near Port Moller has furnished the only Berriasian fossils known from this terrane. These are *Buchia okensis.*

Valanginian. The upper part of the upper half of the Staniukovich Formation has abundant specimens of *Buchia crassicollis* (Keyserling), *B. crassicollis solida* (Lahusen) and rare specimens of *B. sublaevis* (Imlay *non* Keyserling). *Buchia crassicollis* and *B.* cf. *B. keyserlingi* (Lahusen) occur beneath the Nelchina Limestone in the Talkeetna Mountains; this is the easternmost known occurrence of

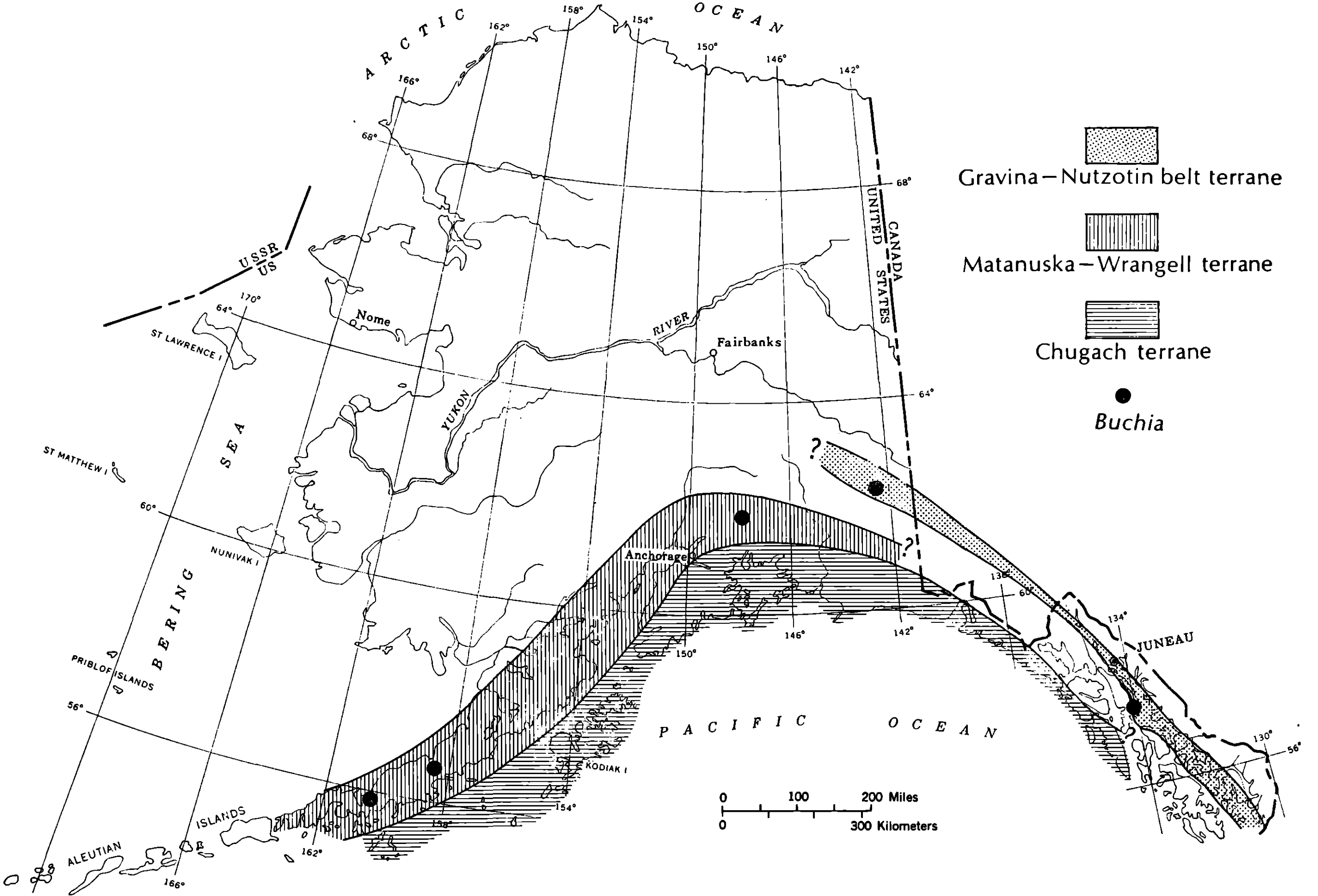

Fig. 3. Distribution of Berriasian fossil localities in southern Alaska.

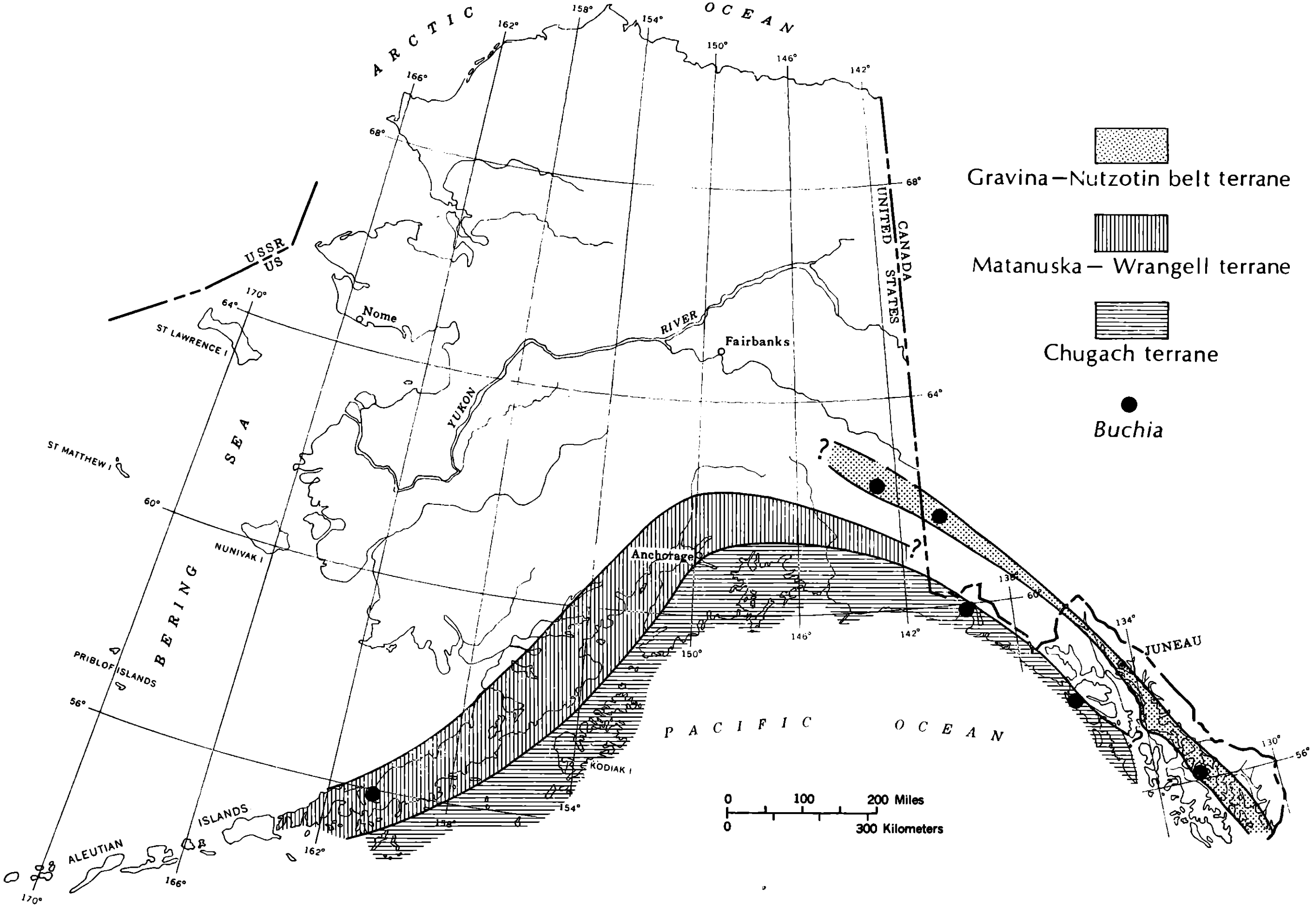

Fig. 4. Distribution of Valanginian fossil localities in southern Alaska.

Valanginian strata in the Matanuska-Wrangell terrane.

Hauterivian. Fossils of this age are rare, with the exception of *Inoceramus* shell debris. Bergquist (1961) reported Hauterivian Foraminifera from the lower part of the Nelchina Limestone and directly underlying siltstone beds; these included *Marssonella oxycona* (Reuss), *Lenticulina münsteri* (Roemer), *Robulus* spp., *Marginulina* spp., and *Vaginulinopsis reticulosa* ten Dam. The ammonite *Simbirskites* sp. occurs beneath the Nelchina Limestone in the Wrangell Mountains (Grantz, Jones, and Lanphere 1966), and *Inoceramus ovatoides* Anderson of late Hauterivian or Barremian age occurs in the limestone.

Barremian. Barremian fossiliferous rocks are known only from two places: the Kamishak Hills on the Alaska Peninsula (Jones and Detterman 1966) and the Kuskulana Pass region of the Wrangell Montains (Fig. 5). In both places, these rocks have been studied only in reconnaissance fashion, and much work is needed before their faunas can be adequately described.

Fossils common to both areas include *Acrioceras* cf. *A. starrkingi* Anderson and large belemnites of the genus *Acroteuthis.* In the Kamishak Hills, several hundred metres of shale and minor pebbly sandstone overlie shale containing many thin beds of limestone composed of *Inoceramus* prisms (Jones and Determan 1966). In the Wrangell Mountains, Barremian sandstone and siltstone rest directly on the Nelchina Limestone or on older Cretaceous rocks where the Nelchina is absent.

Aptian. No strata of Aptian age have been found in southern Alaska, and it seems doubtful that they are present. Despite this lack, no profound orogenic activity appears to have affected southern Alaska, nor was there a drastic change in palaeogeographical pattern as inferred by Jeletzky (1971) for neighbouring Canada. Evidence for warping and erosion is seen in reworked Barremian belemnites in overlying Albian strata in the Wrangell Mountains, but a marked structural discordance is not apparent between the older and younger rocks. Similarly, in the Kamishak Hills, Barremian beds are overlain by Upper Cretaceous rocks (*Pachydiscus kamishakensis* Zone) with very little structural discordance. This suggests that only moderate vertical movements affected these rocks and that no intra-Lower Cretaceous episode of strong folding or mountain building occurred in the entire Matanuska-Wrangell terrane.

Albian. Albian strata are well developed and highly fossiliferous in both the Nelchina area of the Talkeetna Mountains and along the south flank of the Wrangell Mountains. In both areas they have been studied in detail, and the rocks and fossils are fairly well known (Grantz 1960a, 1960b, 1961a, 1961b, 1964, 1965; Matsumoto 1959; Imlay 1960; Jones 1967; Jones and Berg 1964; Jones and MacKevett 1969). These faunas are of particular interest because they are composed of elements known from the Western Interior of Canada, northern Alaska, California, and Oregon, as well as various indigenous species not yet known, or extremely rare, outside southern Alaska.

The Lower Albian assemblage includes the northernmost known components of the well-known Californian *Brewericeras hulenense* fauna (Jones, Murphy, and Packard 1965), including *B. hulenense*, *Douvilleiceras* and *Hulenites.* It also contains elements present in the well-known faunas of the Western Interior of Canada (see Jeletzky 1964), including *Grantziceras* [=*Beudanticeras*], *Arcthoplites* and *Freboldiceras.* The southern extent along the Pacific Coast of this interior fauna is the Queen Charlotte Islands, where both *Grantziceras* and *Arcthoplites* occur (Jones, unpublished data).

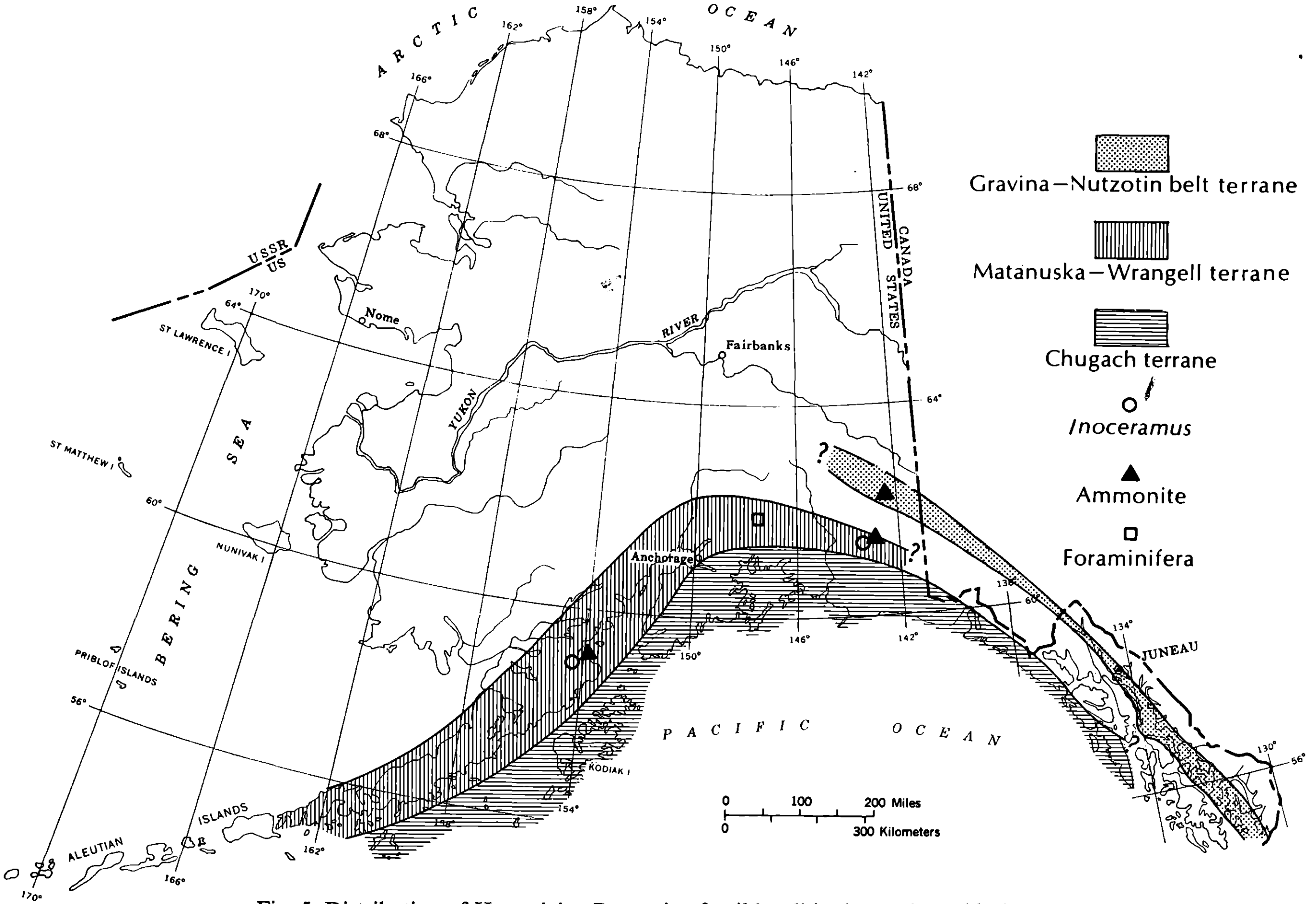

Fig. 5. Distribution of Hauterivian-Barremian fossil localities in southern Alaska.

Middle Albian deposits are essentially unknown in southern Alaska. Only one fragment that may be *Cleoniceras perezianum* (Whiteaves) has been found that is suggestive of a Middle Albian age. This species is common in the Queen Charlotte Islands in strata overlying the Zone of *Brewericeras hulenense* (McLearn 1972).

The Upper Albian of southern Alaska is dominated by *Desmoceras* (*Pseudouhligella*) *dawsoni* (Whiteaves), *Pseudhelicoceras* sp., *Tetragonites jonesi* Murphy, *Actinoceramus concentricus* (Parkinson) and *A. subsulcatus* (Wiltshire), *Inoceramus anglicus* Woods, and a proliferation of marshallitid ammonites, including *Marshallites cumshewaensis* (Whiteaves) and several new species and subgenera. Except for some of the ubiquitous inoceramids, this fauna has little in common with the Western Interior of Canada and northern Alaska. It bears close resemblance to the late Albian faunas of the Queen Charlotte Islands and some resemblance to those of California. In the latter place, marshallitid ammonites are rare, and mortoniceratid forms are relatively common. The northernmost known occurrence of *Mortoniceras* is the Queen Charlotte Islands.

2c. Gravina-Nutzotin belt

The third structural belt in southern Alaska that contains Lower Cretaceous rocks has been called informally the Gravina-Nutzotin belt (Berg *et al.* 1972). This narrow belt extends from the southeastern boundary of Alaska northwestward to its termination in the Alaska Range, a distance of more than 1,100 kilometres. Rocks of this belt comprise a very thick prism of dominantly deep-water flysch-like argillite, graywacke, and minor conglomerate, interbedded with massive lenses of andesitic volcanic rocks. Minor shallow-water and non-marine deposits occur along the southwest margin of the belt.

Numerous granitic plutons of late Mesozoic age intrude the Gravina-Nutzotin belt; the intruded rocks are moderately to severely deformed, and in much of southeastern Alaska, regionally metamorphosed.

Fossils are generally quite scarce in this belt, mainly because of the deep-water origin of the rocks, and abundant specimens are known from only a few scattered localities. The presence of Berriasian strata is indicated by *Buchia okensis* in several places (Fig. 3). In the Nutzotin Mountains, rocks with this species overlie Upper Jurassic strata bearing *Buchia fischeriana.*

Overlying the *B. okensis* beds is another zone characterized by abundant specimens of a new species of *Buchia* related to *B. tolmatschowi* (Sokolov). Ammonite fragments that might be *Tollia* occur with the *Buchia* sp. nov., and a late Berriasian or early Valanginian age is probable. The uppermost *Buchia*-bearing beds in the Nutzotin Mountains contain abundant specimens of *Buchia crassicollis solida* and *B. sublaevis* (Imlay) of late Valanginian age. This is the southernmost known occurrence of *B. sublaevis* (Imlay), which occurs commonly in Valanginian deposits of the Arctic Slope of Alaska (Imlay 1961; Jones and Grantz 1964).

The youngest sedimentary rocks recognized to date in the Gravina-Nutzotin belt are of early Albian age (Fig. 6) and comprise thin-bedded graywacke and argillite interbedded with massive andesite breccias. The fossils are *Arcthoplites* and *Grantziceras*(?), similar to those known from the Matanuska-Wrangell terrane. The presence of Barremian strata is indicated by *Shasticrioceras* sp. and *Pseudolimea* sp. found in graywacke interbedded with volcanic rocks in the Nutzotin Mountains area (Fig. 5).

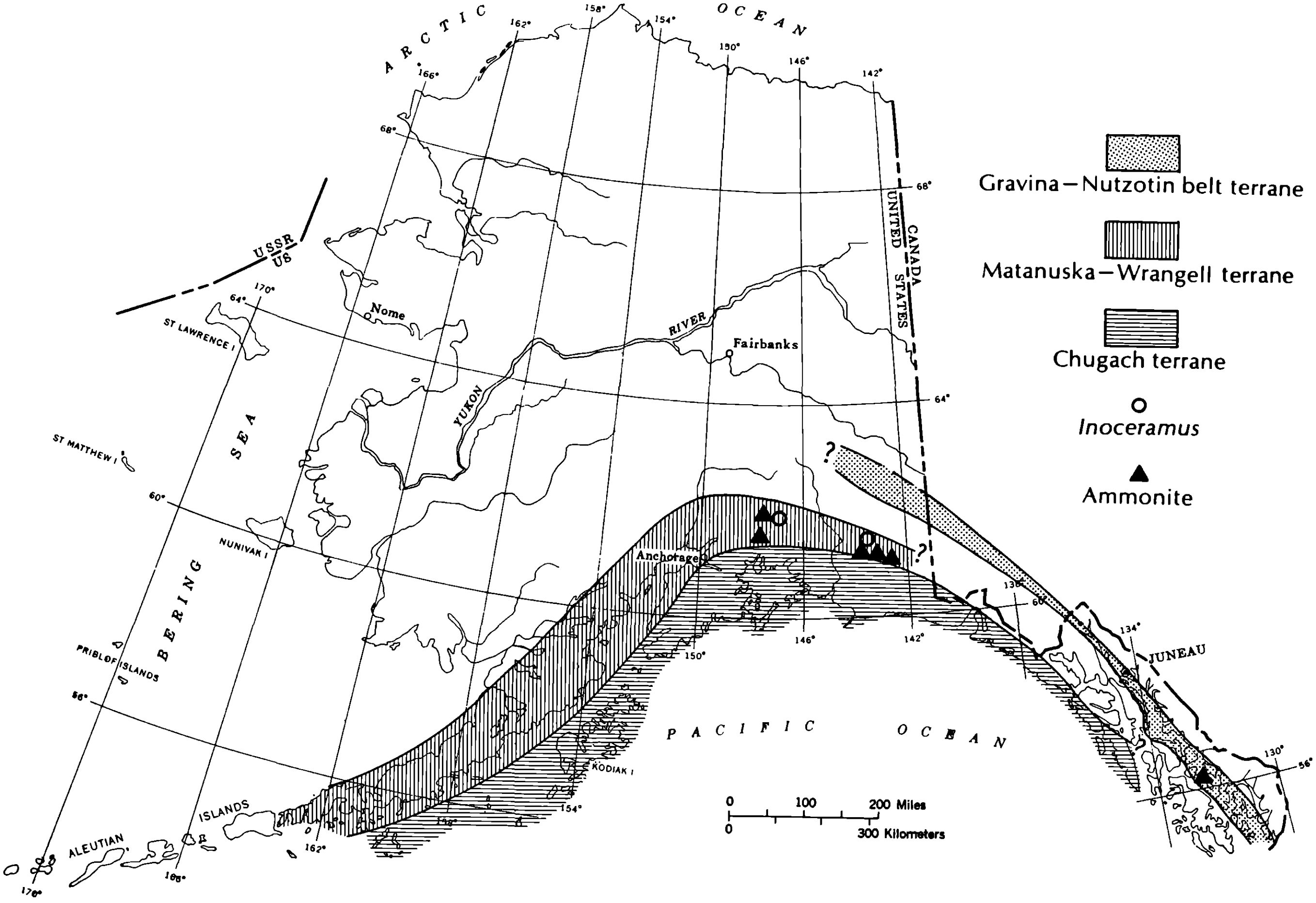

Fig. 6. Distribution of Albian fossil localities in southern Alaska.

3. Tectonic significance of the three late Mesozoic belts in southern Alaska

The formation of a tripartite system of contrasting lithologic belts in southern Alaska (Fig. 7) is believed to be the result of plate-tectonic activity involving interaction between an ancestral oceanic Pacific (=Kula?) plate and the continental American plate (Richter and Jones 1973; Berg *et al.* 1972). Upper Mesozoic deposits of the Chugach terrane may have accumulated in a deep trench formed near the continental margin through subduction of the oceanic plate. The highly deformed and metamorphosed character of these rocks can be attributed to underthrusting along a fossil Benioff zone.

The slightly deformed, unmetamorphosed, and highly fossiliferous deposits of the Matanuska-Wrangell terrane were apparently formed along an unstable continental shelf, depths of water being mainly in the neritic zone. Their tectonic setting corresponds to an arc-trench gap as defined by Dickinson (1971).

The Gravina-Nutzotin belt, with its thick lenses of andesite and comagmatic granitic plutons, represents the remnants of a late Mesozoic volcano-plutonic arc that formed in response to subduction along the continental margin. Sedimentation occurred mainly in deep water; minor shallow-water and non-marine deposits were preserved along the southwest margin of the belt. The highly deformed and metamorphosed nature of this terrane has not yet been adequately explained, but it may be related to movements of a block of older Palaeozoic rocks in southeastern Alaska which has been interpreted as a displaced continental fragment (Jones, Irwin, and Ovenshine 1972).

4. Lower Cretaceous marine climatic zonation and southern limits of the Boreal Realm

Sufficient oxygen-isotopic data are not yet in hand to establish a Lower Cretaceous marine temperature gradient along the Pacific Coast of North America. Analysis of a Hauterivian belemnite from southern Alaska (Fig. 8) gives an inferred temperature of 25·5°C (Harry A. Tourtelot, personal communication, 1972), which seems to be too warm for the latitude (61°N.). Analysis of a probable late Neocomian belemnite from northern Alaska (lat. 69°N.) gives a temperature of 22°C, and a Valanginian belemnite from nearby (lat 68°N.) gives a temperature of 18·5°C (Harry A. Tourtelot, personal communication, 1972). The accuracy of these temperatures in terms of conditions that actually prevailed during the Lower Cretaceous is open to serious question, but the small decline of only 3·5° between southern and northern Alaska suggests that no strong temperature gradient existed in that region. Furthermore, the gross similarity of the faunas from southern Alaska and California implies fairly uniform marine temperatures throughout at least 20° of latitude, with no apparent sharply delimited temperature-controlled subprovinces.

Nevertheless, the southern faunas do differ markedly from those to the north, and fairly discrete faunal provinces can be recognized within the 4,000 kilometre distance separating California from northern Alaska. Jeletzky (1965, 1971) has recognized a North American Boreal Province and a North Pacific Province based on analysis of Cretaceous faunas. As he has already adequately described the differences between these two faunal provinces (Jeletzky 1971), we need only

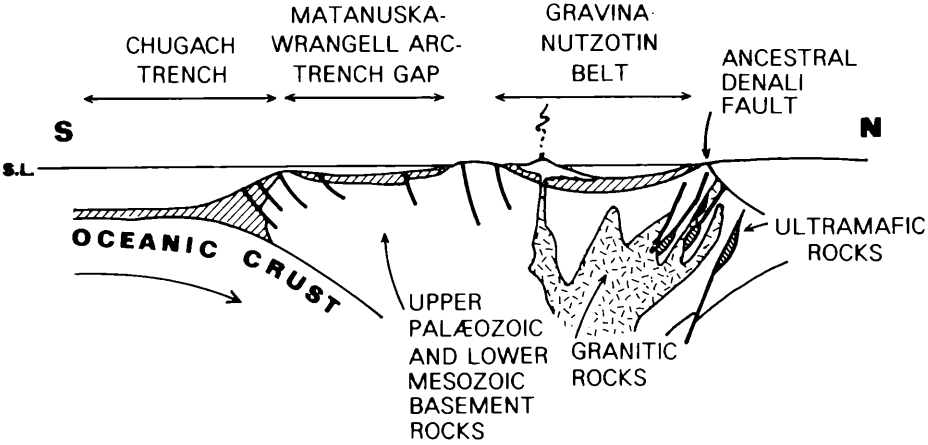

Fig. 7. Interpretation of Upper Jurassic and Lower Cretaceous tectonic elements in southern Alaska.

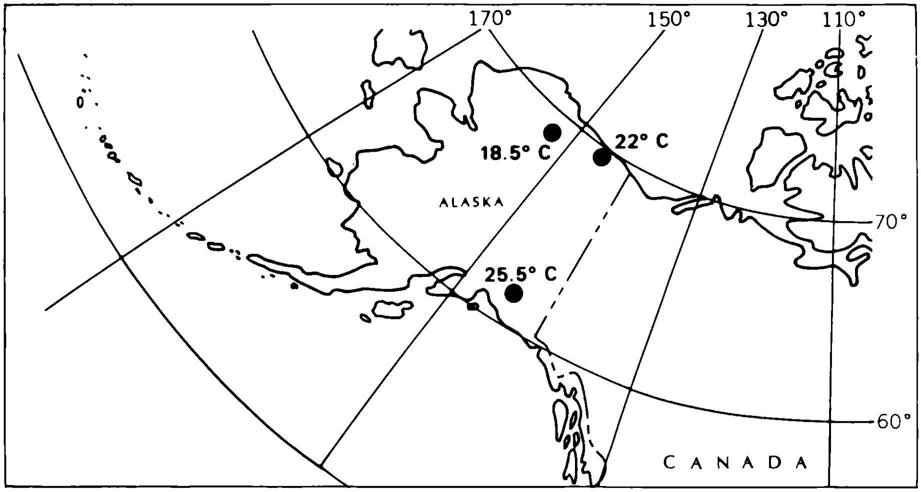

Fig. 8. Oxygen-isotope palaeotemperatures derived from Lower Cretaceous belemnites.

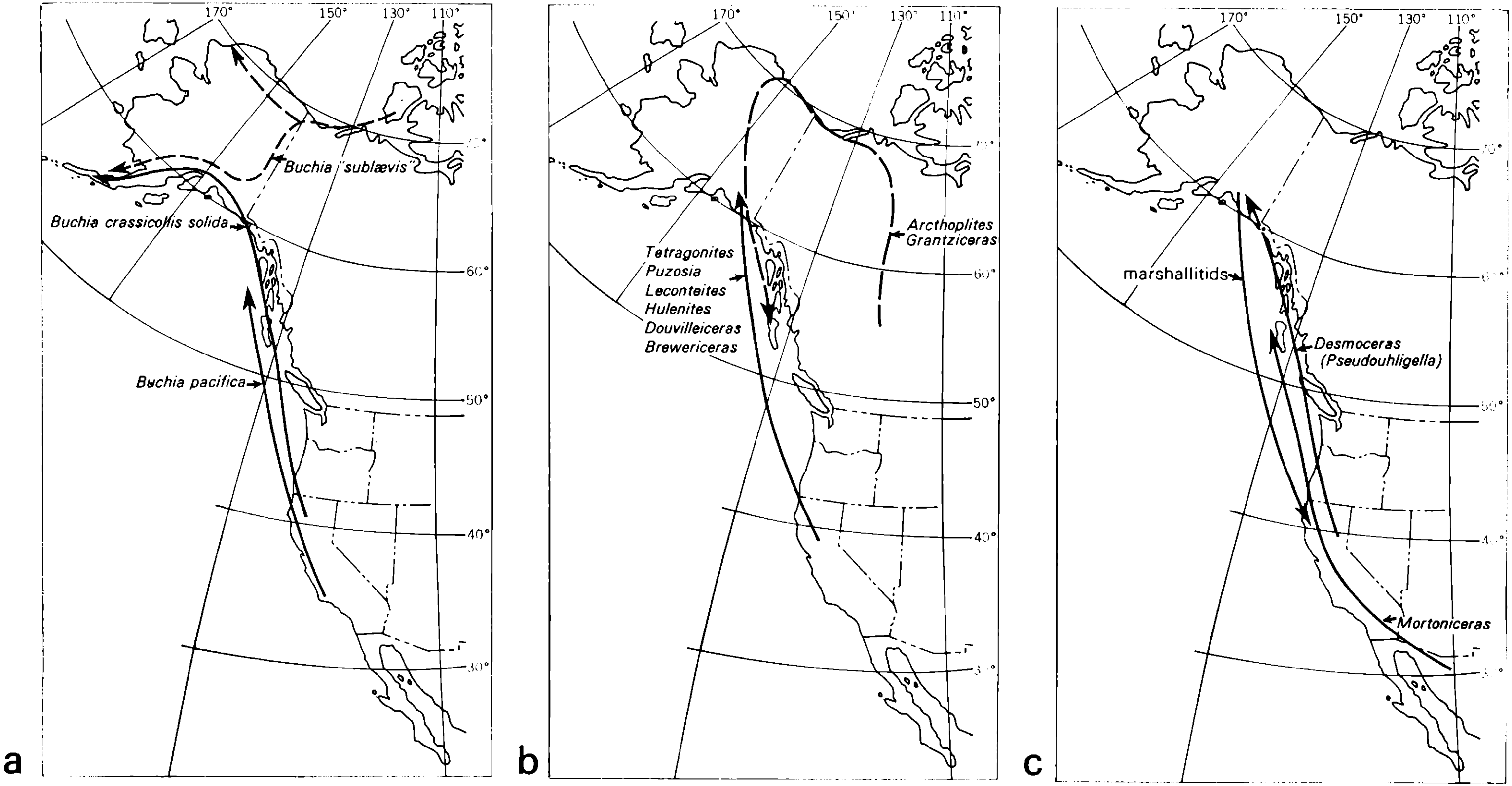

Fig. 9. Geographical ranges of selected Lower Cretaceous genera and species.
a. Valanginian.
b. Lower Albian.
c. Upper Albian.

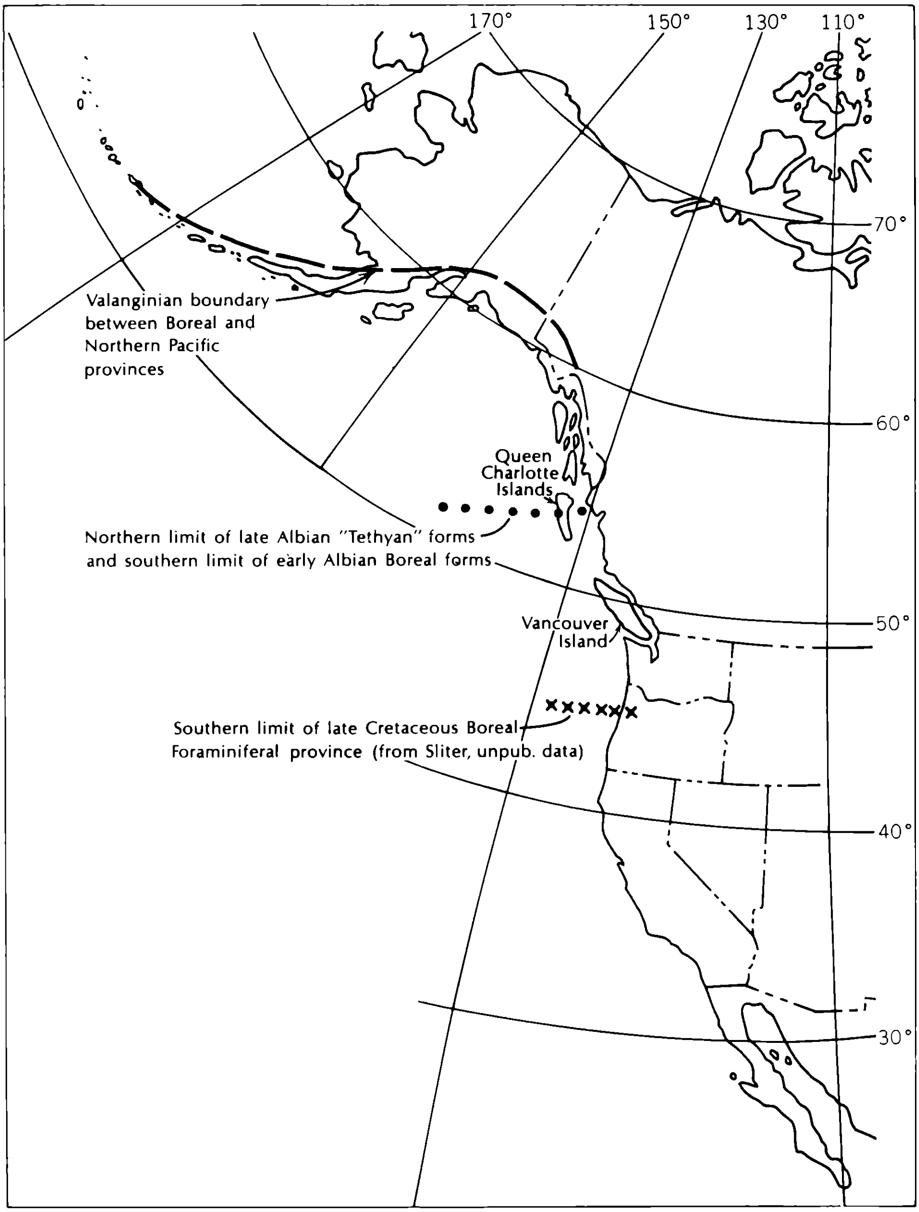

Fig. 10. Postulated boundaries between Lower Cretaceous faunal provinces.

be concerned here with establishing their boundary at different times and in assessing the significance of changes through time in position of the boundary.

On Figures 9a–9c, the known geographical ranges of a few selected genera and species are shown. These were chosen because they seem to be characteristic elements of their faunal province and because their distribution and abundance are fairly well known. Further analysis of the remaining faunal elements may result in substantial revision of the provincial boundaries as herein delimited.

Berriasian faunas from southern Alaska are so meagre that they provide little useful information, except for the fact that *Buchia okensis* ranged from the Arctic Slope of northern Alaska southward to at least Vancouver Island (Jeletzky 1965), and probably to Oregon and California. Valanginian faunas (Fig. 9a) separate rather clearly into a Boreal Province, characterized by *Buchia sublaevis* (Imlay), and a North Pacific Province, characterized by *B. crassicollis solida*. These forms mingle in southern Alaska, which is taken as the approximate boundary of the two provinces.

During the early Albian (Fig. 9b), the southern range of boreal forms, such as *Arcthoplites* and *Grantziceras*, overlaps the northern range of North Pacific forms, such as *Brewericeras*, by nearly 950 kilometres. Hence, no sharp boundary between these two provinces can be drawn, and fairly uniform marine conditions must have existed along the entire continental shelf and inland seas of northwestern North America. During the late Albian, the southern incursion of boreal forms into the North Pacific region ceased, and separation of the two faunas was nearly complete. This change was the probable result of tectonic movements that created barriers to direct faunal interchange.

The northernmost extent of Tethyan forms, such as *Mortoniceras*, during the late Albian is the Queen Charlotte Islands (Fig. 9c). The inability of these forms to reach southern Alaska seems to signal the onset of a somewhat more clearly defined temperature zonation along the Pacific Coast, perhaps induced by lowered temperatures in the north. This cooling trend may have continued, although probably with many fluctuations, well into the Upper Cretaceous, as shown by an oxygen isotope temperature of 21°C for a Maestrichtian baculite from southern Alaska (Tourtelot and Rye 1969), and the location of the southern boundary of the Late Cretaceous boreal foraminiferal province far south of Vancouver Island (Sliter 1972) (Fig. 10).

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Micropalaeontological correlation of the Canadian boreal Lower Cretaceous

T. Potter Chamney

Among foraminifera, endemic forms have to be used for interbasin correlation in the Canadian boreal region, and few of the taxa so far studied (mainly agglutinated, benthonic forms) are of value in international correlation. Significant microfossil assemblage zones are summarised. Correlation of the major lithostratigraphical units by means of these assemblages is illustrated by sections through the main geological provinces. Palaeogeographical maps for various parts of the Lower Cretaceous are based on both surface and subsurface information.

Für eine Korrelation der Schichtfolgen der verschiedenen Becken des kanadischen Borealgebietes wurden endemische Foraminiferen herangezogen. Einige der untersuchten Taxa —besonders benthonische Formen (Agglutinantia)—sind auch von Wert für die internationale Korrelation. Die wichtigsten "assemblage-Zonen" der Mikrofossilien werden aufgezählt. Die Korrelation der bedeutenderen biostratigraphischen Einheiten mit Hilfe dieser Mikrofossil-Gemeinschaften wird anhand von Profilen durch die wichtigeren geologischen Provinzen demonstriert. Den paläogeographischen Karten der verschiedenen Einheiten der Unterkreide liegen sowohl Befunde der Oberflächen-Geologie als auch Befunde von Bohrungen zugrunde.

Parmi les foraminifères, les formes endémiques peuvent être utilisées dans les corrélations de bassin à bassin pour le domaine boréal canadien et seul un petit nombre des taxons jusqu'alors étudiés (principalement des agglutinés benthoniques) possède une valeur internationale de corrélation. Les zones d'association à base de microfossiles significatifs sont présentées sommairement. La corrélation des unités lithostratigraphiques majeures au moyen de ces assemblages est illustrée à partir de coupes relevées dans les principales provinces géologiques. Enfin, des cartes paléogéographiques sont établies sur des informations de surface et de sub-surface pour plusieurs niveaux du Crétacé inférieur.

1. Introduction

1a. Biostratigraphical problems

Most of the problems in Lower Cretaceous biostratigraphy confronting micropalaeontologists in Canada are similar to those in other countries. Because of the great distances involved and the large numbers of interior (epeiric) basins, endemic biotas must be used for interbasin correlation and biochronology. The great distances from the ancient, permanent marine basins and the occurrence of complex structural barriers along the seaway troughs from these marine sources inhibited movement of species. Hence, an examination of numerous local basin microfaunal successions is required before a regional analysis can be attempted. In addition to this major limitation, biostratigraphical work on the vast areas of subsurface deposits is primarily restricted to the coarse clastic, hydrocarbon reservoir trends favoured in exploration by the oil industry, i.e. ancient delta environments. These areas provided biofacies representing mainly the agglutinated, benthonic Foraminifera and other associated organic fossils of the paralic zone. Thus, most of the available taxa recovered are not sufficiently pandemic to enable world-wide correlation. The region of study is quite new and, in time, more international correlation should be possible. Abnormally thick interfingering marine and non-marine

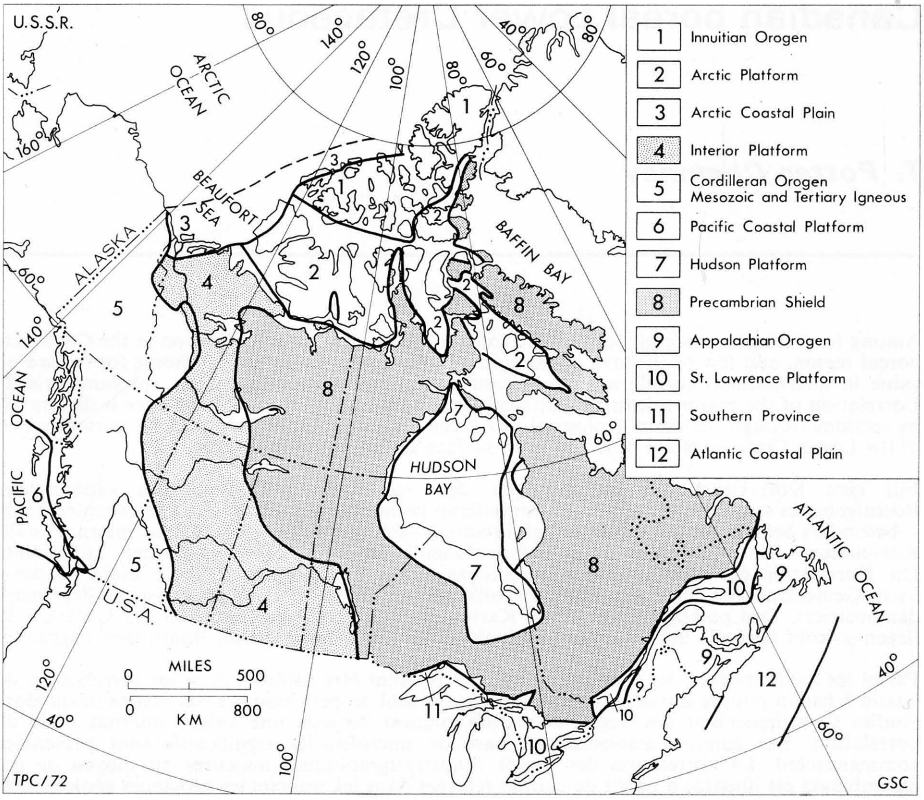

Fig. 1. Geological Provinces.

sequences are present in some basins and pose problems in correlation with the much thinner, classical equivalents in Europe.

This paper is a brief summary of a few significant microfossil assemblage zones which are useful for biostratigraphical determinations. In addition to the obvious marine boreal Lower Cretaceous successions, stratigraphical equivalents in the brackish to fresh-water depositional intervals are included. For the purpose of this paper, all references to the international time divisions are to existing published literature on the surface palaeontology of Canada by Dr. J. A. Jeletzky of the Geological Survey of Canada (see references). The subsurface palaeontology is primarily the result of micropalaeontological studies published by the author (see references). The author agrees with Jeletzky's interpretation of the Canadian Boreal Lower Cretaceous Province (Jeletzky 1971) but differs somewhat in the subjective interpretation of the subsurface micropalaeontological data for the ancient seaway, source "troughs" of boreal marine transgression into the Western Interior (see comments on palaeogeographical maps).

A brief summary of Lower Cretaceous workers in Canada who have contributed to elucidating the stratigraphy of the area begins with the Canada-United States border survey in 1875 by G. M. Dawson. This was followed by contributions through the Geological Survey of Canada by A. R. C. Selwyn, F. H. McLearn,

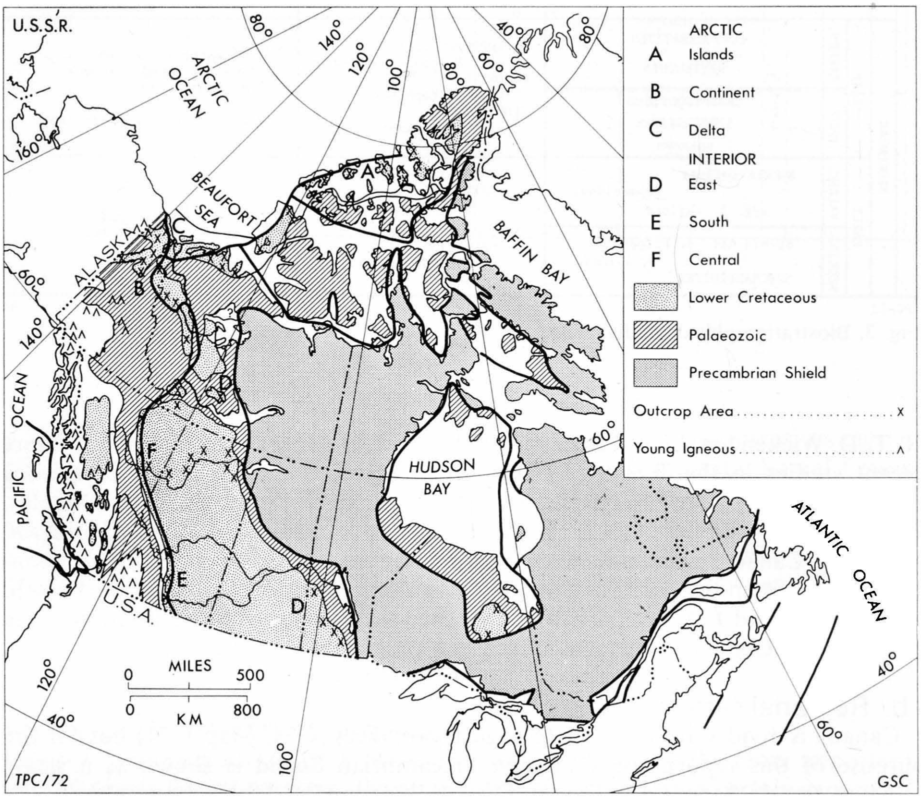

Fig. 2. Distribution of Lower Cretaceous deposits.

SERIES	STAGE	SUB-STAGE		GENERAL MACROFOSSILS	MICROFOSSIL MARKERS	
				after J.A. Jeletzky, 1971	INDEX MICROFOSSILS	SIGNIFICANT ASSOCIATIONS
					(based on uppermost range of the taxa)	
LOWER CRETACEOUS	ALBIAN	UPPER		NEOGASTROPLITES	PSAMMINOPELTA var. *P. subcircularis* AMMOBACULITES var. *A. fragmentarius* PALLAIMORPHINA	cycloid fish scales & bone *Verneuilinoides borealis* *Miliammina manitobensis*
		MIDDLE		GASTROPLITES	HAPLOPHRAGMOIDES var. *H. gigas* GAUDRYINA var. *G. canadensis* var. *G. subcretacea*	*Valvulineria lotterlei* *Gavelinella stictata* *Spiroplectinata bettenstaedti* *G. nanushukensis* *Cyclolepis geinitzi* *Microcarpolithes declivatus*
		LOWER		ARCTHOPLITES BEUDANTICERAS AFFINE SONNERATIA LEMUROCERAS	GLOMOSPIRELLA SARACENARIA var. *S. trollopei* QUADRIMORPHINA (4 ch) TROCHAMMINOIDES var. *T. eilete*	*"Verneuilina" porta* *Dictyometra* sp. *Marginulinopsis* var. *M. collinsi* *Gaudryina barrowensis* *Lenticulina macrodisca* *Miliammina sproulei*
	APTIAN			TROPAEUM AUCELLINA ex gr. *A. aptiensis-caucasica* unnamed Z	SIPHOTEXTULARIA var. *S. rayi* SEROVAINA QUADRIMORPHINA (5 ch) REOPHAX var. *R. tundraensis*	*Pyrobolospora hexapartita* *Pyrulina* var. *P. cylindroides* *Metacypris* spp. *Viviparus* sp. *(operculum)* *Gaudryina tailleuri* *Conorboides umiatensis*
	NEOCOMIAN	LATE	BARREM.	CRIOCERATITES OXYTEUTHIS	HAPLOPHRAGMOIDES var. *H. goodenoughensis* GAUDRYINA var. *G. tappanae* GLOMOSPIRA var. *G. subarctica*	*Glomospirella arctica* *Globulina topagorukensis* *Praebulimina* sp. ?*Sporitoides (Triletes)* spp.
			HAUT.	CRASPEDODISCUS SIMBIRSKITES unknown		
		EARLY	VALANG.	BUCHIA *inflata* *Keyserlingi* aff. *B. inflata*	LITUOTUBA var. *L. gallupi* GAUDRYINA var. *G. milleri*	polymorphinids *Conorboides* sp.
			BERRIAS.	BUCHIA aff. *B. volgensis* *B. okensis* SUBCRASPEDITES		

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Fig. 3. Biostratigraphical subdivisions.

R. T. D. Wickenden, L. S. Russell, G. S. Hume, C. O. Hage and P. S. Warren. More recent studies in the Western Interior areas of the Canadian Lower Cretaceous include the work of C. R. Stelck, E. J. W. Irish, D. F. Stott, R. J. W. Douglas, P. C. Badgley and M. A. Carrigy. In the Arctic mainland areas the Geological Survey of Canada has conducted several major field operations resulting in contributions written by E. J. Tassonyi, E. W. Mountjoy, D. K. Norris, C. J. Yorath, F. G. Young and J. A. Jeletzky, who produced the first complete subdivision of the Arctic Lower Cretaceous in terms of the European stage nomenclature.

1b. Regional setting

Canada is divided into sixteen geological provinces (GSC Map 1–71) but for the purpose of this report, the Canadian Precambrian Shield is shown as a single province (see darkened area, Fig. 1). The modification is adopted to emphasize the configuration of sedimentary deposition in relation to this ancient land massif. This,

STAGE	SUB-STAGE		ARCTIC			INTERIOR PLATFORM			
			A ISLANDS	B CONTINENT	C DELTA	D EAST	E SOUTH	F CENTRAL	
ALBIAN	UPPER		HASSEL FM.	U. ARCTIC RED FM. SE T. Pot SH. beds on HUME RIVER	? present	MOWRY FM. VIKING FM.	L. ASHVILLE FM.	SHAFTSBURY FM.	
	MIDDLE		CHRISTOPHER FM.	NW "RUSTY" BEDS SLATER RIVER FM. NE BENTONITIC SH. ZONE	UNIT 14B	JOLI FOU FM. U. MANNVILLE GRP. O'SULLIVAN BORRADAILE MBRS SWAN RIVER FM.	JOLI FOU FM. "DAKOTA" GRP.	BUCKINGHORSE FM.	? HARMON SH GRAND RAPIDS FM. COMMOTION FM.
	LOWER			NW B.I.U. CONC. SH. SE SANS SAULT FM. & L. ARCTIC RED FM.	UNIT 14C (SANS SAULT EQUIV.) UNIT 15 (B.I.U.)	L. MANNVILLE GRP. ISLAY TOVEL CUMMINGS MBRS.			CLEARWATER FM.
APTIAN			ISACHSEN FM. South North	NW SE SILTY SH ZONE UPPER SANDSTONE DIVISION	UNIT 16	ELLERSLIE FM. DINA-McMURRAY FMS. BASAL QTZ. MBR.	L. BLAIRMORE GRP. Calcareous Zone (OSTRACOD ZONE) ELKO CONGL.	BLUESKY FM. GETHING FM. CADOMIN CONGL.	
NEOCOMIAN	LATE	BARREM.		U.SH.-SILTST. DIV. "shmoo" mudstone beds	UNIT 17	"KOOTENAI" FM. (Kevin-Sunburst sands)	NIKANASSIN FM.	MINNES GRP.	
		HAUT.		red-brn. weathering mudstone beds	NOT PENETRATED				
	EARLY	VALANG.	South MOULD BAY FM. (Upper & some Middle)	LOWER SANDSTONE DIVISION			KOOTENAY FM. (Part)		
		BERRIAS.	North DEER BAY FM. (Upper part)	HUSKY FM. (Upper part)					

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Fig. 4. Lithostratigraphical units.

combined with the Cordilleran orogeny and its associated igneous intrusives on the western edge of the continent, more-or-less confines the continental boreal Lower Cretaceous deposits to the northwest—southeast trending trough of the Western Interior Platform. Figure 2 shows all the known Lower Cretaceous deposits in Canada (GSC Map 1250A). Those on the western edge fall within the Pacific Lower Cretaceous Province and those on the eastern edge are not included here.

2. The depositional sequence

2a. The biochronological sequence

Figure 3 summarises the general macrofossil sequence and the more important micropalaeontological markers: the section below elaborates on certain aspects of this figure.

Jurassic

Upper Tithonian

The *Craspedites* (*Taimyroceras*?) *canadensis* and *Buchia terbebratuloides* s. lato. Zone is represented in part by the *Arenoturrispirillina waltoni* Assemblage Zone (Chamney 1971a, 1971b) in the Arctic areas; the more open marine facies are recognised with the appearance of the *Darbyella volgensis* Assemblage Zone (Tappan 1955). The non-marine equivalents of the Western Interior to the south are represented by the *Aclistochara latitruncata* Assemblage Zone (Peck 1937); the restricted marine facies are distinguished by *Haplophragmoides canui.*

Lower Cretaceous

early Neocomian: Berriasian

The *Buchia okensis* and *B.* sp. nov. aff *volgensis* Zones are represented by the *Lituotuba gallupi* assemblage (Chamney 1971a, 1971b) and *Gaudryina milleri* Assemblage Zone (Tappan 1955).

early Neocomian: Valanginian

Buchia keyserlingi, B. cf. *volgensis* and *B.* sp. nov. aff. *inflata* occur primarily in a coarser clastic lithological facies (Lower Sandstone Division), but it is possible to equate this time interval to the morphological series assemblage of *Haplo-*

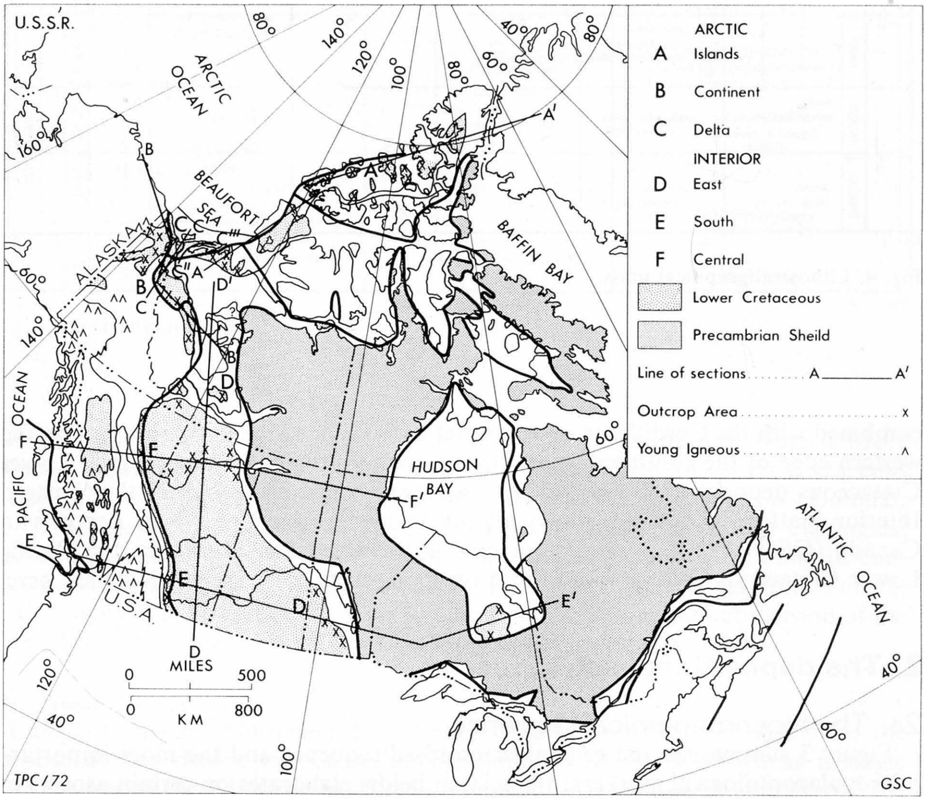

Fig. 5. Index map for geological profiles.

phragmoides canui—goodenoughensis and coarsely-agglutinated *Reophax* (*Proteonina*) spp.

late Neocomian: Hauterivian

The *Cylindroteuthis* cf. *subporrecta*, *Simbirskites* cf. *kleini* and *Lytoceras* (?*Eulytoceras*) cf. *saturnale* Zones represent a transitional facies between the distinctive early Neocomian and the strong marine transgression of the Barremian. *Neobulimina* sp. nov. aff. *subcretacea* is a widespread and significant marker within this depositional interval.

late Neocomian: Barremian

The *Hoplocrioceras* cf. *remondi* Zone is represented by the *Glomospira subarctica* and *Glomospirella arctica* assemblage (Chamney *in* Mountjoy and Chamney 1969) associated with *Haplophragmoides goodenoughensis* (see Chamney 1969a).

Aptian

The *Tropaeum australe*, *Aucellina aptiensis* and *A. caucasica* Zones are recognised by the coarsely agglutinated *Reophax tundraensis* Zone (Chamney, unpublished: GSC open file no. 62) and the *Serovaina* sp. nov. Zone in the early Aptian. A younger assemblage of late? Aptian age is represented by *Siphotextularia* var. *rayi*, some polymorphinids, abundant *Conorboides* sp. nov. and a few *Quadrimorphina* sp. nov. (with 5 ventral chambers).

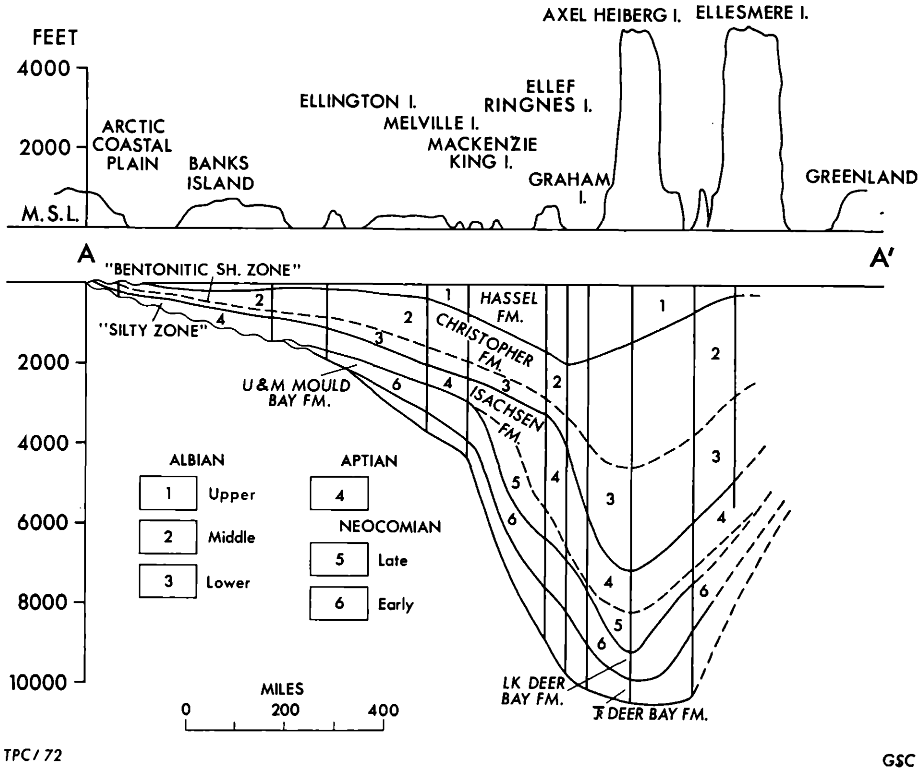

Fig. 6. Geological profile: Arctic Islands, A-A′

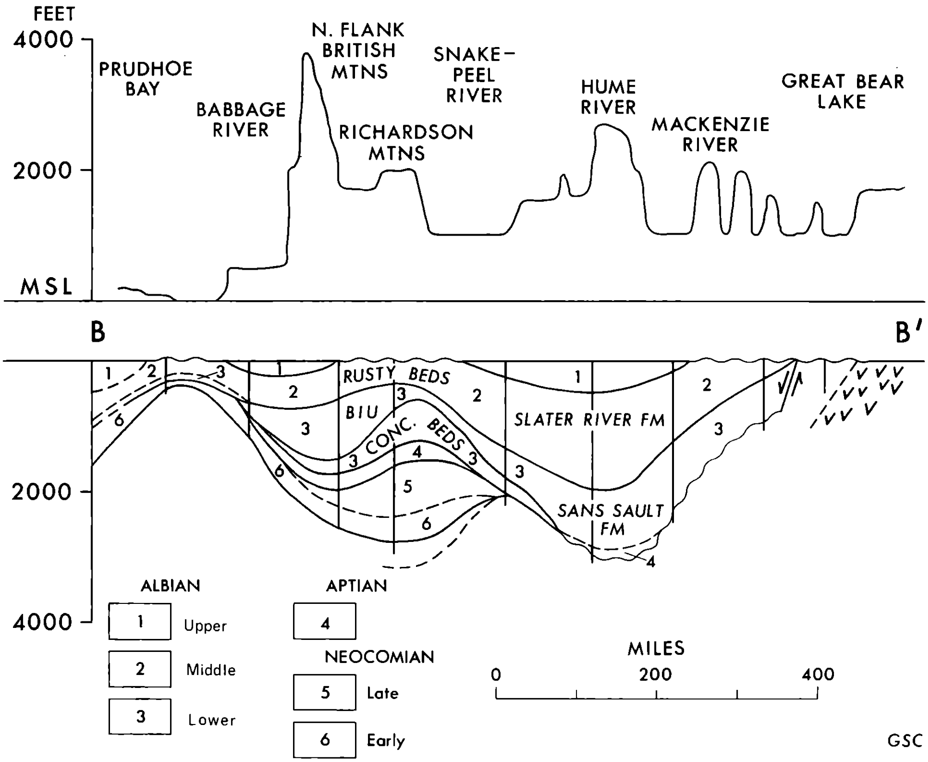

Fig. 7. Geological profile: Arctic Mainland, B-B′.

Lower Albian

The *Sonneratia* sp. s. lato (including *Tetrahoplites* and *Hemisonneratia*) and *Beudanticeras* (*Grantziceras*) *affine* Zones (with pelecypods including *Inoceramus* sp.) are represented by (1) an early assemblage of *Arenobulimina* sp., *Quadrimorphina albertensis* and *Siphotextularia* (*Bimonolina*) sp. (2) a middle assemblage of *Saracenaria trollopei* with *Lenticulina macrodisca* and *Dictyometra* sp., and (3) a late assemblage of *Ammodiscus mangusi* and *Glomospirella* spp. (this is possibly the highest stratigraphical occurrence of *Glomospirella*). (Notes 2 and 3 from Chamney 1964, 1967; Chamney *in* Mountjoy and Chamney 1969.)

Middle Albian

The *Gastroplites* sp. Zone is characterised by an early assemblage of *Gaudryina* spp., including *G. subcretacea, G. canadensis* and *G. nanushukensis,* followed by a later assemblage of *Haplophragmoides gigas* and *Ammobaculites* spp. (Chamney 1967).

Upper Albian

The *Neogastroplites* sp. Zone occurs generally in rocks of shallower marine environment and is recognised by the more primitive, tubular, coiled *Psamminopelta* spp. including *P. bowsheri* and *P. subcircularis,* and *Miliammina manitobensis* (Wickenden 1932), along with *Ammobaculites fragmentarius.* The more open marine facies contain calcareous foraminifers which include *Valvulineria loetterlei*, *Conorboides umiatensis*, *Gavelinella* spp. etc. (Chamney 1964, 1967).

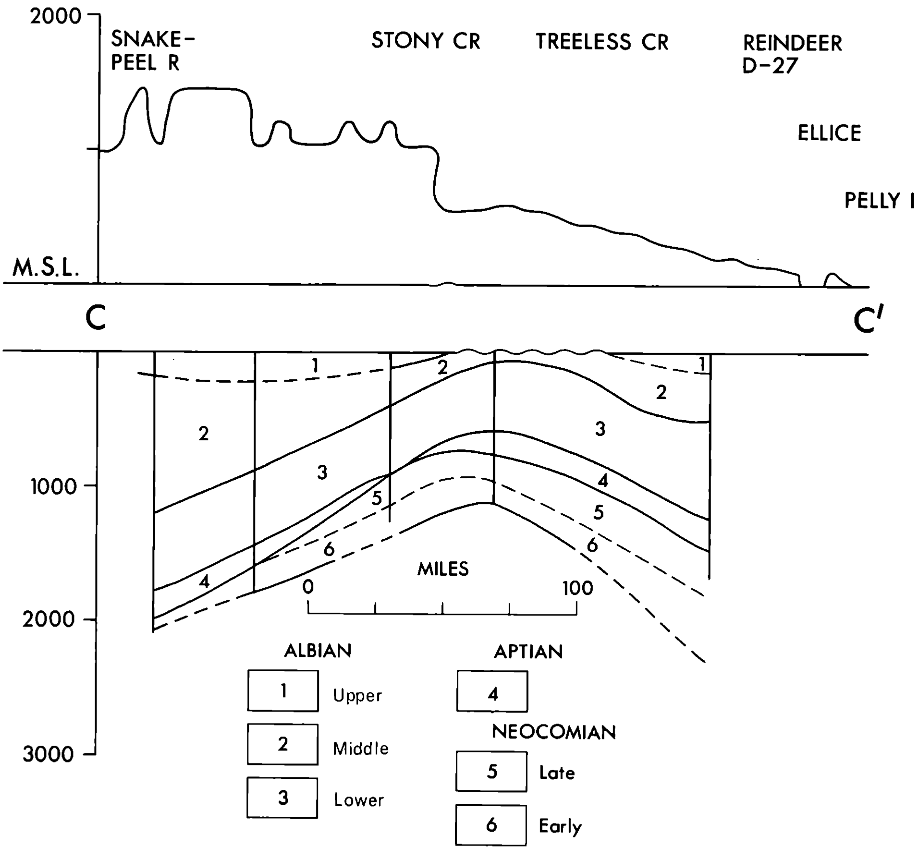

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Fig. 8. Geological profile: Mackenzie River Delta—south to north, C-C′.

Upper Cretaceous

The boundary between the Upper and Lower Cretaceous is commonly marked by a hiatus in deposition, whereas the boundary between the Lower Cretaceous and Jurassic is commonly characterised by continuous deposition. Very general criteria can be reported for identification of this boundary in that either (a) Turonian or (b) Santonian will be resting unconformably on the Lower Cretaceous except in the areas exhibiting a well-developed "Fish Scale" Marker interval, where more continuous deposition could be interpreted. The microfossil biofacies for the Turonian consists of common Globigerinacea with a few agglutinated *Haplophragmoides* spp. and *Gaudryina* spp. The biofacies for the younger Santonian/Lower Cretaceous contact ("Morden" unconformity, Chamney 1969b) is predominantly a radiolarian assemblage of *Spumellaria* spp. and *Dictyometra* spp.

2b. Stratigraphical nomenclature

Figure 4 illustrates the rather complex nomenclatorial situation which results from the previously discussed limitations of the vast distances and isolated interior

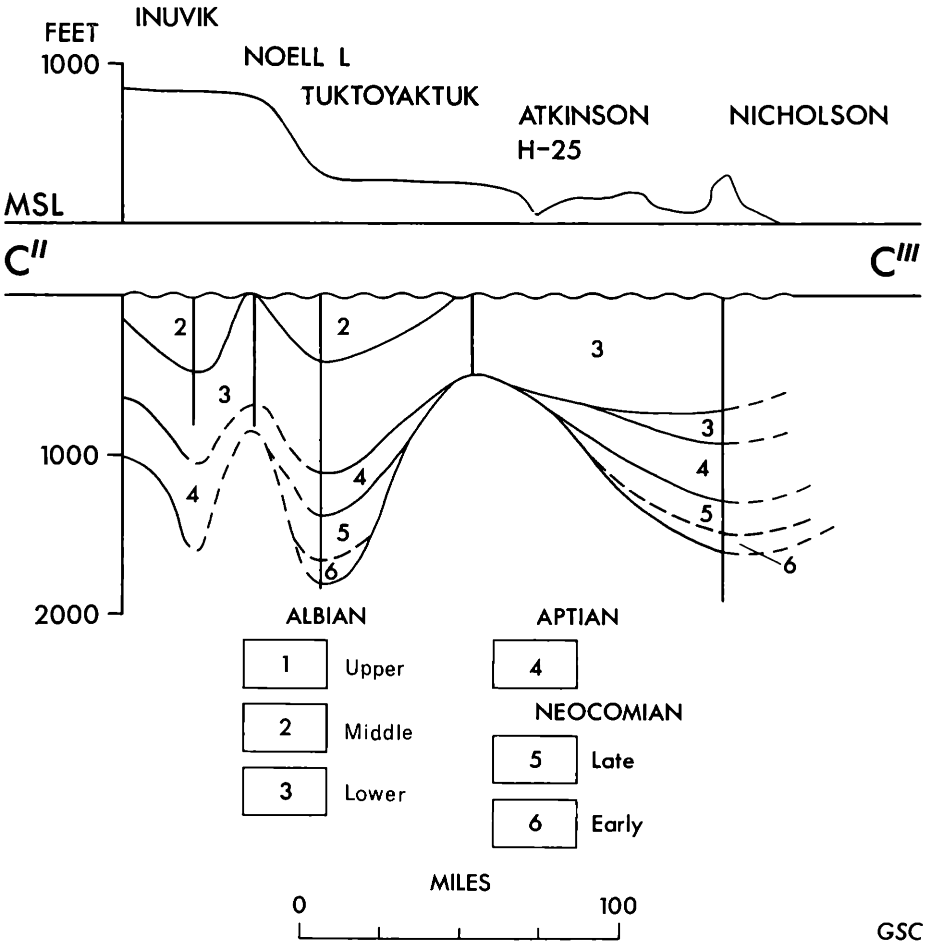

Fig. 9. Geological profile: Mackenzie River Delta—southwest to northeast, C″-C‴.

basins. Only the more commonly used rock-unit terms are selected for this table of formations. Discussion of physical stratigraphy for the hundred or so rock-units would constitute a paper in itself and is not within the scope of this paper. In general the lithology of the Canadian boreal Lower Cretaceous is sandstone, siltstone, mudstone and shale. Clay-ironstone concretions and beds are common throughout the sequence and are significant for different depositional intervals from one geological province to another. The coarser clastic units are associated in one way or another with ancient delta complexes. In the Arctic Islands a general easterly shoreline is postulated as the most active land mass contributing these clastics. The Isachsen Formation serves as the best indicator for the location of the most active coarser sediment source. In this case such activity commenced in post-Valanginian time and continued until the Aptian in the general area of Axel Heiberg Island.

Continuing southwest on to the continent, interpretation of active land masses contributing the coarser clastics becomes more complex. Jeletzky (unpublished:

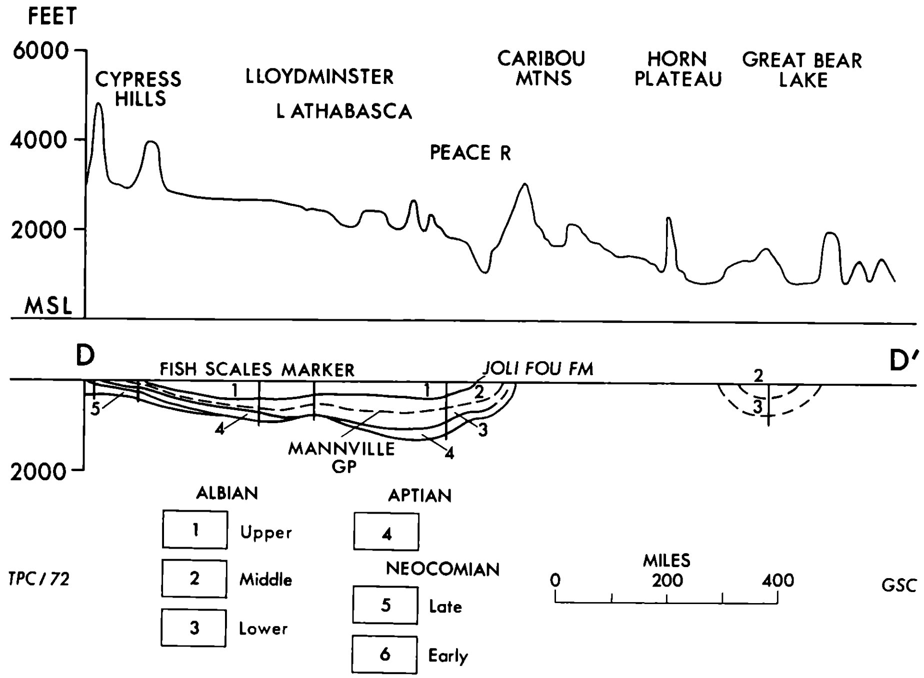

Fig. 10. Geological profile: Interior Platform, east, D-D′.

GSC open file no. 82) has postulated such sediment source areas for the Yukon and Mackenzie River Delta region. Here, the age of the first most active coarser clastic deposition is slightly older than in the Arctic Islands as indicated by the Lower Sandstone Division of the Valanginian. Most rock-units in this area were affected by more than one sediment source area as a result of embayments and trough-like basins within the influence of more than one shoreline. Farther south within the Interior Platform the eastern shoreline was relatively passive. The Lower Cretaceous sequence, in juxtaposition to the western shoreline along the Rocky Mountain Foothills, is represented by predominantly coarser clastic deposition from the Berriasian to late Lower Albian before the first major shale sequence is encountered. The coarser clastic sequence commenced in late Oxfordian-Kimmeridgian (Transition Beds) in the south to ?Kimmeridgian-Tithonian (basal Minnes Group) in the north (Chamney *in* Stott 1969). The Cadomin-Elko Conglomerate along the Rocky Mountain Foothills represents the maximum sediment source uplift to the west in early Aptian time.

3. Geological profiles

The Western Interior and Arctic provinces of known boreal Lower Cretaceous deposits are grouped into six areas (Fig. 2, A to F) in order to illustrate graphically by profiles the biostratigraphical correlations within the major geological provinces.

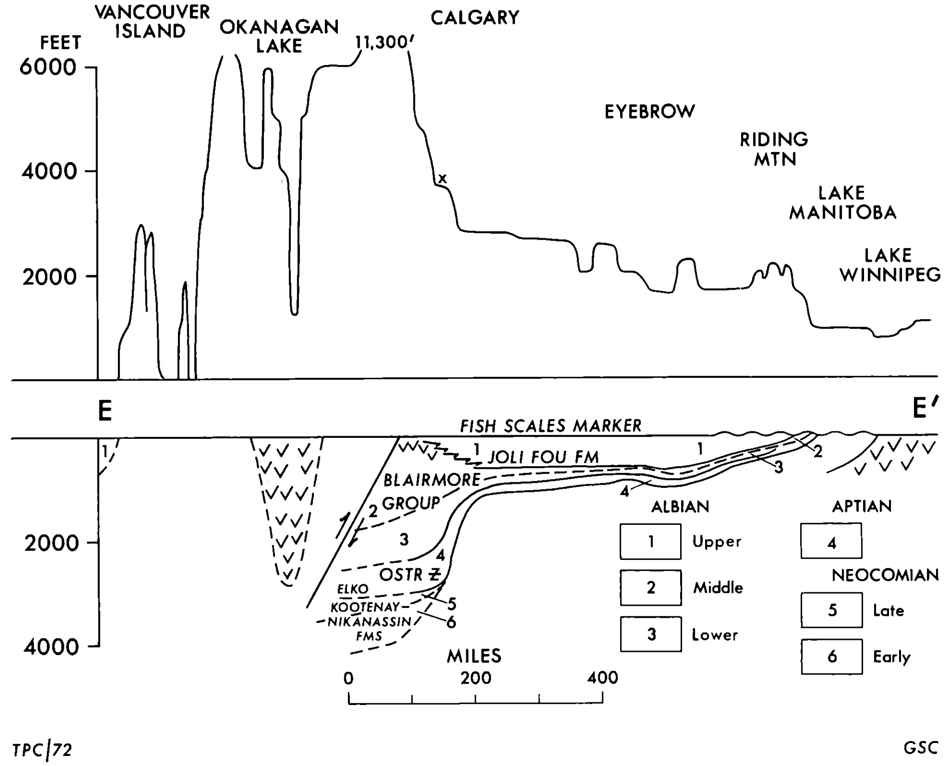

Fig. 11. Geological profile: Interior Platform, south, E-E′.

The profiles are constructed on an upper and lower datum level. The datum for the upper profile is mean sea-level and diagrammatically represents the present topographic relief of the area; the datum for the lower profile is the top of the Lower Cretaceous and represents the thickness of the rock-unit sequence present for each designated control section.

3a. Arctic Islands (Area A of index map, Fig. 5)

The line of section A-A′ for Figure 6 extends approximately 2,400 kilometres from southwest to northeast from the continental edge of the Arctic Coastal Plain to Greenland. More than 3,000 metres of Lower Cretaceous deposits are present in the epicentre of the Sverdrup Basin at Axel Heiberg Island; this represents the greatest thickness of the report area. The Cretaceous-Jurassic boundary is somewhat transitional within the more or less homogeneous shale of the Mould Bay—Deer Bay Formations (Chamney 1971a). The Upper-Lower Cretaceous boundary is quite distinct and is represented by the Morden Unconformity in the southwest portion of the profile (Chamney *in* Stott 1969) and by some volcanics and conglomerates in the base of the Upper Cretaceous in the central and northwest area (Plauchut 1971). Only the Barremian and Hauterivian appear to be unrepresented in

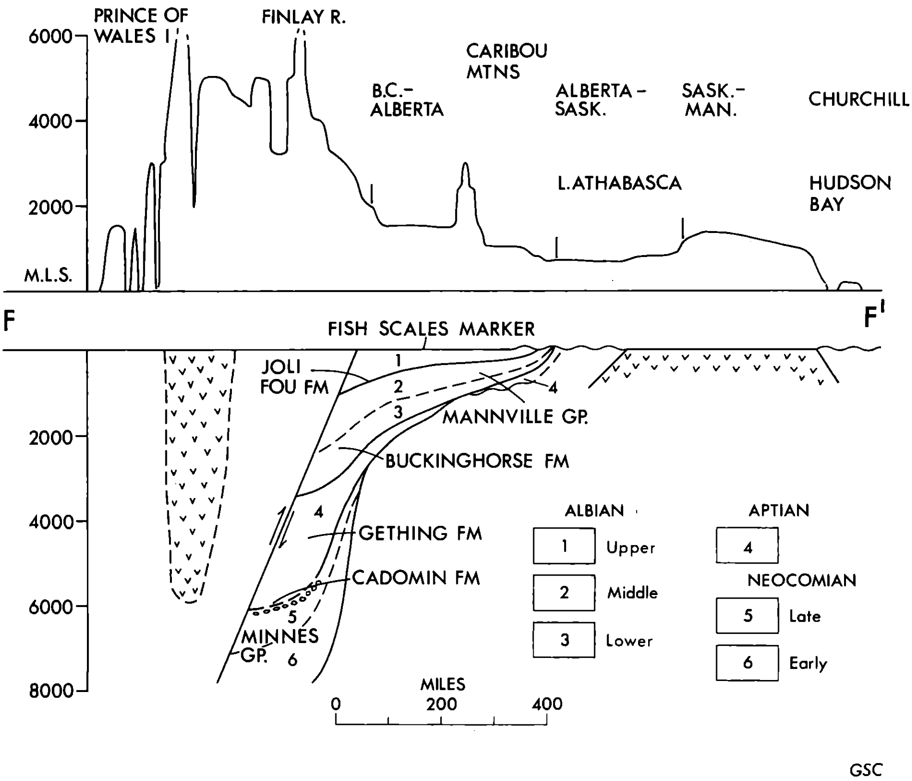

Fig. 12. Geological profile: Interior Platform, central, F-F'.

the depositional sequence; the Upper and part of the Middle Albian are missing in the southwest area as a result of the Morden Unconformity.

3b. Arctic Mainland (Area B of index map, Fig. 5)

The line of section B-B' for Figure 7 extends approximately 1,760 kilometres from the Alaskan coast in the northwest to Great Bear Lake, District of Mackenzie in the southeast. Approximately 1,000 metres of Lower Cretaceous deposits are shown along this line of section but greater thicknesses of Albian "flysch" (Young 1971) are present north of the British Mountains. All stages are represented in the sequence but there is a progressive pinch-out of older rock-units from the boreal marine source in the northwest to the inland, continental marine basins to the southeast. The depositional relationship east of Great Bear Lake is an Upper Cretaceous onlap over the Precambrian Shield. There is also loss of younger depositional intervals due to erosional scour related to the Morden Unconformity The extreme down-cutting action is best represented in the Prudhoe Bay area where Turonian-Santonian strata of the Upper Cretaceous rest unconformably upon the Neocomian. On the east and west margins of this profile, Aptian erosion was considerable but marine deposition occured in the deeper basins (Chamney *in* Mountjoy and Chamney 1969).

3c. Mackenzie Delta (Area C of index map, Fig. 5)

Two sections are given for the Mackenzie Delta. The line of section C-C′ for Figure 8 extends approximately 320 kilometres north from the Snake and Peel River junction in the Yukon Territory to Richards Island in the Delta area of the Beaufort Sea. The oldest strata penetrated by exploratory wells in the Beaufort Sea area are late Neocomian (Barremian?) based on the *Gaudryina tappanae* Zone at a depth of 3,828 metres (12,560 feet) (Chamney 1971a). Projected thicknesses of the older Lower Cretaceous strata plunging beneath the Arctic Ocean give a maximum thickness for the total Lower Cretaceous of approximately 750 metres. This figure approximates to the regional thickness, thus indicating a normal shelf environment during deposition of Lower Cretaceous strata for the Mackenzie River Delta area; the anomalously thick sequence of sediments (greater than 3,300 metres) are mainly of Tertiary age deposited during the Laramide Orogeny.

The influence of the Richardson Mountains uplift during the Valanginian and Hauterivian stages of the Lower Cretaceous resulted in abnormally thick clastic sediment accumulations in the Vitrekwa and Stony Creeks area. This was compensated by considerable thinning by Aptian and post-Lower Cretaceous (Morden Unconformity) erosional scouring. Thus the resulting thickness of the Lower Cretaceous is not more than about 600 metres in any one locality.

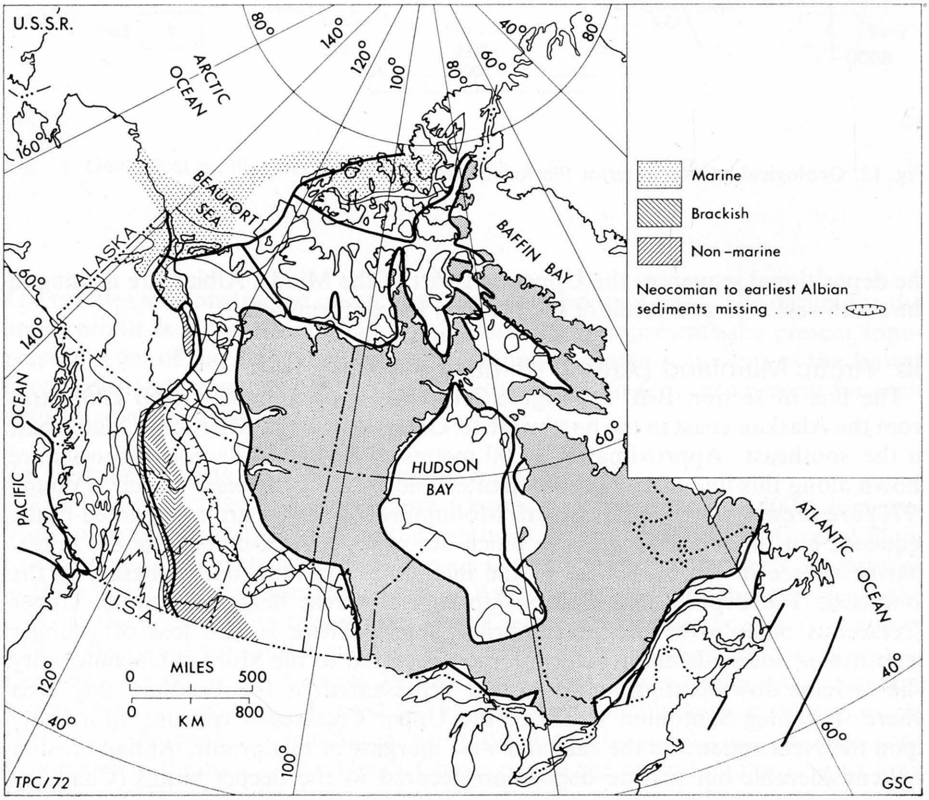

Fig. 13. Palaeogeographical map—early Neocomian.

The line of section C″-C‴ for Figure 9 extends approximately 400 kilometres northeast from the Inuvik area in an arcuate line subparallel to the ancient Lower Cretaceous landmass east of the "Delta" basin. Structural cross-trends to the northwest from the landmass effect an undulating palaeotopographical relief. Thus a combination of the undulating palaeotopography at the base and the previously mentioned Morden Unconformity at the top, results in the most extreme thicknesses of the Lower Cretaceous deposits in the Arctic area; the thicknesses range from 150 to 577 metres.

3d. Interior Platform (East) (Area D of index map, Fig. 5)

The line of section D-D′ for Figure 10 extends approximately 2,400 kilometres northwards from the United States border in the vicinity of the Alberta and Saskatchewan border to Great Bear Lake, District of Mackenzie. Some Neocomian deposits are interpreted to be present in the extreme southern part of the area. These rocks are of nonmarine to brackish-water origin and are equivalent in part to *Metacypris* (*Gomphocythere*) *pahasapensis* Zone (Fig. 3). The remaining Cretaceous stages are represented throughout the area but in very reduced thicknesses and very restricted marine to nonmarine environments. The maximum thickness is in the Peace River area where the deposits are approximately 380 metres thick; the minimum thickness, near the United States border, is approximately 150 metres.

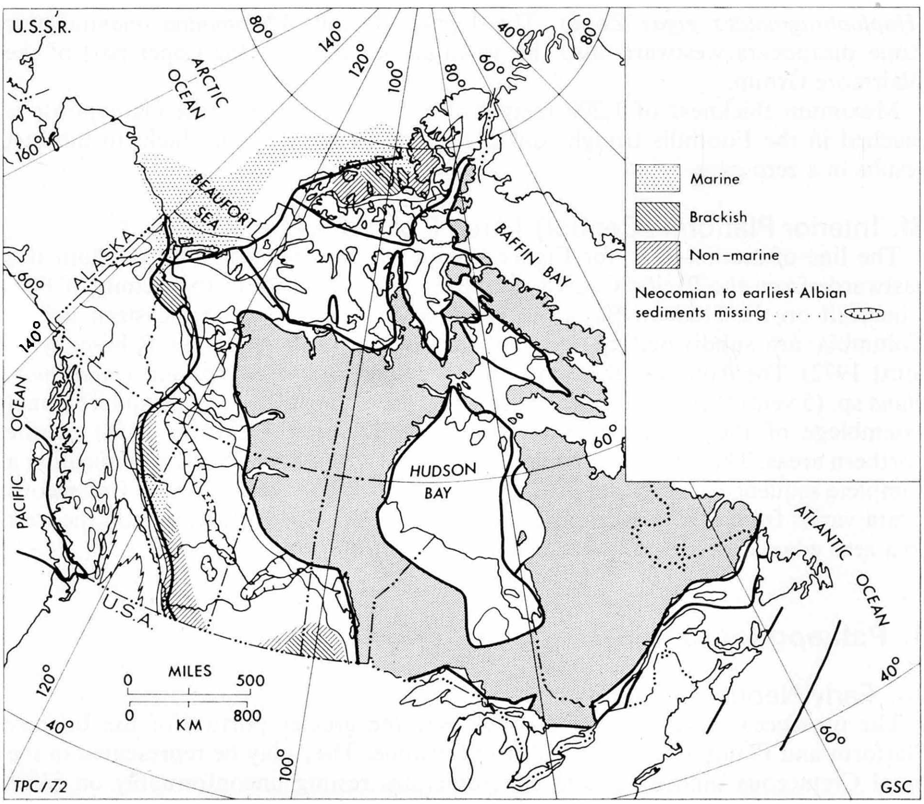

Fig. 14. Palaeogeographical map—late Neocomian.

3e. Interior Platform (South) (Area E of index map, Fig. 5)

The line of section E-E′ for Figure 11 extends approximately 1,920 kilometres eastwards from the Pacific Coast to the Precambrian Shield in the vicinity of Lake Winnipeg. The west coast Lower Cretaceous deposits are assigned to the Pacific microfaunal province (Jeletzky 1971) and thus are not included in this report. Age assignments for the depositional sequence of the Kootenay and Nikanassin Formations are only provisional. The presence of *Titanites giganteus* in the basal Kootenay Formation sandstones (Frebold 1957), together with some evidence from dinoflagellates (Pocock 1964) in the lower part of the Kootenay Formation, indicates an Upper Jurassic age (Upper Tithonian). The remainder of the rock sequence up to the Elko-Cadomin Formation (conglomerate) is thus assigned to the Neocomian and tentatively shown as representing early and late subdivisions; the latter age has been indicated by the *Glomospira* spp. Zone (Chamney's fig. 5 *in* Jansa 1972). The *Metacypris* (*Gomphocythere*) *persulcata* or Blairmore ostracod Zone (Loranger 1951), which is assigned to the Aptian (Chamney unpublished), occurs within the Alberta Basin and in the calcareous "zone" of the Blairmore Formation in some areas of the Foothills. The Albian is difficult to subdivide in the coarse clastic facies of the Foothills trough, but some elements of the "Clearwater Sea" microfauna are present (*Saracenaria trollopei* Zone) to indicate early Albian deposition in this area. The Plains portion of this area to the east is sufficiently more marine with lutitic lithologies to permit good control for both the "Clearwater Sea" Lower Albian and the "Joli Fou Sea" Middle Albian microfaunal facies (*Haplophragmoides gigas* Zone). The Upper Albian *Miliammina manitobensis* Zone disappears westward into the volcanic tuff beds of the upper part of the Blairmore Group.

Maximum thickness of 1,200 metres of existing Lower Cretaceous deposits is reached in the Foothills trough; onlap on to the Precambrian Shield to the east results in a zero edge.

3f. Interior Platform (Central) (Area F of index map, Fig. 5)

The line of section F-F′ for Figure 12 extends approximately 2,400 kilometres eastwards from the Pacific Coast to the Precambrian Shield in the vicinity of Fort Churchill on the Hudson Bay. The Neocomian deposits of northeastern British Columbia are subdivided questionably into early and late ages (Chamney *in* Stott 1972). The Aptian of this same area provided *Serovaina* sp. and *Quadrimorphina* sp. (5 ventral chambers) which, in turn, are associated with the microfaunal assemblage of the Aptian Upper Sandstone Division (Jeletzky 1958) of the northern areas. The remaining Albian microfossil zones are all present, indicating a complete sequence of these deposits. The thickness of the boreal Lower Cretaceous strata varies from a maximum of 2,400 metres in the Foothills trough on the west to a zero edge of onlap on to successively older strata to the east.

4. Palaeogeographical interpretations

4a. Early Neocomian (Figure 13)

The presence of Neocomian deposits over the greater portion of the Interior Platform and Plains areas is difficult to determine. They may be represented in the basal Cretaceous sandstones and conglomerates resting unconformably on older strata. In particular, the areas of subcropping Palaeozoic carbonates exhibit considerable local relief in the palaeotopography and remnants of Neocomian are undoubtedly represented in the depressions as basal quartz sands; overlying, marine transgressions of the Albian provide datable strata. There are some minor differences in interpretation of the palaeogeography from that of Jeletzky (1971). Early Neocomian deposits are interpreted to be present over part of the Tuktoyaktuk Peninsula (see Fig. 9) and nonmarine to brackish deposits are included within the Interior Platform area, which extends the presence of possible early Neocomian strata into the Foothills area. Access to a boreal marine source for the Interior Platform is interpreted to have been through the general area of the present Mackenzie River drainage system. Only sporadic representation of undifferentiated Neocomian strata is present from northeastern British Columbia to the north-plunging Mackenzie Mountains in the District of Mackenzie.

4b. Late Neocomian (Figure 14)

In general, the Arctic marine lithofacies of this depositional interval (which includes the Barremian) comprises somewhat softer shale and mudstones, less resistant to erosion than the underlying Valanginian sandstones and the overlying Aptian and early Albian sandstones. As a result, the pre-Albian and in some areas the pre-Santonian erosional episodes have erased this rock-unit from the present

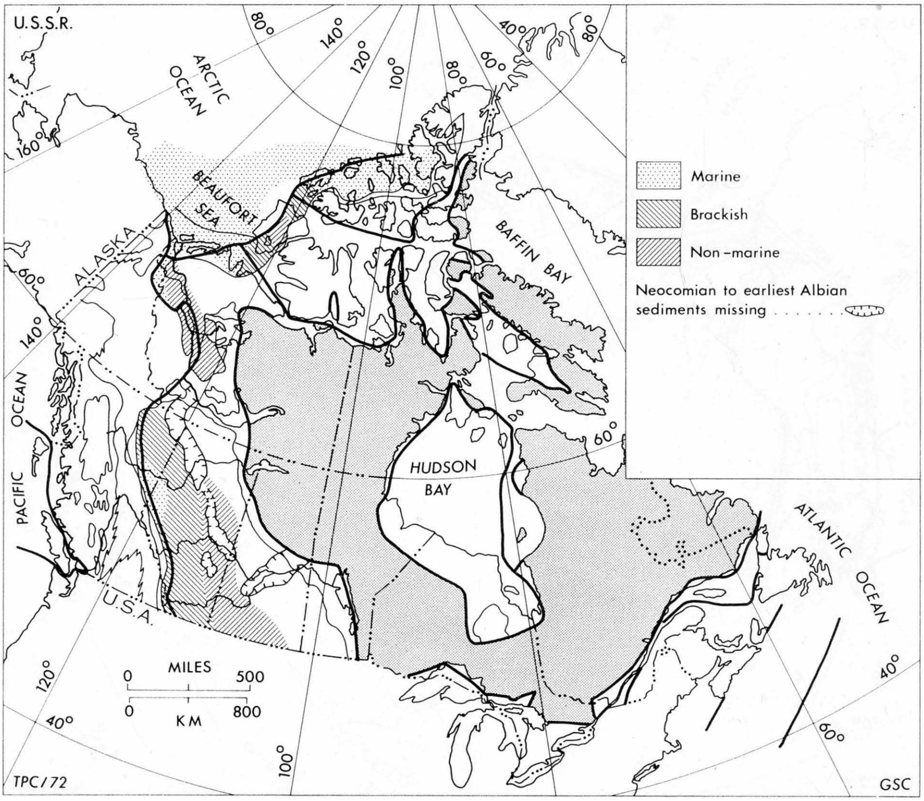

Fig. 15. Palaeogeographical map—Aptian.

sequences (see Figs 6 and 8). But from micropalaeontological evidence of the abundant Foraminifera present throughout the Barremian, it is the strongest Neocomian marine transgression.

Marine intervals have been recognized as far south as northeastern British Columbia (see Fig. 12). Brackish-marine conditions are indicated also in the depositional sequence in the extreme southeastern portion of the study area. There are some minor differences in interpretation of the palaeogeography from that of Jeletzky (1971). These include a greater areal extent of deposition of brackish and nonmarine strata in the Arctic Islands and the extreme southeastern part of the Interior Platform (Manitoba). Marine deposits are interpreted for a part of the central Foothills area of the Interior Platform.

4c. Aptian (Figure 15)

More and more evidence is being accumulated indicating that the Aptian interval in Western and Arctic Canada was a period of very active epeirogenic movements. The marine intervals that have been recognized are within predominantly coarse clastic lithofacies both in the Arctic areas and the Interior Platform. The clastic basal Cretaceous rock-unit resting unconformably upon older Mesozoic and Palaeozoic strata over the greater part of the Plains area is pre-

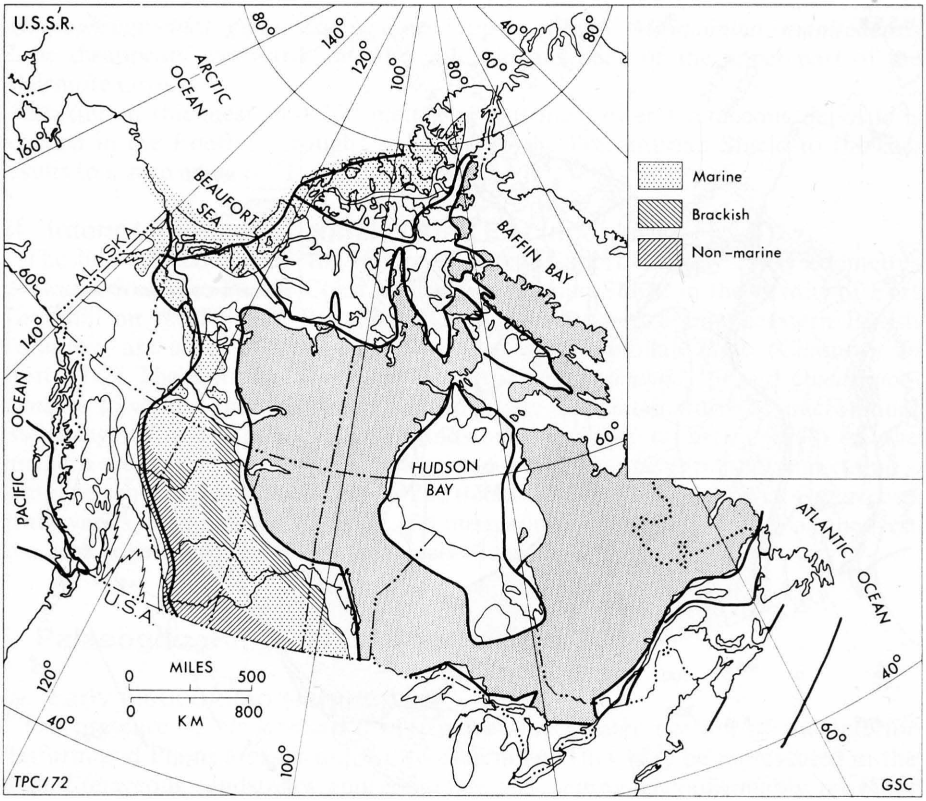

Fig. 16. Palaeogeographical map—Lower Albian.

dominantly non-marine and it is very difficult to assign a precise age. The Foothills trough has recently provided sufficient Aptian foraminiferal control in the Gething Formation and correlations can be extended eastward through the bordering sediments of brackish-water origin of the *M. persulcata* Zone to permit age assignment for a considerable area of the "basal" Cretaceous coarse clastics of the Plains area (*Pyrobolospora hexapartita* Zone).

In the Arctic areas of more continuous deposition, additional difficulties are encountered in delineating Aptian microfossil assemblages from those of the underlying Barremian and the overlying Lower Albian. Similar difficulties are in evidence even in some of the classical European areas where the Aptian was formerly shown as the upper substage of the Neocomian and in other instances has been masked in the depositional sequence of the lowest Albian.

4d. Lower Albian (Figure 16)

The present occurrences of deposits from the early Albian marine transgression do not represent the greatest areal flooding during the Albian stage, but this depositional interval provides the best marine microfauna. The *Saracenaria trollopei* Zone with its associated *Marginulinopsis collinsi* and *Lenticulina macrodisca* assemblage invaded the Interior Platform southward into the Alberta Basin. The

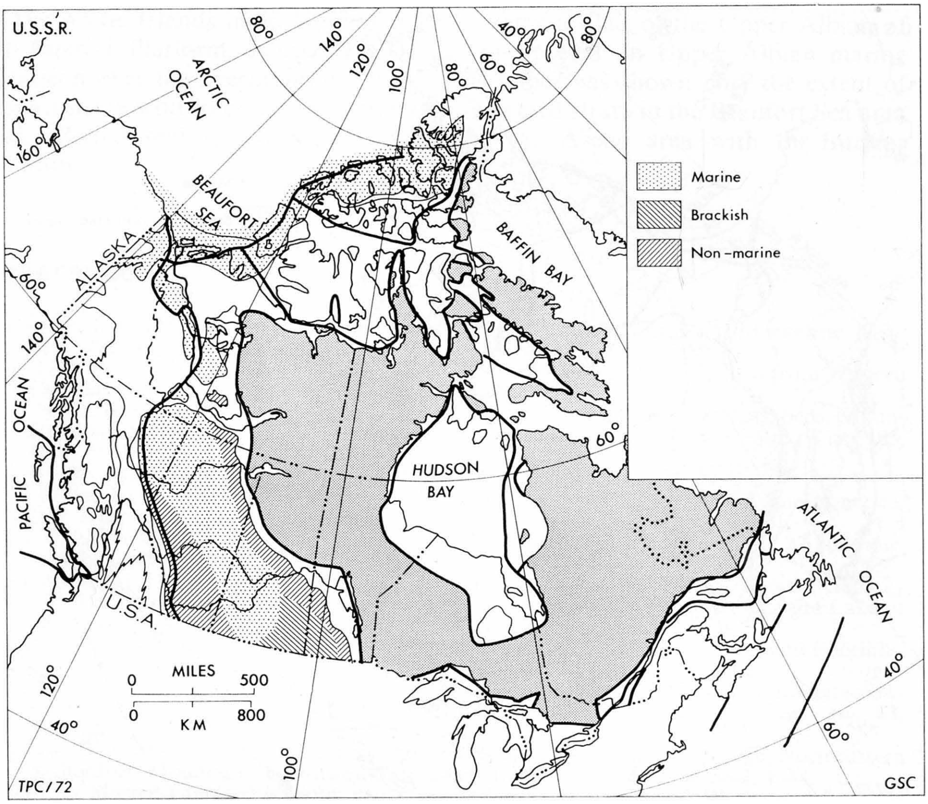

Fig. 17. Palaeogeographical map—Middle Albian.

epicentre for the marine trough is subparallel to the east of the Foothills trough. There appears to be an eastward migration of the epicentre for each successive Cretaceous stage. Within the Albian, the epicentre for marine transgression of the Middle and Upper Albian appears to migrate even farther eastwards. Control data for these interpretations are from subsurface micropalaeontology of the Plains area. Minor differences in interpretation from Jeletzky (1971) result from the inclusion of this latter source for control; several different classes of microfossils from the paralic, brackish to nonmarine environmental zones are used for the interpreted palaeogeography of the Lower Albian.

4e. Middle Albian (Figure 17)

The epicentre of the marine trough in the Interior Platform trends northwest to southeast crossing the Alberta-Saskatchewan border in the vicinity of Lloydminster. The approximate base of the substage in this area is marked by the abundance of *Spiroplectinata bettenstaedti*; the upper boundary is marked by the distinctive zonal index fossil *Haplophragmoides gigas* within the Joli Fou Formation. This latter rock-unit (a grey shale) is one of the most widespread, consistent, lithostratigraphical intervals of the total Cretaceous. Calcareous Foraminifera or other classes of microfossils indicating proximity to open marine conditions are very rare as opposed to the Lower Albian marine transgression.

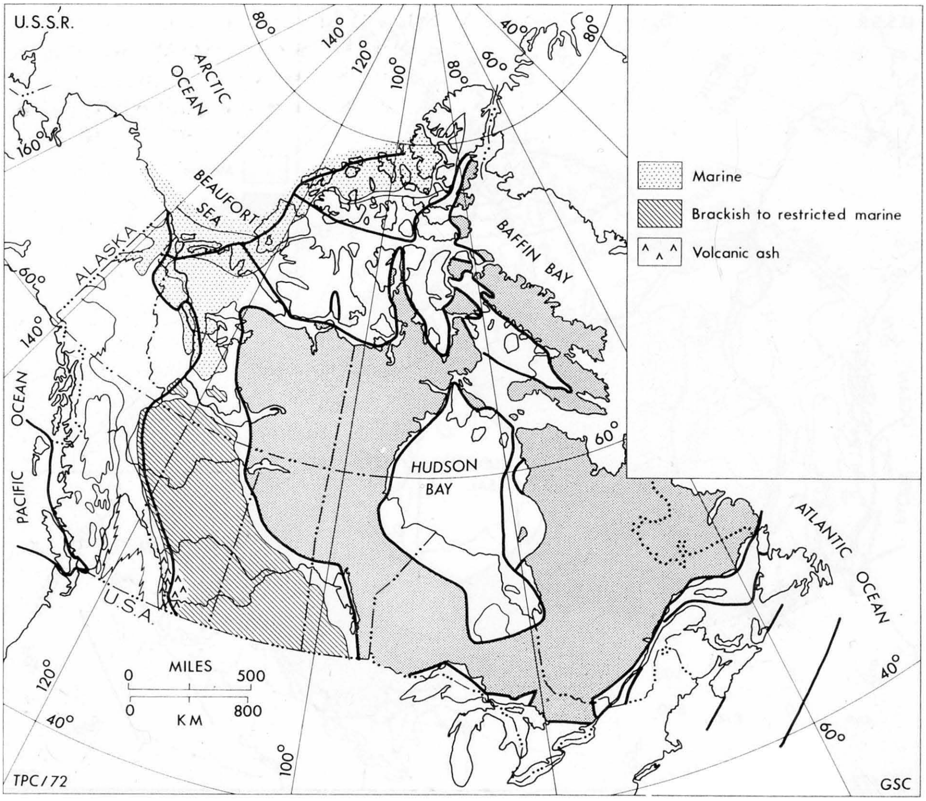

Fig. 18. Palaeogeographical map—Upper Albian.

The Notikewin and Joli Fou Seas of the Middle Albian (Chamney *in* Mountjoy and Chamney 1969) exhibit the effects of both the western and eastern shorelines. Deltaic fans in the west and silty to sandy lithofacies in the east mask the foraminiferal control in these areas. There is an indication of a southern shoreline for the Lower Albian in the vicinity of the United States border. But both the Middle and Upper Albian seas appear to continue southwards into the Western Interior of the United States. The time equivalent of the Middle Albian Joli Fou Formation to the south is the Skull Creek and Kiowa Formations with some possible Gulfian marine source. Jeletzky (1971) did not produce a palaeogeographical map for the Middle Albian substage (*Gastroplites* Zone).

4f. Upper Albian (Figure 18)

The epicentre of marine deposition is somewhat bifurcated in the Interior Platform with the Sweetgrass-Lloydminster Arch separating the two seaways. A very shallow marine to brackish-water environment is interpreted for this area of deposition. The foraminiferal content comprises predominantly primitive, tube-coiled, agglutinated (highly siliceous), benthonic forms. The *Miliammina manitobensis* Zone occurs in the Plains area and is replaced by *Psamminopelta bowsheri* and *P. subcircularis* in northeastern British Columbia and Arctic Canada. In the Arctic areas exclusive of the Arctic Islands, the Grandstand Formation equivalent typifies the good open marine facies with the *Valvulinaria loetterlei* Zone and associated *Gavelinella* spp. The microfaunal assemblage of the Hassel Formation in the Arctic Islands indicates similar bathymetry to that of the Upper Albian of the Interior Platform. Jeletzky (1971) has interpreted an Upper Albian marine incursion over the Precambrian Shield. This paper has shown only the extent of known strata with some extrapolation of interpreted strata in the Beaufort Sea area and inferred seaway "troughs" connecting the Arctic area with the Interior Platform.

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Base and Geological maps:

Geological:	Geol. Surv. Canada Map 1250A Geol. Surv. Canada Map 10–1963 (revised)
Base:	Geol. Surv. Canada Map 1–1970

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Biochronology of the marine boreal latest Jurassic, Berriasian and Valanginian in Canada

J. A. Jeletzky

Marine rocks with boreal faunas of latest Jurassic to Valanginian age occur in the Sverdrup Basin, the Porcupine Plateau—Richardson Mountain Trough, and adjacent parts of the Arctic Coastal Plain. Among macroinvertebrates, only *Buchia* species and ammonites are of value for zonal subdivision. One *Buchia* zone is recognised in the uppermost Volgian and two in each of the Berrisian and Valanginian stages. *Buchia* species are used for internal correlation while ammonites, although irregularly and sparsely distributed, are the principal means of correlation with other parts of the world. One new ammonite species, *Praetollia antiqua*, is described and figured.

Marine Sedimente mit borealen Faunen von Spätjura- bis Valangin-Alter gibt es im Sverdrup-Becken, in dem Porcupine Plateau—Richardson Mountain—Trog und in den benachbarten Gebieten der arktischen Küstenebene Kanadas. Von den Makroinvertebraten eignen sich nur *Buchia*- und Ammoniten-Arten für eine Zonengliederung. Eine *Buchia*-Zone wird im Ober-Wolga und je zwei werden im Berrias und Valangin unterschieden. Die *Buchia*-Arten sind für eine regional begrenzte Korrelation brauchbar. Für Vergleiche mit anderen Teilen der Welt müssen die selteneren und unregelmäßig verbreiteten Ammoniten herangezogen werden. Eine neue Ammoniten-Art, *Praetollia antiqua* wird beschrieben und abgebildet.

Des roches d'origine marine et à faune boréale d'âge jurassique terminal à valanginien se rencontrent dans le Bassin du Swerdrup, la dépression du Plateau Porcupine et des Montagnes Richardson ainsi que dans les régions bordières de la plaine côtière arctique. Parmi les Invertébrés, seules les espèces du genre *Buchia* et les Ammonites jouent un rôle dans la subdivision zonale. Une zone à *Buchia* est reconnue dans le Volgien terminal et deux dans chacun des étages Berriasien et Valanginien. Les espèces du genre *Buchia* sont utilisées pour les corrélations locales, tandis que les Ammonites, en dépit de leur distribution irrégulière et peu abondante, sont les principaux éléments des corrélations sur le plan universel. Une nouvelle espèce d'Ammonite *Praetollia antiqua* est décrite et figurée.

1. Introduction

This paper attempts to summarise and to bring up to date the information now available about the zonal sequence, internal correlation and external correlation of the marine boreal latest Jurassic, Berriasian and Valanginian rocks in Canada. These rocks have received considerable attention since their first outcrop areas were discovered in the eastern Richardson Mountains and the northwestern part of the Canadian Arctic Archipelago during the early nineteen-fifties. Published information is synthesised in several regional papers (Gabrielse 1957; Heywood 1957; Jeletzky 1958-Jeletzky 1972; Plauchut 1971; Tozer 1956, 1960; Tozer *in* Thorsteinsson and Tozer 1970; Tozer and Thorsteinsson 1964) but much remains unpublished. Because of the rapid accumulation of new information the writer's publications are already outdated and, for the same reason, this paper should be regarded as a progress report only.

Many of the diagnostic elements of the Canadian boreal marine faunas discussed in this paper have already been briefly described and/or figured (Jeletzky 1964,

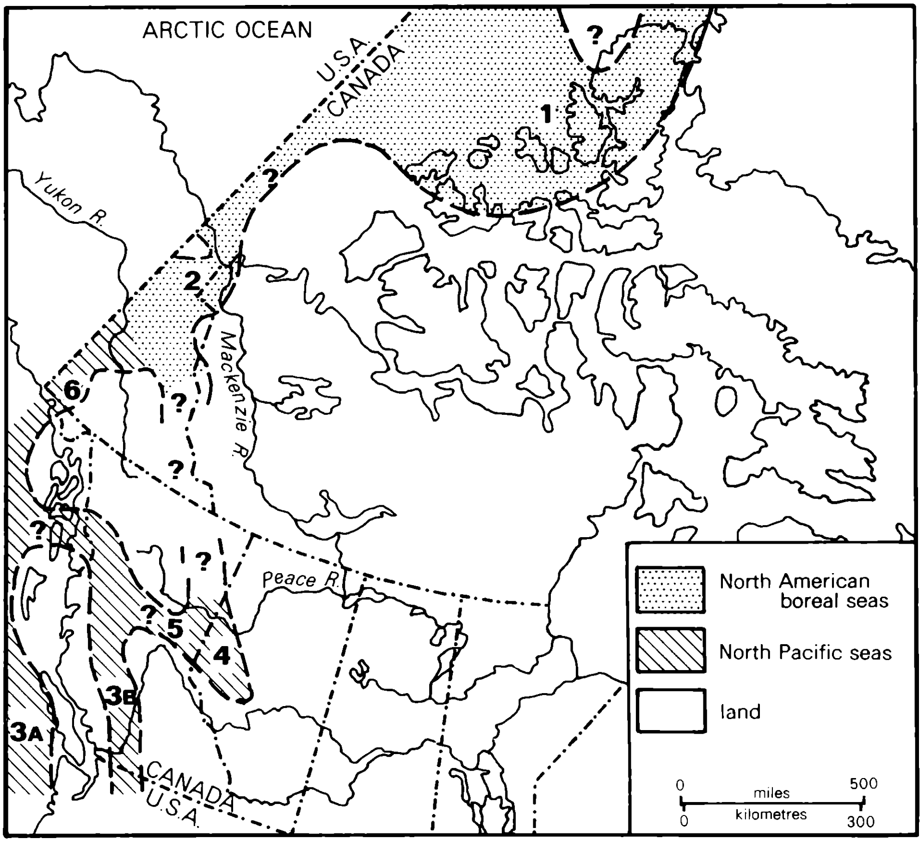


Fig. 1. Latest Jurassic, Berriasian and Valanginian biotic provinces and palaeogeography of western and Arctic Canada.
1 Sverdrup Basin; 2 Porcupine Plateau—Richardson Mountain Trough; 3A Insular Trough; 3B Tyaughton Trough; 4 Peace River Basin; 5 Vanderhoof Seaway; 6 Dawson City Strait.

1965a, 1965b, 1970) while others have received only passing mention. In order to document the presence of these important faunas some of the diagnostic ammonites are described and illustrated in the palaeontological appendix to this paper.

The term "external correlation" is applied to the correlation of the Berriasian and Valanginian rocks of the report area with occurrences elsewhere in Canada and abroad. The ultimate objective of the external correlation attempted in this paper is to recognise the approximate positions of the international standard stages (based on the West European fossil-zones) in the Canadian boreal sequence. The correlation of this sequence with the standard zones and regional stages used in the central part of the Russian Platform and in Northern Siberia will be discussed in detail because it is an indispensable step toward the ultimate goal. Other important early Lower Cretaceous outcrop areas will be considered where necessary. The term "internal correlation" is applied to the correlation of individual outcrop areas and sections situated within the report area and to the working out of a regional zonal sequence applicable to the Canadian boreal succession (see Fig. 2).

2. Palaeogeographical and palaeobiotic setting

The faunas of the Canadian boreal early Lower Cretaceous rocks form part of a separate biotic province (Jeletzky 1970, 1971a, 1971c) named the North American Province of the Boreal Realm (Jeletzky 1970). This province was named Chukotian-Canadian biotic Province by Saks *et al.* (1971). In latest Jurassic, Berriasian and Valanginian time the Canadian part of the province was restricted to parts of the Canadian Arctic Archipelago and parts of the Yukon and Mackenzie District of the Northwest Territories (Fig. 1).

The Western Cordillera of Canada and the Peace River region formed part of the North Pacific Province of the Tethyan Realm at this time (Jeletzky 1970, 1971a, 1971c; Fig. 1 here); they are consequently beyond the scope of this paper except for the purposes of external correlation. They were connected with the Canadian boreal seas by the Vanderhoof and Dawson City seaways (Fig. 1).

The palaeozoogeographical interpretation of early Lower Cretaceous rocks of the Peace River region may be subject to revision in the light of a still unfinished study of their lithofacies (Dr. D. F. Stott, unpublished data).

3. Biochronologically useful macrofossils

Like the rest of the marine Cretaceous faunas of the Canadian part of the North American Boreal Province, the faunas of the Berriasian and Valanginian stages (and of the latest Jurassic) differ markedly from those of other provinces of the Boreal Realm (climatic belt). They are characterised (Jeletzky 1970, 1971a, 1971c; Saks *et al.* 1971) by a lack of diversity in comparison with the coeval faunas of the North Atlantic and North Siberian (= Arctic Province of Saks, Mesezhnikov and Shulgina 1964) Provinces. Because of this extreme impoverishment only a few groups of marine macroinvertebrates have a practical biochronological use.

Ammonites occur only sporadically and are often extremely rare or absent. They belong almost exclusively to the subfamilies Craspeditinae (inclusive of Tolliinae) and Polyptychitinae and are common only in parts of the Canadian Arctic Archipelago succession. Even in that region, characterised by the prevalence of the deeper water, outer neritic, concretionary shales of the Deer Bay Formation, considerable parts of the sequence are all but devoid of ammonites. On the whole, ammonites are considerably more useful for the purpose of external rather than internal correlation and are commonly used only to assess the time ranges of other much more numerous but less reliable index-fossils (mainly *Buchia* species) as well as to effect the approximate correlation of the regional zones with the standard ammonite zones of other regions and the international standard stages.

Within the Canadian boreal region, more-or-less short-ranging and facies-tolerant pelecypods, such as species of *Buchia, Inoceramus* and *Meleagrinella* (apparently including ?*Aucellina schmidti* Sokolov and its Canadian allies), and *Arctotis* have to be used for dating and internal correlation. Other pelecypods appear to be too long-ranging or facies-bound, or both, to be of much use, even as parachronological indices. Of the above mentioned, parachronologically and partly orthochronologically useful pelecypod taxa, *Buchia* has proved to be much superior because of its considerably greater abundance and facies tolerance coupled with its reasonably rapid evolution. Because of their extended (often intercontinental) geographical ranges and short time ranges a number of *Buchia* species were found to be valuable for external correlation.

Belemnites are rare, restricted in occurrence, and usually execrably preserved. All other macrofossil groups are too rare (Jeletzky 1970, 1971a) to be of any practical use. Hence the regional zonal table for Canada proposed herein (Figs 2, 3) is based exclusively on *Buchia* and ammonites. A number of zones are named after two fossils instead of one because of the internal usefulness of *Buchia* species contrasted with the orthochronological, external usefulness of the coeval ammonite species.

4. The Jurassic/Cretaceous boundary and the problem of regional stages

The lower boundary of the Cretaceous is placed at the base of the Berriasian stage in accordance with the now prevalent usage. The Berriasian is interpreted to include the *Berriasella grandis* Zone of the type-area, following the recommendation of the Lyon Colloquium on the Lower Cretaceous (Busnardo, Le Hégarat and Magné 1965). The value of this recommendation has been demonstrated by more recent research (Jeletzky 1968, 1971b; Sazonova 1971) which indicates that in Central Russia the equivalents of the *Berriasella grandis* Zone do not form part of the Upper Volgian stage but are represented by a hiatus between the uppermost Volgian beds (*Craspedites nodiger* Zone) and the late Berriasian Ryazan Beds. In Northern Siberia the equivalent Lower Berriasian beds appear to be represented only by the *Chetaites sibiricus* and *Hectoroceras kochi* Zones and in Canada only by the *Buchia okensis* and *Craspedites* (*Subcraspedites*) aff. *suprasubditus* Zone (see following sections for further details).

Although it represents the youngest known zone of the type Upper Volgian stage (Sazonova 1971), the *Craspedites nodiger* Zone hardly represents the topmost part of the boreal Jurassic. For reasons discussed below, it must be older than the North Siberian Zone of *Chetaites chetae* (e.g. Saks and Shulgina 1964; Saks *et al.* 1965; Saks, Mesezhnikov and Shulgina 1968a) and the *Praetollia antiqua* n. sp. beds of the Canadian Arctic Archipelago. The latter zones are tentatively correlated with the uppermost part (i.e. *Berriasella chaperi* Zone) of the *Virgatosphinctes transitorius* Zone of the European Tethys (Fig. 3).

The formidable difficulties which long stood in the way of a reasonably close correlation of the entirely Tethyan ammonite faunas of the type-areas of the Berriasian and Upper Tithonian stages (e.g. Mazenot 1939; Busnardo, Le Hégarat and Magné 1965; Le Hégarat 1965; Le Hégarat and Remane 1968) with the almost totally Boreal ammonite faunas of the type-areas of the Upper Volgian stage and the Ryazan horizon have been largely overcome recently with the aid of mixed ammonite and/or *Buchia* faunas found in the Jurassic/Cretaceous and Berriasian/ Valanginian boundary beds of eastern Siberia (Shulgina 1967), the central Russian Platform (Sazonova 1971), Western British Columbia (Jeletzky 1965a, 1968, 1971b; Jeletzky and Tipper 1968), Northern California (Imlay and Jones 1970; Jones, Bailey and Imlay 1969) and the Northern Caucasus (Grigorieva 1938; Rengarten 1951).

This situation is reflected in the widespread application of the stage term Berriasian to the basal Cretaceous rocks of the Boreal Realm (e.g. Saks and Shulgina 1962, 1964; Saks, Mesezhnikov and Shulgina 1968a; Jeletzky 1964, 1968, 1970, 1971b; Gerasimov 1955; Sazonova 1958, 1971), where it often supplants regional biochronological terms such as the Infravalanginian substage (e.g. Spath 1924, 1947, 1952), the Lower Valanginian substage (e.g. Bodylevsky 1960, 1967; Voronets 1962; Kemper 1968) or the Ryazanian stage or Ryazan horizon (Bogoslovsky 1902; Sazonova 1967; Casey 1971). In the writer's opinion the progress achieved makes it possible to dispense with the regional stage nomenclature for the equivalents of the Berriasian and Valanginian stages in the Boreal Realm and to use the Tethyan stages throughout its extent. This is undertaken in this paper in the Canadian part of the North American Boreal Province.

5. Biochronology of the marine boreal Berriasian and Valanginian in Canada

5a. Internal correlation

The sequences of macro-invertebrate faunas of all known outcrop areas, and their internal correlation, are summarised in Figure 2, which also includes the inferred ages of their individual zones in terms of the international standard stages. None of these sequences is complete, and one of the principal objectives of the writer's research was therefore to work out a composite, regionally applicable zonal sequence (see Fig. 3) from these incomplete sequences. No attempt was made to zone the non-marine intervals, which are discussed elsewhere (e.g. Stott *in* Douglas *et al.* 1970; Jeletzky 1970).

The latest Jurassic, Berriasian and Valanginian marine boreal rocks are strongly localized in the Canadian part of the North American Boreal Province (see Jeletzky 1968, 1970, 1971a, 1971c; this paper Fig. 1). The presence of shoreward facies changes toward the peripheries of the known outcrops and the presence of coeval nonmarine rocks in several adjacent areas suggests that the major hiatus representing the latest Jurassic to latest Valanginian time over most of Western and Arctic Canada reflects a lack of deposition rather than a subsequent removal of the marine sediments concerned.

On the Canadian mainland the marine boreal latest Jurassic, Berriasian and Valanginian rocks are only known in the Porcupine Plateau-Richardson Mountain Trough and adjacent parts of the Arctic Coastal Plain. This marine basin occupied parts of Northern and West-Central Yukon and adjacent areas of the Mackenzie

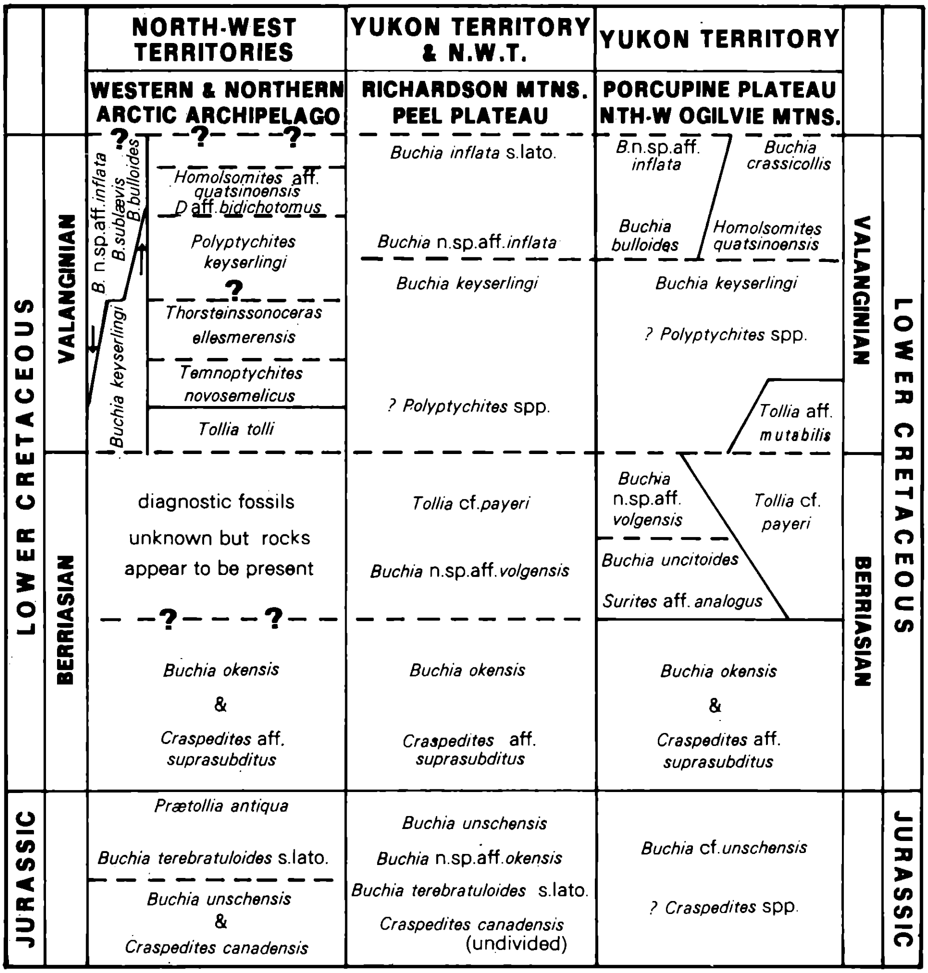


Fig. 2. Principal outcrop-areas and internal correlation of the marine boreal latest Jurassic, Berriasian and Valanginian rocks in Canada.

District. It was connected by the Dawson City Strait with the geosynclinal North Pacific seas of Western British Columbia (Fig. 1). Marine rocks of the same age may be widespread in parts of the Selwyn Basin adjacent to the Dawson City Strait (see Douglas *et al.* 1970). However, the allegedly Lower Cretaceous, mildly metamorphosed rocks of Selwyn Basin have not yet yielded diagnostic fossils.

The rather thick sequence in the Porcupine Plateau-Richardson Mountain Trough is continuous and consists predominantly of marine rocks except in its mid to late Valanginian part (Jeletzky 1958; 1960; 1961; 1971d; 1972). These marine rocks must have been directly connected on a wide front with the marine basin of the Canadian Arctic Archipelago because their macro-invertebrate faunas are closely similar (Jeletzky 1971a).

The value of the sequence in the Porcupine Plateau-Richardson Mountain Trough as a standard for external correlation is strongly reduced by the rarity and poor preservation of ammonites among its predominantly pelecypod faunas (Jeletzky 1964; this paper Fig. 2). The sequence must therefore be correlated externally with the aid of the relatively poorly known sequence of the Sverdrup Basin in the Canadian Arctic Archipelago (see Tozer *in* Thorsteinsson and Tozer 1970) which has provided the bulk of well preserved ammonite faunas of that age in Canada (see Fig. 2).

The succession in the Sverdrup Basin is the only other known outcrop area of boreal latest Jurassic to Valanginian rocks in Canada. The sequence here consists largely of homogenous shale with clay ironstone concretions and bands, comprising the middle and upper parts of the Deer Bay Formation. This shale overlies gradationally the lithologically similar shale of the lower part of the formation which has yielded early to late (but not the latest) Volgian fossils (Jeletzky 1966). The spacial and stratigraphical distribution of all presently known ammonite faunas in the Deer Bay Formation is random (see Tozer *in* Thorsteinsson and Tozer 1970) and none of the sampled sections has yielded more than three latest Jurassic and early Lower Cretaceous faunas. The stratigraphical and chronological relationships of these faunas (Figs 2, 3) had therefore to be deduced from the known stratigraphical and chronological relationships of the same or closely related ammonite faunas found in other parts of the Boreal Realm.

The recently measured and palaeontologically well-sampled latest Jurassic to Valanginian sections of the Khatanga Depression (Saks *et al.* 1959; Saks *et al.* 1963; Shulgina 1965, 1967; Saks, Mesezhnikov and Shulgina 1968a, 1968b; Saks and Shulgina 1969; Voronets 1962) and other areas of Northern and Western Siberia provided an invaluable standard of comparison because of a close affinity, and sometimes a complete identity, of their ammonite faunas with those of the Sverdrup Basin.

5b. The uppermost Jurassic beds and the Jurassic/Cretaceous boundary

Sections are known in the Sverdrup Basin and in the Porcupine Plateau-Richardson Mountain Trough in which the uppermost Jurassic rocks grade imperceptibly into the basal Cretaceous rocks (Jeletzky 1966, 1971b). However, well preserved, diagnostic latest Jurassic ammonites are unknown in the beds immediately underlying the basal Berriasian beds except in one section of the Deer Bay Formation. This section, measured and palaeontologically sampled by R. Thorsteinsson and E. T. Tozer in 1962, occurs about 7 kilometres southwest of Buchanan Lake, Axel Heiberg Island (see Tozer *in* Thorsteinsson and Tozer 1970 and GSC Map 1302A).

A well preserved fauna including *Praetollia antiqua* n. sp. (described in section 6, below), *Craspedites* (*Subcraspedites*) n. sp. indet., *Buchia terebratuloides* (Lahusen) f. typ., *B. terebratuloides* var. *obliqua* Tullberg, and *B. terebratuloides* var. *subuncitoides* Bodylevsky (GSC loc. 52488) was found there in place about 8·5 metres stratigraphically below the lowest bed containing the Berriasian *Buchia okensis* and *Craspedites* (*Subcraspedites*) aff. *suprasubditus* fauna (GSC loc. 52490). The *Praetollia antiqua* fauna was previously recorded (Jeletzky 1966, 1970, 1971b) as the *Tollia* (*Subcraspedites*?) n. sp. and *Buchia* ex gr. *uncitoides* fauna and eventually assigned an uppermost Jurassic age. The reasons for reappraisal of its ammonites are given in section 6.

According to E. T. Tozer (personal communication 1972), who has studied the Buchanan Lake section together with R. Thorsteinsson, the normal stratigraphical position of the *Praetollia antiqua* fauna about 8·5 metres below the *Buchia okensis*

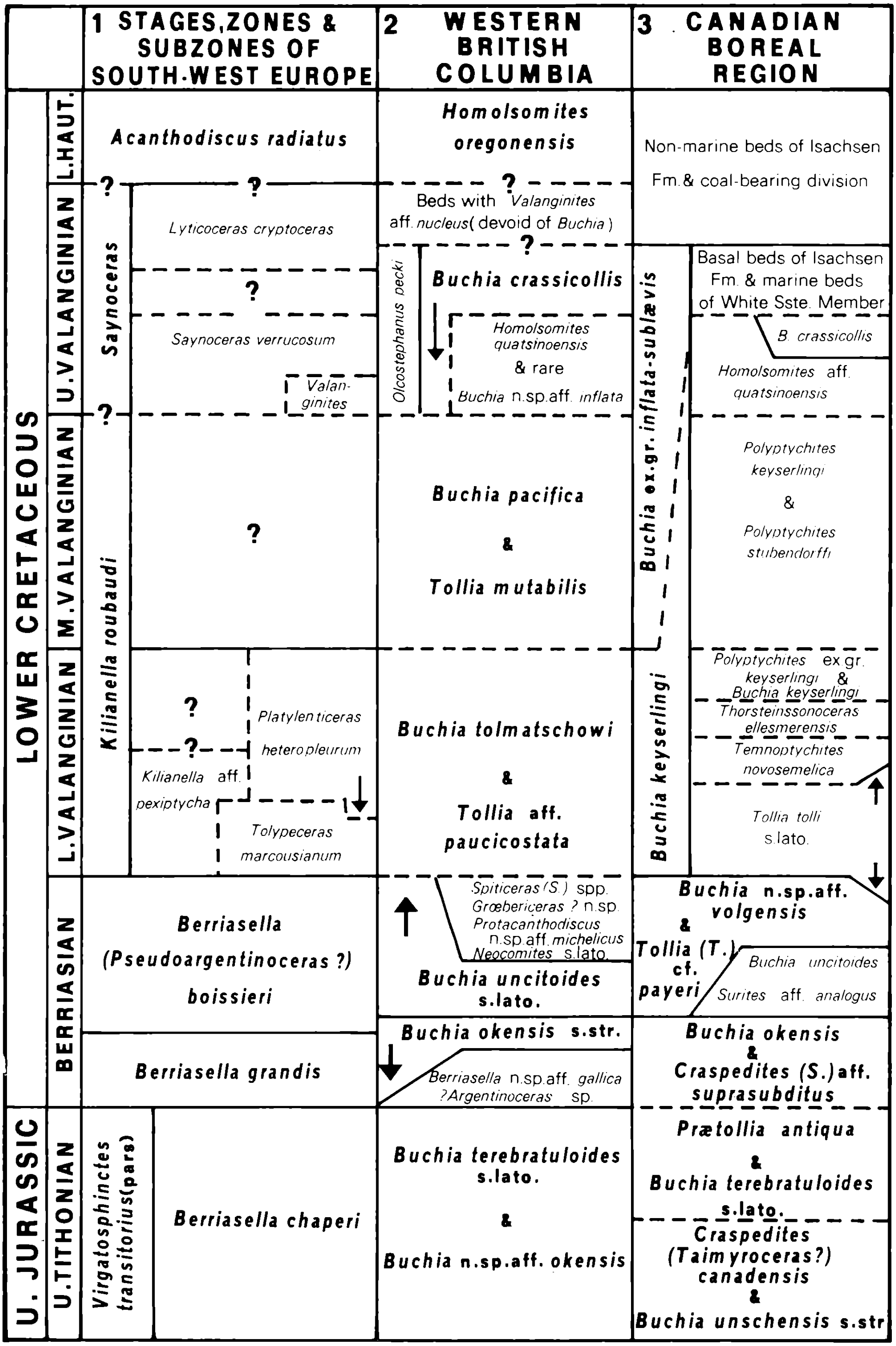
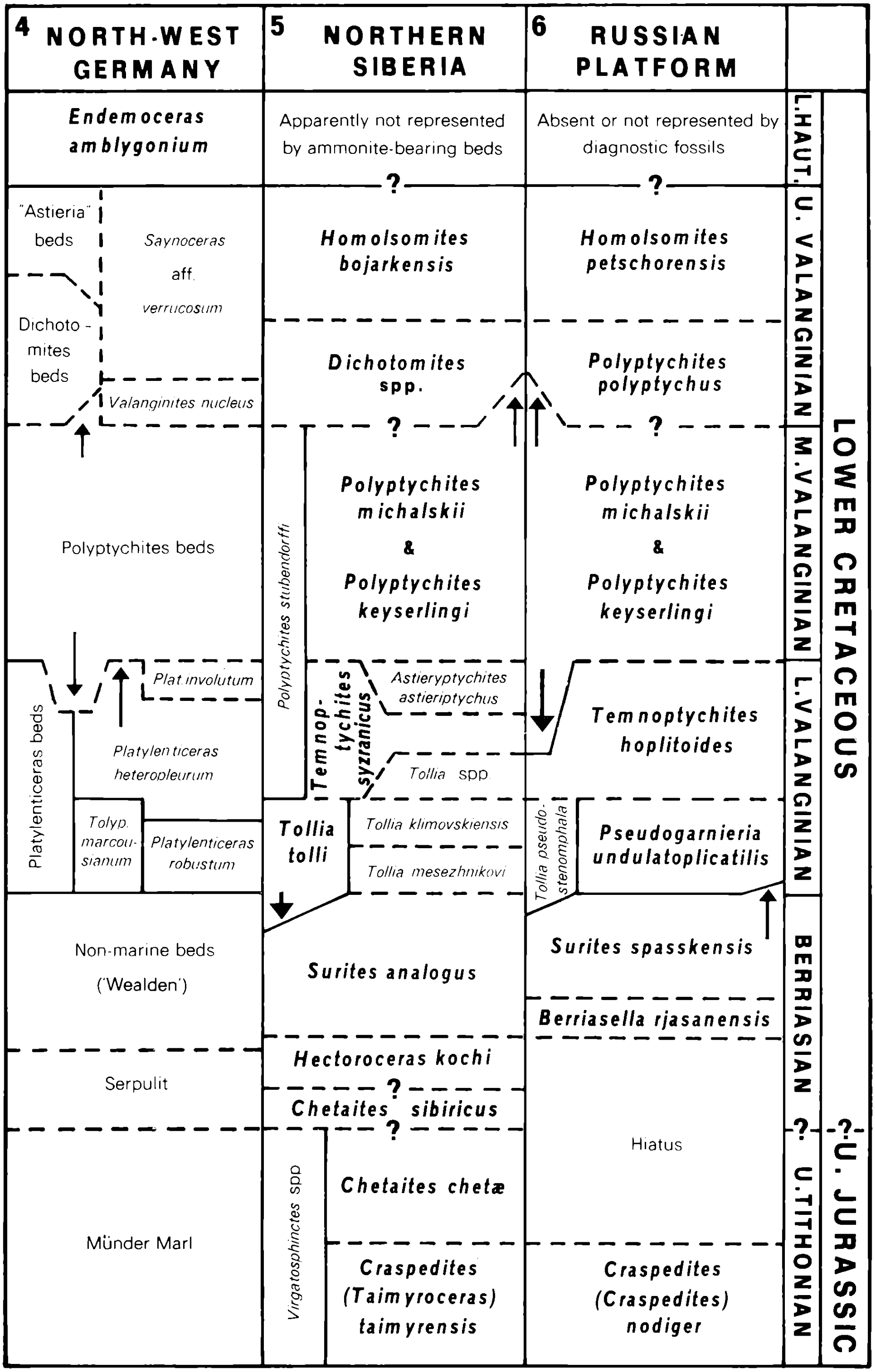


Fig. 3. Biochronology and external correlation of the latest Jurassic, Berriasian and Valanginian rocks of the Canadian part of the north American Boreal Province.
Columns 1 after Lyons Colloquium 1963; Moullade and Thieuloy 1967; Kemper 1968, etc.:



4 NORTH-WEST GERMANY		5 NORTHERN SIBERIA		6 RUSSIAN PLATFORM			
Endemoceras amblygonium		Apparently not represented by ammonite-bearing beds		Absent or not represented by diagnostic fossils		L.HAUT.	LOWER CRETACEOUS
"Astieria" beds	*Saynoceras* aff. *verrucosum*	? **Homolsomites bojarkensis**		? **Homolsomites petschorensis**		U. VALANGINIAN	
Dichotomites beds	*Valanginites nucleus*	**Dichotomites spp.**		**Polyptychites polyptychus**			
Polyptychites beds		? **Polyptychites michalskii & Polyptychites keyserlingi**	*Polyptychites stubendorffi*	? **Polyptychites michalskii & Polyptychites keyserlingi**		M.VALANGINIAN	
Platylenticeras beds	*Plat. involutum*	**Temnop-tychites syzranicus**	*Astieryptychites astieriptychus*	**Temnoptychites hoplitoides**		L.VALANGINIAN	
	Platylenticeras heteropleurum		*Tollia* spp				
	Tolyp. marcousianum / *Platylenticeras robustum*	**Tollia tolli**	*Tollia klimovskiensis*	*Tollia pseudo-stenomphala*	**Pseudogarnieria undulatoplicatilis**		
			Tollia mesezhnikovi				
Non-marine beds ('Wealden')		**Surites analogus**		**Surites spasskensis**		BERRIASIAN	
				Berriasella rjasanensis			
Serpulit		**Hectoroceras kochi** ? **Chetaites sibiricus**		Hiatus			
		?				?	?
Münder Marl		*Virgatosphinctes* spp	**Chetaites chetæ**			U.TITHONIAN	U. JURASSIC
			Craspedites (Taimyroceras) taimyrensis	**Craspedites (Craspedites) nodiger**			

2 after Jeletzky 1965a, 1971c; Jeletzky and Tipper 1968: 3 this paper: 4 after Kemper 1961, 1968, etc.: 5 after Saks *et al.* 1963, 1965; Saks and Shulgina 1969: Shulgina 1965, etc.: 6 after Sazonova 1971, etc.

and *Craspedites* (*Subcraspedites*) aff. *suprasubditus* fauna is well established. The latter fauna occurs about 138 metres above the base of the Deer Bay Formation. There is no reason whatsoever to assume the presence of any faults, erosional intervals or unconformites in the regularly and moderately tilted and well-exposed shale interval separating these two faunas. (Since this paper was written a well preserved uppermost Jurassic fauna consisting of prevalent *Buchia terebratuloides* var. *subuncitoides* (Bodylevsky), less common *B. terebratuloides* s. str., and very rare *Praetollia antiqua* n. sp. was identified from GSC loc. 86878 situated in the headwaters of Bern Creek, northwestern Ogilvie Mountains, northwestern part of Central Yukon (approximate Lat. 66° 01′ 15″ N., Long. 140° 22′ 40″ W). This discovery suggests a more widespread occurrence of the *Praetollia antiqua* fauna in the uppermost Jurassic of Arctic Canada).

The complete absence of *Buchia* forms referable to or comparable with *B. okensis* s. str. and the prevalence of diagnostic late Upper Volgian forms (*B. terebratuloides* Lahusen f. typ., *B. t.* var. *obliqua* Tullberg and *B. terebratuloides* var. *subuncitoides* Bodylevsky; see Bodyelvsky 1936 pl. 1 figs 1–8; pl. 2, figs 1–5; Jeletzky and Tipper 1968; Jeletzky 1971b fig. 2; this paper pl. 4 figs 2–3, pl. 5, fig. 2) precludes the interpretation of the *Praetollia antiqua* fauna as a faunal phase of the *Buchia okensis* Zone and indicates its correlation with some part of the *Buchia terebratuloides* s. lato—*Buchia* n. sp. aff. *okensis* Zone of Western British Columbia (Jeletzky 1971b) and the *Buchia* aff. *B. okensis* Zone of Northern California (Jones, Bailey and Imlay 1969). The late Upper Tithonian age of these *Buchia* zones is proven beyond reasonable doubt by their Tethyan ammonite faunas. In the Boreal Realm the *Praetollia antiqua* fauna appears to be equivalent to part or all of the *Chetaites chetae* Zone of Northern Siberia (Shulgina 1968; Saks and Shulgina 1969; Fig. 3 here) because of its inferred stratigraphical position between the late Upper Volgian *Craspedites* (?*Taimyroceras*) *canadensis* fauna and the basal Berriasian *Buchia okensis* and *Craspedites* (*Subcraspedites*) aff. *suprasubditus* fauna (Jeletzky 1966, 1971b).

The presence of a new *Praetollia* species in the latest Jurassic beds of the North American Boreal Province does not necessarily conflict with the actual age of the

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Plate 1.

1 a-b. *Polyptychites* (*Dichotomites*) aff. *bidichotomus* (Leymerie).
Upper Valanginian, Deer Bay Formation. Ellef Ringnes Island, exact locality unknown. The specimen presumably was found within 60 metres of the contact with the Isachsen Formation. Presented by J. C. Sproule and Associates Ltd. and preserved in the GSC palaeontological collections, GSC. cat. no. 33332.

a, b. Ventral view of outer whorl (a, b) and earlier (b) whorl fragment.

2. *Polyptychites* (*Polyptychites*) *keyserlingi* (Neumayr and Uhlig).
Upper Valanginian, Deer Bay Formation. Amund Ringnes Island, GSC loc. 82695, on the north side of a large diapir: Lat. 74° 40′N, Long. 98° 00′ W. GSC. cat. no. 32592. Ventral view.

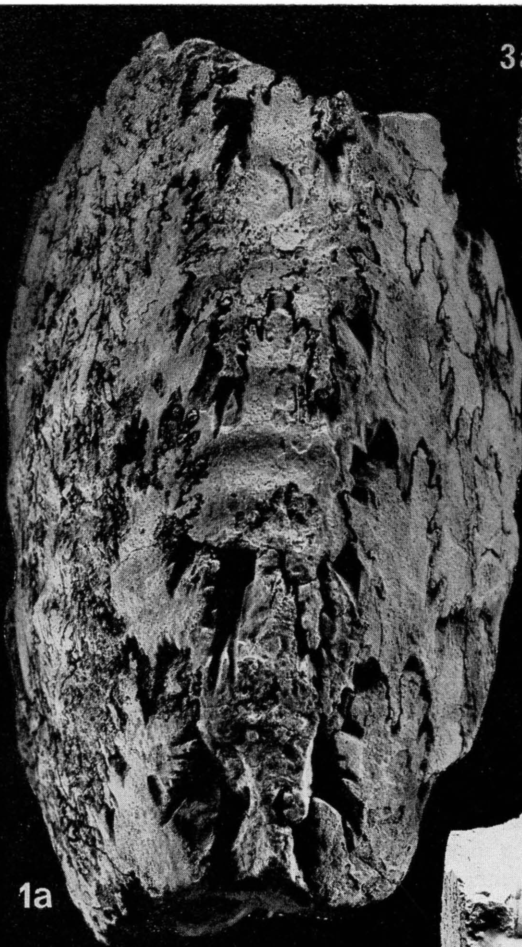
3 a-d. *Valanginites* sp. aff. *V. nucleus* (Roemer).
Uppermost Valanginian or basal Hauterivian, Relay Mountain group. Taseko Lakes Map area, GSC loc. 80218, east side of Tchaikazan Ridge, elevation about 2,280 metres at a point about 5 kilometres east of south of the eastern end of Yohetta Lake: approx. Lat. 51° 12′N, Long. 123° 51′W. GSC. cat. no. 32593.

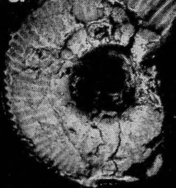
a, b, c. Lateral view (a), ventral view (b), and oblique cross-section (c) of septate part of shell, including penultimate whorl. c shows the almost perfectly circular cross-section characteristic of the genus.

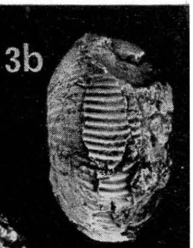
d. Fragment of living chamber.

all figs x 1.

Plate 1


1a


3a


3b


3c


3d


2


1b

Praetollia maynci Zone in East Greenland as Spath's (1952) mid- to late-Berriasian dating of this zone is not well founded. The *Praetollia maynci* fauna was said to occur stratigraphically below the *Hectoroceras* fauna (Spath 1952; Donovan 1964) which was subsequently placed in the late lower Berriasian by Soviet workers (Saks *et al.* 1963; Saks and Shulgina 1964; Saks, Mesezhnikov and Shulgina 1968a). [Since this paper was written the writer learned from Dr. F. Surlyk that *Hectoroceras* and *Praetollia* have almost identical time ranges in sections measured in southern Jameson Land (see Surlyk, this volume). The two genera make their first appearance in the same bed but *Hectoroceras* ranges higher than the *Praetollia.* The writer deduces from this information that, like *Praetollia, Hectoroceras* may possibly range down into the uppermost Jurassic beds in East Greenland and elsewhere]. The underlying ammonite fauna could permit the placement of the *Praetollia maynci* fauna in the Upper Volgian as well as in the basal Berriasian. The *Laugeites*? *parvus* fauna found stratigraphically beneath *Praetollia maynci* (Donovan 1964) in the same unit is of a Lower rather than an Upper Volgian age. The association of specifically indeterminate *Subcraspedites* in the same piece of rock with *Laugeites* on Western Kuhn Island (Donovan 1964) is actually suggestive of an Upper Volgian age of "a single impression of ?*Praetollia*" found nearby in a different exposure of the same unit. As pointed out by Casey (1962) and Donovan (1964), new evidence discredits Spath's (1952) opinion about *Subcraspedites* being diagnostic solely of the Cretaceous. Finally, "*Buchia volgensis* Lahusen" identified by Spath (1952) from the *Praetollia maynci* beds does not seem to belong either to *B. volgensis* s. str. or to *B. okensis* s. str. diagnostic of the Berriasian rocks. Judging by the specimens figured by Spath (1952) these *Buchia* are more comparable with *Buchia terebratuloides* s. lato (including *B. t.* var. *subinflata* and var. *subuncitoides*) and *B.* n. sp. aff. *okensis* than with any of the previously mentioned Berriasian species.

The discovery of the new *Praetollia* fauna in the latest Jurassic of Arctic Canada and the possibility that the *Praetollia maynci* fauna is also Upper Volgian rather than Berriasian in age should not be interpreted in the sense of the genus *Praetollia* being a diagnostic latest Jurassic (latest Upper Volgian or latest Tithonian) genus. Firstly, *Olcostephanus bidevexus* Bogoslovsky and *Pronjaites nikitinoense* Sazonova from the late Berriasian *Berriasella* (*Riasanites*) *rjasanensis* Zone are typical representatives of *Praetollia* in the writer's opinion (see section 6). Secondly, *Praetollia maynci* Spath was recently reported from those beds of the Khatanga Depression, Northern Siberia (Saks, Mesezhnikov and Shulgina 1968a) presumably corresponding to the basal part of the Canadian *Buchia okensis* and *Craspedites* (*Subcraspedites*) aff. *suprasubditus* Zone (see Fig. 3). *Praetollia* Spath appears therefore to be yet another perisphinctid genus crossing the Jurassic/Cretaceous boundary and ranging well up in the boreal facies of the Berriasian stage.

5c. The Berriasian stage

(*i*) *The* Buchia okensis *and* Craspedites (Subcraspedites) *aff.* suprasubditus *Zone.*

Throughout the Canadian part of North American Boreal Province the Jurassic/Cretaceous boundary is placed at the base of beds containing a *Buchia* fauna dominated by large to giant representatives of *Buchia okensis* (Pavlow) f. typ. and *B. okensis* var. *canadiana* (Crickmay) (see Jeletzky 1964 pl. 1 figs 1A–1C, pl. 2 figs 2A–2C).

The rocks of the *Buchia okensis* Zone are widespread in the Porcupine Plateau-Richardson Mountain trough (Jeletzky 1958, 1960, 1961, 1967, 1971d, 1972) where they are mostly represented by 15 to 16·5 metres of multicoloured shale in the upper part of the Husky Formation. The zone is mostly rich in the name fossil and contains rare *Craspedites* (*Subcraspedites*) aff. *suprasubditus* (Bogoslovsky) and *C.* (*S.*) aff. *hoeli* (Frebold) locally. Richly fossiliferous rocks of the zone are equally widespread in the western and northern parts of the Canadian Arctic Archipelago where the zone seems to be confined to the middle part of the Deer Bay shale (Tozer and Thorsteinsson 1964; Tozer *in* Thorsteinsson and Tozer 1970).

Except for very rare, non-diagnostic phylloceratids (Tozer and Thorsteinsson 1964; Jeletzky 1971a), only craspeditid ammonites have been found in the *Buchia okensis* Zone of the Canadian boreal region. The ammonites are represented exclusively by peculiar *Craspedites* (*Subcraspedites*) forms closely allied to *Olcostephanus suprasubditus* Bogoslovsky from the Ryazan beds (= late Berriasian) of Central Russia (Sazonova 1971) and *Ammonites plicomphalus* J. Sowerby, 1822 (including *A. plicomphalus* J. de C. Sowerby, 1823) from the Spilsby Sandstone of eastern England. Closely similar ammonites were also described by Voronets (1962) from the basal Cretaceous beds of the Lena-Anabar area (Paks Peninsula) under the names *Taimyroceras*(?) *bodylevskyi* Voronets and *Subcraspedites* ex gr. *bidevexus* Bogoslovsky. These Siberian forms and the Canadian *Craspedites* (*Subcraspedites*) (see Jeletzky 1964 pl. 2 fig. 1, pl. 3 fig. 2; this paper Pl. 6 Figs a-d) appear to be congeneric with representatives of the genus *Borealites* Klimova (1969), recently erected for craspeditid ammonites from the *Hectoroceras kochi* Zone of Western Siberia. The Canadian *Craspedites* (*Subcraspedites*) aff. *suprasubditus*, the North Siberian *Subcraspedites* ex gr. *bidevexus*, the West Siberian *Borealites fedorovi* and the Central Russian *Olcostephanus suprasubditus* are extremely similar morphologically and presumably closely allied to such late Volgian forms as *Craspedites* (*Craspedites*) *nodiger* (Eichwald) and *Craspedites* (?*Taimyroceras*) *canadensis pseudosubditus* Jeletzky. However, they differ from these older and presumably ancestral *Craspedites* forms in having a more complex suture line with a greater number (four or five) of auxilliary lobes. From the late Berriasian *Surites* these ammonites differ in the absence or very feeble development of the characteristic tongue-shaped forward swing of the secondary ribs on the venter, the prevalence of fasciculate *Craspedites*-like rib bundles (three to five secondaries rising at the same level from a single primary) in middle growth stages (Jeletzky 1964 pl. 2 fig. 1A; this paper Pl. 6 fig. 1a), and a complete loss of sculpture, except for bullae-like primaries, in late growth-stages.

All these apparently congeneric forms are assigned to *Subcraspedites* Spath (*Borealites* being treated as a junior subjective synonym) until such time as the age and generic nature of the type species, *Ammonites plicomphalus* J. Sowerby (1822), is clarified. The external morphology and the ontogenetic development of the sculpture of the type species (see Donovan 1964 pl. 9 figs 1, 2) is extremely similar to that of the Canadian, West Siberian and Central Russian Berriasian forms concerned.

Because of the extremely close morphological similarity of these early Berriasian representatives of *Subcraspedites* with the latest Jurassic completely ribbed *Craspedites* forms, the writer's original decision (Jeletzky 1958, 1968) to treat *Subcraspedites* as a subgenus of *Craspedites* evolutionary transitional to *Surites* and *Tollia* appears preferable to the subsequent proposal (Jeletzky 1964, 1965a, 1971b) to regard it as a subgenus of *Tollia*. It appears that, contrary to current ideas, slightly modified representatives of the completely ribbed stock of the genus *Craspedites* (e.g. *Subcraspedites* sensu stricto) range well up into the Berriasian stage and may dominate at least some early Berriasian ammonite faunas in the Boreal Realm (e.g. in Northern Siberia and in Arctic Canada).

Because of its presence in the same stratigraphical position in Western British Columbia (forming part of the North Pacific Biotic Province) and in Arctic Canada (forming part of the North American Boreal Province) (Jeletzky 1965a, 1971b), the *Buchia okensis* Zone represents an extremely important datum plane for the correlation of the basal Cretaceous beds of the Boreal and Tethyan Realms. *Buchia okensis* is remarkably facies-tolerant and short-ranging (Jeletzky 1965a), and throughout Western and Arctic Canada is just as reliable an index fossil for the early Berriasian as are the best of zonal ammonites. The conclusion of Saks, Mesezhnikov, and Shulgina (1968a) that *Buchia* alone does not permit a reliable delimitation of the Jurassic and Cretaceous systems in the Siberian and North American parts of the Boreal Realm is not applicable to Western and Arctic Canada. This misconception is probably caused by the restriction of the most diagnostic variants of *B. okensis*, such as the large to giant representatives of the typical form and *B. okensis* var. *canadiana*, to the Canadian and American (e.g. Northern Alaska: Imlay 1961) parts of the North American Boreal Province and to adjacent areas of the North Pacific Biotic Province (e.g. Western British Columbia and the State of Washington: Jeletzky 1965a). *Buchia okensis* does not appear to penetrate at all into the early Berriasian rocks of Northern California and ?Oregon (Jones, Bailey and Imlay 1969), or into the *Hectoroceras kochi* Zone of Western Siberia (Klimova 1969). All published representatives of *B. okensis* from northeastern Siberia (Paraketsev *in* Verestchagin *et al.* 1965) and the European Arctic (Sokolov and Bodylevsky 1931; Spath 1947, 1952) represent small to medium-sized, rather closely ribbed variants approaching *B. okensis* var. *subokensis* Pavlow (= *B. spasskensis* Pavlow). When found alone, such forms may be easily confused either with the latest Jurassic *Buchia* n. sp. aff. *okensis* of Jeletzky (*in* Jeletzky and Tipper 1968; Jeletzky 1971b) and Jones, Bailey and Imlay (1969) or with the late Berriasian *Buchia uncitoides* var. *spasskensoides* Crickmay. These forms are known to range, rarely, above and below the *Buchia okensis* Zone.

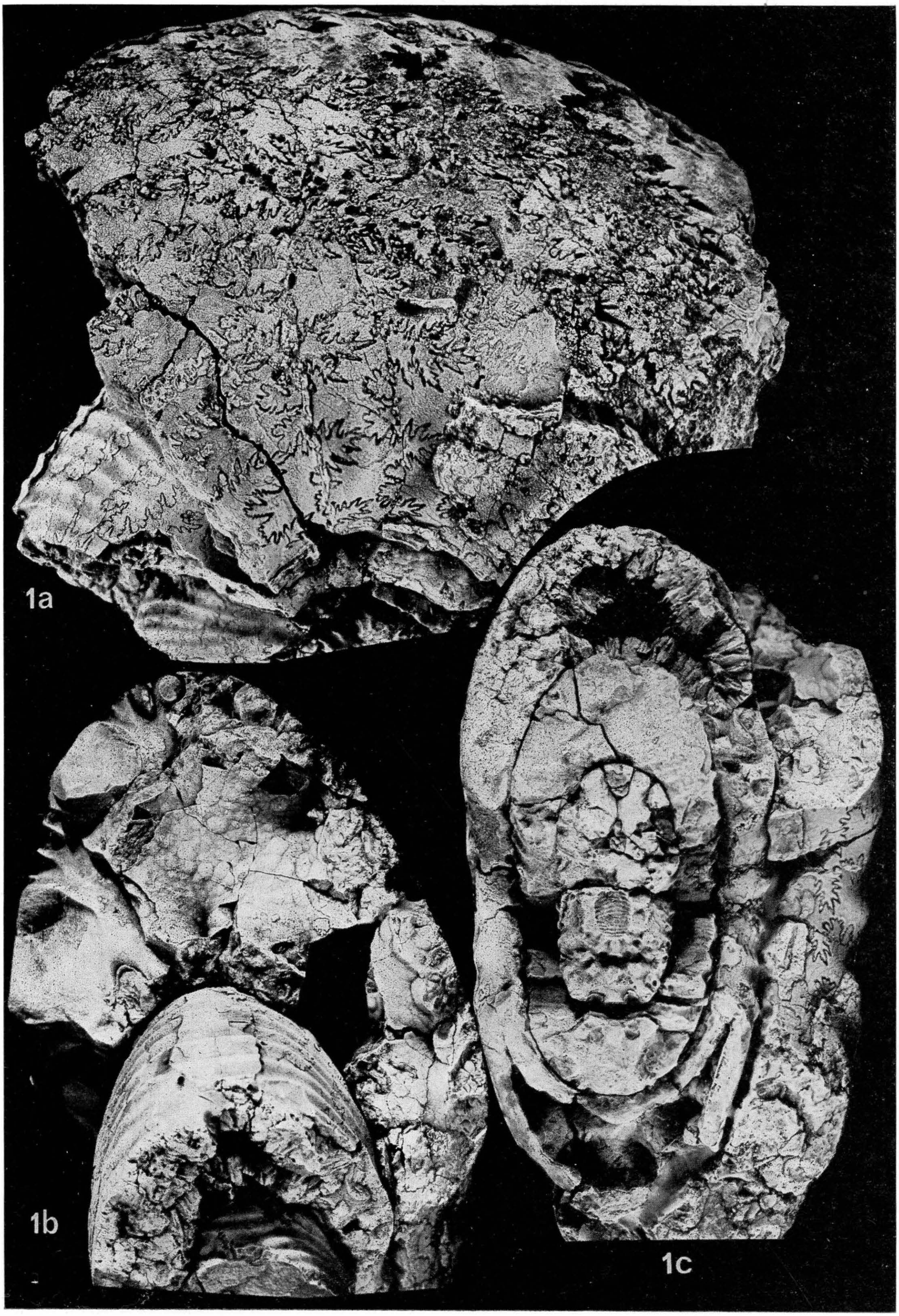
The dating of the *Buchia okensis* Zone as early Berriasian, formerly based on indirect evidence, has been confirmed recently by the discovery of diagnostic late Upper Tithonian ammonites in the next older *Buchia terebratuloides* and *Buchia* n. sp. aff. *okensis* Zone of the Pacific Province, and by that of Berriasian, presumably early Berriasian, berriasellids in the upper part of the *Buchia okensis* Zone proper (Jeletzky and Tipper 1968; Jeletzky 1971b). These critical finds, made in Western British Columbia, agree perfectly with the presence of a different, more diversified, presumably late Berriasian ammonite fauna (Jeletzky 1965a, 1968, 1971b) in the next younger *Buchia uncitoides* Zone of the same region (see also p. 57, below). There is therefore little doubt that the *Buchia okensis* Zone of Arctic Canada is older than the *Berriasella* (?*Pseudoargentinoceras*) *boissieri* Zone of the West European standard and corresponds largely or entirely to the next older *Berriasella grandis* Zone (Jeletzky 1971b).

Plate 2.

1 a-c. *Polyptychites* (*Dichotomites*) aff. *bidichotomus* (Leymerie).
Same specimen as reproduced in Plate 1, figs 1 a-b.

a. Lateral view of outer whorl. Note the polyptychitid suture-line with only three auxiliary lobes.
b. c. Cross-sections of outer (b) and inner (c) whorls.
all figs x 1.

Plate 2



Craspedites (*Subcraspedites*) forms closely allied to and possibly conspecific with *C.* (*S.*) aff. *suprasubditus* (Bogoslovsky) occur in the *Chetaites sibiricus* (with *Praetollia maynci*) and *Hectoroceras kochi* Zones of Northern Siberia and the eastern slope of the Ural Mountains. This suggests an approximate correlation between these Siberian zones and the Canadian *Buchia okensis* Zone. This would also agree with the previously proposed correlation (Jeletzky 1968) of the Canadian zone with part or all of the East Greenland *Hectoroceras* Zone of Spath (1947, 1952) which contains a *Buchia okensis* rather than a *B. volgensis* fauna. The suggested correlation of the *Buchia okensis* Zone with the *Praetollia maynci* Zone of East Greenland (Jeletzky 1968) and *Praetollia maynci* beds of Northern Siberia (this paper, Fig. 3) may have to be withdrawn for reasons discussed above (p. 52).

(*ii*) *The* Buchia *n. sp. aff.* volgensis *and* Tollia (Tollia) *cf.* payeri *Zone*

This zone is so far known only from the Canadian mainland where it is widespread in the Porcupine Plateau-Richardson Mountain trough. In this vast region the zone begins in the uppermost beds of the Husky Formation. It ranges through all but the highest beds of the Buff Sandstone Member of the overlying Lower Sandstone Division and its shale equivalents (Jeletzky 1958, *et seq.*).

Although its fossils are unknown in the Canadian Arctic Archipelago, marine rocks of this zone were apparently deposited in the Sverdrup Basin (Figs 2, 3). This is indicated by an apparent lack of any arenaceous interbeds or erosional boundaries in a sequence of unfossiliferous shale (about 48 metres thick in the Buchanan Lake section) separating the uppermost bed (GSC loc. 52487) with the *Buchia okensis* Zone fauna from the basal bed (GSC loc. 52491) with the *Tollia* (*T.*) cf. *tolli* var. *tolmatschowi* and *Buchia keyserlingi* fauna.

The *B.* n. sp. aff. *volgensis* and *Tollia* (*T.*) cf. *payeri* Zone was originally named the *Polyptychites* (*Tollia*) cf. *tolli* and *Buchia volgensis* Zone (Jeletzky 1958) and then renamed the *Craspedites* (*Tollia*) cf. *payeri* and *B. volgensis* Zone (Jeletzky 1968) because of the more common (though still rare) occurrence and better preservation of *Tollia* (*Tollia*) cf. *payeri* (see Jeletzky 1964 pl. 4 fig. 11). Moderately evolute, *Tollia* (*T.*) *payeri*-like craspeditids apparently range right through the zone. A good example is provided by "*Tollia* (*Praetollia*?) n. sp. A" from the upper member of the Husky Formation (Jeletzky 1964 pl. 4 fig. 8) which is now included in this group.

The dominant *Buchia* of the zone was initially identified as *B. volgensis* (see Jeletzky 1964 pl. 4 figs 5–7, 10), diagnostic of the Berriasian beds of northern Eurasia, but a subsequent study of more extensive and better preserved material showed that it is specifically distinct. *B.* n. sp. aff. *volgensis* appears to be an undescribed species characteristic of Arctic Canada but possibly occurring in northern Alaska (Imlay 1961) and eastern Greenland (unpublished data). Its designation as the primary zonal index (Jeletzky 1971b and this paper) was prompted by its biochronological reliability as well as by the rarity and poor preservation of *Tollia* (*T.*) cf. *payeri* (Toula) throughout the zone.

The records of *Tollia* (*T.*) cf. *tolli* Pavlow from this zone (e.g. Jeletzky 1958, 1968) may be valid in part. However, they are all based on poorly preserved, incomplete specimens which may belong elsewhere. Therefore, and because of the presence of reliably identifiable *Tollia* (*T.*) *tolli* and closely related forms in the Sverdrup Basin in association with the next younger *Buchia keyserlingi* fauna (see below) the writer (Jeletzky 1971b) had abandoned the previously suggested (Jeletzky 1968) correlation of the *Buchia* n. sp. aff. *volgensis* and *T.* (*T.*) cf. *payeri* Zone with the Eurasian zones characterised by *T.* (*T.*) *tolli* and *T.* (*T.*) *pseudostenomphala* Sazonova. The latter two zones are now considered to be faunal facies of the Canadian early Lower Valanginian *T.* (*T.*) *tolli* Subzone (Fig. 3). It seems probable, however (see Sazonova 1961, 1967, 1971; Saks and Shulgina 1969), that *T.* (*T.*) *tolli* and its allies range down into the latest Berriasian (i.e. the upper part of the *B.* n. sp. aff. *volgensis* Zone) as well as into the *Polyptychites*-bearing latest Lower Valanginian beds.

The occurrence of *Surites* aff. *analogus* (Bogoslovsky) in the lower part of the *B.* n. sp. aff. *volgensis* Zone (Jeletzky 1961, 1964 pl. 4 fig. 1) indicates the correlation of these beds with part or all of the late Berriasian *Surites analogus* and *Surites spasskensis* Zones of Siberia and the Russian Platform (Fig. 3). Klimova (1969) regarded *Surites* as a characteristic late Berriasian genus, drawing the boundary between the *Hectoroceras kochi* and *Surites spasskensis* Zones on the first appearance of this genus. However, other workers have cited *Surites* species from beds representative of, or correlative with, the *Chetaites sibiricus* and *Hectoroceras kochi* Zones (e.g. Saks *et al.* 1959; Saks *et al.* 1963; Saks and Shulgina 1964; Saks *et al.* 1965; Saks and Klimova 1967; Saks, Mesezhnikov and Shulgina 1968a). None of these "*Surites*" have been figured or described, to the best of the writer's knowledge. However, the latest available lists of "*Surites*" from the key section of these zones on the Kheta River in the Khatanga Depression (Saks *et al.* 1965) do not include *Surites spasskensis, Surites analogus,* or *Surites* forms allied to these index species of the overlying *Surites spasskensis* and *Surites analogus* Zones of Northern and Western Siberia (Saks and Shulgina 1969 table 1). This suggests that the earlier identifications of *Surites* ex gr. *spasskensis-analogus* from the *Chetaites sibiricus* and *Hectoroceras kochi* Zones made by the same team of Siberian workers were withdrawn by them in the meantime. This conclusion finds additional support in the gradual changes of the zonal scheme proposed by these workers for the Berriasian rocks of Northern and Western Siberia. The earlier (1959–1965) variants interpret the *Chetaites sibiricus, Hectoroceras kochi,* and *Surites analogus* Zones as Subzones of the *Surites spasskensis* Zone, which is treated as a regional Siberian zone. The later variants (1968–1969) interpret these three subzones as independent regional zones, remove the *Surites spasskensis* Zone from the list of North Siberian zones, and interpret the *Chetaites sibiricus* Zone as older than the *Surites spasskensis* Zone of the Russian Platform. The latest variant (Saks and Shulgina 1969 table 1) also admits the correctness of Klimova's (1969) conclusion that in West Siberia (i.e. Northern Urals) *Surites spasskensis* is restricted to beds overlying the *Hectoroceras kochi* Zone.

Thus, whatever the true nature of "*Surites*" in the *Chetaites sibiricus* and *Hectoroceras kochi* Zones of Northern and Western Siberia, the data available suggest that neither *Surites* ex gr. *spasskensis* nor *Surites* ex gr. *analogus* range down into these zones (Fig. 3). The presence of *Buchia uncitoides* s. lato in association with *Surites* aff. *analogus* in the lower part of the *Buchia* sp. nov. aff. *volgensis* Zone provides a link with the *B. uncitoides* Zone of western British Columbia, which contains a diversified Berriasian fauna of Tethyan ammonites, presumably referable to the late Berriasian *Berriasella* (*Pseudoargentinoceras*?) *boissieri* Zone (Jeletzky 1965a, 1968, 1971b).

The upper part of the *Buchia* sp. nov. aff. *volgensis* Zone (overlying the *Surites*-bearing beds) is tentatively correlated with the upper part of the *Surites analogus* and *Surites spasskensis* Zones of Siberia and the Russian Platform rather than with the overlying *Tollia* (*Tollia*) *mesezhnikovi* and *Pseudogarnieria undulatoplicatilis* Zones of the same regions (Fig. 3). This is suggested by the replacement of the

Buchia n. sp. aff. *volgensis* fauna by the *B. keyserlingi* fauna at the top of the zone and by the association of well-preserved *Tollia* (*T.*) *tolli*, *T.* (*T.*) aff. *mutabilis* and allied moderately involute to involute *Tollia* forms with the *B. keyserlingi* fauna. This faunal change is generally accepted as diagnostic of the Berriasian/Valanginian boundary throughout the Boreal Realm (Saks and Shulgina 1969; Sazonova 1971).

The East Greenland beds with *Tollia* (*T.*) cf. *payeri* (Donovan 1964) seem comparable with the Canadian *B.* n. sp. aff. *volgensis* Zone because of the presence of *Surites*.

(*iii*) *Age and correlation of the Ryazan Beds of the Russian Platform*

A clarification of the age of the Ryazan Beds of the Central Russian Platform is critical as it provides an independent control of the correlation of the Canadian boreal fossil zones with those of Tethys: in the discussions above, this correlation is attempted by comparison with the coeval, predominantly Tethyan faunas of western British Columbia and northern California.

Two ammonite zones are distinguished in the Ryazan Beds (Fig. 3), the lower of which is the *Berriasella* (*Riasanites*) *rjasanensis* Zone. Because of the long-reported but insufficiently appreciated association of the index species with *B.* (*P*?) *boissieri* in the basal Cretaceous rocks of the northern Caucasus (e.g. Rengarten 1951; Luppov 1956a; Mordvilko 1956), both Casey (1963) and Jeletzky (1965a, 1968) suggested that the *rjasanensis* Zone of the Ryazan horizon may be of *boissieri* Zone age, and therefore younger than the basal Berriasian (*Berriasella grandis* Zone) of southwest Europe. The following data support this suggestion. According to Sazonova (1971 p. 6) (writer's translation from the Russian): "The association of ammonites of the genus *Neocomites* with *Riasanites* in the Berriasian deposits of central areas of the Russian Platform is especially significant. It indicates a direct connection of the Middle Russian and North-Caucasian basins in the Berriasian and permits a direct correlation of the *rjasanensis* Zone with the *boissieri* Zone of the Mediterranean Berriasian. These data permit one to conclude that the deposits of the *grandis* Zone are absent on the Russian Platform. In this region this time is represented by an interruption of sedimentation. This explains the absence of ammonites ancestral to *Riasanites* among the local fauna of the Volgian sea."

Unfortunately, these conclusions are not reflected in the accompanying correlation table (Sazonova 1971, opposite p. 4) where the *rjasanensis* Zone is placed in the early Berriasian and correlated with the upper part of the *grandis* Zone.

An important North Caucasian fauna, described by Grigorieva (1938) in a paper which was virtually ignored by later Soviet and European workers, includes such diagnostic forms of the *rjasanensis* Zone as *Berriasella* (*Riasanites*) *rjasanensis* var. *maikopensis* Grigorieva and *Protacanthodiscus* (*Euthymiceras*) *transfigurabilis*

Plate 3.

1. *Polyptychites* (*Dichotomites*) aff. *bidichotomus* (Leymerie).
Lateral view of specimen reproduced in Plate 1, figs 1 a-b.

2 a-b. *Polyptychites* (*Polyptychites*) *keyserlingi* (Neumayr and Uhlig).
Same specimen as reproduced in Plate 1, fig 2.

a. Lateral view: rib-pattern and suture-line outlined in white.

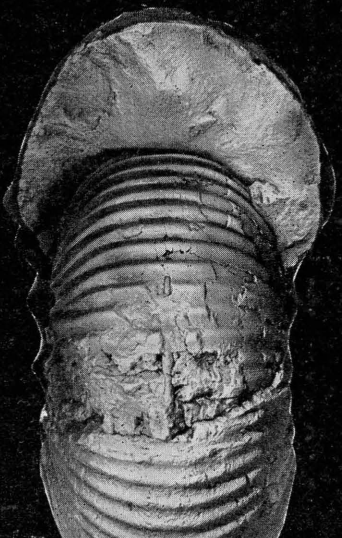
b. Ventral view and cross-section of outer whorl.

all figs x 1.

Plate 3


1


2a


2b

(Bogoslovsky). These ammonites are either associated with such diagnostic late Berriasian species as *Protacanthodiscus* (*Pomeliceras*) *breveti* (Pomel) and *P.* (*Malbosiceras*) *malbosi* (Pictet) or occur in beds overlying those containing these species (Grigorieva 1938 pp. 87–88). According to the latest data available (Le Hégarat *in* Le Hégarat and Remane 1968) forms referable to or comparable with *P* (*P.*) *breveti* and *P.* (*M.*) *malbosi* are only known from the upper beds of the type Berriasian, well above the beds containing the *Berriasella grandis* fauna. It should be pointed out that according to Le Hégarat (*in* Le Hégarat and Remane 1968), the typical *B.* (*P*?) *boissieri* appears to have a much more restricted time range than was believed by Busnardo, Le Hégarat and Magné (1965). It is apparently confined to the Subzones of *Berriasella callisto* and *B. picteti* immediately beneath the assigned Berriasian/Valanginian boundary and stratigraphically well above the basal Berriasian *grandis* Zone.

The North Caucasian representatives of *B.* (*P*?) *boissieri* listed in the Soviet literature have not been described or figured, to the best of the writer's knowledge. There is thus no direct way of knowing whether or not they represent typical forms. However, the other above-mentioned data indicate the late Berriasian age of the basal Ryazan Beds (*rjasanensis* Zone) and suggest that they represent a level high in the Upper Berriasian of the type area. Contrary to the opinion of the majority of recent Soviet workers (e.g. Saks and Shulgina 1964, 1969; Saks *et al.* 1965; Saks, Mesezhnikov and Shulgina 1968a) there is no justification for correlating the *rjasanensis* Zone with the north Siberian *Chetaites sibiricus* and/or *Hectoroceras kochi* Zones; it is correlated here (Fig. 3) with the lowest part of the *Surites analogus* Zone of that region.

The correlation of the *rjasanensis* Zone with the bulk of the Canadian *Buchia okensis* and *Craspedites* (*Subcraspedites*) aff. *suprasubditus* Zone is equally improbable. No representatives of either the giant forms of *B. okensis* f. typ. or of *B. okensis* var. *canadiana* (Crickmay) were figured or mentioned in any of the Russian and Soviet publications dealing with the genus *Buchia*. The lectotype of *B. okensis*, found in the Ryazan Beds on the River Oka (see Pavlow 1907 pl. 1 figs 11a–11c), is a late form comparable with specimens from the topmost part of the Canadian *Buchia okensis* Zone or from the basal part of the *Buchia uncitoides* Zone (Jeletzky 1965a). Its best Canadian match (see Jeletzky 1965a pl. 10 fig. 2) was found in beds apparently representing the basal part of the *Buchia uncitoides*

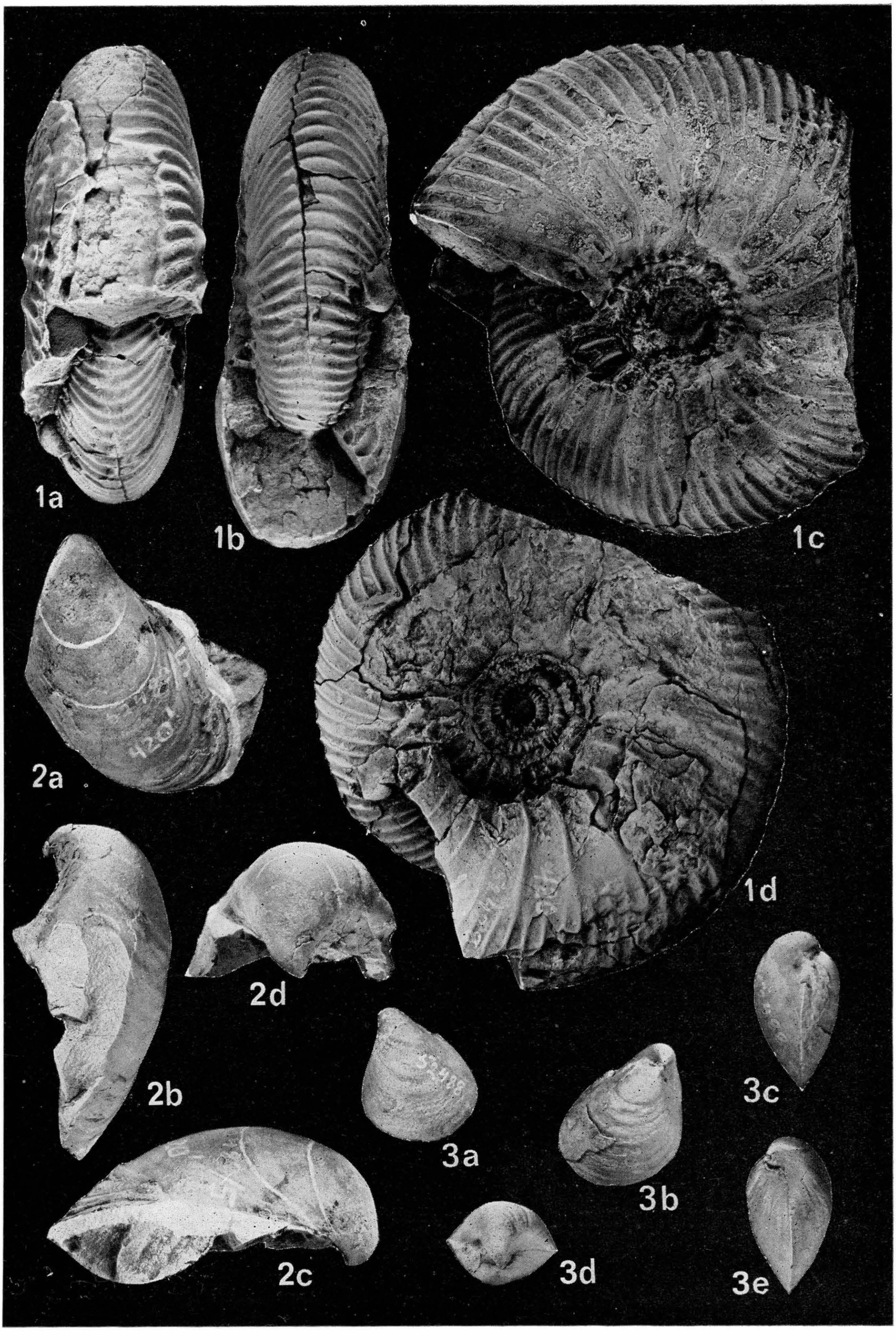
Plate 4.

1 a-d. *Praetollia antiqua* n. sp. Paratype.
Latest Upper Volgian (Upper Jurassic), Deer Bay Formation, 128 metres above the base. Axel Heiberg Island, GSC loc. 52488, 6·4 kilometres southwest of Buchanan Lake. GSC cat. no. 32594.
a, b. Ventral views (a, b) and whorl-section (b) of the last whorl (body chamber).
c, d. Lateral views.

2 a-d. *Buchia terebratuloides* var. *subunctoides* (Bodylevsky).
Horizon and locality as above. GSC cat. no. 32595. Partially preserved left valve.
a. Lateral view of exterior. Two earlier, *B. terebratuloides*-like growth-stages outlined in white.
b. Anterior view. **c.** Posterior view. **d.** Hinge margin and beak.

3 a-e. *Buchia terebratuloides* (Lahusen) f. typ.
Horizon and locality as above.
a, b. External lateral views of left (a) and right (b) valves.
c. Posterior view. **d.** Hinge line and beaks. **e.** Anterior view.
all figs. x 1.

Plate 4



Zone. The same is true of small to medium-sized *B. okensis* var. *subokensis* and *B. uncitoides* var. *spasskensoides*-like forms figured by Gerasimov (1955, 1969) and Pozhariskaya (1971 pl. 27 figs 1–4, pl. 28 figs 1–2, pl. 29 figs 2–4). The *rjasanensis* Zone is here correlated tentatively with the basal beds of the *Buchia* sp. nov. aff. *volgensis* Zone (Fig. 3). However, it may also correspond to unfossiliferous beds separating the *Surites*-bearing lower part of that zone from the topmost beds containing a *Buchia okensis* fauna in Northern Yukon (Jeletzky 1961, corr. table) or to the basal part of the unfossiliferous beds separating the *B. keyserlingi* and *B. okensis* Zones in the Sverdrup Basin.

The regional hiatus separating the basal Ryazan Beds from the latest Upper Volgian beds known (*nodiger* Zone) apparently embraces also the topmost Jurassic rocks of other regions such as the *Praetollia antiqua* beds of the Sverdrup Basin, the *Chetaites chetae* Zone of northern Siberia, and the upper part of the *Buchia terebratuloides* s. lato—*B.* n. sp. aff. *okensis* Zone of the northern Yukon and Western British Columbia (Jeletzky 1971b fig. 2; this paper Fig. 3).

5d. The Valanginian stage

The writer subdivides the restricted boreal Valanginian stage (i.e. the beds confined between the boreal facies of the Berriasian stage and that of the Hauterivian stage) into three substages (e.g. Jeletzky 1965a, 1968). The Lower/Middle Valanginian boundary is placed at the top of the German Platylenticeras Beds, slightly above the base of the *Polyptychites* (*Polyptychites*) *keyserlingi* Zone and the Middle/Upper Valanginian boundary is placed at the base of *Polyptychites* (*Polyptychites*) *polyptychus* Zone (Jeletzky 1965a) or Dichotomites Beds of Kemper (1961, 1968). It does not seem practical to switch to the subdivision of the restricted boreal Valanginian into two substages as proposed by Saks and Shulgina (1962) and Kemper (1968) and now widely adopted in Soviet literature. This is difficult as *Polyptychites* (*Polyptychites*) *michalskii* and *Polyptychites* (*Polyptychites*) *polyptychus*, the index species of the topmost Lower Valanginian and basal Upper Valanginian zones of the Soviet scheme (e.g. Saks *et al.* 1965; Saks and Shulgina 1969) are unknown in North America. In addition, the reliability of *P.* (*P.*) *michalskii* as a zonal index is rather doubtful, judging by the considerable variation of its time ranges in different regions of the northern U.S.S.R. and northwest Germany.

(*i*) *The* Buchia keyserlingi *Zone*

As far as is known, *Buchia keyserlingi* (Lahusen) is connected by transitions with the next older *Buchia* n. sp. aff. *volgensis* and with the next younger *Buchia* ex gr. *inflata-sublaevis* species groups. Mixed *Buchia* faunas are known to be present near the upper and lower boundaries of the *Buchia keyserlingi* Zone and the zonal index is known to range, rarely, way above its zone (probably right to the top of the *Homolsomites* aff. *quatsinoensis* Subzone; see Figs 2, 3).

In the Porcupine Plateau-Richardson Mountain Trough the *Buchia keyserlingi* Zone begins in the uppermost part of the Buff Sandstone Member of the Lower Sandstone Division and its shale equivalents (Jeletzky 1961) and continues into the basal beds of the overlying White Sandstone Member of the division and into its shale equivalents. The *Buchia keyserlingi* Zone is widespread in this region but it rarely yields any fossils other than the index form.

One locality in the Bonnet Lake area (GSC loc. 38788 and 39825), presumably situated low in the *Buchia keyserlingi* Zone, has yielded: *Tollia* (*Tollia*) aff. *mutabilis*

(Stanton), *Partschiceras* sp. indet. and various non-diagnostic pelecypods in addition to *B. keyserlingi* f. typ. and *Buchia* allied to *B.* n. sp. aff. *volgensis* (Lahusen). This fauna indicates the correlation of the lower part of the *Buchia keyserlingi* Zone with some part of the *Buchia tolmatschowi* Zone of Western British Columbia (Jeletzky 1965a) the main part of which can be confidently dated as early Lower Valanginian in terms of the international standard stages. ?*Tollia* (*Tollia*) *anabarensis* (Pavlow), found in the *Buchia keyserlingi* Zone on the eastern slope of Richardson Mountains (Jeletzky 1958, 1968), appears to be of about the same age as the *Tollia* (*Tollia*) aff. *mutabilis* fauna of the Bonnet Lake area.

Rare, poorly preserved fragments of *Polyptychites* (*Euryptychites*)—and *Polyptychites* (*Polyptychites*)-like ammonites found at several localities in the northeastern and northwestern Richardson Mountains (Jeletzky 1961, 1968, and unpublished) are invariably too poorly preserved to serve as the basis for a definite ammonite subzone(s) comparable to one or more of the subzones of the Sverdrup Basin. As the suture lines are either absent or poorly preserved on all available fragments, they may be referable to the more inflated forms of the craspeditid genus *Thorsteinssonoceras* rather than to any of the polyptychitid forms they were previously compared with (Jeletzky 1968). This may account for their association with *Tollia* forms comparable to *T.* (*T.*) *anabarensis* (Pavlow).

The Zone of *Polyptychites* (*Euryptychites*) n. sp. aff. *Polyptychites latissimus* and *Polyptychites anabarensis*?, tentatively proposed by Jeletzky (1968) for beds containing these fragments is withdrawn herewith pending the clarification of their generic nature through further collecting. It seems probable, however, that some at least of these poorly preserved ammonites are true *Polyptychites* (*Polyptychites*) ex gr. *keyserlingi* (Neumayr and Uhlig) as they were found in the topmost beds of *Buchia keyserlingi* Zone containing a mixed fauna of *B. keyserlingi* and *B.* ex gr. *inflata-sublaevis.*

In the Sverdrup Basin, beds in the Deer Bay Formation containing a *Buchia keyserlingi* f. typ. and *B. k.* var. *sibirica* (Sokolov) fauna (Jeletzky 1964) locally contain well-preserved craspeditid ammonites. The *Tollia* (*Tollia*) *tolli, Tollia* (*Temnoptychites*) *novosemelica* and *Thorsteinssonoceras ellesmerensis* faunal horizons treated herein as Subzones of the *Buchia keyserlingi* Zone, can be distinguished in the area (in ascending order; see Fig. 3). The separate existence of the *Tollia* (*Tollia*) *tolli* Subzone characterized by the presence of *T.* (*T.*) *tolli* Pavlow (including *T.* (*T.*) *tolmatschowi* Pavlow and *T.* (*T.*) *latelobata* Pavlow) was recently confirmed by the discovery of an unmixed fauna of *Tollia* (*Tollia*) *tolli* var. *tolmatschowi* Pavlow at GSC loc. 52491 occurring 46·5 metres stratigraphically above the *Buchia okensis* Zone in the Buchanan Lake section (see previous section). The second, *Tollia* (*Temnoptychites*) *novosemelica* Subzone fauna was found unmixed at GSC loc. 52489 in the Greely Fiord (Ellesmere Island) section closely beneath the *Thorsteinssonoceras ellesmerensis* Subzone (see Jeletzky 1965b). Although they were not found in a direct superposition in the same continuous section, the *Tollia* (*Tollia*) *tolli* Subzone is believed to occur immediately beneath that of *Tollia* (*Temnoptychites*) *novosemelica* throughout the Sverdrup Basin (Figs 2, 3).

The Subzone of *Tollia* (*Temnoptychites*) *novosemelica* is locally characterized by the association of its name fossil with more coarsely ribbed representatives of the subgenus *Temnoptychites*, formerly identified as *T.* (*Temnoptychites*) *simplex* (Bogoslovsky) (Jeletzky 1964 pl. 5 fig. 3) but possibly better referred to *T.* (*T.*) *simplex* var. *grandiosus* Voronets because of the large size of its smooth outer whorls.

Bodylevsky's (1967) denial of the *Temnoptychites* nature of the Canadian examples of *T.* (*T.*) *novosemelica* (Sokolov) is mistaken as the ribs are clearly interrupted in the middle of the venter at least on the penultimate whorl (see Jeletzky 1964 p. 38, description of figs 1, 4 and in fig. 4d). In at least one instance *Tollia* (*Tollia*) *tolli* var. *latelobata* Pavlow was found in association with *T.* (*Temnoptychites*) *novosemelica* and *T.* (*T.*) *simplex* var. *grandiosus*, though this could reflect indiscriminate collecting from the outcrop and the scree.

In two sections in Greely Fiord the *Thorsteinssonoceras ellesmerensis* fauna was found stratigraphically above the *Tollia* (*Temnoptychites*) *novosemelica* fauna (Jeletzky 1965b). This craspeditid homeomorph of *Polyptychites* has not been found anywhere else in the Canadian boreal region with the possible exception of poor fragments found in the Porcupine Plateau-Richardson Mountain trough. However, it occurs in the early Valanginian rocks of Spitsbergen and apparently in the glacial boulders on Novaya Zemlya (Jeletzky 1965b), though the latter record was disputed by Bodylevsky (1967) who interpreted it as *Temnoptychites* (?) aff. *vylkoi* Bodylevsky. The occurrence of *Thorsteinssonoceras ellesmerensis* in both the Canadian and European Arctic justifies the recognition of a distinct *T. ellesmerensis* Subzone in the *Buchia keyserlingi* Zone.

True polyptychitid ammonites have not been found in the above discussed three ammonite subzones, all such previous records (Jeletzky 1968 and unpublished reports) possibly representing *Thorsteinssonoceras* fragments. However, elements of the *Polyptychites* (*Polyptychites*) *keyserlingi* fauna have sometimes been seen in fossil collections from the Deer Bay Formation, associated with a *Buchia keyserlingi* fauna devoid of, or poor in, the representatives of the *Buchia inflata-B. sublaevis* species group. Like some of the previously mentioned, poorly preserved polyptychitid ammonites found in the Porcupine Plateau-Richardson Mountain trough in association with the *Buchia keyserlingi* fauna, such collections appear to be referable to the topmost part of the *Buchia keyserlingi* Zone, overlying the *T. ellesmerensis* Subzone (Figs 2, 3).

The external correlation of the *Buchia keyserlingi* Zone depends almost exclusively on its ammonite-bearing Sverdrup Basin sections. The *Tollia* (*Tollia*) *tolli* Subzone should be correlated with the early Lower Valanginian of southwestern Europe (Jeletzky 1965a, 1971b), following Bodylevsky (1956), Luppov (1956b) and Kemper (1961). This is supported by the discovery of various *Tollia* (*Tollia*) forms and *Platylenticeras*? cf. *gevrili* (d'Orb.) in lithologically identical glacial boulders on

Plate 5

1 a-d. *Praetollia antiqua* n. sp. Holotype.

Latest Upper Volgian (Upper Jurassic). Horizon and locality as Plate 4, figs 1 a-d. GSC cat. no. 32597.

a, b. Cross-section of early part of the last whorl and ventral view of part of the septate penultimate whorl. Part of the last whorl removed in fig. b.

c, d. Lateral views. The internal mould of the penultimate whorl shows well-preserved, strongly ascendant sutures.

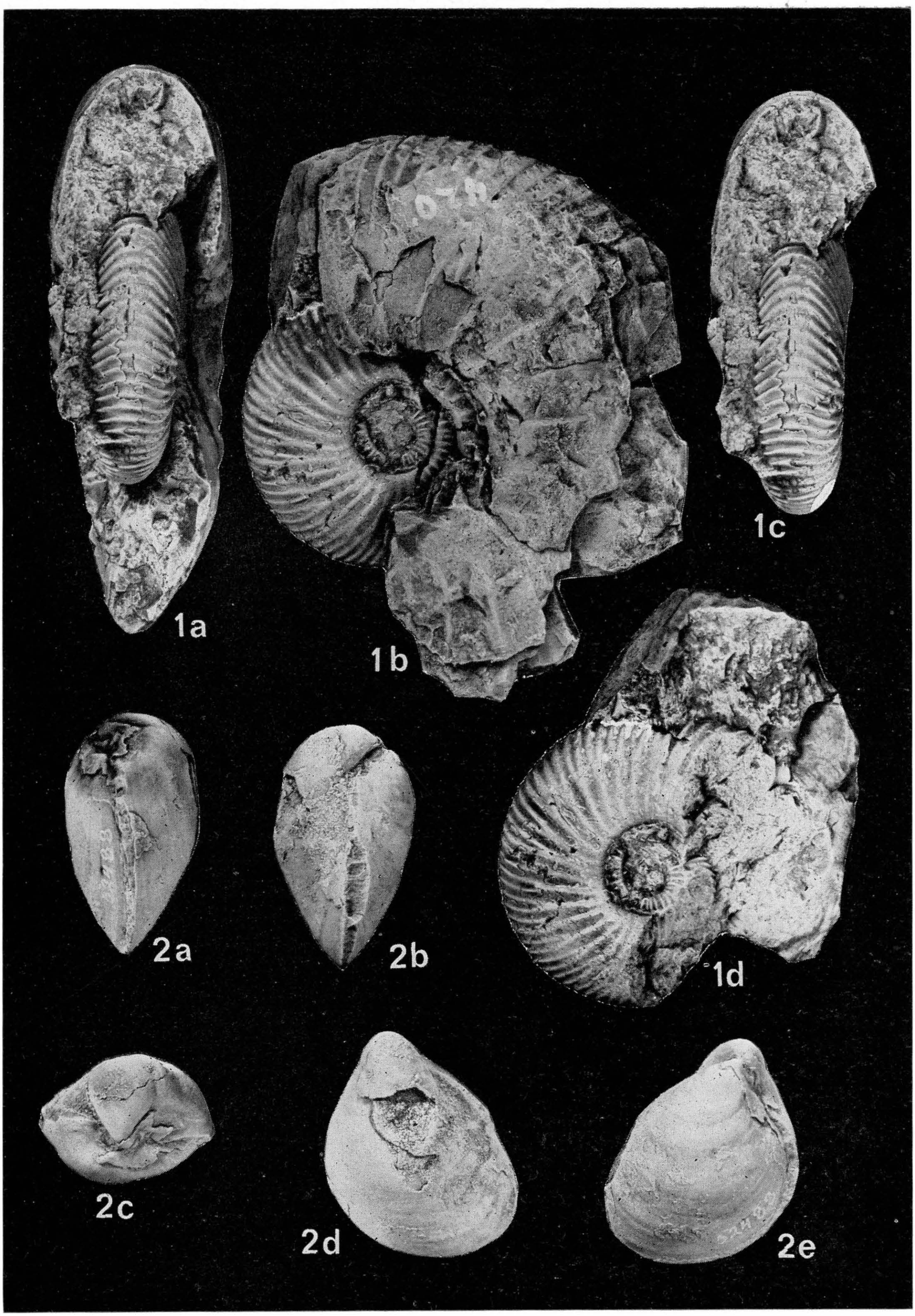
2 a-e. *Buchia terebratuloides* var. *obliqua* (Tullberg).
Horizon and locality as Plate 4, figs 1 a-d. GSC cat. no. 32598.

a. Anterior view. **b.** Posterior view. **c.** Hinge line and beaks of both valves.

d, e. Lateral views of left (d) and right (e) valves.

all figs x 1.

Plate 5



Novaya Zemlya (Bodylevsky 1967). More important is the recent description and illustration of *Platylenticeras* aff. *marcousianum* (Koenen) from the *Pseudogarnieria undulatoplicatilis* Zone of the Central Russian Platform (Sazonova 1971 pl. 22 fig. 1), which suggest a correlation with the basal part of the Platylenticeras Beds of northwest Germany, to which *P.* (*Tolypeceras*) *marcousianum* is restricted (Kemper 1968).

Sazonova's (1971) confirmation of the association of the *P. undulatoplicatilis* fauna with *Tollia* (*Tollia*) *pseudostenomphala* supports the correlation of the *P. undulatoplicatilis* Zone with the Siberian *Tollia* (*Tollia*) *tolli* Zone, as *T.* (*T.*) *pseudostenomphala* appears to be a typical representative of the subgenus *Tollia*. However, like the North Siberian and Canadian representatives of the *Tollia* (*T.*) *tolli* group, *T.* (*T.*) *pseudostenomphala* does range down into the uppermost Berriasian (upper beds of the *Surites spasskensis* Zone: Sazonova 1971).

The *Tollia* (*Tollia*) *tolli* Zone can be correlated with the basal part of the *Kilianella roubaudi* Zone (i.e. *K.* aff. *pexiptycha* Subzone) of southeastern France because of the occurrence of *Platylenticeras* (*Tolypeceras*) *marcousianum* and allied species in this part of the French zone. Kemper (1968 table 5) recognised a *P.* (*T.*) *marcousianum* Subzone at the base of the *roubaudi* Zone and the relevant section of Figure 3 follows this interpretation. Thus, there is good reason for thinking that the base of the *K. roubaudi* Zone corresponds approximately with that of the *P. undulatoplicatilis* and *Tollia* (*Tollia*) *tolli* Zones (Fig. 3).

The *Tollia* (*Temnoptychites*) *novosemelica* Subzone of Arctic Canada is approximately equivalent to the lower part of the *T.* (*T.*) *syzranicus* Zone of Northern Siberia and the Northern Urals (Saks and Shulgina 1969) and to the lower part of the *T.* (*T.*) *hoplitoides* Zone of the Russian Platform (Sazonova 1971). Bodylevsky (1967) pointed out that the widespread and biochronologically important *Temnoptychites* Zone is also represented in East Greenland. The dating of this zone varies according to the subdivision of the Valanginian stage favoured by individual workers and whether the workers concerned place the *Tollia* (*Tollia*) *tolli* Zone in the basal Valanginian or the uppermost Berrasian. Because of its stratigraphic position in the Russian Platform region between beds equivalent to those containing *Pseudogarnieria* and earliest Valanginian *Platylenticeras* and those containing the widespread Middle Valanginian *Polyptychites* (*P.*) *keyserlingi* fauna, the *Temnoptychites* spp. Zone of the Boreal Realm is here assigned to the upper part of the Lower Valanginian (Fig. 3). The zone appears to be equivalent to the lower, but not the basal, part of the *Kilianella roubaudi* Zone of southeastern France (Fig. 3).

The *Thorsteinssonoceras ellesmerensis* Subzone was tentatively assigned a late Lower or Middle Valanginian age (Jeletzky 1965b p. 14) and considered as "either slightly older than or about contemporary with some part of the *Polyptychites keyserlingi* and *Polyptychites michalskii* zone of Central and Northern Russia". The writer has since studied several collections of the *Polyptychites* (*P.*) *keyserlingi* fauna from the upper part of the Deer Bay Formation (some associated with the *B. keyserlingi* fauna, other with the overlying *B. inflata-sublaevis* fauna), in which *Thorsteinssonoceras* is absent. For this reason, and because of its occurrence closely above beds containing *Tollia* (*Temnoptychites*) *novosemelica*, the *T. ellesmerensis* Subzone is tentatively considered older than the Canadian *P.* (*P.*) *keyserlingi* fauna and equivalent to the middle part of the *Temnoptychites syzranicus* Zone rather than to the *Astieriptychites astieriptychus* Subzone of Northern Siberia (cf. Saks *et al.* 1965 table 1). It is believed to correspond to the middle part of the *T.* (*Temnoptychites*) *hoplitoides* Zone of the Central Russian Platform (cf. Fig. 3 and Sazonova

1971 table opposite p. 4). The dating and correlation of the *T. ellesmerensis* Subzone is made difficult by the apparent absence of *Astieriptychites* in Canada and an uncertainty concerning the stratigraphical range of *A. astieriptychus* in Northern Siberia.

Some of the above-mentioned collections of the *P.* (*P.*) *keyserlingi* fauna (e.g. GSC loc. 85025) are associated with *Buchia keyserlingi* rather than with the younger *Buchia* ex gr. *inflata-sublaevis* fauna. Because of this and the absence of any earlier Lower Valanginian ammonites, these collections are tentatively placed in the topmost part of the *Buchia keyserlingi* Zone, overlying its *T. ellesmerensis* Subzone (Fig. 3). This is supported by the association of *P.* (*P.*) cf. *keyserlingi* with *Buchia* cf. *keyserlingi* in the lower part of the Beattie Peaks Formation (outside the report area), stratigraphically below beds containing the *Buchia* ex gr. *inflata-sublaevis* fauna (Jeletzky 1968). The same relationships were noted in the Porcupine Plateau-Richardson Mountains trough (see above, p. 63).

The beds characterised by the *P.* (*P.*) *keyserlingi-B. keyserlingi* association are placed in the latest Lower Valanginian because of the occurrence of the earliest representatives of *P.* (*P.*) *keyserlingi* (and *P.* (*P.*) *michalskii*) in association with the latest *Tollia* (*Tollia*) forms in the upper part of the Platylenticeras Beds of northwest Germany (Kemper 1968). A similar fauna described by Donovan (1953) from East Greenland greatly puzzled the writer (Jeletzky 1965a pp. 42–43). However, it too can now be placed in the latest Lower Valanginian and correlated with the uppermost part of the Canadian *B. keyserlingi* Zone and with the uppermost Platylenticeras Beds. For these reasons, the Lower/Middle Valanginian boundary in Canada is placed at the top of the *B. keyserlingi* Zone rather than at the first appearance of polyptychitid ammonites (Fig. 3).

The correlation of the *P.* (*P.*) *keyserlingi* beds of the *B. keyserlingi* Zone with the upper part of the Platylenticeras Beds indicates their approximate correspondence to beds in the middle part of the *Kilianella roubaudi* Zone of the European Tethys, corresponding to the top part of its *Platylenticeras heteropleurum* Subzone (compare Kemper 1961 table 2, 1968 table 5, and Fig. 3 here).

(*ii*) *The* Buchia *ex gr.* inflata-sublaevis *Zone*

In the Porcupine Plateau-Richardson Mountains trough this zone begins closely above the base of the White Sandstone Member of the Lower Sandstone Division and extends into its middle part. In the central part of the trough it occurs in the upper part of the equivalent bluish-grey shale unit (Jeletzky 1961), stratigraphically above the *Buchia keyserlingi* fauna. The zone is also widespread in the uppermost Husky Shale (equivalent to the White Sandstone Member) in the Bonnet Lake-Barn Mountain area (Jeletzky 1971d), as well as in the uppermost Husky Shale and in the Lower Sandstone Division of the north-western part of the Ogilvie Mountains (Jeletzky 1971d).

In the Sverdrup Basin the zone is apparently restricted to the uppermost 100 to 130 metres of the Deer Bay Formation (Tozer *in* Thorsteinsson and Tozer 1970) in those Ellef Ringnes Island sections where the stratigraphical position of its fossils in relation to the overlying Isachsen Formation is reasonably well known. Some stratigraphically unassigned collections are assumed to represent approximately the same level. Elements of the *B.* ex gr. *inflata-sublaevis* fauna ascend into marine interbeds in the basal part of the overlying Isachsen Formation (Tozer *in* Thorsteinsson and Tozer 1970).

The *Buchia* ex gr. *inflata-sublaevis* fauna is widespread throughout the Canadian boreal region. It is characterised by the prevalence of strongly swollen *Buchia* which include *B. inflata* (Toula) and varieties, *B. sublaevis* (Keyserling) and varieties, *B.* n. sp. aff. *inflata* and *B. bulloides* (Lahusen) (see Jeletzky 1964 for illustrations of these). Of these forms, the taxonomic status of which is still obscure, *B.* n. sp. aff. *inflata* is by far the most common. In spite of the strong specific and subspecific variability of these *Buchia*, both horizontally and vertically, no way has yet been found to utilize this variation for regionally or inter-regionally valid zones or subzones.

Zonal subdivision and external correlation is, therefore, dependent on ammonites. In the Porcupine Plateau-Richardson Mountains trough, the *B.* ex gr. *inflata-sublaevis* Zone rarely yields any fossils other than *Buchia*, but in the Sverdrup Basin the zone is locally rich in well-preserved craspeditid and polyptychitid ammonites, belemnites and gastropods. Here it is possible to recognise a *Polyptychites* (*P.*) *keyserlingi* fauna in the lower part of the zone and a *Homolsomites* aff. *quatsinoensis* fauna in the upper, though not the topmost, part. These ammonite faunal horizons are treated as subzones of the *B.* ex gr. *inflata-sublaevis* Zone.

The *P.* (*P.*) *keyserlingi* fauna, of which the *P.* (*Euryptychites*) *stubbendorfi* fauna (Jeletzky 1964) appears to be but a lateral facies, is unique in the diversity of its polyptychitid ammonites, which include *P.* (*P.*) *keyserlingi* (Neumayr and Uhlig) (see Pl. 1, fig. 2; Pl. 3, fig. 2a, b), *P.* (*P.*) ex aff. *tschekanowskii* Pavlow (possibly only an extreme variant of *P.* (*P.*) *keyserlingi*), *P.* (*P.*) cf. *densicosta* Pavlow, *P.* (*P.*) cf. *densicosta* or *ramulicosta* Pavlow, *P.* (*E.*) *stubendorffi* (Schmidt) f. typ., *P.* (*E.*) *stubendorffi* var. *middendorffi* Pavlow, *P.* (*Dichotomites*) ex aff. *ascendens* Koenen, a generically indeterminate craspeditid and *Acroteuthis* (*Acroteuthis*) cf. *arctica* Blüthgen var. *elata* Saks and Nalnyaeva. This subzone is known on Ellef Ringnes Island (GSC loc. 37867), Amund Ringnes Island (GSC loc. 85023, 82695), North Amund Ringnes Island (GSC loc. 85059) and Axel Heiberg Island (GSC loc. C–4749). Not all of the polyptychitid ammonites listed above have been found at each locality, but there are enough species in common to conclude that all five localities contain partial faunules of the same Middle Valanginian fauna. This is referable to the principal part of the *P.* (*P.*) *keyserlingi* Zone of northwest Europe (Koenen 1902; Kemper 1968) and to the *P.* (*P.*) *michalskii* Zone of the Russian Platform (Sazonov 1956; Sazonova 1961, 1967; Gerasimov *et al.* 1962) and Northern Siberia (Saks and Shulgina 1962, 1969; Saks *et al.* 1963; Saks *et al.* 1965). Judging by data provided by Koenen (1902) and Kemper (1961, 1968) the mid-Valanginian bulk of the *P.* (*P.*) *keyserlingi* Zone (or "Polyptychites Schichten") corresponds

Plate 6

1 a-d. *Craspedites* (*Subcraspedites*) aff. *suprasubditus* (Bogoslovsky).

Lower Berriasian (*Buchia okensis* and *C.* (*S.*) aff. *subprasubditus* Zone), Deer Bay Formation, 136·6—140 metres above base. Axel Heiberg Island, GSC loc. 26171, 6·4 kilometres southwest of Buchanan Lake. GSC cat. no. 32599 (collected by Dr. J. Souther, 1955).

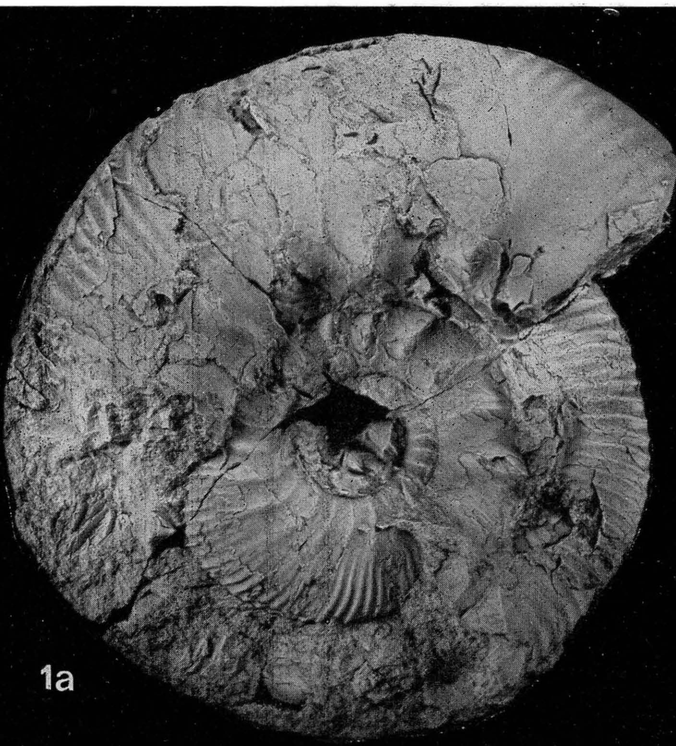
a. Lateral view showing the fine, dense, *Craspedites*-like ribbing of the inner whorls, closely similar to that of *Subcraspedites plicomphalus* var. *sowerbyi* Spath (see J. de C. Sowerby 1923, pl. 404). The fragmentary penultimate whorl and the last whorl (living chamber) have considerably coarser, more bullate ribs resembling those of the holotype of *S. plicomphalus* (J. Sowerby 1822). Only the beginning of the living chamber is preserved.

b, c. Ventral views (b, c) and whorl section (b) of last preserved whorl.

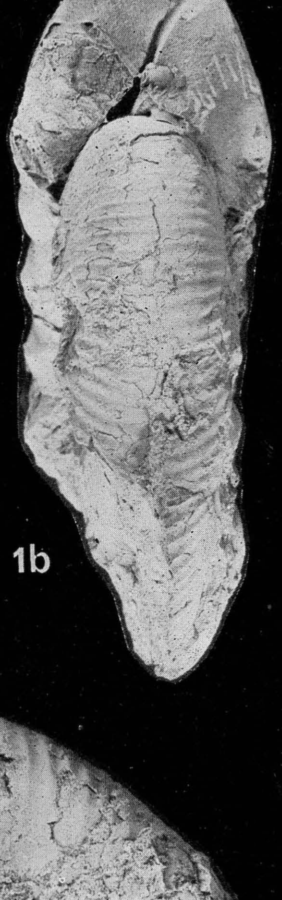
d. Lateral view of last preserved whorl (including the very beginning of the body chamber).

all figs x 1.

Plate 6

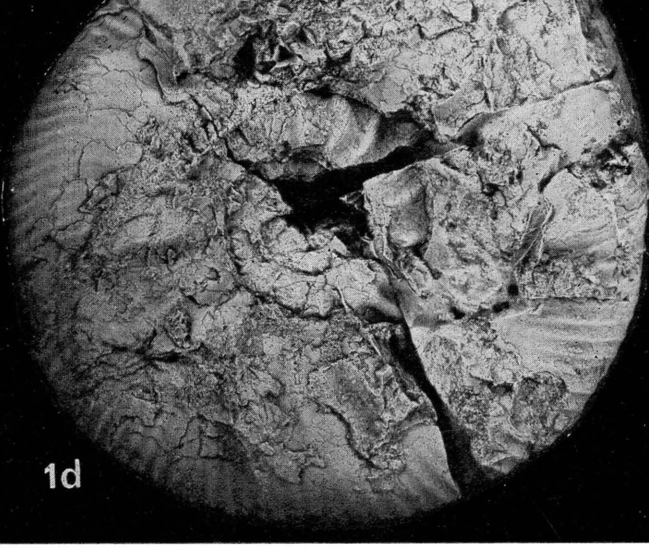


1a



1b

1c



1d

roughly to the upper part of the *Kilianella roubaudi* Zone of southwest Europe (Fig. 3).

Prior to the discovery of typical, well-preserved representatives of *P.* (*P.*) *keyserlingi* in the lower part of the *Buchia* ex gr. *inflata-sublaevis* Zone of the Sverdrup Basin, these beds were named the *Euryptychites stubendorffi* s. lato. Zone (Jeletzky 1964). This zonal term is now replaced by that of the *P.* (*P.*) *keyserlingi* Subzone (Fig. 3). In addition to needlessly complicating the zonal nomenclature, the use of *P.* (*E.*) *stubendorffi* is inappropriate because of its longer time-range. Fragments resembling *P.* (*E.*) *stubendorffi* have been seen in association with *Homolsomites* aff. *quatsinoensis* in the uppermost beds of the Deer Bay Formation. This species appears, furthermore, to range down into the late Lower Valanginian *Temnoptychites syzranicus* Zone in Northern Siberia (Saks and Shulgina 1969).

The writer disagrees with Bodylevsky's (1956) proposal to rename the Russian Middle Valanginian *P.* (*P.*) *keyserlingi* figured by Pavlow (*in* Pavlow and Lamplugh 1892 pl. 8 (5) fig. 13) and Bogoslovsky (1902 pl. 1 fig. 1) as *P.* (*P.*) *volgensis* and *P.* (*P.*) *okensis* respectively. Such extreme splitting does not serve any useful taxonomic purpose, needlessly complicates the zonal nomenclature and obscures the true geographical range of a polytypic mid-Valanginian index species which retains its basic morphological characteristics from England and northwest Europe to Arctic Canada. The replacement of *P.* (*P.*) *keyserlingi* by *P. michalskii* as the zonal index in the European and Asiatic parts of the U.S.S.R. does not appear to be necessary either, especially as these two species co-exist in northwest Germany (Kemper 1968) as well as in the U.S.S.R. The writer endorses Kemper's (1968 pp. 31–32) recent complaint that it is now impossible to identify most *Polyptychites* specimens because of such extreme splitting.

Ammonites diagnostic of the *Homolsomites* aff. *quatsinoensis* Subzone are rare. In the Sverdrup Basin this subzone has so far been found only on Ellef Ringnes Island (GSC loc. 21899, 48835 and 80752) where all its occurrences appear to be in the uppermost 65 metres of the Deer Bay Formation (see Tozer *in* Thorsteinsson and Tozer 1970).

In the Porcupine Plateau-Richardson Mountain Trough the subzone occurs in the northwestern part of the Ogilvie Mountains (Jeletzky 1971d) and in the Bonnet Lake—Blow Pass area (GSC loc. 88281). In both instances the zonal fossils occur in the uppermost beds of the Husky Formation which in these areas replaces laterally most or all of the Lower Sandstone Division, including its mid to late Valanginian beds (Jeletzky 1971d).

Plate 7

1 a-d. *Praetollia antiqua* n. sp. Paratype.

Latest Upper Volgian (Upper Jurassic). Horizon and locality as Plate 4, figs. 1 a-d. Largest specimen studied, with most (almost one half of the last whorl) of the adult living chamber preserved.

a. Lateral view showing the gradual coarsening of the ribs and the equally gradual replacement of sharp-topped primaries by obtuse bullae on the last (adult) whorl. The ribbing persists to the end.

b. Ventral view and whorl section of last whorl.

c. Whorl sections across the line of breakage shown in fig. 1a. The smooth, globose, innermost whorl is visible.

d. Lateral view, showing well-preserved ribbing at the beginning of the last whorl.

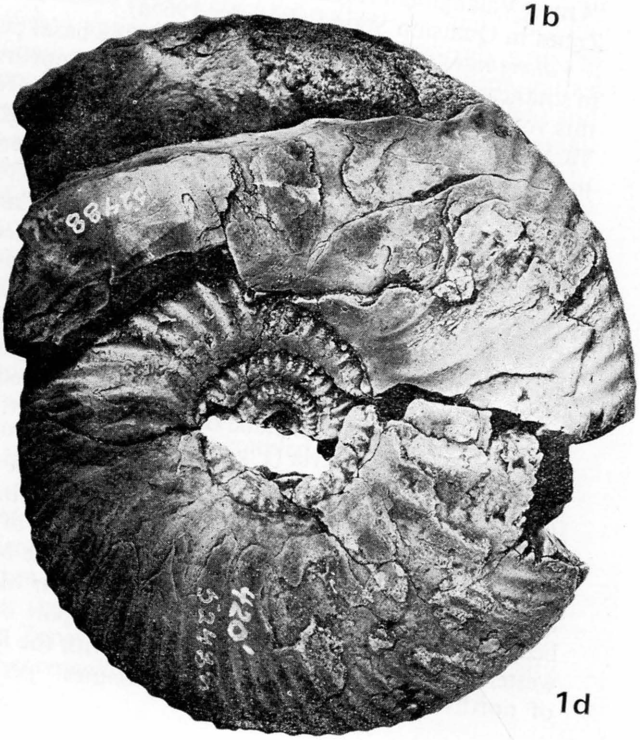
all figs x 1.

Plate 7

1a

1b

1c



1d

In the Sverdrup Basin the *H.* aff. *quatsinoensis* fauna includes the name fossil (Jeletzky 1964 pl. 11 fig. 5, pl. 12 fig. 4, pl. 13 fig. 6), *Polyptychites* (*Dichotomites*) aff. *bidichotomus* (Leymerie) (this paper, Pl. 1 figs 1a, b, Pl. 2 figs 1a-c, Pl. 3, fig. 1), *P.* (*Euryptychites*?) sp. indet. juv., *Acroteuthis subquadratus* (Roemer) emend. Swinnerton (Jeletzky 1964 pl. 11 fig. 2) and probably *Cylindroteuthis* (*Communicobelus*) n. sp. (Jeletzky 1964 pl. 10 fig. 1). In the Porcupine Plateau-Richardson Mountain Trough the *H.* aff. *quatsinoensis* Subzone includes *H. quatsinoensis* (Whiteaves) s. str., *P.* (*D.*) aff. *bidichotomus, Buchia crassicollis* (Keyserling) s. str. and *B. crassicollis* var. *solida* (Lahusen), in addition to the ubiquitous *B.* ex gr. *inflata-sublaevis* group.

The late Valanginian age of the *H.* aff. *quatsinoensis* Subzone is established by the presence of typical *H. quatsinoensis, B. crassicollis* f. typ. and var. *solida* in its southernmost known exposures. All these fossils are diagnostic of the *B. crassicollis* Zone of western British Columbia and the Pacific seaboard of the United States (Jeletzky 1965a; Imlay 1960; Imlay and Jones 1970). The reasons for assigning a general late Valanginian age to the *B. crassicollis* Zone of western North America have been discussed by Jeletzky (1965a) and Imlay and Jones (1970). This assignment is supported by the discovery of *Valanginites* aff. *nucleus* (Roemer) (see Pl. 1 figs a–d) in the Taseko Lakes map-area in western British Columbia (Jeletzky and Tipper 1968). This was found in beds lying immediately and apparently gradationally beneath early Hauterivian beds with *Homolsomites oregonensis* (Anderson) in a continuous but overturned section. The *V.* aff. *nucleus* beds (which did not yield *Buchia*) are evidently younger than any part of the *Buchia crassicollis* Zone of the Pacific slope because of their stratigraphical position closely below the lowest occurrence of *H. oregonensis.* They are presumably equivalent to the unfossiliferous "Latest Valanginian Rocks" occurring between the *B. crassicollis* and *H. oregonensis* Zones in Quatsino Sound (Jeletzky 1965a).

Valanginites appears to be restricted to the basal part of the Upper Valanginian in southeast France (Thieuloy, this volume) and northwest Germany (Kemper 1968, this volume). However, the Mexican representatives from the upper member of the Taraises Formation (Imlay 1938) are younger, though apparently still Valanginian in the writer's opinion. A late Valanginian age is therefore suggested for the *V.* aff. *nucleus* beds of Western British Columbia.

The *H.* aff. *quatsinoensis* Subzone of Arctic Canada probably represents the lower part only of the North Pacific *B. crassicollis* Zone, as *H. quatsinoensis* is restricted to the lower part of this zone in the Quatsino Sound sections (Jeletzky 1965a) and elsewhere in western British Columbia. This, and the association of *P.* (*D.*) aff. *bidichotomus* with *H.* aff. *quatsinoensis*, suggests that the *H.* aff. *quatsinoensis* Subzone is entirely of early Upper Valanginian age and roughly equivalent to the early Upper Valanginian Dichotomites Beds of northwest Germany, the *Polyptychites polyptychus* Zone of the Russian Platform, and the *Dichotomites* spp. Zone of northern Siberia (Fig. 3).

The uppermost part of the *B.* ex gr. *inflata-sublaevis* Zone, lying above the *H.* aff. *quatsinoensis* Subzone, is confined to the marine interbeds in the basal beds of the predominantly non-marine Isachsen Formation of the Sverdrup Basin, and to the equivalent, middle, part of the White Sandstone Member of the Lower Sandstone Division in the Porcupine Plateau-Richardson Mountain Trough (Fig. 3). These beds appear to be equivalent to the upper part of the *Buchia crassicollis* Zone of western North America and correlative with the lower part of the "Astieria" Beds of northwest Germany, the "*Dichotomites*" *petschorensis* Zone of the Russian

Platform, and the *Homolsomites bojarkensis* Zone of northern Siberia. Because of the above discussed occurrence of *V.* aff. *nucleus* in beds younger than the *B. crassicollis* Zone, this uppermost part of the *B.* ex gr. *inflata-sublaevis* Zone probably does not include the uppermost Valanginian of southwest Europe (Fig. 3).

The Siberian *Homolsomites bojarkensis* Zone was tentatively dated as early Hauterivian by Shulgina (1965), but its late Upper Valanginian age is indicated by its stratigraphical position immediately above the early Upper Valanginian *Dichotomites* spp. Zone and a much greater similarity of *H. bojarkensis* Shulgina and *H. indistinctus* Shulgina to the early Upper Valanginian *H. quatsinoensis* (Whiteaves) and *H.* aff. *quatsinoensis* than to the early Lower Hauterivian *H. oregonensis* (Anderson) and *H. packardi* (Anderson). Shulgina's tentative dating may have been caused by the tendency (incorrect in the writer's opinion) of Soviet workers to place beds with *Lyticoceras* s. lato (i.e. *Lyticoceras cryptoceras* Zone of Fig. 3) in the basal Hauterivian (e.g. Saks *et al.* 1965). An early Hauterivian dating of these beds was recommended by Debelmas and Thieuloy (1965) but subsequently the majority of western workers have included them in the late Valanginian (e.g. Moullade and Thieuloy 1967; Thieuloy, this volume). In East Greenland the highest *Buchia*-bearing beds of the Mount Niesen section have been placed in the latest Valanginian because of the presence of *Lyticoceras* (e.g. Spath 1946; Donovan 1957; Jeletzky 1965a).

The importance of this conflict of opinions is stressed by the fact that all of the allegedly early Hauterivian records of *P.* (*D.*) *bidichotomus* on the Russian Platform, in the Crimea, and in the Caucasus (see Shulgina 1965) are of late Valanginian age in terms of the placement of the Valanginian/Hauterivian boundary adopted here (Fig. 3).

The Central Russian Platform Zones of *Polyptychites polyptychus* and "*Dichotomites*" *petschorensis* (Bogoslovsky) appear to be correlative respectively with the *Dichotomites* spp. and *Homolsomites bojarkensis* Zones of Northern Siberia, rather than with the *Dichotomites* spp. Zone alone as proposed by Saks *et al.* (1965) and Shulgina (1965). In the writer's opinion *Olcostephanus petschorensis* Bogoslovsky (1902 pl. 12 figs. 1a–d) is not a *Dichotomites* but a *Homolsomites* closely allied to *H. indistinctus* and *H. quatsinoensis.* This is clearly indicated by its distinctive, strongly ascendant, craspeditid external suture-line consisting of two lateral and at least four auxiliary lobes (Bogoslovsky 1902 pl. 12 fig. 1d). The true *Dichotomites bidichotomus,* also occurring in European Russia, is a polyptychitid characterised by a different suture line, suspensive in the auxiliary part and consisting of two lateral and no more than three auxiliary lobes (Bogoslovsky 1902 pl. 13 fig. 1c; Arkell *et al.* 1957 fig. 458, 1c). Like the traditional misidentification of *Homolsomites* with *Dichotomites* in North America (e.g. Anderson 1938; Jeletzky 1965a *pars.*), the generic misidentification of *O. petschorensis* appears to be caused by an underestimation of the taxonomic value of the suture line coupled with an overestimation of that of the ribbing habit. The latter is most unreliable at generic level, being apt to recur in almost identical form in a number of homoeomorphic polytychitids and craspeditids (Jeletzky 1965b, 1966).

The extension of the geographical range of *Homolsomites* of the *H. quatsinoensis*—*H. bojarkensis* group from western North America to the European part of the U.S.S.R. indicates the late upper (but not the latest) Valanginian age of the *H. petschorensis* and *H. bojarkensis* Zones and their approximate contemporaneity with the upper part of the *Buchia crassicollis* Zone of western North America.

6. Systematic palaeontology

Genus *Praetollia* Spath 1952 (= *Pronjaites* Sasonova 1971, subj.)

Type-species. Praetollia maynci Spath 1952 (original designation).

Diagnosis. Tollia-like, discoidal, involute to moderately evolute phragmocones with a craspeditid external suture-line that is approximately straight and strongly ascendant through most or all of the distance between the ventral lobe and the umbilical seam and has four to five auxiliary lobes in addition to two lateral lobes; the fine, dense, *Tollia*-like ribbing of the early and intermediate whorls gradually becomes coarser and more widely spaced on the adult ultimate (or penultimate) whorl. The primary ribs on the last (adult) whorl resemble those of fully-ribbed *Craspedites* or *Surites* in becoming thickened, shortened, and more strongly elevated (sometimes faintly to distinctly bullate).

Remarks. The genus *Praetollia* was based on execrably preserved intermediate and early whorls which do not seem to differ materially from the corresponding whorls of more densely ribbed, involute *Tollia* forms. The Canadian *P. antiqua* is important in providing, for the first time, such intermediate whorls in an undistorted state (Pl. 5 figs 1a–d) and in association with well-preserved penultimate whorls and what appear to be parts of an adult living chamber (Pl. 4 fig. 1b; Pl. 7 figs 1a, d). This necessitates a reappraisal of the morphology and taxonomic position of *Praetollia*.

According to Spath (1952 p. 13), *Tollia* differs from *Praetollia* "chiefly in its more sigmoidal costation, with thickening of the primary stems which are more distantly spaced, and there is an increase in the peripheral projection of the secondaries . . .". To these distinctions Spath (1952 p. 14) added that "There is no indication of the constrictions, so characteristic of *Tollia*, and the ribbing on the whole is much straighter". These minor distinctions only apply to the corresponding growth stages of *Tollia tolli* Pavlow (1914 pl. 12 fig. 2a) and other comparably coarsely-ribbed *Tollia* forms (e.g. *Tollia payeri* Toula 1874 pl. 1 fig. 1, or *T. emelianzevi* Voronets 1962 pl. 32 fig. 2). Already the comparable growth stages of *T. tolmatschowi* Pavlow (1914 pl. 13 fig. 1), which in the writer's opinion is only a variant of *T. tolli*, are indistinguishable from *Praetollia maynci* in the spacing and relative straightness of the ribbing and in the appearance of primary stems. Other representatives of *Tollia*, such as *T. mutabilis* (Stanton) var. *mutabilis* (see Imlay 1960 pl. 28 figs 5–11) are characterised by even denser and straighter ribbing than that of *P. maynci*. The morphological features discussed above are, furthermore, known to be extremely variable at infraspecific level (as, for example, in *T. mutabilis*: see Imlay 1960) and so are unsuitable for the erection of even a subgenus, let alone a full genus. The presence or absence of constrictions is an equally unreliable distinction. Donovan (1964) was therefore justified in treating *Praetollia* as a junior synonym of *Tollia* on the evidence then available. The Canadian specimens of *P. antiqua* show, however, that the intermediate and adult stages of *Praetollia* differ from the comparable growth-stages of *Tollia*.

The primary ribs of *Tollia* remain thin, long and pinched until they disappear altogether on the outer whorls. In contrast, those of *Praetollia* become markedly shortened, and thickened, although still pinched and sharp-crested, on the last, and sometimes on the penultimate, whorl. They may also become distinctly bullae-like and rounded in cross-section (as in *Craspedites canadensis pseudosubditus*) on part or all of the living chamber of the largest specimens (e.g. pl. 7 figs 1a, d). The similarity of sculpture and shell-shape of fully-grown *P. antiqua* (Pl. 4 figs 1a–d, Pl. 7 figs 1a–d) to those of the strongly sculptured variant of *Craspedites* (*Taimyroceras*?) *canadensis*, i.e. the subspecies *pseudosubditus* (see Jeletzky 1966 pl. 2 figs 3, 4), is so close that there is every reason to accept the derivation of *P. antiqua* (and hence that of *Praetollia*) directly from such uppermost Volgian forms of *Craspedites* (*Taimyroceras*?). The latter differ from *Praetollia* in their radial or only slightly ascendant, simpler suture-line (Jeletzky 1966 fig. 1J) and in the interruption of secondaries in the middle of the venter.

The similarity of ribbing in *Tollia* and *Praetollia* appears therefore to be limited to the early and intermediate growth-stages. The adult *Praetollia* reverts to a more *Craspedites*-like morphology.

The external suture-line of all known *Praetollia* species (i.e. *P. maynci* Spath, *P. bidevexa* (Bogoslovsky), *P. nikitinoense* (Sazonova) and *P. antiqua*) appears to differ from that of many late Berriasian and Valanginian representatives of *Tollia*, including *T. tolli*, in being more strongly ascendant and approximately straight throughout or almost throughout the distance between the ventral lobe and the umbilical seam (see Spath 1952 figs 1a, 1b, pl. 4 fig. 2; this paper, Pl. 5 figs 1a, b, d). Thus, it is more like that of *Surites* ex gr. *spasskensis*. The external sutures of many *Tollia* species (see figs in Pavlow 1914; Saks and Shulgina 1969; Imlay and Jones 1970; Toula 1874) are either less ascendant throughout or are only comparably strongly ascendant in their adventral parts. The strongly ascendant parts of the latter sutures embrace either the first and second lateral lobes or these two lobes plus the first auxiliary lobe (or, rarely, the first and second auxiliary lobes). The remaining, adumbilical, part of the external suture-line is for the most part either only feebly ascendant or subradially directed. It may be feebly suspensive in some forms. Strongly ascendant adventral parts of such suture-lines may grade into their less ascendant to feebly suspensive parts, causing a more-or-less regularly adorally arched appearance in some *Tollia* suture-lines. In other *Tollia* each of the two parts of the external suture is more-or-less straight. Consequently an adorally directed knick occurs at their junction.

Further research is required to evaluate the constancy of these distinctions of the *Praetollia* suture-line, as some *Tollia* external suture-lines (e.g. Pavlow 1914 pl. 4 fig. 3a) appear indistinguishable from those of *Praetollia.*

Praetollia antiqua sp. nov. Pl. 4 figs 1a–d; Pl. 5 figs 1a–d; Pl. 7 figs 1a–d.

1966 Undescribed craspeditid ammonite: Jeletzky, pp. 20, 43.
1970 *Subcraspedites* n. sp. Jeletzky, table XI-8.
1971b *Tollia* (*Subcraspedites*?) n. sp. Jeletzky, p. 4, fig. 2.

Holotype. GSC Cat. no. 32597 (figured Pl. 5 figs a–d).

Material. Ten fragmentary to almost complete specimens, mostly undeformed but in part strongly weathered, from a horizon 129·5 metres above the base of the Deer Bay Formation in the Buchanan Lake section (see p. 47 for geographical detail); GSC loc. 52488.

Diagnosis. Praetollia characterised by a moderately evolute (umbilicus 34% to 35% of the diameter), shell; the biplicate, fine, dense (33–38 primary ribs per whorl) sculpture lasts to whorl heights of 20–25 mm; in subsequent growth stages it is replaced by coarser and more widely spaced, predominantly triplicate ribbing. In this triplicate growth-stage, many secondaries are either indistinctly attached to sigmoidally bent and pinched but heavy primary ribs, or are intercalated between them; as the ribbing coarsens, primary ribs may become blunt, somewhat swollen and bullate on the adult body-chamber.

Measurements. Holotype (GSC Cat. no. 32597) 81·5; 40; 34; 34.
Figd specimens: GSC 32600 91 (approximately) ; 43; 35; 35.
GSC 32594 74 (approximately); 40; 38; 34.
(Dimensions are in the order: diameter of shell in mm, whorl height in mm, whorl height as percentage of diameter, width of umbilicus as percentage of diameter).

Description. The earliest whorls (up to 6–7 mm diameter) are almost globose, with rounded whorl section. At higher diameters the whorl is higher than wide (1·1–1·2), the whorl section oval with a narrowly rounded venter and slightly to feebly convex flanks, which gradually contract all the way towards the venter from an ill-defined and rounded umbilical shoulder (Pl. 5 figs 1a, c). Each whorl covers from two-thirds to three-quarters of the preceding whorl. Variation of whorl shape is restricted to slight changes in convexity of the flanks and equally slight changes in the relative height of the whorl.

The earliest whorls are seen only in exposed parts of larger shells. They appear to remain completely smooth to a whorl height of about 3–4 mm. Fine, dense, biplicate ribs then appear. The primary ribs are closely spaced, straight to feebly flexed, and usually moderately inclined forward. They begin on the upper half of the umbilical wall and bifurcate at mid-flank or slightly higher. The secondary ribs are generally slightly flexed and invariably strongly inclined forward; they cross the venter in a pronounced forward bend and without any mid-ventral weakening (Pl. 5 figs 1a, c). All ribs are high, pinched and sharp-topped in well-preserved, shell-covered specimens (Pl. 4 figs 1a–d) but have a considerably more subdued, round-topped appearance on internal moulds (Pl. 5 figs 1a–d). The secondaries are almost invariably firmly attached to the primaries, and intercalated secondaries are rare. The number of primaries varies from 33 to 38 per whorl; an estimate of 76–78 secondaries per whorl is based on counting 38 or 39 secondaries on a half whorl of the holotype between whorl-heights of about 14 and 20 mm. The best preserved specimen of *P. maynci* figured by Spath (1952 pl. 3 fig. 2), has an estimated 40 primaries and 92 secondaries.

This biplicate sculpture persists to whorl-heights of 20 to 25 mm, where triplicate rib bundles begin to intercalate with the biplicate ones (Pl. 5 fig. 1d). The triplicate bundles may have a fasciculate appearance. After another fifth or quarter of a whorl biplicate rib bundles become rare to absent, the well-formed triplicate bundles begin to alternate with unattached single ribs (which begin at about mid-flank) and some quadriplicate bundles appear. Connections between primaries and secondaries become indistinct, and in many instances the primary ribs are only clearly connected with one or two secondaries, the others being indistinctly connected or intercalated between adjacent bundles. In this growth-stage, primary ribs tend to become more markedly flexed and forwardly inclined. Simultaneously, they become distinctly shorter (between one-third and two-fifths of the whorl's height), heavier and much more widely spaced (20–21 primaries per whorl above 25 to 30 mm whorl height). They remain sharp-topped and pinched to the adoral part of the adult bodychamber, when they may become round-topped and somewhat swollen (Pl. 5 fig. 1b). Secondary ribs also retain their fine, high, pinched and sharp-topped appearance (Pl. 4 figs 1a, c, d) except on internal moulds where they have a subdued, rounded, *Craspedites*-like aspect. Unlike the primary ribs, the secondaries do not seem to decrease in number per whorl during growth. As in the biplicate stage, they are flexed and strongly forwardly inclined, crossing the venter in a pronounced forward bend without any mid-ventral weakening (Pl. 4 figs 1a, b). Because of its persistence without weakening to the end of the largest, presumably adult, living chambers (Pl. 7 figs 1a, d) the triplicate ribbing is presumed to be the adult habit of *P. antiqua*. The weakening of sculpture on one flank of the largest body-chamber available (Pl. 7 fig. 1a) appears to be the result of weathering.

The suture-line of *P. antiqua* is typical of the genus.

Comparison with other species. *P. bidevexa* (Bogoslovsky 1897 pl. 3 figs 1–3) resembles *P. antiqua* in its similarly evolute whorl and in the coarsening, wider spacing and indistinct connection of primary and secondary ribs on the intermediate and outer whorls (the living chamber of *P. bidevexa* is unknown), but the biplicate growth-stage ends earlier (at a whorl-height of 10–12 mm). *P. bidevexa* has a relatively higher and more slender whorl with a disc-shaped section (instead of the oval section of *P. antiqua*) and a considerably more narrowly-rounded venter.

P. maynci differs from comparable growth-stages of *P. antiqua* in having an involute whorl, considerably finer and denser ribbing, and predominantly biplicate ribbing to a greater whorl-diameter (to at least 30 mm in the specimen figured on pl. 3 fig. 2 of Spath 1952). It is difficult to compare whorl sections as all Spath's (1952) figured *P. maynci* are strongly distorted. However, *P. maynci* apparently has a higher-whorled, more slender, and narrowly-ventered shell, in this respect being closer to *P. bidevexa*.

P. nikitinoense (Sazonova 1971) differs from *P. antiqua* in its lower whorl-section (Sasonova 1971 pl. 9 fig. 5a) with blunt venter, and in the prevalence of triplicate rib-bundles at a whorl diameter of only 12 mm, and possibly less. This poorly-known form is placed in *Praetollia* only tentatively, because of the close similarity of its ribbing to that of *P. bidevexa*. "*Praetollia*" *nikitinoense* may be an early *Tollia*-like growth-stage of a large *Craspedites* (*Subcraspedites*) species.

Genetic relationships. *P. antiqua* is believed to be an endemic form which evolved in the Sverdrup Basin from a late Upper Volgian *Craspedites* (see generic discussion, above) through the modification of the suture-line and disappearance (or primary absence) of the interruption of ribs on the venter. Transitional forms are as yet unknown, as *Craspedites* of the *canadensis* group and *P. antiqua* have not yet been found in the same continuous section.

Ammonites closely similar to *P. antiqua* in ribbing, whorl-section and suture-line occur in the (younger) basal Berriasian beds of the Sverdrup Basin (e.g. "*Tollia* (*Subcraspedites*) aff. *spasskensis*": Jeletzky 1964 pl. 2 fig. 4). These forms are, however, intermediate whorls of large, low-whorled, heavily bullate adults properly referred to *Craspedites* (*Subcraspedites*) ex gr. *suprasubditus* (see Pl. 6, figs 1a–d). Their close similarity to *P. antiqua* is ascribed to their direct derivation from the same root-stock (*Craspedites* (*Taimyroceras*?) *canadensis*).

The apparent absence of *Praetollia*-like craspeditids in the Berriasian rocks of the Sverdrup Basin and the presence of *Praetollia* in coeval rocks of East Greenland, North Siberia and the Russian Platform suggests the emigration of this stock soon after its naissance in the Sverdrup Basin during the latest Jurassic. It is too early to say whether *Praetollia* is a direct ancestor of *Tollia* as suggested by Spath (1952 p. 13) or an unrelated, strongly homoeomorphic offshoot of the more persistent *Craspedites* stock.

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The Jurassic-Cretaceous boundary in Jameson Land, East Greenland

Finn Surlyk

An almost complete sequence of Upper Jurassic-lowermost Cretaceous shales and sandstones occurs in Jameson Land. In latest Volgian or earliest Ryazanian time the succession was folded into a shallow syncline. The synclinal trough was transgressed by the sea from the south in Ryazanian time and filled with clastic sediments. Successively younger rocks rest with tectonic overstep on the gently folded sequence. Ammonites characteristic of the *Chetaites chetae* Zone (uppermost Volgian) occur 200 metres below the unconformity, whereas the oldest fossils found in the filling of the synclinal trough are characteristic of the *Surites spasskensis* Zone (Middle Ryazanian). Presumably the Jurassic-Cretaceous boundary is situated in the upper part of the folded sequence and not at the unconformity.

In Jameson-Land ist eine fast vollständige Folge von Ton- und Sandsteinen des Oberjura und der Unterkreide vorhanden. Zur Zeit der jüngsten Wolga- oder der frühesten Ryazan-Stufe wurde die Schichtfolge zu einer flachen Synkline gefaltet. Dieser Synklinal-Trog wurde im Ryazan vom Süden aus vom Meer erobert und mit klastischen Sedimenten angefüllt. Jüngere Schichten liegen mit "tectonic overstep" auf der schwach gefalteten Abfolge. Für die Zone des *Chetaites chetae* (hohe Wolga-Stufe) typische Ammoniten sind 200 m unterhalb der Diskordanz beobachtet worden. Demgegenüber gehören die ältesten in der Synklinalfüllung auftretenden Fossilien in die Zone des *Surites spasskensis* (Mittel-Ryazan). Vermutlich liegt die Jura-Kreide-Grenze im höheren Abschnitt der gefalteten Folge und nicht an der Diskordanz.

La Terre de Jameson offre une séquence quasi complète de schistes et de grès d'âge jurassique supérieur à crétacé essentiellement inférieur. Au Volgien terminal ou au Ryazanien basal, ces couches furent plissées dans un synclinal peu profond. La dépression synclinale fut recouverte au Ryazanien par une transgression marine en provenance du Sud et fut comblée par des dépôts clastiques. Des sédiments de plus en plus récents reposent en discontinuité tectonique sur cette séquence modérément plissée. Des Ammonites caractéristiques de la zone à *Chetaites chetae* (Volgien terminal) ont été récoltées 200 mètres environ sous la discordance, alors que les fossiles les plus anciens recueillis dans le remplissage de la dépression synclinale caractérisent la zone à *Surites spasskensis* (Ryazanien moyen). La limite Jurassique-Crétacé se situe probablement à la partie supérieure de la séquence plissée et non au niveau de la discordance.

1. Introduction

Sediments of Lower and Middle Jurassic age exposed along the southeastern coast of Jameson Land have been known for a long time (see Rosenkrantz 1934 and Callomon 1961). However, the Upper Oxfordian and ?Lower Kimmeridgian age of the immediately overlying beds was known only from a few ammonites described by Spath (1935 pp. 35, 78; pl. 13 fig. 5; pl. 15 fig. 3) while Lower Cretaceous sediments exposed in a small area on the south coast of Jameson Land were described by Aldinger in 1935. The faunas collected by Aldinger were described by Spath (1947).

Until 1968 the interior of southern Jameson Land was, however, completely unknown. In the years from 1968 to 1971 the whole of Jameson Land was mapped under the auspices of the Geological Survey of Greenland. In 1970 and 1971 the author mapped the Upper Jurassic and Lower Cretaceous sediments of southeastern Jameson Land (Surlyk and Birkelund 1972). A surprisingly complete Upper Jurassic sequence was found and the Lower Cretaceous succession established by Aldinger (1935) was completely revised.

Surlyk *et al.* (in press) established a formal lithostratigraphy for the whole sequence comprising in total 7 formations spanning in time from the Rhaeto-Liassic Kap Stewart Formation to the Ryazanian Hesteelv Formation. A review of the stratigraphical scheme is given by Surlyk and Birkelund (1972).

2. Geological setting

Throughout Jurassic time the present Jameson Land was covered by the sea, and marine shales and sandstones were deposited with a dominance of sandy facies towards the north and shaly facies towards the south. The subsidence was greatest towards the north where a very complete sequence is found (Surlyk and Birkelund 1972, fig. 9) whereas in southern Jameson Land the sequence includes several major gaps. The general dip of the beds is towards the south-southwest and consequently the youngest sediments are found along the southern and southwestern coast of Jameson Land. In Upper Jurassic time the following formations were deposited: the sandy Olympen Formation of Upper Callovian-Middle Oxfordian age (found only in northern Jameson Land), the shaly Hareelv Formation of Upper Oxfordian-Middle Kimmeridgian age (southernmost occurrences probably include younger horizons) and the sandy Raukelv Formation of Middle Kimmeridgian-Upper Volgian (lowermost Ryazanian ?) age. The Ryazanian Hesteelv Formation overlies the Raukelv Formation and, to the southeast and south, the Hareelv Formation with angular unconformity.

The boundary relations of the Hareelv, Raukelv and Hesteelv Formations are rather complicated and of great importance for the understanding of the Jurassic-Cretaceous boundary in Jameson Land. The formations are therefore described in some detail here.

The Danish lithostratigraphical terms as well as some topographical names are translated below to ease reading of the paper. According to normal stratigraphical practice the names should, however, be used in their Danish form.

Ø = island
Elv = river
Fjeld = mountain
Bjerg = mountain

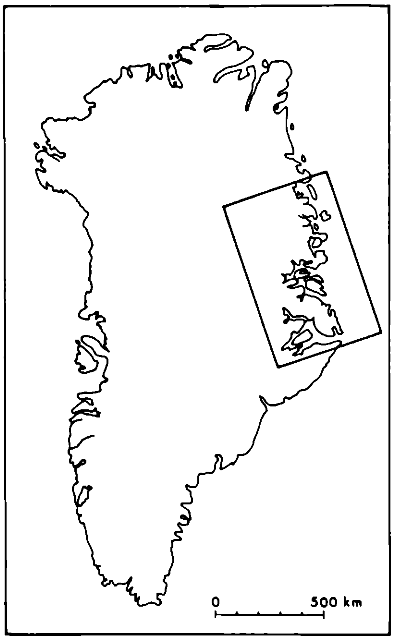


Fig. 1. Map of Greenland showing the position of the area covered by Fig. 2.

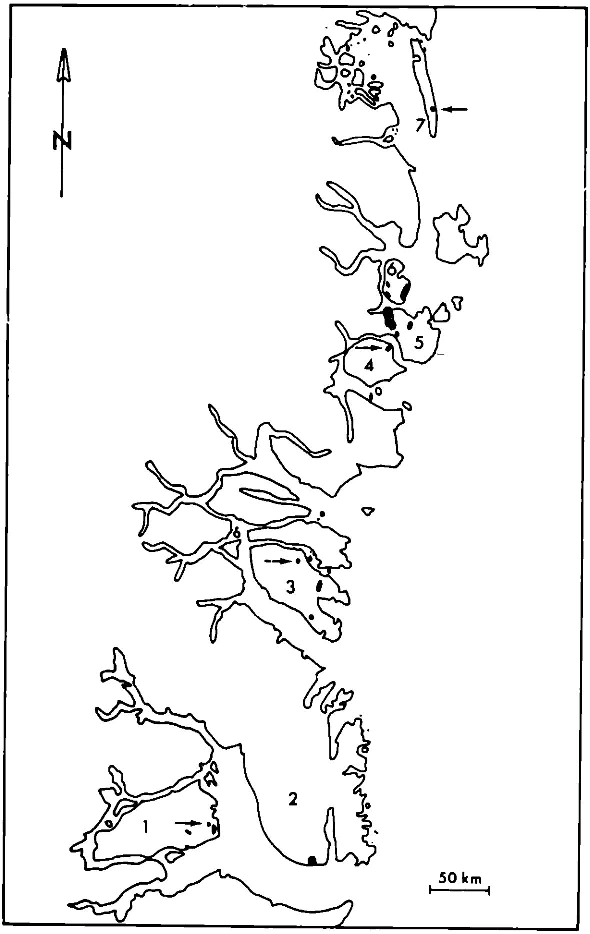


Fig. 2. Map of central East Greenland. Distribution of Ryazanian and Valanginian rocks shown in black. Arrows indicate the smaller outcrops. 1: Milne Land. 2: Jameson Land. 3: Traill Ø. 4: Clavering Ø. 5: Wollaston Forland. 6: Kuhn Ø. 7: Store Koldewey Ø. Based on Donovan (1957 fig. 12), Håkansson *et al.* (1971) and the author's observations.

Hareëlv Formation = Hare River Formation
Raukelv Formation = Rauk River Formation ("rauk" is Scandinavian for a characteristic form of exposure of rocks).
Hesteëlv Formation = Horse River Formation
Crinoid Bjerg Member = Crinoid Mountain Member.
Muslingeëlv Member = Mussel River Member

2a. The Hareelv Formation

The formation was established by Surlyk *et al.* (in press; see also Surlyk and Birkelund 1972). The formation is about 200 metres thick and overlies the Middle Jurassic Vardekløft Formation (Callomon 1961; Surlyk *et al.*, in press). It is composed of black and grey shales with large, irregular lenses and layers of yellow

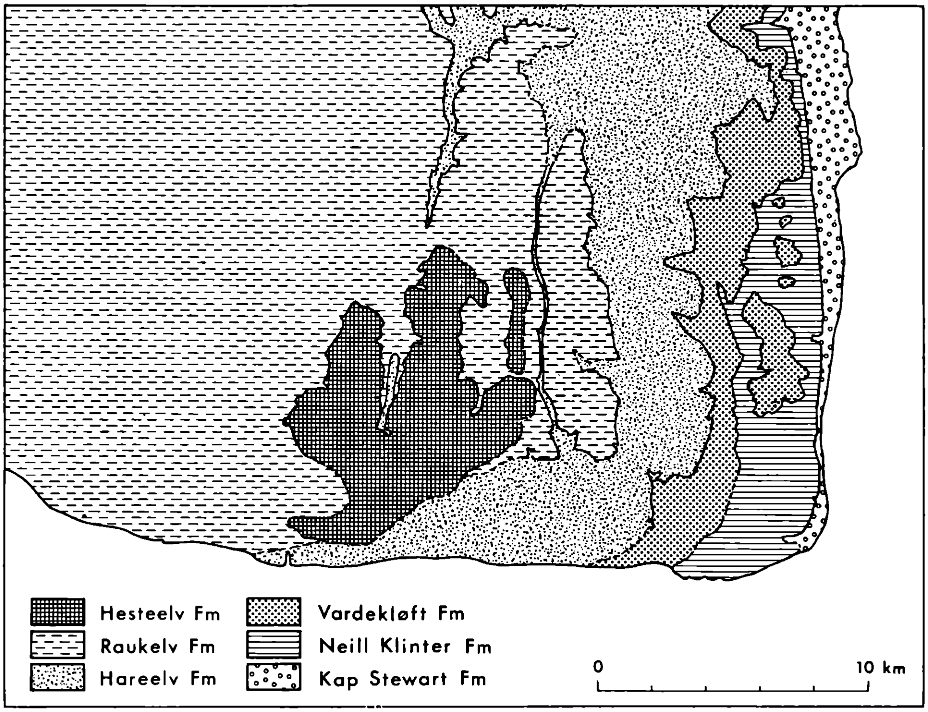


Fig. 3. Geological map of south Jameson Land. Stippled line between formations indicates that the boundary is inferred. The limits of the northeastern exposure of the Hesteelv Formation are rather uncertain as several dolerite sills and dykes disturb the bedding here. The Kap Stewart Formation is of Rhaetic-Liassic age, the Neill Klinter Formation of Pliensbachian-Toarcian, the Vardekløft Formation of Bajocian?-Middle Callovian, the Hareelv Formation of Upper Oxfordian-Lower (Middle?) Volgian, the Raukelv Formation of Middle-Upper Volgian (lowermost Ryazanian?), and the Hesteelv Formation of Ryazanian age.

sandstone. The shales are micaceous and often contain thin beds of loose, light sandstone and occasional calcareous or ferruginous concretions. Normally the shales are fine-grained but at some horizons sandier, lighter grey shales occur. The bedding planes are sometimes covered with a thin layer of mica. The shales often shows intense bioturbation by deposit feeding animals, but well-defined trace-fossils are rare except for occasional meandering trails. The shales are marine as they contain ammonites, bivalves and scattered inarticulate brachiopods throughout.

The boundaries between the shales and the sandstones are always knife-sharp. The sandstone lenses are of a very irregular shape. They may attain a length of several hundred metres and a thickness of 100 metres. The sandstones are well-sorted, medium-grained and rich in mica and sometimes in glauconite. Large, angular pieces of black shale are often incorporated in the basal parts of the sandstones. The lateral contact between the sandstone and the shale is normally curved in cross-section and ribbed longitudinally, and flame structures are developed on the surface of the sandstone body.

The shales are penetrated by numerous yellow sandstone dykes and sills. The sills are often transgressive and may continue into dykes. The thickness of the dykes varies from a few millimetres to about 20 centimetres. The shales only rarely show

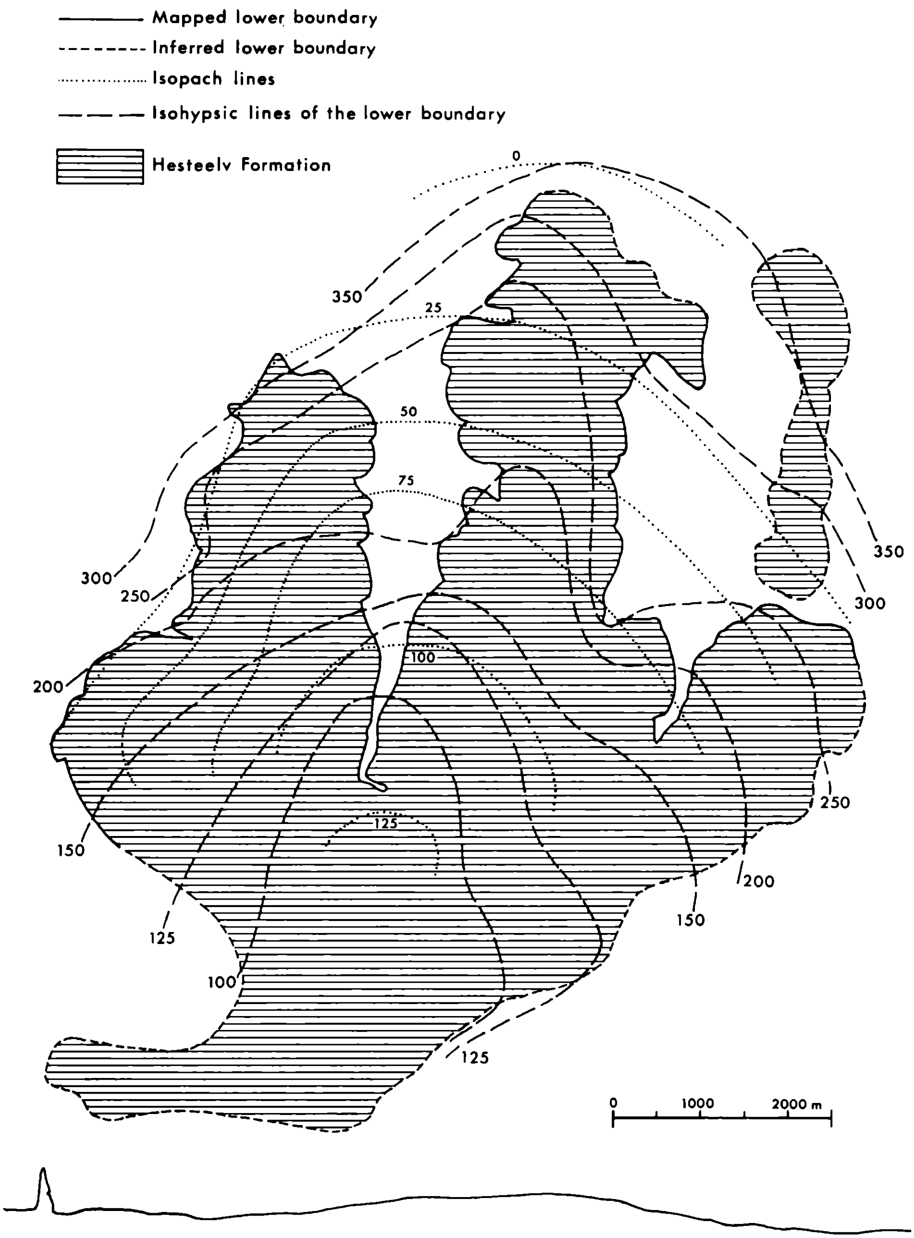


Fig. 4. Isopach map of the Hesteelv Formation with structure contour map of the lower boundary of the formation superimposed. All numbers are in metres.

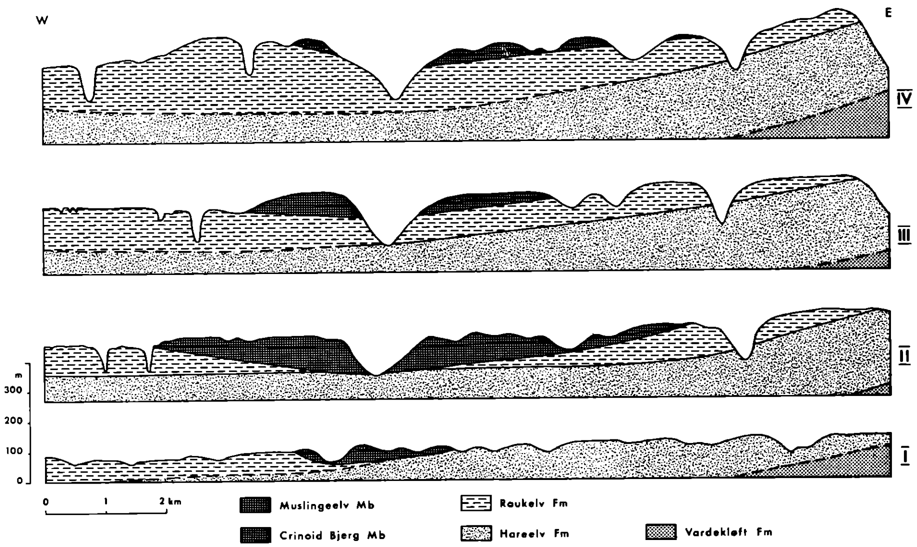


Fig. 5. West-east sections through the Hesteelv Formation in south Jameson Land. Positions of sections I-IV are indicated on Fig. 6. The Hesteelv Formation is divided into a lower Crinoid Bjerg Member and an upper Muslingeelv Member. The two members have the same shading but are separated by a heavy line on the sections.

disturbance at the contact with the dykes. The density of dykes and sills is greatest in the vicinity of the large sandstone lenses.

Inorganic sedimentary structures and trace-fossils are very rare in the massive sandstone. However, the tops of many of these almost structureless sandstone lenses often show trough cross-bedding.

Silicified wood and charcoal are very common in the sandstones and often form the cores of concretions in the shales. In some of the harder glauconitic sandstone lenses rare ammonites and small bivalves (e.g. smooth and costate pectinids) are found, but normally the massive sandstones are completely free of fossils.

The depositional environment of this formation would appear to have been of a rather unusual kind. The rocks are marine throughout and there is no evidence to indicate place of deposition in relation to the coast. The large sandstone lenses have the same shape as normal channel sands. They were, however, deposited under marine conditions and at a time when the shales were at least relatively hardened—judging from the angular shape of the shaly pieces incorporated at the bottom of many of the "channel sands". These features, combined with the existence of numerous sandstone dykes and sills of undoubtedly intrusive nature, suggest the following depositional regime. Along a coast a sequence of clastic sediments was deposited with near-shore sands gradually passing into black mud off-shore. Triggered by some unknown mechanism, presumably earthquakes, the sand moved seaward as slumping masses and eroded deep channels in the more-or-less hardened fine-grained deposits.

Deposition of the sand-flows was followed by intrusion of sandstone dykes and sills and the sand settled with expulsion of water. By erosion and rotation of the lateral parts of the sand bodies the large-scale longitudinal side-ridges were developed and flame structures were formed. The rotational nature of these large ridges can be seen from their shape and their repeated occurrence, one above the other, and from the orientation of the mica flakes. The cross-bedding found at the top of the "channels sands" was probably formed by reworking of the exposed part of the sand bodies after the sand had settled in the eroded channels.

The Hareelv Formation is found in the southern half of Jameson Land (Fig. 3; see also map in Surlyk and Birkelund 1972). Only in the southwestern part is it covered by younger deposits.

In the basal shales of the formation a rich fauna of Upper Oxfordian ammonites is found (*Decipia* and *Amoeboceras*) (Callomon 1961; Surlyk *et al.*, in press). Higher parts have yielded amoeboceratids, *Rasenia* and ?*Aulacostephanus,* indicating the presence of the whole of the Lower Kimmeridgian (Surlyk *et al.,* in press). Sparse finds of ?*Subdichotomoceras* above may indicate a Middle Kimmeridgian age for the upper part of the sequence (Surlyk *et al.,* in press). Only a very few badly preserved ammonites have been collected in southernmost Jameson Land, where the formation is directly overlain by the Ryazanian Hesteelv Formation, and the extent of the hiatus cannot be established with certainty.

2b. The Raukelv Formation

Upwards the shales and "channel sands" of the Hareelv Formation pass more-or-less gradually into a sequence of very coarse, light-coloured sandstones, about 300 metres thick, designated as the Raukelv Formation by Surlyk *et al.* (in press).

Aldinger (1935) described a sequence of large-scale cross-bedded sandstones from the area around the river Raukelv as the top member of the Lower Cretaceous sediments (i.e. what is now the Hesteelv Formation). These sandstones are now known to underlie the Hesteelv Formation and constitute the top beds of the Raukelv Formation. They are of Upper Volgian-?very early Ryazanian age and dip beneath the sediments of the Hesteelv Formation (Fig. 5).

The Raukelv Formation consists of cyclically alternating, massive or large-scale cross-bedded sandstone units and shaly siltstones. The sandstone horizons vary in thickness from 10–50 metres and form conspicuous marker beds.

The sandstones are white or yellow, but commonly weather to brown or dark-red colours. They are composed almost solely of quartz grains, and in many of the massive and cross-bedded layers glauconite plays an important role. The degree of sorting is very poor, the grain-size is mainly in the coarse sand or gravel fraction. Large quartz pebbles are very common.

The massive beds are sometimes divided into large irregular sheets with a thickness of 0·1–0·3 metres. These sheets may represent very flat cross-bedding. In the basal part of the formation platy, red-brown sandstone with parting lineation or small-scale linguoid ripples often occurs.

Palaeocurrent directions in the cross-bedded sandstones are very uniform, often varying within only a few degrees in an area of several square kilometres (Fig. 9). The main transport direction is towards the southeast. Viewed from the air the foresets can be seen to form large fans (Fig. 9).

The foresets are tangential or, more rarely, sigmoidal (Fig. 8). They normally show graded bedding with gravel at the base passing within a few centimetres into medium-grained sand. The form sets are tabular, commonly with erosional surfaces, and vary in thickness from 0·3–10 metres.

A characteristic cyclicity is often observed. The modal cyclothem commences

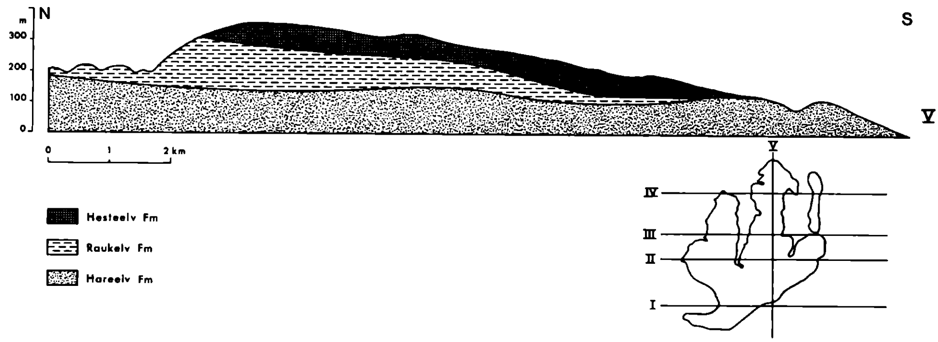


Fig. 6. North-south section through the Hesteelv Formation in south Jameson Land. Inset a map of the distribution of the formation showing the position of the section and the 4 sections on Fig. 5.

with one or two large-scale cross-stratified sandstones each 5 to 10 metres thick. The top surface is erosional, penetrated by numerous vertical burrows and covered with a thin ferruginous crust. This is followed by a massive, poorly-sorted sand- or gravelstone, 5–10 metres thick, sometimes with ammonites, bivalves and crinoids, and again with an erosional, burrowed, iron-impregnated top surface. It is overlain by silty or fine-sandy intensely bioturbated shale with rare ammonites and bivalves.

Numerous variations on this theme are seen, but the main features—cross-bedded sandstone, followed by massive sandstone, followed by shale—play a very important role throughout the formation.

Many of the sandstones contain brown ferruginous concretions, which vary in size from 1 centimetre to 1 metre and in shape from perfectly ball-shaped to completely irregular masses.

Petrified tree-trunks with a diameter up to 0·5 metre are common in some horizons. In the massive, coarse sandstones and gravelstones, ammonites, bivalves, and crinoids are often present in great numbers. Pavements of large, smooth pectinids with the convex side up or shell-beds with no preferred orientation of the fossils are seen at several places. In the cross-bedded sandstones only very few body-fossils (rare ammonites and oysters) have been observed, but vertical burrows such as mantled U-tubes and *Monocraterion* are characteristic of the sediment.

Thin horizons of brownish, silty or sandy shale occur between the sandstones. They normally weather out as large, concretionary, ellipsoidal bodies. The shales contain rare ammonites and bivalves and occasionally large plant fragments. They are intensely bioturbated and contain a wealth of trace-fossils.

In the western part of the area one of the shale horizons thickens considerably (to about 70 metres) and assumes a grey-black colour.

The Raukelv Formation is found in the southernmost part of Jameson Land and forms extensive plateaus. Only in the extreme southernmost part of the area is the formation covered by the Ryazanian Hesteelv Formation.

In the basal part of the formation perisphinctids of ?Middle Kimmeridgian age are found. Higher beds contain successive faunas of *Pavlovia, Dorsoplanites, Epipallasiceras* and *Laugeites* of Upper Kimmeridgian (Middle Volgian) age and *Subcraspedites* and *Chetaites* of Upper Volgian age (Surlyk *et al.* in press).

The specimens of *Chetaites* are found several hundred metres below the unconformity between the Raukelv Formation and the Ryazanian Hesteelv Formation. Between the *Chetaites* horizon and the unconformity a few hitherto undetermined ammonites have been found (one was described but not figured by Spath 1947, pp. 51–52).

Stratigraphical sequences of the ammonites and therefore the biostratigraphical zonation of the Raukelv Formation are not yet perfectly understood. All the fossils were collected bed-by-bed in measured sections with exact altitude and localization indicated. However, owing to the low topography and especially to the nature of the rocks—thick massive or large-scale cross-bedded sandstones—it is often very difficult to combine and correlate the individual sections with certainty. Furthermore, the upper part of the Raukelv Formation possibly includes several minor unconformities. Thus a flexure trending east-west with a southerly dip seems to have been formed before the deposition of the upper 200 metres or so of the Raukelv Formation i.e., immediately below the layers with ammonites close to *Chetaites chetae*. The supposed flexure runs through the northernmost exposure of the Hesteelv Formation (Fig. 3). Another flexure is seen in the section on Figure 6, and is also revealed in the changing dip of the axis of the synclinal trough in which the Hesteelv Formation was deposited (Fig. 4).

These structures are difficult to see on the ground and are mainly interpreted from aerial photographs. Recent erosion often follows the giant foresets of the large-scale cross-beds resulting in a kind of exposure which, when viewed from a distance, gives a perfect illusion of a monoclinal fold.

Contrary to the pessimistic prophecies of Donovan (1957 p. 58)—"Further work in the area is desirable, but might not be very rewarding"—it must be stated that the whole interior of southern Jameson Land from the northernmost occurrence of the Raukelv Formation and southwards (Fig. 3) is extremely well exposed. More detailed field work in the future will doubtless yield much supplementary information on the succession of the critical ammonite faunas of the Jurassic-Cretaceous boundary.

2c. The Hesteelv Formation

In late Volgian or very early Ryazanian time the Jurassic sequence was folded into a shallow syncline with an axis dipping a few degrees towards the south. After a short break in sedimentation the synclinal trough was transgressed from the south in Ryazanian time. The whole succession deposited in the synclinal trough comprises the Hesteelv Formation, established by Surlyk *et al.* (in press).

In the southern part of the trough the formation is developed as uniform black shales. Upwards and towards the margins the shales become more sandy and are characteristically developed as light-brownish, irregularly silty and fine-sandy shales. The lower dark shales are almost totally free of carbonate. Upwards the carbonate content in the shales increases to about 55%. The degree of sorting is medium to poor.

The lower half of the shaly sequence (designated as the Crinoid Bjerg Member by Surlyk *et al.*, in press) weathers to a greyish colour, whereas the upper half weathers light-yellow-brown. Thin yellow layers of loose sandstone occur. The shales are very micaceous and often contain numerous small pieces of reworked dark-grey shale. They weather out into huge ellipsoidal concretionary bodies and contain light-brown calcareous concretions sometimes with barytes-filled cracks. The bedding-planes are often covered with finely comminuted plant debris. Large pieces of wood occur at many horizons and some have been bored by bivalves. The shales often show intense bioturbation and well-defined trace-fossils are found at many levels. The shales grade upwards into grey-brown, fine-grained sandstones with parting lineation or linguoid ripples.

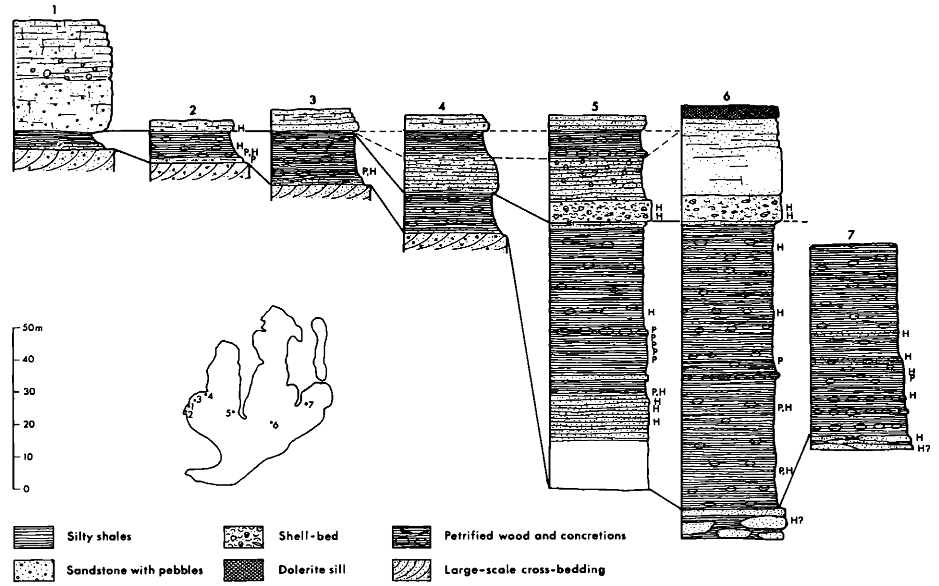


Fig. 7. Sections and litho-units of the Ryazanian Hesteelv Formation. The lower solid line indicates the boundary between the Raukelv Formation—or in sections 5, 6 and 7 the Hareelv Formation—and the Crinoid Bjerg Member. The upper solid line indicates the boundary between the Crinoid Bjerg Member and the Muslingeelv Member. The stippled lines enclose the upper shaly unit of the Muslingeelv Member. The positions of the sections are shown on the inset map. H = *Hectoroceras kochi*. P = *Praetollia maynci*. H? in section 6 indicates that the determination is doubtful. H? in section 7 indicates that the specimen was not collected *in situ*.

Ammonites are common in most horizons but are normally flattened or crushed. However, in the calcareous horizons their preservation is better and they are here accompanied by bivalves which are often found preserved in life position.

The member is found in the major part of the distributional area of the formation, but has wedged out at the northern and easternmost localities (Fig. 5).

The shaly Crinoid Bjerg Member is overlain with a rather sharp contact by a characteristic, sandy shell-bed, which can be traced as a marker horizon in the central part of the area. The matrix between the shells is a hard, grey calcareous sandstone or gravelstone often containing larger quartz pebbles. The fossil assemblage is dominated by large, thick-shelled bivalves with subordinate ammonites and belemnites (Fig. 10). The bivalves are in most cases found with the shell preserved. At some localities (e.g. the type locality of the formation; section 6 on Fig. 7) the shells are mainly orientated parallel with the bedding. The number of fossils decreases upwards but this is to some extent merely a matter of preservation, for a clear transition can be seen from a fauna with shells preserved, through beds with fossils preserved as casts, to beds where the fossils are only recognisable as thin curved, white lines. The shell-bed is followed by massive or cross-bedded light sandstones and in the central part of the area by a thin sequence of brownish, micaceous shale of the same type as the shales characteristic of the Crinoid Bjerg Member (sections 4 and 5 on Fig. 7). These shales are overlain by massive or large-scale cross-bedded sandstones with vertical burrows. The surfaces of the sets are erosional, penetrated by burrows, corroded and covered by a thin ferruginous crust. Perfectly spherical concretions varying in size from a few millimetres to 0·5 metre are very common in many of the sandy horizons. The whole sequence from the shell-bed and upwards comprises the Muslingeelv Member (designated by Surlyk *et al.*, in press).

The Crinoid Bjerg Member contains the ammonites *Hectoroceras kochi* Spath and *Praetollia maynci* Spath. In the shell-bed *H. kochi* is the only ammonite found with some rare exceptions. In the highest sandstones *H. kochi* is found together with a few specimens of *Surites,* probably close to *S. poreckoensis* Sazonov (see Surlyk *et al.*, in press, pl. 4, fig. 4). Consequently the whole fauna is of Lower Cretaceous, Ryazanian age.

In an isolated occurrence on the summit of the tectonically disturbed J. P. Kochs Fjeld a few ammonites of presumed Valanginian age were found (see Surlyk *et al.*, in press, pl. 4, fig. 5).

2d. Dating the unconformity

About 200 metres below the unconformity separating the Raukelv Formation from the Hesteelv Formation there occurs a rich assemblage of ammonites which includes forms close to *Chetaites chetae* Shulgina (Surlyk *et al.*, in press, pl. 3, figs 3, 4). Approximately 100 metres higher in the succession several ammonites were found which apparently belong to a new, undescribed genus. From about the same level but further westwards an assemblage of *Buchia* and ammonites was collected. One of the ammonite species might well be a predecessor of *Hectoroceras.* It is more sharply keeled along the venter and the general rib pattern is the same but the ribs are straighter than those of *Hectoroceras.* It is associated with several smaller ammonites some of which may be related to *Praetollia.* The general character of the assemblage is thus suggestive of a Ryazanian age.

Many badly preserved ammonites occur in the top beds of the Raukelv Formation. One collected by Säve-Söderbergh in 1933 was described but not figured by Spath (1947 pp. 51–52). Spath was much confused by the ammonite as he thought it came from the top beds of the Ryazanian Hesteelv Formation. We now know that this part of the sequence in fact constitutes the top beds of the underlying Raukelv Formation (see p. 87). I have collected many specimens of badly preserved ammonites from the same locality. A reliable generic determination is not possible, but they may be related to *Praetollia.*

Hectoroceras kochi occurs together with *Praetollia maynci* and probably another species of *Praetollia* in the basal beds of the Hesteelv Formation immediately above the unconformity. After this paper was submitted for publication the author's collections were examined by Dr. J. A. Jeletzky. It became apparent that the latter species of *Praetollia* (Pl. 1c) is conspecific with or very closely related to *Praetollia antiqua* Jeletzky (described as a new species by Dr. Jeletzky in this volume). Furthermore a single specimen (only living chamber preserved) of "*Subcraspedites* (= *Borealites*)" aff. *suprasubditus* (Pl. 1 d, e, f) and a single specimen of *Buchia okensis* (Pl. 1a, b) were found higher in the succession, in the shell-bed of the Hesteelv Formation. The two latter species are both diagnostic of Jeletzky's lowest Berriasian zone in Canada (Jeletzky, this volume).

Praetollia antiqua was previously known only from Canada by about 9 specimens from a single bed 8·5 metres below the lowest bed containing *Buchia okensis* and "*Subcraspedites* (= *Borealites*)" aff. *suprasubditus.* Their relative stratigraphical position in Canada and in Jameson Land is thus almost identical.

Based on its occurrence together with *Buchia terebratuloides* Lahusen f. typ., *B. t.* var. *obliqua* Tullberg and *B. terebratuloides* var. *subuncitoides* Bodylevsky, *Praetollia antiqua* is placed in the late Upper Tithonian in Canada (Jeletzky, this volume: but see also Casey and Rawson, this volume).

In Jameson Land *P. antiqua* is found together with *H. kochi* and *P. maynci* and therefore placed in the Ryazanian Zone of *Hectoroceras kochi* (see Table 1).

Several explanations might be put forward to explain this discrepancy in stratigraphical occurrence:

(1) The Jurassic-Cretaceous boundary falls within the *Hectoroceras kochi* Zone and both *Praetollia maynci* and *H. kochi* cross the boundary.

(2) *Praetollia antiqua* crosses the Jurassic-Cretaceous boundary.

(3) The long distance correlations by means of species of *Buchia* placing *P. antiqua* in the topmost Tithonian are not valid.

I am of the opinion that (1) can be excluded as all Russian and West European workers seem to agree that *H. kochi* is placed well up in the Berriasian or Ryazanian (see Table 1).

As *P. antiqua* is found in only one single bed in Canada its range is unknown and (2) might be correct. Thus its Canadian occurrence would correspond to the lower part of its range and the Greenland occurrence to the upper part.

A correlation from Canada to Jameson Land on the basis of species of *Buchia* is very difficult, but the majority of the *Buchia* species found in the upper part of the Raukelv Formation, i.e. below the unconformity and below *P. antiqua*, seem to show Cretaceous affinities (Jeletzky, personal communication 1972).

Dr. Jeletzky's identification of the three above mentioned species in East Greenland is of extreme importance for the correlation between Europe, Greenland and Canada. As the faunal successions in East Greenland fit well with those of England and Siberia it is to be hoped that additional ammonite discoveries in Canada will solve the problems of the position of the Jurassic-Cretaceous boundary in that region, as long distance correlations by means of *Buchia* seem to meet with great difficulties.

In summary, ammonites diagnostic of the highest Volgian zone in Russia, viz. the *Chetaites chetae* Zone, are represented 200 metres below the unconformity in Jameson Land. They are followed by assemblages of undescribed and often badly preserved craspeditid ammonites presumably related to *Subcraspedites, Hectoroceras* and *Praetollia*. Separated by the unconformity follows an ammonite assemblage diagnostic of the second Ryazanian zone in Russia, the *Hectoroceras kochi* Zone. Thus there is still no fossil evidence for the lowest Ryazanian zone—the *Riasanites rjasanensis* Zone.

Plate 1.

1a, b. *Buchia okensis* (Pavlov). x 0·66. GGU No. 138190, MMH No. 12821. Muslingeelv Member (the shell bed). Ryazanian. Eastern bank of Muslingeelv, 2·5 km south of section 5 (Fig. 7).

2. *Praetollia* cf. *antiqua* Jeletzky. x 0·66. GGU No. 138146, MMH No. 12822. Lateral view. Crinoid Bjerg Member. Rayazanian. Associated in the same piece of rock with *Hectoroceras kochi* Spath. Eastern bank of Muslingeelv at river level, 1·7 km. south of section 5 (Fig. 7).

3a-c. "*Subcraspedites*" (=*Borealites*) aff. *suprasubditus* (Bogoslovsky). x 0·66. GGU No. 138191. MMH No. 12823. Muslingeelv Member (the shell bed). Ryazanian. Eastern bank of Muslingeelv, 2·5 km south of section 5 (Fig. 7).

a. Peripheral view. x 0·66. Impression of *Hectoroceras kochi* on the left side of the specimen.

b. Lateral view. x 0·66.

c. Lateral view. x 0·66. Impression of *H. kochi* on the lower left part of the specimen.

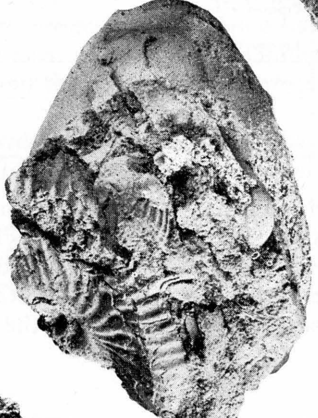
All three specimens were determined by Dr. J. A. Jeletzky. The specimens are housed in the Mineralogical Museum, Copenhagen. Photos by J. Aagaard.

Plate 1


1a


1b


2


3a


3b

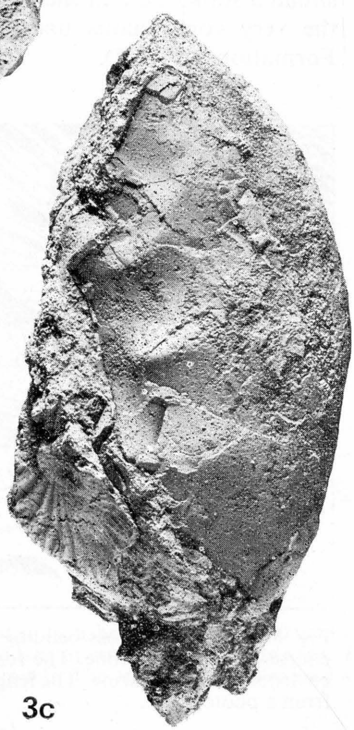

3c

Table 1. Correlation of the Middle Volgian-lowermost Valanginian deposits in Russia and southern Jameson Land.

Stages		Sachs et al., 1968		Basov et al., 1970	Surlyk et al., in press
		North Ural	Basin of Volga River	Bay of Anabar	Southern Jameson Land
Valanginian				Polyptychites stubendorffi	cf. Polyptychites mokschensis
				Neotollia klimovskiensis	
Ryazanian		Tollia payeri		Bojarkia mesozhnikowi	Surites aff. poreckoensis Hectoroceras kochi Hectoroceras kochi Hectoroceras kochi Praetollia maynci
		Surites analogus	Surites spasskensis	Surites analogus	
		Hectoroceras kochi		Hectoroceras kochi	
		?	Riasanites rjasanensis	Chetaites sibiricus	
Volgian	Upper	?	Craspedites nodiger	Chetaites chetae	Aff. Chetaites chetae
				Craspedites taimyrensis	Subcraspedites sp.
		Craspedites subditus	Craspedites subditus	Craspedites okensis	
		Kachpurites fulgens	Kachpurites fulgens		
	Middle	Laugeites (?) vogulicus Laugeites groenlandicus	Epivirgatites nikitini	Epivirgatites variabilis	Laugeites (?) vogulicus

This succession strongly suggests that the unconformity corresponds to the upper part of the *rjasanensis* Zone or to the boundary between the *rjasanensis* Zone and the *kochi* Zone. Therefore the Jurassic-Cretaceous boundary presumably is situated somewhere in the upper 200 metres of the Raukelv Formation and not at the very conspicuous unconformity separating the Raukelv and the Hesteelv Formations (Fig. 11).

Fig. 8. Large-scale cross-bedding characteristic of the Raukelv Formation. The sediment is a coarse-grained sandstone. The foresets are tangential with an erosional top. The depositional environment was marine. The length of the hammer in the centre of the figure is 28 cm. Drawn from a photograph.

It must be remembered, however, that the sequence described above is only found along the western margins of the distributional area of the Hesteelv Formation. As is easily seen from the geological map (Fig. 3) and the cross-sections (Fig. 5) the Hesteelv Formation overlies the Raukelv Formation (M. Volgian-?lowermost Ryazanian) towards the west, north and northeast, whereas towards the southeast and south it overlies the Hareelv Formation (U. Oxfordian-L. Volgian).

There are several possible explanations for this. Thus it might be suggested that the sediments of the Raukelv Formation in the southeastern part of the area had been removed by erosion prior to the deposition of the Hesteelv Formation, i.e., immediately after the period of folding. Another possibility is that there is a gradational change in facies from west to east in sediments of the same age. This implies that the top beds of the Hareelv Formation, where it is overlain by the Hesteelv Formation, should be of at least Upper Volgian age. The Hareelv Formation has not yielded fossils from this critical part of the sequence, but Spath (1936 pl. 30 fig. 1) figured a specimen of *Dorsoplanites jamesoni* collected loose immediately south of the southernmost exposure of the Hareelv Formation. Here the Raukelv Formation has completely wedged out. In Milne Land this species is only known from the presumed upper part of the so-called Glauconitic Series and is of Middle Volgian age (probably from the zone of *P. albani,* see Spath 1936 p. 79, 149 and Mikhailov 1966).

There is thus slight evidence in favour of a change in facies from the sandy Raukelv Formation towards the northwest to the shaly Hareelv Formation towards the southeast.

Finally, the boundary relations of the three formations can be viewed as a part of the geological structure of Jameson Land as a whole. As shown for parts or all of the Jurassic-Cretaceous sequence by Callomon (1961), Surlyk and Birkelund (1972)

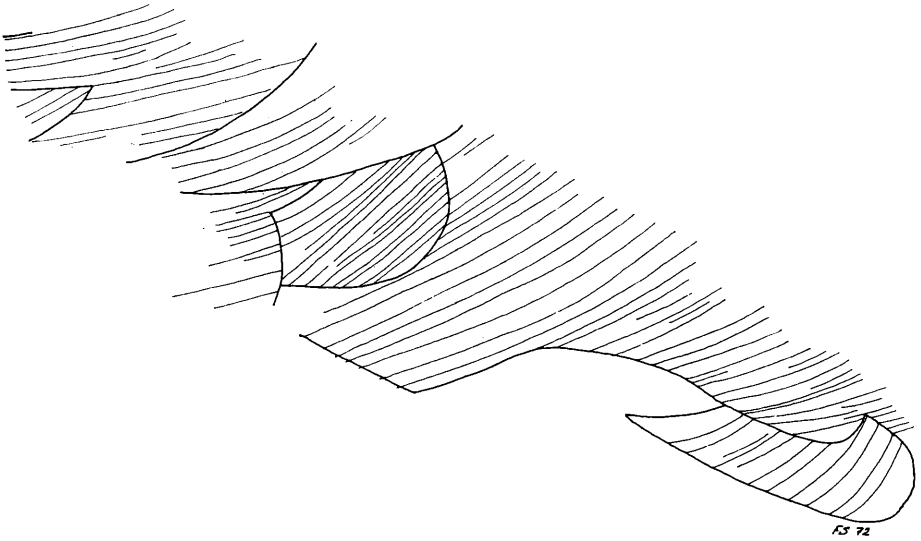


Fig. 9. Drawing (from an oblique aerial photograph taken at a height of about 300 m above ground surface) of the Raukelv Formation showing huge fans of cross-bedded sandstones. The sets are about 2 m thick. Transport direction from right to left. The area is several km long and 3–500 m wide.

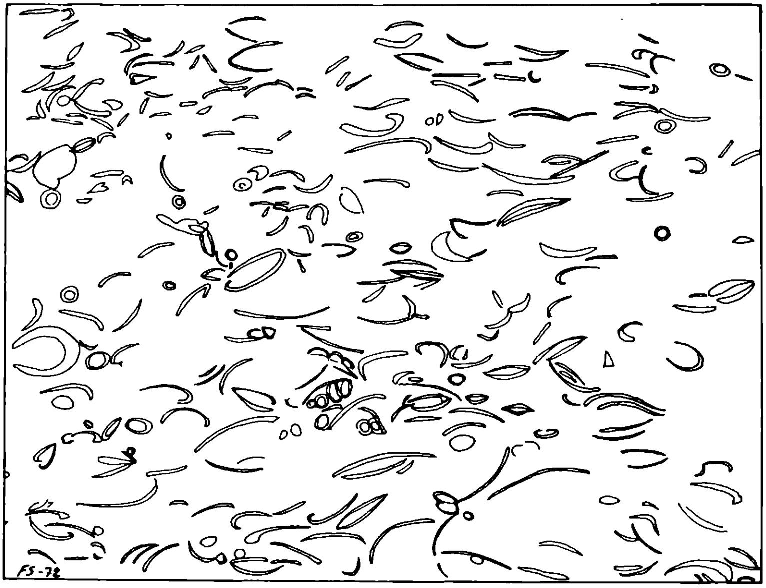


Fig. 10. Detail of Muslingeelv Member, Hesteelv Formation. The rock consists of large bivalves, ammonites, belemnites and other fossils in a matrix of calcareous sandstone. The dimensions of the figured area are 60 x 44 cm. Drawn from a photograph.

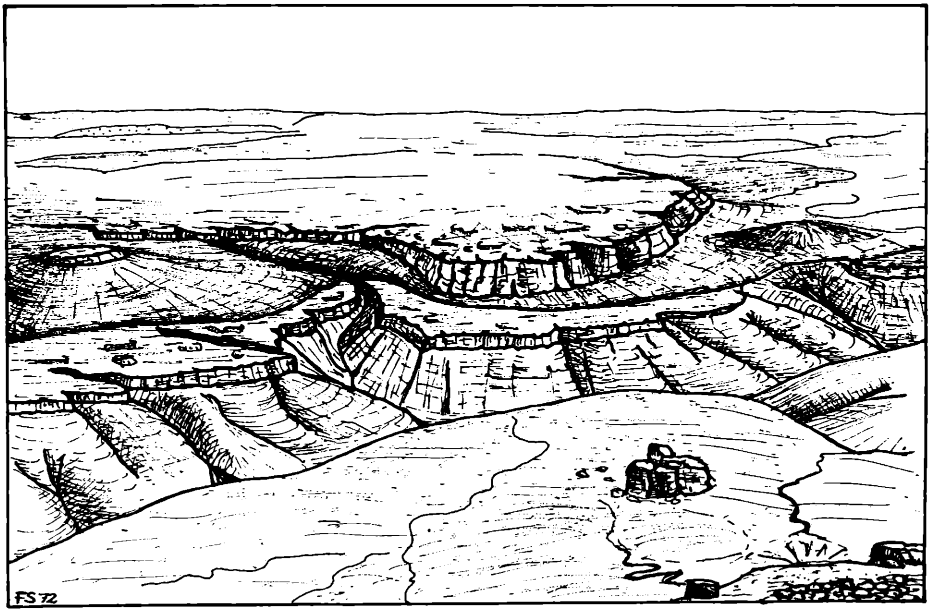


Fig. 11. Drawn from an aerial photograph of southernmost Jameson Land, looking southeast. Centrally in the figure the angular unconformity between the Hesteelv Formation and the Raukelv Formation is clearly seen. Note the overstep of the 35 m thick, massive sandstone of the Muslingeelv Member on to the lower sandstones of the Raukelv Formation and the corresponding thinning of the intervening shales of the Crinoid Bjerg Member. The central part of the figure corresponds to the western part of section II (Fig. 5) and to section 1 on Fig. 7.

and Surlyk *et al.* (in press), the subsidence of the depositional basin was greatest towards the north throughout the period. Here a very complete succession is found in a predominantly sandy near-shore facies. Proceeding southwards the facies gradually changes to off-shore marine silty shales. The individual zones become much thinner and several gaps occur. Thus Callomon (1961, p. 262) noted that the Middle Jurassic zone of *Cranocephalites borealis* is only a metre or two thick in south Jameson Land, but rapidly thickens to perhaps 120 metres further north.

The boundary relations of the Hesteelv Formation fit well into this general picture. To the south and southeast we find a rather thin, shaly sequence, probably with several gaps, which to the north and northwest rapidly thickens and becomes more sandy. In this way the rare and isolated finds of completely unexpected fossils are explained, as, for example, the above mentioned *Dorsoplanites jamesoni* or the mysterious specimen of *Cardioceras* (*Subvertebriceras*) *densiplicatum* found in southeastern Jameson Land (Spath 1935 pl. 15 fig. 3; see also Callomon 1961 p. 264). The latter, Middle Oxfordian, ammonite was not found *in situ*, but it could only have been derived from the few metres of strata lying between the Middle Callovian and Upper Oxfordian shales. In contrast, the Middle Oxfordian is several hundred metres thick in north central Jameson Land.

3. The Jurassic-Cretaceous boundary in East Greenland

Donovan (1964) reviewed the Volgian and Berriasian localities and faunas of East Greenland. Only a few of the localities have since been visited. Nevertheless the localities are re-examined in the following pages as recent work in Russia throws new light on several of the ammonite successions.

In East Greenland sediments of Volgian and Ryazanian age are known from five places, namely southern Jameson Land, Milne Land, northern Wollaston Forland, western Kuhn Is. and eastern Kuhn Is. (Fig. 2). The Volgian and Ryazanian rocks of Jameson Land have been described in some detail above. The other areas will be reviewed in turn.

3a. Milne Land

The Jurassic-Cretaceous boundary sequence is exposed in the mountains Hartz Fjeld, Kronen and Bays Fjelde in eastern Milne Land. These important sections and their faunas have been described by Rosenkrantz (1929), Parat and Drach (1933, 1934), Aldinger (1935), Spath (1935, 1936), Callomon (1961), Donovan (1964) and Håkansson *et al.* (1971)

The youngest formation on Milne Land is the Hartzfjeld Formation which is up to 300 metres thick. The lower boundary of the formation is very sharp. It commences with 30–50 metres of massive and cross-bedded light sandstone topped in the "Lingula Ryg" by a very fossiliferous marker bed (the "Lingula Bed" of Aldinger 1935). The bed is thickest and most coarse-grained to the south. Another marker bed crowded with casts of wood occurs at about the same level as the "Lingula Bed" in the western and northern localities.

Above these marker beds follows a sequence of over 200 metres of rhythmically alternating dark shaly sandstones and light massive sandstones. The upper part of this sequence is dominated by dark, sandy shales. In Hartz Fjeld the top 70 metres of the formation consists of thick sandstones which may be very coarse or conglomeratic. (Description of the succession is based on Håkansson *et al.* 1971.)

The "Lingula Bed" contains *Laugeites groenlandicus* (Spath) of upper Middle Volgian age (see Table 1). Only 15 metres higher *Tollia groenlandica* (Spath) and *Tollia bidevexa* (Bogoslovsky) occur (Donovan 1964). According to Donovan (1964) *T. bidevexa* and *T. tolli* Pavlov are probably synonyms and the assemblage is therefore of Upper Ryazanian age (see Table 1).

The whole Upper Volgian and the three lowest Ryazanian zones are therefore missing in the Milne Land succession. Above the horizons with the two species of *Tollia* no ammonites have yet been found.

3b. Northern Wollaston Forland

At the mountains Niesen and Rigi, sections through Volgian, Ryazanian and Valanginian rocks were described by Maync (1949). The Ryazanian part of the fauna collected by Maync was dealt with by Spath (1952). In 1952, 1956 and 1957 the area was visited by several field parties and the results were summarized by Donovan (1964).

It was revealed that a correct combination of the data of the different geologists was very difficult as they probably did not examine exactly the same sections and as there may be discrepancies between their altitude measurements. Furthermore, the Volgian part of Maync's section (1947 fig. 19) has only slight resemblance with the same section figured again by Maync (1949 fig. 30) or with Donovan's description (1964 p. 11).

I have tried in the following to give combined succession recalculated to Donovan's altitudes (1964 p. 11).

The exposure starts at an altitude of 27 metres, beginning with grey pebbly sands which pass up into alternating yellow sand and grey or black shales. At 115 metres this sequence is followed by whitish sands with bands of sandstone. Several prominent conglomerate horizons occur up to about 250 metres. Upwards follow calcareous grey and reddish sandstones which at about 500 metres gradually pass into sandy limestones.

Laugeites? *parvus* Donovan and *Laugeites intermedius*? Donovan occur at 90 metres. They are found together with *Laugeites groenlandicus* in western Kuhn Is. and are therefore presumably of upper Middle Volgian age (see Table 1).

At 255 metres the *Praetollia maynci* assemblage which was described by Spath (1952) and at 268 and 270 metres the *Hectoroceras* sp. nov. figured by Spath (1947 pl. 3, fig. 2) were collected.

At 300–305 metres there occurred *Tollia payeri*? (Toula), *Surites tzikwinianus* (Bogoslovsky), *Surites spasskensis* (Nikitin) and *Surites* sp. ind. (Donovan 1964).

At 360–370 metres *Praetollia maynci*?, *Surites* sp. ind. and *Tollia payeri*? were present and at 400 metres a questionable *Tollia payeri* (Spath 1952 pl. 4 fig. 8 and Donovan 1964 p. 30).

Finally, typical Valanginian *Polyptychites* start at 414 metres. The succession from 255 metres to about 400 metres is of Middle to Upper Ryazanian age. There is thus no evidence for the presence of any of the Upper Volgian zones or of the *Rjasanites rjasanensis* Zone. Nevertheless, the part of the section between 90 metres and 255 metres has not yielded any ammonites and it is therefore possible that renewed work in the area will give evidence of a more complete zonal record.

3c. Western Kuhn Island

Close to the coast, low sections through conglomerates, sands, sandstones and dark grey shales are found in the stream valleys. According to Donovan (1964 p.12) the dip of the rocks exposed in the valley sides is in many cases nearly the same as the gradient of the stream, and consequently it is very difficult or impossible to place the isolated exposures in stratigraphical order. The most common ammonite is *Laugeites* and Donovan (1964) reported the following species: *L.* aff. *groenlandicus*, *L. intermedius*, *L. parvus*, *L.* n. sp. and *L. jamesoni*. The four first-mentioned species are all found together (locality 10 of Donovan 1964) and the assemblage can be dated to the upper Middle Volgian on the basis of *L.* aff. *groenlandicus*.

Maync found one specimen of *Subcraspedites* aff. *preplicomphalus* associated in the same piece of rock with *Laugeites parvus*, but Spath (1952) assumed that these specimens were derived as he considered *Laugeites* a Jurassic and *Subcraspedites* a Cretaceous ammonite. Maync (1949 p. 28) emphasized that from a lithological point of view there was nothing to indicate a non-sequence and the reworking of Jurassic fossils. Casey (1962) and Donovan (1964), for palaeontological reasons, also showed that Spath's theory was unnecessary.

The sole indication of possible Ryazanian rocks in western Kuhn Is. is a single impression of a *Praetollia*? from Donovan's locality 6.

3d. Eastern Kuhn Island

As mentioned by Donovan (1964 p. 13) an exposure of Upper Ryazanian rocks must exist somewhere on the east coast of Kuhn Is. since *Tollia payeri* was collected here by a German expedition (1870–71). The locality has not been re-discovered.

4. Conclusions

The most complete and best exposed Volgian-Ryazanian sequence in East Greenland is the section from southern Jameson Land described in the present paper. The highest Jurassic zone identified is the *Craspedites nodiger* Zone (with its upper Subzone of *Chetaites chetae*) and 200 metres higher this is followed by the Middle Ryazanian Zone of *Surites spasskensis*. Thus the only zone not identified is the lowest Cretaceous Zone of *Riasanites rjasanensis*. However, this zone may yet be present within the 200 metres of undated sandstones. It is to be hoped that future collecting will demonstrate its presence.

The Upper Volgian has not been found in the Niesen succession on northern Wollaston Forland but there is an undated sequence of 165 metres above Middle Volgian and below Middle Ryazanian.

In Milne Land the Middle Volgian is followed within 15 metres by Upper Ryazanian, while on western Kuhn Is. the discovery of *Subcraspedites* aff. *preplicomphalus* may indicate the existence of low Upper Volgian and *Praetollia*? of Ryazanian. In eastern Kuhn Is. Upper Ryazanian occurs but the locality is unknown.

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The Jurassic-Cretaceous transition: the non-marine ostracod faunas

F. W. Anderson

The transition from the Jurassic to the Cretaceous was marked by a world-wide development of brackish to fresh-water lagoons in which the ostracod faunas were dominated by species of *Cypridea*. In the northern hemisphere, these Cypridean faunas have been found in Canada, the United States, southern England, France, Spain, north Germany, the Netherlands, Denmark, Sweden, Poland, the Jura and the U.S.S.R. A sequence of characteristic Cypridean assemblages is well established in England and Germany. It is suggested that throughout the northern hemisphere a similar sequence was followed until at different times and in different places it was brought to an end by one of several marine transgressions.

Der Übergang Jura/Kreide ist weltweit durch Vorhandensein von Brack- und Süßwasser-Becken gekennzeichnet. Die Ostrakoden-Faunen dieser Becken werden von *Cypridea*-Arten beherrscht. Auf der nördlichen Hemisphäre wurden solche Cyprideen-Faunen in Kanada, den USA, Südengland, Frankreich, Spanien, Norddeutschland, den Niederlanden, Dänemark, Schweden, Polen, im Jura und in der USSR gefunden. Eine Abfolge charakteristischer *Cypridea*-Gemeinschaften wurde in England und Deutschland nachgewiesen. Es ist anzunehmen, daß auf der gesamten nördlichen Hemisphäre ähnliche Abfolgen vorhanden sind. Sie endeten zu unterschiedlichen Zeiten in den verschiedenen Gebieten jeweils durch eine der zahlreichen marinen Transgressionen.

Le passage du Jurassique au Crétacé fut marqué par un développement universel de lagunes saumâtres ou d'eau douce où les espèces du genre *Cypridea* étaient dominantes au sein des populations d'Ostracodes. Dans l'hémisphère Nord, ces faunes à *Cypridea* ont été recueillies dans de nombreux pays: le Canada, les Etats-Unis, l'Angleterre méridionale, la France, l'Espagne, l'Allemagne du Nord, les Pays-Bas, le Danemark, la Suède, la Pologne et l'U.R.S.S. Une succession d'associations caractéristiques à *Cypridea* est bien établie en Angleterre et en Allemagne. Il est suggéré qu'une succession identique dut se développer sur tout l'hémisphère Nord jusqu'à ce que l'une des diverses transgressions marines y mit un terme, à des époques et des lieux différents.

1. Introduction

A characteristic feature of the transition between the Jurassic and Cretaceous Periods is the world-wide distribution of areas in which brackish to fresh-water conditions developed. The ostracod faunas in these areas were dominated by the very numerous species of a single genus, *Cypridea,* one of the few in which the carapace has an antero-ventral beak and notch.

In the northern hemisphere such deposits are found in the western mountain areas of the United States and Canada from Alberta to Oklahoma, and in Europe in a belt stretching from Spain and southern England, through France, Germany and Poland to Siberia. In the southern hemisphere Cypridean faunas are found in Brazil (Bahia) and west Africa (Congo Basin).

The distribution of these deposits suggests the possibility that they may have developed in similar circum-polar climate zones north and south of the equator. If this was the case then the poles were not in their present position, and, what is much more speculative, the orientation of the North American continent was very different from that now obtaining.

2. Cypridean assemblages

The study of the systematics of the Cypridean faunas in what are now widely separated areas has led inevitably to the creation of a large number of specific names for the members of this genus and has tended to obscure the fact that in Europe at least there is a recognisable sequence of faunal assemblages. In the present paper an attempt is made to equate these assemblages throughout the northern hemisphere, based whenever possible on material actually seen by the author and ignoring, legitimately or not, the age previously assigned to these assemblages.

These Jurassic-Cretaceous transition faunas are most completely known in southern England and the sequence of assemblages found there forms a standard of reference with which those from other areas can be referred.

2a. England

Ten distinct assemblages can be recognised in the sediments lying between the marine Portlandian and the marine Aptian (Anderson 1967; Anderson, Bazley and Shephard-Thorn 1967; Anderson and Bazley 1971: for description of many of the species see also Anderson 1939, 1941, 1966; Barker 1966; Sylvester-Bradley 1941).

Assemblage 1. Lower Purbeck from the top of the marine Portland to the Hard Cockle Limestone (but not including the passage beds of Buckinghamshire and Wiltshire which may in part be of Portlandian age). The ostracod fauna is limited. The genus *Cypridea* is represented by the small, inverse, spinose species *C. dunkeri* Jones; a medium-sized, smooth-shelled form with a triangular profile *C. primaeva* Anderson; and the large punctate *C. tumescens* (Anderson). Of other genera *Fabanella boloniensis* (Jones) is often very abundant, accompanied by *F. ansata* (Jones) and *Mantelliana purbeckensis* (Jones).

This lowest division of the Purbeck Beds includes the main algal development and evaporite deposits.

Assemblage 2. Lower to Middle Purbeck from the Hard Cockle Limestone to the Cinder Beds. To the fauna of Assemblage 1 is added *C. peltoides* Anderson, a medium-sized, punctate species which is probably the ancestor of the later

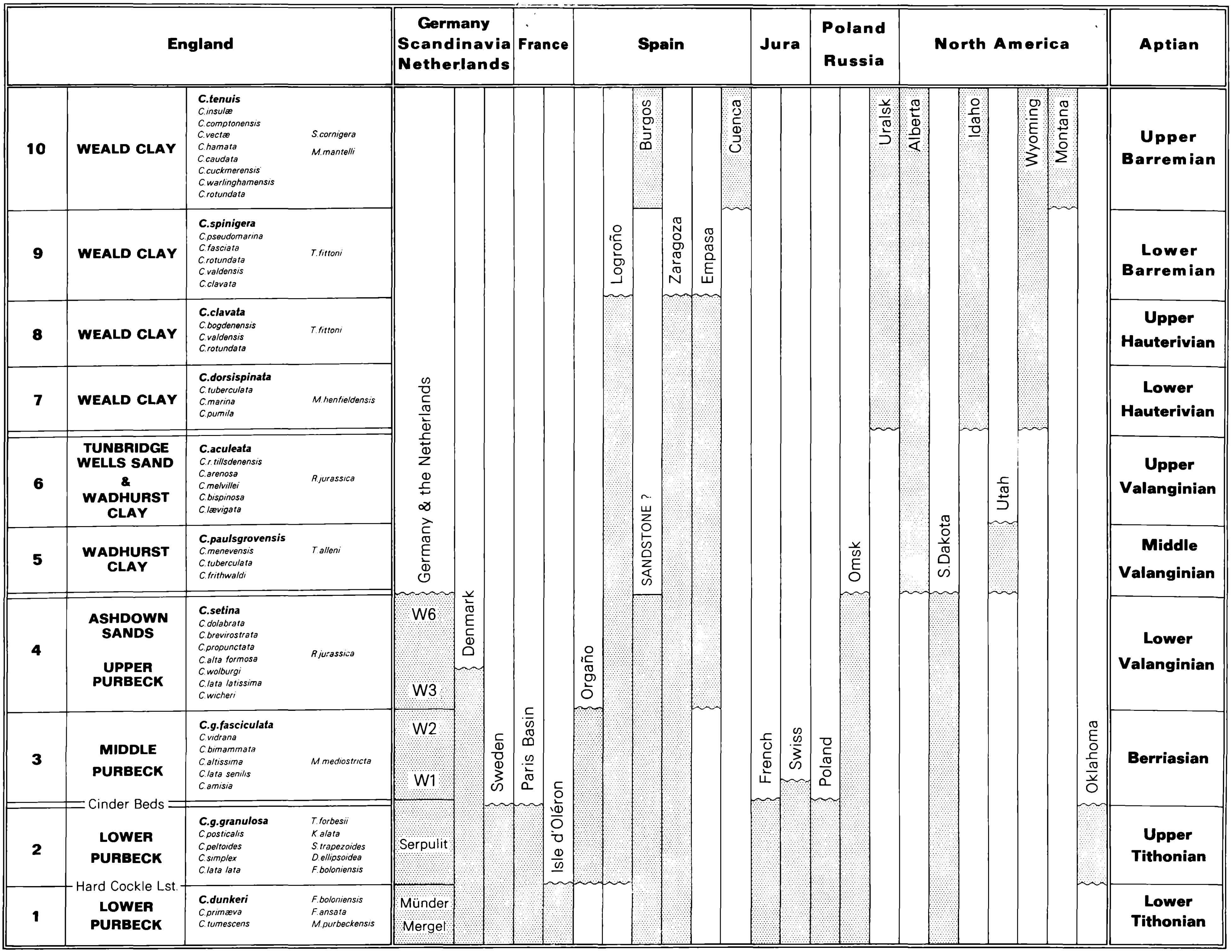

Fig. 1. This chart shows the sequence of ostracod assemblages in the English Purbeck and Wealden and the extent to which they are thought to occur in other parts of the Northern Hemisphere.

The relative positions of the contemporaneous Continental stages, Tithonian to Aptian are highly speculative as these are based entirely on marine faunas the component species of which occur only rarely if at all in the brackish-water Cypridean assemblages.

The columns referring to occurrences in Russia and particularly those in the United States and Canada are liable to considerable revision in the light of future work.

C. amisia-propunctata group; *C. granulosa granulosa* (J. de C. Sowerby) a medium-sized, tuberculate form; *C. simplex* Anderson a small, smooth-shelled species; *C. varians* very like *C. simplex* but spinose; and *C. lata lata* Martin a medium-sized, finely-punctate shell with a triangular outline. *C. posticalis* Jones with its distinctive posterior swelling is found only in the higher part of this assemblage. Other than species of *Cypridea* this assemblage contains *F. boloniensis, Damonella ellipsoidea* (Wolburg), *Mantelliana wealdensis* (Wolburg), *Rhinocypris jurassica* (Martin), *Damonella buchaniana* Anderson, *D. pygmaea* (Anderson), *Eoparacypris weedonensis* Anderson, *Scabriculocypris trapezoides* Anderson, *Klieana alata* Martin, *Theirosynoecum forbesii* (Jones) and others.

Assemblage 3. Middle Purbeck, Cinder Beds to Broken Shell Limestone. This assemblage is particularly characterised by the tuberculate form *C. granulosa fasciculata* Jones; by the similarly shaped but unornamented *C. altissima* Martin; *C. lata senilis* Anderson; several medium-sized punctate species, i.e. *C. amisia* Wolburg, *C. vidrana* Wolburg, *C. inaequalis* Wolburg, *C. martini* Wolburg, *C. andersoni* Wolburg; and an inverse spinose form *C. bimammata* Harbort. The most characteristic non-Cypridean species is *Macrodentina mediostricta* (Sylvester Bradley).

Assemblage 4. Upper Purbeck and basal Wealden (Ashdown Sand); Broken Shell Limestone to the base of the Wadhurst Clay. This very characteristic assemblage consists of predominantly smooth-shelled forms such as *C. setina* Anderson, *C. dolabrata* Anderson, and the inverse *C. wolburgi* Anderson. In addition *C. propunctata* Sylvester Bradley and the inverse form *C. brevirostrata* Martin are common. Also peculiar to this assemblage are *C. wicheri* Wolburg and *C. morula* Anderson two species with a boss-like, tubercular ornament; *C. ventrosa* Jones a smooth-shelled, sparsely tuberculate form with a marked ventral swelling; *C. tuberculata adjuncta* Jones a multituberculate species; and *C. lata latissima* Anderson.

Assemblage 5. Lower half of the Wadhurst Clay. This restricted fauna is dominated by the inverse species *C. paulsgrovensis* (Anderson) and *C. menevensis* (Anderson). At some horizons the multispinose species *C. tuberculata tuberculata* (J. de C. Sowerby) is abundant. In addition to species of *Cypridea, Theriosynoecum alleni* Pinto and Sanguinetti is common and at the base of the Wadhurst Clay the fauna is usually dominated by *Mantelliana phillipsiana* (Jones).

Assemblage 6. Upper part of the Wadhurst Clay, and the Tunbridge Wells Sand including the Grinstead Clay. Many new forms appear at about the middle of the Wadhurst Clay including the dominant species *C. aculeata* Jones and the closely related *C. arenosa* Anderson. Also present are the inverse, spinose species *C. bispinosa* Jones; the large, smooth, small-beaked *C. laevigata* (Dunker); the very small, multispinose *C. melvillei* Anderson which is often very abundant; and the small, unispinose *C. recta tillsdenensis* Anderson. Other than species of *Cypridea* the commonest form is *Rhinocypris jurassica* (Martin).

Assemblage 7. Lower Weald Clay. The most marked faunal break in the Purbeck-Wealden succession occurs at the base of the Weald Clay. Only two species survived from lower assemblages, i.e. *C. valdensis* (J. de C. Sowerby) and *C. tuberculata.* The most characteristic form is *C. dorsispinata* (Anderson) a smooth-shelled ostracod in which, as the name indicates, the large spines, usually two in number on each valve, are confined to the dorsal half of the shell. Less abundant are the multispinose *C. marina* Anderson and *C. pumila* Anderson in which the spines are confined to the posterior half of the shell, and the inverse, spinose *C. clavata* Anderson.

Other than species of *Cypridea, Miocytheridea henfieldensis* (Anderson) is often very abundant.

Assemblage 8. Middle Weald Clay. This assemblage is dominated by two species, the inverse form *C. clavata* and the large punctate *C. valdensis*. Less common but characteristic is the inverse, spinose species *C. bogdenensis* Anderson, and a medium-sized finely punctate form *C. rotundata* Anderson. *Theriosynoecum fittoni* (Mantell) is common at some horizons.

Assemblage 9. Middle Weald Clay. The multispinose species *C. pseudomarina* Anderson is the form most characteristic of this assemblage, accompanied by *C. valdensis, C. clavata* and *C. rotundata*. Two species are common to this and Assemblage 10, i.e. *C. fasciata* Anderson, and the unispinose *C. spinigera* (J. de C. Sowerby). Again *T. fittoni* is common at some horizons.

Assemblage 10. Upper Weald Clay. This assemblage is very distinctive. It includes a smooth-shelled, small-beaked species *C. tenuis* Anderson; the unispinose species *C. hamata* Anderson and *C. caudata* Anderson; a small, bispinose form *C. cuckmerensis* Anderson; the multispinose *C. warlinghamensis* Anderson; the small, dorsally sulcate *C. insulae* Anderson; a medium-sized, punctate species *C. vectae* Anderson; and a large, flat-ventered, spinose form *C. comptonensis* Anderson. In addition the earlier species *C. valdensis, C. rotundata, C. fasciata* and *C. spinigera* are also found.

As the top of the Weald Clay is approached such species as *Sternbergella cornigera* (Jones), *Mantelliana mantelli* (Jones) and *Theriosynoecum fittoni* (Mantell) become increasingly abundant.

2b. Germany

Martin (1940) recorded the sequence of ostracod faunas from the boreholes at Thören and Rodewald in north Germany. The lowest recorded fauna (at Rodewald, 401·50 metres) contained *Macrodentina retirugata* (Jones) and is probably the equivalent of the uppermost Portlandian of Dorset (Barker 1966) and the Portland-Purbeck passage beds of Buckinghamshire (Barker 1966) and Wiltshire (Anderson 1941; Sylvester-Bradley 1941). Above this level Martin recorded *C. valdensis* (*C. tumescens**), *C. dunkeri, C. lata, C. binodosa, C. punctata* (*C. peltoides*), *C. posticalis, C. altissima* (? *C. peltoides eurygaster*) and *T. forbesii*. This list of species is convincing evidence of the presence of Assemblage 2 and probably also of Assemblage 1.

Assemblage 3 follows with *C. mammilata* (*C. granulosa fasciculata*) and *C. altissima*, and Assemblage 4 with *C. brevirostrata, C. bispinosa* (*C. bimammata*), *C. angulata* (*C. dolabrata*) and *C. jonesi* (*C. tuberculata adjuncta*).

Wolburg (1959) gave a very detailed account of the north German 'Wealden' ostracod faunas which makes correlation with the English sequence relatively easy. His 'Wealden' 1 and 2 clearly contain Assemblage 3 with the base of W1 at about the position of the Cinder Beds horizon. The fauna, *C. granulosa granulosa, C. granulosa fasciculata, C. lata, C. altissima, C. bimammata, C. amisia, C. martini, C. vidrana* and *C. paulsgrovensis* (*C. acuta*), is characteristic.

Assemblage 4 includes Wolburg's 'Wealden' 3–6. Again the fauna is typical including *C. setina, C. recta, C. wicheri, C. jonesi* (*C. tuberculata adjuncta*), *C. alta, C. valdensis obliqua* (*C. obliqua*), *C. andersoni, C. dolabrata, C. brevirostrata, C. inaequalis, C. menevensis* (*C. penshurstensis*) and *C. paulsgrovensis* (*C. acuta*).

'Wealden' 6 is overlain by marine Middle Valanginian.

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*Names that follow in parentheses are the present author's own interpretation.

2c. The Netherlands

The ostracod sequence (Sung 1955) includes representatives of the English assemblages 1–4. Assemblage 1, recorded as Lower Purbeck, is represented by *M. retirugata, M. purbeckensis,* and *C. polita* (*F. boloniensis*) and probably includes the Portland-Purbeck passage beds. Assemblage 2, which Sung recorded as Middle Purbeck, contains *C. posticalis, C. granulosa, C. carinata* (*C. dunkeri*) and *C. polita* (*F. boloniensis*). Assemblage 3 follows with *C. mammilata* (*C. granulosa fasciculata*), *C. lata, C.* aff. *altissima, C. spinigera* (? *C. bimammata*) and *C. menevensis* (*C. penshurstensis*). Assemblage 4 contains *C. valdensis* (*C. obliqua*), *C. angulata* (*C. dolabrata*), *C. brevirostrata, C. biangulata* (*C. setina rectidorsata*) and *C. wicheri.*

In the Netherlands therefore the Purbeck-Wealden followed much the same sequence as that of north Germany.

2d. Denmark

The lowest group of strata in Bornholm described by Christensen, i.e. the Rabekke Formation, contains *Neocytheridea bononiensis* (*F. boloniensis*), *Cypridea* aff. *inversa* (*C. dunkeri*) and *Klieana alata,* a fauna which suggests that Assemblages 1 and 2 may be represented. The sands and gravels of the Robbedale Formation above contained no ostracods but could be the equivalent of the strata containing Assemblage 3. The highest beds seen, the Jydegaard Formation, contain, in the lower beds, a fauna which suggests Assemblage 4, i.e. the Upper Purbeck of England.

2e. Sweden

In Scania (Christensen 1968) the lowest beds seen, the Fyledal Clay, are probably of Portlandian age, at least in the upper part. They are followed by sands apparently barren of ostracods. The overlying Vitabäck Beds contain a typical Lower Purbeck fauna including *F. boloniensis, M. purbeckensis, S. trapezoides* and *C. valdensis praecursor* (*C. tumescens praecursor*). The fragment identified as *Cypridea* sp. ex. gr. *setina* is unlikely to be that species.

Though the evidence is sparse, Assemblages 1 and 2 appear to be represented.

2f. France

The Purbeck Beds of the Paris Basin are reported by Oertli (1963) to contain *C. dunkeri, C. valdensis praecursor* (*C. tumescens praecursor*), *C. granulosa, C. binodosa, R. jurassica, "Cypris" purbeckensis* (*M. purbeckensis*), *"Cypris" pygmaea* (*D. pygmaea*), *S. trapezoides, F. polita* (*F. boloniensis*), *K. alata,* and *P. serpentina.* As Oertli (1963) suggested, this is a typical Lower Purbeck fauna, i.e. Assemblages 1 and 2 at least are represented. The Lower Purbeck rests on Portlandian and is succeeded by unfossiliferous strata.

Donze (1960) assigned the sequence of marls (Beds 2–22) overlying the Portlandian of the Isle d'Oléron to the Lower Purbeck. The ostracod faunas collected by Donze and independently by the author confirm this. Some 10 metres below the top of the Portlandian limestones the assemblage is dominated by *M. retirugata* as in the Portland-Purbeck passage beds in England.

The lowest marls (Donze, Bed 22) contain *C. tumescens, C. peltoides, M. cyrton, T. forbesii, B. dilatata* and *R. jurassica.* Above (Donze, Beds 19–21) is a similar assemblage with the addition of *F. boloniensis.* This assemblage remains essentially the same to the top of the section where a dolomitic limestone (Donze, Bed 2) is overlain by the Sable des Landes.

Thus the whole of this sequence could be assigned to Assemblage 1. Beds 4–6 contain some gypsum and in the upper part of the sequence at some levels are strata reminiscent of the 'Broken Beds' of the Dorset Coast.

2g. Spain

In Spain (Oertli and Peyhernès 1972), Purbeck-Wealden strata are found on both sides of the Ebro Basin. In the north, in the Gorges d'Orgaño, Oertli and Peyhernès (1972) have recorded a fauna which includes *C. granulosa, C. valdensis praecursor* (*C. tumescens praecursor*), *F. polita* (*F. boloniensis*) and *Dictyocythere mediostricta* (*M. mediostricta*). This fauna suggests Assemblages 2 and 3, but the underlying strata are said to be marine Upper Berriasian and those overlying are marine Upper Valanginian which should indicate a position much higher in the Purbeck-Wealden sequence.

Southeast of Logroño the Purbeck appears to be represented by the Oncala Shales (Assemblages 2–4) which contain *C. granulosa, C. tuberculata adjuncta* and *T. forbesii.* The Cubreton Shales above contain *C. aculeata* (Assemblage 6) and the Enciso Shales *T. fittoni* (?Assemblage 8). It is possible that in this area the Purbeck-Wealden succession may be as complete as in England.

To the west of Logrono at Montorio, north of Burgos, a fauna typical of Assemblage 10 has been collected. It includes *C. valdensis, C. warlinghamensis, C. tenuis, C. fasciata* and *C. rotundata.* So at least in this area the highest Wealden is present. In this same area ostracods have been collected which suggest that the Purbeck sequence is also reasonably complete; *C. peltoides, C. granulosa, C. tumescens, C. lata, C. brevirostrata, F. boloniensis* and *M. mediostricta* indicate Assemblages 1–4.

In the area of Zaragoza the lowest Purbeck seen contained *C. dunkeri* (Assemblages 1–2). Above, *C. setina, C. dolabrata, C. amisia, C. recta* and *C. paulsgrovensis* suggest Assemblages 4–5. At a still higher level forms resembling *C. bogdenensis, C. pumila* and *C. clavata* probably indicate Assemblages 7–8, so that in this area too the Purbeck-Wealden sequence may be complete.

In the area west of Valencia no ostracods have been seen which indicate the presence of Purbeck strata but much of the Wealden appears to be present. Assemblage 4 is indicated by *C. brevirostrata,* 5 by *C. menevensis,* 6 by *C. aculeata* and *C. recta,* 7 by ?*M. henfieldensis* and 8 by *C. rotundata.* Above this are marine strata probably of Lower Barremian age.

An Assemblage 10 fauna has been found near Cuenca containing *C. caudata, C. warlinghamensis,* and *C.* cf. *rotundata.*

2h. The Jura

Carozzi (1948) described sections in the Purbeck of the Swiss Jura and submitted ostracod-bearing samples to the writer. Two years later Mr. W. Heap of Swanage collected material from sections in the same area, which was described by Anderson in 1951.

No ostracods were found in Carozzi's lowest division, the 'Couches dolomitiques inférieures', but it is probable that these beds are the equivalent of the gypsum bearing strata of S. England. The 'Couches lacustres inférieures' above contain *C. dunkeri, C. tumescens, F. boloniensis, T. forbesii, E. weedonensis* and *D. ellipsoidea,* a fauna typical of Assemblage 2. Ostracods were absent in the 'Intercalation marine moyenne' but this division could represent the marine interlude between Assemblages 2 and 3, i.e. the Cinder Beds horizon of southern England. The highest beds, the 'Couches lacustres supérieures', contained *C. tumescens* and *C. granulosa protogranulosa* and in one section (Feurtilles) *C. granulosa fasciculata* and *M. mediostricta,* representing Assemblage 3. According to Carozzi, in all sections the 'Couches lacustres supérieures' were overlain by the 'Couches saumâtres supérieures' of Berriasian age.

In the French Jura (Pontarlier) only *C. dunkeri* and *F. boloniensis* have been identified with certainty. It is probable that only Lower Purbeck Beds (Assemblages 1 and 2) are represented in this area.

2i. Poland

Bielecka and Sztejn (1966) have reported on the ostracod faunas of sixteen boreholes to the west and northwest of Warsaw. Six assemblages (A-F) were distinguished. Of these, the lower (D, E, F) contain *C. inversa* (*C. dunkeri*), *C. valdensis praecursor* (*C. tumescens praecursor*) and "*Cypris*" *purbeckensis* (*M. purbeckensis*). These beds, which contain gypsum deposits, appear to correspond to the lower part of the English Lower Purbeck. Divisions B and C contain *C. dunkeri* and *C. binodosa* and probably represent the upper part of the English Lower Purbeck. Division A, which contains Foraminifera, *Palaeocytheridea compacta* Wolburg and *C.* cf. *posticalis,* appears to be the equivalent of the Cinder Beds and that part of the Middle Purbeck lying immediately below.

As Bielecka and Sztejn (1966) concluded, the Purbeck Beds in Poland are mainly of Lower Purbeck age (Assemblages 1 and 2). They are overlain by marine Berriasian.

2j. The Soviet Union

No western European species of *Cypridea* have been identified from the Purbeck-Wealden of Russia and a study of those illustrated (see Liubimova 1965; Liubimova, Kazmina and Reshetnikova 1960) suggests that this is probably correct. But in some cases there is a fairly close resemblance between Russian and English species, enough to suggest that a sequence of *Cypridea* assemblages of similar type is to be found in both countries.

From the Uralsk area the following species have been recorded, and are compared with similar English forms: *Cypridea koskulensis* Mandelstam (an inverse form resembling *C. bogdenensis*), *C. tagigalensis* Liubimova (cf. *C. tuberculata*), *C. karatajgysensis* Liubimova (cf. *C. insulae*), *Rhinocypris echinata* (cf. *R. jurassica*). The general impression is that this is a Weald Clay fauna, possibly Assemblages 7 to 10.

From the area near Omsk the following ostracods have been recorded: *Cypridea bispinaformis* Liubimova (cf. *C. varians*), *C. inaccessa* Liubimova (cf. *C. brevirostrata*), *C. conculae* Liubimova (cf. *C. setina*), *C. vitimensis* Mandelstam (cf. *C. granulosa*), *C. sulcata* Mandelstam (cf. *C. bimammata*), *C. koskulensis* Mandelstam (cf. *C. dunkeri*), *C. consulta* Mandelstam (cf. *C. penshurstensis*), *C. pertricosa* Kazmina (cf. *C. dolabrata*) and *C. accliva* Kazmina (cf. *C. alta*). This fauna suggests that in this area only Purbeck Beds are present, probably Assemblages 1 to 4 are represented.

2k. North America

As with Russian ostracod faunas, the North American Purbeck-Wealden fauna cannot be equated specifically with that in Europe but again there are resemblances which suggest that a similar sequence of assemblages obtained.

In Alberta Loranger (1951) has reported on the ostracods from the Blairmore Formation. Only two of these were species of *Cypridea*, i.e. *C. tilleyi* Loranger, a multispinose species not unlike *C. pumila* (Assemblage 7) and *C. wyomingensis* Peck which could be related to *C. tuberculata* (Assemblage 5 or 7). The two species Of '*Candona*', *C. stirlingensis* Loranger and *C. devillensis* Loranger, invite comparison with *Mantelliana phillipsiana* or *M. mantelli* (Assemblages 5 to 10). Of the various species of *Metacypris* recorded (Peck 1951), Pinto and Sanguinetti (1962) accept only *M. angularis* Peck which they list as an Aptian-Albian species. The same authors have renamed *M.persulcata* Peck as *Bisulcocypris albertensis* Pinto and Sanguinetti, a species said to be of Aptian age.

In general this assemblage suggests a horizon high in the Weald Clay. It is referred to the *M. persulcata* Zone of Peck, a group of strata about 20 m. in thickness lying between a Quartz Sand Series below and a Glauconitic Sand Series above. One is tempted to compare this sequence with that in England, where the Atherfield Clay with abundant *T. fittoni* lies below the glauconitic part of the Lower Greensand and above the sandy beds of the middle Weald Clay.

The attempt to compare the Upper Jurassic-Lower Cretaceous ostracod faunas of the United States with those of western Europe is based as far as possible on material seen by the author, disregarding, rightly or wrongly, the fact that some are regarded as Aptian, Albian or even Tertiary in age. A typical example is *Cypridea avardensis* (Swain) from the Eocene of Utah, which bears a close resemblance to *C. dorsispinata* of the basal Weald Clay.

In the Morrison Formation of Oklahoma (Peck 1951) are forms resembling *Darwinula leguminella, D. oblonga, Timiriasevia mackerrowi, Theriosynoecum forbesii, Bisulcocypris dilatata, Rhinocypris jurassica, Eoparacypris macroselina, E. weedonensis* and *Mantelliana cyrton*. This appears to be a typical Lower Purbeck fauna (Assemblages 1 and 2). In addition Peck recorded *Pseudocypridina piedmonti* (cf. *Cypridea granulosa*) which certainly suggests a similar horizon.

From South Dakota are species resembling *C. tumescens praecursor, C. peltoides* and *T. forbesii* (Assemblages 1–2), *P. piedmonti* (cf. *C. granulosa*) and *C.* (*P.*). *inornata* (cf. *C. setina*) (Assemblages 3–4). Probably the whole of the Lower Purbeck is represented here.

In Idaho, *C. wyomingensis* Peck is a spinose form like *C. tuberculata,* and *C. brevicornis* resembles *C. spinigera*; both seem to indicate a Weald Clay fauna.

In Wyoming, *C. quadrata* Peck resembles *C. rotundata,* while *C. skeeteri* includes a variety of forms some not unlike *C. insulae* and *C. warlinghamensis* (Assemblage 10). *C. compta* is very like *C. aculeata* (Assemblage 6), and *C. obesa* resembles *C. rotundata* (Assemblages 9 and 10). Thus the general impression is that the Weald Clay and perhaps the upper part of the Hastings Beds horizons are represented in Wyoming.

The species recorded from Montana include *C. longispina* Peck which is very like *C. caudata* from the Weald Clay (Assemblage 10).

If the foregoing comparisons can be maintained then there is in North America a central zone running north-northwest—south-southeast from Alberta through Montana to Wyoming containing strata of predominantly Upper Weald Clay age, flanked to the west by a parallel zone from Idaho to Utah with Lower Weald Clay assemblages and to the east from South Dakota to Oklahoma by a series of Purbeck-type assemblages.

3. Discussion

One of the first difficulties to be aware of, as Triebel (1941) pointed out many years ago, is that homeomorphy in ostracoda is by no means uncommon. This is especially true of the species of *Cypridea*. In the first place variation in the outline of the shell is limited, so that similarly shaped carapaces are met with at very different horizons. In the second place the texture of the shell surface shows only slight variation, from smooth through finely punctate to coarsely punctate and may be considerably modified by the type of preservation. Thirdly, the kind of ornament is limited, i.e. the shell may carry pustules, tubercules, spines or boss-like protuberances and though the pattern of this ornament is very variable there is clearly a limit to the number of arrangements possible. Again, the size and definition of the rostrum and alveolus (beak and notch) can vary from being almost obsolete as in the subgenus *Pseudocypridina* to strongly developed as in *C. valdensis*, and lastly the cyathus may be triangular, blunt or acute, cupate or lunate.

Thus, although a very large number of different combinations are possible, some patterns do tend to be repeated. For example, the ornament pattern consisting of a single sub-central tubercle is found in *C. bimammata bimammata*, *C. wicheri torosa*, *C. aculeata eppili*, *C. bispinosa suthrigensis*, *C. recta tillsdenensis*, *C. clavata gordana*, *C. hamata*, *C. valdensis claudii* and *C. spinigera*. It is true that these unispinose forms can be distinguished by other characters but the possibility of confusion still remains.

In the foregoing account of the ostracod assemblages in areas outside western Europe and in particular in the American Continent this is a very real difficulty. Two possibilities exist: either the Cypridean faunas so characteristic of the Jurassic-Cretaceous boundary continued to exist in some places into the Upper Cretaceous or even into the Tertiary, reproducing assemblages similar in appearance to those known from older strata, or these Cypridean faunas were only developed during the Jurassic-Cretaceous transition in which case the evidence for the later age to which some of these assemblages have been assigned will need to be re-assessed.

The world distribution of the Cypridean faunas suggests that they were at least in part climatically controlled and apparently lay along a circum-polar belt. If in both hemispheres the Cypridean belts occupied a similar latitude, i.e. were symmetrically placed north and south of the equator, then the equator at that time must have been north of its present position, say at about the Tropic of Cancer, and the pole would have been located in the North Pacific somewhere along the Arctic Circle.

Climatically, such a position for the equator well suits the faunal and floral evidence of the time. It would mean that the climate of the Cypridean belt was similar to that now found in the southern Mediterranean—north African area. The evaporites, algal limestones, the plants (including the abundant remains of *Chara*) and especially the vertebrate faunas all suggest a near sub-tropical climate.

In the southern hemisphere the assumed position of the continental masses during this transition period is in accord, e.g. the approximation of South America to Africa brings the Bahia Beds of Brazil alongside the Cypridean fauna of the Congo Basin In the northern hemisphere, North America poses a difficult problem. If in fact the Cypridean belt lay more or less along a parallel of latitude then the orientation of that continent must have been very different from that of today. But, if, when the North Atlantic was formed, North America was pivoted about the Canadian shield into its present position rather than simply drifting westwards maintaining its present orientation, then the Cypridean belt of that continent can be brought into line with its European counterpart.

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The geographical distribution of Lower Cretaceous Terebratulacea in Western Europe

F. A. Middlemiss

The Lower Cretaceous Terebratulacea fall into (i) a Boreal fauna confined to England and north Germany (ii) a Jura fauna characteristic of the Jura, southern France and eastern Spain, and (iii) a Tethyan fauna. The distribution of the Tethyan fauna is essentially correlated with the Alpine fold belts, of the Jura fauna with areas of intra-cratonic folding outside the Alpine belts, and of the boreal fauna with the north European foreland. The faunas in Lower Cretaceous times lived approximately parallel to the edge of Tethys and to palaeolatitudes. Control of the distribution was partly by the lay-out of land and sea and partly by palaeoclimate, especially temperature and salinity.

Bei den Terebratulaceen der Unterkreide sind drei Faunen unterscheidbar: 1. die auf England und Norddeutschland beschränkte Boreal-Fauna, 2. die Jura-Fauna des Jura-Gebietes, von Südfrankreich und Ostspanien und 3. die Tethys-Fauna. Die Tethys-Fauna ist im wesentlichen an die Gesteine der alpinen Ketten gebunden. Die Jura-Fauna ist typisch für die Gebiete intracratonischer Faltung außerhalb der alpinen Ketten und die Boreal-Fauna für das nordeuropäische Vorland. Die Faunenverteilung zur Zeit der Unterkreide verlief generell annähernd parallel zum Tethysrand und zu den geographischen Breiten der damaligen Zeit. Im einzelnen hing sie teils von der Land-Meer-Verbreitung und teils vom Klima ab, besonders von Temperatur und Salzgehalt.

Les Terebratulacea éocrétacés se répartissent (1) en une faune boréale limitée à l'Angleterre et l'Allemagne du Nord, (2) en une faune de faciès jurassien caractéristique du Jura, du Midi de la France et de l'Espagne orientale et (3) en une faune mésogéenne. La répartition de la faune mésogéenne correspond essentiellement aux chaînes alpines plissées, celle de la faune jurassienne aux aires plissées intra-cratoniques, externes à la chaîne alpine, et celle de la faune boréale à la plate-forme nord-européenne. Au Crétacé inférieur, l'habitat de ces faunes s'établissait à peu près parallèlement au bord de la Mésogée et aux paléolatitudes. Cette distribution était déterminée tant par la localisation des rivages que par les conditions paléoclimatiques et plus particulièrement la température et la salinité.

1. Introduction

This contribution to the symposium is a by-product of the monographic revision of the Lower Cretaceous Terebratulidina of western Europe, upon which I am at present engaged. The English Aptian fauna has been described previously (Middlemiss 1959, 1962a, 1962b, 1968a) as have some faunas from southwest France (Middlemiss 1968b).

The plotting of the distribution of species on the maps has mainly been done from evidence of specimens that I have personally seen either in the field, in museums or in collections that have been sent to me, although in some cases (mainly in the U.S.S.R.) published figures have had to be relied upon. As most palaeontologists find, it is difficult to place much trust in published faunal lists which are not accompanied by good figures (cf. Ager 1971), but in rare cases I have had to do this.

The map depicting the whole Lower Cretaceous has several species which are not shown on any other map owing to the difficulty of ascertaining their precise age.

The paper should be read strictly as a report on work in progress and perhaps subject to considerable future changes of opinion.

2. The Faunas

The Lower Cretaceous Terebratulacea in western Europe fall into three geographical groups. There are firstly those northern species which are found in England and north Germany and are unknown south of the English Channel and the Ruhr-Harz line. Secondly, there are some species which are closely associated with the limits of Tethys and are very rare northwest of a line joining the Bay of Biscay, Lyons, the Jura Mountains and the Bohemian Massif. Between these groups there can be recognized a third assemblage of species, to some extent intermingling with the first two, but particularly characteristic of the Jura Mountains and the southeast part of the Paris Basin. There are also a few ubiquitous species which occur in association with all three groups.

(i) *The boreal fauna.* This consists of some sixteen species. Two of these belong to the genus *Rouillieria* Makridin, a thoroughly boreal genus known also from the Upper Jurassic of the Russian Platform, eastern and southern England and the Boulonnais. The genus *Praelongithyris* is common in England and north Germany but is also reported from Turkmenistan (Vogdanova and Lobacheva 1966). The genera *Rhombothyris* and *Platythyris* are so far known only in England and only in the Aptian. The remaining six species are known only in the English Aptian, although the genera *Sellithyris* and *Cyrtothyris*, to which they belong, also have species in the ubiquitous group.

(ii) *The Tethyan fauna.* The dominant characteristics of this fauna are the presence of the Pygopidae (*Pygope*, *Pygites*, *Antinomia, Nucleata* and their close relatives), of a group of undescribed species related to '*Terebratula*' *subsella*, and of '*Terebratula*' *moutoniana* d'Orbigny.

(iii) *The Jura fauna.* This fauna is given individuality by the presence of species and sub-species of *Loriolithyris*, of the ribbed terebratulids formerly erroneously referred to *Eudesia*, of *Sellithyris essertensis* and *S. campichei* (although the latter is rare and local) and of '*Terebratula*' *collinaria,* '*T*' *aubersonensis* and '*T*' *villersensis. Sellithyris carteroniana* and *Musculina sanctaecrucis,* although typical of the Jura fauna, also appear in north Germany during the Hauterivian. '*Terebratula*' *salevensis* should possibly be regarded as a member of the Tethyan rather than the Jura fauna as it does not occur in the Paris Basin and has an undescribed congeneric relative which is known only in northern and eastern Spain and the Balearic Islands. (iv) *The ubiquitous species*. *Sellithyris sella,* with its sub-species, is abundant in both the boreal and Jura faunas. In addition, its presence in the Tethyan province is attested in central Switzerland, in the Bakony Forest of Hungary (Detre 1968) and in Turkmenistan (Vogdanova and Lobacheva 1966). *Cyrtothyris cyrta* is widespread in the boreal and Jura faunas, even though four other species of the genus are known only in England and another (Calzada 1972) is apparently confined to eastern Spain and southwestern France (and possibly the Jura).

3. Chronological review of the Lower Cretaceous stages

Looking back into the Upper Jurassic, it seems that at least some elements of the Tethyan fauna at that time ranged much further northwards than in the Cretaceous. *T. subsella*, and related species such as those described by Barczyk (1969), occur in the Oxfordian of England, southwest Germany, the Holy Cross Mountains of Poland and the Russian Platform. By Kimeridgian times *T. subsella* extended no further north than the Boulonnais, and the Volgian saw a further southward retreat of these forms to the Pays de Bray. The Spilsby Sandstone of Lincolnshire, the Sandringham Sands of Norfolk and the Portland Beds in southern England and the Boulonnais contain terebratulids of entirely boreal affinities, e.g. *Rouillieria ovoides* and '*Terebratula*' *bononiensis*.

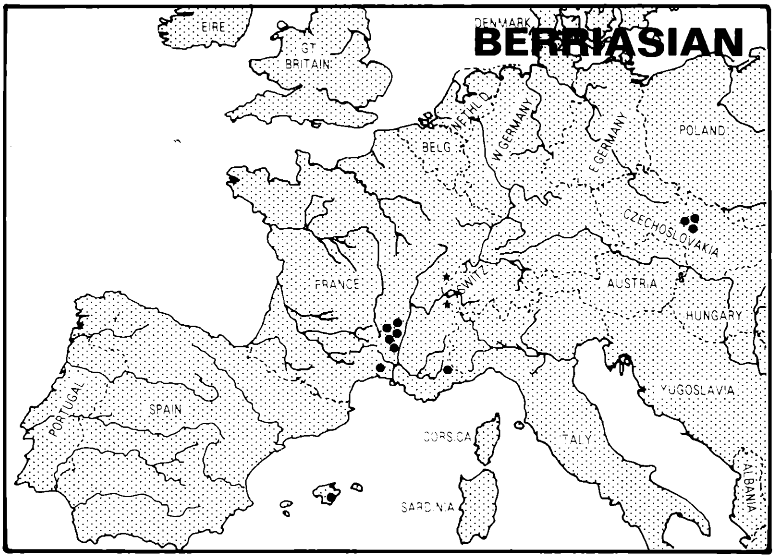

Fig. 1. Berriasian terebratulid distributions.

▲ boreal fauna ● Tethyan fauna
★ Jura fauna ■ ubiquitous species

In the Berriasian, brachiopod records appear scanty, partly because of the difficulty of separating Berriasian from Valanginian faunas in many areas. The most striking feature is the exclusive presence of the Tethyan assemblage at the type locality (Berrias, southern France) and also at Stramberk (Moravia).

In the Valanginian the Jura fauna appeared in strength and the boreal fauna is known in England and Germany. The Hauterivian saw a mass advance of the Jura fauna northwards, with the transgressing sea, into the Paris Basin. It is interesting to note that this was also the time when at least two members of this fauna, *S. carteroniana* and *M. sanctaecrucis*, and one of the Tethyan fauna (*T. moutoniana*), made their way into the north German part of the boreal basin (but not as far as England). Elements of the Jura fauna also appeared in the Crimea and north Caucasus (Smirnova *in* Drushchits and Kudryavtsev 1960) and Turkmenistan (Vogdanova and Lobacheva 1966).

The Barremian was a time of marine regression in the Paris Basin (Corroy 1925; Stchepinsky 1954) and in correlation with this the Jura fauna is poorly represented there and is only present in the base of the Barremian and again at the top of the stage, representing a minor transgression. The poverty in terebratulids of the north German and north English areas at this time, however, is more probably to be explained by a deepening of the basin, since the lithologies in both northern England and north Germany become markedly of deeper-water type, while transgressive shallow-water lithologies are poorly developed.

The Aptian, in general, saw a series of small marine transgressions. In Germany, however, the transgressive shallow-water deposits of this age have not been preserved, except to a small extent around Ahaus (Westphalia) (Kemper 1963). In general the lithologies, like those of the Barremian, seem to represent a deepening of the basin without the development of any very extensive fringe of shallow marginal sedimentation. In the English Aptian, on the other hand, shallow-water lithologies are well preserved and are characteristic of the stage in the southern half of the country. For this reason the boreal brachiopod fauna gives the impression of being concentrated in England at this time.

In England south of the Thames the Aptian faunas are contained in marine sediments which succeed the non-marine Wealden facies. I have elsewhere (Middlemiss 1962b) given in some detail stratigraphical arguments for the belief that this transgression did not reach England from the south, across France, but from the southwest, from the early Atlantic. During the Upper Cretaceous there is little evidence of a southwesterly connection with the Atlantic, according to investigations of the geology of the western approaches to the English Channel; indeed a recent paper (Curry *et al.* 1970) speaks of a "structural high" in that area at that time. It is probable therefore that the Lower Aptian transgression in southern England marks an appearance, perhaps the first, of Atlantic waters in northern Europe but that this seaway was subsequently closed during the major mid-Cretaceous folding and upwarping which so powerfully affected southwest England and the central and western English Channel area (Dingwall 1971).

Another possibility is that the Lower Aptian transgression came from the north, round the western end of the London land-mass. Post-Aptian erosion has left little evidence of deposits of that age in the English Midlands but their former presence is attested by derived *Deshayesites* in the Upper Aptian beds there (Casey 1961). Unfortunately the Lower Aptian terebratulid fauna in southern England is too poor to provide much evidence in itself, since it consists almost entirely of the ubiquitous species *S. sella,* and could equally well fit a transgression of northern origin.

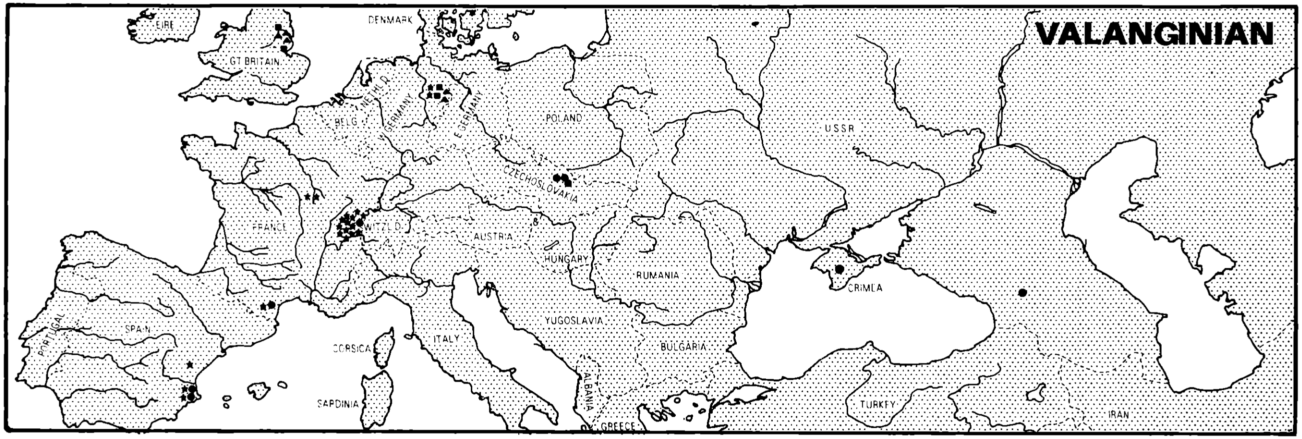

Fig. 2. Valanginian terebratulid distributions (for explanation see Fig. 1).

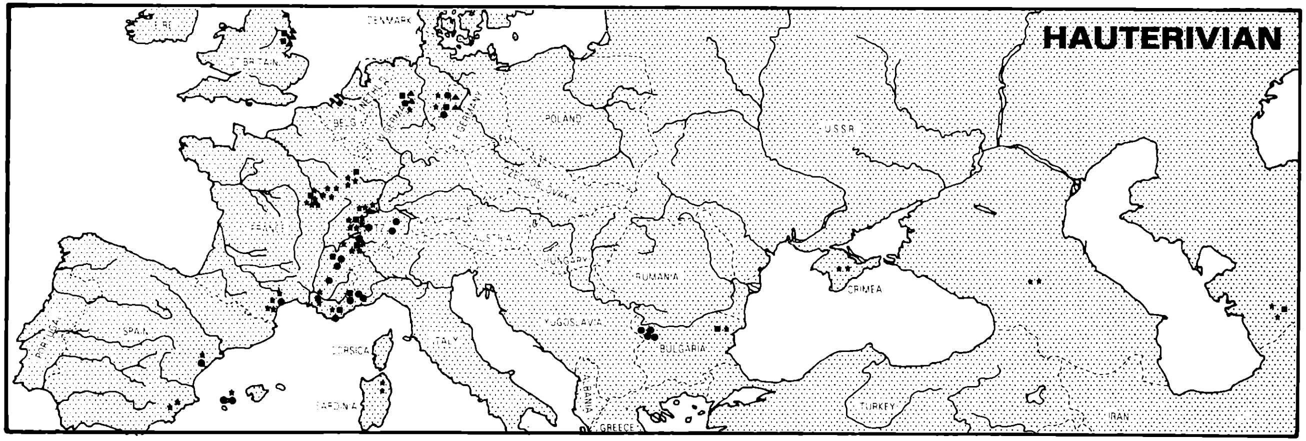

Fig. 3. Hauterivian terebratulid distributions (for explanation see Fig. 1).

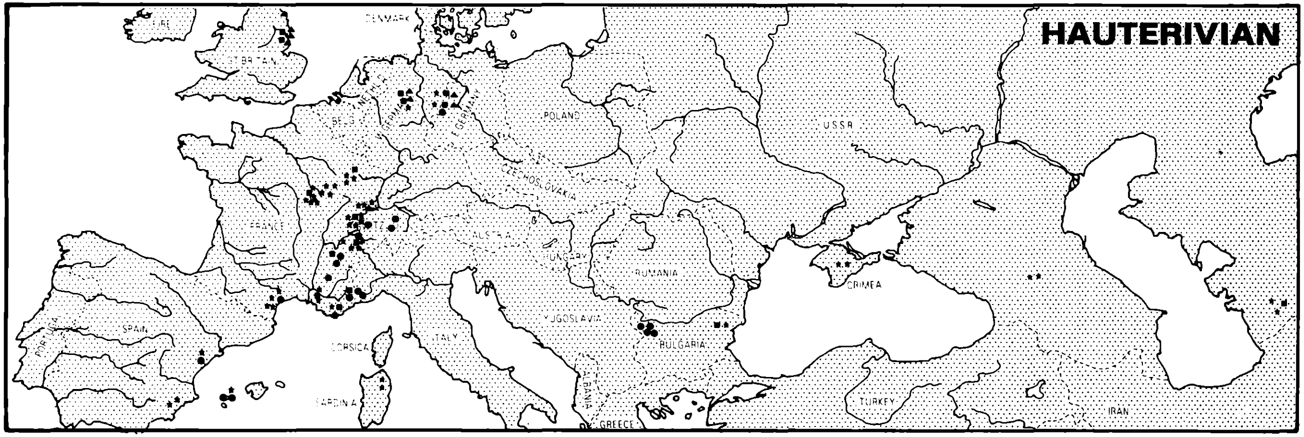

Fig. 3. Hauterivian terebratulid distributions (for explanation see Fig. 1).

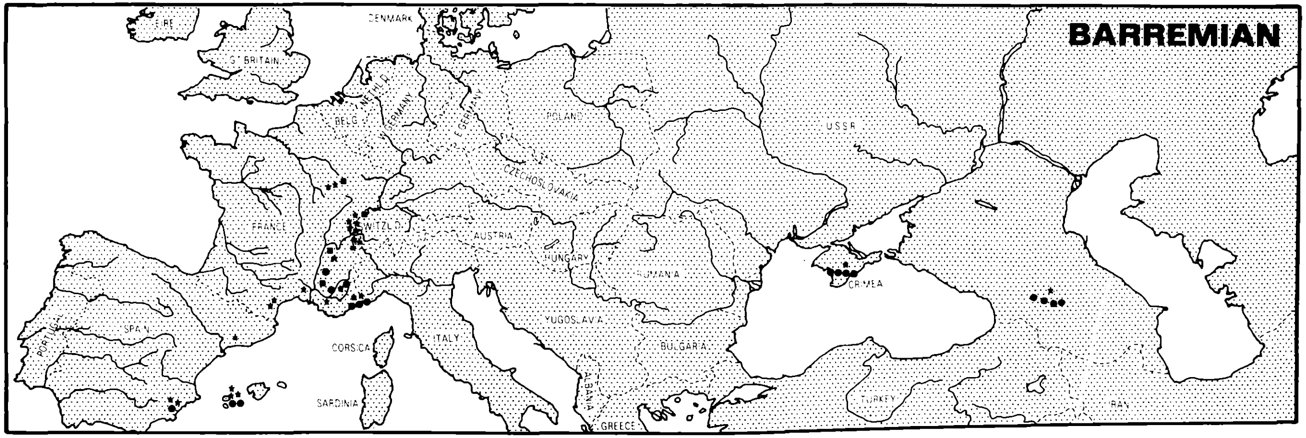

Fig. 4. Barremian terebratulid distributions (for explanation see Fig. 1).

Southern affinities of the earliest Aptian fauna in southern England are suggested by, amongst other things, the rhynchonellids (*Sulcirhynchia*), the gastropod *Cassiope* and, above all, the compound corals (abundant *Holocystis* and very rare *Isastraea*) which are otherwise almost unknown in the boreal Lower Cretaceous. In the Upper Aptian there are also a few rudists, such as *Toucasia*, the only occurrences of rudists in the boreal Lower Cretaceous. Perhaps it is most likely that the transgression came from both directions. Certainly in the Upper Aptian there was a considerable invasion of the southern English area (Surrey, and the Isle of Wight) by boreal elements from the north, such as *Rhombothyris* and *Platythyris*.

It is significant in this connection that it was also in the Aptian that a major marine transgression took place in the Iberian area, especially along the whole of the north Spanish coast—perhaps the result of a phase in the opening of the Bay of Biscay. What is particularly interesting here and in Portugal is the appearance in the Aptian of members of the Tethyan assemblage. It is more likely that these reached the area from the Atlantic than through the urgonian environment which prevailed in the Pyrenean region and appears to have been uncongenial to these species. This, in turn, recalls the well-known occurrence of the thoroughly Tethyan genus *Pygope* in the Valanginian of eastern Greenland (Ager 1967). Had the Atlantic already opened so far north, providing a channel along which the Tethyan brachiopods migrated northwards? The thought is tempting. On the other hand some authorities consider it unlikely that the Atlantic was already open further north than Britain (Bott and Watts 1971) and the (undescribed) brachiopod fauna which occurs along with *Pygope* in East Greenland appears to have more affinity with that described by Dagis (1968) from northern Siberia and it is possible that its origins are in that direction, although, of course, a marine connection does not necessarily mean oceanic-type crust.

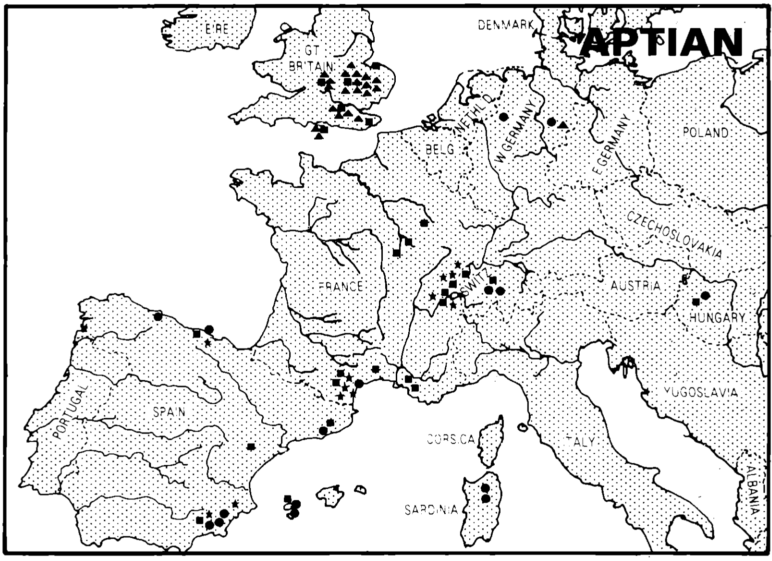

Fig. 5. Aptian terebratulid distributions (for explanation see Fig. 1).

A final point about the Aptian transgression is that, as described later, it carried into the German part of the boreal basin, along with the southern-derived ammonites *Deshayesites* and *Aconeceras*, at least one species of Tethyan terebratulid.

4. Discussion

A recent symposium on faunal provinces (Middlemiss, Rawson and Newall 1971) emphasized that there remains a great deal of disagreement as to why distinctive faunal provinces have existed and indeed as to whether they have existed at all. The boreal, Tethyan and Jura faunas distinguishable among the Lower Cretaceous Terebratulacea are geographical associations of species on a large scale and hence presumably deserve the title of faunal provinces. What were the causes of this geographical distinction of faunas?

The point which emerges most clearly from consideration of the maps is the parallelism between the distribution of the faunas and certain aspects of the tectonic structure of Europe. The northern limit of the Tethyan fauna follows, with some interesting exceptions, the northern margin of the Betic geosyncline in Spain and the Balearic Islands, the western and northern margins of the Alpine External Zone and the flysch zone of the Carpathians through Moravia, Poland, Ruthenia, Rumania and Bulgaria, then across to the central Crimea, the northern Caucasus and the Kopet Dagh in Turkmenistan. The Jura fauna is essentially associated with areas of intra-cratonic folding outside the truly Alpine tectonic belt—the Iberian and Cantabrian chains, the Pyrenean and Provençal chains and the Jura itself. Eastwards such areas, if present, have disappeared beneath the molasse basins or the northwardly displaced edge of the flysch zone; consequently there is little sign of the Jura fauna east of the Jura until a few elements of it reappear in the Crimea, Caucasus and Kopet Dagh. The boreal fauna is entirely of the north European foreland.

The apparent interdigitation of the Tethyan and Jura faunas in southeast France is due to the presence of the Vocontian trough, carrying Tethyan species a considerable distance west of the Alpine margin, in contrast to Provence where the influence of the positive area of the Maures massif was dominant. The occurrence in eastern Sardinia of a small fauna comparable to that of Provence and eastern Spain (Dieni, personal communication; Dieni and Massari 1965) is of particular interest, especially as there is no sign of this fauna in Corsica (Durand Delga, personal communication), or Sicily (Stramondo 1958), where the Lower Cretaceous is of Alpine type. This occurrence supports the hypothesis that Corsica and Sardinia were in Cretaceous times part of a Corso-Sardinian-Maures-Catalonian massif which broke up at the time of the rotation of Spain and the folding of the Pyrenees and Provence (Eocene). It is suggested that Corsica and Sardinia rotated in an anti-clockwise manner, Sardinia having formerly occupied a position north of the Balearic Islands, between them and the Catalonian massif (Durand Delga, in press).

Briefly, the faunas seem to have occupied three belts more or less parallel to the margin of Tethys. Restoration of Spain, Corsica and Sardinia to their pre-rotation positions and making allowance for the northward tectonic displacements of the Alpine chains would seem to indicate that those faunal belts were in Cretaceous times considerably more parallel to latitude than they are now.

The 'Tethyan' fauna is thus intimately associated not with the Tethyan bathyal facies, but with the boundary of that facies. The lithological associations of the fauna seldom suggest deep-water conditions. In the Berriasian at Berrias, for example, although Tethyan species occur apparently unmixed with Jura-type influences, there is evidence of shallow-water sedimentation in the part of the succession richest in the brachiopods—hard-grounds, detrital quartz, with brackish-water organisms appearing at the base of the overlying Valanginian (le Hégarat *in* Middlemiss and Moullade 1970). Brachiopods are not characteristic of the apparently deep-water calpionellid limestones of the lower part of the Berriasian here or in Provence and Corsica. There is a general tendency for members of this fauna to occur in very fine-grained light-grey limestones, as at Berrias, or fine-grained marly limestones, as at Stramberk and in the Vocontian trough, and this may be particularly true of *Pygope, Pygites* and *Antinomia* (cf. Ager 1967); on the other hand this does not necessarily apply even to other Pygopidae (*Nucleata* occurs in neritic bioclastic limestones in northern and eastern Spain). Other species of this fauna may occur in bioclastic limestones (eastern Spain) or glauconitic limestones (Alpes Maritimes).

Perhaps the most surprising development among the Tethyan species is the appearance of '*T*'. *moutoniana* in north Germany, rarely during the Hautervian but in considerable numbers during the Aptian. Schloenbach (1866) writes of this as the commonest species in the Aptian at Ahaus, which is confirmed by examination of the collections from that locality at Münster, and it appears to be the only brachiopod in the Aptian strata between Hanover and Hildesheim, in both cases confined to a marly lithofacies. This seems to be part of the general northward migration of southern forms which characterized the Hauterivian and more especially the Aptian. Nineteenth century German writers gave the name "*moutoniana*" to a number of different brachiopods but these seem to be the only occurrences of the true d'Orbigny species. It did not travel as far as England. It is possible that this species, and those members of the Jura fauna which, as mentioned above, appeared in north Germany during the Hauterivian, migrated northwestwards along the Polish-Danish strait in the manner suggested by Raczyńska, Donze and others (this volume). On the other hand, the apparent complete absence of brachiopods from the Lower Cretaceous of central Poland, and of the Jura fauna from the Carpathians, give rise to some doubt as regards this route. The more likely possibility that during the Hauterivian and Aptian, at least, there was direct marine communication from the Jura region across central Germany to the Lower Saxony basin is suggested.

The Jura assemblage of species occurs in a variety of sedimentary types: bioclastic limestones (Jura and Paris Basin), marls (Jura), sandy limestones (Paris Basin). The distribution of the Jura fauna has a general association with that of the urgonian limestone facies, but, in fact, the brachiopods are not characteristic of the massive limestones of this facies; on the contrary they are often found in great numbers in the highly calcareous orbitoline marl horizons interbedded with the massive limestones (southwest France, northern and eastern Spain). An exception is *Loriolithyris russillensis*, of which life-assemblages are sometimes found in the urgonian limestone, as at the type locality (Orgon, Bouches du Rhône). The members of this fauna are never found in situations suggestive of a deep-water environment. The species which penetrated into the boreal basin in the Hauterivian are strictly confined there to the shallow-water marginal facies.

In the boreal basin the occurrence of terebratulids is almost entirely associated with neritic conditions, which in this context means lithofacies of sands, conglomerates, sandy limestones and sandy limonite-oolite ironstones. The beds richest in brachiopods are usually those that show clear signs of condensed deposition, notably the Upper Valanginian—Lower Hauterivian upper Claxby Ironstone of north Lincolnshire (Penny and Rawson 1969), the conglomeratic calcareous beds of similar age on the flanks of the Salzgitter salt stock (Germany), as at Grenzlerburg (Kauenhowen 1926), and the Upper Aptian beds of the south Midlands of England (Bonney 1875). There seems little doubt that these represent, in general terms, shoreline deposits, although not necessarily mainland shores. The clay lithofacies of the offshore deposits yields few brachiopods, even where rich benthonic faunas indicate well-oxygenated bottom conditions, as in the lower parts of the Speeton Clay in Yorkshire and of the clay facies between Hanover and Hildesheim. *Rugitela*, *Terebratulina* and *Lingula* were more tolerant of the clayey environment and most brachiopods found in the Hauterivian and Barremian clay facies can be referred to these genera. Terebratulids are almost unknown in the Speeton Clay apart from a few very rare forms apparently related to *Rouillieria.* The occurrences of '*Terebratula*' *moutoniana* in the Hauterivian and Aptian of Germany, referred to above, are confined to the clay facies.

Control of the distribution of these faunas by depth of water can therefore probably be ruled out. All were, in general, shallow-water forms (with possible exceptions among some Pygopidae). Obvious geographical barriers apparently did not exist between the Tethyan and Jura faunas at any time during the Lower Cretaceous. Between the Jura and boreal faunas there clearly were open sea connections at least during the Hauterivian and the Aptian. On the other hand, a marine connection did not necessarily mean faunal mixing, as is clearly shown by map 5. There is no reason to believe that by the later part of the Aptian there was not a marine connection between the Jura-Paris Basin area and southern England and, indeed, all authors have postulated such a connection. Yet, apart from *S. sella,* the terebratulid faunas have nothing in common. The channel between them was

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Fig. 6. The geographical distribution of Lower Cretaceous Terebratulacea in western Europe.

Boreal fauna ▲

1. *Rhombothyris extensa* (Meyer); 2. *R. microtrema* (Walker); 3. *R. meyeri* (Walker); 4. *R. conica* Middlemiss; 5. *Platythyris comptonensis* Middlemiss and *P. Minor* Middlemiss; 6a. *Sellithyris coxwellensis* Middlemiss; 6b. *S. upwarensis* (Walker); 7a. *Cyrtothyris uniplicata* (Walker); 7b. *C. cantabridgiensis* (Walker); 7c. *C. seeleyi* (Walker); 7d. *C. dallasi* (Walker); 9. *Praelongithyris* spp.; 22. *Rouilliera* sp. nov.; 23. *R. walkeri* (Davidson).

Jura fauna ★

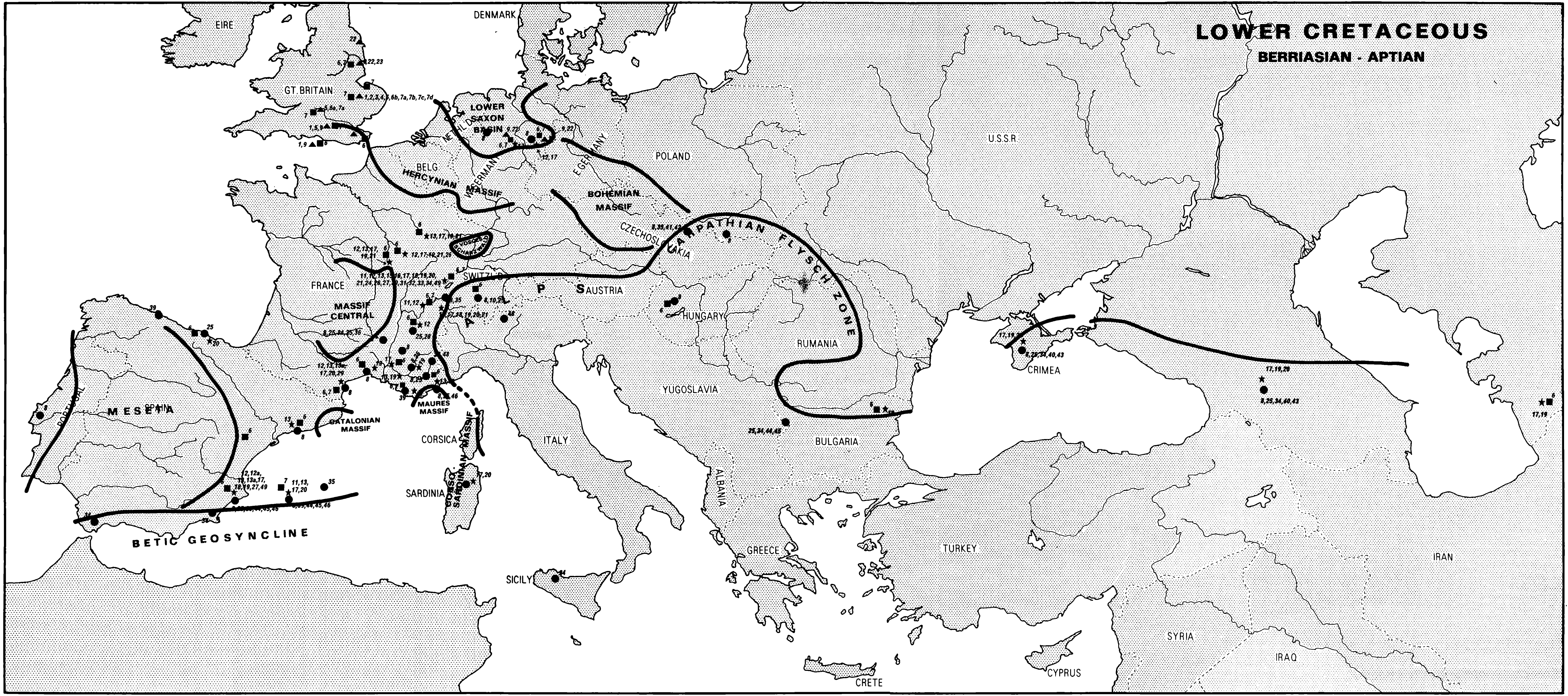
11. *Sellithyris essertensis* (Pictet); 12. *S. carteroniana* (d'Orbigny); 13. *Loriolithyris russillensis* (de Loriol); 15. '*Eudesia*' *ebrodunensis* Agassiz; 16. '*E*'. *cruciana* Pictet; 17. *Musculina sanctaecrucis* (Catzigras); 18. '*Terebratula*' *sueuri* Pictet; 19. *Loriolithyris valdensis* (de Loriol); 20. '*Terebratula*' *salevensis* de Loriol; 21. '*Eudesia*' *semistriata* (Defrance); 24. '*E*' *marcousana* (d'Orbigny); 26. '*Terebratula*' *collinaria* d'Orbigny; 27. '*T*'. *aubersonensis* Pictet; 29. *Loriolithyris latifrons* (Pictet); 31. *Sellithyris campichei* (Pictet); 32. '*Terebratula*' *villersensis* de Loriol; 33. *Loriolithyris germaini* (Pictet); 49. '*Terebratula*' spp. aff. *dutempliana.*

Tethyan fauna ●

8. '*Terebratula*' *moutoniana* d'Orbigny; 10. '*Terebratula*' *alpina* Rollier; 25. *Nucleata* spp.; 28. '*Terebratula*' *iserensis* Rollier; 34. *Pygope* spp.; 35. *Pygites* spp.; 36. '*Terebratula*' *euthymi* Pictet; 39. '*Terebratula*' sp. aff. *salevensis*; 40. *Weberithyris moisseevi;* 41. *W. moravica;* 42. *Dictyothyris* spp.; 43. *Antinomia* spp.; 44. '*Terebratula*' sp. aff. *subsella* (species C); 45. '*T*' sp. aff. *subsella* (species A); 46, '*T*' sp. aff. *subsella* (species D); 47. '*T*' sp. aff. *subsella* (species B); 48. 'T' *euganeensis* Pictet.

Ubiquitous species ■

6. *Sellithyris sella* (Sowerby) and subspecies; 7. *Cyrtothyris cyrta* (Walker).



LOWER CRETACEOUS

BERRIASIAN - APTIAN

probably narrow and shallow, with a high energy environment (Corroy 1925; Middlemiss 1962b), and for various reasons continued to constitute an effective barrier to brachiopod migration. It is noteworthy, when considering the effects of palaeogeography, that in the Albian, when further transgressions had considerably widened the seaways (see, for example, the maps given by Schott *et al.* 1967 a, b, 1969), brachiopod distribution became much more uniform in western Europe.

It is possible to discern a broad correlation with lithology; the Tethyan forms are associated mainly with sediments poor in terrigenous detritus; the boreal forms entirely with terrigenous sediments. The Jura fauna in this respect is intermediate, but nearer akin to the Tethyan than to the boreal. It is unlikely, however, that lithological association is in itself sufficient to explain the control of these faunas; there are too many exceptions among the Tethyan fauna and the associations of the Jura fauna are too wide for this to be satisfactory.

We are left with two factors which are essentially part of palaeogeography in a broad sense—temperature and salinity. In considering the influence of temperature it should be borne in mind that the Tertiary tectonic structures have to be unfolded in order to arrive at Lower Cretaceous palaeogeography. The Alpine-Carpathian front must be pulled back southwards; Iberia, Corsica and Sardinia possibly re-rotated northwards. As remarked above, such adjustments would make the distribution of the faunas considerably more parallel to latitudes, and presumably to climatic belts, than they now appear. There is some evidence suggesting a direct effect of temperature differences in that some species attained larger average and maximum size in southerly than in northerly latitudes, particularly well seen in the case of the ubiquitous species *S. sella* (Middlemiss 1968a, 1968b).

Salinity is closely linked with temperature and other palaeoclimatic factors and also with palaeogeography. The whole picture of lithologies and faunas along the margins of Tethys in the Lower Cretaceous, dominated as it is by limestones, with the vast outcrops of massive urgonian facies, the rudists, orbitolines and hermatypic corals, speaks for warm climatic conditions with relatively little land-derived material being washed in; thus perhaps there was also a relatively dry climate, leading probably to relatively high salinity. In the boreal Lower Cretaceous there are no pure limestones like those of the south, no rudists (with the significant exception in the English Aptian already mentioned), practically no hermatypic corals (with the same significant exception), no orbitolines (again significantly they appear in the English Albian), and obviously a great deal of land-derived detritus coming into the sea. It seems difficult to avoid the conclusion that the climate was cooler and wetter (cf. Hallam 1969, 1971 for discussion of similar ideas relating to the Jurassic).

The conclusion can therefore be tentatively stated that the distribution of the faunas was controlled partly by the geographical layout of land and sea, particularly in the case of the boreal fauna, and partly by palaeoclimatic influences.

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The distribution of Lower Cretaceous (Berriasian — Barremian) rhynchonelloid and terebratelloid brachiopods in the northern hemisphere

E. F. Owen

The majority of rhynchonelloid and terebratelloid brachiopods were widely distributed during the Neocomian and Barremian. However, the rhynchonelloids *Lacunosella*, *Monticlarella* and *Peregrinella* form a distinctive "Alpine" fauna within the Tethyan Realm, while certain genera are limited to the Boreal Realm: *Ptilorhynchia*, *Fusirhynchia* and *Uralorhynchia* occur in Siberia and *Rhynchonella* in northwest Europe. The terebratelloids *Oblongarcula* and *Rugitela* occur in northwest Europe, the southeastern part of the Paris Basin and the northwest Jura. Factors influencing these distributions include bottom conditions and temperature. There is evidence of a northward migration of some brachiopod genera, probably from the northern margins of Tethys.

Die Mehrheit der rhynchonelliden und terebratelloiden Brachiopoden-Arten hatte im Neokom und Barreme eine weite Verbreitung. Jedoch bildeten die rhynchonelliden Formen *Lacunosella, Monticlarella* und *Peregrinella* eine ausgesprochen "alpine" Fauna innerhalb des Tethys-Gebietes, während bestimmte andere Gattungen auf das Borealgebiet beschränkt sind: *Ptilorhynchia, Fusirhynchia* und *Uralorhynchia* kommen in Sibirien und *Rhynchonella* in NW-Europa vor. Die terebratelloiden Formen *Oblongarcula* und *Rugitela* wurden in NW-Europa, im Südostteil des Pariser Beckens und im NW-Jura beobachtet. Zu den Faktoren, die auf die Verbreitung Einfluß hatten, gehörten die Verhältnisse am Meeresboden und die Temperatur. Bei einigen Brachiopoden-Gattugen gibt es Hinweise auf Nordwanderungen. Sie erfolgten wahrscheinlich vom Nordrand der Tethys aus.

La plupart des Brachiopodes rhynchonelloïdes et térébratelloïdes étaient largement répartis durant le Néocomien et le Barrémien. Toutefois, les Rhynchonelloïdes *Lacunosella, Monticlarella* et *Peregrinella* constituent une faune "alpine" particulière à l'intérieur du domaine mésogéen, tandis que d'autres genres sont limités au domaine boréal: *Ptilorhynchia, Fusirhynchia* et *Uralorhynchia* en Sibérie et *Rhynchonella* dans le Nord-Ouest de l'Europe. Les Térébratelloïdes *Oblongarcula* et *Rugitela* se rencontrent dans le Nord-Ouest européen, le secteur Sud-Est du Bassin parisien et le Nord-Ouest du Jura. Les conditions du fond et la température sont deux des facteurs responsables de ces distributions. Il est démontré l'existence d'une migration vers le Nord de quelques genres de Brachiopodes, probablement depuis les rives septentrionales de la Tethys.

1. Introduction

In the northern hemisphere, Lower Cretaceous brachiopods are found mainly in the Old World and few examples are known from North America. Published records are sparse and represent the few scattered localities (generally European) which have been extensively studied. Hence this paper incorporates much unpublished information, based on collections which I have examined in German, French and Swiss museums and especially on collections in the British Museum (Natural History): these collections include many undescribed faunas. Even so, the distribution-patterns recognized here reflect a very incomplete state of knowledge and will doubtless require modification as research proceeds.

The ecological control of these brachiopod distributions is clearly demonstrated. The substrate and bottom conditions have played an important part in preserving lineages through geological time and it is not surprising to find that the same or similar morphological patterns persist within the limits of a given environment.

Conversely, their dependence on bottom conditions means that fossil brachiopods are found only in certain types of sediment, mainly of shallow-water origin. In northwest Europe in particular, Lower Cretaceous brachiopods are often found in condensed sequences. In north Germany they are especially common in Valanginian to Hauterivian impure limestones and ironstones deposited along the southeastern margin of the Lower Saxony Basin, and in sandstones of similar age fringing the southern margin (see Kemper, this volume, for discussion of these facies). The English faunas described from the Claxby Ironstone (Owen 1965, 1970; Owen and Thurrell 1968) came mainly from a late Valanginian-early Hauterivian condensed horizon at the top of the ironstone at Nettleton, north Lincolnshire (Penny and Rawson 1969). It is, therefore, impossible to be very specific in determining the geological range or geographical distribution of many of these northwest European forms.

2. Patterns of distribution

At generic level, several rhynchonelloids and terebratelloids have a wide distribution from Turkmenistan and the Caucasus westwards to Morocco, Spain and southern and central France and northwestwards to north Germany and northeast England, and possibly to East Greenland. The rhynchonelloids *Sulcirhynchia, Lamellaerhynchia, Belbekella* and *Plicarostrum* and the terebratelloids *Belothyris* and *Terebratella* are distributed through most or all of this region, though individual species may be much more restricted.

Other genera have a more limited distribution, and among these two distinct groups can be recognised.

2a. The Alpine group

This group is apparently confined to the finer-grained, deeper-water sediments of the Alpine chain of southern France, Switzerland, the Carpathians and the Caucasus. The genera are probably related to the late Triassic or early Jurassic members of Ager's (1960) "Alpine" group, which lived in a similar environment and region. The Lower Cretaceous "Alpine" fauna is dominated by the rhynchonelloid *Lacunosella*, associated with *Monticlarella*. There are no reliable records of terebratelloids from this association, but the terebratulids *Pygites* and *Nucleata* are characteristic. The rhynchonelloid *Peregrinella* is another member of the same fauna, but may have lived in shallower water and have been transported to the deeper-water facies (Ager 1965). Some of these "Alpine" genera also occur as rare elements in the "Infravalanginian" and Valanginian faunas of East Greenland, again in the finer-grained sediments.

2b. The boreal group

A limited number of rhynchonelloids have a clearly boreal distribution: *Ptilorhynchia, Fusirhynchia* and *Uralorhynchia* occur in Siberia, while *Rhynchonella s.s.* is known only from northwest Europe. The terebratelloids *Oblongarcula* and *Rugitela* occur in northwest Europe but have also been recorded further south, from the southeastern part of the Paris Basin and the adjacent northwest Jura, where they occur with more widespread genera.

3. Distribution of genera

3a. The Rhynchonellidae

Lacunosella

This genus can be distinguished from other rhynchonellidae by its strong, sharply defined and deeply incised costae, constant subtriangular outline and well-developed median fold and sulcus. Internally it possesses characteristic falcifer crura, from which broad, plate-like structures extend anteriorly, instead of the simple, hook-like and more commonly occurring radulifer crura.

The earliest Cretaceous Lacunosellinae are represented by the Berriasian species *Lacunosella contracta* (Hombre-Firmas), *L. malbosi* (Pictet), *L. decipens* (d'Orbigny) and the longer-ranging species *L. guerini* (d'Orbigny), *L. eichwaldi* (Nutzubitz) and other species assigned to the genus *Kolhidaella* Moisseev, a synonym of *Lacunosella.* The genus extended to the beginning of the Upper Barremian and is commonly found in the Basses Alpes, at Castellane in southern France, and also occurs in Switzerland, the Carpathians, northwestern Caucasus and the Crimea (Fig. 1a). The genus is also represented in the Valanginian of Traill Island, East Greenland, by the form recorded by Muir-Wood (1953) as "*Rhynchonella*" cf. *decipiens* d'Orbigny.

Monticlarella

This is a small, striate rhynchonelloid (Fig. 1b) which, like *Lacunosella,* also originated in the Upper Jurassic. Representative species are found associated with the Lacunosellinae in the finer-grained sediments of Valanginian-Barremian age, extending from the Caucasus to southern France. It is interesting to note that the association of *Monticlarella* with the Lacunosellinae occurs throughout its geological range and even extends into the Turonian (Owen 1968) where it is found with *Orbirhynchia,* a descendant of *Lacunosella.*

Peregrinella

The distribution of the unusual rhynchonelloid brachiopod *Peregrinella* (Fig. 1b) has been discussed at length by Biernat (1957) and Ager (1967). One Lower Cretaceous species deserves special mention. This is *P. multicarinata* (Lamarck) and its varieties, which ranges from the Valanginian to the Upper Hauterivian.

It appears to be concentrated in the middle Neocomian limestones of the south of France in the vicinity of Montpellier, but the same species was recorded by Biernat (1957) as a rare fossil from the northwestern Carpathians, Moravia in Czechoslovakia and Wieliczka, Poland and, rather surprisingly, from Mecklenberg in Germany. It is also recorded from north Italy, Transsylvania, the Crimea and the northwestern Caucasus. It is usually found in limestones and Ager (1965) suggested that it probably lived in a shallow-water habitat and was transported to deeper-water facies after death.

A further species, *Peregrinella whitneyi* Gabb, represents the extreme western limits of the genus. It has been described from the Lower Cretaceous white limestones of western California, U.S.A.

Ptilorhynchia, Fusirhynchia

Ptilorhynchia was originally described from the Upper Jurassic of California (Crickmay 1933) and is also known from the Upper Jurassic (? Portlandian) of British Columbia (Owen 1972). The geographical and geological range of the genus (Fig. 1a) is now extended to the Valanginian of northern Siberia, from which horizon Dagis (1969) described two species, *P. glabra* and *P. seducta.* Dagis also described a genus *Fusirhynchia* from the Upper Volgian and Valanginian of the Urals; the Valanginian species was named *F. secreta.* According to the published serial sections of the type species, *Fusirhynchia* (including *F. secreta*) is probably a junior subjective synonym of *Ptilorhynchia.*

Uralorhynchia

This genus was proposed by Dagis (1969) for a large, coarsely costate rhynchonelloid from the Berriasian of the northern Urals. It is difficult to connect it with any genus known from the Upper Jurassic or Lower Cretaceous, but it possibly developed from the same stock that gave rise to *Mosquella* (Makridin 1955) from the Upper Jurassic of the Russian Platform. *Uralorhynchia* has not been recorded from any locality other than that of its original description (Fig. 1a).

Rhynchonella

Previous records of the distribution of *Rhynchonella* sensu stricto by Ager (1957) and Childs (1969) have shown that the genus originated in the Upper Jurassic of the Moscow basin and extended westwards to Poland, north Germany, the central French Jura and England.

Lower Cretaceous species are known only from condensed Valanginian and Hauterivian deposits in north Germany and northeast England, and from the English Barremian (Fig. 1a). The genus is thus limited to the Boreal Realm. *Rhynchonella speetonensis* Davidson occurs in the Speeton Clay at Speeton, Yorkshire, in the top Claxby Ironstone of Nettleton, Lincolnshire, and in argillaceous sediments in the Brunswick and Hannover areas of north Germany (Owen and Thurrell 1968). *R. parkhillensis* Owen and Thurrell was described from the Fulletby Beds (Barremian) of Lincolnshire.

Sulcirhynchia

During the earlier part of the Lower Cretaceous, *Sulcirhynchia* (Burri 1956) was apparently limited to deposits of Valanginian age in the Swiss Jura and nearby localities in the southeastern part of the Paris Basin, where it is represented by the type-species *S. valangiensis* (de Loriol) (Fig. 2). The genus is almost certainly

Fig. 1a. Distribution of *Lacunosella*, *Rhynchonella*, *Ptilorhynchia* and *Uralorhynchia*.

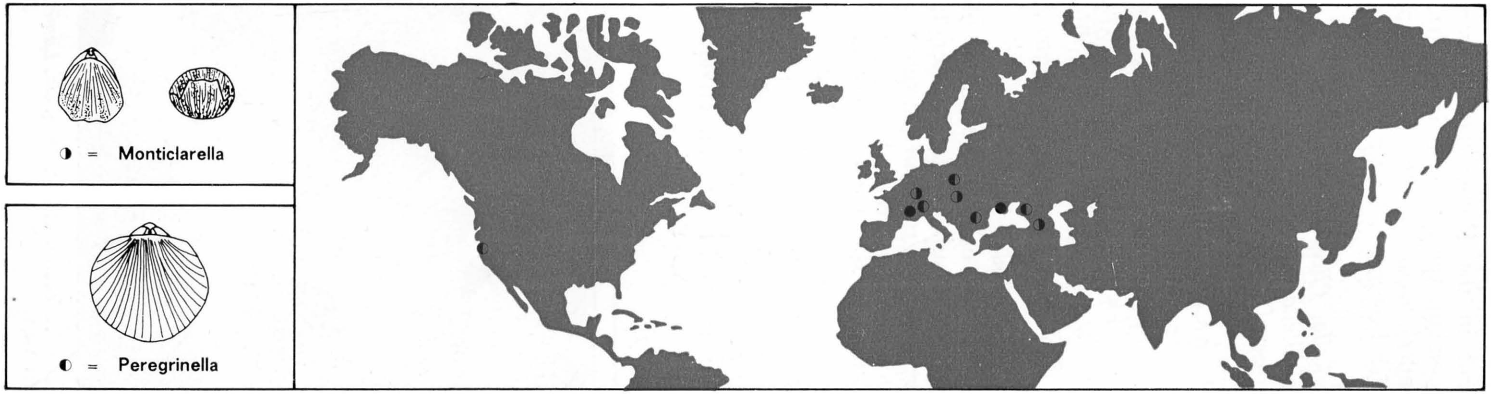

Fig. 1b. Distribution of *Peregrinella* and *Monticlarella*.

present in the Hauterivian limestones of Mogador, Morocco. Later, post-Neocomian, species occur in northern Spain and southern England: *S. miliani* (Bataller) occurs in the Spanish Upper Aptian and *S. hythensis* Owen in the English Lower and Upper Aptian (Owen 1956).

Belbekella, Plicarostrum

Belbekella was described from the Lower Cretaceous of Georgia (Fig. 2) by Moisseev (1939). It is found, as in the case of *Lamellaerhynchia,* in the more argillaceous limestones and higher energy deposits of Turkmenistan, northern and southern Caucasus and the Crimea. It is probably also present in the Neocomian limestones of Morocco. *Plicarostrum* Burri (1956) apparently occurs in the Hauterivian of southern France, Turkmenistan and the Caucasus as well as in the type locality in Switzerland. This genus is probably a junior synonym of *Belbekella* and the distribution of the two genera is combined under "*Belbekella*" on Figure 2.

Lamellaerhynchia

Basing his original definition of *Lamellaerhynchia* on the type species, *Rhynchonella rostriformis* (Roemer) from north Germany, Burri (1956) extended the geographical range of the genus to the Swiss Jura. It is now known to have a much more widespread distribution (Fig. 2). From Turkmenistan a species was described as *Belbekella kopetdaghensis* by Vogdanova and Lobacheva (1966). This is probably the species described from the Basses Alpes and Maritime Alpine regions of southern France by Jacob and Fallot (1913) under the name *Rhynchonella multiformis* var. *castellanensis. L. kopetdaghensis* is very closely related to *L. hauteriviensis,* described by Burri (1956) from Le Landeron in the Swiss Jura. Similar forms in the Hauterivian limestones in Mogador, western Morocco,

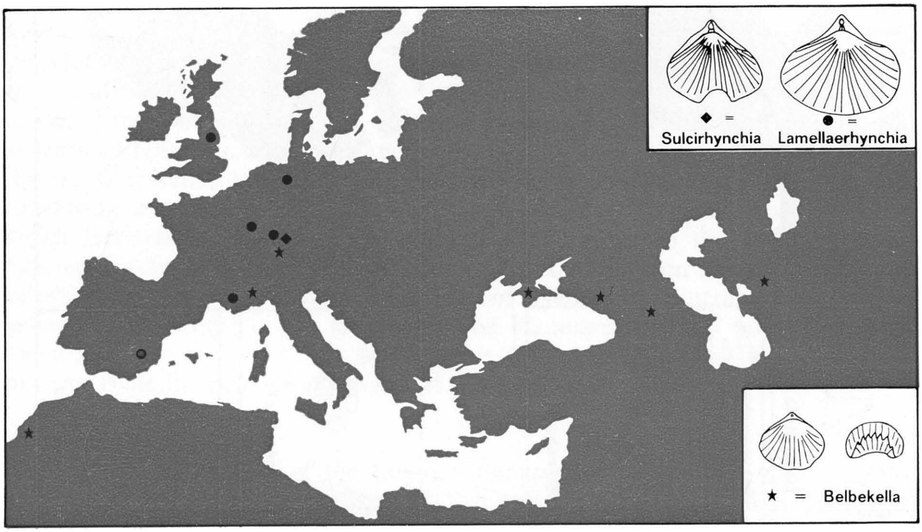

Fig. 2. Distribution of *Sulcirhynchia, Lamellaerhynchia* and *Belbekella* in the Valanginian and Hauterivian.

were noted by Roch (1930) who attributed them to *Rhynchonella multiformis* (Roemer) (=*R. rostriformis*).

The genus is also known from England, where it is common in the Claxby Ironstone of Nettleton, north Lincolnshire (Owen and Thurrell 1968) and occurs in the Speeton Clay. One species of Barremian age with an apparent boreal distribution is *L. rawsoni* Owen and Thurrell, described from the Fulletby Beds of Dalby Park, Lincolnshire. It is also a fairly common fossil in the Barremian ironstones at Fortuna Quarry, near Salzgitter, north Germany.

Several specimens of a *Lamellaerhynchia* similar to the British and north German species *L. walkeri* (Davidson), and also examples of a form close to *L. rostriformis,* have been found in the Valanginian at Wollaston Foreland, East Greenland.

Morphologically, *Lamellaerhynchia* changes very little through its stratigraphical and geographical range, apart from the development of a regular fold and sulcus and some thickening of the anterior margin of the shell in southern forms, which tends to replace the asymmetrical anterior commissure characteristic of north German and English species.

3b. The Terebratellidae

There are two main groups of terebratelloids, the costate and the smooth-shelled forms. The former include *Oblongarcula* and "*Terebratella*", and the latter *Rugitela* and *Belothyris.*

Oblongarcula

The costate terebratelloids *Oblongarcula puscheana* (Roemer) and *O.* cf. *oblonga* (J. Sowerby) (Fig. 3) which Roemer (1841) cited from north Germany are fairly common fossils in the shales and argillaceous limestones of Valanginian to

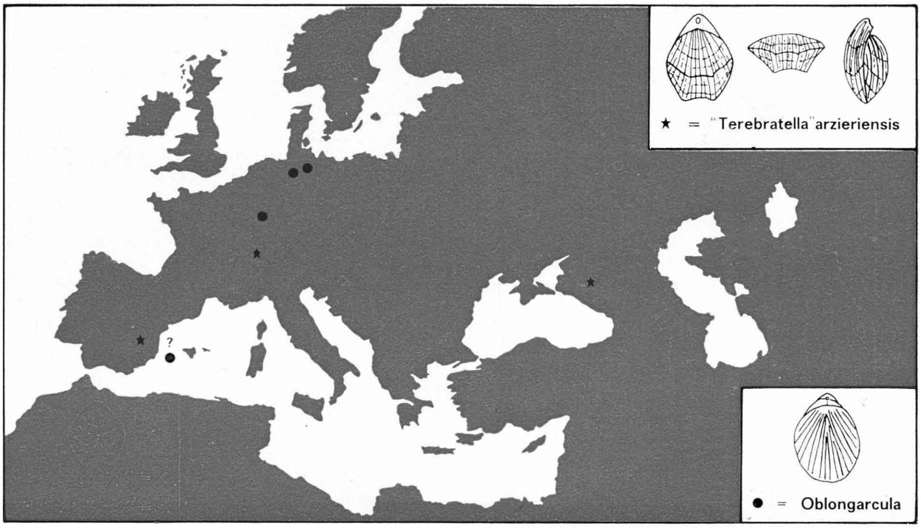

Fig. 3. Distribution of *Oblongarcula* cf. *oblonga* (J. de C. Sowerby) and "*Terebratella*" *arzieriensis* (de Loriol).

Hauterivian age of that area. They are also recorded from a similar facies and horizon at Auxerres and Marolles in the eastern part of the Paris Basin. These species are not, however, found in brachiopod-rich beds of comparable lithology and age at Nettleton in England, nor does the genus appear in Britain until Lower Aptian times and then only in the southeast, where it is confined to the shallow-water facies of the Lower Greensand of Kent, the Isle of Wight, Upware, Brickhill and Faringdon.

One poorly-preserved specimen said to be an *Oblongarcula* has been found in Hauterivian limestones on the island of Ibiza, but this appears to be a more finely costate form than the typical and the record needs further investigation.

"Terebratella"

"Terebratella" arzieriensis (de Loriol) (Fig. 3) is a costate terebratelloid species which occurs in the Valanginian of the Jura Mountains, Switzerland, from whence it was first described. Very closely related forms, differing only slightly in outline and costation, occur in beds of similar age in eastern Spain and have been described as *Terebratella marini* and *T. riosi* by Bataller (1947). Another closely related form from the Hauterivian of the northwest Caucasus was figured by Drushchits and Kudryavtsev (1960) as *Terebratella jaccardi* (de Loriol).

Rugitela

Two terebratelloids with a restricted distribution are the smooth-shelled *Rugitela roemeri* Owen and the associated species *R. hippopus* (Roemer). The two species occur in the marly limestones of north Germany and in beds of Hauterivian age at Salins-les-Bains in the Jura mountains and at St. Dizier in the eastern Paris Basin. In these areas, *Rugitela roemeri* is by far the more commonly occurring of the two species, but in the condensed top Claxby Ironstone

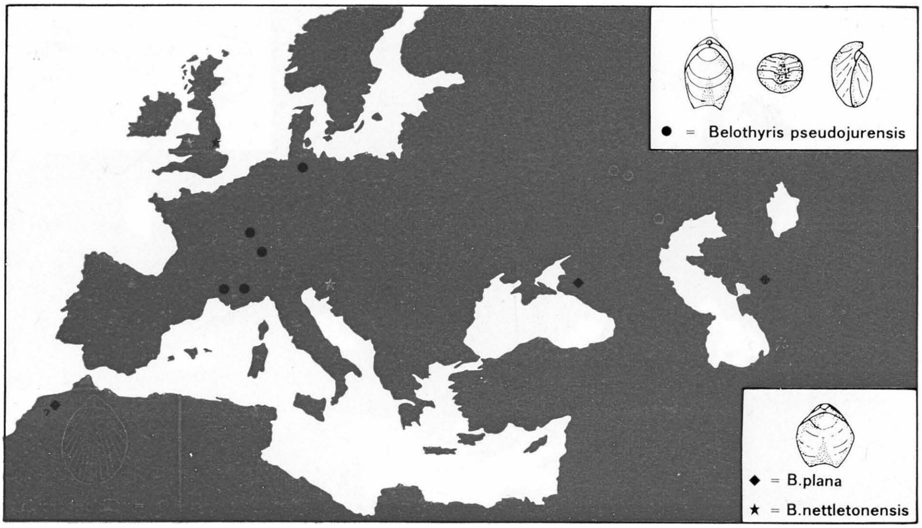

Fig. 4. Distribution of representative species of *Belothyris*. The record of *B. plana* in Morocco has still to be confirmed.

at Nettleton in northeast England, where the two species also occur, the reverse is true; *R. hippopus* is comparatively common while *R. roemeri* is rare. The two species are obviously further developments of earlier, Upper Jurassic, forms which were well established throughout north Germany and northeastern France and their ancestry could probably be traced to similar stocks from the Russian Platform which were flourishing at the time.

Belothyris

Belothyris has a wide distribution (Fig. 4): from the northern Caucasus it extends westwards to Morocco, southern France, Switzerland and the southeast part of the Paris basin, north Germany and northeastern England. The type-species, *Belothyris plana* Smirnova, is more closely related to the north African species from Morocco and the form which occurs in the Basses Alpes and La Clape and Narbonne areas of southern France than to *B. pseudojurensis* (Leymerie), which is a fairly common brachiopod in the Upper Valanginian and Hauterivian deposits of the Swiss Jura and adjacent part of the Paris Basin. The latter species occurs, though rarely, in the condensed Valanginian-Hauterivian sediments in north Germany. *B. nettletonensis* Owen is a related form which occurs as a rare fossil in the top Claxby Ironstone of Nettleton, England (Owen 1970).

4. Discussion

In searching for influences affecting the distribution of these brachiopod faunas one should take into account not only the bottom conditions but also temperature. In addition to faunas of relatively limited distribution, such as the "Alpine" group within the Tethyan Realm, one can also recognize a more widely distributed fauna readily adaptable to differing substrates but seemingly sensitive to temperature change. Although it is difficult to determine the exact age of many elements of this fauna, it seems probable that at least part originated in the northern borders of Tethys and spread northwards to central France, the Jura, the Paris Basin, north Germany and northeast England. The main changes occurred in late Valanginian to Hauterivian times. The idea that this northward movement reflects climatic changes accords with current theories regarding an increase in overall temperatures of several degrees, leading to a levelling of temperatures in an area extending from the Mediterranean to Scandinavia in mid to late Lower Cretaceous times.

The northward movement continued in post-Hauterivian time, as evidenced by *Sulcirhynchia*. This genus is apparently not represented in beds of Neocomian age further north than the Jura and the adjacent part of the Paris Basin, even though bottom conditions in northeast England and north Germany at that time would probably have been conducive to its maintenance. It first appeared in England in the Lower Aptian, and with associated genera probably migrated from as far south as Spain and possibly north Africa rather than from France and Switzerland.

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Lower Cretaceous (Ryazanian - Barremian) marine connections and cephalopod migrations between the Tethyan and Boreal Realms

P. F. Rawson

Palaeogeographical maps for the early Lower Cretaceous show several seaways between the Boreal and Tethyan Realms: these provided routes open to faunal migration. Northwest Europe was part of the Boreal Region but the cephalopod sequence shows distinct Tethyan influence, starting during the Upper Valanginian and reaching a peak in the mid-Hauterivian. Some Tethyan immigrants formed significant populations inter-fingering with (i.e. temporarily displacing) boreal faunas while other smaller populations and "stray" specimens mingled with boreal groups. Similar mixing occurred in other, latitudinally-orientated, areas. Temperature control was probably important in upholding the Tethyan/boreal distributional pattern.

Wie paläogeographische Karten der frühen Unterkreide demonstrieren, existierten einige Meeresverbindungen zwischen dem borealen Reich und der Tethys. Sie ermöglichten Faunen-Wanderungen. So zeigt NW-Europa, obgleich Teil des borealen Reiches, bei Betrachtung der Ammoniten-Faunen deutliche Einflüsse von der Tethys. Diese wurden prägnanter zur Zeit des Ober-Valangin und erreichten ihren Höhepunkt in der Mitte des Hauterive. Einige der einwandernden Tethys-Arten bildeten bedeutende Populationen, die boreale Arten ablösten und zeitweise verdrängten. Andererseits mischten sich auch kleinere Populationen und "Irrläufer" mit borealen Gruppen. Ähnliche Mischungen von Faunen verschiedener geographischer Breiten gab es auch in anderen Gebieten. Die Temperatur war vermutlich der für die Verbreitung der Boreal- und Tethys-Faunen entscheidende Faktor.

Les cartes paléogéographiques dressées pour le début du Crétacé inférieur montrent l'existence entre les domaines boréal et mésogéen de plusieurs liaisons marines, qui servirent d'itinéraires aux migrations fauniques. Le Nord-Ouest de l'Europe faisait partie de la Province boréale, mais les séquences à Céphalopodes témoignent d'une influence mésogéenne caractérisée qui débute au Valanginien supérieur et atteint son intensité maximale à l'Hauterivien moyen. Certains immigrants mésogéens formaient des populations significatives qui s'intercalaient dans les faunes boréales (i.e. les remplaçaient temporairement), tandis que d'autres populations moins importantes ainsi que des spécimens "égarés" se mêlaient aux assemblages boréaux. Un mélange comparable s'effectuait aussi entre des domaines de même latitude. Le facteur température jouait probablement un rôle important en maintenant le mode de répartition des éléments mésogéens et boréaux.

1. Introduction

The Tethyan and boreal Mesozoic seas were never completely separated, even in Tithonian and Berriasian (Volgian and Ryazanian) times when maximum marine regression occured. The two regions were connected by transient or more permanent seaways along which faunas could migrate: clearly, the fewer and narrower the connections the more likely some areas were to become almost completely isolated, with the resultant development of local endemic faunas.

Adams and Ager (1967) have shown how loosely and in what varying ways the term "Tethys" has been used; related problems arise over the use of "Boreal", "Boreal Realm" (or "Province") and "Boreal Region". Although "Boreal Realm" should refer to a zoogeographical region characterised by the distribution of certain ammonites (or other faunal elements), the term has often been used in a different sense, referring to a discrete palaeogeographical entity separated from the Tethyan

Fig. 1. Valanginian palaeogeography of the Boreal Region—based on a present-day polar projection.

Region by major land barriers (whose importance and extent varied considerably with time) but linked by seaways. This palaeogeographical area is referred to here as the "Boreal Region"; the region (Figs 1, 2) includes the Boreal Ocean (centred on the present Arctic Ocean) fringed by a series of shallow-water, epicontinental seas extending southwards over parts of North America, northern Europe and Siberia. The Boreal Region, so defined, corresponds in general with the Boreal Realm (Province) but includes marginal areas (such as northwest Europe) which were inhabited at times by Tethyan ammonites. The distribution of other invertebrates does not necessarily follow the ammonite pattern.

This paper is concerned essentially with Ryazanian-Barremian cephalopod, especially ammonite, faunas of mixed origin occurring in the Boreal Region, but reference is also made to some more southerly faunas of boreal origin.

2. Palaeogeography and marine connections

A palaeogeographical map of the Boreal Region in Valanginian times (Fig. 1) has been compiled from several sources, including Jeletzky (1971) for Canada, Schott *et al.* (1967, 1969) for much of northern Europe and various Soviet sources, including Saks, Shulgina and Sasonova (1972), for European Russia and Siberia. It is apparent that the present-day continental masses were continental in Lower Cretaceous times though certain areas were extensively flooded by epicontinental seas. The present-day Arctic was the site of the "Boreal Ocean", the centre of dispersal of many boreal ammonites (Arkell 1956).

On Figure 2 the same palaeogeographical features are plotted on a Cretaceous reconstruction map, kindly supplied by Dr. A. G. Smith of Cambridge University. Apart from the difference in position of the north pole, the main difference between the two maps is that the North Atlantic is considerably narrower, and the North Pacific seaway much broader. These differences should be taken into consideration in any study of faunal distribution.

The Valanginian palaeogeographical reconstructions are used as a basis for discussion in this paper. Ideally, separate maps should be used for each stage but at present the Valanginian appears best documented and on the scale used the changes in paleogeography with time are generally small: significant differences are discussed where necessary.

Both the pre-drift and present-day reconstructions indicate several marine connections between the Boreal and Tethyan Regions, most of which are well established. In the west there was doubtless an extensive connection from the North Pacific Tethyan region to the Boreal Ocean, either between Kamchatka and Alaska or to the west of Kamchatka: sedimentary and faunal evidence for this is well preserved in Asiatic Russia (e.g. Saks *et al.* 1972) and North America (e.g. Imlay 1960). A narrower connection between the North American Pacific Coast and Arctic Canada is termed the Dawson City Strait (Jeletzky 1971). Most of North America and Greenland were land, though there is increasing support for the idea that a seaway through the Cretaceous North Atlantic linked western Tethys with the Boreal Ocean via a narrow channel between East Greenland and the Scandinavian Shield (Fig. 2). Originally postulated because of apparent faunal links between East Greenland and Tethys (see section 3c) some sedimentary evidence is now being obtained.

Further east, the Danish-Polish furrow (see Marek and Raczyńska, this volume) formed a marine corridor between the northern North Sea Basin and the Carpathians: the latter fringe the northern margin of Tethys. Open from the Ryazanian (Schott *et al.* 1967, 1969), the furrow also provided a continuous connection with north Germany during the Valanginian and Hauterivian before being closed at its southern extremity by a regression during late Hauterivian or early Barremian times.

To the east of the Baltic Shield an embayment from the Boreal Ocean flooded the Pechora region and Moscow Basin to connect through the Lower Volga region with Tethys (Caucasus). Eastwards, Central Asia formed an east-west landmass bounded to the east by the Pacific Ocean.

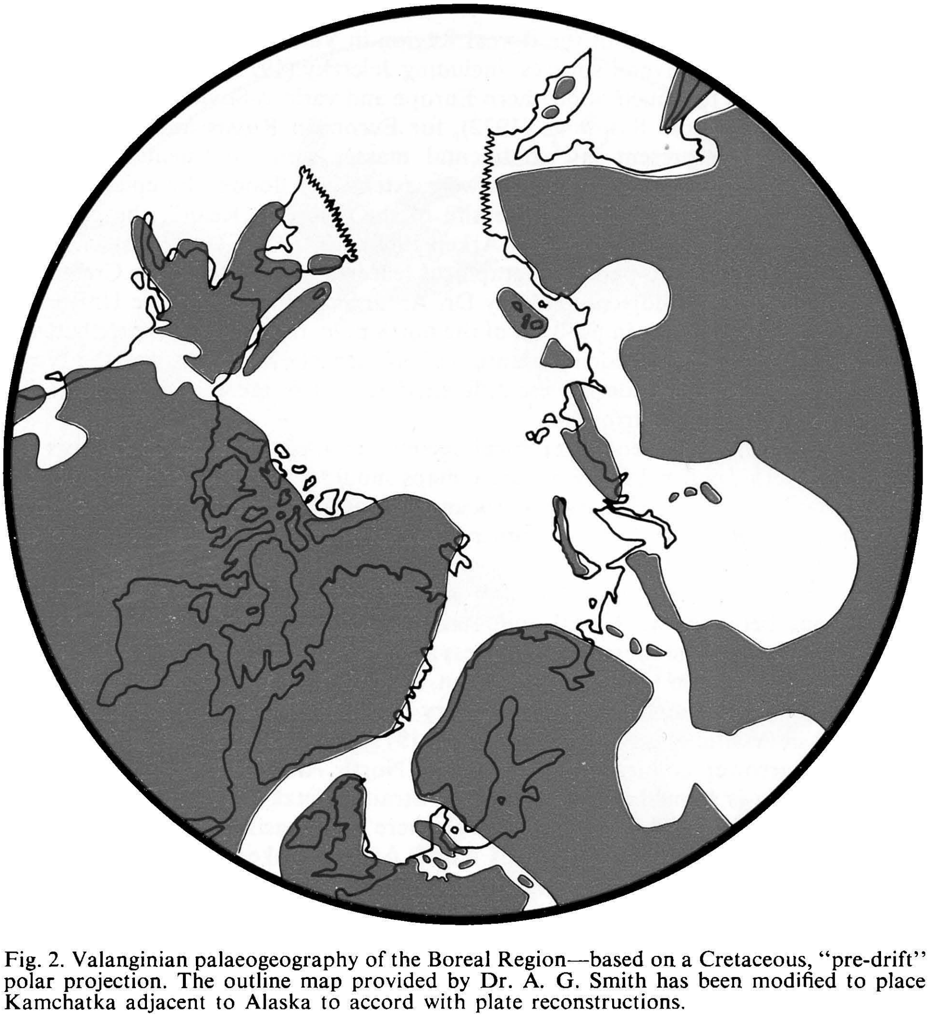

Fig. 2. Valanginian palaeogeography of the Boreal Region—based on a Cretaceous, "pre-drift" polar projection. The outline map provided by Dr. A. G. Smith has been modified to place Kamchatka adjacent to Alaska to accord with plate reconstructions.

The palaeogeographical pattern outlined above changed radically during the series of world-wide marine transgressions which began during the Aptian but reached a peak in the Albian and early Cenomanian.

3. Faunal migrations

3a. Patterns of migration

During Ryazanian-Barremian times there is clear evidence of faunal migration along the seaways connecting Tethyan and Boreal Regions. Two types of migration can be distinguished: "mass migration" and isolated "straying". Some ammonites and belemnites (e.g. *Riasanites* in the Ryazanian of the Moscow Basin, *Hibolites* in the Hauterivian of northwest Europe) originated in Tethys and migrated northwards in considerable numbers to evolve further and form the dominant population in marginal areas of the Boreal Region, temporarily displacing boreal faunas. Others "strayed" singly or in small numbers, sometimes penetrating far into the Boreal Region where they are found at widely scattered localities: occasional phylloceratid ammonites are a notable example. Such "strays" or small populations are usually found in association with more abundant boreal genera.

Before one generalises on faunal distributions certain major limitations should be considered (see Middlemiss and Rawson 1971; Jeletzky 1971). In particular, faunas under comparison may not be of precisely the same age. Secondly, the relationships between contemporaneous faunas, both within a province and between provinces, can be considerably blurred by taxonomic differentiation, which may reflect differences in preserved growth stages rather than real biological distinction. For these reasons I will concentrate on a small part of the Boreal Region, namely northwest Europe, where the faunas are relatively well known and where I have first-hand field experience. Other areas are discussed in more general terms.

3b. Cephalopod faunas and migration in northwest Europe

The shallow sea extending over much of northwest Europe probably connected round the Scottish land-mass with a seaway extending from Greenland to Tethys (Fig. 2). From Ryazanian to Hauterivian times there was a second, more direct, connection through the Danish-Polish furrow to the Carpathians. Thus the region was open to direct Tethyan influence through at least part of the Lower Cretaceous.

There are two main areas of outcrop in northwest Europe. In north Germany (Schott *et al.* 1969; Kemper, this volume) there are good sections and innumerable borehole records through the major facies types, especially along the southern margin of the Lower Saxony Basin and in the central basin facies. In eastern England occasional sections through the varied sediments of the eastern basin (Lincolnshire and Norfolk) are supplemented by the excellent coastal section of the Speeton Clay in Yorkshire.

The overall similarity of the invertebrate faunas in the two areas was recognised over a hundred years ago (Roemer 1841; Judd 1870) and a study of the literature coupled with extensive field-work has convinced me that the cephalopod sequence in both areas is essentially the same. There are breaks in the succession in both areas and some faunas may be of limited distribution, but many of the specific differences are in name only and reflect size or preservational differences—or the nationality of the original author. Although the main sections have been extensively collected from for over 150 years, new finds are still being made which help to confirm the homogeneity of the fauna. In this section a generalised northwest European sequence is reviewed in relation to the probable origin of each major element (genus or subfamily) of the cephalopod fauna.

(*i*) *The belemnite faunas.* In his classic study of the Speeton Clay of England, Lamplugh (1889) proposed four major biostratigraphical units, the A, B, C, and D Beds, each characterised by a belemnite genus. The D Beds (Ryazanian—early Lower Hauterivian) and the B Beds (late Upper Hauterivian—Lower Aptian) yield the boreal genera *Acroteuthis* and *Oxyteuthis* respectively. The intervening C Beds (Hauterivian) contain hundreds of *Hibolites,* a characteristically Tethyan genus which periodically migrated northwards during both the Jurassic and Lower Cretaceous. The A Beds (Upper Aptian—Albian) are typified by a related genus, *Neohibolites.* The north German belemnite sequence is identical. Thus through the Lower Cretaceous there is an alteration of Boreal and Tethyan genera (Fig. 3), as recognised and discussed by Pavlow (*in* Pavlow and Lamplugh 1892). There is only a very limited overlap of forms: for example a few specimens of *Acroteuthis* (*A. festucalis* Swinnerton group) occur in the Lower C Beds (*Hibolites* Zone) at Speeton.

(*ii*) *The ammonite faunas.* The range of common ammonite genera is summarised in Figure 3. In northwest Germany the Ryazanian stage is represented by the Upper Serpulit and non-marine "Wealden", and ammonites are found only in eastern England. The genera (see Casey, this volume) are all boreal forms belonging to the Craspeditidae (Craspeditinae and Tolliinae).

The transgression which flooded north Germany at the beginning of the Valanginian was accompanied by the appearance of large numbers of *Platylenticeras.* There is a single record of this form from Speeton (J. Doyle collection) but the genus is otherwise not known from England. Its apparent rarity is probably due to preservation failure in a part of the English succession which is often poorly fossiliferous or condensed. The origin of *Platylenticeras* is problematic: formerly regarded as a Tethyan ammonite, the genus may be a craspeditid (boreal) derivative (Kemper, this volume). A few late tolliids and early polyptychitids occur with *Platylenticeras* (Kemper 1964), foreshadowing the appearance of rich faunas of distinctive boreal ammonites, *Polyptychites* and allies, in the Upper Valanginian.

In the higher part of the Upper Valanginian, other ammonites occur, generally as minor faunal elements: several genera are typically Tethyan. Of these, *Neohoploceras* occurs in the Claxby Ironstone of north Lincolnshire and in a remanié nodule bed (D2D) in the Speeton Clay (Rawson 1971b): *Dicostella,* now known from the same Speeton horizon, is found in the German Arnoldien Schichten and is an important inter-regional marker (Kemper 1971): *Leopoldia* and *Bochianites* occur in this Speeton nodule bed and in north Germany, and *Saynoceras* is recorded from the latter area. Late Valanginian and early Hauterivian olcostephanids from northwest Europe include both cosmopolitan and apparently endemic forms, but require thorough taxonomic revision.

Three genera dominate the Hauterivian faunas. The Lower Hauterivian is typified by abundant *Endemoceras* (Thiermann 1963; Rawson 1971b), a neocomitid apparently endemic to northwest Europe. There is, however, little doubt that the genus was derived from Tethyan *Neocomites.*

The distinctive boreal genus *Simbirskites* (*Speetoniceras*) appears immediately above the last *Endemoceras* at Speeton, only to be replaced almost completely a little higher in the succession by abundant *Aegocrioceras.* In Germany, the *Aego-*

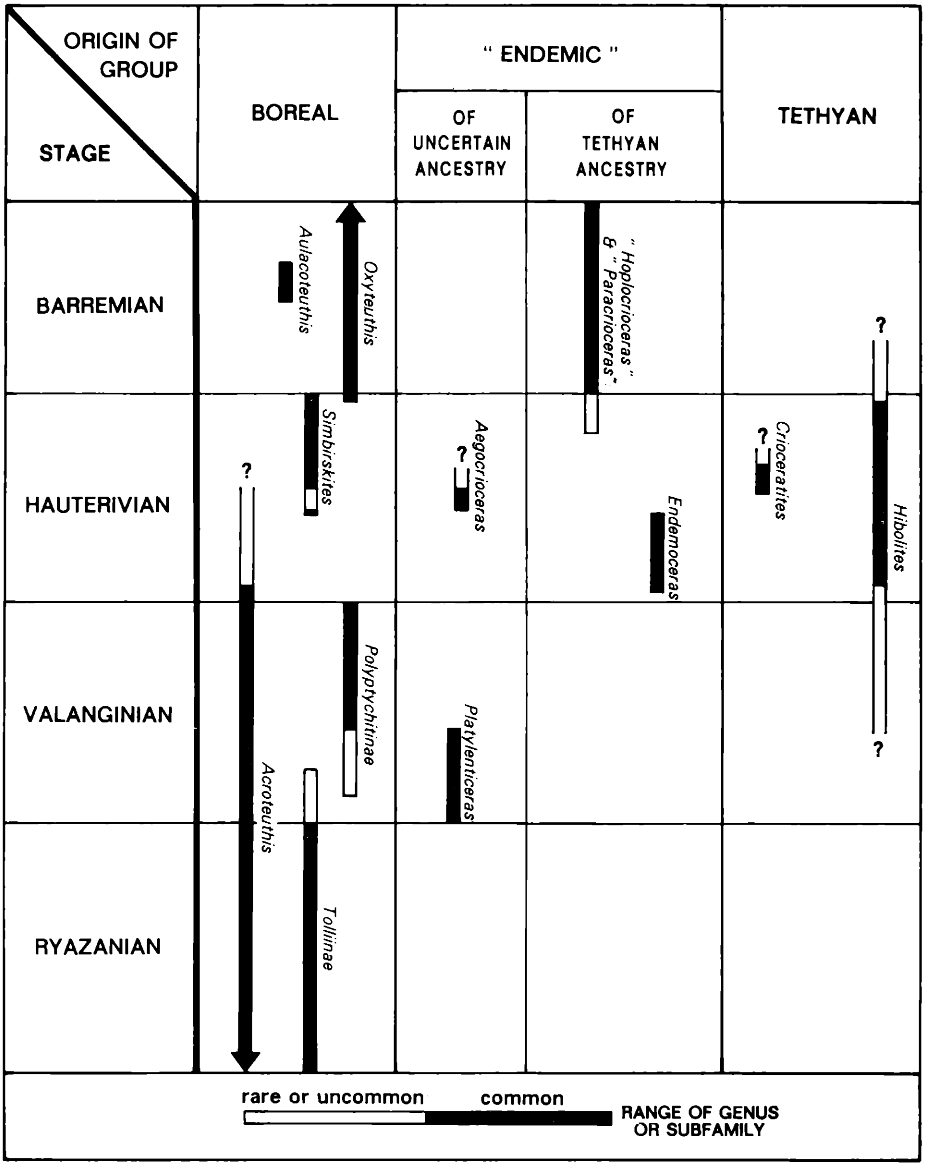

Fig. 3. Range and origin of dominant elements in the northwest European Ryazanian—Barremian cephalopod faunas.

crioceras horizon (lower *capricornu* Zone) is separated from the Endemoceras Schichten by barren strata, though the (intervening) *Speetoniceras* fauna is now known from the Gildehauser Sandstone (Kemper, this volume). *Aegocrioceras* is a crioceratitid ammonite of uncertain ancestry apparently endemic to northwest Europe. Few *Simbirskites* are known from the beds with *Aegocrioceras,* but it reappears immediately above (subgenera *Simbirskites* s.s. and *Milanowskia*) and generally remains the dominant ammonite through the rest of the Hauterivian.

Although *Endemoceras, Aegocrioceras* and *Simbirskites* are the commonest Hauterivian genera, several others occur with them. In north Germany, rare *Acanthodiscus* occur in the Endemoceras Schichten: species identical with German forms occur in the Polish furrow (e.g. Marek and Raczynská, this volume), the Jura (Baumberger 1903–10) and the Crimea (Karakasch 1907) but are very rare in the deeper-water facies of southeast France (Moullade and Thieuloy 1967). The genus is never common but appears to have a distribution related to the shallow-water facies surrounding the Central European landmass. Other northwest European neocomitids (e.g. *Distoloceras*) are probably endemic derivatives of *Endemoceras.*

Distinctive Hauterivian Tethyan immigrants include *Spitidiscus, Crioceratites, Hypophylloceras* and *Lytoceras.* Two thin horizons at Speeton (C8A, C5L: Rawson 1971b fig. 3) yield *Spitidiscus* and the type species, *S. rotula* (Sowerby), was first described from here. The genus appears at a comparable level in north Germany, in the Gildehauser Sandstone ("*Valdedorsella*" in Kemper 1968 pl. 19 figs 7, 10, 11). *Crioceratites* first occurs with late *Aegocrioceras* (Figs 3, 4) in the mid-Hauterivian where it is represented by typical members of the *C. duvalii* group. Crioceratitids reappear at various higher levels: certain species were utilised as zonal forms in north Germany (Koenen 1902), where they are locally common though usually occurring as flattened impressions. A curious record from Bed C4 at Speeton is that of *Protaconeceras,* otherwise known only from the Hauterivian of Patagonia (Casey 1954).

The Barremian usually contains very few ammonites and the fauna is almost exclusively composed of fragmentary crioceratitids, apparently endemic but probably derived from Tethyan forms. The species (mostly described by Koenen 1902) are generally assigned to the ill-defined genera *Hoplocrioceras* and *Paracrioceras* (Spath 1924) and the whole fauna requires revision. These northwest European forms had apparently attained a stage of evolution similar to that of contemporaneous genera elsewhere: fragments of strongly tuberculate early Barremian forms resemble *Emericiceras* while other Barremian heteromorphs with short shaft and terminal hook (*Hoplocrioceras phillipsi* (Phillips) group) are remarkably similar to *Acrioceras* from the Tethyan Barremian.

Thus it is clear that the northwest European cephalopod faunas contain several distinctive Tethyan elements and at least one genus (*Endemoceras*) which while apparently endemic is clearly derived from a Tethyan form. In general the Tethyan immigrants are minor elements of the fauna, but *Hibolites* and *Crioceratites* formed dominant or significant populations.

While the dominant boreal or Tethyan ammonite genera alternate (i.e. interfinger) in the sequence, rarer Tethyan elements are mixed with boreal forms. The same holds true for belemnite genera, but the relationship between belemnite and ammonite distributions is more complex. Tethyan *Hibolites* co-existed during the Lower Hauterivian with *Endemoceras* (and occasionally with boreal *Buchia!*) but during the Upper Hauterivian with an essentially boreal ammonite fauna. Hence there is no simple pattern of alternating migrations from north or south, and it is noteworthy also that while *Hibolites* could migrate in large numbers its Tethyan companion, *Duvalia,* remained restricted to Tethys.

Tethyan influence in northwest Europe first became noticeable during the Upper Valanginian and reached a peak during the mid-Hauterivian. Ryazanian cephalopod faunas were exclusively boreal, Lower Valanginian and Barremian ones possibly so. Migration was not a one-way process, for boreal genera are recorded

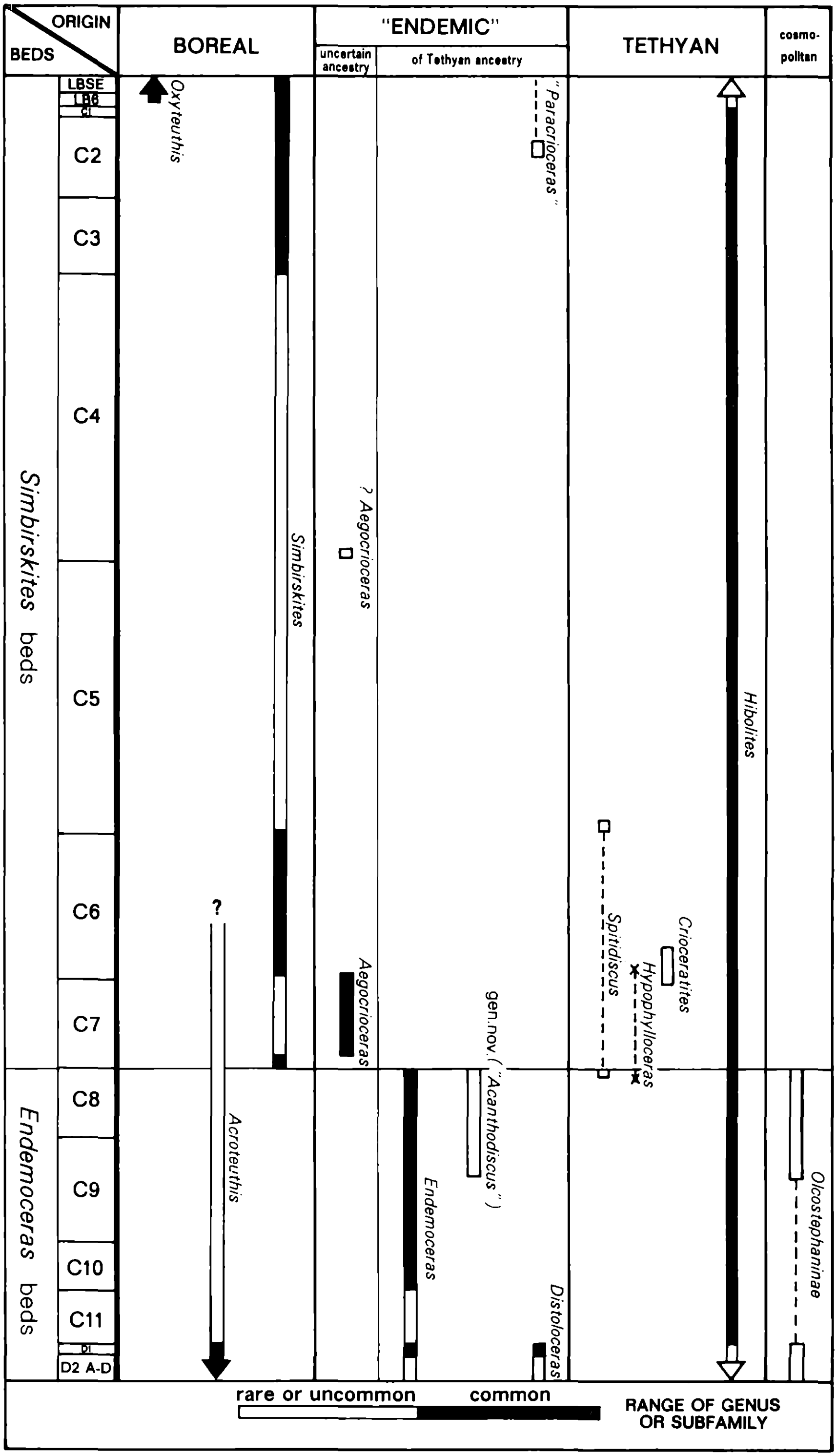

Fig. 4. Range and origin of the Speeton Clay Hauterivian cephalopod faunas. This figure is based on material collected by the author, and the ranges are simplified from a detailed chart in Rawson 1971b (fig. 3). Thickness of beds in the left-hand column is drawn to scale.

from southwest Europe, especially in the shallow-water facies of the Jura and adjoining parts of the Paris Basin (e.g. Leymerie 1841–42; Baumberger 1903–10) and in southern France (Thieuloy, this volume).

3c. Ammonite migrations in other regions

Similar patterns of distribution, again related to the proximity of north-south seaways, are seen in other parts of the world. Jeletzky (1971 p. 76) has stressed that intermingling of Tethyan and Boreal faunas occurred in sublatitudinally orientated regions, related to the climatic belts: the northwest European faunas support this conclusion. The Pacific Coast of North America is another such region and is of particular interest for comparison with northwest Europe. Berriasian-Barremian (and younger) ammonites are known from California to Alaska, and from the Canadian Western Interior and Arctic regions. Ammonites occur at widespread localities in this vast region, and are generally rare: for example, the Washington, Oregon and Californian Berriasian-Hauterivian faunas described by Imlay (1960) and Imlay and Jones (1970) are represented by only about 800 specimens, 200 of which belong to one species (*Tollia mutabilis*) from a single locality in California. Hence correlation and the study of faunal distributions cannot be attempted in detail comparable with that of European works.

The occurrence of both Tethyan and boreal faunas led Jeletzky (e.g. 1971) to recognize two provinces in the Canadian Lower Cretaceous. The North American Boreal Province (Western Interior and Arctic Canada) is part of the Boreal Realm and is characterised by a low diversity fauna of genera, some apparently endemic, belonging to typical boreal groups. The North Pacific Province (Pacific Coast of Canada, extending down to adjacent parts of the U.S.A.) contains boreal, endemic and Tethyan genera but is regarded by Jeletzky (1971 p. 11) as part of the Tethyan Realm. It is probably better regarded as a region of overlap of the two realms, as intimated by Imlay (1960) and Imlay and Jones (1970).

Along the Pacific Coast there were several periods of "mass migration" from south to north and vice-versa, resulting in alternating sequences of boreal or Tethyan character. The endemic genera also show boreal or Tethyan affinity and some may be congeneric with more widely distributed forms. Isolated "straying" also occurred, such as the phylloceratid *Partschiceras* recorded from the Sverdrup Basin in the North American Boreal Province (Jeletzky 1971 p. 20).

In general, boreal faunas of Ryazanian and early Valanginian age were limited to Arctic Canada, while the Pacific Coast from British Columbia to California was inhabited by Tethyan olcostephanids and berriasellids, such as *Spiticeras* and *Neocomites*. Southward migration of boreal elements on at least two occasions in the later Valanginian is indicated by the dominance of *Tollia* of the *T. mutabilis* group as far south as California, followed by the spread of *Homolsomites* (a derivative of *Tollia*) through the whole region.

The Lower Hauterivian marine faunas of the North Pacific Province are characterised by *Wellsia* (Imlay 1957), regarded by Jeletzky (1971) as a late *Homolsomites*. Rocks of this age are unknown in marine facies in the Canadian boreal region, but younger Hauterivian strata from here to California are characterised by boreal simbirskitids: provincial genera in the United States see (Imlay 1960) are probably at least in part congeneric with sub-genera established in Europe (see Rawson 1971a). Within the North Pacific Province these ammonites co-existed with characteristic Tethyan forms, such as *Spitidiscus,* phylloceratids, lytoceratids and crioceratitids. Barremian faunas everywhere from California to Arctic Canada consist mainly of heteromorph genera presumably of Tethyan derivation (Jeletzky 1971).

This pattern of migration resulted in a more extensive overlap and mingling of boreal and Tethyan forms than occurred in northwest Europe, and probably represents a broader connection between the two realms (see Figs 1, 2). The faunas appear analogous in situation to the west European Upper Jurassic faunas, where alternations of boreal and Tethyan ammonites (the boreal and Tethyan "spreads" of Arkell 1956) reflect the oscillating position of the local margins of the two realms in a region of extensive marine connection.

Evidence for a marine connection through the North Atlantic (Figs 1, 2) linking Tethys with East Greenland was indicated (Donovan 1957 p. 150) by the occurrence of phylloceratid and lytoceratid ammonites in a Valanginian fauna from Traill Island (Donovan 1953; Middlemiss and Rawson 1971). The "Tethyan" individuals form approximately 7% of the total number of ammonite specimens collected and therefore occur in much higher proportion than the same groups do in northwest Europe. Tethyan influence is also apparent in brachiopod faunas of the same age (Donovan 1957; Middlemiss, this volume; E. F. Owen, this volume). The occurrence of these Tethyan elements so far north could indicate a warm-water current from the south (Ager 1971).

The marine connection through the Lower Volga region had a significant influence on faunal migration. Although the ammonites of the Russian Platform are mainly boreal, the lower part of the (condensed) Ryazan horizon is characterised by abundant *Riasanites,* a berriasellid of Tethyan origin which flourished in these northern waters before being replaced by *Surites.* In the Upper Barremian another genus of Tethyan origin, *Matheronites,* is sufficiently important to be used as a zonal marker.

Boreal faunas must have migrated southwards along the same seaway for the Crimea and northern Caucasus have long been famed for the occurrence of a mixed boreal/Tethyan assemblage (e.g. Karakasch 1907; Drushchits and Kudryavtsev 1960): here there appears to have been a true mixing rather than an interdigitation of faunas. These mixed faunas have been used above all others for attempting a correlation between boreal and Tethyan sequences.

4. Geological significance of the faunal migrations

4a. The origin of the Lower Cretaceous faunal realms

The fact that faunas *were able* to migrate along the north-south seaways and sometimes establish evolving populations outside their normal domain must be taken into account in the study of the origin of the Tethyan and Boreal Realms. The mass migrations (spreads) were limited to marginal (overlap) areas arranged latitudinally. The same was true during the Upper Jurassic when marine connections were often broader and more extensive. The latitudinal control was presumably temperature (related to the disposition of climatic belts) as suggested by many workers since the time of Neumayr (1883) and Uhlig (1911) but rejected recently by Hallam (1969, 1971) for the Jurassic, mainly because of the evidence of a more equable climate and the apparent absence of an "Antiboreal" (Austral) Realm. Certainly temperature gradients were probably far less during the Jurassic and Cretaceous than they are at the present day, when a marked bipolarity of faunas occurs. However, an inital slight gradient (suggested by Hallam (1971) as contributing to differentiation *within* the Boreal Realm) would presumably result in minor lateral changes at specific level. Following the Middle Jurassic regression, the Boreal Region formed an inland sea, possibly with reduced salinity (Hallam 1971). Faunal differentiation would continue in this isolated region, so that when renewed transgression occurred the boreal faunas had evolved sufficiently to remain sharply distinct from those of Tethys. A slight temperature gradient could then suffice to retain the boreal/Tethyan distribution pattern.

In the relatively open waters of the southern hemisphere differentiation would have remained at a lower taxonomic level and therefore less easily distinguished in the fossil record. Apparently endemic species, and even genera, of neocomitids occur in the South American Neocomian and could represent an Austral Realm analagous to that claimed, for example, for the foraminifera (Scheibnerova, this volume).

4b. Biostratigraphical correlation

The Berriasian-Barremian stages and their zones were defined in southeast France and Switzerland and based on Tethyan faunas. The entirely different faunas of the Boreal Realm can be correlated only in areas of faunal overlap, especially in the Northern Caucasus and Crimea. It is now apparent that several other regions could provide valuable information, including the "boreal" area of northwest Europe where horizons with Tethyan immigrants form valuable interregional markers (Kemper 1971).

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Ammonite faunal provinces in the Middle and Upper Albian and their palaeogeographical significance

H. G. Owen

Faunal links between the Arctic and European epicontinental seas at various times during the Albian permit some correlation to be made between the totally different ammonite zonal sequences in the European and Arctic areas. It seems that the Albian Arctic epicontinental sea was isolated from both the European and Pacific areas during much of the Middle and Upper Albian. Apparently ephemeral sea-connections with the European area were made through a fault-bounded strait including in its confines East Greenland and Spitsbergen. A similar link appears to have existed between the Arctic and North Pacific areas. The palaeogeography of the boreal region is discussed in the light of recent work on continental displacement.

In den europäischen und arktischen Gebieten liegen im Alb vollkommen verschiedene Ammoniten-Abfolgen vor. Trotzdem gab es in verschiedenen Zeiten einige gemeinsame Komponenten, die eine ungefähre Koordination ermöglichen. Es hat den Anschien, als wäre das arktische Epikontinental-Meer während der meisten Abschnitte des Mittel- und Ober-Alb sowohl vom europäischen als auch vom pazifischen isoliert gewesen. Offenbar waren kurzfristige Seeverbindungen zum europäischen Raum vorhanden. Sie folgten einer von Verwerfungssystemen begrenzten Straße, die über Ostgrönland und Spitzbergen verlief. Eine ähnliche Verbindung scheint zwischen der Arctic und dem nordpazifischen Raum bestanden zu haben. Die Paläogeographie des borealen Gebietes wird unter Heranziehung der Ergebnisse der jüngsten Arbeiten über die Kontinental-Verschiebung diskutiert.

Des jalons fauniques reconnus à divers niveaux d'âge albien entre les mers épicontinentales arctique et européenne permettent l'établissement de corrélations entre les zonations, basées sur les Ammonites et totalement différentes, des domaines européen et arctique. Il semble que la mer épicontinentale arctique ait été isolée à la fois de la province boréale et de la province pacifique durant la plus grande partie de l'Albien moyen et supérieur. Apparemment, des connections marines éphémères se sont établies avec la province européenne par l'intermédiaire d'un chenal d'effondrement incluant dans ses confins le Groenland oriental et le Spitzberg. Un maillon semblable paraît avoir existé entre les domaines arctique et Nord-Pacifique. Enfin, la paléogéographie de la province boréale est discutée à la lumière des travaux récents sur la dérive continentale.

1. Introduction

During the Albian, faunal links are known to have occurred between the Arctic and European epicontinental seas in the Lower Albian *Leymeriella tardefurcata* Zone and *Otohoplites raulinianus* Subzone of the *Douvilleiceras mammillatum* Zone, in the Middle Albian *Hoplites dentatus* Zone, and in the early Upper Albian *Dipoloceras cristatum* Subzone of the *Mortoniceras* (*M.*) *inflatum* Zone.

In the Gault Clay of Folkestone, England, R. Casey discovered, in the nodules of Bed VIII (*Dipoloceras cristatum* Subzone), an unusual ammonite recognized by Spath as a new species of the Canadian Albian ammonite genus *Gastroplites* (Casey 1936; Spath 1937). This, the holotype of *Gastroplites cantianus* Spath, is the only specimen known from outside the Arctic-North American Boreal Province. Work by the Swiss geologists Stauber and Maync during Lauge Koch's 1936–38 expedition to East Greenland allowed Spath (1943, 1946) to record the occurrence of Lower Albian *Leymeriella,* Middle Albian *Hoplites*, *Euhoplites* and *Dimorphoplites*, and Upper Albian ? *Hysteroceras* of European Province affinity associated with ammonites of Arctic affinity, such as the Lower Albian *Arcthoplites* and basal Upper Albian *Gastroplites.* Unfortunately, the material collected by Stauber, which includes the bulk of the material cited by Spath, cannot be traced at present. The description of the Albian sediments by Maync (1949) between Kuhn Island and Cape Franklin, Donovan (1953) on Traill Island, and Donovan (1957) on East Greenland as a whole, gives a good general picture of the succession and provides additional information on the ammonite sequence. However, many questions on the degree of representation of European ammonite zones and subzones, and the nature of the interfingering or mixing of the Arctic and European elements of the fauna still remain unanswered.

Nagy's (1970) work on the Albian of southern Spitsbergen provides an excellent picture of the Albian sequence there, and the relationship between the Arctic and European provincial faunas becomes more clear. His paper shows the presence in Spitsbergen of sediments representing (in terms of the European zonation discussed below, p. 147) the upper part of the *Leymeriella tardefurcata* Zone; the *Otohoplites raulinianus* Subzone of the *Douvilleiceras mammillatum* Zone (Lower Albian); the *Hoplites* (*Isohoplites*) *eodentatus* Subzone and either the *Lyelliceras lyelli* or the *Hoplites spathi* Subzone of the *Hoplites dentatus* Zone, together with the late *Euhoplites loricatus* Zone sediments (Middle Albian); and probably the *Dipoloceras cristatum* Subzone (basal *Mortoniceras inflatum* Zone, Upper Albian) with the association of *Euhoplites* and *Gastroplites.*

In Canada, Jeletzky (e.g. 1964, 1968, 1971) in particular has provided an ammonite zonal and subzonal classification for the Albian sediments of the Canadian, north Alaskan and United States mid-west regions. The zonal scheme reflects the importance of the ammonite subfamily Gastroplitinae in the Albian of Jeletzky's (1971) North American Boreal Province. Following the *Beudanticeras affine* Zone of Lower Albian age, there is an interval labelled "Zone F" by Jeletzky (1968 pp. 17–18, fig. 1) which may prove to be of Middle Albian age when ammonites are found in it. This in turn is followed by an Upper Albian sequence initially characterized by species of *Gastroplites* and later by *Neogastroplites.* In general the ammonite fauna is an impoverished one and was undoubtedly isolated from the faunas characteristic of adjoining areas through most of the Albian.

The work of Russian geologists on their Arctic Albian sediments leaves many questions unanswered concerning both the zonal representation and the detailed stratigraphy. It is clear, however, from the work of Pergament (1969 p. 114) that in the Kamchatka Peninsula and Anadyr regions, the *Gastroplites*-bearing sediments assigned to a *Gastroplites* spp. Zone are present, permitting a correlation with the *D. cristatum* Subzone (*M. inflatum* Zone) at the beginning of the Upper Albian. The *Neogastroplites* spp. Zone is also present. It is apparent that in Kamchatka at least there was either mixing or interfingering of ammonites more typical of the Pacific Faunal Province. Nonetheless, it is clear that the Russian Arctic Albian up to and including the *Neogastroplites* spp. Zone sediments belongs to the Arctic-North American Boreal Province. At the top of the Albian sequence in the Anadyr region, however, *Stoliczkaia* has been recorded, a genus of almost world-wide occurrence in late Albian sediments.

Further information on the nature of the distribution of the Arctic-North American Boreal and North Pacific provincial faunas is provided by McLearn (1972) on the ammonite faunas of the Queen Charlotte Islands in the coastal area of British Columbia. The Upper Albian fauna in particular is distinct from that of north Alaska, although closely comparable to that of western Alaska, the Pacific coastal area of North America to the south, and to Japan. This forms part of the North Pacific Province of Jeletzky (1965, 1971).

More recent work in the Boreal Realm has, therefore, indicated the presence of three distinct ammonite faunal provinces, particularly in the Upper Albian but probably in the Middle Albian as well. The object of this paper is to review briefly the evidence for links between the Arctic-North American Boreal Province and the European and North Pacific Provinces and to suggest reasons for their occurrence together with the long intervening periods of apparent isolation of the Arctic area. It is hoped that this paper will further stimulate discussion on an important aspect of faunal distribution and to point out an important new palaeogeographical factor concerned with continental displacement.

2. Middle and Upper Albian ammonite zonal schemes and faunal provinces in the Boreal Realm

2a. European or Hoplitinid Province

The ammonite zonal and subzonal scheme for the Albian proposed by Spath (1941 p. 668) has been modified and given greater precision by Casey (e.g. 1961) and the writer (Owen 1971a, 1971b). Its provincial character is now clear, and Figure 1 shows not only the scheme but what links there are with the Albian Arctic area. The zonal scheme reflects accurately the succession and dominance of the hoplitinid ammonites and led the writer to term the European Province in the Middle Albian, the Hoplitinid Province (Owen 1971a pp. 130–133). This province includes all the shelf-sea areas of Europe and Transcaspia. At the same time the scheme also shows the major incursions of lyelliceratid, brancoceratinid, mojsisovicsiinid and mortoniceratinid elements more typical of the so-called Tethyan Realm, or perhaps more accurately the Albian Tethyan-Gondwana ammonite Province, situated to the south.

These southern-derived incursions are apparent through much of the Middle Albian, but are particularly marked in the *Lyelliceras lyelli* Subzone of the *Hoplites dentatus* Zone and the *Mojsisovicsia subdelaruei* Subzone of the *Euhoplites loricatus* Zone (Owen 1971a p. 129). Up to the *A. intermedius* Subzone in the Middle Albian, the Tethyan element tends to increase in numbers and diversity as one proceeds south

	European or Hoplitinid Faunal Province		Boreal region links with		Arctic or Gastroplitinid Faunal Province	
	Zones	Subzones	Europe	N.Pacific	Zones	Subzones
UPPER ALBIAN	*S. dispar*	*S. dispar M.(D) perinflatum*		AK		
		A. substuderi				
	M.(M.) inflatum	*C. auritus*		K	*Neogastroplites*	*N. mclearni* *N. americanus* unknown *N. cornutus* *N. selwyni*
		H. varicosum				
		H. orbignyi			unknown	
		D. cristatum	F EG S	K	*Gastroplites*	*G? liardense* *G. canadensis* *P. pattoni*
MIDDLE ALBIAN	*E. lautus*	*A. daviesi*	EG		Zone F	
		E. nitidus				
	E. loricatus	*E. meandrinus*				
		M. subdelaruei				
		D. niobe				
		A. intermedius	?S			
	H.(H) dentatus	*H.(H) spathi*	?EG ?S			
		L. lyelli	?S			
		H.(I.) eodentatus	S			

Fig. 1. Ammonite zonal schemes in the European or Hoplitinid Province and the Arctic-North American Boreal or Gastroplitinid Province, and the links between them. F = Folkestone (Kent), EG = East Greenland, S = Spitsbergen, K = Kamchatka Peninsula, AK = Anadyr-Koryak Region.

from England to the southern part of the Paris Basin. This reflects the proximity of the Morvano-Vosges Strait linking the Paris Basin with Tethys throughout the Albian stage. Whether this increase in the southern element continued for the remainder of the Middle Albian is not clear as higher sediments over much of the Paris Basin were removed by early Upper Albian erosion.

In the Upper Albian, the hoplitinid ammonites were still endemic to the European epicontinental seas. However, the southern element in the ammonite fauna increased rapidly in the early part of the *Mortoniceras inflatum* Zone, and permanently colonized the European area to co-exist with the hoplitinid element. But the European Province is still definable in the Upper Albian as the Hoplitinid Province with the presence of such genera as *Euhoplites* and *Discohoplites* on the one hand, and *Anahoplites*, *Epihoplites*, *Semenovites*, *Callihoplites*, *Pleurohoplites* and *Arrhaphoceras* on the other. They are accompanied by genera such as *Dipoloceras*, *Mortoniceras*, *Hysteroceras* and *Stoliczkaia* which are of very widespread geographical occurrence in Tethyan, southern and Pacific areas.

During the Middle Albian the Hoplitinid Province extended at least into East Greenland and southern Spitsbergen. How much further north it extended into the Arctic-North American Boreal Province is unknown, but the sudden appearance of *Gastroplites* in the basal Upper Albian sediments suggests an earlier Middle Albian developmental stage of this Arctic stock which is not recorded even in Spitsbergen or East Greenland. This suggests that the Arctic-North American Boreal Province was isolated from the European Province during the Middle Albian.

A direct marine communication between the European Province and the Arctic-North American Boreal Province is indicated in the *Diploceras cristatum* Subzone by the previously discussed record of *Gastroplites cantianus* in Bed VIII at

Folkestone, by an apparent intermixing of ammonites of the two provinces in East Greenland, and by the association of a *D. cristatum* Subzone *Euhoplites* with *Gastroplites* in southern Spitsbergen. At present, no other Middle or Upper Albian marine communication is known between these two provinces.

2b. Arctic-North American Boreal Province

This province includes the epicontinental seas of Arctic and mid-western Canada and directly adjoining areas of the United States, northern Alaska, the Anadyr region and Kamchatka Peninsula, and Arctic Russia. By this definition the province is a combination of the Arctic Province of Russian geologists and the North American Boreal Province of Jeletzky (1971). It can be termed the Gastroplitinid Province.

Jeletzky's (1968 fig. 1) correlation of part of the *Beudanticeras affine* Zone with the basal part of the Middle Albian *Hoplites dentatus* Zone in the sense of Casey (1961 p. 498) and Owen (1971a p. 119) is not proved: it appears to be entirely of Lower Albian age in the strict sense. The writer has pointed out (Owen 1971a pp. 137–138) that if any Middle Albian sediments are present in Canada they are likely to occur in Jeletzky's "Zone F" which includes the thick shales in the Fort St. John Group in northern Alberta and northeastern British Columbia.

The zonal scheme for part of the Upper Albian sequence in the Arctic-North American Boreal Province has been discussed by Jeletzky (1968, 1971) and Pergament (1969). It is immediately apparent that the zonal and subzonal sequence, based essentially on species of *Gastroplites* and *Neogastroplites*, is totally different from that of the European Province. The occurrence of *G. cantianus* in the *Gastroplites* Zone, together with the single example of *Dipoloceras* cf. *fredericksburgense* Scott in the *Gastroplites* ? *liardense* Subzone may indicate that the whole of the *Gastroplites* Zone is the equivalent of the *Dipoloceras cristatum* Subzone. There is at present no evidence upon which to base an exact correlation of the *Neogastroplites* Zone with the European sequence. However, its position must be contemporaneous with part of the *Mortoniceras inflatum* Zone because at Anadyr, north of Kamchatka, *Stoliczkaia* occurs above sediments containing *Neogastroplites* (Pergament 1969).

Jeletzky (1971 p. 14) has demonstrated clearly that the ammonite fauna of the Arctic-North American Boreal Province during the Upper Albian formed an impoverished and essentially isolated community with very little connection with adjoining provinces. Pergament's (1969) work suggests that within the *Neogastroplites* Zone there existed some marine connection with the North Pacific Province, and it is possible that in the near future a correlation with the European Province by a roundabout route through "Tethys" may be made.

2c. North Pacific Province

This Province covers the region of the Albian North Pacific Ocean and its fringing shelf and geosynclinal seas. The imperfect zonal scheme for this province has been discussed most recently by Jeletzky (1971 p. 8) and, posthumously, by McLearn (1972 pp. 16–19) in terms of its application to the west coast region of Canada and southern Alaska. However imperfect the zonal scheme for this province might be, it is immediately apparent that the very diverse Albian ammonite fauna consists of elements of distinct Tethyan aspect, including genera belonging to families such as the Phylloceratidae, Lytoceratidae, Tetragonitidae, Desmoceratidae, and Kossmaticeratidae. In the Upper Albian in particular there are ammonites, such as the mortoniceratids, which are of almost world-wide distribution, though absent from the Arctic-North American Boreal Province.

3. Middle and Upper Albian palaeogeography in the Boreal Region

The concept of continental displacement or "drift" by the process of ocean-floor spreading and plate tectonics is now firmly established. Before discussing briefly its effect on Boreal palaeogeography it is necessary to make the following definitions of terms used in this contribution. The terms ocean and oceanic are here applied to any sea area produced by the process of ocean-floor spreading, but extended to include the surrounding continental margins. An epicontinental or shelf-sea covers an area of continental plate only. Unfortunately, the terms "sea-floor" spreading and continental drift are deeply entrenched in the literature. Nonetheless, ocean-floor spreading is more correct and the term would help prevent confusion. Continental drift would be better termed continental displacement as movement of large continental and oceanic blocks along transform faults is as important in its effect as ocean-floor spreading.

Our knowledge of the development of the North Altantic is based essentially on the detailed mapping of the sequence of magnetic reversal anomaly lineations (or dykes) in the ocean-floor, supplemented by borings carried out during the Deep Sea Drilling Project (JOIDES). Vogt, Anderson and Bracey (1971) and Vogt and Johnson (1971) have shown that the southern part of the North Atlantic had commenced to develop by ocean-floor spreading about 180 million years ago. Oxfordian deposits are found in a truly oceanic environment from off the Gulf Coast of the United States northwards to the area south of Newfoundland, and off the corresponding West African coast.

The initial faulting of what was later to become the northern North Atlantic from the position of the Azores northwards, appears to have occurred around the Jurassic-Cretaceous boundary. Major graben faulting (produced by lateral tension) is to be seen in the south and western areas of the British Isles (e.g. Wood and Woodland 1971; Blundell, Davey and Graves 1971; Owen 1971b, Owen in discussion of Blundell *et al.* 1971), in East Greenland where Vischer (1943) and Haller (1969) have demonstrated the lateral extensional history of the coastal belt in the late Jurassic and Lower Cretaceous, and in the Norwegian Basin and west Barents Sea (Johnson *et al.* and Emelyanov *et al. in* Delany 1971). The opening of the Bay of Biscay and the development of the Aquitaine Basin was well under way in the early Cretaceous as the Atlantic Ocean spread northwards. Laughton (1971) has shown that further north, ocean-floor spreading commenced first in the Labrador Sea in late Upper Cretaceous times and this can be correlated with the advance into West Greenland of an Upper Cretaceous marine fauna (e.g. Birkelund 1965). Spreading did not commence in the Denmark Strait, Norwegian and Greenland seas until the Eocene, at a point in time when ocean-floor spreading ceased in the Labrador Sea.

In the Arctic region there is strong evidence that spreading commenced in the Amerasian Basin in the late Cretaceous and finished within the Tertiary and can be directly related to the opening of the Labrador Sea-Davis Strait and Baffin Bay area. The Eurasian Basin without question is a product of Tertiary to Recent ocean-floor spreading. The foregoing brief review of the developmental history of

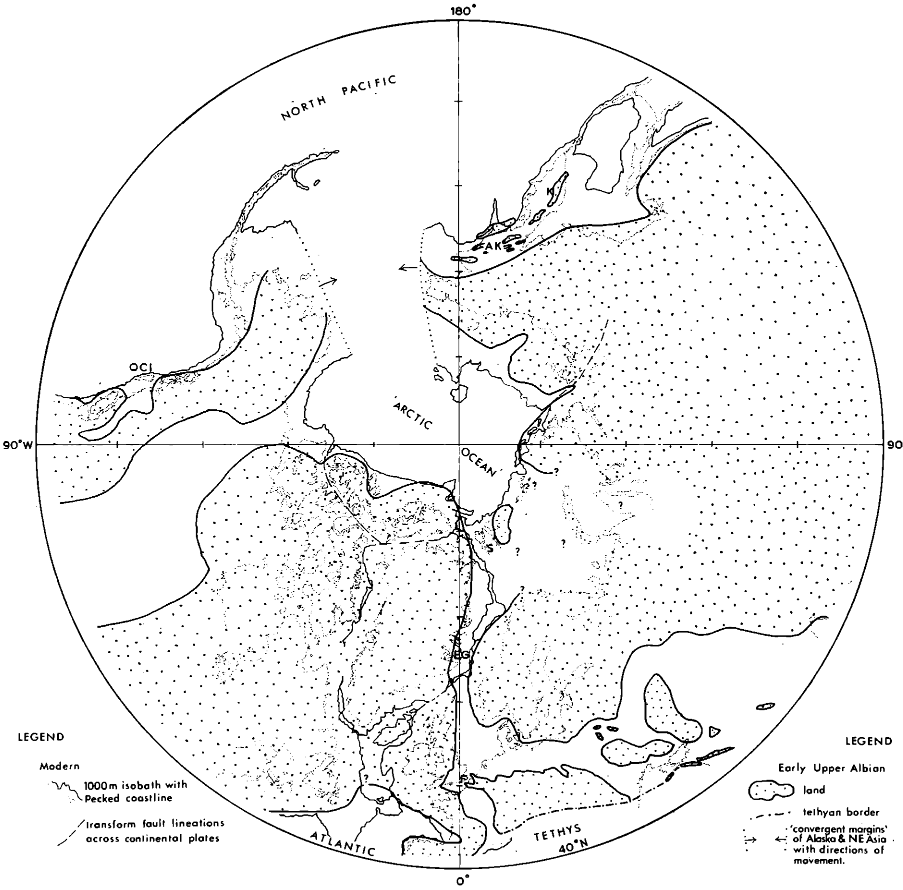

Fig. 2. Conventional reconstruction of the Boreal Region and adjacent areas produced by rotating the North American and Greenland continental plates to their approximate Albian position. The 0° Meridian runs, therefore, through Greenwich. Projection is standard Zenithal Equidistant of a portion of a globe representing the modern mean diameter of the Earth. The distribution of basal Upper Albian epicontinental seas and oceanic areas is based on Verestchagin *et al.* (1968) for Russia, Jeletzky (1971) for North America and the author for Europe. Locality symbols are as in Figure 1: QCI = Queen Charlotte Islands.

the North Atlantic and Arctic Ocean sets the scene for the two reconstructions of the Boreal Region in the Albian presented here (Figs 2, 3).

Figure 2 shows the conventional reconstruction of the Arctic in the Albian before the late Mesozoic to Recent period of ocean-floor spreading. Superimposed upon this map is the distribution of epicontinental seas. The reconstruction of the arc from Alaska, through Canada, Greenland, northern Europe and Russia is based on the lateral opening of the North Atlantic and complies with the accounts by Harland (e.g. 1969). It is plotted on a map projection representing a portion of a globe of modern mean diameter and surface curvature. However, the reconstruction is biased towards providing the best fit for the Arctic region and would, if extended

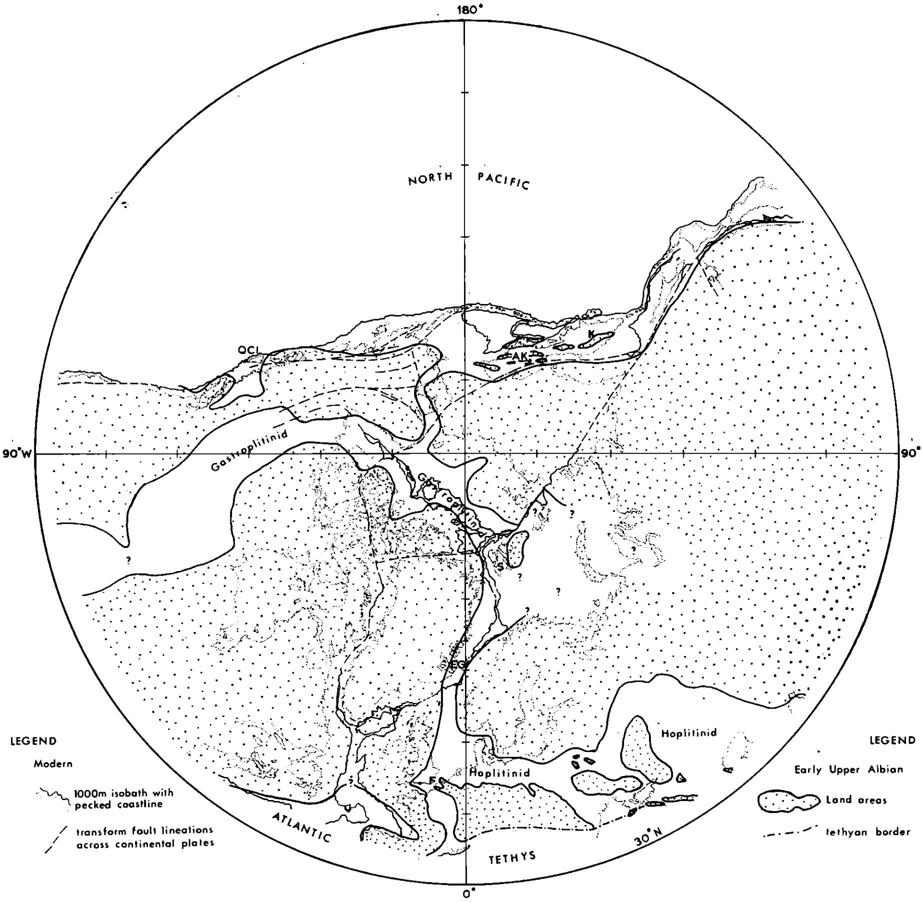

Fig. 3. Reconstruction of the Boreal Region and adjacent areas produced by rotating North America, Greenland, Europe and Asia in accordance with the ocean-floor spreading data from the Atlantic and Pacific Oceans, together with the partial elimination of movements along major transcurrent faults. Projection is standard Zenithal Equidistant of a portion of a globe with a diameter approximately 88% of that of the modern mean diameter. Sources of palaeogeographical information are as in Figure 2. The positions of principal pre-Albian and post-Albian to present-day transcurrent fault lineations are taken essentially from King *et al.* (1969) and Atlasov *et al.* (1969). Locality symbols are as in Figure 1: QCI = Queen Charlotte Islands.

southwards, produce unacceptable, very wide, wedge-shaped "oceanic areas" for the Caribbean and western Tethys. It is immediately apparent that the Albian "Arctic Ocean" in this map has a greater surface area than its modern counterpart, and one which would in fact have been contracting since Oxfordian times; moreover, it has a wide oceanic connection with the North Pacific. This directly contradicts what is known of the developmental history of the late Mesozoic to Recent Arctic Ocean which is one of increase of area, and not decrease and subduction of older ocean-floor as would have to be the case. Similarly, if such a wide connection existed between a large Arctic Ocean and the North Pacific, why is the Albian fauna of the Arctic-North American Boreal Province so restricted and *isolated*?

Figure 3 represents a reconstruction of the Arctic region which complies not only with the ocean-floor spreading history of the Arctic Ocean, but also with the Lower Cretaceous magnetic anomaly lineation pattern for the North Pacific (e.g. Hayes and Pitman 1970). Moreover, it complies with the Mesozoic to Recent tectonic history of the entire region. It explains also why the Albian Arctic-North American Boreal Province, an almost land-locked epicontinental sea, had such an impoverished fauna, for there were only two narrow sea connections; one with the North Pacific Ocean, the other with the European epicontinental sea. A third tenuous connection with the Gulf coast region of the United States by way of the mid-western states has been suggested by Jeletzky (1971 pp. 44–46). The distribution of seas shown in Figure 3 represents the basal Upper Albian *D. cristatum/Gastroplites* Zone.

The writer has drawn attention to the widespread tectonic activity in the *Dipoloceras cristatum* Subzone (1971a pp. 128, 148), and has demonstrated the renewal of movement along an older late Jurassic or early Cretaceous fault in the Thames Estuary region of southeast England (Owen 1971b). It is possible that this short period of tectonic activity opened a sea-connection between the European and Arctic seas along the narrow strait extending from the North Sea towards Spitsbergen.

The reconstruction given in Figure 3 is based on one of a series of world maps produced by the writer to illustrate the Mesozoic to Recent break-up of Pangaea by development of ocean basins. These reconstructions agree with the ocean-floor spreading patterns known up to this time, together with the geometric fit, tectonic and stratigraphical evidence. They are based entirely on the concept of an expanding Earth at least from the early Mesozoic to the present day. The Arctic Region forms but one of a number of critical areas whose developmental history supports this concept of expansion.

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Ostracod migrations from the Mesogean to Boreal Provinces in the European Lower Cretaceous

Pierre Donze

The ostracod genera *Euryitycythere*, *Kentrodictyocythere*, *Parexophthalmocythere* and *Cythereis* are discussed as examples of genera which migrated from the Mesogean Province to the Boreal Province. All four genera first appeared in southeast France (Mesogean Province) during the Lower Berriasian (*Berriasella grandis* Zone) but are not known at this stratigraphical level anywhere other than in the Mediterranean region. Southern forms appeared in Poland and north Germany during the Valanginian and in eastern England during the Hauterivian. The significance of these faunal migrations is discussed in relation to palaeogeography and climate.

Die Ostrakoden-Gattungen *Euryitycythere*, *Kentrodictyocythere*, *Parexophthalmocythere* und *Cythereis* werden hier als Beispiele von Gattungen diskutiert, die von der mesogäischen Provinz in die boreale Provinz einwanderten. Alle vier Gattungen erschienen zuerst im Unter-Berrias (Zone der *Berriasella grandis*) von Südost-Frankreich (mesogäische Provinz). Von keiner anderen Stelle außerhalb des Mediterrangebietes sind diese Gattungen aus diesem stratigraphischen Niveau bekanntgeworden. Diese südlichen Formen erscheinen in Polen und Norddeutschland während des Valangin und in Ostengland erst im Hauterive. Die Bedeutung dieser Migrationen und ihre Abhängigkeit von Paläogeographie und Klima werden diskutiert.

Les genres d'Ostracodes *Euryitycythere*, *Kentrodictyocythere*, *Parexophthalmocythere* et *Cythereis* ont été choisis comme exemples de genres ayant migré de la Province mésogéenne vers la Province boréale. Ils apparaîssent dans le Sud-Est de la France (Province mésogéenne) durant le Berriasien inférieur (Zone à *Berriasella grandis*), mais ne sont pas connus à ce niveau stratigraphique ailleurs que dans la région méditerranéenne. Ils atteignent ensuite la Pologne et l'Allemagne du Nord au Valanginien, puis l'Est de l'Angleterre à l'Hauterivien. La signification de ces migrations est discutée en fonction de la paléogéographie et du climat.

1. Introduction

The increase in knowledge of ostracod microfaunas in recent years has clearly demonstrated the importance of faunal migrations from the Mesogean to Boreal Provinces in the European Lower Cretaceous. Although it is outside the scope of the present work to deal with the fauna as a whole, four examples are used here to elucidate this phenomenon. These are the genera *Euryitycythere* Oertli 1959, *Kentrodictyocythere* Donze 1968, *Parexophthalmocythere* Oertli 1959 and *Cythereis* Jones 1849.

The Mesogean origin of all these genera cannot be doubted. They appeared in southeast France, in the Mesogean Province, in the Lower Berriasian (*Berriasella grandis* Zone) (Donze 1964, 1965), but they are not known elsewhere at this stratigraphical level. To demonstrate the faunal differentiation that existed in the Berriasian between north and south Europe, one must compare the fauna of southeast France with that described by Neale (1962) from the Speeton Clay of Yorkshire. Their obvious dissimilarity indicates that both areas were quite distinct at this time. However, a little later things began to change. In the Valanginian of Poland and of northwest and east Germany, southern forms appear, notably *Euryitycythere, Kentrodictyocythere* and *Parexophthalmocythere.* In the Hauterivian these are joined by *Cythereis.* It is during this stage that these genera reached the Boreal Province proper (Lincolnshire and Yorkshire).

2. Genera

2a. *Euryitycythere* Oertli

Apatocythere? subtilis, originally described from the Valanginian of northwest Germany by Bartenstein and Brand (*in* Bartenstein 1959), was subsequently made type species of a new genus, *Euryitycythere* (Oertli 1959). It is now known that far

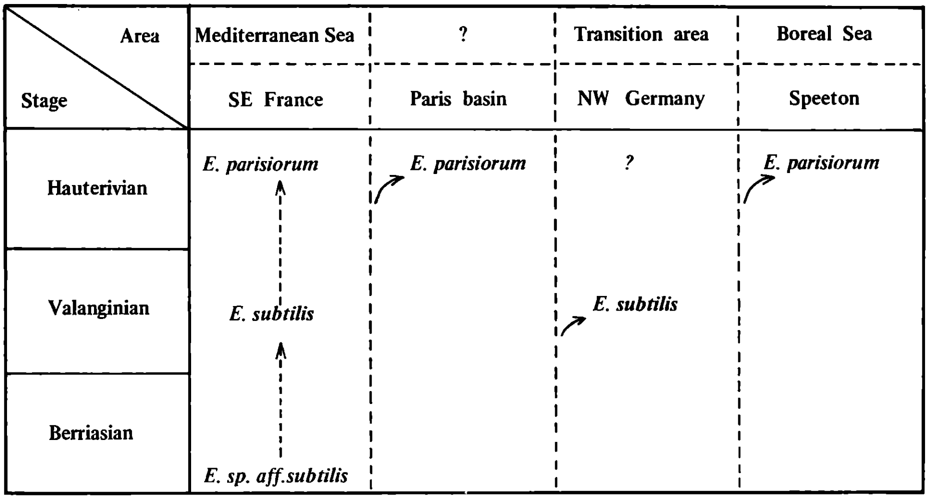

Fig. 1. Development and migration of *Euryitycythere*

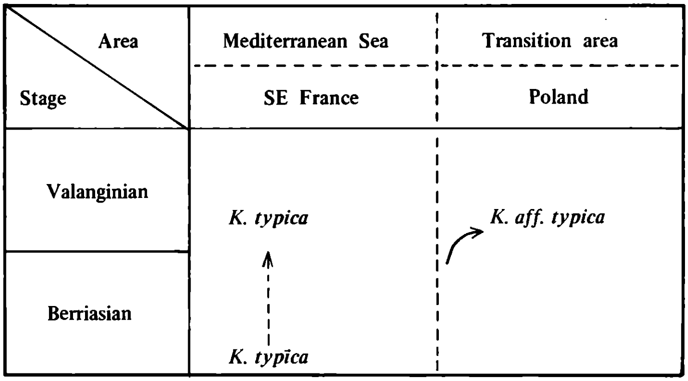

Fig. 2. Development and migration of *Kentrodictyocythere*

from being restricted to the north European area, the genus was well represented throughout southeast France and that it appeared there earlier. In the Lower Berriasian (*Berriasella grandis* Zone) of southeast France examples of this genus occur that are very close to *E. subtilis,* which they precede. The Valanginian contains typical specimens of *E. subtilis*, and the Upper Hauterivian the species *E. parisiorum* Oertli; the latter was originally described by Oertli (1959) from the Hauterivian of the Paris Basin. Moreover, the discovery by Neale (1962) of *E. parisiorum* in the Hauterivian of the Speeton Clay indicates that at this time the genus had already spread into the Boreal Province, as shown Figure 1.

2b. *Kentrodictyocythere* Donze

This genus was proposed (Donze 1968) for a new species (*K. typica* Donze) from the Berriasian of Marignac-en-Diois(Drôme). At present only two species are known from the Berriasian-Lower Valanginian, but in southeast France the genus persists till the Lower Barremian and several species still await description.

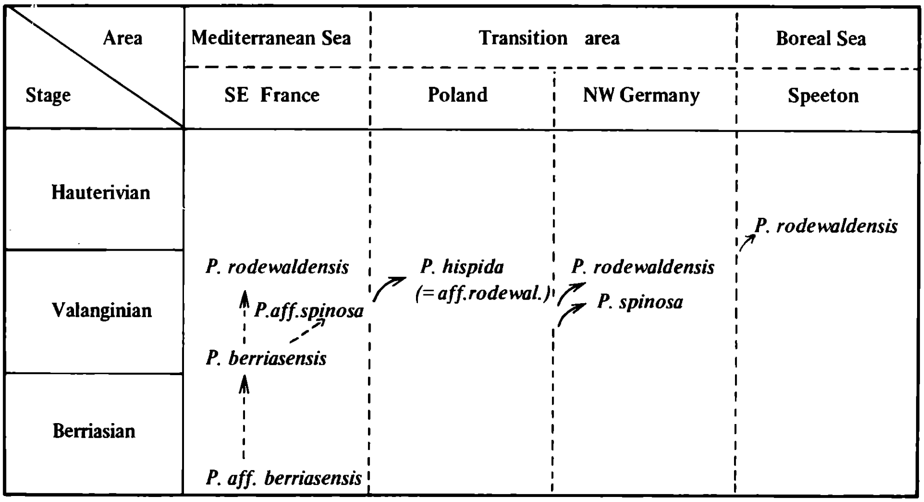

Fig. 3. Development and migration of *Parexophtalmocythere*

To the author's knowledge, this genus has never been recorded in the Boreal Province till now. Nevertheless, it appears to be present there. A specimen from the Valanginian of Nawal in Poland, figured by Malecski (1960 p. 114 pl. 8 figs 2a, b) as *Loxoconcha* sp., is clearly *Kentrodictyocythere* and is close to *K. typica*. There is every reason to expect other records of this genus in the Boreal Province in the future.

2c. *Parexophthalmocythere* Oertli

The genus *Parexophthalmocythere* Oertli (1959), which was proposed for Lower Valanginian to Lower Hauterivian species in northwest Germany, is known in southeast France from horizons as early as the Lower Berriasian by the species *P. berriasensis* Donze, which continues into the basal Valanginian. In addition, the Valanginian of southeast France contains forms close to *P. spinosa* (Bartenstein and Brand) along with *P. rodewaldensis* (Bartenstein and Brand). In Poland the genus begins with the species *P. hispida* Malecski from the Valanginian of Wawal, and this species is very close to *P. rodewaldensis*. According to Neale (1962), the genus occurs in the Speeton Clay only in the Hauterivian, where it is represented by *P. rodewaldensis*.

2d. *Cythereis* Jones

Unlike the preceding genera, which became extinct in the Lower Cretaceous, *Cythereis* persists to the top of the Cretaceous. In north Europe, the first representatives of this genus are apparently from the basal Hauterivian. The species *C. senckenbergi* Triebel from the Lower Hauterivian of northwest Germany (Triebel 1940; Kemper 1968) is also known from east Germany (Dreyer 1968) and from Speeton (Neale 1962) at approximately the same stratigraphical level.

In southeast France this species also occurs in the Hauterivian, but it is preceded there by other species of the same genus; *C. matura* Oertli (1966) is found in the Upper Valanginian and *C. prisca* Donze (1968) in the basal Valanginian. Recent

Area / Stage	Mediterranean Sea	Transition area		Boreal sea
	SE France	NW Germany	E Germany	Speeton
Hauterivian	*C. senckenbergi* ↑	↗ *C. senckenbergi*	↗ *C. senckenbergi*	↗ *C. senckenbergi*
Valanginian	*C. matura* ↑ *C. prisca*			
Berriasian	↑ *C. prisca*			

Fig. 4. Development and migration of *Cythereis*

research indicates that the latter had appeared already in the Lower Berriasian. It is, therefore, at present the oldest known representative of the genus *Cythereis*.

Thus, after a slow period of development in the Mesogean Province this genus rapidly spread northward (Fig. 4); consequently its importance throughout Europe tends to increase until its acme in the middle of the Cretaceous.

3. Conclusions

In the light of the evidence outlined above, it seems that some of the ostracod genera living in the north European boreal region during the Lower Cretaceous were of mesogean origin. In this respect, the Lower Cretaceous contrasts with the Upper Jurassic when the two provinces were obviously distinct. This contrast tends to become blurred from the beginning of the Cretaceous onward by a gradual homogenisation of the fauna.

From the palaeogeographical point of view, the occurrence of forms such as *Parexophthalmocythere, Euryitycythere* and *Kentrodictyocythere* in the Valanginian of northwest and east Germany, or Poland, implies that marine connections between the two provinces were already established at this time. The appearance of these faunas earlier in Poland than in northwest Germany suggests that there was a marine connection through the Carpathians, as advocated by Lewinski (1932).

However, despite the possibility of marine communications, faunas would probably have remain distinct if palaeoecological conditions had remained really dissimilar. Indeed, it is known how much ostracods are dependent upon environmental conditions. Changes probably occurred at the beginning of the Cretaceous that modified previous conditions considerably. Certain sedimentological evidence indicates the possibility of changes in climate in southeast France at the close of the Jurassic (Donze and le Hegarat 1972). The southerly retreat of reef conditions by several hundred kilometres during the Berriasian could indicate a decrease in temperature in this part of Europe. On the other hand, the presence at Speeton of *Protocythere* in the Valanginian and of *Cytherelloidea* in the Hauterivian suggests, as noted by Neale (1967), an increase in temperature in the Lower Cretaceous of northern Europe. Such temperature changes could have resulted, from the Berriasian onward, in a certain uniformity of palaeoclimatic conditions throughout Europe with a corresponding trend towards the homogenisation of faunas.

Acknowledgment: I thank Mr. G. Pinckney (Queen Mary College, London) for translating the French text.

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The distribution of Lower Cretaceous (Berriasian-Barremian) foraminifera in the Speeton Clay of Yorkshire, England

B. N. Fletcher

The Lower Cretaceous Speeton Clay of Yorkshire, England, is divided into numerous lithostratigraphical units which provide an invaluable reference for micropalaeontological sampling and for plotting the distribution of foraminifera. Five distinct faunas (Berriasian—early Hauterivian) occur in the D Beds; these reflect strong vertical variation in ecological conditions. The rich fauna of the C Beds (Hauterivian) contains many long-ranging forms, but the established ammonite zones can be distinguished on the basis of their foraminiferal content. There is a steady decline in the fauna through the Lower B Beds (late Hauterivian—Lower Barremian). Comparisons are made between the Speeton and northwest German foraminiferal faunas.

Der Speeton Clay, der die Unterkreide in Yorkshire (England) vertritt, ist in zahlreiche lithostratigraphische Einheiten unterteilt worden. Diese bilden die unentbehrliche Basis für die mikropaläontologische Probenentnahme und für das Auftragen der Reichweiten der Mikrofossilien auf den Verbreitungstabellen. Fünf unterschiedliche Faunen treten in den D-Beds auf (Berrias bis tiefes Hauterive). Sie sind das Ergebnis eines starken Wechsels der ökologischen Verhältnisse in der Vertikalen. Die reiche Fauna der C-Beds (Hauterive) enthält viele langlebige Formen. Trotzdem ist es möglich, die Ammoniten-Zonen mit Hilfe der Foraminiferen-Führung zu bestimmen. In den unteren B-Beds (junges Hauterive bis Unter-Barrême) ist eine ständige Abnahme der Fauna zu verzeichnen. Die Foraminiferen von Speeton und Nordwestdeutschland werden verglichen.

L'argile éocrétacée de Speeton en Yorkshire (Angleterre) est subdivisée en nombreuses unités lithostratigraphiques qui constituent une série de référence inestimable pour l'échantillonnage micropaléontologique et le relevé de la distribution des foraminifères. Cinq faunes distinctes se succèdent dans les niveaux D (Berriasien-Hauterivien basal); elles témoignent d'une importante variation verticale des conditions écologiques. La riche faune des niveaux C (Hauterivien) contient maintes formes de grande longévité, mais les zones bâties avec les ammonites peuvent être distinguées sur la base de leur contenu en foraminifères. La faune décline régulièrement tout au cours des niveaux B inférieur (Hauterivien terminal—Barrémien inférieur). Enfin, des comparaisons sont établies entre les faunes de Foraminifères de Speeton et celles d'Allemagne du Nord-Ouest.

1. Introduction

The Speeton Clay crops out along the southern part of Filey Bay, Yorkshire, England, where it forms low coastal cliffs extending for a distance of 1·2 kilometres. Here all the stages of the Lower Cretaceous are represented from the Berriasian, which lies unconformably upon the Kimmeridge Clay, to the Albian Red Chalk, which passes upwards into the Cenomanian White Chalk. This locality thus provides the most continuous exposure of the boreal Lower Cretaceous in northwest Europe.

The Lower Cretaceous succession is essentially an argillaceous one and the cliff exposures are badly affected by landslipping and faulting and are frequently obscured by downwash. The Upper Barremian, Aptian and Albian are generally poorly exposed. The more reliable sections for study are those which occur intermittently on the foreshore when a combination of favourable tides and winds has swept part of the beach clear of sand and shingle.

The Speeton Clay is approximately 100 metres thick at the type locality, but at Fordon, which lies 9·5 kilometres to the west-northwest, it has increased to some 365 metres (Dilley, in discussion of Neale 1968), with the Hauterivian twice as thick as it is on the coast (Fletcher, unpublished Ph.D. thesis 1966).

The first attempts at a subdivision of these clays were by Leckenby (1859) and Judd (1868) and this was followed by the classic paper by Lamplugh (1889) who recognised four major biostratigraphical subdivisions based upon belemnite faunas. These are, from the top downwards:

A Beds	Zone of *Belemnites minimus* (*Neohibolites minimus*) and allies
B Beds	Zone of *Belemnites semicanaliculatus*? (*Oxyteuthis brunsvicensis*) and allies
C Beds	Zone of *Belemnites jaculum* (*Hibolites jaculoides*) and varieties
D Beds	Zone of *Belemnites lateralis* (*Acroteuthis lateralis*) and allies.

The above divisions were subdivided by Lamplugh on a lithostratigraphical basis. Lamplugh's B Beds were further subdivided by Kaye (1964), the C Beds by Fletcher (1969) and the D Beds by Neale (1960, 1962a) and the horizons of the micropalaeontological samples dealt with in this paper are accurately recorded according to the subdivisions of these authors.

It was Sherlock (1914) who first systematically described foraminifera from the Speeton Clay, showed their distribution in the various subdivisions of the Speeton succession and attempted to compare the distribution of species recorded at Speeton with those of the Gault at Folkestone, the Hils Clay of Germany, the Gault of Montcley, the Red Chalk of Speeton and Recent foraminifera from the "Challenger" expedition. It is interesting to read Sherlock's conclusion that the Speeton Clays "except for a few horizons are almost without Microzoa" for the present writer has an abundance of material and only in the Lower D Beds do samples barren of foraminifera occur.

Sherlock's paper remained the only paper dealing with the foraminifera of the Speeton Clay until Khan (1962) compared some of the foraminifera from Speeton with those of Germany. The imprecise location of Khan's samples makes his study of limited value.

The work by Rawson (1971a, 1971b) on the ammonite faunas at Speeton has enabled the Hauterivian foraminifera sequence to be related to a modern ammonite zonal scheme for the first time.

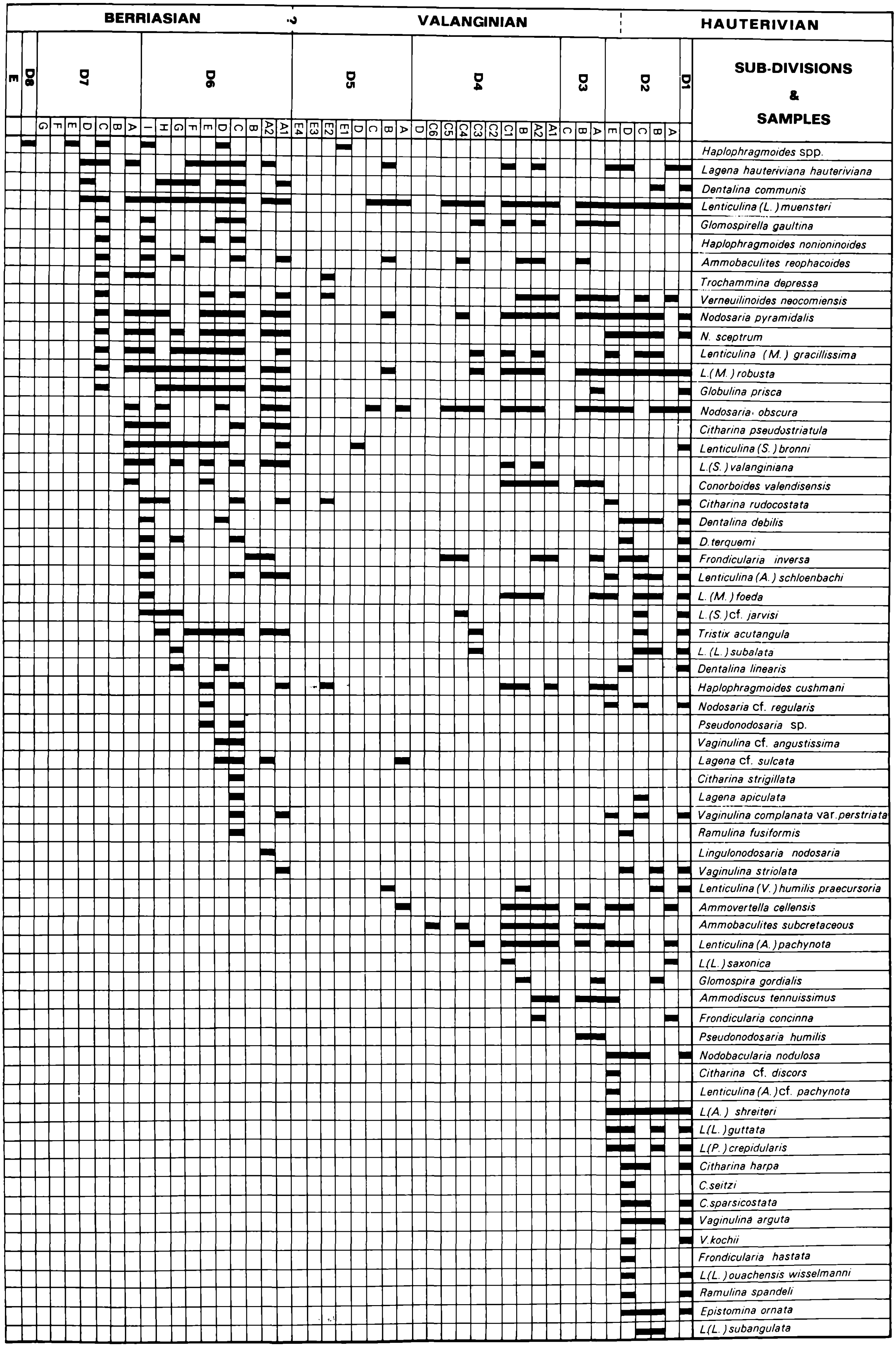

BERRIASIAN
?
VALANGINIAN
HAUTERIVIAN
SUB-DIVISIONS & SAMPLES
E
D8
D7
G F E D C B A
D6
I H G F E D C B A2 A1
D5
E4 E3 E2 E1 D C B A
D4
D C6 C5 C4 C3 C2 C1 B A2 A1
D3
C B A
D2
E D C B A
D1
Haplophragmoides spp.
Lagena hauteriviana hauteriviana
Dentalina communis
Lenticulina (L.) muensteri
Glomospirella gaultina
Haplophragmoides nonioninoides
Ammobaculites reophacoides
Trochammina depressa
Verneuilinoides neocomiensis
Nodosaria pyramidalis
N. sceptrum
Lenticulina (M.) gracillissima
L. (M.) robusta
Globulina prisca
Nodosaria obscura
Citharina pseudostriatula
Lenticulina (S.) bronni
L. (S.) valanginiana
Conorboides valendisensis
Citharina rudocostata
Dentalina debilis
D. terquemi
Frondicularia inversa
Lenticulina (A.) schloenbachi
L. (M.) foeda
L. (S.) cf. jarvisi
Tristix acutangula
L. (L.) subalata
Dentalina linearis
Haplophragmoides cushmani
Nodosaria cf. regularis
Pseudonodosaria sp.
Vaginulina cf. angustissima
Lagena cf. sulcata
Citharina strigillata
Lagena apiculata
Vaginulina complanata var. perstriata
Ramulina fusiformis
Lingulonodosaria nodosaria
Vaginulina striolata
Lenticulina (V.) humilis praecursoria
Ammovertella cellensis
Ammobaculites subcretaceous
Lenticulina (A.) pachynota
L. (L.) saxonica
Glomospira gordialis
Ammodiscus tennuissimus
Frondicularia concinna
Pseudonodosaria humilis
Nodobacularia nodulosa
Citharina cf. discors
Lenticulina (A.) cf. pachynota
L. (A.) shreiteri
L. (L.) guttata
L. (P.) crepidularis
Citharina harpa
C. seitzi
C. sparsicostata
Vaginulina arguta
V. kochii
Frondicularia hastata
L. (L.) ouachensis wisselmanni
Ramulina spandeli
Epistomina ornata
L. (L.) subangulata

Fig. 1

2. Distribution of the foraminifera

2a. The D Beds

On the basis of the foraminifera the D Beds can be subdivided into five units:

Fauna 1. Beds D2D to D1
Fauna 2. Beds D4C1 to D2E
Fauna 3. Beds D5E to D4C2
Fauna 4. Beds D7D to the top of D6
Fauna 5. Beds D8 to D7E.

Fauna 5 Beds D8–D7E. Immediately overlying the thin Coprolite Bed at the base of the Lower Cretaceous succession are the black shales of D8 which contain a sparse, restricted fauna of arenaceous foraminifera. All the forms have been assigned to the genus *Haplophragmoides*, but because of their crushed and distorted preservation they have been left under open nomenclature. They show close affinities with *Haplophragmoides neocomiensis* (Chapman), *H. concavus* (Chapman) and *H. fontinensis* (Terquem). Similar forms of *Haplophragmoides* have been recorded from the Tithonian and Berriasian of northwest Bulgaria (Jovcheva and Trifonova 1961), the Infra-Valanginian of Poland (Sztejn 1960, 1964), and the Wealden 6 to Mittel Valendis of Germany (Bartenstein and Brand 1951).

The black shaly clays of D8 with their pieces of phosphatic material and occasional grains of glauconite, may have accumulated in brackish-water conditions, perhaps in a shallow arm of the sea, which allowed the belemnites *Acroteuthis sublateralis* and *A. lateralis* to drift in. The glauconite grains may have been derived and do not necessarily indicate true marine conditions. No ammonites have been found in D8 or the lower D7 beds, and unfortunately the foraminifera are probably more indicative of ecological conditions than of age of strata.

Fauna 4 Beds D7D to the top of D6. Here a marked improvement in ecological conditions is reflected in the increased number of both calcareous and arenaceous foraminifera. Whilst only three species occur in Bed D7D, twenty-two are present in D6A1. The genera *Glomospirella*, *Ammobaculites*, *Trochammina*, *Verneuilinoides*, *Nodosaria*, *Citharina*, *Frondicularia*, *Lagena*, *Lenticulina*, *Dentalina*, *Vaginulina*, *Lingulonodosaria*, *Globulina*, *Ramulina*, *Tristix*, *Conorboides* and *Hoeglundina* all make their first appearance at this horizon. Restricted to these beds are *Haplophragmoides nonioninoides* (Reuss), *Lenticulina* (*M.*) *striatacostata* (Reuss), *Vaginulina* cf. *angustissima* Reuss, and *Citharina strigillata* (Reuss).

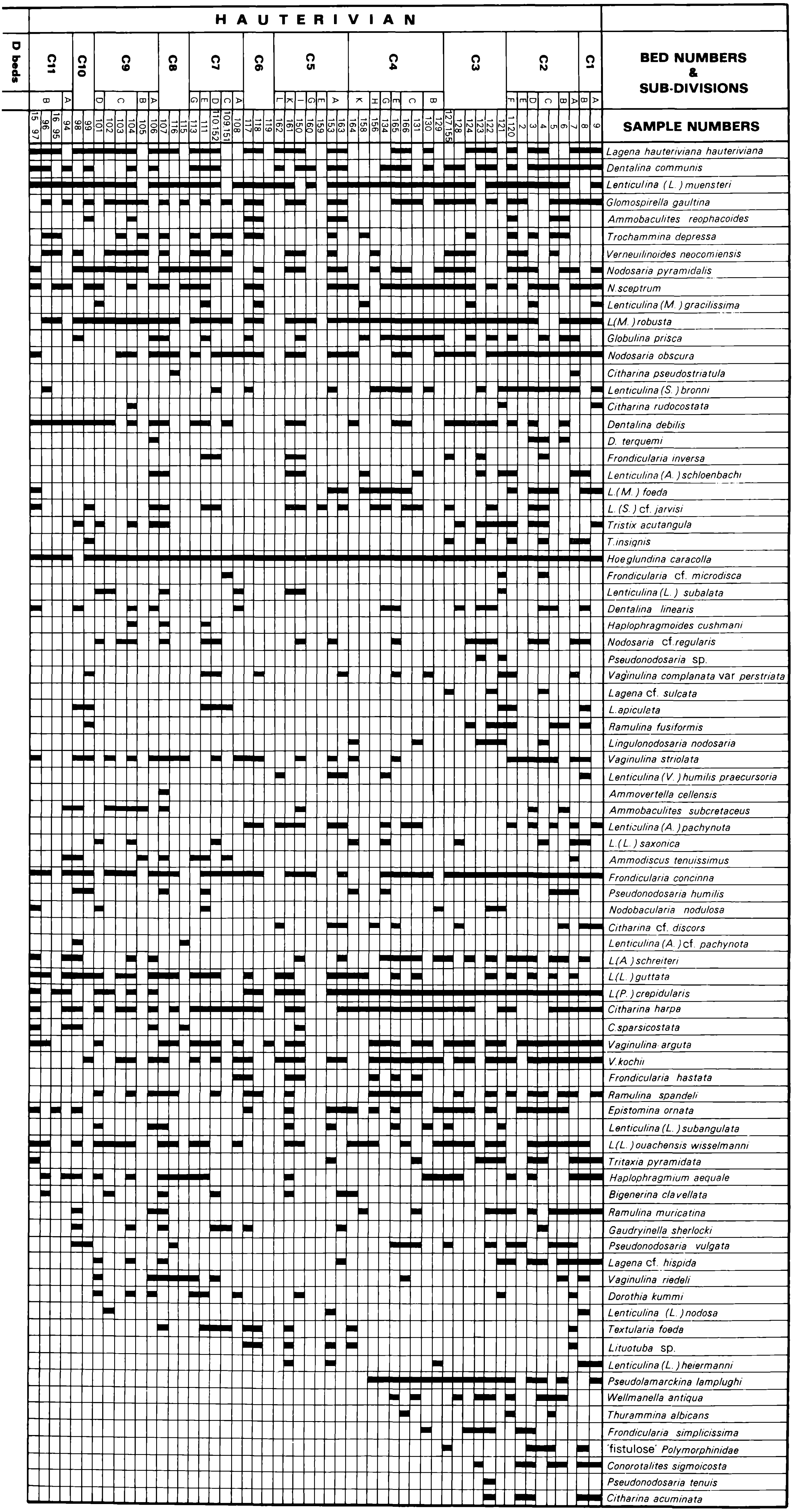
All the foraminifera in these beds are also found in the Mittel Valendis of Germany. In contrast, the ostracods are restricted to these beds and are not comparable with any other known fauna (Neale 1962b). Neale (1962b) suggests the ostracods have affinities with the Volgian of the Emba region in Russia rather than with the Lower Cretaceous, although the ammonites (Neale 1962a) point to a Berriasian age. With foraminiferal assemblages it is difficult to distinguish between Berriasian and Valanginian, although strata of Valanginian age tend to have a greater variety and number of species. In northwest Bulgaria the Berriasian microfauna includes *Haplophragmoides* aff. *neocomiensis*, *Verneuilinoides neocomiensis* (Mjatliuk) and *Glomospirella gaultina* (Berthelin) all of which occur in this Speeton fauna. The evidence of both ammonoidea and foraminifera suggests a Berriasian age for these beds and the absence of *Ammovertella cellensis* Bartenstein and Brand, a zone fossil for the Mittel Valendis, adds weight to this view.

Fauna 3 Beds D5E–D4C2. These beds are characterised by their paucity of foraminifera, both as regards numerical abundance and number of species, and the total absence of ostracods. Lithologically they are grey to greyish-brown pyritic clays and mudstones in which the brachiopod *Lingula* occurs quite commonly, together with various species of *Acroteuthis.* Shallow water is suggested by the presence of *Lingula* though the belemnites indicate connection with the open sea. It is probable that these deposits were laid down in the littoral zone under reducing conditions; an environment in which only the more tolerant foraminifera could live and even those in small numbers. *Lenticulina* (*V.*) *humilis praecursoria* Bartenstein and Brand occurs in D5B, a form which Bartenstein and Brand (1951) described from the Mittel and Ober Valendis (i.e. Lower and Upper Valanginian: see Kemper, this volume) of northwest Germany. At Speeton this species is a long-ranging one occurring from D5B to LB3. *Ammovertella cellensis* occurs for the first time in D5A though is rather rare and *Ammobaculites subcretaceous* Cushman and Alexander in D4C'6. In Bulgaria this latter species is found in the Valanginian but is absent from the Berriasian. Kemper (1961) recorded *Ammobaculites subcretaceous* in northwest Germany in Wealden 6 and the lower and middle part of the Platylenticeras-Schichten, and *Ammovertella cellensis* in the middle and upper part of the Platylenticeras-Schichten. The fauna at Speeton suggests that the beds between D5B and D4C2 are Lower Valanginian and can be correlated with the lowest and middle Platylenticeras-Schichten and may range downwards to the Wealden 6 in terms of the northwest German succession.

The greater part of the D5 subdivision, that is Beds D5C to D5E, contains a sparse fauna with long-ranging species. No age can be assigned to these beds at present.

Fauna 2 Beds D4C1 up to and including D2E. The return of good marine conditions in Bed D4C1 is reflected in the rich benthonic fauna which persists to the top of the D Beds and up into the C Beds. Here *Ammodiscus tenuissimus* (Gumbel), *Glomospira gordialis* (Jones and Parker), *Nodobacularia nodulosa* (Chapman), *Frondicularia concinna* Koch, *Citharina* cf. *discors* (Koch), *Lenticulina* (*L.*) *saxonica* Bartenstein and Brand, *L.* (*L.*) *guttata* (Dam), *L.* (*A.*) cf. *pachynota* (Dam), *L.* (*A.*) *schreiteri* (Eichenberg), *L.* (*A.*) *crepidularis* (Roemer) and *Pseudonodosaria humilis* (Roemer) appear for the first time. It is in these beds that *Ammovertella cellensis* and *Conorboides valendisensis* Bartenstein and Brand have their greatest abundance. In northwest Germany *Conorboides valendisensis* is a short-lived index-fossil of the Mittel Valendis whilst *Ammovertella cellensis* Bartenstein and Brand, is most plentiful at the boundary between Mittel and Ober Valendis.

The ostracods *Protocythere hannoverana* Bartenstein and Brand, *Schuleridea praethorenensis* Bartenstein and Brand, and *Dolocytheridea wolburgi* Bartenstein and Brand, which occur in these beds, suggest a correlation ranging from Mittel Valendis 1 to the top of Ober Valendis 1 of Germany (Neale 1962b). The foraminifera indicate a similar correlation, though in terms of the German succession, they may range as high as Ober Valendis 3. It would appear that the Ostracoda here are more sensitive indicators of age of strata and Neale (1962b) suggests that as the D2D beds are of Hauterivian age Ober Valendis 2, 3 and 4 are missing: the ammonite evidence also supports Neale's assessment (Rawson 1971b).


HAUTERIVIAN
D beds
C11
C10
C9
C8
C7
C6
C5
C4
C3
C2
C1
BED NUMBERS & SUB-DIVISIONS
B
A
D
C
B
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SAMPLE NUMBERS
15 97
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Lagena hauteriviana hauteriviana
Dentalina communis
Lenticulina (L.) muensteri
Glomospirella gaultina
Ammobaculites reophacoides
Trochammina depressa
Verneuilinoides neocomiensis
Nodosaria pyramidalis
N. sceptrum
Lenticulina (M.) gracilissima
L. (M.) robusta
Globulina prisca
Nodosaria obscura
Citharina pseudostriatula
Lenticulina (S.) bronni
Citharina rudocostata
Dentalina debilis
D. terquemi
Frondicularia inversa
Lenticulina (A.) schloenbachi
L. (M.) foeda
L. (S.) cf. jarvisi
Tristix acutangula
T. insignis
Hoeglundina caracolla
Frondicularia cf. microdisca
Lenticulina (L.) subalata
Dentalina linearis
Haplophragmoides cushmani
Nodosaria cf. regularis
Pseudonodosaria sp.
Vaginulina complanata var perstriata
Lagena cf. sulcata
L. apiculata
Ramulina fusiformis
Lingulonodosaria nodosaria
Vaginulina striolata
Lenticulina (V.) humilis praecursoria
Ammovertella cellensis
Ammobaculites subcretaceus
Lenticulina (A.) pachynota
L. (L.) saxonica
Ammodiscus tenuissimus
Frondicularia concinna
Pseudonodosaria humilis
Nodobacularia nodulosa
Citharina cf. discors
Lenticulina (A.) cf. pachynota
L. (A.) schreiteri
L. (L.) guttata
L. (P.) crepidularis
Citharina harpa
C. sparsicostata
Vaginulina arguta
V. kochii
Frondicularia hastata
Ramulina spandeli
Epistomina ornata
Lenticulina (L.) subangulata
L. (L.) ouachensis wisselmanni
Tritaxia pyramidata
Haplophragmium aequale
Bigenerina clavellata
Ramulina muricatina
Gaudryinella sherlocki
Pseudonodosaria vulgata
Lagena cf. hispida
Vaginulina riedeli
Dorothia kummi
Lenticulina (L.) nodosa
Textularia foeda
Lituotuba sp.
Lenticulina (L.) heiermanni
Pseudolamarckina lamplughi
Wellmanella antiqua
Thurammina albicans
Frondicularia simplicissima
'fistulose' Polymorphinidae
Conorotalites sigmoicosta
Pseudonodosaria tenuis
Citharina acuminata

Fig. 2

Fauna 1 Beds D2D up to and including D1. A true Hauterivian fauna occurs in D2D with the appearance of *Citharina harpa* (Roemer), *C. seitzi* Bartenstein and Brand, *C. sparsicostata* (Reuss), *Vaginulina arguta* Reuss, *V. kochii* Roemer, *Frondicularia hastata* Roemer, *Lenticulina* (*L.*) *eichenbergi* Bartenstein and Brand, *L.* (*L.*) *ouachensis wisselmanni* Bettenstadt, *Ramulina spandeli* Paalzow and *Epistomina ornata* (Roemer). The ostracods *Cythereis senckenbergi* Triebel and *Protocythere triplicata* (Roemer) which also occurs in these upper D Beds are well-known species in the Lower Hauterivian Endemoceras-Schichten (*noricum* and *bivirgatus* zones of Bartenstein and Bettenstaedt 1962) of Germany. *Dorothia kummi* (Zedler) which is common in the Ober Valendis and the upper part of the Endemoceras-Schichten in Germany does not occur at Speeton until Bed C9 (*Endemoceras regale* Zone). The distinctive species *Triplasia georgsdorfensis* (Bartenstein and Brand) has not been recorded from the Lower Cretaceous of Britain though in northwest Germany and Denmark it is an index-fossil occurring in the top of the upper Valanginian and in the Hauterivian, and is particularly plentiful in the *E. noricum* Zone. In these countries, however, it is a facies fossil confined to littoral conditions.

Beds D2D to D2A belong to the *E. amblygonium* Zone and Bed D1 to the *amblygonium-noricum* condensed horizon (Rawson 1971b).

2b. The C Beds

These beds, in contrast to the D Beds, do not show distinct microfaunal units separated by relatively barren strata, but have a very rich fauna with many long ranging forms. The occurrence of *Hoeglundina caracolla* (Roemer), *Haplophragmium aequale* (Roemer), *Citharina harpa* and *Epistomina ornata* clearly indicates their Hauterivian age. *Hoeglundina caracolla* is very common, often occurring in vast numbers and forming the bulk of the washed residue. Similarly *Lenticulina muensteri* (Roemer) is common throughout most of the C Beds although never occurring in "floods" as does *Hoeglundina caracolla,*

Beds C11 to C8 belong to the *regale* Zone (Rawson 1971b) and in C11, the basal member of the C Beds, *Haplophragmium aequale, Bigenerina clavellata* Loeblich and Tappan and *Tritaxia pyramidata* Reuss occur for the first time. Other forms occurring for the first time in this zone are *Ramulina muricatina* Loeblich and Tappan, *Gaudryinella sherlocki* Bettenstaedt, and *Pseudonodosaria vulgata* (Bornemann) in the C10 Beds; *Lagena* cf. *hispida* Reuss, *Vaginulina riedeli* Bartenstein and Brand, *Dorothia kummi, Lenticulina* (*L*) *nodosa* (Reuss) in C9 and *Textularia foeda* Reuss in C8. *Ammovertella cellensis* is last seen at Speeton in the *regale* Zone.

Rawson (1971a, 1971b) in describing the Hauterivian ammonite sequence recognised a sharp faunal change at the C8/C7 boundary with the sudden appearance of *Simbirskites,* followed closely by *Aegocrioceras.* This faunal change is not reflected in the foraminiferal sequence. The foraminifera of the *Simbirskites* (*Sp.*) *inversum* Zone (Bed C7) are for the most part long-ranging forms. In the succeeding *S.* (*M.*) *speetonensis* Zone (Beds C5A to base of C6) *Lenticulina* (*L*) *heiermanni* Bettenstaedt is recorded in C5. This species occurs for the first time at a similar horizon in northwest Germany where Zedler (1961) recorded it in the "*Crioceras*" *seeleyi* Zone, the lower part of which is provisionally correlated with the higher part of the *speetonensis* Zone at Speeton.

In C4, the *S.* (*C.*) *gottschei* Zone of Rawson (1971a), two useful species, *Pseudolamarckina lamplughi* (Sherlock) and *Wellmanella antiqua* (Reuss), occur.

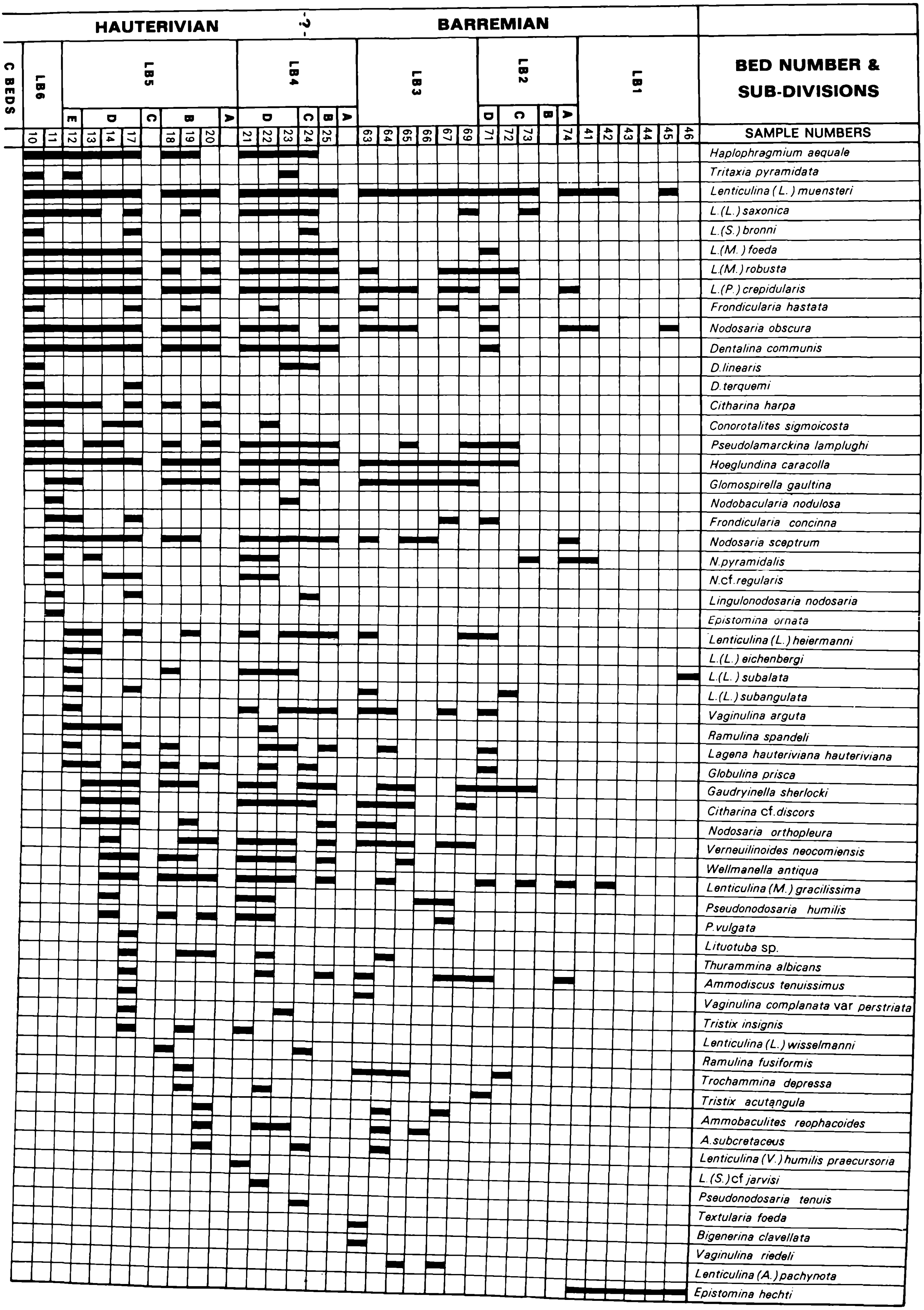
In northwest Germany *Wellmanella antiqua* Reuss occurs most abundantly in the Upper Hauterivian (*seeleyi* and *tenuis* Zones of Bartenstein and Bettenstaedt 1962) though its total range is Lower Hauterivian to Middle Barremian. At Speeton it ranges from Beds C4 to LB3.

Beds C3 to C2D are 3·6 metres thick and represent the *S.* (*S.*) *marginatus* Zone. These beds, like the rest of the C Beds, have a typical Hauterivian fauna with *Lenticulina* (*L*) *muensteri*, *L.* (*M.*) *robusta* (Reuss), *L.* (*P.*) *crepidularis* (Roemer), *Vaginulina kochi* and *Nodosaria obscura* Reuss occurring in large quantities. The *marginatus* Zone can be distinguished however by the appearance of *Conorotalites sigmoicosta* (Dam) and *Citharina acuminata* Reuss. *Conorotalites sigmoicosta* is a short-lived form ranging from the Upper Hauterivian (*marginatus* Zone) to the lower Barremian (*rarocinctum* Zone) at Speeton. The Speeton forms coil both dextrally and sinistrally though with the latter predominating. This species has a similar restricted range in Heligoland (Bartenstein and Kaever, in press) and in northwest Europe is regarded as a valuable zone-fossil ranging from Upper Hauterivian to Lower Barremian.

2c. The Lower B Beds

A marked diminution in the number of genera and species of foraminifera is seen as successively higher horizons in Lower B are sampled. The base of these beds contains a rich and varied fauna, whereas in the uppermost beds only four species occur. This gradual reduction from the rich Hauterivian fauna is seen in Germany as well as in England and is a reflection of a deterioration in the environment. In the field this is seen in the very black clays which are frequently finely laminated and contain abundant pyrite—characteristics associated with reducing conditions. Spath (1924), on the basis of the ammonites, recognised that the lower part of the Lower B Beds was of Hauterivian age but did not indicate the position of the Hauterivian/Barremian boundary in the field. Foraminifera such as *Haplophragmium aequale*, *Epistomina ornata*, and *Citharina harpa* in these lowest beds also indicate a Hauterivian age. In Germany, *Haplophragmium aequale* is not found above the *Simbirskites* (*C.*) *tenuis* Zone, in the Upper Hauterivian, and at Speeton it has not been recorded above the highly glauconitic LB4C Bed. *Citharina harpa* is last seen in Bed LB5B and in northwest Germany ranges up to the base of the "*Crioceras*" *strombecki* Zone at the top of the Hauterivian. *Epistomina ornata*, again an essentially Hauterivian form, ranges up to Bed LB6. *Lenticulina muensteri* and *Hoeglundina caracolla* occur abundantly in all samples up to and including LB2D. *Conorotalites sigmoicosta*, which first occurs in Bed C3 and dies out in LB4D, is a valuable and easily recognised index-fossil. In Bed LB1 at the top of the Lower B Beds *Epistomina hechti* Bartenstein, Bettenstaedt and Bolli is the dominant foraminifera with *Lenticulina muensteri* and *Nodosaria obscura* occurring in smaller numbers. *Epistomina hechti* is a form which ranges in northwest Germany from the Lower Barremian (*fissicostatum* Zone) to the Middle Barremian (*denckmanni* Zone). It is the characteristic species of Hecht's (1938) "Epistomina D7" zone of northwest Germany and is also found in the Barremian of Trinidad. In Bulgaria it is also a useful index-fossil, where it is recorded in the Upper Barremian (Bartenstein and Kovatcheva 1970). *Lenticulina* (*L.*) *heiermanni*, though present in the C Beds, is numerically strongest in the Lower B Beds, and is also found in the Barremian of the Vocontian trough (Flandrin, Moullade and Porthault 1962).

The distribution of the foraminifera in these beds is very similar to that in equivalent strata in northwest Germany and suggests that the Hauterivian/


HAUTERIVIAN
-?-
BARREMIAN
C BEDS
LB6
LB5
LB4
LB3
LB2
LB1
E
D
C
B
A
D
C
B
A
D
C
B
A
BED NUMBER & SUB-DIVISIONS
10
11
12
13
14
17
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19
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25
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SAMPLE NUMBERS
Haplophragmium aequale
Tritaxia pyramidata
Lenticulina (L.) muensteri
L.(L.) saxonica
L.(S.) bronni
L.(M.) foeda
L.(M.) robusta
L.(P.) crepidularis
Frondicularia hastata
Nodosaria obscura
Dentalina communis
D. linearis
D. terquemi
Citharina harpa
Conorotalites sigmoicosta
Pseudolamarckina lamplughi
Hoeglundina caracolla
Glomospirella gaultina
Nodobacularia nodulosa
Frondicularia concinna
Nodosaria sceptrum
N. pyramidalis
N. cf. regularis
Lingulonodosaria nodosaria
Epistomina ornata
Lenticulina (L.) heiermanni
L.(L.) eichenbergi
L.(L.) subalata
L.(L.) subangulata
Vaginulina arguta
Ramulina spandeli
Lagena hauteriviana hauteriviana
Globulina prisca
Gaudryinella sherlocki
Citharina cf. discors
Nodosaria orthopleura
Verneuilinoides neocomiensis
Wellmanella antiqua
Lenticulina (M.) gracilissima
Pseudonodosaria humilis
P. vulgata
Lituotuba sp.
Thurammina albicans
Ammodiscus tenuissimus
Vaginulina complanata var perstriata
Tristix insignis
Lenticulina (L.) wisselmanni
Ramulina fusiformis
Trochammina depressa
Tristix acutangula
Ammobaculites reophacoides
A. subcretaceus
Lenticulina (V.) humilis praecursoria
L.(S.) cf jarvisi
Pseudonodosaria tenuis
Textularia foeda
Bigenerina clavellata
Vaginulina riedeli
Lenticulina (A.) pachynota
Epistomina hechti

Fig. 3

Barremian boundary may tentatively be placed as high as Bed LB4C, some 5·8 metres above the base of the B Beds.

Rawson (1971a, 1971b) includes Beds C2C to LB5E in his *variabilis* Zone and suggests that the Hauterivian/Barremian boundary should be drawn provisionally at the base of LB5D. Ammonites are very rare and virtually indeterminable above LB6, though *Hoplocrioceras fissicostatum* has been recorded in Bed LB3.

3. Conclusions

The very detailed lithostratigraphical subdivisions of the Speeton Clay have provided an essential framework for the accurate localisation of micropalaeontological samples and have allowed the distribution of the foraminifera to be studied in detail.

The D Beds, which range from the Berriasian to the Lower Hauterivian, show distinct faunal changes. The lowest beds contain only *Haplophragmoides* but these beds are succeeded by a rich fauna in D7D to the top of D6. The foraminifera in these beds also occur in the Lower Valanginian of Germany but the absence of *Ammovertella cellensis* together with the evidence of both ostracods and ammonites suggest that their age is Berriasian.

From Bed D5E to D4C2 adverse ecological conditions prevailed and the fauna is a sparse one, though the presence of *Ammovertella cellensis* and *Ammobaculites subcretaceous* permit a correlation of the upper part of these beds (D5B–D4C2) with the Platylenticeras-Schichten of Germany. The boundary between Berriasian and Valanginian cannot be recognised precisely within the D5 Beds.

The boundary between the Valanginian and Hauterivian can be clearly placed between Beds D2E and D2D. The Hauterivian beds have a good marine fauna of benthonic foraminifera, with distinctive index foraminifera and assemblages, which enable all the ammonite zones of Rawson (1971a, 1971b) to be distinguished. This rich fauna gradually declines throughout the Lower B Beds (Hauterivian/Barremian) until in LB1 the characteristic Barremian species *Epistomina hechti* dominates the sparse fauna.

The Lower Cretaceous microfauna at Speeton is strikingly similar to that of the Boreal Province of northwest Germany, Holland, Denmark and Poland. In Germany all the ammonite zones can be distinguished on their microfauna and the present study has shown that it is possible to correlate much of the Speeton succession on the basis of the foraminifera. The distribution of the foraminifera at Speeton is almost identical with that of the Upper Hauterivian and Barremian of Heligoland (Bartenstein and Kaever, in press) which facilitates the correlation of the Lower Cretaceous of eastern England across the North Sea Basin and into the northwest European mainland.

The number of species of Lower Cretaceous benthonic foraminifera which occur at Speeton as well as in other widely separated parts of the world is impressive. Bartenstein, Bettenstaedt and Bolli (1957) described the Barremian foraminifera from two formations in Trinidad, those of the Cuche Formation of the Central Range and the Toco Formation in the easterly part of the Northern Range. Whilst they draw attention to the similarity with northwest Germany, the comparison with the Lower Barremian of Speeton is equally striking. Of some ninety species described from Trinidad forty also occur at Speeton. The stratigraphical value of the Lower Cretaceous benthonic foraminifera from widely different parts of the world is further emphasized by the fact that a large porportion of benthonic foraminifera are not restricted to a Boreal or Tethyan Province but are common to both.

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Ostracoda as means of correlation in the Boreal Lower Cretaceous, with special reference to the British marine Ostracoda

John W. Neale

A map shows the distribution of land and sea in early Cretaceous times. Records of British marine Ostracoda are tabulated and it is shown that the species may be used to recognise the stages of the Lower Cretaceous in northwest Europe. Finer divisions may also be recognised, but in this respect the most profitable approach may lie in detailed phylogenetic studies. A phylogeny of *Cytherelloidea* is attempted, and it is suggested that a temperature gradient may explain most of the differences between Boreal and Tethyan faunas in late Lower Cretaceous times.

Anhand einer Karte wird die Meeres-Verbreitung in der frühen Kreide-Zeit demonstriert. Aus den vorgeführten Reichweiten-Tabellen der englischen marinen Ostrakoden geht deutlich hervor, daß die Arten zur Erkennung der Stufen der Unterkreide in Nordwest-Europa herangezogen werden können. Auch feinere Unterteilungen werden angedeutet, doch sind bessere Ergebnisse von phylogenetischen Detailstudien zu erwarten. Weiter wurde der Versuch unternommen, die Phylogenie der Gattung *Cytherelloidea* zu klären. Es wird vermutet, daß die meisten Unterschiede zwischen den Tethys- und Boreal-Faunen dieser Gattung in der jüngeren Unterkreide auf einen Temperatur-Gradienten zurückgeführt werden können.

Une carte présente la répartition des continents et des mers au Crétacé inférieur. Les Ostracodes marins mentionnés en Grande-Bretagne sont répertoriés et on démontre que l'utilisation de leurs espèces est possible pour la reconnaissance des étages du Crétacé inférieur dans le Nord-Ouest de l'Europe. Des subdivisions plus fines peuvent aussi être admises, mais à cet égard les études phylogénétiques détaillées constituent l'approche la plus fertile. Une phylogénèse de *Cytherelloidea* est tentée, et il est suggéré que le facteur thermique peut expliquer la plupart des différences présentées par les faunes boréale et mésogéenne au sommet du Crétacé inférieur.

1. Introduction

Ostracoda have many advantages which favour their use in correlation. Not only are they a highly organised group of invertebrates but they also live in a wide variety of environments, ranging from fully marine, through brackish- to fresh-water. They have even been recorded from terrestrial environments! In consequence they can be used where other means fail and in this country a series of papers by Anderson, stretching back over more than three decades, has established their value in correlating the (non-marine) English Wealden deposits, both within this country and with similar deposits on the continent (see also Anderson, this volume). More recently the striking correlation which can be made between Brazil and Gabon in West Africa on the basis of non-marine cyprideinid ostracods has been demonstrated by Krommelbein (1966) and Grekoff and Krommelbein (1967).

The principal purpose of this contribution is to examine the stratigraphical value and correlation potential of the British marine ostracods. To place this study in some sort of geographical perspective, an early Cretaceous palaeogeographical map (Fig. 1) is included. The early Cretaceous position of the present-day continents is based on a map produced for a symposium held in Cambridge in December 1971 (Smith, Briden and Drewry 1973) and kindly provided in advance of publication by Dr. J. C. Briden. Whilst the plotted distribution of land and sea is frankly speculative, and increasingly so away from the Atlantic and European area, the map serves to emphasise the vastly different world of Cretaceous times. Of note are the separation of the Boreal and Tethyan Realms, the proximity of Greenland to eastern England which is reflected in the similarity of the early Cretaceous macrofaunas, and the suggestion of a connection between England and Portugal round the north of Scotland at this time.

2. British marine Ostracoda

"Marine" is difficult to define. Salinity may be regarded as the prime ecological control affecting Ostracoda (see Neale 1965) and it is obvious that on any definition the typical cyprideinid faunas are excluded from consideration. More difficult are faunas such as those described by Kilenyi and Allen (1968) from the Weald Clay of Surrey and Sussex. Here new species of *Hutsonia* and *Schuleridea* occur associated with other forms, both genera being regarded as tolerant of a wide variation in salinity from the order of 10‰ to fully marine conditions, 35‰. The association of these with presumed mesohaline to low polyhaline genera such as *Fabanella* and *Sternbergella* suggests that the environment was never truly euhaline and, in consequence, these and allied faunas are not taken into account. This leaves a large number of species which may be considered typically euhaline.

The first Monograph on Ostracoda to be published in Britain was Jones' (1849) Monograph on the Cretaceous Ostracoda which preceded Baird's treatment of Recent species by one year. Jones and Hinde covered further species in a supplementary monograph in 1890. In Europe little further interest was taken in Cretaceous ostracods until a resurgence of interest in connection with the north German oilfield was responsible for a series of papers by Weber (1934) and Triebel (1938a, 1938b, 1940). Thereafter interest quickened and a re-examination of the British Lower Cretaceous was started in the 1950's. A series of papers by Neale (1960 *et seq.*) and Kaye (1963 *et seq.*) has covered 238 taxa from the marine Lower

Cretaceous in Britain. Since the literature is widely dispersed and difficult to handle the known distribution and occurrence of these taxa are tabulated here (Table 1). (By an oversight *Cytheropteron punctata* Kaye 1964a and *C. lamplughi* Kaye 1965d, a new name for the former, were both plotted, which explains the apparent presence of 239 and not 238 taxa). The taxonomy has been updated and is considered accurate at the time of writing but like all such compilations will shortly need modification since Christiansen (personal communication) informs me that the form described as Cf. *Cyprione oblonga* (Roemer 1839) by Neale (1960) has been found in some abundance by the Danish Geological Survey and will shortly be published as a new species assigned to the genus *Aaleniella.*

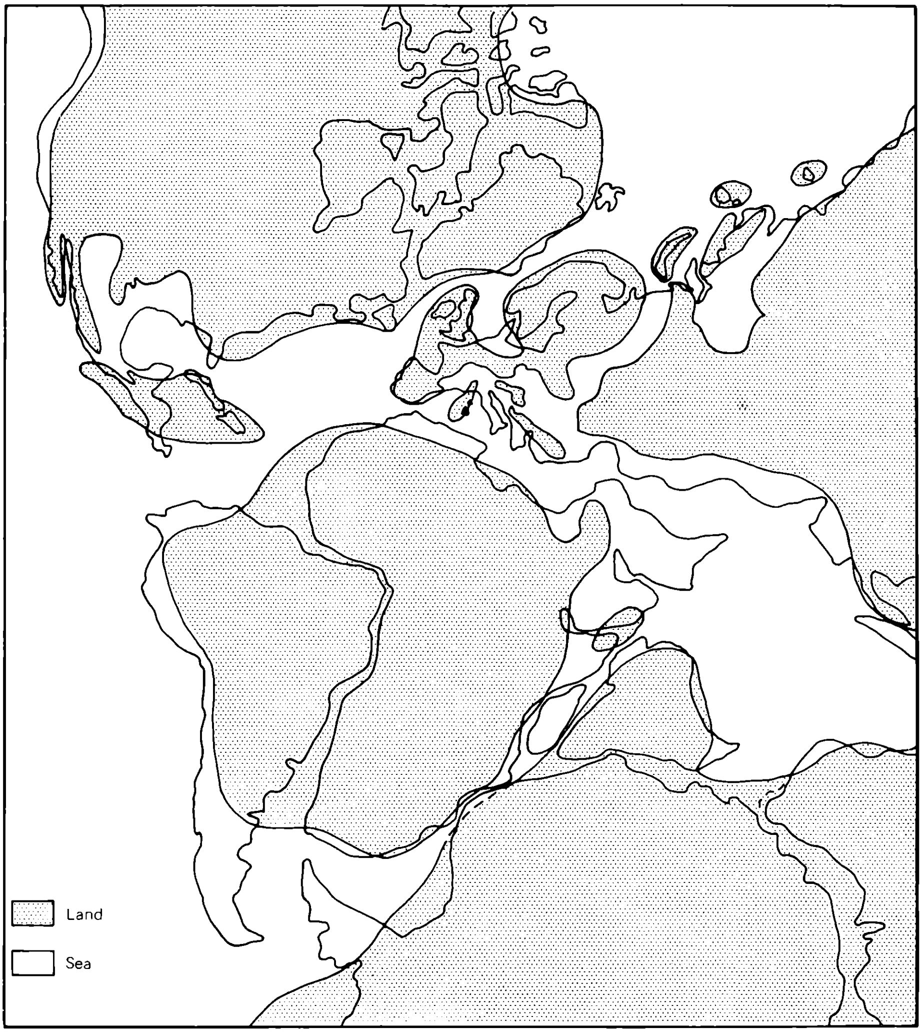

Fig. 1. Suggested distribution of land and sea in early Cretaceous time.

Problems arise in taxonomy which are familiar to all palaeontologists. Here they have been exacerbated by two factors. Firstly, the sudden upsurge of interest in Lower Cretaceous ostracods which resulted in a considerable output of taxonomic work from many countries concentrated into the period 1959–1967. This naturally resulted in a number of inadvertent synonyms. Secondly, there has been the difficulty of producing good illustrations which has since been solved by the development of the electron scanning microscope.

Nevertheless, once these problems have been overcome, the ostracods prove to be of considerable value and inspection of the distribution table immediately establishes two facts:

(*a*) The various Cretaceous stages may be recognised by their quite distinct ostracod faunas, and in the case of the higher part of the Lower Cretaceous finer divisions may be recognised.

(*b*) The early faunas are confined to the boreal seas of northern England, only becoming more widespread in the Aptian and Albian when transgression produced marine environments in the south of England. This, of course, only confirms what has been known on the basis of other evidence since the last century.

3. Correlation outside the British Isles

At the outset one may state that unfortunately no Cretaceous ostracod faunas have been described from Greenland and so nothing can be said about correlation to the northwest. The earliest British marine faunas are considered to be Berriasian in age and provide a very distinctive suite of species characterised by *Cytheropterina triebeli, Mandelstamia sexti, Orthonotacythere speetonensis, Schuleridea juddi*, and others. Although nothing has been published which would indicate this, the fauna appears to be fairly widespread and has been used by commercial firms to diagnose Berriasian from the shelf seas round Britain. It has also been found by the Danish Geological Survey (Christiansen, personal communication) in the North Sea area and Jutland. Attempts to make a direct correlation with Tethyan faunas at this time have proved disappointing (Neale 1966, 1967). More recently, however, there have been exciting developments in the records of *S.* aff. *juddi*, *S.* aff. *rhomboidalis* and *O.* cf. *speetonensis* from the Sierra de Sintra and adjoining areas of Portugal by Rey *et al.* (1968). Here they are associated with *Lycopterocypris? sabaudiae* Donze, *Paracypris* aff. *arcuatilis* Donze, and *Cytherella turgida* Donze, found in the Berriasian of France. This suggests an early connection between the Boreal and Tethyan Realms via Portugal and it is on this evidence that the coastline is drawn in this area in Figure 1. *Cytherelloidea rehburgensis* Bartenstein and

Table 1

The areas of occurrences in the British Isles are shown by different symbols and open symbols are used to join occurrences where intermediate records are lacking or, in a few cases, to indicate uncertain horizon. Records of taxa in other countries are noted in the right-hand column. The papers in which the taxa were originally described are listed in the references at the end of this paper.

Table 1. Stratigraphical distribution and geographical occurrence of British marine Cretaceous Ostracoda.

BRITISH MARINE CRETACEOUS OSTRACODA	BERRIASIAN	VALANGINIAN	HAUTERIVIAN	BARREMIAN	APTIAN	LOWER ALBIAN	MIDDLE ALBIAN	UPPER ALBIAN	EUROPE
1. Mandelstamia cf. M.sexti Neale 1962	▲								
2. Orthonotacythere speetonensis Neale 1962	▲▲								Q?
3. Schuleridea juddi Neale 1962	▲▲								Q?
4. Mandelstamia sexti Neale 1961	▲▲								
5. Palaeocytheridella teres Neale 1962	▲▲								
6. Paracypris caerulea Neale 1962	▲▲								
7. Cytheropterina triebeli Neale 1962	▲▲								
8. Cytherura (?) sp.a Neale 1962	▲								
9. Pontocypris felix Neale 1962	▲								
10. Palaeocytheridella cf. P.subhexangulata (Sharapova 1937)	▲								
11. Orthonotacythere reticulata Neale 1962		▲▲▲							
12. Protocythere hannoverana Bartenstein & Brand 1959		▲▲▲▲							G
13. Cytheropterina eboracica Neale 1962		▲▲▲							
14. Orthonotacythere globosa Neale 1962		▲▲▲							E?
15. Schuleridea praethoerenensis Bartenstein & Brand 1959		▲▲▲							G
16. Paracypris parallela Neale 1962		▲▲▲							
17. Stravia crossata Neale 1962		▲▲▲							
18. Dolocytheridea wolburgi Bartenstein & Brand 1959		▲▲▲							G
19. Palaeocytheridella sp.a Neale 1962		▲							
20. Stillina acuminata Neale 1962		▲▲							
21. Cytherella valanginiana Neale 1962		▲							
22. Orthonotacythere sp.a Neale 1962		▲	▲						
23. Neocythere sp. nov. Neale 1962			▲						
24. Exophthalmocythere anterospinosa Neale 1962			▲						
25. Cytherella exquisita Neale 1962			▲						
26. Paracypris sinuata Neale 1962			▲						E GP?
27. Orthonotacythere diglypta Triebel 1941			▲						E GP?
28. Mandocythere (C.) frankei frankei (Triebel 1938a)			▲						FGP S
29. Protocythere (P.) hechti Triebel 1938a			▲						EFGP S
30. Protocythere (P.) triplicata (Roemer 1841)			▲						B EFGP?S
31. Acrocythere hauteriviana hauteriviana (Bartenstein 1956)			▲						E G
32. Cytherelloidea ovata Weber 1934			▲						E GP
33. Cytherella fragilis Neale 1962			▲						E
34. Euryitycythere parisiorum Oertli 1959			▲						EF
35. Schuleridea lamplughi Neale 1962			▲						
36. Apatocythere (A.) spinosa Neale 1962			▲						E
37. Bythocythere? sp.cf.B.nescia Lübimova 1955			▲						
38. Gen.A sp.a Neale 1962			▲						
39. Monoceratina bispinata Weber 1934			▲						B G
40. Parexophthalmocythere rodewaldensis B & B 1959			▲						E GP
41. Cythereis senckenbergi Triebel 1940			▲▲						B EF?G
42. Dolocytheridea reightonensis Neale 1962			▲▲						EFG
43. Pontocyprella superba Neale 1962			▲▲						E?
44. Orthonotacythere anglica Neale 1960			▲▲						
45. Schuleridea thoerenensis werlensis Grundel 1966*1			▲						EFGP?
46. Schuleridea wendenensis Neale 1960			▲						
47. Mandocythere (C.) frankei fordonensis (Neale 1962)			▲						E GP
48. Haplocytheridea kummi Triebel 1938b			▲						GP
49. Cf. Cyprione oblonga (Roemer 1839)			▲						
50. Macrocypris ? sp.α Neale 1960			▲						
51. Dicrorygma speetonensis Christensen 1965			▲						
52. Orthonotacythere ramulosa Sharapova 1939			▲ ▲						E R
53. Dolocytheridea hilseana (Roemer 1841)			▲▲▲						GP
54. Orthonotacythere cf. O.diglypta Triebel 1941			▲						
55. Paracypris sp.α Neale 1960*2			▲						
56. Acrocythere hauteriviana laeva Neale 1960			■ ▲▲	■■					
57. Amphicytherura roemeri (Bartenstein 1956)			■	■■					E
58. Cytheropteron (Eocytheropteron) novum Kaye 1964a			▲▲	■■▲					
59. Neocythere (P.) pustulosa Kaye 1965a			■■						E
60. Schuleridea rhomboidalis Neale 1960			■ △△	■■ △▲					Q?

*1 = Schuleridea aff.S.thorenensis (Triebel) Neale 1960; *2 According to Grundel 1966 = Protoargilloecia ? parva (by Kaye 1965b as Macrocypris)

▲Yorkshire. ■Lincolnshire. ●S.E. England. ♦ Isle of Wight.

Table 1—continued

BRITISH MARINE CRETACEOUS OSTRACODA	BERRIASIAN	VALANGINIAN	HAUTERIVIAN	BARREMIAN	APTIAN	LOWER ALBIAN	MIDDLE ALBIAN	UPPER ALBIAN	EUROPE
61. Apatocythere (A.) simulans Triebel 1940			■	■ ▲					G
62. Schuleridea bilobata (Triebel 1938b)			▲	▲ ▲					EF?G
63. Eucytherura reticulosa (Chapman 1894)			■	■■					
64. Pseudobythocythere ornata Kaye 1965b			■	■▲					
65. Quasihermanites bicarinata Gründel 1964*[1]			■	■■					E
66. Cytheropteron (C.) rugosa Kaye 1965a			■	■□□	◆■				
67. Cytheropteron (I.) exquisita Kaye 1964a			▲	■□	□□■				E
68. Neocythere (N.) protovanveeni Kaye 1963b			■	■■□					
69. Apatocythere (W.) ellipsoidea Triebel 1940			■	■ ▲					EFG
70. Dolocytheridea reightonensis neali Gründel 1966*[2]			▲	△					EF
71. Dolocytheridea intermedia Oertli 1958			■	■■▲					F
72. Eucytherura nettletonensis Kaye 1964b			■	■■□	○○●				E
73. Dicrorygma minuta (Kaye 1963c)			▲	△△△	◆◇■				E
74. Macrocypris? sp.β Neale 1960			▲						
75. Orthonotacythere inversa costata Kaye 1963e			▲						EF
76. Eucytherura (V.) neocomiana Kaye 1964a			▲						E
77. Acrocythere sp.α Neale 1960			▲						
78. Cytherelloidea anomala Kaye 1963a			▲ ■	△△▲ ■					E G
79. Pontocyprella mandelstami Kaye 1965b			▲	△▲▲					
80. Macrocypris parva Kaye 1965b			▲	▲▲△	□■■				
81. Acrocythere sp.β Neale 1960			▲						
82. Cytherelloidea pulchra Neale 1960			■ ▲	▲					E
83. Cytheropteron (C.) punctata Kaye 1964a			▲	▲▲					
84. Cytheropteron (C.) lamplughi Kaye 1965d			▲	▲▲					
85. Cytherelloidea dalbyensis Kaye & Barker 1966				■■					
86. Amphicytherura bartensteini Kaye & Barker 1966				■■					
87. Eucytherura nuda Kaye 1964a				▲▲▲					
88. Orthonotacythere inversa inversa (Cornuel 1848)				■■ ▲					F
89. Orthonotacythere blanda Kaye 1963e				■■					
90. Orthonotacythere problematica Kaye & Barker 1966				■■					
91. Euryitycythere sp.B Kaye & Barker 1966				■■					
92. Stravia brevis (Cornuel 1846)				■■					EFGP
93. Schuleridea cf. S.bernouilensis Grosdidier 1964				■■					
94. Cytheropteron (C.) reightonensis Kaye 1964a				■■▲▲ ▲					
95. Cythereis cf. C.geometrica Damotte & Grosdidier 1963b				■■					
96. Eucytherura ornata Kaye 1964a				▲△△	□■■				
97. Pseudobythocythere vellicata (Chapman 1894)				■■					
98. Protocythere inornata Kaye 1964b				■■□□	□□●				
99. Cythereis blanda Kaye 1963d				■■▲ ▲	△○○	●●●	●●●●	●●●	
100. Cytherelloidea elongata Kaye 1963a				▲▲					
101. Acrocythere hauteriviana anomala Neale 1960				▲▲					
102. Orthonotacythere inversa tuberculata Kaye 1963e				▲▲	△□■■				
103. Haplocytheridea parallela Kaye 1963c				▲▲					
104. Cythereis acuticostata Triebel 1940				▲▲					G
105. Cytherella speetonensis Kaye 1963a				▲	▲				
106. Cytherelloidea sp.α Neale 1960				▲					
107. Macrocypris? sp.γ Neale 1960				▲					
108. Cytherella pyriformis (Cornuel 1846)				▲					
109. Schuleridea hammi (Triebel 1938b)				▲					G
110. Cytherelloidea cf. C.ovata (Roemer 1841)				□	□■■				
111. Protocythere intermedia Kaye 1963d*[3]					▲▲				
112. Schuleridea derooi Damotte & Grosdidier 1963b					◆◆◆ ■■				F
113. Neocythere (P.) cf. N.bordeti (Damotte & Grosd. 1963b)					◆◆◆ ■■				F
114. Pontocyprella rara Kaye 1965b					▲ ■■				E G
115. Cytheropteron (E.) stchepinskyi (Damotte & Grosd. 1963b)					◆				F
116. Orthonotacythere atypica Kaye 1965a					◆				
117. Orthonotacythere sp.A Kaye 1965a					◆				
118. Cythereis geometrica Damotte & Grosdidier 1963b					◆				F
119. Veenia cf. V.florentinensis Damotte 1961					◆				
120. Cythereis cf. C.blanda Kaye 1963d					◆				

*[1] = Ranocythereis caistorensis Kaye 1965c; *[2] = Dolocytheridea intermedia Oertli, Kaye 1963c pars
*[3] According to Kemper 1971 = P.speetonensis Kaye 1963d.
B=Bulgaria. D=Denmark. E=East Germany. F=France. G=West Germany. H=Holland. P=Poland. Q=Portugal.
R=Russia. S=Switzerland.

Table 1—continued

BRITISH MARINE CRETACEOUS OSTRACODA	BERRIASIAN	VALANGINIAN	HAUTERIVIAN	BARREMIAN	APTIAN	LOWER ALBIAN	MIDDLE ALBIAN	UPPER ALBIAN	EUROPE
121. Orthonotacythere catalaunica Damotte & Grosdidier 1963b					♦				F
122. Protocythere (P.) croutesensis Damotte & Grosdidier 1963b					♦				F
123. Schuleridea sulcata Kaye 1965a					♦				
124. 'Cythere' bairdiana Jones 1849					●●				
125. Cytherelloidea sp.2 Kaye 1965a					♦				
126. Orthonotacythere inornata Kaye 1965a					♦				
127. Euryitycythere sp. Kaye 1965a					♦				
128. Neocythere (P.) cf. N.pustulosa Kaye 1965a					♦				
129. Schuleridea alata Kaye 1965a					♦				
130. Veenia compressa Kaye 1965a					♦◊	◊◊D	DDD	◗	
131. Batavocythere gaultina (Kaye 1963d)					♦				E G
132. Cythereis geometrica fittoni Kaye 1965a					♦				
133. Eucytherura chapmani Kaye 1964b					♦●				
134. Cytherella ovata (Roemer 1841)					■■	▢▢—	—	→	B EFG P
135. Cytherella cf. C.parallela (Reuss 1846)					♦♦	◊◊◊	◊▲△	△△△△	EF H?P
136. Krausella minuta Triebel 1936					■■				G
137. Cytheropteron (I.) lindumensis Kaye & Barker 1965					■■				
138. Cytheropteron (C.) cf. C.inaequivalve Bonnema 1941					■■				
139. Cytheropteron (C.) novum reticulatum Kaye & Barker 1965					■■				
140. ?Stillina cf. S.fluitans (Bonnema 1941)					■■				
141. Orthonotacythere sp.B Kaye & Barker 1965					■■				
142. Protocythere (P.) derooi Oertli 1958					■■ ♦				F
143. Protocythere (P.) mertensi langtonensis Kaye & Barker 1965					■■				
144. Cythereis bekumensis Triebel 1940					■■				G
145. Cythereis sutterbyensis Kaye & Barker 1965					■■				
146. Cythereis gatyensis Damotte & Grosdidier 1963*[1]a					♦♦	◊◊ ○/△	○/△ ●/▲		EF
147. Dolocythere rara Mertens 1956					■■ ●				E G
148. Monoceratina tricuspidata (Jones & Hinde 1890)					■■				
149. Cytherelloidea sp. Kaye 1964b					●				
150. Cytheropteron (C.) vesiculosum (Chapman 1894)					●				
151. ?Cytheropteron costuliferum (Chapman 1894)					●				
152. Cytheropteron (E.) comptonense Kaye 1964b					●				
153. Neocythere (C.) denticulata Mertens 1956					●	○○○	○●●	●●●	EFG P?
154. Clithrocytheridea sp. Kaye 1964b					●				
155. Veenia robusta Kaye 1964b					●				
156. Bairdia sp. Kaye 1964b					●				
157. ?Macrodentina sp. Kaye 1964b					●				
158. Cythereis angulatoides Kaye 1965d*[2]					●				
159. Cythereis cristata Kaye 1964b					●				
160. Neocythere (N.) vanveeni Mertens 1956*[3]					●	○○△	▲△△	△○○	EF?G
161. Pseudobythocythere goerlichi Mertens 1956						▲▲▲			E G
162. Cytherelloidea chapmani (Jones & Hinde 1890)						●●●	●●●●		
163. Cytherelloidea stricta (Jones & Hinde 1890)						●●●	●●●●	● ●/▲ ●/▲	EFG
164. Mandocythere (M.) harrisiana (Jones 1870)						●●●	●●●● ▲▲▲	●●●●	EFG P
165. Protocythere consobrina Triebel 1938a*[4]						●●●	●●●●		EFG
166. Protocythere rudispinata (Chapman & Sherborn 1893)						●●●	●●●●		G
167. Cythereis folkestonensis Kaye 1964c						●●●	●●●●	●●●	
168. Cythereis lurmannae Triebel 1940						●●●	●●●●	●●●	EFG P
169. Cythereis reticulata (Jones & Hinde 1890)						●●●	●●●●		EFG P?
170. Platycythereis gaultina (Jones 1849)						●●●	●●●●	●●●	EFG P
171. Platycythereis laminata Triebel 1940						●●●	●●●●		EFG
172. Isocythereis fissicostis Triebel 1940							▲▲▲	▲▲▲	EF?GP?
173. Protocythere (P.) mertensi Kaye 1963d						▲			E G
174. Dolocytheridea cf. D.bosquetiana (Jones & Hinde 1890)						▲	△○○	●●●	
175. Clithrocytheridea sp.A Kaye 1963c						▲			
176. Cytherelloidea williamsoniana (Jones 1849)							▲		P?
177. Cytherelloidea knaptonensis Kaye 1963a							▲▲▲▲	●/▲ ●/▲ ●/▲	
178. Pontocyprella harrisiana (Jones 1849)							△▲△	△△△	B E GH?P
179. Eucythere trigonalis (Jones & Hinde 1890)							▲		EFGP
180. Eucythere solitaria Triebel 1940							▲△▲△		E G

*[1]=Cythereis lamplughi Kaye 1963d; *[2] as C.angulata Kaye 1964b; *[3] As N.vanveeni ventrocostata n.subsp. by Grundel 1966; *[4]According to Grundel 1966, sensu Kaye 1964c - P.albae Damotte & Grosdidier 1963a.
▲ Yorkshire ;■ Lincolnshire ;● S.E.England ; ♦ Isle of Wight ; ◗ Devon ; W Wiltshire

Table 1—continued

BRITISH MARINE CRETACEOUS OSTRACODA	BERRIASIAN	VALANGINIAN	HAUTERIVIAN	BARREMIAN	APTIAN	LOWER ALBIAN	MIDDLE ALBIAN	UPPER ALBIAN	EUROPE
181. Neocythere (P.) lingenensis (Mertens 1958)							▲▲▲		E G
182. Habrocythere fragilis Triebel 1940							▲■■ ▲▲		E G
183. Veenia triebeli (Deroo 1956)							▲▲▲		
184. Protocythere (P.) speetonensis Kaye 1963d							▲▲▲	▲▲▲	G R
185. Protocythere lineata (Chapman & Sherborn 1893)							▲▲▲ ●●●	▲▲▲ ●●●	E P
186. Saxocythere dividera (Grundel 1964)*[1]							▲▲▲	▲▲▲	E G
187. Cythereis corrigenda Kaye 1964c							●●		EF?G
188. Cythereis bonnemai Triebel 1940							▲▲▲	▲▲▲	EFGP
189. Isocythereis fortinodis Triebel 1940							▲▲▲		EF?G
190. Eucytherura ansata Weingeist 1949							▲▲▲		
191. Clithrocytheridea aff. C.nana Triebel 1938b							▲▲▲		EF?G
192. Cytheropteron (C.) nanissimum fenestrata Kaye 1965d							●		
193. Clithrocytheridea heslertonensis Kaye 1963c							● ▲ ◆		
194. Veenia florentinensis Damotte 1961							●●●	●	
195. Paracypris wrothamensis Kaye 1965d							●●●	●●●	
196. Orthonotacythere fordensis Kaye 1965d							●		
197. Orthonotacythere spinifera Kaye 1965d							●○○	●	
198. Monoceratina sp. Kaye 1965d							w		
199. Eucytherura rectangulata Kaye 1964a							▲▲▲		E
200. Polycope nuda Kaye 1965d							●●	○○○○	
201. Polycope oweni Kaye 1965d							○○	●●○○	
202. Pontocyprella semiquadrata Kaye 1965d							○○	●●○○	E P
203. Cytheropteron (C.) milbournei Kaye 1965d							●●		EH?
204. Monoceratina longispina (Bosquet 1854)							●●●	●○○	
205. Neocythere (P.) tenuis Kaye 1965d							●●●	●●●	
206. Schuleridea jonesiana (Bosquet 1852)							▲	●●●●	EFGH?
207. Cytherelloidea parawilliamsoniana Kaye 1963a							▲		
208. Krausella sp. Kaye 1965d							●●		
209. Bairdia pseudoseptentrionalis (Mertens 1956)							○○	●●○	G
210. Argilloecia valvula Kaye 1965d							○	●○	
211. Cytheropteron (E.) protonsa Kaye 1965d							●		
212. Cythereis thorenensis Triebel 1940*[2]								●●●●	E F
213. Macrocypris exquisita Kaye 1964c								●●●●	
214. Acrocythere striata Kaye 1965d								●●	
215. Cytheropteron? (I.) obscura Kaye 1965d								●●	
216. Cytheropteron (C.) arguta Kaye 1965d								●● ●●	
217. Cytheropteron nanissimum nanissimum Damotte & Grosd. 1963a								●●	E F
218. Hemicytherura euglyphea Kaye 1965d								●●	E
219. Eucytherura aff. E.nuda Kaye 1964a								●●	
220. Neocythere (P.) semilaeva Kaye 1963b								▲▲▲	
221. Schuleridea dimorphica Kaye 1965d								●●	
222. Dolocytheridea typica Kaye 1965d								●●	
223. Dolocytheridea bosquetiana (Jones & Hinde 1890)								●●●●	EFGP
224. Cythereis glabrella Triebel 1940								●●△▲	E GP
225. Cythereis pinhayensis Kaye 1965d								●●	
226. Alatacythere robusta langi Kaye 1965d								●●	
227. Conchoecia sp.A Kaye 1965d								●	
228. Conchoecia? sp.B Kaye 1965d								●	
229. Orthonotacythere minutissima Kaye 1965d								●	
230. Neocythere (P.) hieroglyphica Kaye 1963b*[3]								▲▲▲	
231. Monoceratina umbonata (Williamson 1847)								●● ▲▲	B?EHP?
232. Alatacythere robusta robusta (Jones & Hinde 1890)								●○	
233. Platycythereis chapmani Kaye 1964c								●●	
234. Cytherelloidea globosa Kaye 1964c								●	
235. Veenia barringtonensis Kaye 1964c*[4]								●	F
236. Cythereis nuda (Jones & Hinde 1890)								●	
237. Macrocypris simplex Chapman 1898								● ▲	
238. Monoceratina cf. M.longispina (Bosquet 1854)								●	
239. Monoceratina bonnemai Kaye 1964c								●	

*[1] =Protocythere tricostata Triebel sensu Kaye 1963d & 1964c according to Kemper 1971; *[2] by Kaye 1964c. According to Grundel 1966 = Cythereis hirsuta Damotte & Grosdidier 1963a; *[3] According to Grundel 1966= N.(P.) steghausi (Mertens 1956); *[4] According to Damotte 1968 Protocythere (M.) lapparenti Damotte & Grosdidier 1963a.

B-Bulgaria D-Denmark E-East Germany F France G W. Germany H Holland P Poland Q-Portugal
R-Russia S-Switzerland

Brand, which occurs in the Valanginian of Germany, is also found in the highest rocks assigned to the Berriasian in this area.

The boreal Valanginian fauna is equally diagnostic and characterised by *P. hannoverana, D. wolburgi* and *S. praethoerenensis.* These occur in Germany as well as Britain and indicate a spreading of the marine area to the south at this time.

The Hauterivian is the best known stage in this part of the column and yields a large number of distinctive species. Forms such as *M. frankei, P. hechti* and *P. triplicata* are widespread and have been recorded from France, Germany, Poland and Switzerland. *P. triplicata, M. bispinata* and *C. senckenbergi* have also been recorded from Bulgaria and the faunas are apparently more widespread than in earlier times. This striking increase in spatial distribution of boreal species may not be quite so startling when the lower faunas in eastern Europe are better known.

The diagnostic features of the higher faunas may easily be ascertained from the table and it may be noted that in dealing with the Barremian, Malz (1970) has recently drawn attention to the resemblance between ostracod faunas in the Mediterranean Lower Cretaceous of Rumania and the equivalent boreal faunas of central Europe whilst recognising the presence of new elements such as the genus *Schulapacythere,* a homoeomorph of *Schuleridea.*

The Aptian and Albian are well defined and divisions finer than the stages may be recognised. There are, however, less species in common with southern France than might be expected at first sight. This is most probably related to ecological differences and examination of the question of whether it is possible to recognise finer divisions based on Ostracoda than those outlined above may suggest an explanation.

4. Phylogeny and Ecology

The detailed study of changes within a single genus and the construction of their phylogenetic development seems to offer the best hope for the recognition of fine divisions within the Lower Cretaceous. Many genera are now known in sufficient detail to enable tentative phylogenies to be constructed and *Protocythere* and *Cythereis* spring readily to mind. At this stage all that can be done is to point the way and here *Cytherelloidea* is considered as an example. In a detailed study, Bettenstaedt (1958) has already shown how *Cytherelloidea ovata* evolves throughout the German Hauterivian and the author (Neale 1966) has suggested the way in which evolution progressed in a limited number of forms in the early Cretaceous. Since then our knowledge of species of *Cytherelloidea* has increased considerably and it is possible to suggest the hypothetical family tree shown in Figure 2, which incorporates many Lower Cretaceous species. Full discussion is outside the scope of this contribution but attention may be drawn to a number of salient points of interest. The reticulate or pitted branch is, as far as is known, developed only in the Tethyan Realm where it is found particularly in France, the Lebanon and Tanzania. Detailed examination of a continuous series of forms might yield profitable stratigraphical results although as a whole they are more difficult to work with than the costate forms. The many-ribbed forms, both concave-down (*C. salimaensis* line) and concave-up and wrinkled (*C. varicosa*) are also confined to the Tethyan Realm as is the interesting cryptogene *C.* sp. *B* described from the Aptian of Tanzania by Bate and Bayliss (1969). Of the costate forms the stratigraphically valuable *C. ovata* plexus worked out by Bettenstaedt (1958) has already been mentioned. Two or three

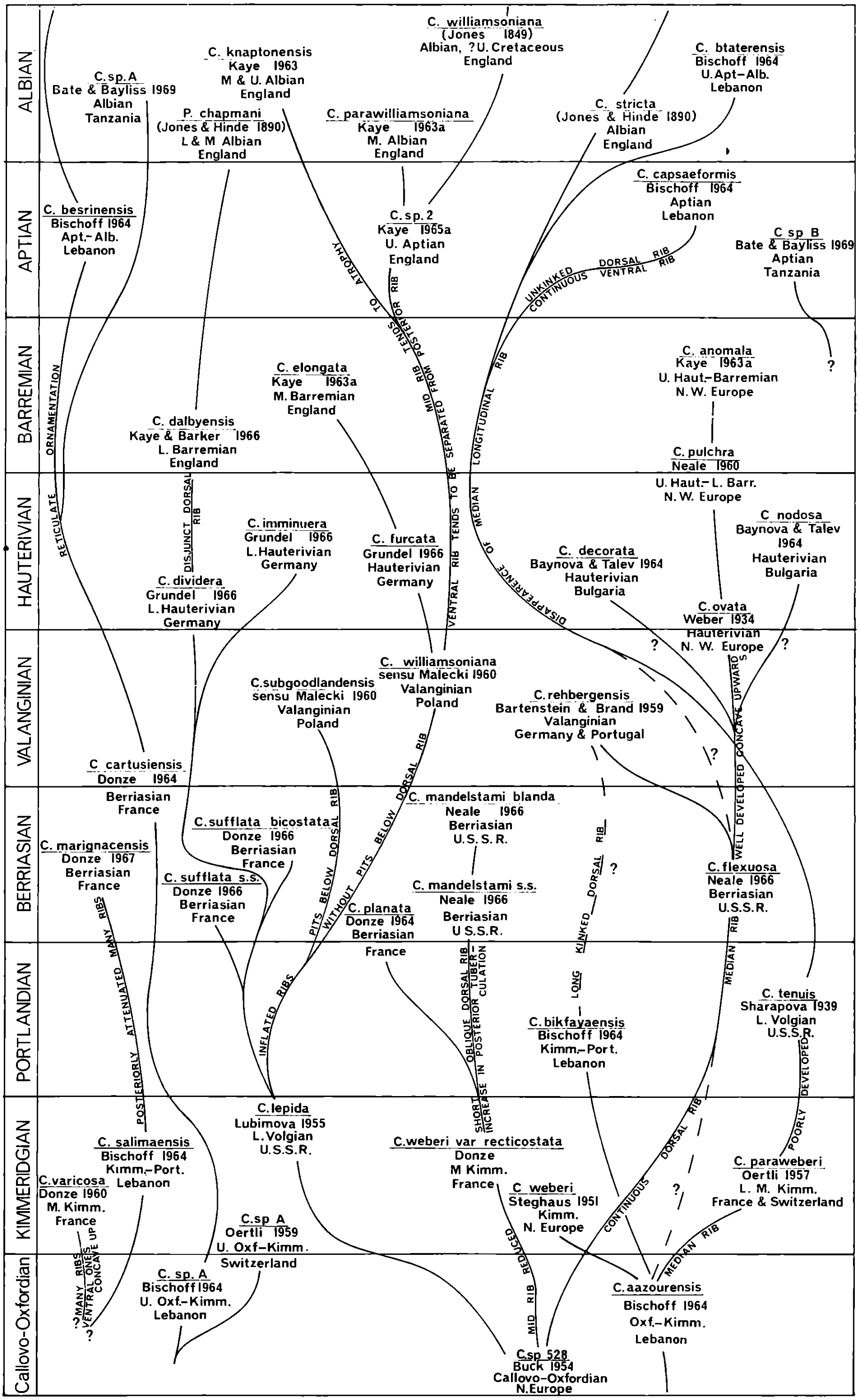

Fig. 2. Hypothetical phylogeny of some Upper Jurassic and Lower Cretaceous *Cytherelloidea.*

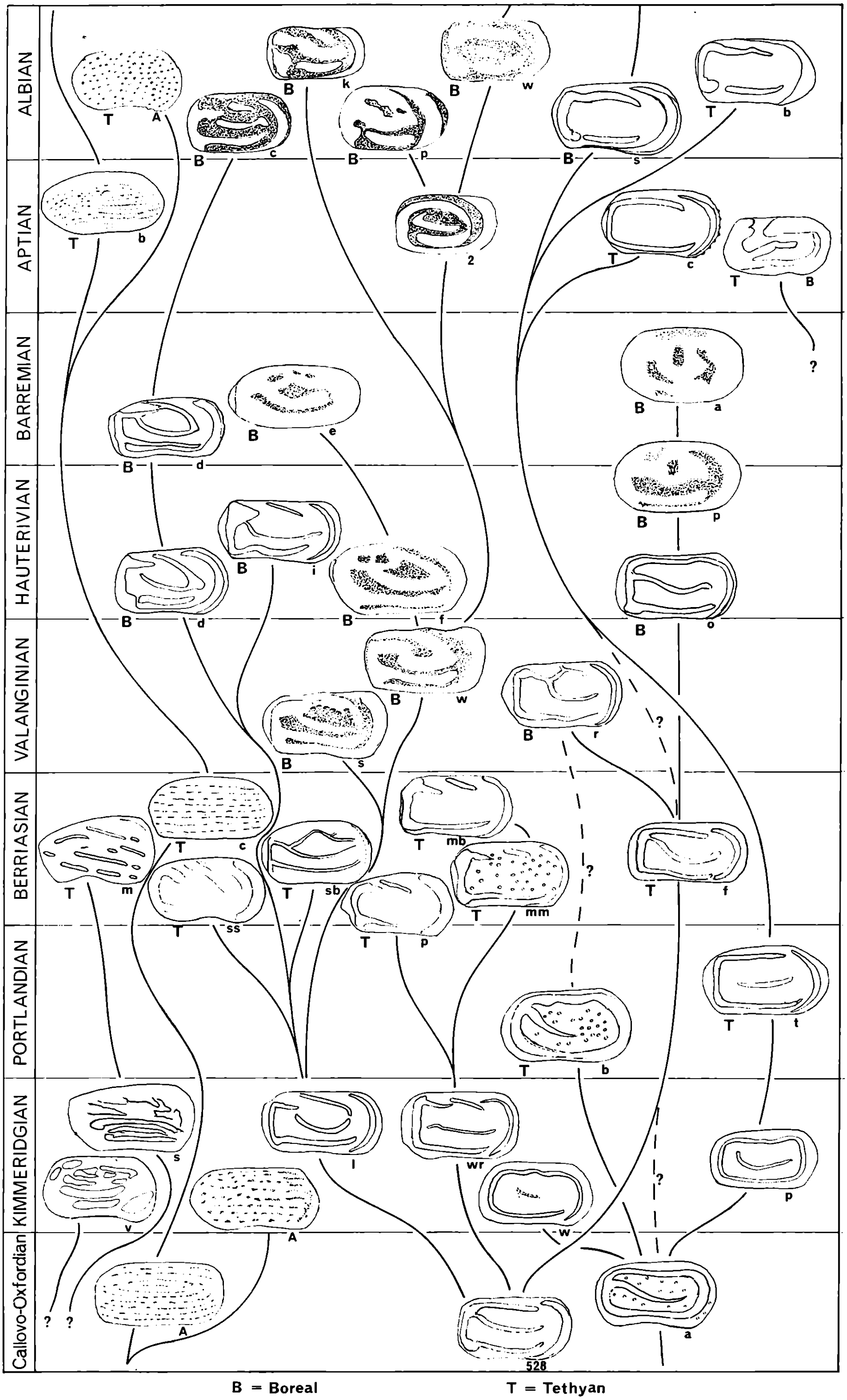

Fig. 2 (cont.). Small letters are initial letters of specific names.

other large groups would appear to merit similar attention, notably the *C. dividera*—*C. dalbyensis* line with its fine ribbed characteristic pattern, the inflated ribbed plexus culminating in *C. knaptonensis, C. parawilliamsoniana* and its allies, and the rectangular ribbed group which leads to *C. stricta.*

All this would provide an interesting programme of work for the future, but there is another reason for selecting *Cytherelloidea* as an example which bears on ecology. Little has been written specifically on the ecology of marine Lower Cretaceous Ostracoda in the Boreal Realm although they have been covered in part by Neale (1968, 1971) in Britain, and by Kemper in Germany whose latest paper (1971) makes some interesting suggestions concerning depth zonation. *Cytherelloidea,* however, is a genus that is alive today and we do know something of its ecological requirements. Sohn (1962) has studied this and extrapolated back to the Upper Cretaceous. He concluded that unlike the allied *Cytherella* it is essentially a warm water genus with a minimum temperature requirement of approximately 10°C. If one may assume the same requirements in the past as today, one may thus regard it as a warm water indicator and reference to Figure 2 brings to light some interesting facts.

Whilst *Cytherelloidea* is well known in the uppermost Jurassic and Berriasian of Tethys it is unknown in the Boreal Realm to the north at this time. It appears at the top of the Berriasian in Portugal and in the Valanginian of Poland and Germany, and makes it first appearance in Britain in the Hauterivian. If our inferences are correct, then this implies a warming up of the seas which extends northwards in early Cretaceous time and at the same time suggests a temperature gradient from south to north. Now it is known that temperature as an ecological factor is second only to salinity in affecting the distribution of ostracods and thus it seems likely that most of the differences between Tethyan and boreal faunas in late Lower Cretaceous times can be explained in terms of temperature rather than by geographical isolation. Andreev and Mandelstam (1971) have already suggested that temperature-climatic zonation governed the dispersal of marine ostracods in the analagous case of Tethys and western Siberia in the early Cretaceous.

Study of *Cytherelloidea* raises another interesting point for the occurrence of *C. rehburgensis* in both Portugal and Germany has already been noted. No *Cytherelloidea* have yet been found in either the Berriasian or Valanginian rocks of Britain and so it seems that in this case intercommunication between the two former areas must have been through Tethys and not through the boreal area.

5. Conclusions

In Britain, as in north-west Europe generally, the boreal marine Ostracoda provide an excellent means of correlating the Lower Cretaceous rocks at the stage level and finer divisions may also be recognised. The first stage of palaeontological investigation, that of taxonomic analysis, is almost complete. The second stage involving detailed comparative studies requires co-operation and joint projects and it is to be hoped that this Symposium will foster such co-operation between workers in both western, central and eastern Europe and in the Boreal and Tethyan Realms. When this is accomplished we can move forward to the final stage of synthesis. This, coupled with detailed phylogenetic studies of individual genera, augurs well for the stratigraphical correlation of the Lower Cretaceous in the European area.

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Palynological time-correlation of English Wealden with boreal marine successions

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Using palynological samples from the Sandringham Sands of Norfolk, and from the Claxby and Fulletby successions of Lincolnshire, time-correlations are made with the reference scale of the Warlingham borehole Wealden Beds. The fossils are mainly from the group *Cicatricosisporites* and are handled by a recently described method (see Hughes and Moody-Stuart 1969) for detailed correlation. Some theoretical difficulties are briefly discussed; these include the nature of the uncertainty and the step correlations required in correlating fresh-water with marine strata.

Auf der Basis von palynologischen Proben aus den Sandringham Sanden von Norfolk und aus den Claxby- und Fulletby-Abfolgen von Lincolnshire wird eine Korrelation mit dem Standard-Profil der Wealden-Beds, der Warlingham-Bohrung, durchgeführt. Die zur Korrelation benutzten Fossilien gehören hauptsächlich zur Gruppe des *Cicatricosisporites*. Sie werden nach einer kürzlich beschriebenen Methode (Hughes and Moody-Stuart 1969) zur Feinstratigraphie herangezogen. Einige theoretische Schwierigkeiten werden kurz diskutiert. Dazu gehören der Grad der Unsicherheit und die nur schrittweisen Korrelationen, die sich bei einem Vergleich von Süßwasser- mit marinen Folgen ergeben.

L'analyse palynologique de prélèvements effectués dans les Sables de Sandringham en Norfolk et les formations de Claxby et Fulletby en Lincolnshire, permet d'établir des corrélations chronostratigraphiques avec l'échelle de référence des séries wealdiennes du forage de Warlington. Les organismes appartiennent principalement au groupe de *Cicatricosisporites* et sont traités suivant une méthode récemment décrite (Hughes and Moody-Stuart 1969) en vue de corrélations détaillées. La discussion de quelques difficultés théoriques est brièvement abordée; celles-ci ont trait à la nature de l'incertitude et à la progression échelonnée caractéristiques des corrélations entre formations marines et d'eaux douces.

1. Introduction

An important local requirement in Britain is for detailed time-correlation of the virtually non-marine Wealden succession of southern England with the traditional international stratigraphical scale of the marine Cretaceous of Europe. As a preliminary step, a generalised correlation was made on tectonic and sedimentary grounds (Allen 1955), in particular to refute certain erroneous German correlations for the English rocks (see also Anderson and Hughes 1964).

With the possible exception of occasional euryhaline ostracods or acritarchs, detailed time-correlation between these very different facies must rely on fossil plant data, principally from miospores. In practice there is such a large gap of outcrop failure and of stratal removal between the Weald and southern France, that correlation of the Wealden with the marine successions of northern England (Lincolnshire and Yorkshire) is more feasible. This paper provides a partial palaeobiological framework which amplifies and to some extent corrects the correlations made earlier with northern England (Hughes 1958); the present uncompleted work continues and it now benefits from the much greater knowledge of the marine successions published in the last decade.

2. Palynological method employed

The palynological information available in 1958, including that of Couper (1958), was of reconnaissance grade for the Wealden; there was therefore only the possibility of coarse stratigraphical subdivision of the Wealden itself. By subsequently using much more data from selected categories only, more detailed internal correlations between separate Wealden sequences have been obtained (Hughes and Moody-Stuart 1967b, 1969; Hughes and Croxton, 1973). The method (see Hughes and Moody-Stewart 1969) was designed for continuous refinement as new data became available, and involved strongly-based taxa without priority (biorecords), comparison records of stated significance, and correlation brackets of palynological events in the reference sequence. Except that it is slow and therefore data selection is of prime importance, the method produces satisfactory results. These results may subsequently be combined into presentations as zonal schemes if the number of correlations is sufficient (de Jekhowsky 1958); such zonal presentations are however not relevant to improved correlation, and in fact hinder it as they tend to freeze effort at their own level of achievement.

Involved in the correlations so far made in the Wealden is the problem of interpretation of palynological facies (Hughes and Moody-Stuart 1967a; Batten 1972, 1973). Facies interpretations have yet to be extended (Hughes and Pacltova 1972) into the fully marine environment. In brief the miospores most favourable for correlation within the Wealden may be rare or poorly preserved in the marine margin; *Cicatricosisporites* for instance, is found in ferruginous oolith and other marine sedimentary facies but the numbers available and more particularly the locality frequency may cause the acceptance of a lower standard of probability for correlations. Other palynomorphs such as the bisaccates which might serve better in this situation have not yet been closely enough studied, nor has there been relevant success in extracting usable characters from them.

The time-correlations given below in this interim work are therefore of mixed origin, depending partly on recently erected biorecords, and partly on older taxa. They are presented however in a form capable of subsequent refinement.

3. Documentation of events for time-correlations

No new taxa are erected. The events are numbered and should be treated as in Hughes and Moody-Stuart (1969). Figure 1 shows the reference scale, those parts of the sequences that are relevant to this paper, and only the actual correlations as unbroken lines across the chart; dashed lines represent uncertainty of definition, and the vertical placing in each column of formation names and samples numbers implies approximation but not time-correlation.

The Warlingham events are presented in detail in Hughes and Moody-Stuart (1969) (events 1–70), and in Hughes and Croxton 1973 (events 71–115). Selected events from Norfolk and Lincolnshire successions (see Fig. 1) are described in terms of fossil content, preparation and sample data:

116 Event *NC49*, 01 06 72 CICATR: 41 % cfA 1 *AT*, 51 % cfA 4 *AW*, 6 % cf. 3 *AR*, 2 % cf. 7 *Cl*.
Preparation. V270/2: 5 mins HN03. Palynological facies: 8 % other pollen, 6 % *Classopollis*, 49 % bisaccates, 34 % 'other ferns', 3 % *Cicatricosisporites;* fern spore size index 51 : 42 : 07. Sample: NC49, Norfolk, West Dereham Cut, TL653997, 300 metres west of Abbey Station, 4 metres below working surface; high in *Hectoroceras* beds, 1·5 metres below prominent sandstone; light grey, unconsolidated fine quartz sand, well-sorted 80–100μm, glauconite.

117 Event *C/RC/5*, 26 05 72 CICATR: 83% cfA 4 *AW*, 2% cf. 1 *AT*, 13% cf. 3 *AR*, 2% cf. 7 *Cl*.
Preparation. V267/2; 10 mins HN03. Palynological facies: 16% other pollen, 3% *Classopollis*, 43 % bisaccates, 37 % 'other ferns', 1 % *Cicatricosisporites*; fern spore size index 52 : 37 : 11. Sample: C/RC/5, Norfolk, King's Lynn by-pass cutting, TF652201, west of Mintlyn Wood; *Surites* zone, Bed 11 (coll. R. Casey); medium grey, unconsolidated fine quartz sand, unsorted 50–300μm, glauconite.

118 Event *CL33*, 07 09 72 CITCATR: present in order of decreasing abundance—cfA 4 *AW*, cfA 1 *AT*, cf. 7 *Cl*, cf. 6 *B5*, cf. 8 *C2*, cf. 9 *AP*.
Preparation. V057/1; 30 mins HN03. Palynological facies: 32% other pollen, 5% *Classopollis*, 11 % bisaccates, 44% 'other ferns', 4% *Cicatricosisporites*; fern spore size index 50 : 38 : 12. Sample: CL33, Lincolnshire, Hundleby brickpit (Swinnerton 1941, p. 204); Hundleby Clay; grey-brown siltstone 20–30μm, ferruginous ooliths 200–300μm.

119 Event *II ucz*, 19 04 57 MONOSULC: *Clavatipollenites* identified from several specimens.
Preparation. BP55/2, 4: 6 hrs HN03. Palynological facies: 30% other pollen, 2% *Classopollis*, 18 % bisaccates, 11 % 'other ferns', 1 % *Cicacricosisporites*, 38 % dinoflagellates and acritarchs. Sample: II ucz, Lincolnshire, Alford Pumping Station borehole (1932), depth 46·1–48·8 metres (151–160 feet); near base of Lower Roach, lower Fulletby Beds; grey fine siltstone, ferruginous ooliths 300μm, plant fragments >500μm, small marine bivalve shells.

120 Event *II k*, 09 09 72 CICATR: high % cf. 25 Cicatr *B21* and cf. 28 *DG* (see Hughes and Croxton 1973).
Preparation. BP41/2,5: 7 hrs HN03. Palynological facies: 18% other pollen, 3% *Classopollis*, 34% bisaccates, 33% 'other ferns', 3% *Cicacricosisporites*, 9% dinoflagellates and acritarchs. Sample: II k, Lincolnshire, Alford Pumping Station borehole (1932), depth 39·3–39·6 metres (129–130 feet), top of Lower Roach, lower Fulletby Beds; grey siltstone, few ferruginous ooliths, plant fragments, mica flakes. This event and the last are based on old preparations, and although the observations concerned in the events have been recently checked, it appears likely that with new preparations the correlation brackets can be improved.

4. Time-correlation statements

116 Event *NC49*: between events 4 *WM 1987/1-3* and 10 *WM 1945*; on predominance of cfA 1 *AT* and cfA 4 *AW*, with only dubious cf. 7 Cl.

117 Event *C/RC/5*: between events 10 *WM 1945* and 14 *WM 1924/8-9*; on predominance of cfA 4 *AW*, and the presence of cf. 7 *Cl*.

118 Event *CL 33*: between events 30 *WM 1873/8* and 43 *WM 1819/5*; on presence of both cf. 8 *C2* and cf. 6 *B5*; further observation of the same taxa will shorten this bracket. This correlation cancels an earlier one using this sample (Hughes 1958).

119 Event *II ucz*: between WM 1415/6 and WM 1333/10; on the first appearance in this section of *Clavatipollenites hughesii*.

120 Event *II k*: between WM 1333/10 and event 103 *WM* 1060/9; on the presence of cf. 25 *B21* cf. 28 *DG*.

The above correlation statements are made in the same form as those in Hughes and Moody-Stuart (1969), with the intention that they should be refined later by the author or by others.

5. Comment on published work

As explained in Hughes (1971) it has not proved possible to use for this special stratigraphical purpose the taxa previously erected in this field.

The description of the palynology of the original type localities of Valangin and Hauterive in Switzerland (Millioud 1967) is a reconnaissance work which is valuable for facies indications, but which has very limited correlations value; the taxa used (for example) for the *Cicatricosisporites/Appendicisporites* group are so poorly

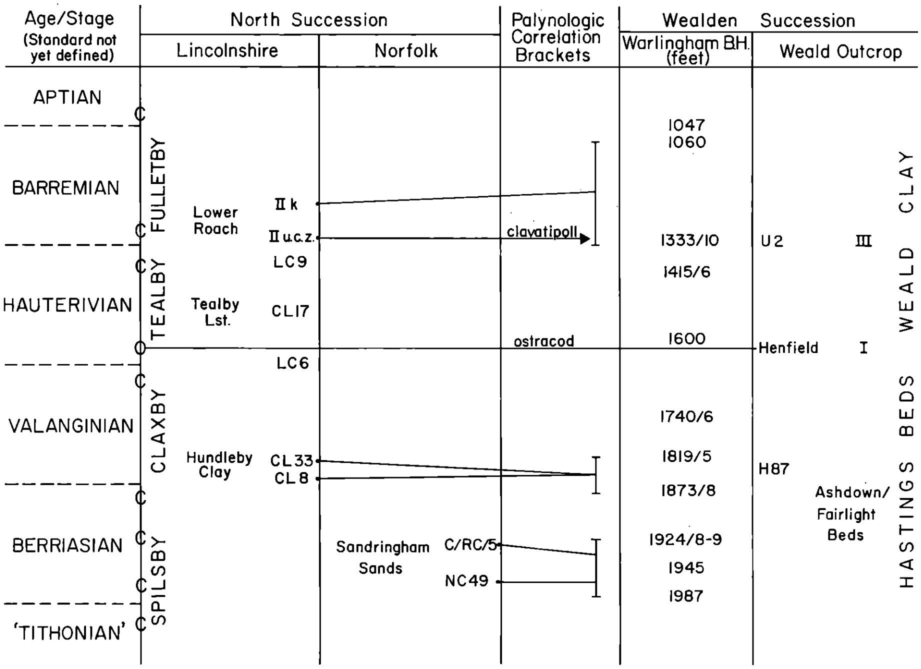

Fig. 1. Palynological time-correlations between English 'Boreal' successions and the Wealden succession at Warlingham borehole. C = cephalopod correlations from Lincolnshire to reference scale sections at Speeton or abroad: 0 = the ostracod occurrence of *Orthonotacythere diglypta* Triebel reported by Anderson *et al.* (1967, p. 191). This table is intended only as a basis to which future correlation will be added.

based (by their original authors) or have been extended to such long ranges that they give no indication of age better than 'early Cretaceous'. This is a criticism of the general system, not of the author concerned (see also discussion in Hughes and Moody-Stuart 1969 p. 106).

Burger (1966) was, not surprisingly for the time, much concerned with identifying the Jurassic/Cretaceous boundary; this however remains meaningless or impossible until such a boundary is finally designated for the Standard Scale by the Stratigraphy Commission of the International Union of Geological Sciences (I.U.G.S.); until then there can be no palaeobiological basis for recognising such a boundary. Correlation between rocks can however proceed without reference to the Standard Scale, and it is possible to make sufficient interpretations of Burger's taxa and distributions to correlate his Dutch strata with the lower part of the English Wealden. Neither this work, nor that of Döring (1965) appear to use sufficiently narrow-based taxa to be of service in time-correlations with the marine strata.

6. Some difficulties

6a. Standard stratigraphical scale

Neither the period/system boundary nor the age/stage boundaries have yet been agreed and ratified by the I.U.G.S. Stratigraphy Commission, and therefore there is as yet no standard scale. The Jurassic/Cretaceous boundary at present is part of what can be called a traditional stratigraphical scale, which is broadly understood but lacks boundary definitions; the final selected section and point may of course be outside Europe. The various age/stage boundaries are each uncertain in definition in different ways, and are not by any means ratified. All scale boundaries in Figure 1 are therefore shown by broken lines as undefined. Logically perhaps the whole left-hand column should be omitted.

6b. Northern England succession

Despite elaborate zonal work and correlation with northern countries by Casey, Neale, Kaye and Rawson, the precise time-correlation with the French succession (less its boundary definitions) must remain uncertain. Parts of the Lincolnshire and Norfolk successions are selected here for palynological purposes, but the correlation with Yorkshire (Speeton) is scarcely complete. Purely for the purposes of this diagram (Fig. 1) therefore the principal sectors of effective cephalopod correlation are shown by letters across the vertical line between Lincolnshire and the scale.

6c. Theoretical considerations

The samples here taken in Lincolnshire and Norfolk are time-correlated to an event bracket on the Warlingham borehole Wealden scale; similar samples from the same succession are taken to have been correlated (in the past) with Speeton using cephalopods and these can be taken to have been expressed as event brackets as shown in Figure 2A. However, as indicated by the direction arrows on the lines these correlations are one-way and cannot be taken for instance to give information on the time-correlation of sample WM 1845 (within the bracket) with Lincolnshire, let alone with Speeton. On the facts given in the diagram WM 1845 could be considerably earlier than D4C at Speeton if CL33 proved to correlate closely with WM1819/6 and with D4C. This also appears if the time position of CL33 is

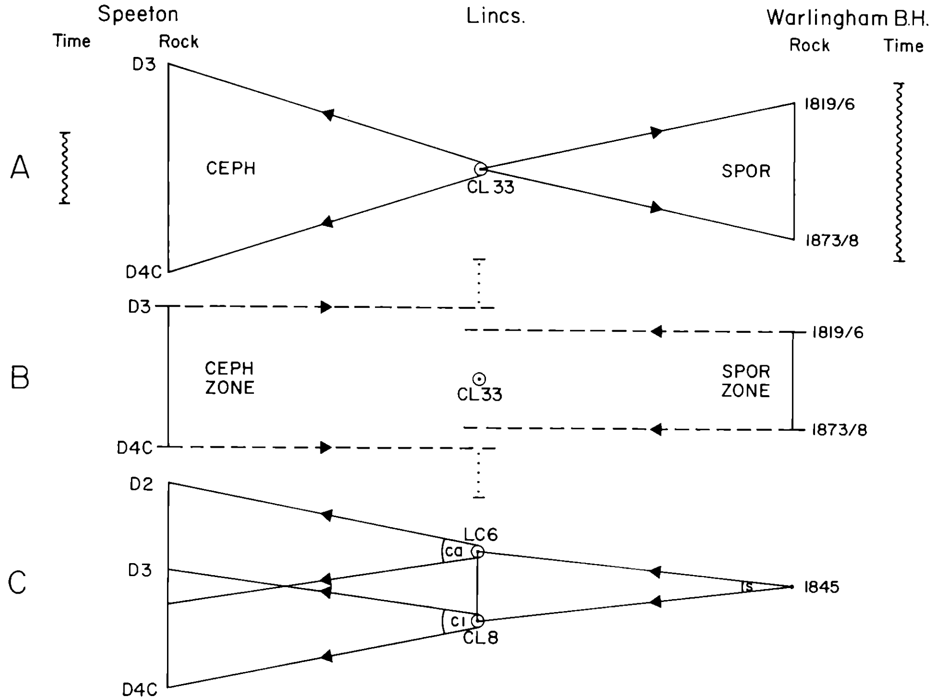

Fig. 2. Diagrammatic representation (only) of theoretical difficulties of correlation between entirely separate facies through a mixed facies. A, type of statements made in this paper; B, expression of such statements through biozones; C, sequential correlation statements actually required for the possibility of meaningful refinement.

expressed (Fig. 2B) in terms of palynological or cephalopod biozones i.e. if the uncertainties are added.

For the true time-correlation of the point WM 1845 in terms of a stratigraphical scale it is necessary to proceed in steps (Fig. 2c). This means that the Lincolnshire rock section would have to be described palynologically in full, at least for agreed selected characters. Then, as shown in Figure 2C, WM 1845 could be expressed as correlated against a time bracket of events LC6 and CL8. Points in this Lincolnshire succession could be correlated by brackets as shown with Speeton. Uncertainty in the two steps is cumulative and therefore the aim must be to reduce all the angles subtended on the diagram by the brackets.

No such correlationof non-marine to marinecan bemade without two steps but as far as possible any additional steps should be avoided. The diagrams (Fig. 2) are given solely to discuss the principle and are not to be taken to conflict with the actual time-correlations to date as shown in Figure 1.

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The ammonite succession at the Jurassic-Cretaceous boundary in eastern England

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Eastern England (Spilsby province) is the only region in northwest Europe where a sequence of ammonite faunas may be followed across the Jurassic-Cretaceous boundary. Ten chronozones ranging from high Middle Volgian to topmost Ryazanian (Tithonian-Berriasian) are established in the Spilsby Sandstone (Lincolnshire) and Sandringham Sands (Norfolk) and arranged in a new zonal scheme that illuminates occurrences in Siberia and eastern Europe. The basal Speeton Clay (Yorkshire) is placed high in the Ryazanian. Assimilation of the Spilsby province into the North Sea basin system was marked by the arrival in England of basal Valanginian ammonites of Russo-German affinities.

Ost England (die Spilsby Region) ist das einzige Gebiet NW Europas, in dem die Jura-Kreide-Grenze in einer Ammoniten führenden Abfolge verläuft. Zehn Chronozonen können vom hohen Mittel Wolga bis zum obersten Ryazan (Tithon-Berrias) im Spilsby Sandstone (Lincolnshire) und in den Sandringham Sands (Norfolk) unterschieden werden. Mit Hilfe dieses neuen Zonenschemas ist auch eine neue Wertung der äquivalenten Ablagerungen in Sibirien und Ost Europa möglich. Der tiefe Speeton Clay (Yorkshire) muß in das hohe Ryazan gestellt werden. Die Einbeziehung der Spilsby Provinz in das Beckensystem des Nordsee-Raumes wird gekennzeichnet durch das Auftreten von frühen Valangin-Ammoniten, die deutliche Beziehungen zu russischen und deutschen Gruppen erkennen lassen.

L'Angleterre orientale (province de Spilsby) est la seule contrée d'Europe du Nord-Ouest où une séquence faunique d'Ammonites peut être suivie de part et d'autre de la limite Jurassique-Crétacé. Dix chronozones s'échelonnant du sommet du Volgien moyen au Ryazanien le plus élevé (Tithonique—Berriasien) sont crées dans les Grès de Spilsby (Lincolshire) et les Sables de Sandringham (Norfolk) et disposées en un schéma zonal nouveau qui explicite les récoltes de Sibérie et d'Europe orientale. La base des Argiles de Speeton (Yorkshire) est placée à un niveau élevé du Ryazanien, Enfin, l'intégration de la province de Spilsby au Bassin de la Mer du Nord fut marquée au Valanginien basal par l'arrivée en Angleterre d'Ammonites d'affinités russo-germaniques.

1. Introduction

In eastern England the Kimmeridge Clay (Jurassic) is succeeded unconformably by a group of sands and clays which had long been regarded as marking the base of the British marine Cretaceous. Chief among these is the Spilsby Sandstone of Lincolnshire and its correlatives in Norfolk, the lower divisions of the Sandringham Sands. Poorly exposed, their fossils indifferently preserved, these beds have hitherto attracted little attention from palaeontologists. The age and systematic position of the few ammonites described from the Spilsby Sandstone continue to be a subject of international controversy.

Although the Sowerbys had illustrated ammonites from the Spilsby Sandstone as long ago as 1822–23, attempts to evaluate the fauna in terms of biostratigraphical correlation were not made until late in the century. It was then that A. P. Pavlov, the distinguished ammonite specialist of Moscow University, entered into collaboration with G. W. Lamplugh of the Geological Survey of the United Kingdom (now the Institute of Geological Sciences) in studying the Speeton Clay of Yorkshire and its presumed correlatives in Lincolnshire. Based on Pavlov's determinations of the ammonites (Pavlov 1889, 1896; Pavlov *in* Pavlov and Lamplugh 1892) and Lamplugh's interpretation of the stratigraphy (*ibid.* 1892; Lamplugh 1896), the conclusion was reached that the Spilsby Sandstone of Lincolnshire afforded a passage from the Jurassic to the Cretaceous. With the possible exception of Woodward (1895), who had described the Spilsby Sandstone as a marine equivalent of the Purbeck Beds, British geologists were unimpressed by Pavlov and Lamplugh's conclusions; the majority continued to take the view that the Jurassic record in eastern England was cut off abruptly in the Kimmeridge Clay and that the Spilsby Sandstone, Sandringham Sands and Speeton Clay marked the beginning of a new sedimentary cycle in the Cretaceous.

The idea that the topmost marine Jurassic with its distinctive fauna of craspeditid ammonites was missing, not only in Britain, but throughout the whole of northwest Europe, received its greatest support from the writings of Spath (1924a). This author rejected Pavlov's determination of an Upper Volgian ("Aquilonian") *Craspedites* in the Spilsby Sandstone and declared the ammonite to belong to a different genus, *Subcraspedites,* to which he referred also the Sowerbys' *A. plicomphalus*, Pavlov's *Olcostephanus stenomphalus* and certain species from the Cretaceous Ryazan Beds of the Moscow region. This position was reaffirmed in 1935, when Swinnerton described the ammonites found in two successive beds near the base of the Spilsby Sandstone in a boring at Fordington, a few kilometres north of Spilsby. Though some of the ammonites found only a few centimetres above the Kimmeridge Clay (and named *Paracraspedites*) looked remarkably like Jurassic pavloviids, their association with *Subcraspedites* and supposed similarity to forms from the Ryazan Beds were thought to establish the Cretaceous age of the assemblage. Subsequently the name *Paracraspedites* was applied to ammonites from the lowest Cretaceous of Greenland, the Moscow Basin, West Siberia, Transcaspia (Spath 1947, 1952; Donovan 1957; Sazonova 1961; Arkell 1957; Saks *et al.* 1963; Luppov and Drushchits 1958), and the Speeton Clay of Yorkshire (Neale 1962). For forty years the Spilsby Sandstone thus assumed international status as the type-horizon for the basal Cretaceous "Subcraspeditan Age" and its index-fossils. Such was the confidence with which this position was accepted that the student reading the chapter on the Jurassic-Cretaceous boundary in Arkell's monumental "Jurassic System in Britain" (1933) would be unaware that different ideas had ever been entertained.

Ten years ago I offered a short paper outlining my reasons for believing that *Paracraspedites* was merely the nucleus of a Portlandian-type pavloviid, well down in the Jurassic, and that *Subcraspedites* was also a Jurassic ammonite (Casey 1962). The views then expressed were further elaborated by a revised correlation whereby the basement-beds of the Spilsby Sandstone and Sandringham Sands were linked to the Upper Lydite Bed at the base of the Portland Beds of the southern Midlands and the newly-defined base of the marine British Cretaceous aligned with the "Cinder Beds" horizon in the middle of the Purbeck Beds, traditionally regarded as wholly Jurassic (Casey 1963). During the intervening years I have been given the opportunity to pursue this research both at home and in the U.S.S.R., picking up the threads where Pavlov and Lamplugh left off. The original museum material on which my conclusions were based has been augmented by collections from new exposures, especially in Norfolk, where excavations for waterways, roads and gas pipelines have revealed a substantial body of stratigraphical and palaeontological information (Casey 1971; Casey and Gallois 1973). In the meantime, the discovery of *Paracraspedites* in the Portland Beds of Dorset (Casey 1964), re-assessment of the Greenland occurrences of *Subcraspedites* (Donovan 1964) and independent dating of the "Cinder Beds" horizon as basal Cretaceous (Bielecka and Sztejn1966; Anderson, this volume) have confirmed the essential details of this correlation. Nevertheless, in the absence of fuller documentation and illustrations, scepticism concerning my interpretation of the ammonite chronology has been voiced in some quarters (e.g. Jeletzky 1965). In a recent authoritative work on the Jurassic-Cretaceous boundary in the Boreal Realm (Saks *et al.* 1972) the Spilsby Sandstone is still dated as wholly Cretaceous on the strength of misidentified Siberian ammonites. The first aim of the present paper is therefore to illustrate and discuss the field and laboratory evidence on which the Spilsby succession is based.

It is shown below that the Spilsby Sandstone and the equivalent parts of the Sandringham Sands contain an unexpectedly full sequence of ammonite faunas spanning the Jurassic-Cretaceous boundary. Although the sedimentary and faunal facies of these deposits are closely parallelled in the Russian Platform (Casey 1971), the sequence also combines elements of the Greenland and Siberian successions. It is thus a key sequence for international correlation and is especially critical in the present state of knowledge for integration of the classic occurrences of the Moscow region with those currently being brought to light in Siberia.

2. Stratigraphical and zonal succession

2a. Zonal classification

The observed distribution of ammonites in the Spilsby Sandstone and correlated strata in eastern England permits the division of the succession into 10 chronozones spanning the Jurassic-Cretaceous boundary, as follows:

	Substages	Chronozones
Cretaceous	Upper Ryazanian	*Peregrinoceras albidum**
		Surites (*Bojarkia*) *stenomphalus*
		Surites (*Lynnia*) *icenii**
	Lower Ryazanian	*Hectoroceras kochi*
		*Runctonia runctoni**
Jurassic	Upper Volgian	*Subcraspedites* (*Volgidiscus*) *lamplughi**
		Subcraspedites (*Subcraspedites*) *preplicomphalus**
		Subcraspedites (*Swinnertonia*) *primitivus**
	Middle Volgian (pars)	*Paracraspedites oppressus**
		Titanites giganteus

In view of the fact that seven of these zones (marked *) are named for the first time, it should be explained that this extended zonal sequence is not a result of splitting of previously established zones. It results from the recognition of ammonite faunas previously undescribed or wrongly placed in the succession. The scheme here presented is, in short, an amplification of knowledge of the ammonite chronology and offers a more refined instrument for both national and international correlation than hitherto. Nevertheless, the Spilsby Sandstone and its equivalents in Norfolk, the Roxham, Runcton and Mintlyn Beds, represent a condensed, marginal facies, their remanié nodule-beds reflecting numerous breaks in deposition. It is unlikely that the sequence is complete. The top of the Volgian, for example, is eroded all over the region and it is possible that neither the highest Jurassic nor the lowest Cretaceous is present. Minor breaks characterize the contacts of the *runctoni*, *kochi* and *icenii* Zones with superjacent strata.

The Upper Volgian-Ryazanian zones of the Spilsby Province are based on successive dominance of one genus or subgenus, in many cases to the exclusion of other ammonites. All these genera belong to a single boreal plexus, the Craspeditinae and their descendants (Tolliinae), and the successive faunas appear to offer examples of evolutionary progression; for example, the lineage starting with *Swinnertonia* and passing through *Subcraspedites* s.s. and *Volgidiscus* to *Runctonia* and *Hectoroceras*, and that from *Surites* (*Bojarkia*) to *Peregrinoceras*. In these circumstances the zonal scheme is more likely to reflect a true chronological sequence than is one based on heterogeneous immigrants.

The following stratigraphical section of the paper supplies the field evidence on which the zonal scheme is based. Its main purpose is to demonstrate the order of succession of the various assemblages. Where bounded by strata lacking ammonites, the limits of the zones are, naturally, arbitrary.

2b. Distribution of outcrops

The Spilsby Sandstone and its correlatives occupy a tract along the western margin of the group mapped as "Lower Greensand and Speeton Clay" on the 10 miles to 1 inch Geological Survey map on which Figure 1 is based. The whole region may be regarded as the emergent edge of a large synclinal structure ("Wolds Syncline" of Donovan 1963), the greater part of which lies below the North Sea. The outcrop falls naturally into three parts:

1. Speeton Clay (Beds E-D6) (Yorkshire), north of the River Humber.
2. Spilsby Sandstone (Lincolnshire), between the River Humber and The Wash.
3. Sandringham Sands (Roxham, Runcton and Mintlyn Beds), south of The Wash.

Fig. 1. Map of eastern England showing outcrop of strata between the Kimmeridge Clay and Gault/Red Chalk (based on Geological Survey 10 miles to 1 inch map).

The Speeton Clay area was marked off from areas of contemporaneous deposition to the south by an intermittently active positive region, the Market Weighton upwarp.

The lower D beds crop out for a few hundred metres along the slipped and faulted coastal section of the Speeton Clay at the southern end of Filey Bay, about 75 kilometres north of the nearest Spilsby Sandstone occurrence.

From a very narrow belt north of Caistor the outcrop of the Spilsby Sandstone widens as it trends southeastwards through Lincolnshire for another 50 kilometres, disappearing under the alluvium fringing The Wash a few kilometres beyond Spilsby. On the other side of The Wash the equivalent beds emerge as the Roxham, Runcton and Mintlyn Beds divisions of the Sandringham Sands. Their outcrop swings westwards to take up a north-south orientation across Norfolk and is traceable for about 50 kilometres to near Southery, at the southern boundary of the county.

A supposed outlier of Spilsby Sandstone at Elsham, north of Caistor, was shown by Kent and Casey (1963) to be a sandy lense in the Kimmeridge Clay (Elsham Sandstone).

2c. Sandringham Sands

An up-to-date account of the stratigraphy of the Sandringham Sands Group, with references to previous literature, is given by Casey and Gallois (1973). These authors divide the group into the following four formations, which provide a framework for discussion of the ammonite zonation:

Leziate Beds (up to 35 m) (Valanginian)	—predominantly incoherent quartz sands
Mintlyn Beds (up to 15 m) (Ryazanian)	—glauconitic clayey sands with bands of brown-weathering clay-ironstone and (especially near base) seams of phosphorite nodules
Runcton Beds (up to 2 m) (Upper Volgian)	—Bright green glauconitic clayey sands with much nodular phosphorite
Roxham Beds (up to 6 m) (Middle Volgian)	—Grey and yellow-green silty sands with pyrite. Persistent hard band at base incorporating derived Kimmeridgian debris

At the southern end of the outcrop the Ryazanian part of the sequence was probably bevelled off during the initial Valanginian transgression. More extensive erosion took place in the Aptian and Lower Albian and the beds are now truncated and overstepped southwards by the Carstone. In addition, there are ample signs of contemporaneous movements in the numerous internal erosion-surfaces, seams of phosphatic nodules and lateral variations in thickness. The most striking is the attenuation of the *kochi* Zone when traced northwards from West Dereham to King's Lynn; others are the localized distribution of the *runctoni* Zone and the areal disconformity at the junction of the Roxham and Runcton Beds (Fig. 2).

Natural exposures of the Sandringham Sands are few and knowledge of the stratigraphy has been built up over the last decade by observation of temporary openings. In the following summary of the succession the bed-numbers of Casey and Gallois (1973) have been retained.

(*i*). *West Dereham*

Excavations for the Fenland Flood Relief channel at West Dereham in 1961–2 provided an extensive section between Wissington Railway Bridge and Pratt's Bridge, Roxham (TL 662996 639995), as follows:

LOWER GREENSAND (CARSTONE) (ALBIAN)		Metres
Beds 19–31	Brown and grey pebbly sands and sandstone with some phosphatic nodules. Rare derived *Subcraspedites*.	c. 7·50
Bed 18	Basement-bed. Pebbles and nodules with residual crags and boulders of Mintlyn Beds. Remanié Lower Albian brachiopods and Lower Aptian ammonites; rare Hauterivian ammonites and *Hectoroceras* cf. *kochi kochi* Spath, *H.* cf. *kochi tenuicostatum* Spath, *H.* cf. *kochi magnum* Spath, *H. larwoodi* sp. nov. enclosed in nodules.	0·025 to 0·20
MINTLYN BEDS (LOWER MINTLYN BEDS)		
	Hectoroceras kochi Zone	
Beds 7–17	Glauconitic, sandy clay with bands of reddish-brown clay-ironstone and a few phosphatic nodules and lignite. Bivalves (mostly *Neocrassina* and *Myophorella*) abundant. *Hectoroceras kochi kochi*, *H.* cf. *kochi tenuicostatum*, *H.* cf. *kochi magnum*, *H.* spp. nov. (*Borealites* (*Borealites*) cf. *fedorovi* Klimova in bed 16).	6·00 to 6·45
Bed 6	Basal Cretaceous nodule-bed. Thickly clustered black phosphatic nodules (derived from destruction of Runcton Beds) in green sandy clay; fossil wood, remanié bivalves and ammonites—*Subcraspedites* (*S.*) *sowerbyi* Spath, *S.* (*S.*) *preplicomphalus* Swinnerton, *S.* (*S?*) *claxbiensis* Spath, *S.* (*S.*) spp. nov., *S.* (*Volgidiscus*) *lamplughi* Spath, *S.* (*V.*) spp. nov., *Craspedites* sp. Friable brown nodules with *Hectoroceras* spp. nov. and *Borealites*? sparsely distributed at top of bed. Channelled into Roxham Beds below.	0·15 to 0·30
ROXHAM BEDS		
	Paracraspedites oppressus Zone	
Beds 2–5	Grey-green, glauconitic, silty sands with pyritic nodules. *Paracraspedites oppressus* sp. nov., *P. stenomphaloides* Swinnerton, *P.* cf. *bifurcatus* Swinnerton, *P.* spp. indet., *Glottoptychinites? trifurcatus* (Swinnerton).	3·00 to 3·50
Bed 1	Grey, pyritic and glauconitic sandstone with derived Kimmeridgian *Pavlovia* and lydite pebbles at base.	0·15

(*ii*). *North Runcton*

The following section was measured in the No. 2 Gas Feeder Main trench at Manor Farm, North Runcton (TF 6515 1555):

UPPER MINTLYN BEDS		Metres
Bed 13	Lilac-grey clay with glauconitic "rafts" seen	1·00
	Surites (*Lynnia*) *icenii* Zone	
Bed 12	Buff and grey phosphatic nodules in grey-green, glauconitic sandy clay. *Surites* (*Lynnia*) *icenii* sp. nov. *S.* (*L.*) spp. nov.	0·05 to 0·10
Bed 11	Buff, sandy clay-ironstone. *Surites* (*Lynnia*) spp. nov.	0 to 0·10
Beds 9–10	Grey sandy clay with clay-ironstone at base.	0·45 to 0·55
LOWER MINTLYN BEDS		
	Hectoroceras kochi Zone	
Bed 8	Small phosphatic nodules clustered in glauconitic sandy clay. *Hectoroceras* sp.	0·05 to 0·10
Bed 7	Dark green, glauconitic, sandy clay.	1·00
	Runctonia runctoni Zone.	
Bed 6	Basal Cretaceous nodule bed. Gritty phosphatic nodules in glauconitic clayey sand. Irregular base. Ammonites in three types of preservation, (i) indeterminable shards of irridescent shell (? *Runctonia*), (ii) black phosphorite with traces of irridescent shell (*Runctonia runctoni* sp. nov., *R.* spp. nov., *Subcraspedites* (*Volgidiscus*) sp. nov)., (iii) black phosphorite only (*Subcraspedites* (*V.*) sp. nov.).	0·10 to 0·15

RUNCTON BEDS

	Subcraspedites (*Volgidiscus*) *lamplughi* Zone	
Bed 5	Vivid green glauconitic clayey sand.	0·15
Bed 4	Friable brown phosphatic nodules. *Subcraspedites* (*V.*) *lamplughi* *S.* (*V.*) spp. nov.	0·025 to 0·10
Bed 3	Dark green glauconitic clayey sand	0·75
	Subcraspedites (*Subcraspedites*) *preplicomphalus* Zone	
Bed 2	Rough black phosphatic nodules. *Subcraspedites* (*S.*) cf. *sowerbyi*.	0·15

ROXHAM BEDS

In this area the Roxham Beds may reach a thickness of 6–7 metres. The basal hard band, with *Paracraspedites*, was exposed in the No. 4 Gas Feeder Main trench (TF 6505 1710) about 1·9 kilometres north of the Manor Farm site. At Constitution Hill, 2 kilometres to the northwest, beds 5 and 6 of the Manor Farm section are combined into a single band of nodules at the base of the Mintlyn Beds (Casey and Gallois 1973).

(*iii*). *The King's Lynn Bypass*

A very important section through the Mintlyn Beds was made accessible during excavations for the King's Lynn Bypass in 1964, when the following was measured:

800 m N 40 W of Church Farm, Bawsey (TF 6563 2089)

		Metres
	Peregrinoceras albidum Zone	
	Buff clay-ironstone with brown weathered crust. *Peregrinoceras* sp. nov., *P.* cf. *albidum* sp. nov., *P.* cf. *pseudotolli* (Neale).	0·30
	Yellow-green clayey sand seen	0·60
Gap	... ... estimated	3·00

Western end of Galley Hill, west of Mintlyn Wood (TF 6508 1987–TF 6530 2010)

Beds 14–18	Buff, slightly glauconitic, clayey sands with clay-ironstone bands.	4·05
	Surites (*Bojarkia*) *stenomphalus* Zone	
Bed 13	Dark grey, glauconitic sandy clay with vivid green sandy bands.	1·60
Bed 12	Buff clay-ironstone. *Surites* (*Bojarkia*) *stenomphalus* (Pavlov), *S.* (*B.*) sp.	0·1 to 0·20
Bed 11	Glauconitic sands and clays with carbonized wood.	0·45 to 0·60
Bed 10	Lenses (up to 1 m.) of clay-ironstone with carbonized wood; fossils plentiful, mainly bivalves. *Surites* (*Bojarkia*) *tealli* sp. nov. *S.* (*B.*) spp.	0·15 to 0·20
Beds 7–9	Glauconitic sands and clays with *Chondrites*-type burrows and clay-ironstone in bands and "doggers". Indeterminable Tolliinae.	4·65 to 4·85
	Surites (*Lynnia*) *icenii* Zone	
Bed 6	Black, rolled phosphatic nodules resting on irregular surface of bed below. *Surites* (*Lynnia*) *icenii* sp. nov., *S.* (*L.*) spp. nov., *S.* (*Bojarkia*) sp.	0·05
Bed 5	Putty-coloured, sandy, clay-ironstone with semi-phosphatized knobs on upper surface. *Surites* (*Lynnia*) sp. nov.	0·10 to 0·20
Bed 4	Blue-green glauconitic clayey sand.	0·40
	Hectoroceras kochi Zone	
Bed 3	Small black and brown phosphatic nodules, much abraded, crowded in dark green clayey sand. *Hectoroceras* cf. *kochi*, *H.* spp. indet., *Borealites* sp. juv.?, in small fragments.	0·15 to 0·20
Beds 1–2	Brown and buff clayey sands, becoming greener below.	0·65

Ammonites being lacking in beds 13–18 of this section, the boundary between the *albidum* and *stenomphalus* Zones is drawn at an arbitrary level. Excavations on the nearby Fairstead Estate (TF 6430 1945) permitted the succession to be followed downwards through the basal Cretaceous nodule-bed, Runcton Beds and Roxham Beds to the Kimmeridge Clay. Here the basal hard bed of the Roxham Beds yielded fragmentary *Paracraspedites*. Only rolled *Subcraspedites* (*Volgidiscus*) spp. were found in the limited exposure of the basal Cretaceous nodule-bed, suggesting a condensed and reworked *lamplughi-runctoni* horizon as seen at Constitution Hill. From the single line of nodules which represents the tail-end of the *kochi* Zone at Castle Rising, 6 km N.E. of King's Lynn, W. Whitaker collected *Hectoroceras* cf. *kochi* during the original survey in 1883. Erratic blocks of basal Roxham Beds/Spilsby Sandstone are particularly abundant in the Drift deposits capping the massive British Industrial Sand pits at Leziate (Bawsey) (TF 675193). These have yielded *Paracraspedites oppressus* sp. nov., *P. stenomphaloides*, *P.* cf. *bifurcatus*, *P.* spp nov., *Glottoptychinites? trifurcatus*, the belemnite *Acroteuthis*, the brachiopod *Rouillieria ovoides* (J. Sowerby) and a rich assemblage of bivalves, largely undescribed.

2d. Spilsby Sandstone

The name Spilsby Sandstone was used by Strahan (1886) for the group of strata between the Kimmeridge Clay and the Claxby Beds of Lincolnshire which Dikes and Lee (1837) had called "Greensand and Sandstone" and Judd (1867) "Lower sand and sandstone". This usage anticipated the formal proposition of the name by Jukes-Browne in the Geological Survey Memoir of 1887. The group has its fullest development in the southern part of the Wolds, where, mainly on the evidence of boreholes and road-cuttings, Swinnerton (1935, 1936) recognised a tripartite division, as follows:

Spilsby Sandstone	Ferruginous Grit	1 m
	Glauconitic Sands	22 m
	Basement Beds	1 m

Casey (1963) divided the group into a Lower Spilsby Sandstone and an Upper Spilsby Sandstone, taking as the dividing-line an important bed of nodules and pebbles (Mid-Spilsby nodule-bed)[1] about the middle of Swinnerton's Glauconitic Sands, first found by Dr. R. G. Thurrell. The stratigraphical classification used hereunder is as follows:

Upper Spilsby Sandstone	
5. Ferruginous Grit	Coarse, grey or brown pebbly sandstone with some iron-ooliths.
4.	Fine- to medium-grained buff, yellow and white sands with sparse calcreted "doggers", becoming coarser and greener near base.
3. Mid-Spilsby nodule-bed	Band of phosphatic nodules of several generations, with small pebbles, mostly chert.
Lower Spilsby Sandstone	
2.	Predominantly coarse, pebbly glauconitic sands and sandstone with calcreted "doggers". Few phosphatic nodules, mostly at top.
1. Basement-beds	Grey sandstone with phosphatic nodules. (Beds A-D of Swinnerton 1935).

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[1] In its original connotation (Casey 1963) the term Mid-Spilsby nodule-bed was extended to include the Basal Cretaceous nodule-beds of the Mintlyn Beds.

The Mid-Spilsby nodule-bed may be traced throughout the whole of the southern Wolds and was located in the IGS Skegness borehole (TF 5711 6398). Important changes in the succession take place along the outcrop, the whole of the Upper Spilsby Sandstone disappearing north of Tealby (Fig. 2). Where the Upper Spilsby Sandstone is developed, in the southern Wolds, its junction with the Claxby Beds (Hundleby Clay facies) is perfectly conformable and in places gradational. Erosion of the Lower Spilsby Sandstone must have commenced in the Ryazanian and continued in the Valanginian. During the Carstone transgression (Lower Albian) the Lower Spilsby Sandstone was denuded down to its base at the northern end of the outcrop.

Except for the calcite guards of belemnites, fossils are generally poorly preserved in these beds, the ammonites of the lower horizons being especially prone to distortion. Most of the older museum material was obtained from small quarries now defunct or from the spoil of the Bardney-Louth railway cutting and is invariably without precise stratigraphical data.

A key section through the Spilsby Sandstone was provided by a series of wells sunk for Boston Corporation Waterworks at Fordington, about 8 kilometres north of Spilsby (TF 416714), mostly by wells No. 1 and No. 2, sunk 3 metres apart in 1933 and 1934 respectively. Drilling commenced at 51·2 metres O.D. and the Spilsby Sandstone (about 22 m thick) was entered at depths of about 52 metres. The following summarized log combines information from both these wells and has been compiled from published sources (Swinnerton 1935, 1941), together with Swinnerton's palaeontological samples deposited in the British Museum (Natural History), the Institute of Geological Sciences and the Department of Geology, University of Nottingham, and specimens and data collected independently by the Borings Department of I.G.S.

CLAXBY BEDS

UPPER SPILSBY SANDSTONE

	Peregrinoceras albidum Zone	Metres
Bed 12	Ferruginous Grit. Hard grey ferruginous sandstone, coarse and pebbly. *Peregrinoceras albidum* sp. nov.	0·90
Bed 11	Grey clayey sand with marcasite	2·75
Bed 10	Hard grey glauconitic sandrock. *P. albidum, P.* cf. *wrighti* (Neale), *P.* sp., *Surites* (*Bojarkia*) sp.	4.10

	Surites (*Bojarkia*) *stenomphalus* Zone	
Bed 9	Fine to medium-grained, glauconitic, grey clayey sands with calcreted "doggers". *Surites* (*Bojarkia*) cf. *stenomphalus*	3·20

	Surites (*Lynnia*) *icenii* Zone	
Bed 8	Mid-Spilsby nodule-bed. Coarse, pebbly sand with phosphatic nodules, partly indurated. *Surites* (s.l.). sp.	0·60

LOWER SPILSBY SANDSTONE

	? *Subcraspedites* (*Volgidiscus*) *lamplughi* Zone	
Bed 7	Coarse glauconitic and pebbly sands becoming finer below	0·90

	Subcraspedites (*Subcraspedites*) *preplicomphalus* Zone	
Bed 6	Glauconitic, pyritous grey sand with calcreted "doggers". *Subcraspedites* (*S.*) *sowerbyi* (coarse form), *S.* (*S.*) spp. in "doggers".	5·65
Bed 5	Loose grey sand.	2·75

BASEMENT-BEDS

	Subcraspedites (*Swinnertonia*) *primitivus* Zone	
Bed 4	Hard grey calcareous sandstone, richly fossiliferous, fossils partly phosphatized. *Subcraspedites* (*Swinnertonia*) *cristatus* Swinn., *S.* (*Sw.*) *precristatus* Swinn., *S.* (*Sw.*) *primitivus* Swinn., *S.* (*Sw.*) *undulatus* Swinn., *S.* (*Sw.*) *subundulatus* Swinn. *S.* (*Sw.*) *parundulatus* Swinn., *S.* (*Sw.*) sp. nov. (= *S* aff. *subpressulus* Swinn. *non* Bogoslovsky).	0·30
Bed 3	Friable grey argillaceous sandstone with small phosphatic nodules. *Subcraspedites* (*Sw.*) cf. *cristatus*, *S.* (*Sw.*) cf. *intermedius* (Donovan), *S.* (*Sw.*) sp. juv. ("*preplicomphalus*" Swinnerton 1935 pl. iii fig. 2*a–b*, *non* fig. 1a), Gen. nov.? (between *Subcraspedites* and Dorsoplanitidae) spp. nov.	0·10
	Paracraspedites oppressus Zone	
Bed 2	Friable grey sand and sandrock, passing down into hard calcareous sandstone. *Paracraspedites oppressus* sp. nov. *P. stenomphaloides*, *P.bifurcatus*, *P.* spp. nov., *Glottoptychinites? trifurcatus*.	0·30
	Titanites giganteus Zone	
Bed 1	Band of black lydite pebbles and phosphatic nodules in hard grey sandstone. Burrows descend into bed below. Rolled Kimmeridgian *Pavlovia*. *Kerberites* cf. *kerberus* Buckman in grey phosphorite.	0·15
	Total	c. 22·00

KIMMERIDGE CLAY

(In the above section Bed 1 = Bed A and lower part of Bed B of Swinnerton 1935; Bed 2 = lower part of Swinnerton's Bed C and upper part of his Bed B; Bed 3 = upper part of his Bed C; Bed 4 = his Bed D).

The Basement-beds may be seen in the Lymn Valley, whence Dr. R. G. Thurrell collected from the basal nodule-bed *Kerberites* cf. *kerberus* and *Kerberites* sp. (in a grey sandy-clay phosphorite with nacreous test) along with the usual Kimmeridgian debris. *Subcraspedites* (*Sw.*) *cristatus* was also found. These beds, together with the lower part of the *preplicomphalus* Zone, were exposed in a road-cutting at Blue Hill, Partney, about 1·2 kilometres north of Spilsby (TF 401 675) (Oakley 1941). In addition to fossils of the *oppressus* and *primitivus* Zones, the following ammonites from the overlying "doggers" of the *preplicomphalus* Zone were collected by Swinnerton, Oakley and others: *Subcraspedites* (*S.*) *sowerbyi*, *S.* (*S.*) cf. *claxbiensis*, *S. preplicomphalus*, *S.* (*S*). sp. nov., and *Craspedites plicomphalus* (J. Sowerby). A similar assemblage has been found in old quarries and roadside exposures at Spilsby, Old Bolingbroke, Toynton, Holton, Salmonby and West Keal. In the southern Wolds the *lamplughi* Zone appears to be preserved only locally beneath the plane of erosion marked by the Mid-Spilsby nodule-bed. The complex character of this bed is clearly illustrated in the old quarry east of the Manor House (formerly The Rectory) at Winceby, near Horncastle (TF 321687). Here, a band of phosphatic nodules and pebbles, about 0·3 metres thick, rests on the guttered surface of the Lower Spilsby Sandstone (Fig. 2). The nodules yield fairly well-preserved *Subcraspedites* (*S*?) *claxbiensis* and *S.* (*S.*) cf. *sowerbyi* either in fragments in light-brown phosphorite or enclosed in friable whitish phosphorite. *Subcraspedites* (*Volgidiscus*) *lamplughi* occurs in rolled fragments, while *Surites* (*Lynnia*) *icenii*, *Surites* (*Surites*) cf. *spasskensis* (Nikitin) and *Surites* spp. are found in brown phosphorite, fragmentary, but with relatively slight abrasion. Unphosphatized *Surites* fragments occur in the matrix of the nodules, together with *Pholadomya* and other bivalves, the whole *mélange* representing an intensive episode of bottom-scour at the beginning of the Upper Ryazanian.

Outcropping crags in the fields northeast of Goulceby (TF 260797) yield *Subcraspedites* (*S.*) cf. *claxbiensis* and *Craspedites thurrelli* sp. nov. at an estimated 3 metres from the base of the formation, followed upwards by a horizon with phosphatized *Subcraspedites* (*Volgidiscus*) aff. *lamplughi.*

The best exposure of the Spilsby Sandstone and Claxby Beds in this area is found along the disused railway cutting between Benniworth and Donington-on-Bain, where the section detailed below may be examined in two high banks (TF 224825; 227824):

Claxby Beds (Hundleby Clay)		Metres
Bed 11	Deeply weathered brown clay seen	2·00
Bed 10	Buff rubbly iron-shot clay crowded with fossils, mostly bivalves.	0·57
Bed 9	Brown clay with iron-ooliths, streaks of iron-pan at top. [Presumed source of *Paratollia* cf. *kemperi* sp. nov., *Propolyptychites* sp. and *Pseudogarnieria* ("*Proleopoldia*") cf. *kurmyschensis* (Stchirowsky).]	0·60
Bed 8	Brown clay	0·24
Bed 7	Soft blue clay, yellow and brown weathering. Slip-plane at base.	0·28
Upper Spilsby Sandstone		
Bed 6	Pale yellowish (in places almost white) medium-grained sand, patchily cemented into sandrock; sparse calcreted "doggers". Source of *Surites* (*Bojarkia*) *stenomphalus*, *S.* (*B.*) *suprasubditus pavlovi* subsp. nov., *S.* (*B.*) spp. nov., *Buchia volgensis* (Lahusen). estimated	7·50
Bed 5	Coarse, pebbly ferruginous sandstone.	0·20
Bed 4	Medium-grained, yellow-brown sandrock.	0·24
Bed 3	Band of small quartz and chert pebbles.	0·05
Bed 2	Mid-Spilsby nodule-bed. Conspicuous band of small pebbles (mostly black and white chert) and phosphatic nodules, locally cemented into lumps.	0·10
Lower Spilsby Sandstone		
Bed 1	Coarse, pebbly sands and sandstone with scattered small pebbles of black chert; decalcified "doggers" full of *Entolium* near base; line of incipient whitish phosphatic nodules with *Subcraspedites* 0·15 metres from top. seen	2·50

Apart from belemnite phragmocones the Mid-Spilsby nodule-bed contains few fossils at this locality; phosphatic nodules are less in evidence than at Winceby, 16 kilometres to the southeast, and contact with the underlying sands is more regular.

This section and its fossils were mentioned briefly by H. Keeping (1882) and W. Keeping (1883 p. 64) and is of importance as the source of two ammonite faunas otherwise poorly known in Lincolnshire. Attributed variously to "Donington", "Benniworth", "Benniworth Haven" or "Little Benenden", the rich haul of fossils obtained from this railway cutting in the last century includes a suite of ammonites from near the base of the Claxby Beds [*Paratollia*, *Pseudogarnieria* ("*Proleopoldia*"), *Propolyptychites*] and another from the calcareous "doggers" of bed 6 (*stenomphalus'* fauna). The lectotype of *Surites* (*Bojarkia*) *stenomphalus* (Pavlov), labelled as from Donington, almost certainly came from here. Other localities which yielded the *stenomphalus* fauna to the early collectors are North Willingham, South Willingham and Tealby.

Owing to the slipped or faulted junction with the Claxby Beds, the Ferruginous Grit cannot be observed in this cutting, though it was seen by Dr. Thurrell in the roadside bank south of Asterby (TF 263789), where it yielded *Peregrinoceras* cf. *wrighti.* This horizon underlies the gravel-pits at Biscathorpe, about 2½ kilometres north of the Benniworth cutting, and unusually well-preserved fossils, including the ammonites *Surites* (*Bojarkia*) sp. nov., *Peregrinoceras albidum* sp. nov., *P. subpressulum* (Bogoslovsky) and allies, in a grey-green, pebbly, argillaceous matrix, are occasionally brought to the surface by the excavators. *Peregrinoceras* cf. *pseudotolli* (Neale) and congeneric forms occur in the clay-ironstone at the bottom of the Hundleby Clay in the old brickyard at East Keal (TF 370638). The same fauna, in a Hundleby Clay lithology, was found at an unspecified locality in the Wainfleet area.

A new sandpit opened at Nettleton Top Barn, southwest of Caistor (TF 108988), examined in collaboration with Mr. S. Kelly, gave a complete section through the Lower Spilsby Sandstone, as detailed below. The non-sequential junction with the Claxby Ironstone could be observed in trial trenches in the adjacent fields.

		Metres
CLAXBY BEDS (CLAXBY IRONSTONE)		
Bed 7	Basement-bed. Conglomerate of small quartz, lydite and derived phosphatized pebbles set in coarse sand and buff marl, pocketed into bed below. Abundant bivalves. up to	0·30
LOWER SPILSBY SANDSTONE		
	Subcraspedites (*Volgidiscus*) *lamplughi* Zone	
Bed 6	Coarse, pebbly, yellow-brown sands with partly decalcified "doggers" (up to 1 m); irregular top, about *Subcraspedites* (*Volgidiscus*) *lamplughi* Spath, *S.* (*V.*) spp., *S.* (*Subcraspedites*) sp. trans. to *Volgidiscus.*	2·50
	Subcraspedites (*Subcraspedites*) *preplicomphalus* Zone	
Bed 5	Coarse, pebbly, yellow-green sands with "carstone" in seams, concretions and interlaced veins.	3·80
Bed 4	Yellow-green, clayey sands with iron-cemented "doggers"	0·30
	Subcraspedites (*Swinnertonia*) *primitivus* Zone	
Bed 3	Band of grey-green and yellow-green, red-weathering, argillaceous sandstone with small pebbles, mostly in nests, and grey-buff-pinkish phosphatic nodules. *Subcraspedites* (*Sw.*) *primitivus*, S. (*Sw.*) *undulatus*, *S.* (*Sw.*) *subundulatus*, *S.* (*Sw.*) *precristatus.*	0·90 to 1·00
Bed 2	Grey-green clayey sands with sparse buff phosphatic nodules. ? *S.* (*Sw.*) *primitivus* (large fragments), *S.* (*Sw.*) *cristatus* (loose on tip).	1·10
	Titanites giganteus Zone	
Bed 1	Basement-bed. Grey-green, brown-weathering sandy clay with black and brown, white-skinned phosphatic nodules, some cemented into clotted masses by blue-grey, gritty phosphorite. *Kerberites* cf. *kerberus* and *Crendonites* sp. in matrix of cementing agent. *Pavlovia* spp., *Pectinatites* spp. in rolled fragments.	0·15
KIMMERIDGE CLAY		

The Zone of *S.* (*S.*) *preplicomphalus* appears to be represented here mainly by unfossiliferous sands and the *oppressus* Zone is lacking altogether. Between Caistor and Melton Ross the Carstone (Lower Albian) incorporates in its pebbly base phosphatized *Subcraspedites* (*Subcraspedites*) spp. and *S.* (*Volgidiscus*) spp., together with debris from the Spilsby Sandstone Basement-beds (rolled *Pavlovia* etc.). Judging by its matrix, the holotype of *S. claxbiensis* Spath (1936 p. 85) originated from the basal Carstone rather than from the Claxby Beds.

2e. Speeton Clay

The clays of the Speeton Cliffs in Filey Bay, on the Yorkshire coast, provide the most complete and best documented single section of the Lower Cretaceous in northwest Europe. Reviews of previous work on this important exposure have been published by Lamplugh (1924) and Swinnerton (1936). It will be unnecessary, therefore, to re-trace the history of controversy concerning the age of the basal beds and their relationship to the Spilsby Sandstone. Suffice to say that Spath's (1924a) assertion that the lowest ammonite bearing beds of the Speeton Clay are Cretaceous is upheld by the present investigation, while his view that these beds are younger than the Spilsby Sandstone requires only slight qualification. The discovery of Berriasian (Ryazanian) ammonites in the lower D beds of Speeton was reported by Neale (1962). He described and illustrated a large assemblage of crushed specimens under the generic names *Laugeites?*, *Paracraspedites, Subcraspedites* and *Tollia.* These were obtained from an interval about 3 metres thick (Beds D6–7) 0·8 metres above the basal nodule-bed ("Coprolite Bed") and 2·12 metres below Bed D4, with rare *Platylenticeras.* Neale believed that the vertical distribution of the ammonites showed a division into two horizons, beds with *Paracraspedites* and *Tollia* below and beds with *Tollia* but without *Paracraspedites* above. Furthermore, the evidence was thought to confirm that *Tollia tolli* pre-dated the *stenomphalus* fauna (as indicated in Spath's zonal table of 1924).

The Speeton fauna of Neale was listed and discussed briefly by Saks and Shulgina (1972 p. 94). Despite the crucial nature of this fauna in the Spilsby Sandstone controversy, no attempt was made by these authors to undertake a systematic revision of the ammonites in question, Neale's species merely being quoted under a more modern generic nomenclature. Saks and Shulgina's conclusion from these ammonites that Beds D6–D8 correspond roughly with the Siberian zones of *Bojarkia mesezhnikowi* and *Surites analogus* does not accord with my own reading of the evidence. More unfortunate is their unqualified acceptance of the records of *Paracraspedites* and *Subcraspedites* from the lower D beds in support of a Berriasian age for these genera.

Neale's original identifications of these lower D beds ammonites are tabulated here against Saks and Shulgina's revised nomenclature and my own determinations (Table 1). It will be seen that apart from a few specimens referred (mostly with reservation) to *Surites* (*Bojarkia*), all generally determinable ammonites are now identified as species of *Peregrinoceras.* In my opinion the whole assemblage belongs to the Tolliinae; there are no craspeditids in the strict sense, let alone dorsoplanitids such as *Laugeites.* In general aspect this lower D beds fauna can be matched in the *albidum* Zone at the very top of the Ryazanian. In terms of the Lincolnshire succession its position falls at the junction of the Spilsby Sandstone and the Hundleby Clay (Fig. 2).

2f. Summary of zonal succession

(*i*). *Relationship with underlying strata:* Titanites giganteus *Zone.*

Everywhere the Spilsby Sandstone and Sandringham Sands rest on the Kimmeridge Clay with a seam of nodules, rolled fossils and lydite pebbles at the junction. The fossils in this junction-bed are mostly ammonites. In the Sandringham Sands area (Norfolk) only the genus *Pavlovia* has yet been found, indicative of the highest horizons of the Kimmeridge Clay, and these are in a phosphatized mudstone mode of preservation consistent with their origin in an argillaceous environment. In Lincolnshire the faunal content at the bottom of the Spilsby Sandstone is more complex. Here, in addition to the usual Kimmeridgian debris, are Portlandian (Middle Volgian) fossils, among which Spath (1947) identified from Nettleton the ammonites *Crendonites* and *Kerberites.* Examples of *Kerberites* have been collected

Table 1. Ammonites from the lower D Beds of the Speeton Clay (Upper Ryazanian, *albidum* Zone).

Neale 1962	*Saks and Shulgina 1972*	*Casey this paper*	*Horizon*
Laugeites ?	—	Tolliinae indet.	D7A, 7B, 7E.
Paracraspedites stenomphaloides Swinn.	*Paracraspedites stenomphaloides* Swinn.	Tolliinae juv. ? *Surites* (*Bojarkia*)	D6H, 6G.
Paracraspedites prostenomphaloides Neale	—	*Peregrinoceras prostenomphaloides* (Neale)	? D7A.
Paracraspedites subtzikwinianus (Bogosl.)	*Surites* (*Surites*) *subtzikwinianus* (Bogosl.)	*Surites* (*Bojarkia*) sp.	D6G.
Subcraspedites preplicomphalus Swinn.	*Subcraspedites* (*Swinnertonia*) *preplicomphalus* Swinn.	*Peregrinoceras* sp. nov.	D6Aδ, D6G–H.
Subcraspedites aff. *cristatus* Swinn.	—	*Peregrinoceras* sp. nov.	D6I.
Subcraspedites sp.	*Subcraspedites* sp.	*Peregrinoceras* sp. nov.	D6Aδ.
Tollia wrighti Neale	*Tollia wrighti* Neale	*Peregrinoceras wrighti* (Neale)	D7A?, 7B, 6I.
Tollia cf. *payeri* Toula	*Bojarkia* cf. *payeri*	Tolliinae juv.	D6F.
Tollia stenomphala (Pavlov)	*Surites* (*Bogoslovskia*) *stenomphalus* (Pavlov)	? *Surites* (*Bojarkia*) spp. juv.	D6Aβ.
Tollia pseudotolli Neale	*Tollia pseudotolli* Neale	*Peregrinoceras pseudotolli* (Neale)	D6Aδ.
Tollia cf. *tolmatschowi* Pavlov	*Tollia* cf. *tolmatschowi* Pavlov	Tolliinae indet.	D6Aβ.
Tollia sp.	*Tollia* sp.	Tolliinae indet.	D6Aβ.

from this bed in the Lymn Valley and from the Fordington cores. All examples of this genus examined from the Spilsby Sandstone, though incomplete and showing some signs of reworking, are not badly damaged and most of them retain patches of nacreous test. Furthermore, they are preserved in a blue-grey, slightly sandy, glauconitic and phosphatized rock identical with that of the cementing agent of the bed itself. Some of the "*Crendonites*" recorded by Spath are in a similar lithology (though these may include forms more properly assigned to other genera).

In the past the fossils in the junction-bed have been too readily dismissed as "derived" and of no stratigraphical significance. Lamplugh (1896) believed that the contents of this bed were not so much "derived" as condensed, resulting from the prolonged drifting to and fro of material on the sea-bottom. He pointed out that fossils in beds of this type invariably belonged to the "missing" zones. I have previously (Casey 1962) endorsed Lamplugh's views in so far as acknowledging that *Kerberites* and other Portlandian ammonites in the junction-bed are not much older than *Paracraspedites,* the earliest unquestionably indigenous ammonite in the Spilsby sequence. At Worth Matravers, Dorset, *Kerberites* (GSM 109556) has since been found directly underlying *Paracraspedites* in the unbroken lithological sequence of the "Shrimp Bed", at the top of the Portland Stone. *Kerberites* is one of the best known ammonites in the main mass of the Portland Stone, currently assigned to the Zone of *Titanites giganteus.* The Spilsby-Kimmeridge junction-bed marks the long interval of inhibited deposition that followed the Mid-Volgian uplift of Britain. Evidently a shallow sea had re-occupied parts of Lincolnshire already by *giganteus* Zone times (or even earlier) and the former extension of the Portlandian far beyond its present outcrop in southern England may be deemed established.

Sowerby's *A. giganteus* is the type-species of *Gigantites* Buckman 1921 (= *Titanites* Buckman 1921) and was obtained from the Portland Beds of the Vale of Wardour, not, however, from the restricted *giganteus* Zone of Arkell (1935) but from the underlying *Kerberites okusensis* Zone (House 1958). The present paper follows Arkell (1957) in merging the *okusensis* horizon into the *giganteus* Zone.

(*ii*). Paracraspedites oppressus *Zone.*

Throughout Norfolk and South Lincolnshire this zone consists of glauconitic clayey sands locally indurated into sandstone and without phosphatization. It has a maximum thickness of 6 metres south of King's Lynn (Roxham Beds), but diminishes northwards to about 0·3 metres in the Spilsby Sandstone Basement-beds around Spilsby and has disappeared altogether at Nettleton, near the northern end of the outcrop. In Norfolk the zone appears from beneath the Cretaceous disconformity at West Derham, where it comprises the basal remnants of the Roxham Beds, about 3·5 metres thick. Fossils, including the diagnostic ammonite *Paracraspedites*, are invariably crushed, whether occurring as pyritic moulds in the sand, as at West Dereham, or in the basal sandstone, as at North Runcton and King's Lynn. In Lincolnshire the zone is best known from its occurrence in the Spilsby Sandstone Basement-beds of the Fordington wells and in the Partney road-cutting. This zone accounts for the bulk of the Spilsby Sandstone-basal Roxham Beds erratics found in the Drift of Norfolk and Suffolk. Judging by their size (up to 2 m) and distribution and their obvious identity with the indurated base of the Roxham Beds seen *in situ*, they are not far-travelled (Casey and Gallois 1973). Possibly they originated in the off-shore region of South Lincolnshire. Large *Paracraspedites* from these erratics, indistinguishable from the well-known

Portland "giants", have found their way into East Anglian museums (King's Lynn, Norwich, Ipswich) or have been used as garden ornaments (photographs in I.G.S.).

Besides the ammonites *Paracraspedites oppressus, P. stenomphaloides, P. bifurcatus, P.* spp. nov., and *Glottoptychinites? trifurcatus*, the zone yields a rich fauna of bivalves and belemnites. The associated brachiopods include the large *Rouillieria ovoides* which gives an independent check on the Middle Volgian dating of the fauna (Ager 1971).

In the Southern Basin the zone is present in the top part of the "Shrimp Bed" of the Portland Stone of Dorset (Casey 1964) in a sublithographic stone quite unlike the Spilsby Sandstone. Here the zone passes down imperceptibly into the *giganteus* Zone, characterized by species of *Titanites*, *Kerberites*, and others.

(*iii*). Subcraspedites (Swinnertonia) primitivus *Zone*.

This basal division of the Upper Volgian substage has been identified in England only in Lincolnshire. It is essentially Swinnerton's Bed D (with the top few centimetres of Bed C) of the Spilsby Sandstone Basement-beds, first described from the Fordington wells and subsequently found at Partney, the Lymn Valley and Nettleton Top. The same horizon was evidently encountered in the Donington borehole, whence Pringle (1919) recorded "*Craspedites* cf. *nodiger*", subsequently identified by Swinnerton with his *S. cristatus*. Species of *Subcraspedites* found in this zone, mostly crushed, belong exclusively to the subgenus *Swinnertonia*, endemic to this horizon (*S. cristatus, S. precristatus, S. primitivus, S. undulatus, S. parundulatus, S. subundulatus* Swinnerton spp.). In the lower part of the zone there are poorly preserved ammonites which may prove to be a new form linking *Subcraspedites* with the Dorsoplanitidae. The zone consists of grey argillaceous sand or sandstone with phosphorite and has its maximum observed thickness of 2 metres at Nettleton. The apparent absence of *Swinnertonia* among the Kimmeridgian-Spilsby Sandstone derivatives at the base of the Carstone north of Caistor may suggest that the *primitivus* Zone did not extend as far north as the overlying divisions of the Upper Volgian.

(*iv*). Subcraspedites (Subcraspedites) preplicomphalus *Zone*.

This zone occupies the middle part of the Upper Volgian substage and appears to be present throughout the whole length of the Sandringham Sands-Spilsby Sandstone outcrop. Originally of wider extent, its boundaries were clipped back by erosion at the end of the Jurassic and again during the Lower Albian. At West Dereham its fossils are found only as a phosphatized remanié in the basal Cretaceous nodule-bed along with forms of the succeeding *lamplughi* Zone (Fig. 2). Its presence is inferred at the base of the Runcton Beds of the King's Lynn area. The zone has its fullest development in the Lincolnshire Wolds in the 4–8 metres of Lower Spilsby Sandstone above the Basement-beds, consisting of coarse glauconitic sands, locally cemented into "doggers". Ammonites are fairly common in the "doggers", though generally crushed, and comprise *S.* (*S.*) *sowerbyi, S.* (*S.*) *preplicomphalus, S.* (*S.*) cf. *claxbiensis, S.* (*S.*) spp. nov., *Craspedites plicomphalus* and *C. thurrelli* sp. nov. This zone also provides some of the erratic blocks of Spilsby Sandstone found in the Norfolk Drift.

(*v*). Subcraspedites (Volgidiscus) lamplughi *Zone*.

Representing the top part of the Upper Volgian substage and the highest horizon of the British Jurassic, this zone has the same areal distribution as the *preplicomphalus*

Zone below. In Lincolnshire it takes in the top few metres of the Lower Spilsby Sandstone, though its junction with the *preplicomphalus* Zone is here arbitrary. The coarse glauconitic sands of this zone contain many pebbly layers and 'doggers". Unlike those of the zone below, fossils on this horizon commonly have a phosphorite infilling (and are consequently less crushed) and low-grade phosphorite cements patches of the sand. This zone indicates an episode of shallowing of the sea prior to the interval of erosion that terminated the Jurassic. Throughout the region its junction with the overlying beds is sharp and disconformable and in places it was eroded away completely by the Lower Ryazanian transgression. Fossils from this zone account for the bulk of the rolled debris in the basal Cretaceous nodule-bed of Norfolk. Ammonites collected *in situ* belong exclusively to *Volgidiscus* or to forms transitional between *Volgidiscus* and *Subcraspedites* s.s.

(*vi*). Runctonia runctoni *Zone.*

This zone has been traced for about 3 kilometres in the neighbourhood of North Runcton, near King's Lynn, where it forms the local representative of the basal Cretaceous nodule-bed at the bottom of the Mintlyn Beds. Usually less than 0·3 metres thick, in places it contains material derived from the underlying *lamplughi* Zone. Ammonites were apparently abundant on this horizon, though mostly reduced to shards of irridescent shell. Preservation of this zone at North Runcton, albeit vestigial, was probably as fortuitous as its discovery. Originally it may well have been spread over the whole of the Norfolk area and then swept away by one of the strand-line oscillations that marked the Jurassic-Cretaceous transition (reflected in the Durlston Beds "marine bands"). The diagnostic ammonite *Runctonia* gen. nov. being known nowhere else, the zone is referred to the Cretaceous on *a priori* grounds, as discussed in the section on correlation.

(*vii*). Hectoroceras kochi *Zone.*

First described from Greenland by Spath (1947), the *kochi* Zone has since been found widely over North and West Siberia (Saks *et al.* 1963). In Britain it has been found only in Norfolk. Uplift and erosion at the end of the Lower Ryazanian had reduced it to a southwards-thickening wedge of strata, and this was further attacked during the Aptian and Lower Albian. At West Dereham it forms the bottom 8 metres of the Mintlyn Beds, truncated by the Carstone; its original thickness is not known.

Hectoroceras kochi and congeneric forms occur throughout this thickness as clay-ironstone or phosphorite steinkerns in a fauna dominated by the bivalve *Neocrassina.* Species of *Borealites* occur as rarities in the highest clay-ironstone band and phosphatic nodules enclosing *Hectoroceras* contribute to the basal conglomerate of the Carstone. The zone dwindles away northwards to a line of nodules, traceable to Castle Rising (Casey and Gallois 1973).

(*viii*). Surites (Lynnia) icenii *Zone.*

This zone is taken to mark the base of the Upper Ryazanian. It is best known from exposures in the vicinity of King's Lynn, where it forms about a metre of glauconitic sands and clay with clay-ironstone and seams of phosphatic nodules. The Mid-Spilsby nodule-bed of South Lincolnshire represents an even more marginal facies of this zone. *Surites* of the subgenus *Lynnia* nov. are the characteristic ammonites of this horizon, though *Surites* (*Surites*) and *Surites* (*Bojarkia*) both occur as minority elements.

(*ix*). Surites (Bojarkia) stenomphalus *Zone.*

The term "*stenomphalus* Zone" is adopted from Pavlov (1891) but with a narrower meaning, as explained below. As used herein, the zone corresponds to a large part of the Upper Spilsby Sandstone, consisting of about 4–6 metres of fine to medium sands, commonly glauconitic and with a few calcreted "doggers". These "doggers" are the principal source of fossils and their scarcity makes it difficult to fix a boundary with the *albidum* Zone above. In Norfolk the zone, in Mintlyn Beds facies, is about 10 metres thick in the King's Lynn neighbourhood. Here it is seen to rest on the *icenii* Zone, but its junction with the *albidum* Zone cannot be determined at present owing to the lack of a continuous ammonite-bearing sequence. *Surites* (*Bojarkia*) *stenomphalus, S.* (*B.*) *suprasubditus pavlovi* subsp. nov., and other undescribed *Bojarkia* characterize the zone. This is the horizon of *Buchia volgensis* figured by Woods (1905) from the Spilsby Sandstone of Donington.

(*x*). Peregrinoceras albidum *Zone.*

This zone is considered to terminate the Ryazanian and includes the topmost part of the Mintlyn Beds and the topmost part of the Upper Spilsby Sandstone. Restricted to the southern end of the Lincolnshire Wolds and an area south of King's Lynn, the outcrop of these beds must have extended over a wider territory in Pleistocene times. This is suggested by the distribution of *Peregrinoceras albidum* and allies in Drift deposits as far afield as Letchworth, Hertfordshire, and Highgate Hill, London. *Peregrinoceras albidum* sp. nov., *P. rosei* sp. nov., *P. subpressulum, P. wrighti, P. pseudotolli,* together with a few undescribed *Bojarkia,* are the characteristic ammonites of this zone. In South Lincolnshire a similar fauna ranges up into the Claxby Beds (Hundleby Clay) and the base of that formation is therefore assigned to the *albidum* Zone. In the present state of knowledge the crushed *Peregrinoceras* fauna found in the lower D beds (D6–7) of the Speeton Clay can be correlated only with this broad *albidum* Zone.

(*xi*). *Relationship with overlying strata:* Paratollia *horizon.*

In Norfolk the Ryazanian Mintlyn Beds are succeeded by sands of presumed Valanginian age (Leziate Beds) (Casey and Gallois 1973), but they lack determinable ammonites. In north Lincolnshire the Valanginian Claxby Ironstone rests disconformably on Lower Spilsby Sandstone. It is only at Speeton and in the southern Lincolnshire Wolds that the sequence holds promise of elucidating the Ryazanian/Valanginian boundary in Britain. At Speeton the highest *Peregrinoceras* (Ryazanian) is separated from the "*Astarte* Bed" (D4) with rare *Platylenticeras* (Valanginian) by an interval of about 2 metres of clay ("*Lingula* Bed" or D5) which has so far yielded no ammonites (Neale 1962). Near Benniworth and Donington, northwest of Horncastle, indications have been obtained of the presence of an important early Valanginian ammonite fauna in the basal Claxby Beds (Hundleby Clay). This fauna comprises species of *Paratollia* gen. nov., *Propolyptychites* and *Pseudogarnieria* ("*Proleopoldia*"), which equates simultaneously with occurrences in the *Pseudogarnieria undulatoplicatilis* Zone of the Russian Platform and the Platylenticeras Schichten and Bentheim Sandstone of northwest Germany. Only *Paratollia* has yet been collected *in situ* in Lincolnshire and it is too early to say whether the apparent absence of *Platylenticeras* in the assemblage is significant. Further investigation of the Valanginian sequence is beyond the scope of the present study, but the need for search to be redoubled in D4–5 at Speeton and at Benniworth is obvious.

(*xii*). *Zonal correlation within the Spilsby Province.*

The complex zonal stratigraphy of the Sandringham Sands, Spilsby Sandstone and basal Claxby Beds and its relationship to the Speeton Clay is illustrated by five critical sections (Fig. 2), representing the southern and northern ends of the Norfolk and Lincolnshire outcrops and the Lower D beds of the Filey Bay exposure (Speeton). The chief features to be noted are that, despite the better development of the *oppressus* Zone at the top of the Middle Volgian in Norfolk, the Upper Volgian is here thin and incomplete. This substage reaches its greatest thickness in the Nettleton area of north Lincolnshire. Conversely, the Lower Ryazanian has its fullest development in the south and appears to be totally absent in eastern England north of The Wash. The Upper Ryazanian is well represented in the area around King's Lynn and in the southern part of the Lincolnshire Wolds, but is absent from the two extremities of the combined Lincolnshire-Norfolk outcrop; it reappears in the lower D beds of the Speeton Clay.

3. Evolution of the Spilsby Province

The Spilsby Sandstone and its correlatives were laid down in a shallow arm of the sea that remained in occupation of eastern England after the Middle Volgian uplift of Britain had isolated the region from the Portland-Purbeck basin to the south (Casey 1971). This was only one of a number of large-scale movements, possibly connected with a critical phase in North Atlantic sea-floor spreading, that reshaped European geography at that time. Reactivated areas of uplift that dominated the physiography of the Spilsby province were (i) the London-Ardennes massif to the south, (ii) the Pennines to the west and (iii) the east-west trending Northumbrian arch or Mid-North Sea high to the north. A more direct control on sedimentation in the Spilsby province was exercised by the Market Weighton upwarp: whether the Mid-Netherlands ridge to the southeast had any influence is unknown.

Among the ammonites, these great changes in the distribution of land and sea had the effect of accentuating faunal provincialism by the creation of new areas of endemic evolution. Thus, the widespread *Pavlovia* regime of the Boreal Realm was replaced by many new local developments such as the virgatitids of the Russian Platform and other specialised dorsoplanitid and craspeditid offshoots, distributed in different areas from Siberia to southern England.

Within the framework of the palaeobiogeographical classification introduced by Krimgolts and others (1968) for the Jurassic of the U.S.S.R. and adjoining territory, the Spilsby region may be regarded as having formed during the Upper Volgian-Lower Ryazanian an independent province of the Arctic Subrealm allied to the Greenland Province. In the Upper Ryazanian the Spilsby Province became part of the Boreal-Atlantic Subrealm, having strong faunal links with the Volgian and West Siberian Subprovinces of the East European Province. It disappeared as a separate entity after the Ryazanian. These links with Greenland and Siberia suggest that the Spilsby sea was open to the north. Tenuous connections with southern England by way of the Bedfordshire straits appear to have been maintained until the end of the Middle Volgian and another corridor may have remained open through Denmark and Poland to the Moscow-Volga area, permitting circulation of the dorsoplanitid *Paracraspedites*. These channels of communication were severed during the phase of marine regression of the Upper Volgian. The Spilsby Province was then taken over by the true craspeditids, apparently immigrants from the

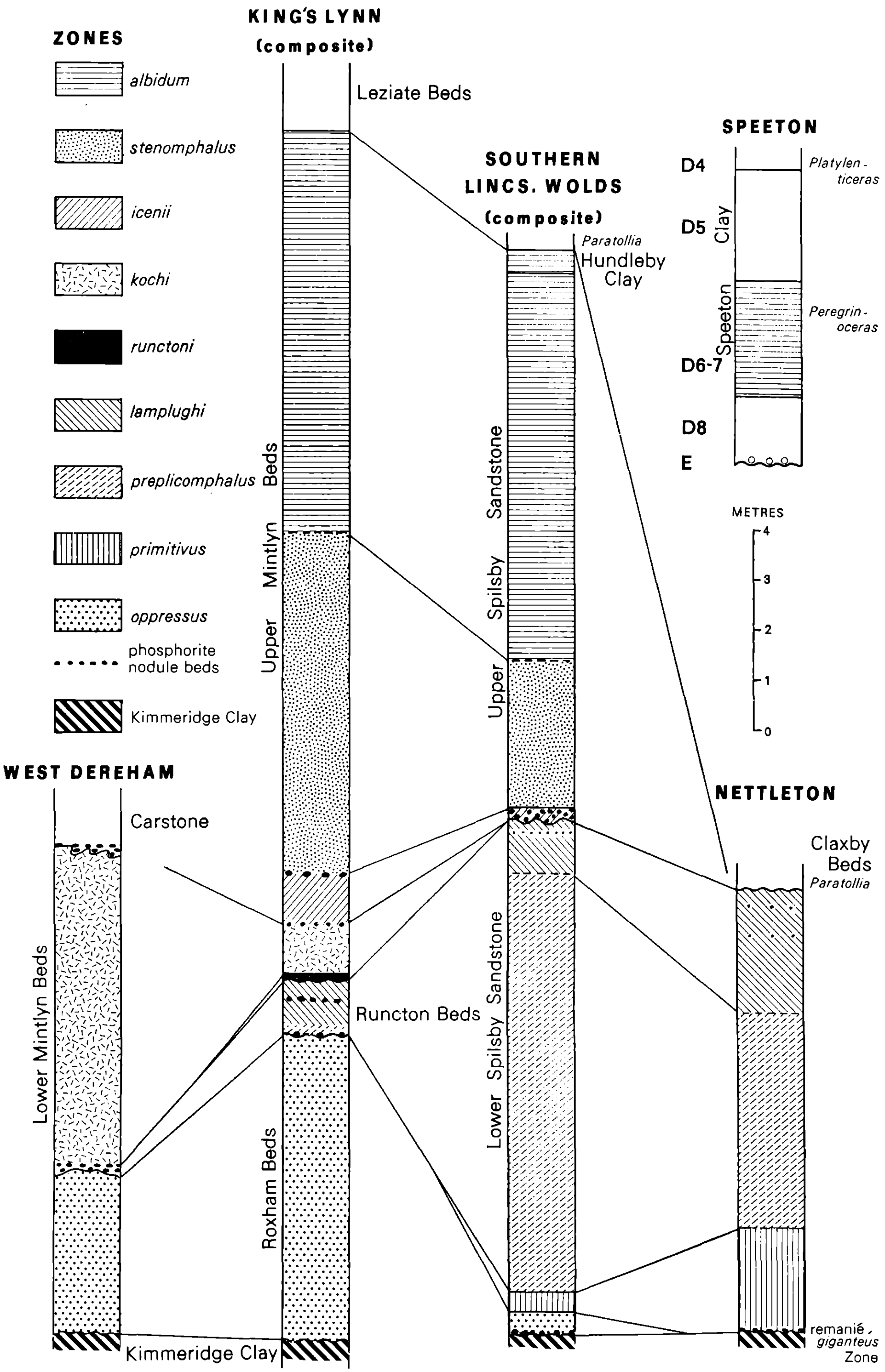

Fig. 2. Comparative vertical sections of Spilsby Sandstone and correlatives in eastern England.

north. The main stock (*Subcraspedites*) appears to have evolved from laugeitid ancestors well represented in East Greenland. Thence onwards, until the end of the Lower Ryazanian, the Spilsby sequence was characterized by an endemically evolving lineage—*Swinnertonia*—*Subcraspedites* s.s.—*Volgidiscus*—*Runctonia*—*Hectoroceras*—and the province may indeed have been at or near the centre of dispersal of these ammonites. *Craspedites* of the *nodiger* and *subditus* types, groups well represented in the Upper Volgian of the Boreal-Atlantic Subrealm (Russian Platform and West Siberia), may have infiltrated into the Spilsby province by rounding the northern lobe of the Scandinavian Shield, but evidence of an interchange of ammonites with the south is wholly lacking. Even the Ryazanian transgression, which carried the berriasellid *Riasanites* northwards across Poland and flooded the Lower Saxony and Purbeck Basins with brackish seas (Upper Serpulit and "Cinder Beds"), failed to break the craspeditid monopoly in the Spilsby Province.

Late in Lower Ryazanian times a few primitive Tolliinae (*Borealites*) appeared in Norfolk and in the Upper Ryazanian this subfamily (*Lynnia, Surites* s.s., *Bojarkia, Peregrinoceras*) invaded the province in strength, displacing the ancestral Craspeditinae altogether. This was a period of renewed transgression both on the Russian Platform and in the Spilsby Province and the most likely date for the re-opening of direct communication between Spilsby and Moscow, as suggested by Sazonova's (1971) palaeogeographical map of eastern Europe. Unhappily, the record of *Surites* in the Warsaw region (Marek 1963) that supports this reconstruction cannot be confirmed, the relevant specimens being, in my opinion, misidentified *Riasanites* and other berriasellids. It was the Valanginian transgression, marked by the arrival of the *Paratollia* fauna to eastern England, that finally submerged the Spilsby Province in a wider European identity.

It seems, therefore, that the land barriers to marine migration erected across Europe during the Volgian were progressively broken down during the Ryazanian and Valanginian. Links between the Spilsby basin and the ammonite province of eastern Europe seem to have been re-established in the Upper Ryazanian. Schott *et al.*'s (1967, 1969) view of the palaeogeography of the German North Sea basin suggests that migration routes from southern Europe, probably via Poland, were opened at that time. The fact that Tethyan ammonites did not use them shows that geographical isolation was only one of the factors controlling ammonite provincialism (see also Rawson, this volume).

From the structural and sedimentary viewpoint, the picture presented by the Spilsby province is one of slow deposition, with shifting centres of downwarping, pauses in sedimentation with formation of phosphorite, sea-floor erosion and re-working of older deposits. In short, a typical near-shore, marginal facies, repeated in the Lower Greensand and other shallow-water deposits of the European Upper Jurassic-Lower Cretaceous. Although the influence of the Market Weighton upwarp may be seen in the disappearance of the topmost Middle Volgian and the whole of the Ryazanian near Caistor, it is important to note that activation of this upwarp was not necessarily in phase with regional movements. In the south the change from Portland to Purbeck conditions indicates a renewed period of marine regression during the Upper Volgian traceable over large areas of Europe. In Lincolnshire, however, considering the generally marginal nature of Spilsby deposits, the Upper Volgian may be described as the period of most active and widespread sedimentation, particularly well developed near Caistor. Here, only the feeble development of nodular phosphorite at the top of the Lower Spilsby Sand-

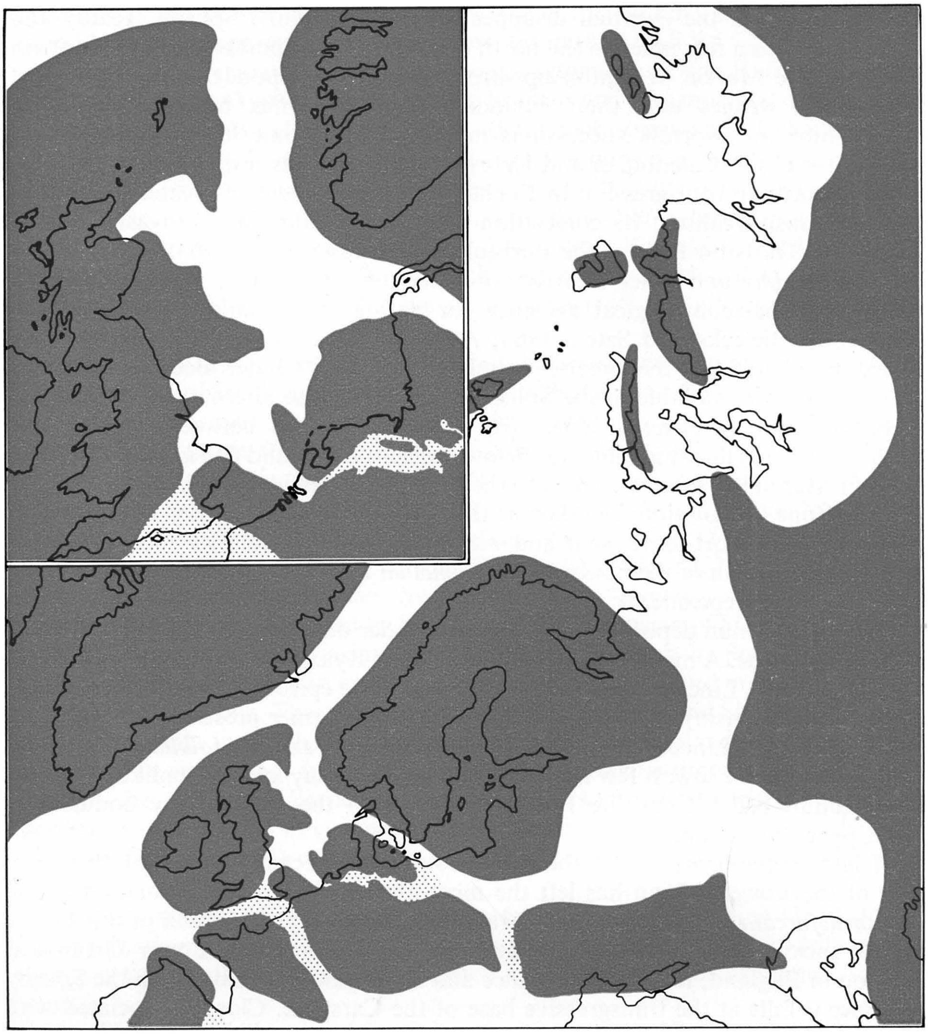

Fig. 3. Palaeogeographical reconstruction of part of the Boreal Realm during the Ryazanian, with inset map showing Britain and adjacent area of Europe. (Detail after Smith 1971; Enay 1972; Dunn *et al.* 1973.) Areas of continental deposition stippled.

stone reflects the episode of marginal deposition recorded in the condensed and incomplete Runcton Beds of Norfolk. In this respect the Norfolk occurrence accords better with the regional picture of marine retreat at the end of the Jurassic, e.g., soil-bed ("Mammal Bed") in the Lulworth Beds of Dorset, pre-Whitchurch Sands folding in Buckinghamshire and contemporary movements in the Boulonnais and the Osterwald phase of folding in Saxony (Casey and Bristow 1964; Casey 1971).

The diachronous base to the Claxby Beds, with northwards-growing disconformity, indicates another important episode of earth-movement felt in north Lincolnshire. This episode, like the wedging out of the Upper Tealby Clay and

Roach Stone and the eventual disappearance of the whole Spilsby, Tealby and Langton groups a few miles to the north illustrates the importance of the southern margin of the Market Weighton upwarp. Lack of correspondence in position of sedimentary wedges and their bounding disconformities between the north Lincolnshire and Norfolk successions may express tectonic independence in the basement-rocks (? Caledonian and Hercynian fold-systems respectively).

The Ryazanian transgression in England is another event of greater complexity than previously realised. Its correlation with the "Cinder Beds" invasion at the base of the Durlston Beds of the Purbeck Basin (Casey 1962, 1963) was based on palaeogeography and other indirect considerations. Ironically, now that there is independent palaeontological evidence for dating the "Cinder Beds" as basal Cretaceous (Bielecka and Sztejn 1966; Anderson, this volume), the problem has shifted to identifying the precise correlative of the "Cinder Beds" among the alternatives now available in the Spilsby Province. These alternatives, in order of probability, are (i) *runctoni* Zone, (ii) unnamed interval between *runctoni* and *kochi* Zones, (iii) unnamed interval below *runctoni* Zone, and (iv) *kochi* Zone. This area of research has been narrowed to the Norfolk succession, of which the vestigial *runctoni* Zone is provisionally taken as the earliest Cretaceous. The "Cinder Beds" invasion was a short-term event and was followed immediately by an episode of retreat. Destruction of the newly-formed *runctoni* Zone in Norfolk may be inferred to date from this episode.

Lower Ryazanian deposition was resumed under unstable conditions in Norfolk in the *kochi* Zone. A marine advance in the Upper Ryazanian brought the return of the sea to south Lincolnshire (and perhaps the saline episode of the "Scallop Beds" to the Purbeck basin). There is no evidence for the former presence of Ryazanian deposits in north Lincolnshire. Only the uppermost Ryazanian (*albidum* Zone) can be identified in the lowest few metres of the Speeton Clay and it is unlikely that the basal nodule-bed ("Coprolite Bed") is older than the Mid-Spilsby nodule-bed, i.e., Upper Ryazanian.

Of later movements within the Cretaceous that affected the Spilsby Province, that of the Lower Albian has left the most obvious signs. Corresponding to the mid-*tardefurcata* break of Casey (1961a), the sedimentary expression of this Lower Albian movement may be seen throughout the length of the Lower Greensand outcrop in England, in northern France and in northwest Germany. In the Spilsby Province it falls at the transgressive base of the Carstone. Closely associated with the Red Chalk, this formation marks the beginning of the so-called Upper Cretaceous transgression in the North Sea. Strahan's view that the most important break in the Lincolnshire Cretaceous series occurs at the base of the Carstone (Strahan 1886) is thus endorsed and declared to be valid also for Norfolk and probably for the whole of the North Sea basin system.

4. Correlation with the Russian platform and Siberia

4a. Introduction

Eastern England is the only region in northwest Europe where a sequence of ammonite faunas may be followed across the Jurassic-Cretaceous boundary. Its correlation with comparable regions such as the Russian Platform, North and West Siberia, East Greenland and Canada is thus of prime importance for fixing a standard ammonite chronology at that level. Since the Greenland and Canadian occurrences are dealt with in detail elsewhere in this volume, attention is concentrated here on comparison with the successions in the U.S.S.R.

The history of research into the ammonite sequences of the Russian Platform, which provides the type-localities for the Volgian and Ryazanian stages, has been reviewed by Sazonova (1961, 1965, 1967, 1971), Gerasimov and Mikhailov (1966) and Gerasimov (1971, *in* Krimgolts *et al.* 1972). Knowledge of the successions in the northern territories of the U.S.S.R. has advanced rapidly in recent years mainly through the work of Bodylevsky (1967), Voronets (1962), Shulgina (1967, 1968, 1969) and Saks and his co-workers (1959, 1962, 1963, 1965, 1967, 1969, 1972). The sequences of zones given in Table 2 are those currently employed in the two main regions of the U.S.S.R., though there are local variants and alternative nomenclature, as noted below.

Casey's (1962, 1963, 1964, 1971) dating of the Spilsby Sandstone as ranging from high Middle Volgian (*olim* Lower Volgian) to Ryazanian ("Berriasian") was not accepted by Saks and Shulgina (1972) on the following grounds: (1) Casey did not describe or illustrate the ammonites; (2) Neale's (1962) illustrations and descriptions of *Paracraspedites* and *Subcraspedites* from the Berriasian part of the Speeton Clay, which follows immediately on the Kimmeridgian, supported Spath's and Swinnerton's basal Cretaceous ("Infravalanginian") dating of the Spilsby Sandstone, which also rests directly on the Kimmeridge Clay; (3) the critical species *Paracraspedites stenomphaloides* Swinnerton and "*Subcraspedites plicomphalus* (Sowerby)" had been identified by Shulgina in the Berriasian of Siberia; (4) Jeletzky (1965) had favoured a Berriasian age for *Subcraspedites* of the Spilsby Sandstone; and (5) a typical Neocomian assemblage of belemnites is found in the lower part of the Spilsby Sandstone. These views were embodied by Saks and Shulgina (1972) in a correlation table in which the relevant strata in eastern England were equated with post-Volgian successions in the U.S.S.R. and at the same time firmly tied zone by zone to the Tethyan (Berriasian) sequence of southeast France. Volgian and Berriasian were treated as consecutive intervals and no comment was made on the fact that Casey's (1964) correlation implied a considerable overlap between these two stages.

Since the scheme of correlation proposed by Saks and Shulgina (1972) for the Spilsby Sandstone and equivalent strata in eastern England is emphatically rejected by the present author, the views on which it is based must be examined point by point.

(1, 2). The original illustrations and descriptions that enabled a Lower Cretaceous age for *Paracraspedites* and *Subcraspedites* to be confidently accepted have always been available and the publication of figures of *A. plicomphalus* J. Sowerby and other critical Lower Spilsby Sandstone ammonites by Donovan (1964) did not overcome entrenched opinion. The fact that Neale's (1962) pictures of *Peregrinoceras* and allies from the Speeton Clay were accepted as evidence of the occurrence of *Paracraspedites* and *Subcraspedites* in the Berriasian speaks for itself.

(3). Shulgina's "*Subcraspedites plicomphalus* (Sowerby)" is a nomenclatorial hybrid of *Subcraspedites sowerbyi* Spath (= *A. plicomphalus* J. de C. Sowerby 1823) and *Craspedites plicomphalus* (J. Sowerby 1822) and the Siberian ammonite to which the name was applied belongs to a later, homoeomorphous group referred in the systematic section of this paper to *Borealites* (*Ronkinites*). Her "*Paracraspedites*" also have only a superficial resemblance to the Middle Volgian genus that correctly bears the name and are no more *Paracraspedites* than the Hauterivian *Speetoniceras* is a Kimmeridgian *Pavlovia.*

(4). Jeletzky's (1965) comments on Casey's dating of the Spilsby Sandstone are now largely irrelevant and were modified in a subsequent paper (Jeletzky 1966).

(5). Analysing the belemnite distribution, Saks and Nalnyaeva (1972) were more cautious about the age of the Spilsby Sandstone than were Saks and Shulgina in the same work. In an earlier publication Saks and Nalnyaeva (1966) had placed the belemnites of the Lower Spilsby Sandstone in the Volgian. Although they have now assigned both the upper and lower divisions of the formation to the Berriasian, the lower part is qualified by "(? Volgian beds)". They listed nine species of *Acroteuthis* from the Spilsby Sandstone, seven in the lower part and six in the upper, with four species common to both divisions. Of the four species shown as ranging into the upper beds, three are forms recorded in the U.S.S.R. only from "Berriasian" strata, namely *A. lateralis* (Phillips), *A. sublateralis* Swinnerton and *A. explanatoides* (Pavlov).

Saks and Nalnyaeva drew their data on the Spilsby belemnites from Swinnerton's monograph (1936–55), which is now out of date so far as the stratigraphy of the Spilsby Sandstone is concerned. Moreover, it was written before Gustomesov's (1956) isolation of the subgenus *Microbelus*, which characterises the lower levels of the Spilsby Sandstone. In his monograph Swinnerton treated members of this subgenus as juvenile *Acroteuthis* s.s., though he had originally identified the Portlandian-Volgian *A. mosquensis* (Pavlov), a typical *Microbelus*, from the Spilsby Sandstone Basement-beds (Swinnerton 1935).

The horizons of *A. lateralis, A. sublateralis* and *A. explanatoides* were determined by Swinnerton mainly from spoil from one of the Fordington wells, near Spilsby, and are too vague to fix positions in terms of the present zonation. Excepting certain "juveniles" from the Basement-beds, all specimens of the three critical species were recorded individually as having been collected from depth-ranges that start in the *albidum* or *stenomphalus* Zone and terminate downwards in Bed 7 (see p. 202). No ammonites are preserved from Bed 7 and this horizon is assigned to the topmost Upper Volgian (*lamplughi* Zone) with reservation. Whether any of the relevant belemnites did originate as low as Bed 7 is not known. Equally uncertain is the significance of Swinnerton's (1936) statement that *A. lateralis* is associated with species of *Subcraspedites* in the middle of the Spilsby Sandstone, his broad interpretation of the ammonite genus covering both Volgian and Ryazanian forms. All that can be said at present is that these three typical Ryazanian belemnites appear together in or just below the Mid-Spilsby nodule-bed. When these dubious records are put aside the "typical Neocomian" aspect of the Lower Spilsby Sandstone belemnite fauna vanishes.

4b. Middle Volgian

Despite the discovery in recent years of new ammonite links, a final solution to the long-standing problem of integrating the Tithonian, Portlandian and Volgian stages has yet to be reached. As a step towards recognition of a global standard for the terminal Jurassic, the Russians extended the Volgian stage down to the *Gravesia* horizon at the base of the Tithonian and introduced a tripartite division of the Volgian, the old Lower Volgian becoming Middle Volgian (Gerasimov and Mikhailov 1966). Gerasimov and Mikhailov's correlation of the *zaraiskensis, virgatus* and *nikitini* Zones of the type Middle Volgian with the Portland Beds of Dorset was challenged by Casey (1967). Pointing out that the Dorset sequence was more than ten times as thick as the Middle Volgian succession with which it was compared, Casey suggested that the Volgian stage in its type-section at Gorodishche, in the middle reaches of the River Volga, was not only greatly condensed, but incomplete. Identification of the genera *Crendonites, Behemoth* and *Kerberites,* indicative of the *giganteus* and *gorei* Zones of the Portland Beds, in the Middle Volgian of the Russian Platform (Mikhailov 1957) was considered unsound; it was inferred that the upper part of the Portland Beds was unrepresented at Gorodishche, there being a hiatus between the *nikitini* and *fulgens* Zones. Casey (1968) subsesequently reported the presence of crushed ammonites indistinguishable from *Paracraspedites* (Pl. 1, fig. 4) in the topmost Middle Volgian at Gorodishche. This means that the postulated gap in the Russian section does not fall at the Middle/Upper Volgian boundary, but perhaps at the thick band of phosphatic nodules at the base of the unit currently assigned to the *nikitini* Zone.

Gerasimov and Mikhailov (1966) abolished the *Lomonossovella blakei* Zone, which previous authors had placed above the *nikitini* Zone as the topmost Middle Volgian (*olim* Lower Volgian). Possibly a more profound analysis of the fauna of the *nikitini* Zone at Gorodishche and its relationship to the *nikitini* Zone of the Moscow synclise will lead to the re-instatement of the *blakei* Zone (as in Table 2) or to the recognition of another unit corresponding to the *Paracraspedites oppressus* Zone.

Correlation of the remanié *giganteus* Zone of the basal Spilsby Sandstone and the overlying *oppressus* Zone of Lincolnshire and Norfolk with the Dorset sequence is firmly established by the occurrence of conspecific and allied species of *Kerberites* and *Paracraspedites* in the topmost part of the Portland Stone. The change from Portland to Purbeck conditions was not synchronized over the whole of southern England and it is improbable that in Dorset this event happened to coincide with the beginning of the Upper Volgian. The basal part of the Purbeck (Lulworth) Beds may also fall within the *oppressus* Zone. With the termination of normal marine conditions at the end of the Portland Beds southern England was closed to ammonite immigration until the Aptian.

4c. Upper Volgian

There is no direct evidence from the U.S.S.R. for placing the Zone of *Subcraspedites* (*Swinnertonia*) *primitivus* at the base of the Upper Volgian. This correlation relies on the occurrence of a primitive form of *Swinnertonia* in the Laugeites Beds of East Greenland, at the junction of the Middle and Upper Volgian, on the fact that the zone follows conformably on the *oppressus* Zone and on the dating of the overlying *S.* (*S.*) *preplicomphalus* Zone. Future work may show the need to recognize a separate faunal band at the base of the *primitivus* Zone, where poorly preserved ammonites apparently intermediate between Craspeditidae and Dorsoplanitidae occur. It is uncertain, therefore, whether the main development of *Swinnertonia* coincided with the appearance of the Russian *Kachpurites* at the base of the Upper Volgian. Possibly the *primitivus* Zone corresponds wholly or in part to the combined Zones of *Kachpurites fulgens* and *Craspedites subditus* of the Russian Platform. This idea is supported by the presence in the *preplicomphalus* Zone of *Craspedites plicomphalus* (J. Sowerby), an analogue of *C. nodiger* (Eichwald), the index ammonite for the highest Upper Volgian of the Russian Platform.

Since Rosanov (1909) demonstrated the wide extent of the *Craspedites nodiger* Zone in the Moscow region, comparable faunas of *Craspedites* (*C.* cf. *nodiger, C. pseudonodiger* Shulgina, *C. bodylevskyi* Ershova) have been found at about the same level (*taimyrensis* Zone) in North Siberia and West Spitsbergen (Shulgina 1969; Ershova 1969). Above the *nodiger* Zone s.s. an additional horizon may be recognized locally beneath the transgressive Ryazan Beds in the Volga region, characterized by *Craspedites kaschpuricus* (Trautschold) (Sazonov 1962). Until recently "*Garniericeras*" *tolijense* (Nikitin) was commonly listed as a fossil of this horizon. It is a matter for speculation whether this record relates to a species of *Garniericeras*, *Shulginites*, *Volgidiscus* or some other form. The general absence of *Volgidiscus* in the Moscow and Leningrad collections from these very fossiliferous beds (cf. Gerasimov 1969) makes it more likely that the English *Subcraspedites* (*Volgidiscus*) *lamplughi* Zone is missing in this region. It is assumed provisionally that it falls within the erosional gap found at the Volgian/Ryazanian boundary throughout the Russian Platform. In terms of the Siberian sequence, this gap is currently assumed to be filled by the *Chetaites sibiricus* Zone (Saks and Shulgina 1972), but for reasons given below it is here tentatively assigned to the *Chetaites chetae* Zone. That is to say, the missing interval in the Russian Platform sequence is credited to the Volgian rather than to the Ryazanian or "Berriasian" *sensu rossico.*

4d. Ryazanian

On the Russian Platform generally and especially in the type-area along the right bank of the River Oka, in Ryazan province, southeast of Moscow, the Ryazan Beds are greatly condensed (in places less than 1 m thick). Ammonites are abundant, but owing to reworking of the sediments division into beds is to some extent subjective and the vertical distribution of certain species is still obscure (Gerasimov 1971). Two zones are recognized in the Ryazan Beds: the *Riasanites rjasanensis* Zone (Lower Ryazanian) and the *Surites spasskensis* Zone (Upper Ryazanian). Owing to the highly condensed sequence and to provincialism of the ammonite faunas, especially in the Lower Ryazanian, correlation of these zones in terms of the ammonite zonations worked out in Siberia and other northern territories (Table 2) is difficult, as is reflected in the two contrasting interpretations emanating recently from the U.S.S.R. (Sazonova 1971; Saks and Shulgina 1972).

Gerasimov (1971) pointed out that the occurrence of *Surites* (*Surites*) *spasskensis* (Nikitin) already in the *rjasanensis* Zone (upper part, personal communication) makes this an unsuitable index-fossil for the Upper Ryazan Beds and proposed that *Surites tzikwinianus* (Bogoslovsky) (here referred to the subgenus *Bojarkia*) be used instead. The occurrence of *Surites* (*S.*) *spasskensis* or a close ally low in the *kochi* Zone of the River Boyarka section (Saks and Shulgina 1972) in northern Siberia would seem to support Gerasimov's assertion and at the same time suggest that the *kochi* Zone represents only part of the *rjasanensis* Zone or even overlaps with the *spasskensis* Zone as defined by Sazonova (1971) for its type-area. Saks and Shulgina (1964) and Saks and others (1965) had originally regarded the *sibiricus, kochi* and *analogus* horizons of the north as divisions of a broad *spasskensis* Zone that embraced the whole Ryazanian, with the *sibiricus* level treated as a straightforward lateral replacement of the *rjasanensis* Zone of the Volga region. This concept of the relationship of the *sibiricus* and *rjasanensis* Zones was repeated by Shulgina (1967). Much the same view was taken by Sazonova (1971), who saw the *rjasanensis* Zone (with a missing interval at its base) covering the same time-span as the *sibiricus* Zone, and the *kochi* and *analogus* horizons as divisions of a restricted *spasskensis* Zone. The occurrence of rare *Hectoroceras* in the top part of the *sibiricus* Zone (Shulgina *in litt.*) indicates that there is no break of importance between this zone and the *kochi* Zone. Sazonova (1971) also makes the point that there is no hiatus between the *rjasanensis* and *spasskensis* Zones. It is hard to understand why Saks and Shulgina (1972) now equate the *kochi* Zone with the

Table 2. Suggested correlation of the Jurassic-Cretaceous boundary zonations of eastern England, Siberia and the Russian Platform.

EASTERN ENGLAND			N. & W. SIBERIA	RUSSIAN PLATFORM	
LEZIATE BEDS (pars)	Claxby Beds (pars)	*Paratollia*	*Neotollia klimovskiensis*	*Pseudogarnieria undulatoplicatilis*	VALANGINIAN (pars)
MINTLYN BEDS	Upper Spilsby Sandstone	*Peregrinoceras albidum*	*Surites (Bojarkia) mesezhnikowi*	*Surites (Surites) spasskensis*	UPPER RYAZANIAN
		Surites (Bojarkia) stenomphalus			
		Surites (Lynnia) icenii	*Surites (Caseyiceras) analogus*		
		Hectoroceras kochi	*Hectoroceras kochi*	*Riasanites rjasanensis*	LOWER RYAZANIAN
		Runctonia runctoni	*Chetaites sibiricus*		
RUNCTON BEDS	Lower Spilsby Sandstone	*Subcraspedites (Volgidiscus) lamplughi*	*Chetaites chetae*		UPPER VOLGIAN
		Subcraspedites (Subcraspedites) preplicomphalus	*Craspedites (Taimyroceras) taimyrensis*	*Craspedites nodiger*	
		Subcraspedites (Swinnertonia) primitivus	*Craspedites okensis*	*Craspedites subditus*	
				Kachpurites fulgens	
ROXHAM BEDS		*Paracraspedites oppressus*	*Epivirgatites variabilis*	*Lomonossovella blakei*	MIDDLE VOLGIAN (pars)
?		*Titanites giganteus*			

whole of the *rjasanensis* Zone and place the latter above the *sibiricus* Zone. Possibly they wished to have a post-Volgian zone to fit the theoretical basal Berriasian interval below the *rjasanensis* Zone postulated by Jeletzky (1965, 1968). Contrary to the opinion of Shulgina and her colleagues, who place the *Chetaites chetae* Zone in the Jurassic, Sazonova (1971) thought that this zone should be placed in the Lower Cretaceous, quoting Bodylevsky in support. In the present writer's opinion this question is academic, since if current concepts of the Berriasian stage are adhered to, the *chetae* Zone is simultaneously Jurassic (Volgian) and Cretaceous (Berriasian *sensu gallico*) (Table 2).

The five zones of the English marine Ryazanian are apportioned among the two zones of the condensed Ryazan Beds, the *runctoni* and *kochi* Zones being regarded provisionally as representing the *rjasanensis* Zone (Lower Ryazanian), and the *icenii*, *stenomphalus* and *albidum* Zones as equivalent to the *spasskensis* Zone (Upper Ryazanian).

With its erosion surfaces above and below and its remanié, endemic ammonite fauna, the *Runctonia runctoni* Zone cannot be placed in terms of the Russian zonations except by indirect evidence. One line of approach is to fix its position in relation to the "Cinder Beds" transgression of southern England, independently dated as basal Ryazanian on ostracod evidence and palaeogeography (Casey 1963; Bielecka and Sztejn 1966). This is highly suggestive of a basal Ryazanian age also for the *runctoni* Zone, but is not conclusive (see stratigraphy section). The ancestral position of *Runctonia* in relation to *Hectoroceras* and *Praetollia* and its apparent descent from *Volgidiscus* would seem to offer little alternative to equating the *runctoni* Zone with the *sibiricus* Zone as the correlatives of the lower part of the *riasanensis* Zone. This is the arrangement adopted in Table 2, though its tentative nature should be stressed.

Present usage of the term *kochi* Zone means little more than *Hectoroceras*-beds. The East Anglian *kochi* Zone is incomplete and possibly represents only part of its Siberian namesake. The presence of rare *Borealites* (*Borealites*) and the absence of *Borealites* (*Ronkinites*) in England may indicate that our *kochi* horizon falls within the lower part of the zone.

Yet another erosion surface marks the base of the English *icenii* Zone, characterized by species of *Surites* (*Lynnia*), a subgenus apparently endemic to eastern England. Approximate correspondence of this zone to the Siberian and Trans-Uralian Zone of *Surites* (*Caseyiceras*) *analogus* is suggested by the similarity of *Lynnia* and *Caseyiceras*, which may well be divergent offshoots from a single parent stock. The closest English ammonite to *Caseyiceras analogus* is *Surites* (*Bojarkia*) *tealli* sp. nov., which occurs in the lower part of the *stenomphalus* Zone. *Caseyiceras* is well represented in the condensed *spasskensis* Zone of the Russian Platform. It is in the *icenii* Zone that the *Surites* (*S.*) *spasskensis* group appears for the first (and only) time in the English sequence.

The Zone of *Surites* (*Bojarkia*) *stenomphalus* follows conformably on the *icenii* Zone; the characteristic subgenus *Bojarkia* appears as a rarity at the top of the *icenii* Zone and ranges upwards into the *albidum* Zone. Besides the index-ammonite, the English *stenomphalus* fauna includes *S.* (*Bj.*) aff. *bodylevskii* (Shulgina), *S.* (*Bj.*) *suprasubditus* (Bogoslovsky) *pavlovi* subsp. nov., *S.* (*Bj.*) cf. *mesezhnikowi* (Shulgina), *S.* (*Bj.*) *tealli* sp. nov. and a number of allied, undescribed forms, the whole assemblage showing a striking similarity to that of the *S.* (*Bj.*) *mesezhnikowi* horizon of North Siberia. So close are these two faunas that re-instatement of the term *stenomphalus* Zone in place of *mesezhnikowi* Zone should be considered by the appropriate Soviet committee. In the condensed *spasskensis* Zone of the Ryazan Beds the *stenomphalus* fauna is represented by *S.* (*Bj.*) *suprasubditus*, *S.* (*Bj.*) *kozakowianus* (Bogoslovsky), *S.* (*Bj.*) *tzikwinianus* (Bogoslovsky) and *S.* (*Bj.*) *subtzikwinianus* (Bogoslovsky).

The discovery that the true *S.* (*Bj.*) *stenomphalus*, based on the Lincolnshire lectotype, characterizes the middle part of the Upper Ryazanian is an important result of the present investigation. Pavlov's Zone of "*Olcostephanus stenomphalus*" of the Russian Platform had been referred to the Valanginian already by Bogoslovsky (1902). The neotype of the Russian "*stenomphalus*", now called *Surites* (*Bogoslovskia*) *pseudostenomphalus* (Sazonova), said at first to have been obtained from the upper part of the *spasskensis* Zone (Sazonova 1971), has since been assigned to the basal Valanginian *Pseudogarnieria undulatoplicatilis* Zone (Sazonova 1972). Owing to the long-standing confusion between the two species to which the name *stenomphalus* has been applied and the difficulty of assigning definite horizons to the remanié Ryazanian-Valanginian beds of the Volga region, there is still some doubt about the range of *S.* (*B.*) *pseudostenomphalus.* I am inclined to regard this ammonite as a juvenile "*Stchirowskiceras*", a genus placed firmly in the Valanginian by Sazonova (1971, 1972).

Except when it has been used as a replacement name for *spasskensis* Zone (e.g. Sazonova 1961; Glazunova 1963), it is difficult to give a meaning to the widely quoted Russian "*stenomphalus* Zone". Judging by its faunal associates, for example, Bodylevsky's (1967) "*Tollia stenomphala*" from Novaya Zemlya is a Valanginian form, though the position accorded "*Surites stenomphalus*" by Saks and Shulgina (1964) in their correlation chart agrees better with that of the true *stenomphalus* (= *mesezhnikowi*) horizon.

Above the *stenomphalus* Zone in England the genus *Peregrinoceras* enters in strength (*P. albidum* sp. nov., *P. rosei* sp. nov., *P. subpressulum*, *P. wrighti*, *P. prostenomphaloides*, *P. pseudotolli*) and dominates the ammonite faunas of the topmost Spilsby Sandstone, topmost Mintlyn Beds and basal Hundleby Clay. The genus is an analogue of *Tollia*, which replaces it in Siberia and Greenland. Study of the published sections of the *mesezhnikowi* Zone (Basov *et al.* 1970, 1972) reveals that the zone-fossil and its allies occur only in the lower part of the zone and that the genus *Tollia* characterizes the higher levels, ranging up into the *Neotollia klimovskiensis* Zone at the base of the Siberian Valanginian. There is thus room for the equivalents of the *albidum* Zone above a restricted *mesezhnikowi* Zone. *Peregrinoceras* is well represented in the *spasskensis* Zone of the Russian Platform, *P. subpressulum* being common to the two regions.

The *Surites spasskensis* Zone of the Russian Platform thus combines in its remanié beds elements of all three zones of the English Upper Ryazanian. The *mesezhnikowi* (= *stenomphalus*) fauna, while not indicative of the highest Ryazanian, was correctly placed by Saks and Shulgina (1969) below the Valanginian and cannot be of post-Ryazanian age as indicated in Sazonova's (1971) correlation chart.

In the Trans-Uralian region of north Russia the *mesezhnikowi* Zone is replaced by a "Zone of *Bojarkia payeri*" (*Tollia payeri* in Golbert *et al.* 1972). The supposed occurrence of an equivalent horizon of "*Bojarkia* cf. *payeri*" above the *stenomphalus* Zone in eastern England (Saks and Shulgina 1972) presumably rests on the identification of "*Tollia* cf. *payeri* (Toula)" from the Speeton Clay (Neale 1962). The solitary English ammonite so-named is an indeterminate juvenile tolliinid of the *albidum* Zone.

The basal Valanginian *Pseudogarnieria undulatoplicatilis* Zone of the Russian Platform seemingly corresponds in position with the *Neotollia klimovskiensis* Zone of Siberia. An equivalent horizon is present near the base of the Claxby Beds of Lincolnshire, yielding *Pseudogarnieria* ("*Proleopoldia*") cf. *kurmyschensis* (Stchirowsky), *Paratollia* cf. *kemperi* sp. nov. and species of *Propolyptychites*, and in bed D4 of the Speeton Clay, with rare *Platylenticeras*. These isolated finds afford a link also with the Platylenticeras Schichten of northwest Germany.

Saks and Shulgina (1972) have invented an horizon of "*Tollia* cf. *tolmatschowi*" at the base of the English Valanginian. Here again, this seems to have its origin in the record of "*T.* cf. *tolmatschowi* Pavlov" in the D beds of the Speeton Clay (Neale 1962), perhaps coupled with a similar record from the Platylenticeras Schichten of Germany (Kemper 1964). The English record refers to indeterminate Tolliinae of the Upper Ryazanian *albidum* Zone; it is the German occurrence, here described as *Paratollia kemperi* gen. et sp. nov., that belongs to the Valanginian.

5. Correlation with the Tethyan Realm

During the passage from the Jurassic to the Cretaceous the Spilsby Province was part of the Boreal Realm and for geographical and/or ecological reasons was closed to ammonite exchange with the Tethys. Correlation of the Spilsby sequence with the standard Tithonian-Berriasian of the Mediterranean region is therefore indirect and speculative.

5a. Correlation with the marine facies

From the foregoing section it is clear that correlation of the Jurassic-Cretaceous boundary beds of the Russian Platform with those of northern U.S.S.R. is still far from certain. To attempt to carry this correlation over many thousands of kilometres to link isolated regions and diverse faunas is at present premature. Much of the published grounds for integration of Tethyan and Boreal occurrences at this level rest on subjective ammonite determinations for the most part inadequately described and illustrated, if at all. The biochronological significance of some other ammonites is uncertain or in dispute.

At the centre of this controversy has always been the Ryazan Beds of the Russian Platform, which contain among a dominantly craspeditid sequence ammonites (*Riasanites*, *Euthymiceras*) belonging to the Tethyan family Berriasellidae. Nikitin (1888) referred both *Riasanites rjasanensis* of the Lower Ryazan Beds and *Surites spasskensis* of the Upper Ryazan Beds to his Volgian formation, which, under the influence of Mikhailski, he had transferred from the Jurassic to the Cretaceous. It was because of this jumble of Jurassic and Cretaceous strata in Nikitin's "Volgian" that Pavlov renounced this term and substituted Portlandian for what was then called Lower Volgian and coined the name "Aquilonian" for the terminal part of the Jurassic (Upper Volgian). Pavlov (1892) pointed out that the Ryazan Beds were much younger than the horizon of *Virgatites virgatus* with which they had been confused and probably belonged to the Lower Neocomian. The main level of *R. rjasanensis* he subsequently referred to the lower Berrias horizon and the upper, so-called *stenomphalus* (= *spasskensis*) Zone, to the upper Berrias (Pavlov 1896), treating the Berriasian as a buffer-stage between the Jurassic and the Cretaceous. This siting of the Jurassic-Cretaceous boundary through the middle of the Ryazan Beds thus accorded with Kilian's (1895) announcement of the re-discovery of "*Hoplites*" *rjasanensis* in the Upper Tithonian of the Rhône Valley (since refuted). Because he published his results in western Europe, Pavlov's works enjoyed a wide circulation outside Russia and his opinions echoed down the years (Spath 1924a; Arkell 1957; Casey 1962). Bogoslovsky (1897, 1902) had shown, however, that the Ryazan Beds pass transgressively over the Volgian and form a natural base to the Cretaceous.

In the Tethyan Realm, Kilian (1907–10) had concluded that the only practicable base for the Berriasian of southeast France was the lower limit of the *Fauriella boissieri* Zone, which he divided into three horizons. These became the basis for Mazenot's (1939) subzones of *Berriasella grandis*, *B. boissieri* s.s. and *Kilianella* aff. *pexiptycha*. Although Mazenot's revision of the ammonites showed that Kilian had set the point of entry of the *boissieri* fauna too low, his field line, picked out by a lithological change at the base of the *grandis* Subzone, was adhered to.

Working from the Boreal Realm, Casey (1963) drew attention to the reported overlap in the Caucasus of the *Riasanites* fauna with that of "*Subthurmannia*" *boissieri* (Rengarten 1951) and suggested acceptance of the *boissieri* Zone s.s. as the starting point for the Tethyan Cretaceous, the underlying Subzone of *B. grandis* (now Zone of *Pseudosubplanites grandis*) being better placed in the Tithonian. At the Lyon Colloquium this point of view was not without support (e.g. Allen 1965; Wiedmann *in* Barbier and Thieuloy 1965), though it was decided to elevate Mazenot's *K.* aff. *pexiptycha* Subzone to the Valanginian and to take the *grandis* Zone as the provisional base of the Berriasian (Rat 1963). According to Casey 1964, Table 4) the Berriasian stage as thus defined overlaps with the upper part of the Volgian. This view has been endorsed by Zeiss (1965) and Enay (1972), who accept only the Lower and Middle Volgian as equivalent to the Tithonian.

Highlights of ammonite discoveries relevant to the Jurassic-Cretaceous boundary problem since the Lyon Colloquium include the "*Virgatosphinctes*" fauna in the Upper Volgian of North Siberia (Shulgina 1965, 1967), further mixed faunas in the Caucasus (Khalilov 1965, 1971; Egoyan 1971), and Berriasian *Spiticeras* in the Canadian Western Cordillera (Jeletzky 1964). Furthermore, the Tithonian-Berriasian ammonites of southeast France have again been revised (Le Hégarat 1971a, 1971b; Donze and Le Hégarat 1972). According to the last authors, the *boissieri* Zone (with three subzones) should be placed at the top of a new tripartite Berriasian based by the *grandis* Zone.

If we take the base of the Valanginian to be fixed roughly in both realms by the incoming of the Platylenticeratinae and the boreal *rjasanensis* Zone as equivalent to part of the Tethyan *boissieri* Zone, there is little room left in the Berriasian to accommodate the *spasskensis* Zone or Upper Ryazan Beds. There is, however, a large Berriasian interval (*Tirnovella occitanica* and *Pseudosubplanites grandis* Zones) which is either missing on the Russian Platform or embraces strata of Volgian age. Jeletzky (1965) and Sazonova (1971) have assumed that the *grandis* Zone interval is absent below the transgressive *rjasanensis* Zone, while Casey (1964) and Zeiss (1965) saw the *grandis* Zone as equivalent to part of the Volgian. The ammonites of the *rjasanensis* Zone have not been monographed for three-quarters of a century and until such records from this level as "*Neocomites* ex gr. *occitanicus*" (Sazonova 1971) have been clarified it is impossible to say how much of the Berriasian is missing between the *nodiger* and *rjasanensis* Zones.

In parts of southern Russia (Crimea, Transcaspia) *Riasanites* occurs in an ammonite fauna dominated by *Euthymiceras*, a genus diagnostic of high Berriasian (*boissieri* Zone). Both the *rjasanensis* and *spasskensis* Zones are represented in the 12–40 metres of sandstone of the *Euthymiceras euthymi* Zone in the Mangyshlak Peninsula, Transcaspia (Savelev and Vasilenko 1963), if the ammonites are correctly identified.

It may be of significance that in a recent analysis of the distribution of ammonites at the Jurassic-Cretaceous boundary in the Northern Caucasus, Khalilov (1971) does not list *R. rjasanensis* in association with *Fauriella* ("*Subthurmannia*") *boissieri*.

Such typical Ryazan species as *R. rjasanensis* and *Euthymiceras transfigurabilis* (Bogoslovsky) are shown as part of a faunal assemblage in the northwestern part of the region that comprises species of *Pseudosubplanites*, *Berriasella*, *Tirnovella*, *Malbosiceras* and *Mazenoticeras* in the terminology of Nikolov (1966) and Le Hégarat (1971a, 1971b). This enlarges the picture given by earlier authors such as Grigorieva (1938), Rengarten (1951), Eristavi (1952), Mordvilko (1960) and Drushchits and Mikhailova (1966) and suggests the possibility that the *rjasanensis* Zone is a condensed version of more than one Berriasian zone. A more enlightened commentary on these important areas of faunal overlap may be possible when the relevant ammonites have been fully documented and illustrated.

Returning to the far north, it may be noted that Saks and Shulgina (1972) rely heavily on the extinction of the "*Virgatosphinctes*" fauna simultaneously at the end of the Tithonian and at the top of the *chetae* Zone of Siberia as evidence for synchronizing the beginning of the Cretaceous in the two realms. The point of extinction of a given taxon is perhaps the least satisfactory method of dating available to palaeontologists. A generation ago the giant ammonites of the Portland Beds (terminal Middle Volgian) were thought to be the expiring effort of the Dorsoplanitinae (Arkell 1957). Today it is known that relict Dorsoplanitinae (*Chetaites*) remained in occupation of this same region of Siberia throughout the Upper Volgian and the earliest Ryazanian, if the *sibiricus* Zone is correctly dated. It is not known what relationship these Siberian "*Virgatosphinctes*" bear to the *Virgatosphinctes* of the *transitorius* group recorded from the Tithonian of the Caucasus (Egoyan 1971; Khalilov 1971), still less to the macroconch forms of the Himalayan group of *V. broilii* (Uhlig), to which the name *Virgatosphinctes* properly applies (Enay 1973). Zeiss (1968) found the Siberian forms an odd group, not strictly congeneric with any of the known Tethyan faunas and possibly younger than the Tithonian. Even if these Siberian "*Virgatosphinctes*" could be attached firmly to a Tethyan source, these facies-ammonites would be useful for dating only if it could be shown that they were sterile expatriate communities replenished by waves of immigrants from the south. Their numbers and persistence suggest that they were endemically breeding populations and for the present they cannot be taken as proof of a Tithonian age. The same applies to the few berriasellids found with "*Virgatosphinctes*".

Jeletzky (this volume) places the Jurassic-Cretaceous boundary in the Canadian northwest between occurrences of *Borealites* (*Borealites*) (= *Praetollia antiqua* Jeletzky) and *Borealites* (*Ronkinites*) (= *Subcraspedites* aff. *suprasubditus* Jeletzky). In this he is supported by study of *Buchia* faunas which may be traced into the Tithonian-Berriasian of northern California. Judging by the known distribution of the ammonites elsewhere, this puts the Canadian boundary in the middle of the *kochi* Zone, or at the lowest, at the base of that zone, i.e., well above the base of the European boreal Cretaceous according to current opinion. If Jeletzky's (1964) Berriasian *Spiticeras* from Vancouver Island are Tithonian *Proniceras*, as Enay (1973) conjectures, the problem of intercontinental correlation at the Jurassic-Cretaceous boundary becomes particularly acute (see Casey and Rawson, this volume).

5b. Correlation via the continental facies

Areas of contact of marine Berriasian or Ryazanian and non-marine Purbeckian are known in southeast France and Poland and provide vital data for correlation. In the Alpine-Mediterranean Province (Cluse de Chaille and Mont Salève) Berria-

Table 3. Suggested correlation of the marine and continental facies at the Jurassic-Cretaceous boundary in England, N.W. Germany and Poland.

		YORKS.	LINCS.	NORFOLK	DORSET		N.W.GERMANY	POLAND	
VALAN-GINIAN (pars)	D 5-4	Speeton Clay (pars)	Claxby Beds (pars)	Leziate Beds (pars)	Hastings Beds (pars)		Platylenticeras Schichten 'Wealden' 6	Marine Valanginian	VALAN-GINIAN (pars)
UPPER RYAZANIAN	D 8-6 E		Upper Spilsby Sandstone	Mintlyn Beds	U.PURBECK	Durlston Beds	'Wealden' 1-5	Marine 'Berriasian'	?
LOWER RYAZANIAN		▨	▨		M.PURBECK	Cinder Beds	Upper Serpulit	*Riasanites*	BERRIASIAN
UPPER VOLGIAN		▨	Lower Spilsby Sandstone	Runcton Beds ▨	L.PURBECK	Lulworth Beds	Lower Serpulit Münder Mergel	Brackish & Brackish-marine	?
MIDDLE VOLGIAN (pars)		▨	▨	Roxham Beds ▨	Portland Stone			'Portlandian'	TITHONIAN (pars)

sian berriasellids are followed by brackish-water sediments with Lower Purbeck or basal Middle Purbeck ostracods, suggesting that the lower limit of the Berriasian (*grandis* Zone) falls somewhere within the Lower Purbeck (Lulworth) Beds (Donze 1958; Donze and Le Hégarat 1972). In Poland, boreholes west of Warsaw have penetrated a thick series of Purbeck-type strata overlain conformably by marine Ryazanian (Raczynska 1961; Marek 1961). Here the basal Ryazanian ammonite *Riasanites* enters above an ostracod assemblage equivalent to that found just below the "Cinder Beds" of the Dorset Purbecks (Bielecka and Sztejn 1966). Combined ammonite/ostracod data thus puts the Volgian/Ryazanian boundary at the base of the "Cinder Beds" and the Tithonian/Berriasian boundary somewhat more vaguely at a lower level—in the Lower Purbeck (Lulworth) Beds (Table 3). This agrees with the picture presented by the overlapping Tethyan/Boreal ammonite faunas in south Russia, i.e., that the Volgian/Ryazanian boundary is stratigraphically higher than the Tithonian/Berriasian. The importance of the Dorset Portland-Purbeck sequence in this respect is that both reference points (albeit one imprecise) are located in one section. And the inference is clear that between the Middle Volgian (Upper Tithonian) Portland Beds and the basal Ryazanian (Middle or Upper Berriasian) "Cinder Beds" there cannot be room for both the entire Upper Volgian and the full sequence of Lower (and perhaps Middle) Berriasian.

Attempts to find a microfloral solution to this knotty problem of trans-facial correlation at the Jurassic-Cretaceous boundary (Norris 1969) have produced corroborative evidence for a Lower Cretaceous age for the upper half of the Purbecks (Durlston Beds of Casey 1963), but do not take us any further in fixing the Tithonian-Berriasian contact. The palynology of these levels is discussed briefly elsewhere in this volume (Hughes).

Concerning the upper limit of the Berriasian in Dorset, Donze and Le Hégarat (1972) place this at the junction of "Wealden 3 and 4" of the German non-marine sequence, which, following Wolburg (1959), they locate in the lower part of the English Hastings Beds. Correlation of the German "Wealden" with the English Purbeck-Wealden was re-assessed by Anderson and Hughes (1964)[1] on the basis of ostracods and palaeobotany. According to these authors the upper limit of the Berriasian should be drawn at the top of Wealden 5" of the German sequence and well within the Hastings Beds. This is where Allen (1955, 1959) put it in the Hastings Beds on sedimentological and other grounds and its placing agrees better with the German entry of *Platylenticeras* (basal Valanginian) at the top of "Wealden 6". Only a small thickness of brackish-water sediment ("Wealden 6") is left undated; in the Speeton Clay of Yorkshire a similar brackish interval (bed D5) precedes the incoming of *Platylenticeras.*

6. Stage nomenclature at the Jurassic-Cretaceous boundary

A standard terminology for strata at the Jurassic-Cretaceous boundary will not be possible until the base of the Berriasian has been fixed by international consent and its boreal counterpart identified. I am not convinced that the time has come to dispense with regional stage terms; for the present the dual nomenclature Tithonian/Berriasian and Volgian/Ryazanian should be used for the Tethyan and Boreal Realms respectively. The hybrid "Volgian/Berriasian" corresponds to nothing in nature and its use should be discouraged.

The term Ryazanian was proposed (in its Russian form) by Sazonov (1951) for the Ryazan Beds of the Russian Platform. It is a particularly useful term, superior to Kilian's (1895) "Infravalanginian", which if it has a type-locality, falls in the Tethyan Realm. Adherents of the stratotype concept will point out that their condensed and transgressive characters render the Ryazan Beds even less suitable as a stratigraphical standard than the Volgian of the same region. Moreover, their correlation within the Boreal Realm poses the same problems, albeit on a smaller scale, encountered with the Berriasian. Nevertheless, the basal Cretaceous (post-Volgian) ammonite sequences of the Russian Platform, Siberia, Spitsbergen, Greenland and England have a community of character that requires expression in stratigraphical terms. There is no better word than Ryazanian and this name may be considered acceptable as an interim aid towards ultimate recognition of a global Berriasian.

Should the *grandis* Zone be ratified as the lower limit of the Berriasian and the postulated overlap of that stage and the Volgian (Table 3) confirmed, the name of the terminal Jurassic stage in the Boreal Realm would need further consideration. In this event the term Portlandian has obvious merits.

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[1] To avoid possible misunderstanding, it should be pointed out that the term Middle Valanginian as used by Anderson and Hughes corresponds to the German "Mittelvalendis" and is the Lower Valanginian of English and other ammonite workers. Similarly, the term Lower Berriasian has been applied to the Polish *Riasanites* horizon (Lower Ryazanian) (Marek and Raczyńska, this volume), though this level does not correspond to the Lower Berriasian of current French usage.

7. Systematic palaeontology

The following systematic notes are intended to validate new names used in this paper and to clarify usage of existing ones where necessary. They cover only that part of the Spilsby ammonite fauna on which the zonal succession and correlation are based.

The following abbreviations indicate the repositories of cited specimens: GSM = Geological Survey Museum (Institute of Geological Sciences, London); BM = British Museum (Natural History), London; SM = Sedgwick Museum, Cambridge.

Family Perisphinctidae Steinmann
Subfamily Dorsoplanitinae Arkell
Genus *PARACRASPEDITES* Swinnerton 1935

Type-species: P. stenomphaloides Swinnerton, Spilsby Sandstone Basement-beds, Fordington Well, Lincolnshire.

Remarks. The additional material now available shows how much the original finds of *Paracraspedites* at Fordington and Partney had been altered by distortion in the rock and other damage. All of Swinnerton's type-specimens and his unfigured material from these localities are severely flattened juveniles or microconchs. The type of *P. stenomphaloides* is crushed obliquely, the ribs appearing longer on the side not figured; the short secondary ribs on the last half-whorl are worn away in places, enhancing its resemblance to those craspeditids which lose the secondaries with age. The whorl-section was drawn to resemble that of a craspeditid and an incomplete suture-line of this species, though correctly figured, was misinterpreted as showing a craspeditid inversion.

It is now evident that the whorl-shape of *Paracraspedites* is rounded-rectangular, with flattened sides and broadly convex venter as in *Pavlovia.* The ribs are clear-cut and sharply elevated, maintaining their strength throughout. Compared with the ribbing of the Craspeditidae, the elevation is especially noticeable on the venter; here the ribs occasionally exhibit the zig-zag pattern observed in some *Pavlovia* (e.g. Spath 1936 pl. 39 fig. 16). The suture-line has the umbilical retraction typical of the Dorsoplanitinae (Pl. 6 fig. 1; Fig. 4n). Combined with the long straight primaries, strength and rigidity of the secondaries, and the gigantic size of the adult, these features make it impossible to admit the genus to the Craspeditidae. Specimens up to 650 mm diameter have now been collected from the Spilsby Sandstone, making it clear that *Paracraspedites* belongs to the family of "Portland giants", i.e., the Perisphinctidae. A resemblance between *Paracraspedites* and Upper Jurassic pavloviids was noticed by Spath (1947, 1952). At first he explained this by suggesting that the base of the Spilsby Sandstone might include fossils derived from some Portlandian or post-Portlandian deposits not known to occur *in situ* at present day. Later (1952) he abandoned this idea and considered that Basement-bed C (with *Paracraspedites*) could not be much older than the higher beds of the Spilsby Sandstone on account of the occurrence in it of *Subcraspedites preplicomphalus,* a supposed Cretaceous ammonite.

Although the recorded association of *Paracraspedites* and *Subcraspedites* is no longer considered an obstacle to accepting the Jurassic age of the Spilsby Sandstone Basement-beds, it happens that re-examination of the Fordington material (for the most part with depths recorded) does not confirm this association. Here, as in the outcrop sections, *Paracraspedites* and *Subcraspedites* are both obviously native to the rock, but their stratigraphical separation is sharp and definite.

Since publication of my 1962 paper the widespread use of the name *Paracraspedites* in Soviet literature for Ryazanian *Surites* (e.g., Saks *et al.* 1963) has been dropped. Nevertheless, Shulgina (1972) has re-asserted the Cretaceous age of the genus on the strength of its supposed occurrence in the "Berriasian" of Spitsbergen and Siberia.

The Spitsbergen record is based on "*Polyptychites*" *hoeli* Frebold (1929 pl. 2 fig. 3), which Shulgina (1972 p. 155) synonymized with *Paracraspedites stenomphaloides* Swinnerton. Frebold's ammonite was figured in side-view only; its resemblance to Swinnerton's species is superficial and its strongly inverse suture-line with numerous auxiliaries obviates the need for further comparison with *Paracraspedites.*

As for the two Siberian forms figured from the *analogus* and *sibiricus* Zones by Shulgina as conspecific or comparable with *P. stenomphaloides,* the former lacks the venter and in this condition is not distinguishable generically from contemporary *Surites.* Her "*P. stenomphaloides*" from the *sibiricus* Zone (R. Kheta section of the Khatanga depression) agrees more closely with Swinnerton's species, but lacks the rigid, *Pavlovia*-like course of the ribs, especially in the gentle forward curvature of its secondaries. The ventral aspect is also unlike that of *Paracraspedites* (cf. Shulgina 1972 pl. 8 fig. 1b and Pl. 1 fig. 3b herein). Though this ammonite is not a *Paracraspedites,* it bears a remarkable resemblance to the dorsoplanitid *Taimyroceras,* described by Mesezhnikov (1972) from the Middle Volgian of the same region of Khatanga depression (cf. Mesezhnikov 1972, pl. 10 fig. 1 and pl. 11 fig. 1b). Forms with pavloviid sculpture but craspeditid suture-lines have been figured from the Ryazanian Lower Niesen Beds of East Greenland by Donovan (1964 pl. 7) under the generic name '*Surites*'.

Pending investigations of the numerous nominal genera created by S. Buckman for the Portland "giants", the status of *Paracraspedites* must remain uncertain. There are a number of dorsoplanitids that in a crushed condition would be hard to distinguish from Swinnerton's genus, including the Russian *Lomonossovella* and the group of "*Epivirgatites*" *bipliciformis* (Nikitin).

Paracraspedites oppressus sp. nov. Pl. 1 figs 1, 2a–b; Pl. 6 fig. 1

1935 *Paracraspedites* aff. *stenomphaloides* Swinnerton p. 39 pl. 4, fig. 2a.

Holotype. GSM 87564, Portland Stone, "Shrimp Bed", St. Alban's Head, Dorset (W. Heap Collection).

Description. Moderately evolute *Paracraspedites;* at 100 mm diameter umbilicus 32% diameter. At that size ribs about 30 per whorl, round-topped, arising from umbilical seam and crossing flanks with slight forward inclination. Just below mid-flank (on crushed specimens) ribs bifurcate of trifurcate (roughly 3 bifurcations to 1 trifurcation); trifurcation rarely virgatitid. Ribs pass straight over venter with strong elevation. At larger diameters umbilicus progressively widens and ribs close up, venter becoming more convex. Suture-line typically dorsoplanitid, with "suspensive" umbilical lobe.

Remarks. This species differs from *P. stenomphaloides* mainly in its closer ribbing and smaller umbilicus. The secondaries appear abnormally short in the holotype of Swinnerton's species, as also in the original of his pl. 4 fig. 2a, due to oblique crushing. Because of the potential complications introduced by post-mortem deformation in these ammonites, I am figuring both sides of an example of *P. oppressus* from the Bawsey erratics. Specific distinction of the adults of this and allied species may not be possible without breaking the specimen to extract the nucleus. The fragment illustrated in Pl. 6 fig. 1 is the inside of a large segment from the Norfolk Drift, still septate at an estimated diameter of 260 mm.

Genus *KERBERITES* S. Buckman 1924

Type-species. K. kerberus S. Buckman, Portland Beds (*giganteus* Zone), Wiltshire.

Kerberites cf. *kerberus* S. Buckman. Pl. 8, figs 6a–b.

Remarks. The example illustrated in Pl. 8 figs 6a–b, is typical of the fragmentary *Kerberites* fauna present in the remanié *giganteus* Zone of Lincolnshire. It was obtained from the base of the Spilsby Sandstone (bed 1) in one of the Fordington wells and other, slightly larger, fragments have been collected from the same level in the Lymn Valley and at Nettleton. There is good agreement with the inflated variety of *K. kerberus* from the Portland Stone figured by

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Plate 1 all figs × 0·9.

1, 2a–b. *Paracraspedites oppressus* sp. nov.

1 Side view of crushed holotype, Portland Stone, "Shrimp Bed" (*oppressus* Zone), St. Alban's Head, Dorset. W. Heap colln, GSM. 87564.

2a–b Two sides of crushed example, Lower Spilsby Sandstone (Basement-bed: *oppressus* Zone), erratic block, British Industrial Sand pit, Bawsey, Norfolk. GSM. Ce3592.

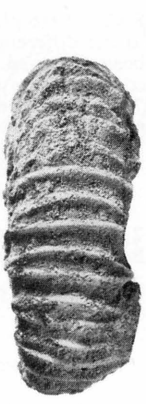
3a–b, 4 *Paracraspedites* sp.

3a–b Side and venter of ventro-dorsally crushed juvenile. Base of Roxham Beds (*oppressus* Zone), No. 4 Gas Feeder Main trench, north of Manor Farm, North Runcton, near King's Lynn, Norfolk. GSM. Ce5744.

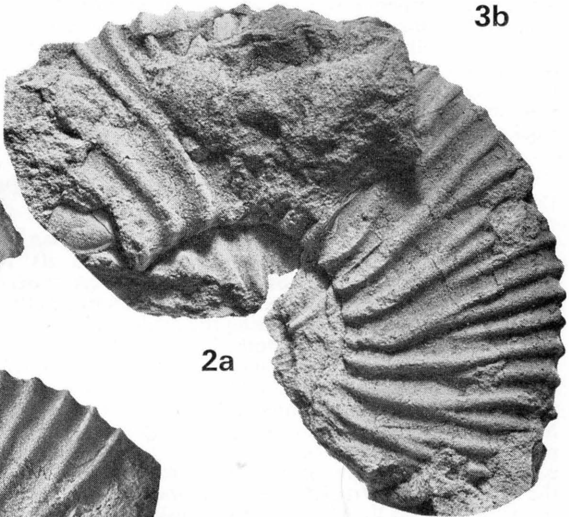
4 Crushed example. Middle Volgian (bed 13) ("*Epivirgatites nikitini*" Zone=*Lomonossovella blakei* Zone), right bank of River Volga, Gorodishche, near Ulyanovsk, U.S.S.R. (Photo Geological Institute, Academy of Sciences U.S.S.R., Moscow).

Plate 1

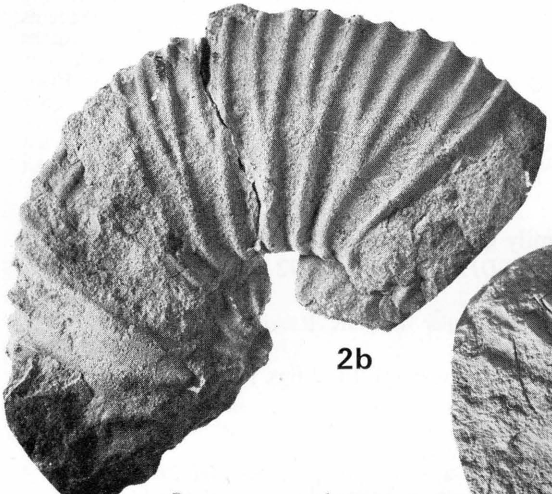
1



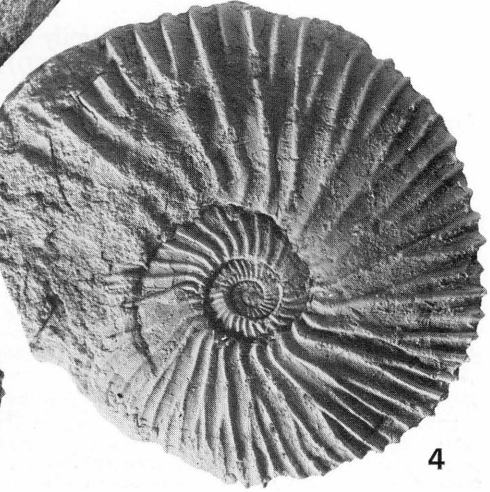
3b



2a



2b



4

3a

Spath (1936 pl. 18 figs 2a–b), but comparison with Buckman's type-specimen is difficult owing to the differences in sizes. Spilsby examples in which the umbilical swellings of the ribs have been removed by abrasion show great resemblance to *Lomonossovella,* which Arkell (1957) considered as a possible Russian equivalent of *Kerberites.* The relationship of the latter to *Titanites* S. Buckman is no clearer than when Spath (1936) discussed the problem and will probably not be elucidated until the Portland Stone ammonites have been monographed.

Genus *GLOTTOPTYCHINITES* S. Buckman 1923

Type-species. G. glottodes S. Buckman, Portland Beds (*giganteus* Zone), Long Crendon, Buckinghamshire.

Glottoptychinites ? trifurcatus (Swinnerton)

1935 *Paracraspedites (?) trifurcatus* Swinnerton, p. 40, fig. 5

Remarks. The genus *Glottoptychinites* resembles *Kerberites* in starting with coarse triplicate ribs on the inner whorls, but the ribbing is more distantly spaced, more elevated, and lacks umbilical swellings. The wretched Spilsby Sandstone specimen which served as a basis for Swinnerton's restored drawing of *Paracraspedites ? trifurcatus* is now supplemented by a few better examples from the Roxham Beds and the basal Spilsby Sandstone erratics of Bawsey. All show strongly elevated ribs that are sharper than those of *G. glottodes,* though Swinnerton's and Buckman's species may well prove to be congeneric.

Family Craspeditidae Spath 1924

This family is taken to comprise an Upper Volgian root-stock (*Craspedites, Subcraspedites, Kachpurites, Taimyroceras, Garniericeras*) with its Ryazanian derivatives *Hectoroceras, Pronjaites, Runctonia* gen. nov. and *Shulginites* gen. nov. etc. The problems involved in classifying the Craspeditidae have been touched upon by Spath (1947) and Jeletzky (1966) and there is something to be said for adopting the facile solution of attempting no suprageneric division at all. Certainly there is little point in following Spath (1952) and Arkell (1957) in separating various heterochronous oxycone offshoots in a "vertical" subfamily Garniericeratinae. It seems useful, nevertheless, to recognise the subfamily Tolliinae (=Suritidae Sazonova). This includes the Upper Ryazanian-Valanginian *Tollia,* its analogue *Peregrinoceras* and its forerunners *Surites, Borealites,* and probably *Praetollia,* which appear to have evolved from the Craspeditinae by a process of proterogenesis judging by the tolliine nucleus of *Borealites.* There are a number of borderline genera insufficiently known for certain allocation to one subfamily or the other, notably *Pronjaites,* best retained in the Craspeditinae. *Craspedites* has been reported from the Middle Volgian of the Rybinsk area (Gerasimov 1960), but the specimens are small and unconvincing.

Subfamily Craspeditinae

Genus *CRASPEDITES* Pavlov 1892

Type-species. Ammonites okensis d'Orbigny, Upper Volgian, Russian Platform.

Craspedites plicomphalus (J. Sowerby). Pl. 2 figs 1, 2; Figs 4a–b.

1822 *Ammonites plicomphalus* J. Sowerby, p. 82, pl. 359.
non 1823 *Ammonites plicomphalus* J. de C. Sowerby, p. 145, pl. 404.
1837 *Ammonites ptychomphalus* T. Brown, p. 17 (*pars*) (pl. xiii, fig. 2 only).
1924a *Subcraspedites ptychomphalus* Spath, p. 78.
1962 *Craspedites plicomphalus* Casey, p. 98.

Holotype. B.M. 43892a, Spilsby Sandstone, Bolingbroke, Lincolnshire.

Remarks. J. Sowerby's original was re-figured by Donovan (1964 pl. 9 fig. 2). I have since been permitted to clean out the umbilicus, which shows only about 8 blunt nodes on the inner whorl, agreeing with the nucleus of a topotype (Pl 2 fig. 2). This confirms what Spath knew already in 1924 and has been repeated by Casey (1962), *viz.,* that J. Sowerby's ammonite could not possibly be the same species figured by his son the following year (J. de C. Sowerby 1823). Now that the inner whorls and suture-line of *A. plicomphalus* are known (Pl. 2 fig. 2;

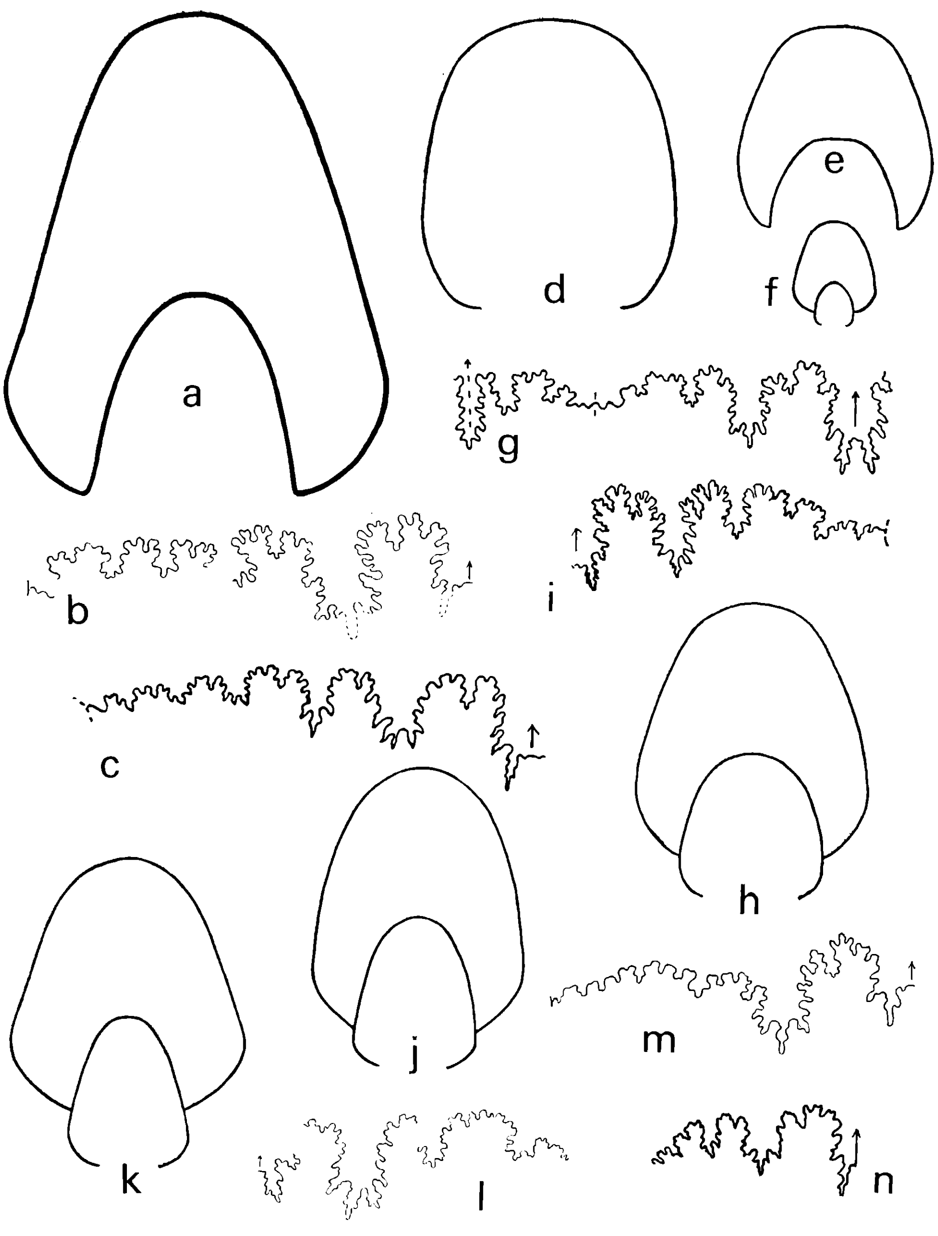


Fig. 4. Whorl-sections and suture lines of *Craspedites*, *Subcraspedites* (*Subcraspedites*), *S.* (*Swinnertonia*) and *Paracraspedites*.

a–b *Craspedites plicomphalus* (J. Sowerby), restored whorl-section of holotype (X 1) and suture-line of topotype figd Pl. 2 fig. 2 (X 1·5). **c** *C. krylovi* Prigorovsky, Upper Volgian, near Moscow, suture-line after Spath 1947 (X 2). **d–g** *Subcraspedites* (*Swinnertonia*) *primitivus* Swinnerton, whorl-sections (X 1) and complete suture-line (X 1·5) of four examples from *primitivus* Zone, Nettleton Top, Lincs. (GSM 107961, 107958, 114744, 114815). **h–i** *Subcraspedites* (*Swinnertonia*) *undulatus* Swinnerton, whorl-section of topotype (GSM 114816) (X 1) and suture-line of holotype after Spath 1947. **j** *Subcraspedites* (*Subcraspedites*) cf. *sowerbyi* Spath, whorl-section (X 1) of example figd Pl. 8 fig. 8. **k–l** *Subcraspedites* (*Subcraspedites*) *sowerbyi* Spath, whorl-section of example figd Pl. 5 fig. 2 (X 1) and suture-line of topotype (GSM 114817) (X 1·5). **m** *Subcraspedites* (*Subcraspedites*) *preplicomphalus* Swinnerton, suture-line of example figd Pl. 3 fig. 4 (X 1·5). **n** *Paracraspedites stenomphaloides* Swinnerton, suture-line of paratype after Swinnerton 1935, with umbilical portion completed.

Fig. 4b) the species is seen to fall easily into the group of *Craspedites nodiger* (Eichwald), *C. mosquensis* Gerasimov and *C. parakaschpuricus* Gerasimov, characteristic of the *nodiger* Zone of the Russian Platform (Gerasimov 1969), thus confirming the view already expressed (Casey 1962).

Craspedites thurrelli sp. nov. Pl. 5 figs 4a–b

Holotype. GSM 100512, *preplicomphalus* Zone, estimated 3 m above base of Spilsby Sandstone, crag in field northeast of Goulceby (TF 260 797), near Donington, Lincolnshire (R. G. Thurrell collection).

Specific characters. Differs from *C. krylovi* Prigorovsky in its slightly closer, less flexuous ribbing, having about 27 primary rib-stems at 60 mm diameter, each rising to two or three secondaries.

Dimensions of holotype.

Diameter (in mm)	*Whorl-height (as % of diam.)*	*Whorl-thickness (as % of diam.)*	*Umbilicus (as % of diam.)*
62	46	c. 35	21

Remarks. The unique holotype is slightly crushed; the suture-line, though imperfectly preserved, shows the tops of the auxiliaries crossing the flank in a straight line parallel with the ribbing and is normal for *Craspedites*. Comparison with *C. krylovi* Prigorovsky (1907) is not intended to imply close relationship, for other species, e.g., *C. unschensis* (Nikitin), have a similar aspect, though combining this with bi-dichotomy of the ribbing (cf. Gerasimov 1969). The straight ribs of *C. thurrelli* foreshadow the costation of *Subcraspedites* (*Volgidiscus*) *lamplughi* Spath, which is also involute in the young, but the smooth venter and strongly ascending suture-line of *Volgidiscus* prevent confusion of the two forms.

Genus *SUBCRASPEDITES* Spath 1924

Type-species. Subcraspedites sowerbyi Spath (1952 p. 18) (=*A. plicomphalus* J. de C. Sowerby 1823 *non* J. Sowerby 1822), Spilsby Sandstone. Bolingbroke, Lincolnshire.

Remarks. Misunderstanding of the type-species of this genus, its systematic affinities and precise stratigraphical position have been the biggest obstacles to solving the problem of the age of the Spilsby Sandstone. The nomenclatorial technicalities are the subject of an application to the International Commission on Zoological Nomenclature (Casey 1974) and have been touched upon elsewhere (Spath 1952; Casey 1962). In retrospect, it would appear that Spath had intended to introduce the name *Subcraspedites* in his paper on the Blake Collection of ammonites from Kachh, India (Spath 1924b), but owing to delay in publication, he anticipated the formal proposition of the name in two earlier papers (Spath 1923, 1924a). Despite the fact that *A. plicomphalus* J. de C. Sowerby 1823, pl. 404, was expressly cited (Spath 1924a) as type-species in preference to *A. plicomphalus* J. Sowerby 1822, most authors have persisted in citing *A. plicomphalus* J. Sowerby 1822, as the type. Others (e.g. Shulgina 1972 p. 121) have disregarded the assertions of Spath (1924a, 1924b, 1947, 1952) and Casey (1962) that the two ammonites belong to different species. In consequence an erroneous concept of *Subcraspedites* has grown up, the adult supposedly possessing the characters of *Craspedites plicomphalus.* In recent Soviet literature the error is compounded by confusing the Sowerbys' ammonites with certain Cretaceous homoeomorphs.

Plate 2 all figs × 0·9.

1, 2 *Craspedites plicomphalus* (J. Sowerby).

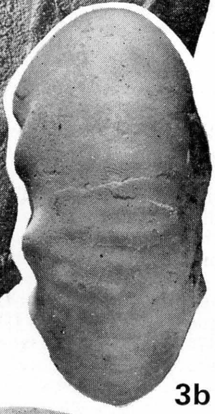
1 Crushed holotype with matrix removed from umbilicus. Spilsby Sandstone, Old Bolingbroke, near Spilsby, Lincolnshire. BM. 43892a.

2 Inner whorls of crushed topotype. Lower Spilsby Sandstone (*preplicomphalus* Zone), Spilsby Hill, Old Bolingbroke, near Spilsby, Lincolnshire. H. H. Swinnerton colln, GSM. 114729.

3a–b *Craspedites parakaschpuricus* Gerasimov (=*C. nodiger* Auctt. *non* Eichwald). Upper Volgian (*nodiger* Zone), Kaschpur, near Moscow, U.S.S.R. GSM. FOR 390 (donated by A. P. Pavlov, 1891).

Plate 2


1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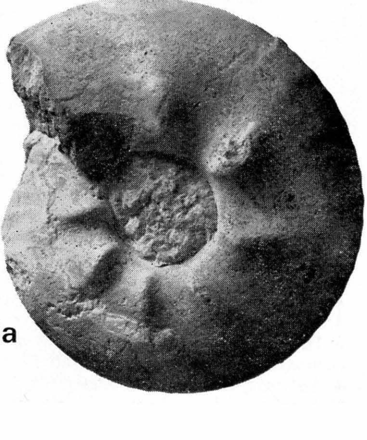
2


3a

Subgenus *SUBCRASPEDITES* s.s.

Remarks. In whorl-section and costation this subgenus is close to *Craspedites*, but whereas the latter remains involute and tends to become feebly ribbed or smooth towards the end, *Subcraspedites* is generally more evolute and has a slightly uncoiling outer whorl with coarse sculpture. Typically the costation on the ventral half of the ammonite is largely a feature of external sculpture and may be only feebly impressed on the internal mould, if at all. This is one of the features that helps to distinguish *Subcraspedites* s.s. from *Borealites*, *Ronkinites* and other Ryazanian homoeomorphs. Siberian forms lately referred to *Subcraspedites* s.s. (Shulgina 1972) are discussed below under *Borealites* (*Ronkinites*) and *Peregrinoceras.*

Subcraspedites (*Subcraspedites*) *sowerbyi* Spath. Pl. 3 figs 2a-b, 3; Pl. 4 fig. 6; Pl. 5 figs 1, 2; Figs 4k–l.

non 1822 *Ammonites plicomphalus* J. Sowerby, p. 82, pl. 359.
1823 *Ammonites plicomphalus* J. de C. Sowerby, p. 145, pl. 404.
1837 *Ammonites ptychomphalus* T. Brown, p. 17 (pars) (pl xiii, fig. 11 only).
1924a *Subcraspedites plicomphalus* Spath, p. 78.
1952 *Subcraspedites sowerbyi* Spath, p. 18.

Holotype. B.M. 43892b, Spilsby Sandstone, Bolingbroke, Lincolnshire.

Remarks. The original of *A. plicomphalus* J. de C. Sowerby (*non* J. Sowerby), i.e. the holotype of *S.* (*S.*) *sowerbyi* Spath, the type-species of *Subcraspedites*, is here figured photographically for the first time. It is a normal Spilsby Sandstone steinkern with a film of test in places. J. de C. Sowerby's restored figure was quite successful, but comparison with Pl. 2, figs 1–2 will show that this ammonite is not the inner whorls of J. Sowerby's *A. plicomphalus*, though it may well have been broken from the matrix of that ammonite.

According to Spath (1947, 1952), Brown (1837) had realised that the Sowerby's ammonites belonged to different species and had renamed the original of J. Sowerby (1822) as *A. ptychomphalus*, a nomenclature adopted by Spath in 1924. On the contrary, Brown's crude copies of the Sowerby's figures were expressly used to illustrate the inner and outer whorls of one and the same species. The manifest spelling error "*ptychomphalus*" ("*plichomphalus*" in the index) was applied to *both* specimens and was in no way intended as a taxonomic revision.

At a diameter of about 80 mm the holotype of *S.* (*S.*) *sowerbyi* shows groups of four to six secondaries which connect indefinitely with elongated primary bullae or rib-stems, 17 on the outer whorl. Due to distortion and imperfect preservation, the ribbing makes an unnatural chevron on the venter and is erased near the end on the flank. Where undistorted, the ribs pass straight over the venter, as in *S.* (*S.?*) *claxbiensis* Spath.

The species is a common form of the *preplicomphalus* Zone (Lower Spilsby Sandstone) and does not occur in the upper beds of the Spilsby Sandstone as conjectured by Spath (1952) and Jeletzky (1965). The example figured by Donovan (1964 pl. 9 fig. 1) is absolutely typical of the state of preservation of the *preplicomphalus* Zone in the southern Wolds. Even in the adult example figured herein (Pl. 5 fig. 1) the ribbing on the outer half of the ammonite is but feebly impressed on the coarse sandstone infilling.

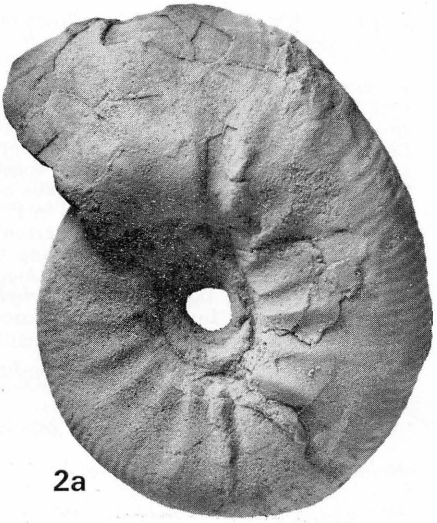
Shulgina's "*Subcraspedites* (*S.*) *plicomphalus*" from the Ryazanian *kochi* Zone of the Boyarka River section of Siberia (Shulgina 1972 pl. 2 figs 1a, b, v) shows a strong superficial resemblance to *S.* (*S.*) *sowerbyi;* the sharpness of the primary ribbing as revealed in the umbilicus, its smoothing outer whorl and the suture-line betray it, however, as a species of *Ronkinites.*

Plate 3 all figs × 0·9.

1 *Subcraspedites* (*Subcraspedites*) sp. nov. cf. *claxbiensis* Spath.
Lower Spilsby Sandstone (*preplicomphalus* Zone), field northeast of Goulceby, near Horncastle, Lincolnshire. R. G. Thurrell colln, GSM. 100516.
2a–b, 3 *Subcraspedites* (*Subcraspedites*) *sowerbyi* Spath.
2a–b Side and venter of holotype (original of *A. plicomphalus* J. de C. Sowerby 1823, *non* J. Sowerby 1822). Spilsby Sandstone, Old Bolingbroke, near Spilsby, Lincolnshire. BM. 43892b.
3 Immature topotype showing ribbing of inner whorls. Lower Spilsby Sandstone (*preplicomphalus* Zone), Old Bolingbroke, Lincolnshire. GSM. 114733.
4 *Subcraspedites* (*Subcraspedites*) *preplicomphalus* Swinnerton.
Example with body-chamber. Lower Spilsby Sandstone (*preplicomphalus* Zone), erratic block with *S.* (*S.*) *sowerbyi* (Pl. 5 fig. 1), British Industrial Sand pit, Bawsey, Norfolk. GSM. Ce3157.

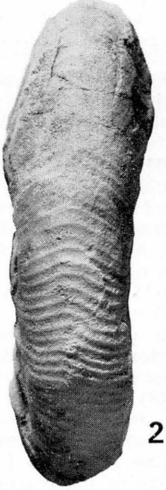
Plate 3

1



2a

3



2b

4

Subcraspedites (*Subcraspedites*) *preplicomphalus* Swinnerton Pl. 3 fig. 4; Fig. 4m.

Holotype. BM 36364, Spilsby Sandstone (bottom 2 m), Partney road-cutting, Spilsby, Lincolnshire.

Remarks. The poorly preserved holotype of this species was picked up on a tip heap. I agree with Spath (1952) that it belongs to an evolute member of the same species-group as *S.* (*S.*) *sowerbyi. Subcraspedites* (*S.*) *preplicomphalus* is not part of the *cristatus-primitivus* (*Swinnertonia*) plexus as Swinnerton supposed, nor is it ancestral to *S.* "*plicomphalus*" (= *S. sowerbyi*), the two species occurring together on the same horizon at Partney and elsewhere. The example figured in Pl. 3 fig. 4 was associated in an erratic block with numerous *S.* (*S.*) *sowerbyi*, one of which is illustrated in Pl. 5 fig. 1. The nucleus from Basement-bed C referred to *S.* (*S.*) *preplicomphalus* by Swinnerton (1935 p. 37 pl. 3 figs 2a, b) belongs to an indeterminable species of *Swinnertonia.* Being an easily recognized and characteristic fossil of the interval between the *primitivus* and *lamplughi* Zones, *S.* (*S.*) *preplicomphalus* is chosen as zonal index rather than *S.* (*S.*) *sowerbyi* on account of the prior use of the term *sowerbyi* Zone in the British Jurassic for a well-known Bajocian horizon.

Subcraspedites (*Subcraspedites ?*) *claxbiensis* Spath. Pl. 4 figs 7a–b.

1936 *Subcraspedites claxbiensis* Spath, p. 85, pl. 36, figs 6a–b.

Holotype. BM C996, Normanby, Lincolnshire (? base of Carstone, ex Spilsby Sandstone).

Remarks. This species is known only by phosphatized nuclei, found either as derived fossils at the base of the Carstone (Albian) in north Lincolnshire or as part of the remanié at the base of the Ryazanian in south Lincolnshire and Norfolk. It differs from typical *Subcraspedites* in having the ribbing equally strong on the internal mould and the test and in its strongly ascending suture-line with well differentiated auxiliaries, as in *Volgidiscus.* The relatively simple ribbing recalls that of *Craspedites okensis crassus* Prigorovsky as figured by Ershova (1969 pl. 2, figs. 2a–b) from the Upper Volgian of Spitsbergen. Some crushed examples from the *preplicomphalus* Zone of south Lincolnshire (e.g. Pl. 3 fig. 1) are provisionally attached to this species, though it is probable that the true *S.* (*S. ?*) *claxbiensis* is of higher horizon. I have been unable to confirm the presence of this species as a derivative at the base of the Claxby bed (see p. 205).

Subgenus *SWINNERTONIA* Shulgina 1972

Type-species. Subcraspedites cristatus Swinnerton, Spilsby Sandstone Basement-beds, Fordington Well No. 1, Lincolnshire.

Remarks. The nominal subgenus *Swinnertonia* was introduced by Shulgina (1972 pp. 123, 138) in the running text of a systematic contribution. Since her concept of the age and characters of the subgenus differ somewhat from those expressed herein, my original MS. diagnosis of *Swinnertonia* (made in 1964) is reproduced as follows:

"Differs from *Subcraspedites* s.s. in more broadly convex ventral area without tendency to smoothness on internal mould; ribbing of inner whorls of more uniform relief and with fewer secondaries (as in *Laugeites*), primaries pinched up or flared on outer whorl; suture-line not markedly ascending".

Swinnertonia comprises a group of early *Subcraspedites* having sutural characters, whorl-shape and ribbing suggesting affinities with the Dorsoplanitinae, especially *Laugeites.* The subgenus includes the forms described by Swinnerton (1935) from Bed D of the Spilsby Sandstone of the Fordington Well (*S. cristatus, S. precristatus, S. undulatus, S. parundulatus, S. subundulatus* and *S. primitivus*). These represent a single plexus in which there is a continuous gradation from *S.* (*Sw.*) *primitivus*, in which the laugeitid stage persists to at least 115 mm diameter, and forms like the paratype of *S.* (*Sw.*) *cristatus* (Swinnerton 1935 pl. 3 fig. 5) which has a coarsely ribbed body-chamber with flared primaries already at 35 mm diameter, thus resembling *Dorsoplanites dorsoplanus* (Vischniakov) (Mikhailski 1890 pl. 11 fig. 2a) in miniature. Swinnerton's originals are all more or less crushed. Whorl-sections and suture-lines taken from uncrushed examples from Nettleton are illustrated in this paper (Figs 4d–i).

The attribution of *S. primitivus* to *Ronkinites* (Shulgina 1972 p. 148) is altogether miscarried.

Donovan (1964) has commented on the close relationship between *Subcraspedites* and the genus *Laugeites.* The latter has a wide distribution in the Middle Volgian and basal Upper Volgian of the Arctic regions and differs from *Subcraspedites* in its whorls of subrectangular cross-section that become smooth in the adult. It is now asserted that the examples of

"*Subcraspedites* aff. *preplicomphalus*" and "*Laugeites* sp. nov." figured by Spath (1952 pl. 4) from the Basal Conglomerate (Laugeites Beds) of Wollaston Forland, East Greenland, are the outer and inner whorls respectively of a species of *Swinnertonia*. To explain the occurrence of a supposed Cretaceous ammonite (*Subcraspedites*) in the same nodule as a Jurassic one (*Laugeites*), Spath assumed that both must be derived. This assumption, already questioned by Maync (1949) and Donovan (1957) on the basis of stratigraphical evidence, has since been refuted (Casey 1962; Donovan 1964).

The aptly named *Laugeites intermedius* Donovan (1964) from Kuhn Island, East Greenland, probably represents an early form of *Swinnertonia* close to that figured by Spath from Wollaston Forland. There is some indication of the presence of a comparable fauna of nascent *Swinnertonia* in the Spilsby Sandstone Basement-beds (e.g. Bed 3 of Fordington).

My examination of the collections does not confirm the recorded association of *Swinnertonia* ("*Subcraspedites* cf. *undulatus*") with *Riasanites*, *Berriasella* and *Neocosmoceras* in the "Infra-valanginian" of northern Poland (Dembowska 1964).

Subgenus *VOLGIDISCUS* nov.

Type-species. Subcraspedites lamplughi Spath, Spilsby Sandstone, Spilsby, Lincolnshire.

Subgeneric characters. Compressed, involute *Subcraspedites* with closely spaced ribbing and smooth venter. Sculpture only feebly impressed on internal mould, coarsening on uncoiling adult body-chamber. Suture-line with strongly ascending series of auxiliary elements.

Remarks. Volgidiscus characterizes the topmost part of the Lower Spilsby Sandstone and is represented by *S.* (*V.*) *lamplughi* and a number of undescribed forms differing mainly in degree of inflation. Nuclei of some of the more compressed internal moulds were at first mistaken for "*Garniericeras*" of the group of "*G.*" *tolijense* (Nikitin) (Casey 1970), but study of larger collections, aided by casts and photographs of Nikitin's types, has revealed important differences (see *Shulginites* gen. nov.). *Volgidiscus* carries to extreme the tendency seen in *Subcraspedites* s.s. for the ribbing to be a feature of external ornament only. This is well shown in the example figured in Pl. 6 fig. 2a–b, in which a large part of the (calcite) test still covers the phosphorite internal mould. The coarse umbilical nodes of the adult are illustrated in the phosphorite steinkern from Nettleton shown in Pl. 5 fig. 3. The true *Garniericeras* is an involute oxycone with a sweeping forward curve to the septal edge (Fig. 5m).

Subcraspedites (*Volgidiscus*) *lamplughi* Spath. Pl. 4 figs 8a–b, 9a–b; Pl. 5 fig. 3; Pl. 6 figs 2a–b; Figs 5j–k.

1892 *Craspeditus subditus* Pavlov, p. 116, pl. xiii (vi), fig. 5.
1924a *Subcraspedites* sp. nov. Spath, p. 78.
1936 *Subcraspedites lamplughi* Spath, pp. 81, 180.

Holotype. B.M. C 34981, Spilsby Sandstone, Spilsby, Lincolnshire (G. W. Lamplugh colln)

Remarks. This species is based upon the original "*Craspedites subditus*" from which Pavlov (1892) correctly inferred the Volgian ("Aquilonian") age of the Lower Spilsby Sandstone. The specimen is a fragmentary white phosphorite steinkern with patches of calcite test adhering to the (detachable) inner whorl, i.e., the normal mode of preservation of the *lamplughi* Zone ammonites. In order to confirm that ventral smoothness is a feature of external ornament from an early diameter, phosphorite moulds of this species from the West Dereham basal Cretaceous nodule-bed were dissected to expose the testiferous inner whorls (Pl. 4 figs 9a, b).

The compressed species of *Volgidiscus* illustrated in Pl. 6 fig. 3, provided the suture-line attributed to a new species of *Subcraspedites* between *S. primitivus* and *S. lamplughi* (Spath 1947 text-fig. 6f).

Genus *SHULGINITES* nov.

Type-species. Oxynoticeras tolijense Nikitin, presumed Lower Ryazanian, River Tolya, West Siberia. Lectotype: original of Nikitin 1884 p. 65 pl. 2 fig. 7 (Klimova *in* Saks *et al.* 1972 p. 202).

Generic characters. Involute, very compressed, discoidal, with venter subacute in young, narrowly rounded in adult. Subdued costation of close, almost straight, forwardly-inclined primary stems, with gently curved secondaries bifurcating or trifurcating at low angle from just above middle of sides. Suture-line strongly ascending, with curved septal edge, as in *Hectoroceras*.

Remarks. Despite its frequent quotation in the literature, the generic affinities and geological horizon of "*O.*" *tolijense* have remained obscure. Under the name *Garniericeras tolijense*, the species has been commonly quoted from the Upper Volgian of the Russian Platform, more particularly from the topmost beds above the main development of the *nodiger* Zone (Sazonov 1961, 1962). Bodylevsky (1936), however, was of the opinion that in the Trans-Uralian region the glauconitic sandstone with "*G*". *tolijense* was of lowest Cretaceous age and it is listed as such by Mesezhnikov and others (*in* Saks *et al.* 1963, chart). More recently, Klimova (1969) has recorded the species (as *Hectoroceras tolijense*) in association with *Borealites* in the *kochi* Zone of the same region (River Yatriya section). Examples described and figured by Klimova (*in* Saks *et al.* 1972 p. 202 pl. 40 figs 1–4) subsequently, however, do not agree with Nikitin's originals and indicate instead a form closer to *Hectoroceras kochi tenuicostatum* Spath.

Since much of the confusion surrounding "*O.*" *tolijense* has been caused by lack of modern illustrations, I am, in Pl. 6 figs 4a–b, figuring one of Nikitin's metatypes from the collections of the Leningrad Mining Institute, which I was permitted to examine in 1963. The photographs were kindly supplied by Dr. N. I. Shulgina of the Institute of Geology of the Arctic, Leningrad.

Shulginites has the sutural characters of *Hectoroceras* and the ribbing of that genus in shadow form, though it lacks the funnel-shaped umbilicus and strength of ribbing of *Hectoroceras*. The Upper Volgian *Garniericeras* is a true oxycone and its suture-lines show a degree of "degeneration" not found in *Hectoroceras* or *Shulginites*. In the Spilsby *Volgidiscus*, another Upper Volgian group wrongly attached to "*O.*" *tolijense*, resemblance to *Shulginites* is confined to the juvenile internal mould (Pl. 4 figs 8a–b). The suture-line of *Volgidiscus* is different again (Fig. 5k, l) and the test has strong ribbing concentrated on the lower half of the flank, the umbilicus noded in the adult.

Future investigation will show whether the Volgian records of "*G.*" *tolijense* on the Russian Platform pertain rightly to *Volgidiscus*. The "*Garniericeras* aff. *tolijense*" figured by Shulgina (1969 pl. 38 figs 1a, b) from the topmost Volgian Zone of *Chetaites chetae* in the basin of the River Kheta, Siberia, appears to be a *Shulginites*.

The genus is named in honour of Dr. N. I. Shulgina of Leningrad.

Genus *RUNCTONIA* nov.

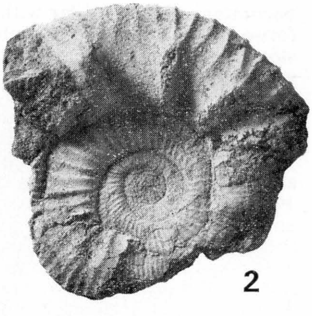
Type-species. R. runctoni gen. et sp. nov., Lower Mintlyn Beds (*runctoni* Zone), North Runcton, near King's Lynn, Norfolk.

Plate 4 all figs × 0·9.

1 *Subcraspedites* (*Swinnertonia*) *subundulatus* Swinnerton.
Topotype with body-chamber. Lower Spilsby Sandstone (*primitivus* Zone), depth 70 m, Fordington No. 2 Well, Lincolnshire. GSM. 114742.
2 *Subcraspedites* (*Swinnertonia*) *cristatus* Swinnerton.
Topotype with part of body-chamber. Horizon and locality as Fig. 1. H. H. Swinnerton colln, GSM. 114743.
3 *Subcraspedites* (*Swinnertonia*) *primitivus* Swinnerton.
Septate holotype. Horizon and locality as Fig. 1. BM. 36350.
4, 5 *Subcraspedites* (*Swinnertonia*) sp. juv.
Lower Spilsby Sandstone (*primitivus* Zone).
4 Impression of natural negative. Horizon and locality as Fig. 1. GSM. Zq280.
5 Ventral view of a specimen from Nettleton Top Barn, showing dorsoplanitine nucleus of *Swinnertonia*. GSM. 114744.
6 *Subcraspedites* (*Subcraspedites*) sp.
Immature example for comparison with Figs 4, 5. Lower Spilsby Sandstone (*preplicomphalus* Zone), Old Bolingbroke, Lincolnshire. GSM. 114734.
7a–b *Subcraspedites* (*Subcraspedites?*) *claxbiensis* Spath.
Side and front views of phosphatized nucleus (abraded at the end). Base of Carstone (ex Spilsby Sandstone), Nettleton Valley, Lincolnshire. P. F. Rawson colln, GSM. 114735.
8a–b *Subcraspedites* (*Volgidiscus* subgen. nov.) aff. *lamplughi* Spath.
Phosphatized nucleus illustrating involute juvenile stage of compressed form. Basal nodule-bed (bed 6) of Mintlyn Beds (ex Runcton Beds, *lamplughi* Zone), Fenland Flood Relief Channel, West Dereham, Norfolk. GSM. Ce1966.
9a–b *Subcraspedites* (*Volgidiscus* subgen. nov.) *lamplughi* Spath.
Side and venter of nucleus with test (which ends at bleb of phosphate on venter), dissected from outer whorls to demonstrate that ventral smoothness is not merely a feature of internal mould. Horizon and locality as Fig. 8. GSM. Ce 1903.
10a–c *Surites* (*Bojarkia*) *tealli* sp. nov.
Side, ventral and front views of holotype. Mintlyn Beds (bed 10 *stenomphalus:* Zone), King's Lynn Bypass, Galley Hill, Mintlyn Wood, near King's Lynn, Norfolk. GSM. Ce4407.

Plate 4


1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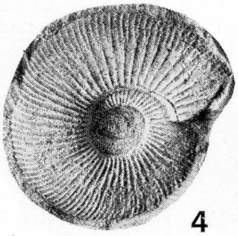
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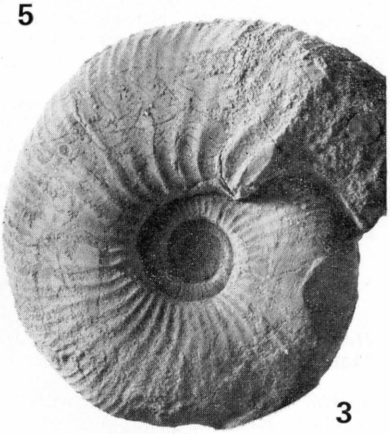
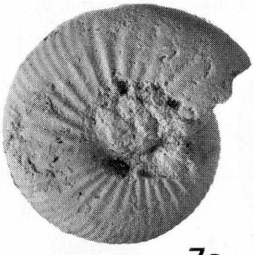

3


8a


8b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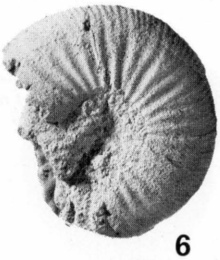
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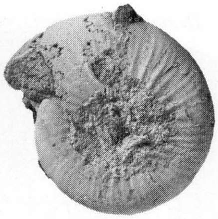
9b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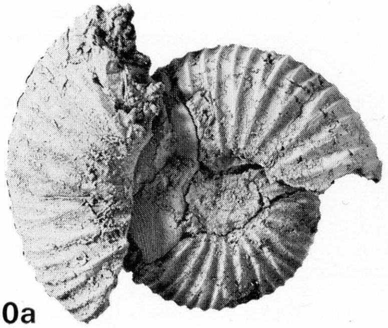
7b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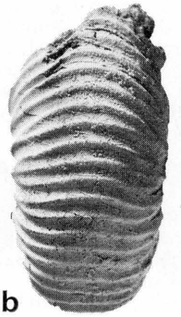
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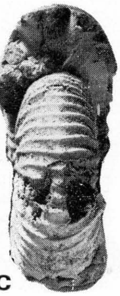

10c

Generic characters. Moderately compressed craspeditids with narrow umbilicus and poorly defined umbilical wall. Whorl-section at first subelliptical with narrowly arched venter, becoming subrectangular with flattened or feebly convex venter. Narrow flexuous ribs lean forwards from above the umbilical seam and bifurcate at a low angle from about middle of sides to form sickle-shaped curve; a few short intercalatories occur. Ribs at first absent on venter, but with change in whorl-shape they pass over venter with forward bend. Adult whorls poorly known, apparently tending to smoothness with concentration of sculpture at umbilical and ventrolateral areas. Suture-line strongly ascending, with numerous shallow auxiliaries.

Remarks. Great interest attaches to *Runctonia* as affording a clue to the ancestry of *Hectoroceras* and its associate *Praetollia.* In morphological features it stands almost half-way between *Volgidiscus* and *Hectoroceras.* The sickle-shaped ribbing directed forwards on the venter, and subacute venter of the young are characters linking *Runctonia* with *Hectoroceras*, while the normal umbilicus and suture-line point to a connexion with *Volgidiscus.* In the middle growth-stages there is perhaps even closer resemblance to *Praetollia*, enhanced by the tendency in both *P. maynci* and *R. runctoni* for the secondaries to increase in number during growth. *Praetollia* is still incompletely known, and the suite of crushed specimens from Wollaston Forland, E. Greenland, on which Spath (1952) based his diagnosis of the genus, remains practically the only source of information. Examination of this material (in the Universitetets Mineralogisk-Geologiske Institut, Copenhagen) shows the ribbing to be sharper than that of *R. runctoni*, with less emphasis on the primaries, and the venter is rounded and ribbed in the juvenile.

Since the holotype-mould of *P. maynci* Spath, the type-species of *Praetollia,* is distorted and the original illustration (Spath 1952 pl. 3, fig. 2) gives a misleading idea of the ribbing, I am figuring an impression in which the distortion has been corrected (Pl. 7 fig. 8). The group of "*Olcostephanus*" *bidevexus* Bogoslovsky (1897 pl. 3 figs 1a, b, 2a, b, 3, 4) (= *Pronjaites* Sazonova 1971), which Gerasimov (*in* Sazonova 1962) attaches to *Praetollia,* has a wider umbilicus, narrowly arched venter and ribbing of a different type, branching from low on the flank and with numerous intercalatories.

Runctonia runctoni gen. et sp. nov. Pl. 7 figs 5a–b, 6a–b, 7a–b; Figs 5f–h.

Holotype. GSM. Ce 5348, basal nodule-bed of Mintlyn Beds, North Sea gas pipe-line trench, Manor Farm, North Runcton, near King's Lynn, Norfolk.

Specific characters. Runctonia with smooth venter to c. 30 mm diameter. Ribs at first almost regularly bifurcating, in ratio of 17 primaries to 36 secondaries per half-whorl at 50 mm diameter. With increase in diameter intercalatories appear, primaries become emphasised, and ribs cross feebly convex venter with arcuate bend.

Dimensions of holotype.

Diameter (*in mm*)	*Whorl-height* (*as % of diam.*)	*Whorl-thickness* (*as % of diam.*)	*Umbilicus* (*as % of diam.*)
50	46	29	21

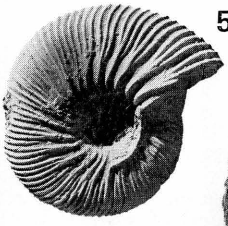
Plate 5 all figs × 0·9.

1, 2 *Subcraspedites* (*Subcraspedites*) *sowerbyi* Spath.
Lower Spilsby Sandstone (*preplicomphalus* Zone).
1 Example with body-chamber (abraded at end). Erratic block with *S.* (*S.*) *preplicomphalus* (Pl. 3, fig. 4), British Industrial Sand pit, Bawsey, Norfolk. GSM. Ce3188.
2 Venter of uncrushed body-chamber. Field northeast of Goulceby, near Horncastle, Lincolnshire. R. G. Thurrell colln, GSM. 100514.
3 *Subcraspedites* (*Volgidiscus* subgen. nov.) aff. *lamplughi* Spath.
Compressed form showing umbilical folds on outer whorl, strongly·ascending suture-line and short body-chamber. Lower Spilsby Sandstone (*lamplughi* Zone: bed 6), Nettleton Top Barn. S. Kelly colln, GSM. 114731.
4a–b *Craspedites thurrelli* sp. nov.
Holotype, side and ventral views. Horizon and locality as fig. 2. R. G. Thurrell colln, GSM. 100512.
5a–b *Paratollia* cf. *kemperi* gen. et. sp. nov.
Side and venter of juvenile example. Claxby Beds, Bardney-Louth Railway cutting, "Little Benenden", near Donington-on-Bain, Lincolnshire. SM. B12222.
6 *Propolyptychites* sp.
Juvenile. Claxby Beds, *Paratollia* horizon, Bardney-Louth Railway cutting, Benniworth Haven, near Donington-on-Bain, Lincolnshire. SM. B11120.

Plate 5


2


1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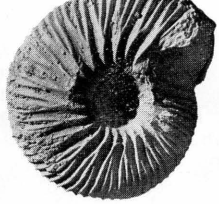
5b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3


4b


4a

Remarks. The type material consists of six phosphatised examples with patches of nacreous test, none complete. In addition there is a large number of nacreous chips from the fragmentation of this or some allied ammonite having a body-chamber comparable with that of *Surites* (*Bojarkia*) *suprasubditus pavlovi* subsp. nov. (Pl. 9) in size and sculpture.

Genus *HECTOROCERAS* Spath 1947

Type-species. H. kochi Spath, presumed "Infravalanginian" (Ryazanian), S. W. Jameson Land, East Greenland.

Remarks. Following the original discovery of this genus in Greenland (Spath 1947), it was reported in the "Berriasian" of eastern England (Casey 1961b) and has since proved to be a characteristic fossil in the basal Cretaceous succession in North and West Siberia. Its oxycone form, funnel-like umbilicus, and sickle-shaped ribs bifurcating high on the flank make this an easily recognized ammonite. Hitherto only the type-species, *H. kochi,* with its subspecies, *magnum* Spath and *tenuicostatum* Spath, has been described, apart from certain Siberian forms referred to *H. tolijense* (Nikitin) (Klimova *in* Saks *et al.* 1972). All the well-preserved and photogenic English examples of *Hectoroceras* were obtained from a single temporary exposure of the Mintlyn Beds at West Dereham, Norfolk. It is therefore not known whether the vertical distribution of the many undescribed species, with and without *H. kochi,* reflects a natural sequence or fortuitous local detail. These will be described in a future publication.

Hectoroceras larwoodi sp. nov. Pl. 7 fig. 4.

Holotype. GSM Ce 5096 (external mould), base of Carstone (Bed 18, *ex* Mintlyn Beds, *kochi* Zone), Fenland Flood Relief channel, West Dereham, Norfolk.

Specific characters. Similar to *H. kochi tenuicostatum* Spath (1947 pl. 1, fig. 1a) but with feebler, more flexuous ribbing, showing periodic bi-dichotomy from low on the flank.

Remarks. This distinctive species of *Hectoroceras* is illustrated because it occurs above the main development of *H. kochi* in the Mintlyn Beds and may prove of biostratigraphical value. The species is named in honour of Dr. G. P. Larwood, who assisted in the original reconnaissance of the Flood Relief channel at West Dereham.

Subfamily Tolliinae Spath 1952

Genus *BOREALITES* Klimova 1969

Type-species. B. fedorovi Klimova, Ryazanian, *kochi* Zone, West Siberia.

Remarks. Borealites was originally defined to include *B. fedorovi* Klimova, "*Olcostephanus*" *suprasubditus* Bogoslovsky of the Ryazan Beds and "*Tollia* (*Subcraspedites*) aff. *suprasubditus*" and "*T.* (*S,?*) cf. *payeri*" of Jeletzky (1964) from Berriasian rocks in Arctic Canada. To these were later added *B. radialis* Klimova, *B. mirus* Klimova and *B, explicatus* Klimova (Klimova 1972) and *B. ? suritiformis* Klimova (*in* Golbert *et al.* 1972) from the *kochi* Zone of the Trans-

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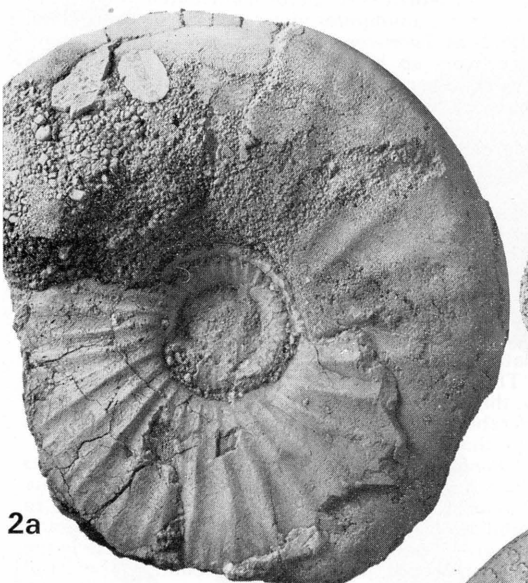
Plate 6 all figs. × 0·95.

1 *Paracraspedites* cf. *oppressus* sp. nov.
Portion of inner whorls of large example, still septate at c. 260 mm diameter. Drift (ex Spilsby Sandstone Basement-bed, *oppressus* Zone), Dunham, near Swaffham, Norfolk. C. B. Rose colln, Norwich Castle Museum.
2a–b *Subcraspedites* (*Volgidiscus* subgen. nov.) *lamplughi* Spath.
Side and venter of example with portions of (calcite) test, Spilsby Sandstone, Claxby, Lincolnshire. SM. B12205.
3 *Subcraspedites* (*Volgidiscus* subgen. nov.) aff. *lamplughi* Spath.
Phragmocone of compressed form (suture-line Fig. 51), Spilsby Sandstone, Normanby, Lincolnshire. BM. C73374.
4a–b *Shulginites tolijensis* (Nikitin).
Side and venter of topotype. Jurassic-Cretaceous boundary beds, River Toliya, eastern slope of northern Urals, U.S.S.R. Museum of Mining Institute, Leningrad. (Photo by courtesy of N. I. Shulgina).

Plate 6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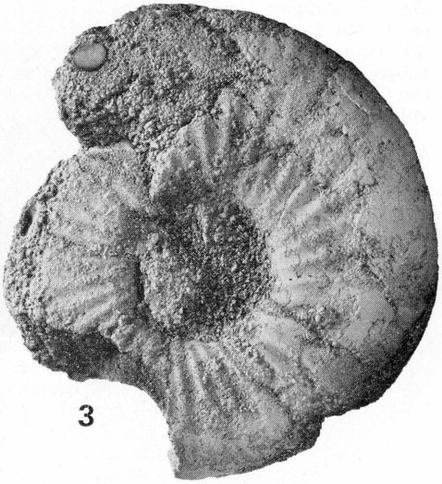
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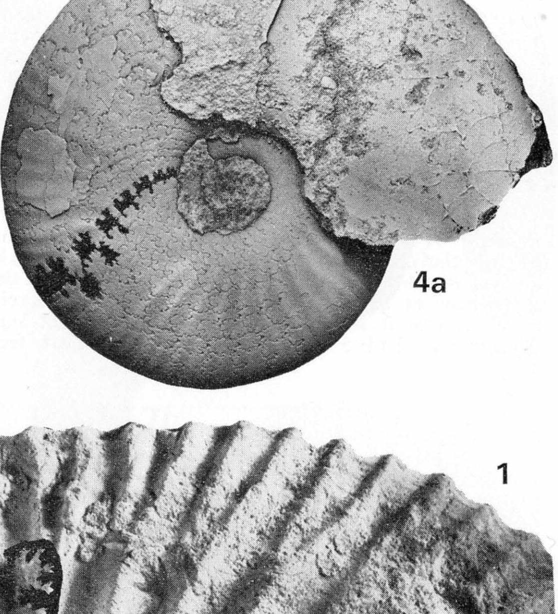
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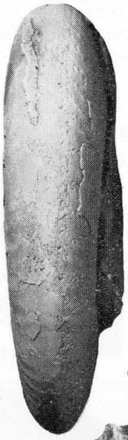
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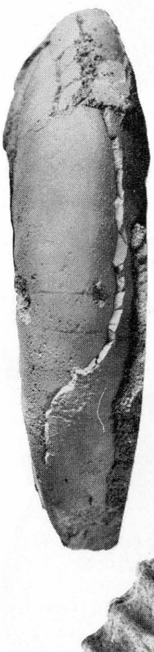
2b


1

Uralian border of West Siberia. As conceived by the present author, the genus *Borealites* s.s. comprises Klimova's species from West Siberia, the North Siberian form attributed to *suprasubditus* by Shulgina (1972 pl. 5 figs 1–2, pl. 6 figs 3–6); ammonites illustrated by Voronets (1962 pl. 31 figs 2a, b, v. pl. 45 figs 1–2, pl. 52 fig. 2) as *Taimyroceras ? bodylevskyi* Voronets and *Subcraspedites* ex gr. *bidevexus* Bogoslovsky, from an horizon in the Lena-Anabar region subsequently assigned to the *sibiricus* Zone by Basov and others (*in* Saks *et al.* 1972 p. 32), and the Canadian *Praetollia antiqua* Jeletzky, assigned by its author to the Jurassic (Jeletzky, this volume).

While the original "*O.*" *suprasubditus* (Bogoslovsky 1897 pl. 1) has the characters of *Surites* (*Bojarkia*), the Canadian form attached to this species is here regarded as a form of *Ronkinites* allied to *R. anglicus* (Shulgina).

Ronkinites and *Borealites* are closely associated in geological occurrence, geographical distribution and in morphological features and are treated as only subgenerically distinct. Both have tolline inner whorls, and judging by casts of *B. fedorovi* kindly sent me by Dr. V. N. Saks, these exhibit constrictions in some specimens, as in *Ronkinites*. Data from Siberia suggests that the more strongly ribbed *Borealites* s.s. is the first to appear, in the *sibiricus* Zone, and become more diversified in the lower part of the *kochi* Zone. The primitive *B.* (*B.*) *bodylevskyi* (Voronets) leans towards *Ronkinites* and may be seen as a generalized from near the root-stock of late *Borealites* s.s. and *Ronkinites*. The latter appears in the *kochi* Zone (? upper part) and ranges into the succeeding *analogus* Zone. This agrees with the Canadian sequence, in which *Borealites* s.s. (= *Praetollia antiqua* Jeletzky, this volume) is found below *Ronkinites*. In Greenland, also, crushed ammonites probably referable to *Borealites* s.s. have been obtained from a level near the base of the *kochi* Zone (Surlyk this volume, Pl. 1 fig. 3).

The tolline inner whorls and suture-line of *Borealites* s.s. point to closer affinities with *Surites* than with the Volgian *Subcraspedites,* to which it was subordinated as a subgenus by Shulgina (1972). The relationship of *Borealites* to *Praetollia*, a form of much the same age, is hard to assess at present. So far as is known, the umbilicus of *Praetollia* remains small throughout and the thin, close ribbing of its type-species, *P. maynci* Spath, remarkably *Hectoroceras*-like in the middle growth-stages, does not develop the thickened primaries of *Borealites.* The basal Valanginian *Surites* (*Bogoslovskia*) produces a similar morphology in the young, though with bolder ribbing projected in a tongue-like extension on the venter. In the adult *Bogoslovskia* (= *Stchirowskiceras* Sazonova 1971) the ribbing becomes closer and feebler on the ventral half of the shell, the final stage resembling in sculpture that of *Surites* (*Bojarkia*) *suprasubditus* (Bogoslovsky).

Subgenus *BOREALITES* s.s.

Borealites (*Borealites*) cf. *fedorovi* Klimova. Pl. 8 fig. 7.

Remarks. A fragment from the top of the Lower Mintlyn Beds (Bed 16, *kochi* Zone) of the Flood Relief channel at West Dereham (GSM Ce 3092) has an estimated diameter of 40 mm. In its oval whorl-section and the forwards projection of the ventral ribbing it compares well with *B. fedorovi* or *B. surítiformis* Klimova; but in the relatively early aquisition of dominantly triplicate ribs it shows better agreement with *B. suprasubditus* Shulgina *non* Bogoslovsky (Shulgina 1972 pl. 5 figs. 2a, b). The characteristic feature of this fragment, however, is its

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Plate 7 all figs × 0·9.

1–3 *Hectoroceras kochi* Spath.
Impressions from natural negatives and venter of clay-ironstone steinkern. Mintlyn Beds (*kochi* Zone), Fenland Flood Relief Channel, West Dereham, Norfolk. GSM. Ce3818, GSM. Ce1946, GSM. Ce2428.

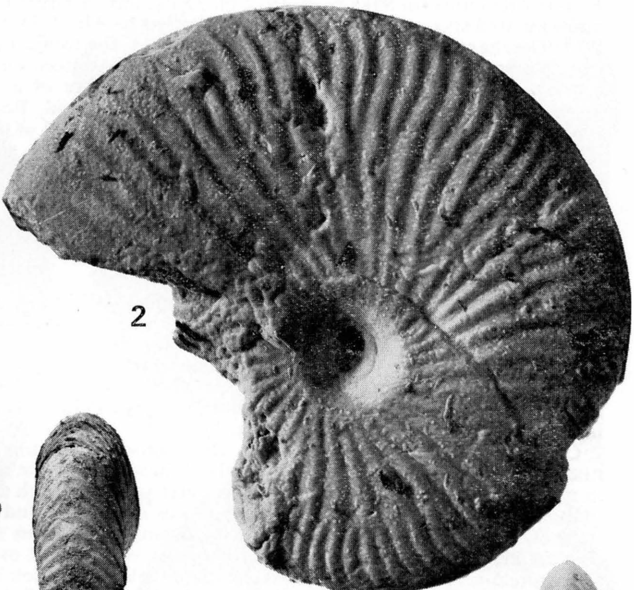
4 *Hectoroceras larwoodi* sp. nov.
Impression from holotype-mould. Base of Carstone (bed 18) (ex Mintlyn Beds, *kochi* Zone), Fenland Flood Relief Channel, Abbey Station, West Dereham, Norfolk. GSM. Ce5096.

5a–b, 6a–b, 7a–b *Runctonia runctoni* gen. et. sp. nov.
Basal nodule-bed of Mintlyn Beds (bed 6: *runctoni* Zone), No. 2 Gas Feeder Main trench, Manor Farm, North Runcton, near King's Lynn, Norfolk.
5a–b Side and venter of holotype, GSM. Ce5348.
6a–b Side and venter of paratype, showing beginning of ventral union of ribs. GSM. Ce5347.
7a–b Side and venter of body-chamber fragment. GSM. Ce5343.

8 *Praetollia maynci* Spath.
Impression from holotype-mould, Ryazanian, north coast of Wollaston Forland, Lindemans Fjord, East Greenland. Specimen illustrated Spath 1952 pl. 3 fig. 2, but ventrolateral distortion here corrected. Universitetets Mineralogisk-Geologiske Institut, Mineralogisk Museum, Copenhagen.

Plate 7


1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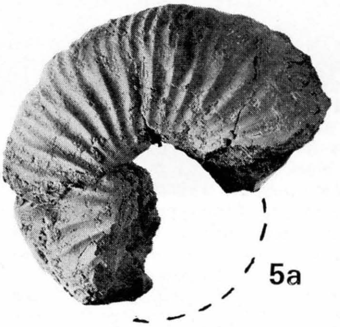
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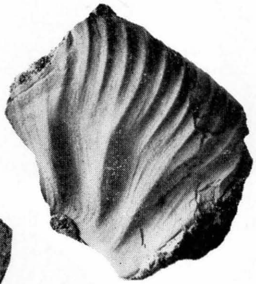
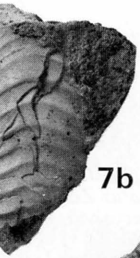

7a


3


6a


6b


7b


4


8

almost virgatitid mode of trifurcation, which occurs, though less markedly, in *B. fedorovi* and *B. mirus* Klimova (*in* Saks *et al.* 1972 pl. 35 fig. 3a). A larger example of possibly the same or a more inflated species of *Borealites* was collected by Mr. J. Doyle from the *Hectoroceras* beds of West Dereham (GSM Zm7976). In this specimen the tolliid nucleus, with regularly bifurcating ribs, is preserved as a hollow mould; the outer whorl agrees with *B. fedorovi* so far as it goes, but is too badly crushed for critical comparison. A piece of a *Tollia*-like nucleus found in the *kochi* Zone of the King's Lynn Bypass (Mintlyn Wood, Bed 3) may or may not belong to *Borealites*. Another doubtful nucleus was found at the base of the zone (bed 6) at West Dereham.

Subgenus *RONKINITES* Shulgina 1972

Type-species. Subcraspedites (*Ronkinites*) *rossicus* Shulgina, Ryazanian, *kochi* Zone, R. Boyarka, N. Siberia.

Remarks. Formally proposed in 1972 by Shulgina (1972 p. 147) as a subgenus of *Subcraspedites,* with *S.* (*R.*) *rossicus* as type-species, the name was first used in 1970 (*in* Basov *et al.* 1970 p. 21) in connexion with *Taimyroceras ? bodylevskyi* Voronets of the *sibiricus* Zone of the Anabar section. From photographs and specimens kindly supplied by Dr. N. I. Shulgina, I have concluded that this subgenus of *Borealites* should be enlarged to include "*S.* (*S.*) *plicomphalus*" and "*S.* (*S.*") *anglicus* of the same author (Shulgina 1972 pls 1, 2, 3, pl. 4 fig. 1), and perhaps also her "*Praetollia maynci*" (*ibid*, pl. 6 fig. 1).

Compared with *Subcraspedites* s.s., the diagnostic features of *Ronkinites* are its *Surites*-like nucleus, with tardy appearance of umbilical thickening to the ribs, well-differentiated auxiliaries in the suture-line, and the nature of the outer whorls, which are devoid of sculpture except for umbilical bullae. There are minor differences of ribbing and whorl-shape, and faint constrictions, when present, are another distinguishing feature. In accordance with this concept of *Ronkinites*, the type-species, *B.* (*R.*) *rossicus*, is regarded as an extreme form in which the appearance of umbilical bullae is unusually delayed. Resemblance of *Ronkinites* to *Subcraspedites* is in the middle growth-stages only. Reference of *B.* (*R.*) *anglicus* and *B.* (*R.*) "*plicomphalus*" (Shulgina) to *Subcraspedites* s.s. results from a faulty concept of the type-species of that genus, produced by combining the characters of the small, finely ribbed *A. plicomphalus* J. de C. Sowerby (= *Subcraspedites sowerbyi* Spath) and those of the large *A. plicomphalus* J. Sowerby (= *Craspedites plicomphalus*), with its ribless and coarsely noded outer whorl.

Borealites (*Ronkinites*) is represented in the *Buchia okensis* Zone of Arctic Canada by "*Tollia* (*Subcraspedites*) aff. *suprasubditus*" and "*Tollia* (*Subcraspedites*) aff. *spasskensis*" of Jeletzky (1964 pl. 2 figs 1 a–c; pl. 3 figs 2 a–d).

Genus *SURITES* Sazonov 1951

Type-species. Surites pechorensis Sazonov, Ryazan Beds, Russian Platform.

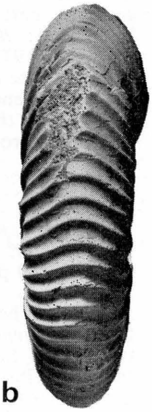
Plate 8 all figs × 0·9.

1a–b, 2, 3 *Surites* (*Bojarkia*) *stenomphalus* (Pavlov).
Upper Spilsby Sandstone (*stenomphalus* Zone).
1a–b Side and venter of slightly crushed lectotype, with matrix cleaned from umbilicus. Donington-on-Bain, Lincolnshire. SM. B11111.
2 Fragmentary example from the Bardney-Louth railway cutting, Benniworth Haven, near Donnington-on-Bain, Lincolnshire. SM. B93301.
3 Example showing uncrushed venter. North Willingham, Lincolnshire. GSM. 30896.
4a–b, 5a–b *Surites* (*Lynnia* subgen. nov.) *icenii* sp. nov.
Mintlyn Beds (bed 12: *icenii* Zone), No. 2 Gas Feeder Main trench, Manor Farm, North Runcton, near King's Lynn, Norfolk.
Side and venter of paratype, GSM. Ce5311. (4a–b) and holotype, GSM. Ce5298 (5a–b).
6a–b *Kerberites* cf. *kerberus* S. Buckman.
Side and venter of typical fragment. Lower Spilsby Sandstone (Basement-bed: *giganteus* Zone), depth 71·9 m, Fordington No. 2 Well, Lincolnshire. GSM. Zq275.
7 *Borealites* (*Borealites*) cf. *fedorovi* Klimova.
Impression from natural mould. Mintlyn Beds (bed 16: *kochi* Zone), Fenland Flood Relief Channel, West Dereham, Norfolk. GSM. Ce3092.
8 *Subcraspedites* (*Subcraspedites*) aff. *sowerbyi* Spath.
Ventral view of example with (calcite) test removed in places. Note that ribbing is greatly reduced in strength on the internal mould. Lower Spilsby Sandstone, Claxby, Lincolnshire. SM. B11112.

Plate 8


2


1a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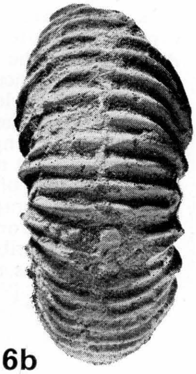
6a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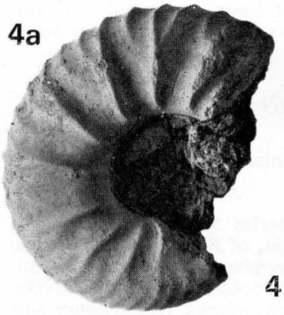
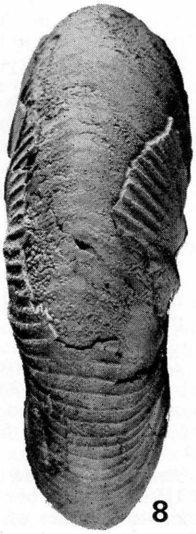

4a


4b


7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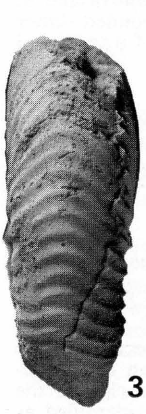
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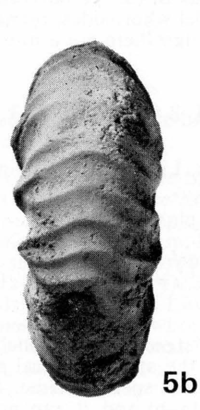
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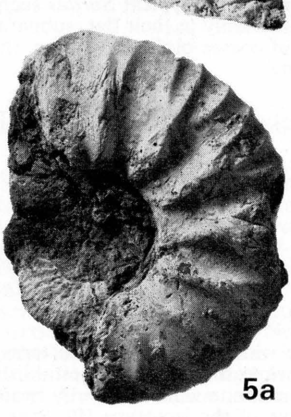

5a

Remarks. This genus has been fully discussed and illustrated by Sazonova (1971) from material from the Moscow-Volga region. In the present paper the scope of the genus is widened to embrace certain species-groups (subgenera) originally described as independent genera. These are: *Bogoslovskia* Sazonova 1965 (=*Stchirowskiceras* Sazonova 1971), *Caseyiceras* Sazonova 1971, and *Bojarkia* Shulgina 1969, to which is added *Lynnia* subgen. nov., described below. These all possess moderately compressed or slightly depressed whorls and a suture-line with an ascending series of auxiliaries. The ribs are regularly biplicate in the young and bend forwards on the venter; a more complex ribbing generally develops in mid-life but only umbilical and/or ventro-lateral remnants of it survive at large diameters.

Subgenus *BOGOSLOVSKIA* Sazonova 1965

Type-species. Bogoslovskia pseudostenomphala Sazonova 1971 (=*Olcostephanus stenomphalus* Pavlov 1889 p. 59 pl. 3 fig. 10 only), basal Valanginian, Russian Platform.

Remarks. The nominal genus *Bogoslovskia* was first used without diagnosis (Sazonova 1961) for "*Olcostephanus*"*stenomphalus* Pavlov; this species was based on two examples, one from the Spilsby Sandstone of Lincolnshire, the other from the Lower Valanginian of the Russian Platform (Pavlov 1889). When the genus was formally and validly proposed in 1965 Sazonova made it clear that it was based on Pavlov's Russian syntype, despite the fact that Spath (1947) had designated the English specimen as lectotype. As stated by Jeletzky (1968), the two ammonites are subgenerically distinct, and as the original Russian "*O.*" *stenomphalus* is lost I had considered seeking authority of the International Commission on Zoological Nomenclature to designate the Lincolnshire example as the taxonomic basis for *Bogoslovskia* under Article 70. In the meantime, the proposition of the name *Bojarkia* for the species-group that includes this Lincolnshire form (Shulgina *in* Saks and Shulgina 1969) and the selection of a neotype for Pavlov's missing Russian one (renamed *B. pseudostenomphala*) by Sazonova (1971) changes the situation. I am now of the opinion that stability of nomenclature is best served by adhering to the type-species *pseudostenomphala* Sazonova, which is to be regarded as a replacement name for *Bogoslovskia stenomphala* Sazonova *non* Pavlov (Article 70 (b) (i)) on transference of both Sazonova's and Pavlov's species to *Surites.*

From photographs and specimens kindly supplied by Dr. I. G. Sazonova and Dr. N. T. Sazonov and from examination of their material in Moscow, I have concluded that the ammonites described by Sazonova under the generic name *Stchirowskiceras* represent the adult stages of species of *Bogoslovskia.*

Subgenus *BOJARKIA* Shulgina 1969

Type-species. Bojarkia mesezhnikowi Shulgina, Upper Ryazanian, *mesezhnikowi* Zone, R. Boyarka, West Siberia.

Remarks. In my interpretation, *Bojarkia* comprises the Arctic species *S.* (*Bj.*) *mesezhnikowi* (Shulgina), *S.* (*Bj.*) *bodylevskii* (Shulgina) and *S.* (*Bj.*) *payeri* (Toula, of Russian authors), the English Upper Ryazanian *S.* (*Bj.*) *stenomphalus* (Pavlov), *S.* (*Bj.*) *surprasubditus pavlovi* subsp. nov., and *S.* (*Bj.*) *tealli* sp. nov., together with a number of species described by Bogoslovsky (1897, 1902) from the Ryazan Beds, e.g., "*O.*" *suprasubditus*, *kozakowianus*, *tzikwinianus* and *subtzikwinianus*. These differ from typical *Surites* such as *S.* (*S.*) *pechorensis* Sazonova and *S.* (*S.*) *spasskenisis* (Nikitin) notably in their flat, subparallel whorl-sides, broadly rounded venter and relatively early loss of coarse biplicate ribbing, though there are a number of transitional forms in the Ryazan fauna.

Surites (*Bojarkia*) *stenomphalus* (Pavlov). Pl. 8 figs 1a–b, 2, 3; Figs 6a–b.

Lectotype. Sm B 11111, Spilsby Sandstone, Donington, Lincolnshire, designated Spath 1947, p. 23.

Dimensions of lectotype.

Diameter (in mm)	*Whorl-height* (*as % of diam.*)	*Whorl-thickness* (*as % of diam.*)	*Umbilicus* (*as % of diam.*)
63·5	43	?	26

Remarks. In view of the widespread use of the term "*stenomphalus* Zone", especially in the USSR, it has been of prime importance to establish the stratigraphical position and systematic affinities of the ammonite which correctly bears this specific name. I have cleaned the matrix from the umbilicus of the lectotype (Pl. 8 fig. 1a–b) and it can now be identified as

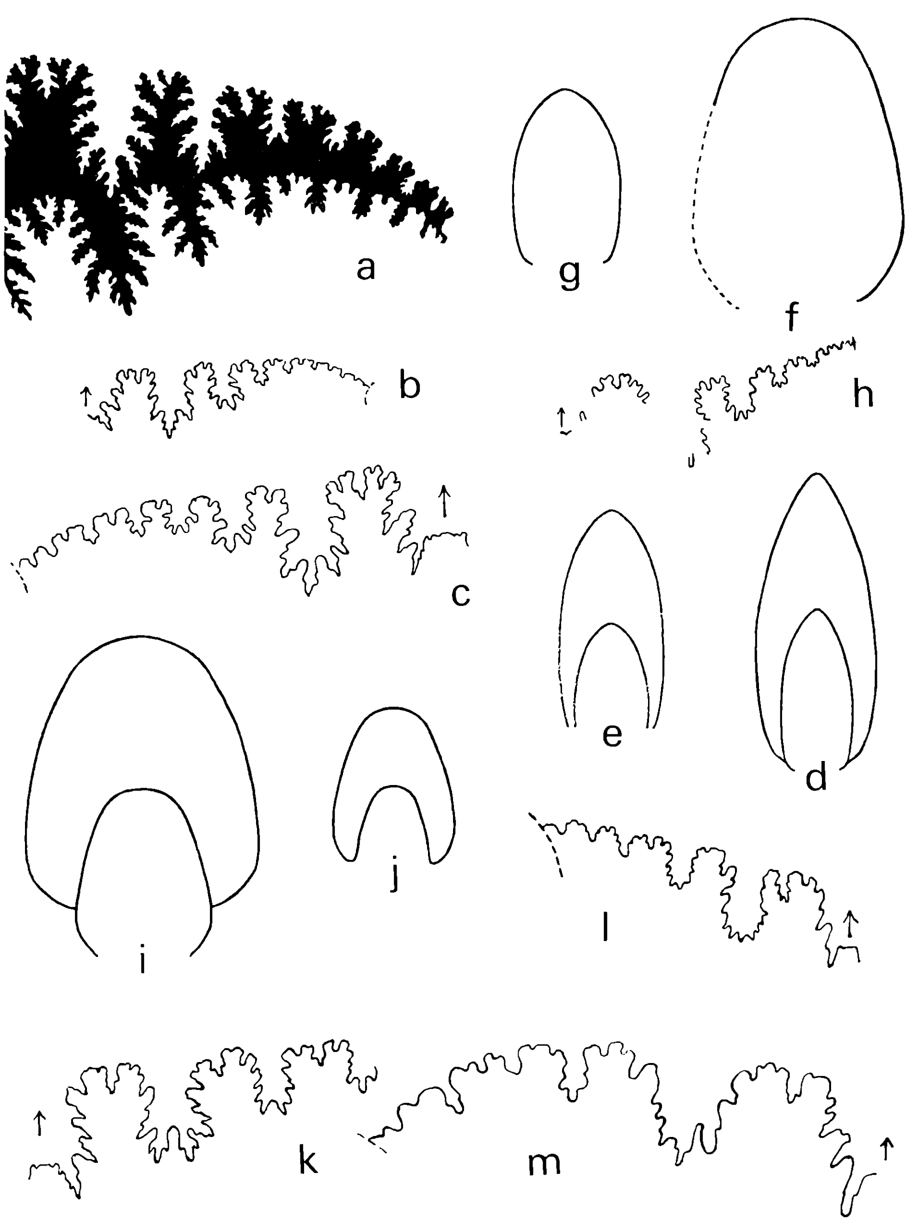


Fig. 5. Whorl-sections and suture-lines of *Hectoroceras*, *Runctonia*, *Subcraspedites* (*Volgidiscus*) and *Garniericeras*.

a *Hectoroceras* cf. *kochi magnum* Spath, *kochi* Zone, West Dereham, Norfolk (GSM GT 4), suture-lines (X 1). **b–d** *Hectoroceras kochi* Spath, suture-lines of Greenland examples after Spath 1947, and whorl-section of example figd Pl. 7 fig. 3 (X 1). **e** *Hectoroceras* cf. *kochi tenuicostatum* Spath, *kochi* Zone, West Dereham, Norfolk (GSM GT 44) (X 1). **f–h** *Runctonia runctoni* gen. et sp. nov., whorl-section of paratype figd Pl. 7 figs 7a–b, and holotype (X 1) and suture-line (composite) of holotype (X 1·5). **i** *Subcraspedites* (*Volgidiscus*) sp. nov., base of Carstone (ex Spilsby Sandstone), Caistor, Lincs. (GSM VW 565), whorl-section (X 1). **j–k** *Subcraspedites* (*Volgidiscus*) *lamplughi* Spath, whorl-section of West Dereham, Norfolk, example (ex Runcton Beds) (GSM Ce 1886) (X 1) and suture-line of holotype after Spath 1947. **l** *Subcraspedites* (*Volgidiscus*) aff. *lamplughi* Spath, suture-line of example figd Pl. 6 fig. 3, after Spath 1947. **m** *Garniericeras catenulatum* (Fischer), Upper Volgian, near Moscow, suture-line after Spath 1947.

belonging to the characteristic ammonite species of the Upper Spilsby Sandstone "doggers", which yielded numerous examples to the early collectors (British Museum, Geological Survey Museum, Sedgwick Museum, York Museum, etc.), probably mostly from the Bardney-Louth railway cutting, though labelled Donington, North Willingham, Benniworth Haven and Tealby. In recent years the species has been collected from Fulletby Manor, Lincolnshire, and from the Mintlyn Beds of the King's Lynn Bypass. An example of 175 mm diameter in typical Spilsby Sandstone lithology was obtained from the Drift of Redisham, Norfolk (Norwich Castle Museum). Comparison of the Spilsby Sandstone example illustrated in Pl. 8 fig. 2, and the Siberian *S.* (*Bj.*) *mesezhnikowi* (Shulgina) (*in* Saks and Shulgina 1969 pl. 1 fig. 2) will show that the two species are very close, if not conspecific. According to Sazonova (1971 p. 72) the latter nominal species is a subjective synonym of *Pavlovites krestensis* Aristov, proposed earlier in the same year (Aristov *in* Ivanov and Aristov 1969). Whether or not this postulated synonymy will be upheld, the identity or near identity of *S.* (*Bj.*) *stenomphalus* and *S.* (*Bj.*) *mesezhnikowi* has obvious implications in the field of biochronology and international correlation.

Having correctly described the lectotype as originating in the Spilsby Sandstone, Pavlov (*in* Pavlov and Lamplugh 1892) later said that it was obtained from the Claxby Beds, an error that was rectified in a subsequent publication (Pavlov 1896). Neale's "*Tollia stenomphala*" from the Speeton Clay (Neale 1962) is too small and too poorly preserved for identification with any of the Spilsby Sandstone or Mintlyn Beds species, though it may well belong to the subgenus *Bojarkia*.

Surites (*Bojarkia*) *suprasubditus* (Bogoslovsky) *pavlovi* subsp. nov. Pl. 9.

Holotype. SM B12202, Spilsby Sandstone *stenomphalus* Zone, Benniworth Haven, near Donington-on-Bain, Lincolnshire.

Subspecific characters. Differs from typical form in closeness of ribbing, there being about 26 umbilical plications at 125 mm diameter compared with about 20 in the lectotype of *S.* (*Bj.*) *suprasubditus* (Bogoslovsky 1897 pl. 1, fig. 1).

Dimensions of holotype.

Diameter (in mm)	*Whorl-height (as % of diam.)*	*Whorl-thickness (as % of diam.)*	*Umbilicus (as % of diam.)*
162	39	28	25

Remarks. The holotype is an almost complete adult with just over half a whorl of body-chamber, though crushed in places. The test is preserved only in the umbilical region. Its mode of preservation indicates origin in the calcreted "doggers" of the *stenomphalus* Zone, still well exposed in the Benniworth Haven cutting, where it was collected together with *S.* (*Bj.*) *stenomphalus* (Pavlov) and allies.

Comparison with Bogoslovsky's types of "*Olcostephanus*" *suprasubditus* from the Ryazan Beds, in the Chernyshev Geological Museum, Leningrad, and illustrations of a topotype (Sazonova 1971 pl. 4 figs 2, 2a) suggests that the English ammonite is merely a geographical variant or subspecies of the Russian one. Its presence in the *stenomphalus* Zone helps to establish the zonal representation in the condensed Ryazan Beds.

Surites (*Bojarkia*) *tealli* sp. nov. Pl. 4 figs 10a–c.

Holotype. GSM. Ce 4407, Mintlyn Beds (bed 10), *stenomphalus* Zone, King's Lynn Bypass, Galley Hill, Mintlyn Wood, King's Lynn, Norfolk.

Specific characters. Differs from *S.* (*Bj.*) *stenomphalus* in having depressed whorls; ribs regularly bifurcating (about 25 per whorl at 50 mm diameter) until about 60 mm diameter, when occasional trifurcation begins.

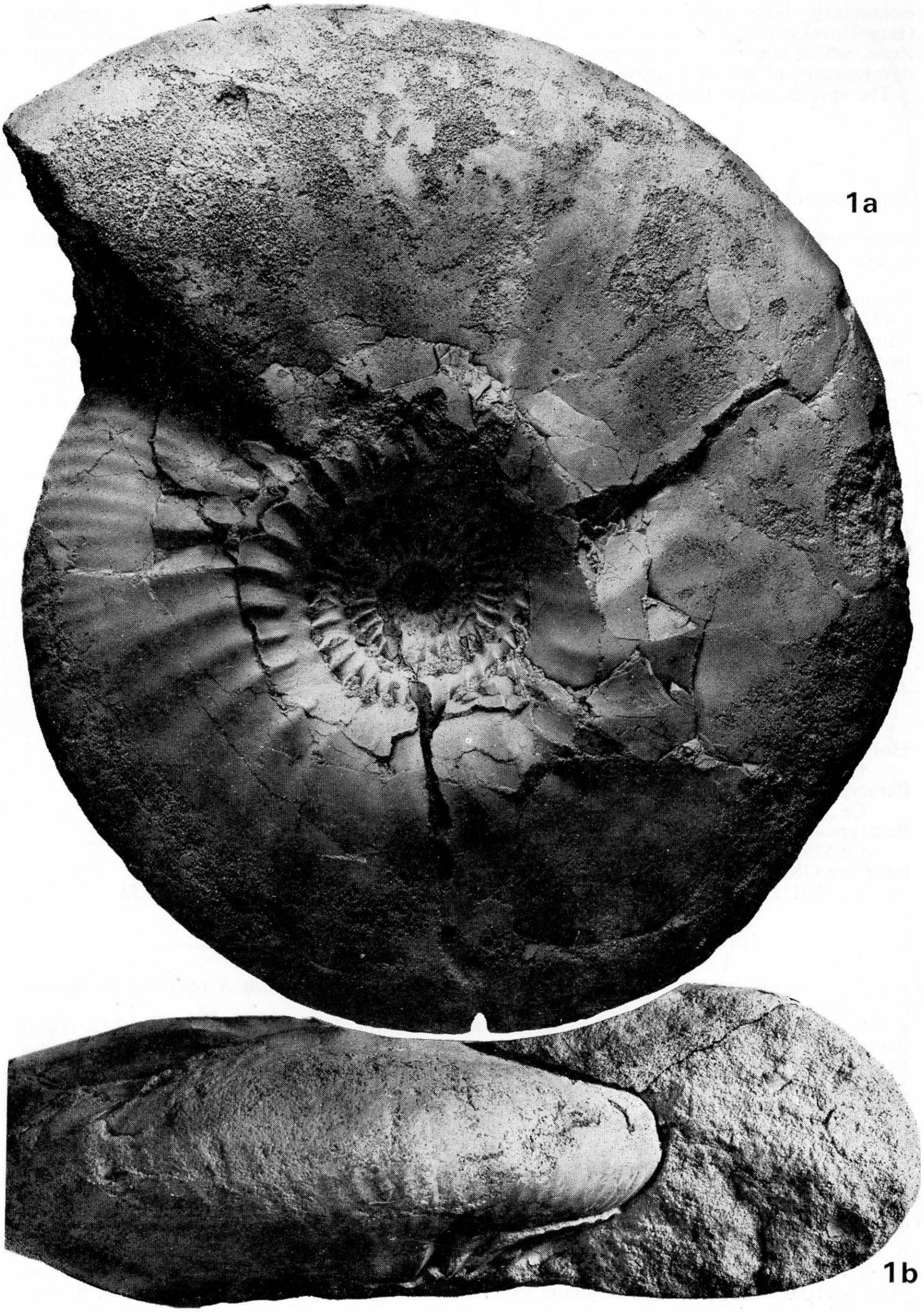
Dimensions of holotype.

Diameter (in mm)	*Whorl-height (as % of diam.)*	*Whorl-thickness (as % of diam.)*	*Umbilicus (as % of diam.)*
c. 65 (44)	41	48	28

Plate 9 all figs × 0·9.

1a–b *Surites* (*Bojarkia*) *suprasubditus* (Bogoslovsky) *pavlovi* subsp. nov.
Side and front view of holotype. Upper Spilsby Sandstone (*stenomphalus* Zone), Bardney-Louth railway cutting, Benniworth Haven, near Donington-on-Bain, Lincolnshire. SM. B12202.

Plate 9



Remarks. This species is represented by several incomplete examples from the clay-ironstone "doggers" of bed 10 of the King's Lynn Bypass (see p. 200). Its specific characters link *Bojarkia* with the subgenus *Caseyiceras*, which comprises evolute *Surites* with depressed whorls and dominantly bifurcating ribs, such as *S.* (*C.*) *caseyi* (Sazonova) and *S.* (*C.*) *analogus* (Bogoslovsky) of the Ryazan Beds. The horizon of *S.* (*Bj.*) *tealli* is low in the *stenomphalus* Zone, which accords with the position of the Siberian *S.* (*C.*) *cnalogus* Zone below the main development of *Bojarkia* (*mesezhnikowi* Zone).

The specific name honours J. J. H. Teall, one of the early students of Norfolk geology.

Subgenus *LYNNIA* nov.

Type-species. Surites (*Lynnia*) *icenii* sp. nov., Upper Ryazanian (*icenii* Zone), eastern England.

Subgeneric characters. Surites with subquadrate whorl-section and coarse ribs that branch mostly in threes from point high on flank.

Remarks. This subgenus is represented by a number of species in the interval between the *kochi* and *stenomphalus* Zones in England, though it does not appear among the rich *Surites* faunas of the Russian Platform. "*Olcostephanus*" *clementianus* Bogoslovsky of the Ryazan Beds is, however, an allied form with bifurcating, rather than trifurcating, ribs. A similar high furcation point and stout whorls are seen in *Surites subanalogus* Shulgina and other forms of the Siberian *analogus* Zone, though these, like the original *Surites* (*Caseyiceras*) *analogus* (Bogoslovsky), lack the coarse trifurcating ribbing of *Lynnia*.

Surites (*Lynnia*) *icenii* sp. nov. Pl. 8 figs 4a–b, 5a–b; Figs 6 l–m.

Holotype. GSM. Ce 5298, Mintlyn Beds, *icenii* Zone, bed 12, North Sea gas pipe-line trench, Manor Farm, North Runcton, near King's Lynn, Norfolk.

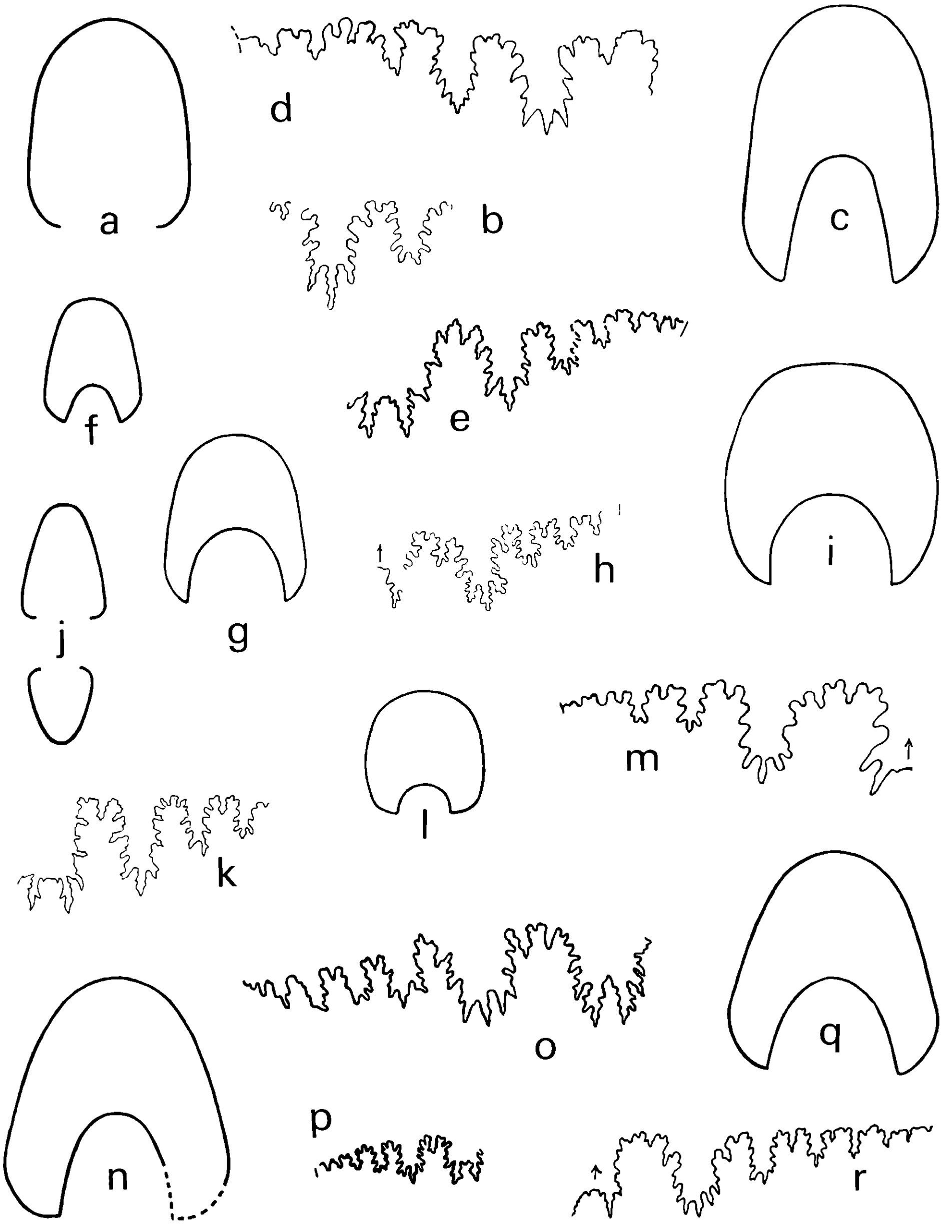
Specific characters. Small species of *Lynnia*, 42–56 mm diameter, at which size last half-whorl has about 8 strongly elevated primaries, each corresponding to 3 short secondaries. Secondaries mostly connect with primary stems, a few free-ending; all cross venter with well-marked forward bend. Umbilicus eccentric.

Dimensions of types.

	Diameter (*in mm*)	*Whorl-height* (*as % of diam.*)	*Whorl-thickness* (*as % of diam.*)	*Umbilicus* (*as % of diam.*)
Holotype GSM. Ce 5298	56	38	40	33
Paratype GSM. Ce 5311	48	37	37	34
Paratype GSM. Ce 5299	45	35	34	34
Paratype GSM. Ce 5301	42	38	38	35

Fig. 6. Whorl-sections and suture-lines of *Surites* (*Bojarkia*), *S.* (*Lynnia*), *S.* (*Surites*), *Peregrinoceras*, *Borealites* (*Borealites*), *B.* (*Ronkinites*) and *Paratollia*.
a–b *Surites* (*Bojarkia*) *stenomphalus* (Pavlov), whorl-section of example figd Pl. 8 fig. 3 (X 1) and incomplete suture-line of chorotype (GSM 30979). **c–d** *Surites* (*Bojarkia*) *suprasubditus* (Bogoslovsky), Ryazan Beds, U.S.S.R., whorl-section (X 1) and suture-line after Bogoslovsky 1897. **e** *Surites* (*Bojarkia*) *mesezhnikowi* (Shulgina), *mesezhnikowi* Zone, Siberia, suture-line after Shulgina 1972. **f** *Peregrinoceras* cf. *wrighti* (Neale), whorl-section of example figd Pl. 10 figs 9a–b (X 1). **g–h** *Peregrinoceras albidum* sp. nov., whorl-section (X 1) and suture-line (X 1·5) of holotype. **i** *Peregrinoceras rosei* sp. nov., whorl-section of holotype (X 1). **j–k** *Paratollia kemperi* gen. et sp. nov., Platylenticeras Schichten, northwest Germany, whorl-section (X ·75) and suture-line after Kemper 1964. **l–m** *Surites* (*Lynnia*) *icenii* sp. nov., whorl-section (X 1) and suture-line (X 3) of two paratypes (GSM Ce 5299, 5313). **n** *Borealites* (*Borealites*) *fedorovi* Klimova, *kochi* Zone, West Siberia, whorl-section of holotype (from plaster replica) (X 1). **o** *Borealites* (*Ronkinites*) *anglicus* (Shulgina), *kochi* Zone, West Siberia, suture-line after Shulgina 1972. **p** *Borealites* (*Ronkinites*) *plicomphalus* (Shulgina *non* J. Sowerby), *kochi* Zone, West Siberia, suture-line after Shulgina 1972. **q** *Surites* (*Surites*) *poreckoensis* Sazonov, Ryazan Beds, U.S.S.R., whorl-section of holotype (X 1). **r** *Surites* (*Surites*) *spasskensis* (Nikitin), Ryazan Beds, U.S.S.R., suture-line after Nikitin 1888.

Fig. 6.



Remarks. Bed 12 of the Manor Farm section and the corresponding nodule-bed in the King's Lynn Bypass yielded a large number of *S.* (*L.*) *icenii,* mostly as scaphitoid body-chambers, two-thirds of a whorl in length. Here, as in the Mid-Spilsby nodule-bed, examples over 50 mm diameter are exceptional. The specific name commemorates the Ancient British East Anglian tribe, the Iceni.

Genus *PEREGRINOCERAS* Sazonova 1971

Type-species. Olcostephanus pressulus Bogoslovsky, Ryazan Beds, Russian Platform.

Remarks. Peregrinoceras is a close ally of the genus *Tollia* Pavlov 1913, but whereas the latter bears periodic constrictions, becomes smooth in the adult, with narrowly rounded venter, *Peregrinoceras* maintains strong ribbing and a subrectangular, broad-ventered whorl-shape throughout. The two genera are not always easy to separate in the young or in poorly preserved material, however. Both appear more or less simultaneously late in the Ryazanian, and the range of *Tollia* in Siberia is said to extend into the Lower Valanginian. Species referable to *Peregrinoceras* have been recorded from the Mangyshlak Peninsula (Transcaspia), the Volga region and eastern England, while known Ryazanian occurrences of *Tollia* seem to be confined to its Siberian type areas and East Greenland (*T. groenlandica* Spath sp.). Possibly *Peregrinoceras* is a southern variant or dimorph of *Tollia.*

Shulgina (1972 p. 123) treats *Peregrinoceras* as a subjective synonym of *Subcraspedites* s.s. This relationship is denied by the subrectangular whorl-shape, forwards projection of the ventral ribbing, thin primary rib-stems, and tolliine nucleus of *Peregrinoceras.* Its overall characters suggest that *Peregrinoceras* is a descendant of the same stock that had earlier produced *Surites* (*Bojarkia*). In England *Peregrinoceras* is the dominant ammonite in the topmost Spilsby Sandstone, basal Claxby Beds (Hundleby Clay) and lower D beds of the Speeton Clay.

Peregrinoceras albidum sp. nov. Pl. 10 figs 7, 8a–b; Figs 6g–h.

Holotype. GSM. Zm3819, Upper Spilsby Sandstone (Ferruginous Grit), *albidum* Zone, dredged from underwater excavations, Biscathorpe Wold gravel pits, near Donington-on-Bain, Lincolnshire. R. G. Thurrell collection.

Specific characters. Moderately compressed and evolute *Peregrinoceras* with subparallel whorl-sides and broadly rounded venter. At 60 mm diameter about 22 thin, elevated primary rib-stems arise from top of low umbilical wall and cross lower half of flank with slight forwards inclination; at mid-flank (coinciding with line of involution) primaries trifurcate, with one or two intercalatories between each pair of primary bundles, making total of about 96 forward-curving secondaries per whorl. These cross venter with pronounced forwards bend. Suture-line with strongly ascending auxiliaries.

Dimensions of holotype.

Diameter (in mm)	*Whorl-height (as % of diam.)*	*Whorl-thickness (as % of diam.)*	*Umbilicus (as % of diam.)*
c.63 (60)	37	31	31

Remarks. Among previously described British species of *Peregrinoceras, P. pseudotolli* (Neale) of the Speeton Clay probably approaches the present species closest, though having a narrower umbilicus and less curved secondary ribs. The latter species, like the more densely ribbed *P. wrighti* (Neale), is difficult to compare owing to the crushed condition of these lower D beds ammonites at Speeton. In the Fordington Well *P. albidum* and a form probably conspecific with *P. wrighti* occur together. In the fauna of the Ryazan Beds *P. albidum* has its closest ally in *P. bellum* Sazonova (1971 pl. 5 figs 2, 2a), distinguished by its greater inflation, tighter coiling, and coarser umbilical plications.

Peregrinoceras rosei sp. nov. Pl. 10 figs 2a-b; Fig. 6i.

Holotype. GSM. 114730, Mintlyn Beds, *albidum* Zone, King's Lynn Bypass, north of Church Farm, Bawsey, Norforlk.

Specific characters. Moderately involute *Peregrinoceras* with subquadrate whorl-section that becomes increasingly flat-ventered with age. Rib density as in *P. albidum,* but rib-stems more prominent at the umbilical edge and ribs more feebler projected forwards on the venter.

Dimensions of holotype.

Diameter (*in mm*)	Whorl-height (*as % of diam.*)	Whorl-thickness (*as % of diam.*)	Umbilicus (*as % of diam.*)
78	40	40	28

Remarks. This species is named after the pioneer Norfolk geologist C. B. Rose. It is illustrated, along with sundry *Peregrinoceras* from the Hundleby Clay and topmost Spilsby Sandstone of Lincolnshire (Pl. 10) to aid the interpretation of the crushed *Peregrinoceras* fauna of the lower D beds of the Speeton Clay (Neale 1962). In a similar crushed condition, *P. rosei* would perhaps be difficult to separate from *P. pseudotolli* (Neale 1962 pl. 45 figs 1–2) at the size of Neale's types.

Subfamily Polyptychitinae Spath 1924

The inclusion of the Polyptychitinae as a subfamily of the Craspeditidae is a departure from current schemes of classification and is prompted largely by consideration of the genus *Paratollia* gen. nov., described below. There are many examples of "convergence" among the boreal Dorsoplanitinae and their craspeditid descendants on the one hand and Tethyan Berriasellidae on the other. It is not improbable that a similar parallel development gave rise to an olcostephanid morphology in both Tethyan (*Spiticeras*, *Olcostephanus*, etc.) and boreal (*Polyptychites*) stocks.

Genus *PARATOLLIA* nov.

Type-species. Paratollia kemperi gen. et sp. nov. (= *Tollia tolmatschowi* Kemper *non* Pavlov), Valanginian, Platylenticeras Schichten, NW Germany.

Generic characters. Primitive Polyptychitinae resembling *Peregrinoceras* in discoidal shape and closeness of costation, but with polyptychitine rib-bundling, and pronounced bi-dichotomy in the adult. Suture-line ascending, *Polyptychites*-like.

Remarks. Paratollia has an obvious affinity with its contemporary *Propolyptychites* Kemper, which is distinguished by its greater inflation and more pronounced bi-dichotomy. The polyptychitine mode of furcation of *Paratollia* occurs already in the Upper Ryazanian *Peregrinoceras prostenomphaloides* (Neale), though in that species true bi-dichotomy is not observed. The Russian *Chandomirovia* (Sazonov 1951), of uppermost Ryazanian-basal Valanginian age, is a more inflated analogue of *Paratollia* having strongly convergent whorl-sides and narrowly rounded venter on which the ribs have a linguiform forwards extension. To *Chandomirovia* I would refer *Polyptychites anabarensis* Pavlov (1914) and to *Propolyptychites* the *Tollia* (*Polyptychites ?*) *mira* of Voronets (1962), both from the basal Valanginian of the Lena-Anabar region of Siberia. *Neotollia* Shulgina (1969) is another Siberian ammonite of the same primitive polyptychitine stream. This combines the ventral ribbing of *Chandomirovia* with regularly bifurcating costation in the young and the ribbing of juvenile *Paratollia* in the adult. The suture-line has numerous auxiliaries. The young *Paratollia* produces a style of ribbing similar to that of the juvenile *Costamenjaites* (Sazonova 1971) from the basal Valanginian of the Volga region, but the umbilical plications and smooth outer whorls of that genus are not duplicated in *Paratollia*. Besides the type species, *Paratollia* embraces "*Tollia* cf. *pseudotolli*" Kemper (1964 pl. 2 fig. 4) and the micromorph *Polyptychites pumilo* Vogel (1959), both from the German Bentheim Sandstone.

Paratollia kemperi gen. et sp. nov. Pl. 5 figs 5a–b; Figs 6j–k.

1964 *Tollia tolmatschowi* Pavlow; Kemper p. 21, pl. 1 figs 3a–b.

Holotype. The original of Kemper 1964 pl. 1 figs 3a–b, from the Platylenticeras Schichten of Suddendorf, northwest Germany.

Specific characters. Involute, compressed *Paratollia*, with convergent whorl-sides and well rounded venter. At 35–50 mm diameter about 24 primaries, each corresponding to bundle of 3 (occasionally 4) flexuous secondaries. Branching at first from lower third of flank (above line of involution); later position of branching varies, one rib of bundle springing from mid-flank; bi-dichotomy appears at c. 40 mm diameter. All ribs thin, sharply elevated and cross venter with forwards sinus.

Remarks. Paratollia kemperi or a close ally occurs near the base of the Claxby Beds of Lincolnshire. All the English examples are small and the whorl-sides are less convergent than in the

German holotype. Specimens from Benniworth Haven were recorded by Spath (1924a p. 79) as *Dichotomites* spp. juv. The ribbing varies to some extent in these Claxby Beds nuclei and more than one species may be represented. A precocious individual from the basal Claxby Ironstone of Nettleton Top (C. W. Wright collection 6538) shows bi-dichotomy of the ribbing already at less than 25 mm diameter.

Family Berriasellidae Spath 1924
Subfamily Platylenticeratinae nov.

Spath (1947) concluded that the "degenerate oxycones of the Lower Neocomian", such as *Platylenticeras, Tolypeceras, Pseudogarnieria* and *Proleopoldia* should be placed in a separate group, *Incertae Sedis*, provisionally attached to the Craspeditidae, their peculiar suture-lines suggesting possible descent from the Jurassic *Garniericeras*. Other authors (e.g., Arkell 1957; Sazonova 1971) have subsequently placed them firmly in the Garniericeratinae, though Arkell had doubts about the inclusion of *Proleopoldia*. Luppov and others (*in* Orlov 1958) transferred this genus to the Neocomitidae.

Kemper's careful study of *Platylenticeras*, based mainly on German occurrences (Kemper 1961), demonstrated the difficulty of separating generically the typical smooth forms of *Platylenticeras* such as *P. heteropleurum* (Neumayr and Uhlig) and *P. gevrilianum* (d'Orbigny) from the noded group of *A. marcousianus* Pictet and Campiche (*Tolypeceras*). There is a similar problem with the "genera" *Pseudogarnieria* and *Proleopoldia*, proposed simultaneously by Spath (1923). Stchirowsky's original material of "*Oxynoticeras*" *undulatoplicatile*, "*O.*" *tuberculiferum*, "*O.*" *marcousi* (= *P. alatyrense* Kemper sp.) and "*Hoplites*" *kurmyschensis*, illustrations of which furnished the basis of Spath's concept of *Pseudogarnieria* and *Proleopoldia*, are deposited in the M.V. and A.P. Pavlov Museum in Moscow. This material was obtained from the Lower Valanginian of the Alatyr district, near Ulyanovsk (formerly Simbirsk); its examination has convinced me that *Pseudogarnieria* and *Proleopoldia* are not separable above the species-level. Duration of the ventrally tuberculate "*Proleopoldia*" condition of the nucleus varies greatly, "*O.*" *undulatoplicatile*, the type-species of *Pseudogarnieria*, representing one extreme, "*H.*" *kurmyschensis* ("*Proleopoldia*") the other. Gerasimov (1971) has already pointed out the specific identity of "*O.*" *undulatoplicatile* and "*O.*" *menensis* Stchirowsky.

Now that the stratigraphical levels and ranges of these ammonites are better understood, it is clear that there is a considerable time-gap separating *Platylenticeras* and its contemporaries from *Garniericeras*, involving the whole of the Ryazanian. Moreover, the morphology of the

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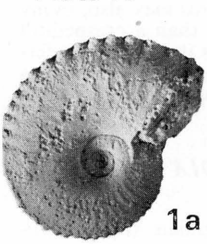
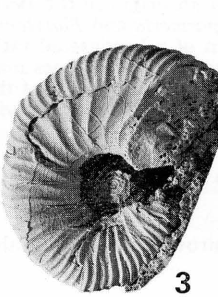
Plate 10 fig. 1 × 1·35; others × 0·9

1a–b *Pseudogarnieria* ("*Proleopoldia*") cf. *kurmyschensis* (Stchirowsky).
Side and venter of septate nucleus. Claxby Beds (*Paratollia* horizon), Bardney-Louth railway cutting. Benniworth Haven, near Donington-on-Bain, Lincolnshire. SM. B12217.
2a–b *Peregrinoceras rosei* sp. nov.
Side and venter of holotype. Mintlyn Beds (*albidum* Zone), King's Lynn Bypass, north of Church Farm, Bawsey, Norfolk. GSM. 114730.
3 *Peregrinoceras* sp. nov. cf. *albidum* sp. nov.
Claxby Beds (Hundleby Clay), old brickworks, East Keal, Lincolnshire. GSM. 114747a.
4 *Peregrinoceras subpressulus* (Bogoslovsky).
Upper Spilsby Sandstone (Ferruginous Grit: *albidum* Zone), excavated material, Biscathorpe Wold gravel pit, near Louth, Lincolnshire. R. G. Thurrell colln, GSM. Zm3813.
5 *Peregrinoceras* cf. *wrighti* (Neale).
Claxby Beds (Hundleby Clay), near Wainfleet, Lincolnshire. B. Smith colln, GSM. Zg652.
6a–b *Peregrinoceras* sp. nov. cf. *albidum* sp. nov.
Glacial Drift (ex Hundleby Clay), King's Lynn Bypass, Castle Rising, near King's Lynn, Norfolk. GSM. 114748.
7, 8a–b *Peregrinoceras albidum* sp. nov.
7 Body chamber fragment, Upper Spilsby Sandstone (*albidum* Zone), depth 60 m, Fordington No. 5 Well, Lincolnshire. H. H. Swinnerton colln, GSM. 114740.
8a–b Side and venter of holotype. Horizon and locality as Fig. 4. R. G. Thurrell colln, GSM. Zm3819.
9a–b *Peregrinoceras* cf. *wrighti* (Neale)
Side and venter of uncrushed example. Upper Spilsby Sandstone (Ferruginous Grit), laneside exposure, Asterby, near Horncastle, Lincolnshire. R. G. Thurrell colln, GSM. 100518.

Plate 10

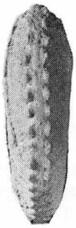


1a

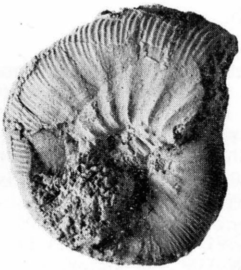


3

2a



1b

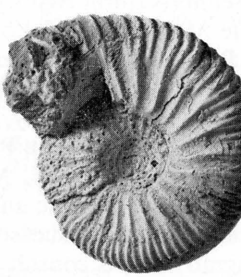


4

7

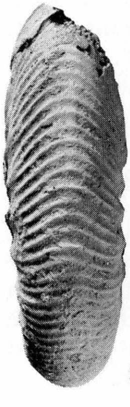
5

6b

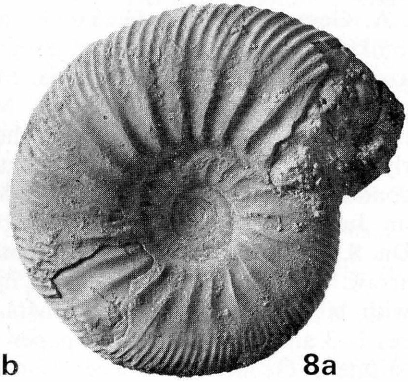


6a

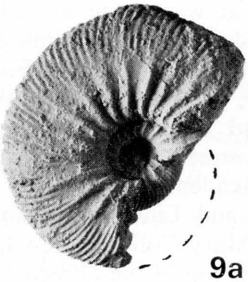
2b



8b



8a



9a

9b

young *Pseudogarnieria* ("*Proleopoldia*") points to an origin in the Berriasellidae rather than the Craspeditidae; the suture-lines of both *Pseudogarnieria* and *Platylenticeras* may also, in my opinion, be derived more readily by simplification of a berriasellid rather than a craspeditid type. This concept of the Platylenticeratinae as berriasellid oxycones makes it easier to understand the Tethyan presence of *Platylenticeras* and to see the arrival of this genus and its allies in northwest Europe and the Russian Platform as connected with the widespread transgressive movements of the Valanginian.

Genus *PSEUDOGARNIERIA* Spath 1923 (= *PROLEOPOLDIA* Spath 1923)

Type-species. Oxynoticeras undulatoplicatile Stschirowsky, Lower Valanginian (*undulatoplicatile* Zone), Russian Platform.

Pseudogarnieria ("*Proleopoldia*") sp. juv. cf. *kurmyschensis* (Stschirowsky). Pl. 10 figs 1a–b.

Remarks. A well preserved juvenile of 23 mm diameter represents the nucleus or "*Proleopoldia*" stage of *Pseudogarnieria*, this being confirmed by its suture-line. It was obtained in the last century from the Benniworth Haven cutting and its cream-coloured calcite test and marly infilling, full of iron-ooliths, indicates origin in the same level of the Claxby Beds as the species of *Paratollia* and *Propolyptychites* collected from the same spot. This specimen (SM. B12217) was seen by Spath before I had developed it from the matrix and recorded by him (Spath 1924a p. 79) as a species of *Lyticoceras* (=*Endemoceras*).

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A correlation of the macrofaunal and microfaunal zonations of the Gault Clay in southeast England

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Two microfossil zonal schemes are proposed for the Gault Clay (Middle—Upper Albian) of southeast England, one based on the Foraminiferida and the other on the Ostracoda. The Gault Clay succession at Copt Point, Folkestone, has been used as a standard, against which the microfaunal and macrofaunal zonations can be compared. A graphical presentation of some of the foraminiferal data (superfamily percentages) has been used for local correlation and also for palaeoecological interpretations. The taxonomy of some of the Foraminiferida and Ostracoda used in the zonal schemes is briefly discussed.

Für den Gault Clay (Mittel- bis Oberalb) Südostenglands werden zwei Zonengliederungen auf mikropaläontologischer Basis vorgeschlagen, die eine nach Foraminiferen, die andere nach Ostrakoden. Die Abfolge vom Copt Point bei Folkestone wird hierbei als Standard-Profil benutzt, mit dem die verschiedenen Gliederungen nach Mikro- und Megafossilien verglichen werden können. Eine graphische Darstellung von Foraminiferen-Zählungen (Prozentwerte der vertretenen Superfamilien) diente einerseits zur lokalen Korrelation und andererseits als Basis für eine paläoökologische Analyse. Die Taxonomie einiger der für das Zonenschema wichtigen Foraminiferen- und Ostrakoden-Arten wird kurz diskutiert.

Deux échelles zonales microfauniques sont proposées pour les Argiles du Gault (Albien moyen et supérieur) du Sud-Est de l'Angleterre, l'une basée sur les Foraminifères, l'autre sur les Ostracodes. La succession des Argiles du Gault à Copt Point, Folkestone, a servi de référence, vis à vis de laquelle peuvent être comparées les zonations micro- et macro-fauniques. Une représentation graphique de quelques données fournies par les Foraminifères (pourcentages superfamiliaux) a été utilisée pour des corrélations locales et des interprétations paléoécologiques. Enfin, la taxonomie de certains des Foraminifères et Ostracodes utilisés dans les échelles zonales est brièvement discutée.

1. Introduction

Although the Gault Clay (Middle-Upper Albian) of southeast England provides a suitable medium for micropalaeontological investigation, it is surprising how few publications have dealt with this stratigraphical interval. The typically grey/blue clay is readily processed, and the microfauna so obtained is usually clean and undamaged. Although several of the more important outcrops are rapidly degrading at present, there are sufficient coastal exposures and working quarries to provide ample research material: added to this is the material that has been obtained by drilling.

Perhaps the greatest deterrent to any major publication on the Foraminiferida of the Gault Clay is the monograph of Chapman (1891-1898). This comprehensive survey has, up till now, made further work unnecessary, although it is now largely out of date and a complete taxonomic revision is badly needed. While this account is not intended as a revision of Chapman's work it will at least provide a modern terminology for those species that are used in the proposed zonal scheme. The taxonomy of the Ostracoda described by Jones (1849) and others has been revised by Kaye (1964, 1965). The main purpose of the present research has been to provide an outline microfaunal zonation of the Gault Clay, based on both the Foraminiferida and Ostracoda, and to compare this with the ammonite succession. This combined faunal study should enable future stratigraphical correlations to be based on complimentary evidence from both the macrofauna and the microfauna. As well as the more usual "zonal" approach, a "statistical" method has been used for the rapid correlation of adjacent successions which is particularly applicable to the study of the borehole material now available in the area under consideration. This technique has provided a great deal of information on the evolution and development of the foraminiferal population and has allowed some degree of regional comparison. It may also have an application in the faunal comparison of different intervals of the stratigraphic column.

2. Previous research

The Gault Clay is best known for its molluscan fauna, although the well-preserved microfauna has been described or mentioned by several authors. Works on the macrofauna have been discussed recently by Casey (*in* Smart *et al.* 1966). The Ammonoidea have received more attention than any other group, and research by Spath (1923-1943), Casey (1954a, 1954b, 1957, 1961) and Owen (1958, 1963, 1971) has led to the fine zonal division which characterizes the Gault Clay sequence, particularly at Copt Point, Folkestone.

In comparison with this weight of macrofaunal research there has been very little progress towards a full assessment of the microfauna. While Chapman's (1891-1898) monograph on the Foraminiferida is in need of revision it does provide a sound basis on which to begin further research, and it is remarkable that this has never been attempted. The only relevent research has been that of Khan (1950a, 1950b, 1952) on the Lower Gault Clay. While the first of Khan's publications considered some of the previously undescribed species, the final paper established three foraminiferal zones for the Lower Gault Clay. Khan's correlation of his zones with the ammonite subzones is now out of date.

Although overseas workers have not actually studied the Gault Clay, several publications have considered the Middle-Upper Albian interval. The majority of these are solely monographic (Bartenstein 1954; Berthelin 1880; Ten Dam 1950; Eichenberg 1933; Fuchs 1967; Neagu 1965; Reuss 1863; Uguzzoni and Radrizzani 1967) although some (Jannin 1965; Malapris 1965; Michael 1966) have attempted some stratigraphical interpretations. While all the above publications are not directly relevant to the present British problems they nevertheless provide essential comparative accounts and have all proved invaluable in the taxonomic revision of Chapman's faunas.

In many ways the study of the Ostracoda has paralled that of the Foraminiferida, although the taxonomy of Jones (1849, 1870), Jones and Hinde (1890) and Chapman and Sherborn (1893) has been revised by Kaye (1964, 1965). As in the case of the Foraminiferida, several overseas workers (Dammotte 1961; Dammotte and Grosdidier 1963; Deroo 1956; Mertens 1956; Oertli 1958) have also provided relevant information on the Middle-Upper Albian.

3. The Copt Point Succession

The Gault Clay succession of Copt Point (TR243364) and East Wear Bay (TR242369) Folkestone, Kent, has been regarded as the stratotype since the work of Price (1874), and the subsequent modifications of Jukes-Browne and Hill (1900). It is to these three workers that we owe the subdivision of the lithological sequence into Beds I-XIII. While these subdivisions can usually be recognised in the immediate vicinity of Copt Point, they are of little use for regional correlation. At the present time almost the whole of the succession is accessible from the "Sulphur Band" at the base of the Gault Clay, to the base of the overlying "Glauconitic Marl" (Lower Cenomanian). There are however two horizons from which samples have not been obtained. The more important of these is within Bed XI, where the sequence is obscured by the road below the Martello Tower. The other part of the succession which is largely inaccessible is Bed XIII, as this is covered by the mobile landslips of East Wear Bay. Accurately located samples through Bed XIII have been obtained from a nearby (TR215378) borehole, which was sunk during the investigations for the Folkestone by-pass. Although the site of this borehole is some 3000 metres from Copt Point, the faunal sequence can be accurately correlated with the fragments of the sucession still exposed in East Wear Bay. The full Gault Clay succession, so compiled, is that shown in Figure 1, and the following discussion refers to that sequence.

3a. The ammonite succession

The richness of the Gault Clay ammonite fauna is well-known, and it is for this reason that it has become a classic example of the zonal subdivision of a faunal sequence. This richness is not only attributable to the favourable conditions of preservation but also to the almost world-wide burst of ammonite evolution in the late Lower Cretaceous (Casey *in* Smart *et al.* 1966). This exceptionally rich ammonite fauna has been studied by Breistroffer (1947, 1965), Casey (1954a, 1954b, 1957, 1961), Destombes and Destombes (1965), Jukes-Browne and Hill (1900), Milbourne (1963), Owen (1958, 1963, 1971), Price (1874), and Spath (1923-1943) and a lengthy repetition of their conclusions is unnecessary. The results of these labours have allowed the compilation of the present ammonite zonation of the Gault Clay. Not only has this zonal sequence been established for a single succession but several workers (e.g. Owen 1971) have shown how accurately it can be used in regional stratigraphical correlation.

3b. The foraminiferal succession

Although there is generally a very rich fauna in the Gault Clay sequence, there are several notable levels of restriction. While the more arenaceous lower levels of the succession (*lyelli* and lower *spathi* Subzones) yield a poor fauna that is restricted to two or three agglutinated species, the low diversity fauna of the *intermedius* Subzone displays no obvious ecological controls. The greensand seam (Bed XII) also contains a reduced fauna, but this may be due to some secondary decalcification. The greater thickness of the succession (Beds XI-XIII) contains a very diverse, rich fauna, while Beds IV-IX, although less diverse, yield very large numbers of some species.

The study of the Foraminiferida has been based mainly on the 30-60 (0·25-0·50 mm.) grain-size fraction as this normally contains the majority of mature, adult specimens. Although the 60-200 fraction usually contains the juvenile individuals, adults of some smaller species are found in this size fraction, including the smaller planktonic species. The zonal scheme has been developed by utilizing the ranges of the more abundant species, and although no mathematical restriction of abundance has been placed on these they would always be encountered in any clay sample of 500 grams. Rarer species, many of which display usefully restricted ranges, have not been used in this zonation. If one were to use these individuals a much finer subdivision would be possible, but the ease of operation would be proportionally reduced.

Two methods of investigation have been used in the present survey. While the normal palaeontological approach has allowed the production of a zonal subdivision of the Gault Clay that has been used successfully in correlative work in southern England, another system of correlation has also been developed. This is a statistical approach (based only on the 30-60 fraction) which has allowed a relatively rapid method of accurate correlation of borehole sequences, particularly in the southeast of England. This method requires the counting of the individuals in each superfamily in every sample. The superfamilies used in this account are those proposed by Loeblich and Tappan (1964).

(*i*) *Superfamily percentages*. The faunal counts of the 30-60 fraction are calculated as percentages of each superfamily, which in the case of the Gault Clay includes members of the Cassidulinacea, Globigerinacea, Lituolacea, Miliolacea, Nodosariacea, and Robertinacea. The Ammodiscacea are usually limited to only a few specimens and for the purpose of the graphs used in this account have been calculated with the Lituolacea. Figure 1 shows that within the Gault Clay there are two very distinctive faunas. In the Lower Gault Clay (Middle Albian, *dentatus* and *lautus* Zones) the fauna is dominated by the Robertinacea while the Upper Gault Clay (Upper Albian, *inflatum* and *dispar* Zones) fauna contains a large percentage of Lituolacea. The other superfamilies occur in fewer numbers throughout the sequence, and while they appear to have little stratigraphical value the Globigerinacea have proved useful in the correlation of Bed XIII.

The dominantly agglutinated (lituolacean) fauna of the lowest part of the sequence (*lyelli* Subzone) decreases through the *spathi* Subzone, and from the top of the *intermedius* Subzone to the base of the *orbignyi* Subzone the Lituolacea are subordinate to the Robertinacea. Four representatives of the latter are

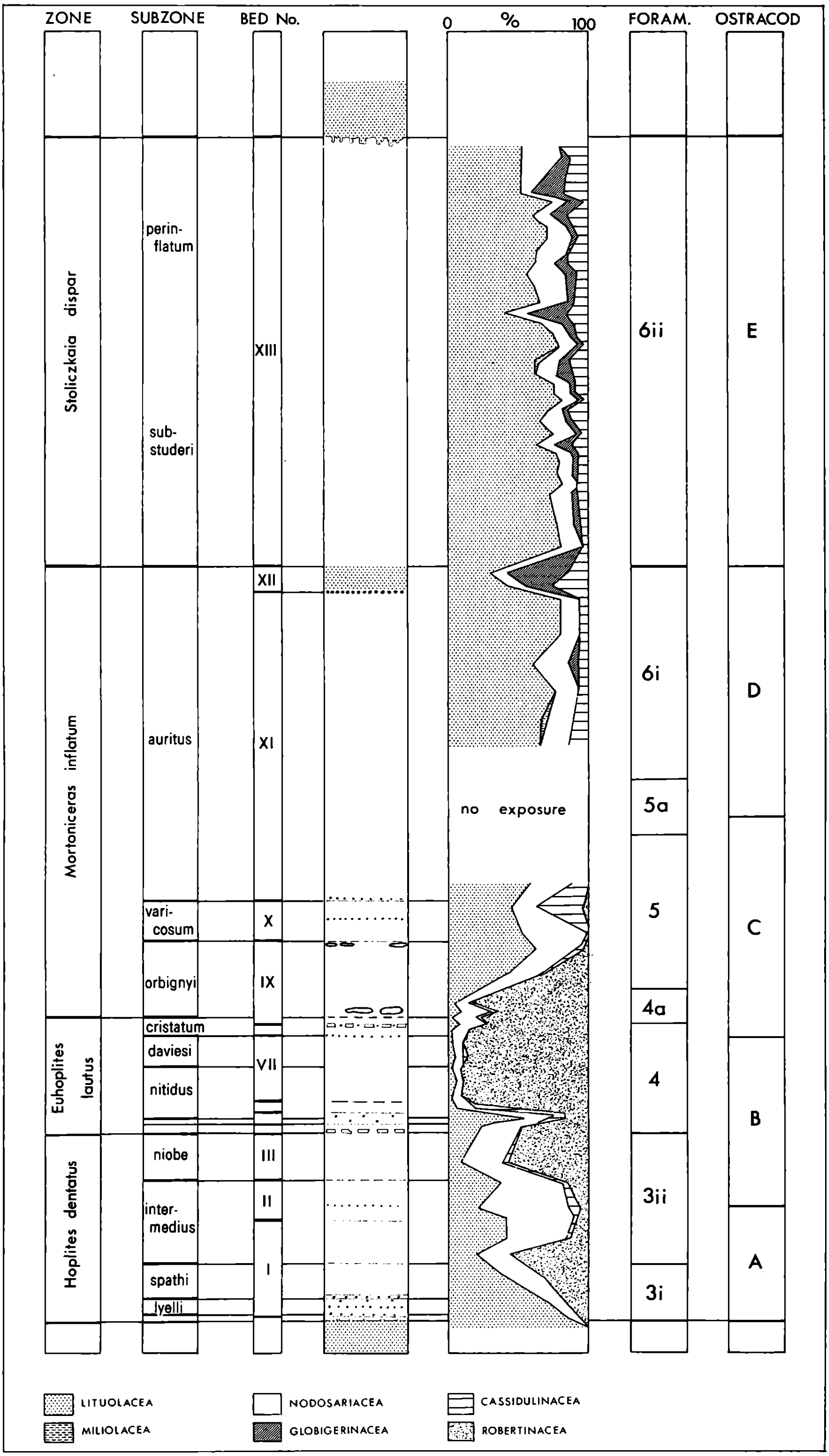

Fig. 1. Foraminiferal analysis of the Gault Clay at Copt Point, Folkestone, Kent.

encountered in the Lower Gault Clay, the commonest being *Epistomina spinulifera* (Reuss). *Hoeglundina chapmani* (Reuss) (Ten Dam) and *H. carpenteri* (Reuss) also occur in substantial numbers, but the fourth species, *Conorboides lamplughi* (Sherlock), is less common. *E. spinulifera* is a very useful zonal indicator, not only because it occurs in large numbers throughout its stratigraphical range, but because of its distinctive appearance. In the Copt Point sequence the earlier assemblages usually contain smaller, less ornamented individuals, although at the *spathi/intermedius* boundary larger specimens are found in a rich fauna. In the *niobe* Subzone the large numbers are associated with an increase in the coarseness of the ornamentation, although it is only in the *nitidus-cristatum* interval, the acme of the group, where this species can account for over 90% of the total 30-60 fraction fauna. Specimens from this interval possess the typical coarse ornamentation in association with the stout marginal spines shown in Figure 3.

A reduction of the robertinacean fauna in the *intermedius* Subzone coincides with an interval of low faunal diversity. Although the graph indicates that the Nodosariacea (*Lenticulina* spp.) are dominant at this level this is largely due to a lack of competition, and not to an actual increase in their numbers. The numbers of *Lenticulina* spp. remain almost constant throughout the whole of the Gault Clay sequence, and it is at occasional levels similar to that under discussion where they show their tolerance to almost any conditions. Those groups that show the most variation (e.g. the Lituolacea and the Robertinacea) would appear to be the more susceptible to ecological changes, and can therefore more easily be used as palaeoenvironmental indicators. The reason for the marked faunal change in the *intermedius* Subzone is not immediately apparent, although several samples from this part of the succession have yielded large amounts of gypsum.

There are marked fluctuations in the superfamily percentage graph near the Bed IV-VI interval, and at this level the robertinacean fauna varies from as little as 20% to as much as 80% of the total. This part of the sequence is discussed more fully in connection with the correlation of the sections at Folkestone and Sevenoaks (p. 284).

There are also marked fluctuations in the microfauna near the Bed VII-VIII and Bed VIII-IX boundaries, and the precise faunal sequence is not completely understood. The *cristatum* Subzone contains a distinctive bed of rounded phosphatic nodules (Price 1874 pp. 140-141; Spath 1943 pp. 756-757; Owen 1971) which represents a non-sequence marking the Lower-Upper Gault boundary (although the top of the *cristatum* Subzone is some 30 centimetres above this level in the Copt Point succession). Evidence for warping and erosion at this level is supported by the present work.

Above the Lower-Upper Gault nodule horizon there is a prominent faunal change in the *orbignyi* Subzone (Bed IX). There is a marked reduction in the robertinacean fauna, which at this level is represented by only one species, *Epistomina spinulifera*. However, the specimens are mostly derived, and show obvious signs of wear and corrosion. It would seem that this reworked fauna above the *cristatum* phosphate bed, while still being included in the superfamily percentage graphs, should not be regarded as being indigenous. There may be a strong case for leaving these specimens out of the faunal counts, and only using the proved *in situ* specimens, but they have been retained as this derived population can be used to obtain an indication of the amount of reworking involved. It would seem likely that the larger the reworked population, the greater the amount of erosion there has been in the immediate vicinity. At Sevenoaks, where almost the whole of the *nitidus-daviesi* interval is missing below the phosphate bed, and where there is a marked reduction of the robertinacean fauna above this level, there appears to be only a small number of reworked individuals. Larger numbers of reworked specimens might be expected near, for example, Ford Place and Paddlesworth where more of the *nitidus-daviesi* Subzones are preserved in a trough. The extent of the zone of reworked specimens may therefore indicate one's position in relation to the troughs and swells produced by the erosion surface below the *cristatum* phosphate bed: differential erosion appears to have been a feature of this level. When all the boreholes from the Maidstone-Westerham section have been studied it may be possible to produce an accurate correlation across some of these features.

The final remnants of the robertinacean fauna at Folkestone are seen in the *varicosum* Subzone (Bed XI) although rare specimens have even been found as high as Bed XIII. By the close of the *orbignyi* Subzone the fauna has already become dominated by the Lituolacea, at this level largely by *Arenobulimina chapmani* Cushman (*Bulimina preslii* Chapman (*non* Reuss) 1892 p. 755 pl. 12 fig. 4). This species is later joined by *A. sabulosa* (Chapman) (*Bulimina preslii* Reuss var. *sabulosa* Chapman 1892 p. 755 p. 12 fig. 5), and these two species dominate the *auritus* (upper)—*perinflatum* Subzones. The upper levels of Bed XI mark the appearance of the Globigerinacea in the 30-60 fraction and although through the greater part of the sequence the only representative of this superfamily is *Hedbergella delrioensis* (Carsey), there is one horizon where large specimens of *Globigerinelloides bentonensis* (Morrow) have been found. At first the planktonic fauna is sporadic in its occurrence in the 30-60 fraction and it is only in the *dispar* Zone (Bed XIII) that there is an almost continuous population of *H. delrioensis*, although there are still marked fluctuations in the numbers at certain intervals. These levels of relative abundance of the planktonic population can be used for accurate local correlation. The high planktonic percentage recorded for Bed XII could be explained in terms of a modification of the environment, although it is also possible that some preservation control may be in operation. The author would however place more emphasis on a faunal control, since if some decalcification was involved it would be expected that the Globigerinacea would be one of the first groups to suffer. The occurrence at this level of large specimens of *G. bentonensis* would appear to add weight to the suggestion that some basic ecological changes are involved.

This separation of the Gault Clay sequence into two main microfaunal units which correspond approximately with the division into the Lower and Upper Gault Clay is not unexpected. The lithological boundary is so marked that one would suspect that there would be a complementary microfaunal and macrofaunal change at this level. It is interesting to speculate why the Robertinacea are restricted to the Lower Gault Clay. The Upper Gault Clay, with its dominantly agglutinated fauna, is in part the lateral equivalent of the highly arenaceous Upper Greensand. It is the base of the Upper Gault Clay which lies above the erosion surface which forms the base of the Cretaceous in the southwest of England. This actively eroding surface provided the detritus for the Upper Greensand in the southwestern counties, with only the finer detritus being carried eastwards towards the southeast of England. It is this finer material which is utilised by, and would encourage the development of, the agglutinating foraminiferids. Conditions in the Lower Gault Clay appear to have been more static, and apart from in the lowest levels, there appears to have been remarkably little detritus available.

The sequence of events discussed above is not only restricted to the Gault Clay; although it is on a slightly different scale in the Lower Greensand, the faunal distribution within the Atherfield Clay is remarkably similar. The Atherfield Clay succession from a borehole (TQ.523523) near Sevenoaks shows the robertinacean and lituolacean populations in a similar relationship to that recorded from the Gault Clay. The faunal details of the Atherfield Clay sequence are shown in Figure 2, which is reproduced by permission of D. J. Carter. The lack of the basal agglutinated fauna which characterizes the Gault Clay may be due to the lack of an arenaceous succession below the Atherfield Clay, and the fading-out of the agglutinated fauna in the 'Upper Atherfield Clay' may be due to the changing conditions, or to the evolutionary state of the Lituolacea. Unlike that of the Gault Clay, the agglutinated fauna belongs mainly to the Ammodiscacea, with *Pelosina* spp. being dominant. The Lituolacea, represented by *Ammobaculites* spp., are less developed, and *Arenobulimina* is absent. The Robertinacea of the 'Lower Atherfield Clay' are dominated by *Hoeglundina* spp., and *Epistomina* is not recorded. In the case of the Atherfield Clay however the faunal changeover is remarkably rapid, although the differing scales used in the two figures tend to obscure this fact. While there is some record of the robertinacean fauna above the 'Lower'/'Upper Atherfield Clay' boundary it only persists for about 40 cm.

It would seem therefore, that while this numerical approach has been designed primarily for correlative work within a single stratigraphical unit there is some value in applying it to palaeoenvironmental analysis. The two graphs shown in Figures 1 and 2 appear to indicate that although the faunas of the two successions are different in detail, the general sequence of events is the same in both. The palaeogeographical implications deduced from the Gault Clay succession would therefore be expected to apply to the Atherfield Clay succession. In any such comparison however, one must take the evolutionary state of the fauna into consideration.

(ii) *Distribution of the Foraminiferida and zonal analysis.* The zonal scheme outlined here can, unfortunately, only be described as being of local application. The planktonic fauna is not suitable for any long-ranging correlation, as it can only be ascribed to a single zone. The fauna, which includes *Hedbergella delrioensis, H. planispira* (Tappan) and *H. infracretacea* (Glaessner) (*Globigerina cretacea* Chapman (*non* d'Orbigny) 1894 p. 588 pl. 13 figs 5-6), is essentially the 'primitive planktonic fauna' of the zone ascribed to the whole of the Lower Cretaceous by Bandy (1967). The Albian zonal indicators (*Planomalina* and *Ticinella*) used by other workers in Europe (Salaj and Samuel 1966) and America (Bandy 1967; Pessagno 1967) have not been found in the Gault Clay. It is interesting to note that while *Planomalina* is absent, non-carinate variants of *Globigerinelloides* are extremely abundant at certain levels in the Upper Gault Clay. A differentiation between the keeled and the non-keeled planktonic foraminifera has been used by Bandy (1964, 1967) for the construction of '*Rotalipora-Globotruncana*' lines in the Middle (following Bandy 1967) and Upper Cretaceous. These lines indicate the latitudinal range within which keeled genera would be expected. If this technique is very tentatively extended into the Upper Gault Clay using *Globigerinelloides* then one may be able to offer some comments on the relationship between an essentially Tethyan fauna (with *Planomalina* and *Ticinella*) in Europe and the Gault Clay's essentially boreal fauna (*Hedbergella* and *Globigerinelloides*). Bandy (1967) indicated that keeled forms are generally limited by the 17°C isotherm which under normal conditions is restricted to latitudes

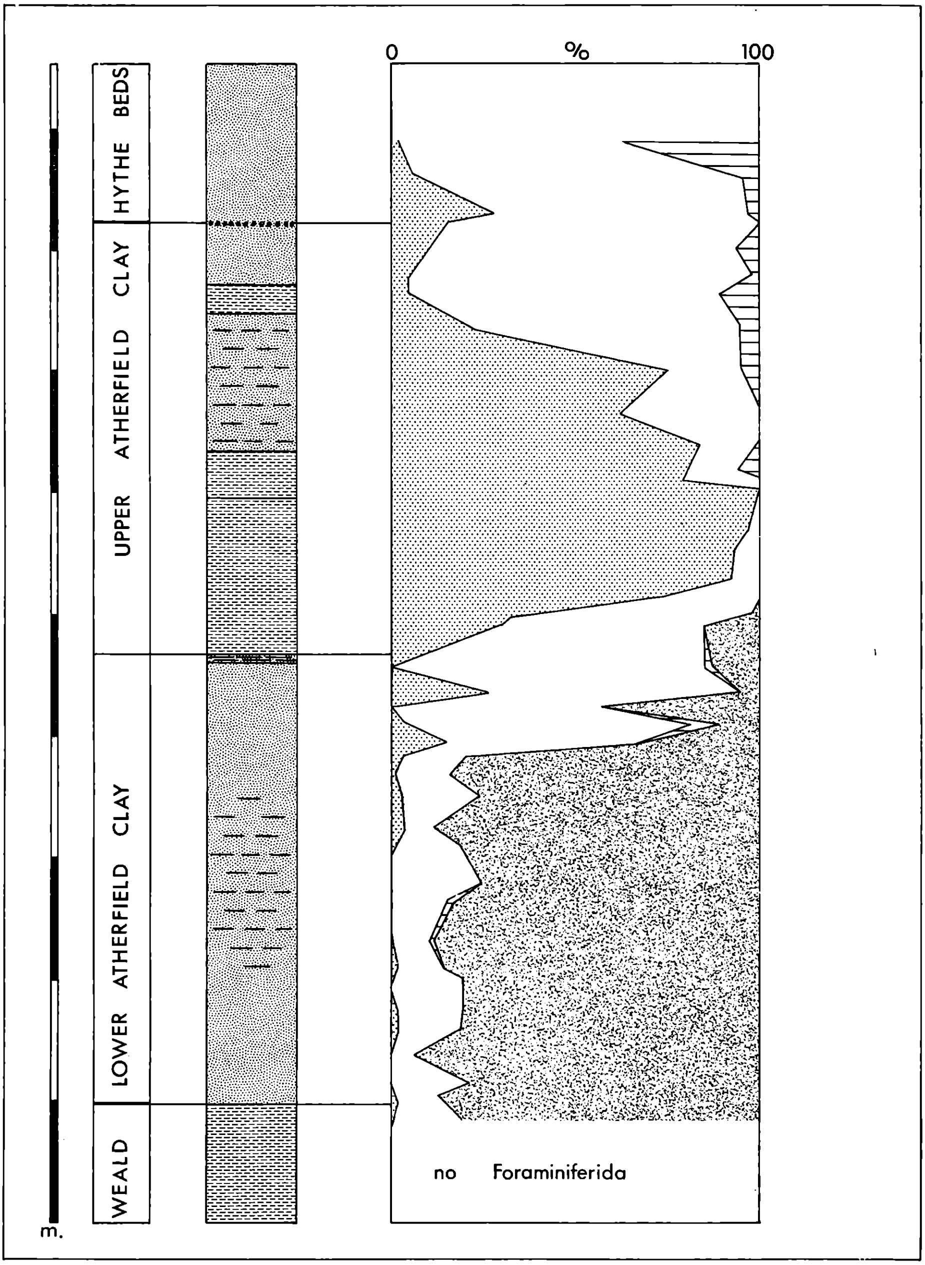

Fig. 2. Foraminiferal analysis of the Atherfield Clay at Sevenoaks, Kent. For explanation of shading see fig. 1. The bipartite division into a "Lower" and "Upper" Atherfield Clay is based on the foraminiferal succession.

20°N and S, although this may, under favourable oceanic conditions, be extended to include latitudes 40°N and S. Southern England in the Middle-Upper Albian has been placed at approximately 30°N (Hart and Tarling, unpublished) and this latitudinal position would, under normal conditions, be outside the latitudinal range of the keeled planktonic foraminiferids. There is however a discrepancy between this conclusion and the palaeotemperatures obtained from the guards of *Neohibolites minimus* (Miller) from the Gault of Folkestone which, according to Bowen (1961), have indicated a water temperature of some 20-23·3°C. This temperature is slightly in excess of that expected at this latitude although the comparatively shallow (Khan 1950b) marine environment of the relatively enclosed Gault sea could have caused this increase. If these temperatures *are* correct then one has to explain the lack of a keeled planktonic fauna. This would require the isolation of the Tethyan and boreal faunas to a greater degree than would be expected from a study of the benthonic foraminiferids, which appear to be almost identical across England, Holland, France, and Rumania. This problem cannot be resolved at the present time.

Although the individual species of planktonic Foraminiferida appear at various intervals in the Gault Clay succession they cannot be used in any meaningful zonation. Even if one could be established it would be of no value in international correlation as all other correlative schemes at this stratigraphical level are based on *Planomalina* and *Ticinella.* Those planktonic foraminiferids which appear to be useful have been utilised in the zonal scheme (e.g. the appearance of *H. infracretacea* is one of the indicators of zone 4a). In addition two of the planktonic species are of some local stratigraphical value.

The occurrence of *Globigerinelloides bentonensis* has already been discussed although some further explanation is necessary. This species has been the subject of much controversy in recent years, and there is still some confusion between it and two other species (*G. eaglefordensis* (Moreman) and *G. caseyi* (Bolli, Loeblich and Tappan)). The problem is summarised here. *G. bentonensis* was initially described as an *Anomalina,* and it was only in 1961 that Loeblich and Tappan recognised the planktonic nature of this species. Loeblich and Tappan (1961) also placed *Anomalina eaglefordensis* Moreman in the genus *Globigerinelloides;* it was only differentiated from *G. bentonensis* in being smaller and less inflated. Shortly after this taxonomic adjustment Low (1964), corroborated by Pessagno (1967), concluded that *G. eaglefordensis* was in fact a benthonic species, and *G. caseyi* (which had been placed in the synonymy of *G. eaglefordensis* by Loeblich and Tappan 1961) was the correct name for these smaller individuals. More recently Eicher (1965) and Eicher and Worstell (1970) have claimed that at certain horizons in the Cenomanian of the Western Interior (U.S.A.) it is almost impossible to differentiate *G. bentonensis* and *G. caseyi* (*G. eaglefordensis*), although throughout the remainder of the succession the size distinction is normally found to hold. In this country *G. caseyi* (which was initially described from the Upper Gault Clay of Arlesey, near Letchworth, Hertfordshire) is usually small, and therefore appears to agree with the observations of Loeblich and Tappan (1961) and Pessagno (1967). There is however one horizon where large specimens of *G. caseyi* can be found, and it is these specimens which compare favourably with specimens of *G. bentonensis* from the Greenhorn Formation of Colorado. Allowing for the stratigraphical interval between the two holotypes, it can only be concluded that both belong to the same species group, the size differentiation being caused by ecological differences. *G. caseyi* has therefore been placed in the synonymy of *G. bentonensis*. The level at which the larger specimens are commonly encountered (although the total range of the species in the Albian is Beds XI-XIII) is in the vicinity of the Bed XI-XII-XIII boundaries. Although the occurrence at Arlesey will be discussed in the stratigraphical section of this account, it must be pointed out that at Arlesey large specimens of *G. bentonensis* are found at the top of the local Gault Clay succession, immediately below the Cambridge Greensand.

The other planktonic species which is of some stratigraphical value is *Hedbergella washitensis* (Carsey). This distinctive, coarsely ornamented species has a most striking distribution in England, even though its total range in other areas is from the Middle Albian to the Middle Cenomanian. In this country it is found only at two very restricted horizons. The first of these is within the uppermost few centimetres of the Lower Gault Clay, immediately below the *cristatum* phosphate bed, while the second is in a similar position immediately below the mid-Cenomanian non-sequence (Carter and Hart in discussion of Kennedy 1969; Hart 1971). These two occurrences, immediately below major stratigraphical non-sequences, are unusual, and while they must be due to ecological controls this is the only species showing such a relationship. It may be possible to show, by further work, that before the erosion and subsequent deepening associated with the two non-sequences there was an interval of shallower conditions, the coarse reticulation of *H. washitensis* being a form of strengthening to withstand the more turbulent conditions. In the southeast of England the occurrence of *H. washitensis* below the mid-Cenomanian non-sequence is associated with an abundance of the small brachiopod *Orbirhynchia mantelliana* (J. Sowerby). In the area to the north of the River Thames the same horizon is represented by the Totternhoe Stone. This band of harder chalk, which has a bed of rolled phosphates at its base, is characterized by an abundance of broken *Inoceramus* prisms. In this case there is some sedimentological evidence of turbulence, but such features are absent in the case of the Gault Clay.

The thirty-four species used in the proposed zonal scheme are shown in Figure 3, which includes both the benthonic and planktonic groups. While several genera are included within this total, two main generic groups provide the more important zonal indicators. The most useful genus is *Arenobulimina*, with *A. macfadyeni* Cushman (*Bulimina orbignyi* Chapman (*non* Reuss) 1892 p. 754 pl 12 fig. 2), *A. chapmani, A. sabulosa,* and *A. frankei* Cushman all being zonal indicators. The *Gavelinella* Brotzen—*Lingulogavelinella* Malapris group—which includes *G. intermedia* (Berthelin) (*Anomalina ammonoides* Reuss: Chapman 1898 p. 3 pl. 1 fig. 4), *G. tormarpensis* Brotzen, *G. reussi* (Khan) (*Anomalina complanata* Chapman (*non* Reuss) 1898 pp. 3–4 pl. 1 fig. 4a–c, and *Anomalina ammonoides* Chapman (*non* Reuss) 1898 pp. 4–5 pl. 1 fig. 5 a–c), *G. cenomanica* (Brotzen), and *L. jarzevae* (Vasilenko)—is also useful, although only *L. jarzevae* has a restricted range. The other species within this group are generally long-ranging forms, although they are nevertheless of some stratigraphical value as the position of any sample can be estimated by the evolutionary state of this whole group.

The zonal scheme proposed here is based on unpublished research by Carter and Hart, which in turn is a modification of the scheme produced during the course of the Channel Tunnel Site Investigation. The prototype zonal scheme for the mid-Cretaceous was published in Bruckshaw *et al.* (1961), and while it has formed the basis for later work, this published scheme was based only on one borehole succession. The present scheme has been tested and modified by regional correlation work in England and northern France. The zones outlined below include species which are not normally used in the full mid-Cretaceous zonal scheme, but they have been included in this account for completeness. The three-fold zonal subdivision of the Lower Gault Clay proposed by Khan (1952) has been found to be untenable. Many of the species he used in his 'frequency-occurrence' scheme have been found to be unreliable and are not used by the present author, while others occur in greater abundance outside the ranges studied and outlined by Khan.

Zone 3 Beds I–III *eodentatus-niobe.*

Subzone 3i Bed I (lower) *eodentatus-spathi.*

The fauna of this subzone is essentially that of the forerunners of the basic groups that continue throughout the Gault Clay. The *Arenobulimina* group is represented by *A. macfadyeni*, while the *Gavelinella/Lingulogavelinella* group is represented by *G. intermedia* and *G. tormarpensis.* Although *Epistomina spinulifera* (Reuss) (*Pulvinulina spinulifera* (Reuss) Chapman 1896 pl. 2 fig. 1a–c), *Hoeglundina carpenteri* (Reuss) (*Pulvinulina carpenteri* (Reuss) Chapman 1898 pl. 1 fig. 11a–c) and *Conorboides lamplughi* (Sherlock) are found at this level they are not important elements of the fauna and the subzone is dominated by the agglutinated species (which also include *Labrospira latidorsata* (Borneman) (*Haplophragmium latidorsatum* (Borneman) Chapman 1892 pl. 5 fig. 12a–b) and *Labrospira nonionoides* (Reuss) (*Haplophragmium nonionoides* Reuss: Chapman 1892 pl. 5 fig. 9a–b)) of which *A. macfadyeni* is the most important.

Subzone 3ii Bed I (upper)–III *intermedius-niobe.*

While the above fauna continues unchanged, *E. spinulifera* and *Hoeglundina chapmani* (Ten Dam) (*Pulvinulina carcolla* (Roemer) Chapman 1898 pl. 1 fig. 9, and *Pulvinulina elegans* (d'Orbigny) Chapman 1898 pl. 1 fig. 8), together with *H. carpenteri,* are more abundant. *H. delrioensis* and *H. planispira* also appear at this level together with *Quinqueloculina antiqua* Franke (*Miliolina venusta* Karrer: Chapman, 1891 pl. 9 figs 5–6, and *Miliolina ferussaci* (d'Orbigny) Chapman 1891 pl. 9 fig. 8). '*Siphouvigerina*' *asperula* (Chapman) (*Sagrina asperula* Chapman 1896 pl. 12 fig. 1) is commonly found in the lower levels of this subzone.

Zone 4 Beds IV-VIII *subdelaruei-cristatum*

The base of the zone is marked by the appearance of *Nodobacularia nodulsa* (Chapman) (*Nubecularia nodulosa* Chapman 1891 pl. 9 fig. 2) with *Dorothia filiformis* (Berthelin) (*Gaudryina filiformis* Berthelin: Chapman 1892 pl. 11 fig. 7), and the loss of *C. lamplughi.* The fauna of the greater part of this zone is dominated by large, highly ornamented specimens of *E. spinulifera.* The faunal change at the *cristatum* phosphate bed has already been discussed on p. 272. As the exact details of the changeover at this level are still imperfectly understood when considered in a regional context it has been necessary to include a transitional zone between zones 4 and 5.

Transitional zone 4a Bed IX (lower) *cristatum*(upper)-*orbignyi*(lower).

At the base of transitional zone 4a, the level of the *cristatum* phosphate bed, there is an important faunal turnover with the appearance of a typically Upper Albian fauna which includes *A. chapmani, Citharinella pinnaeformis* (Chapman) (*Frondicularia pinnaeformis* Chapman 1894 pl. 3 figs 9–11), *Spiroloculina papyracea* Burrows, Sherborn and Bailey, *Vaginulina mediocarinata* Ten Dam (*Vaginulina strigillata* Reuss: Chapman 1894 pl. 8 figs 3–4), *G. cenomanica,* and *H. infracretacea.* At the same level the *A. macfadyeni* fauna is severely reduced while *H. chapmani*

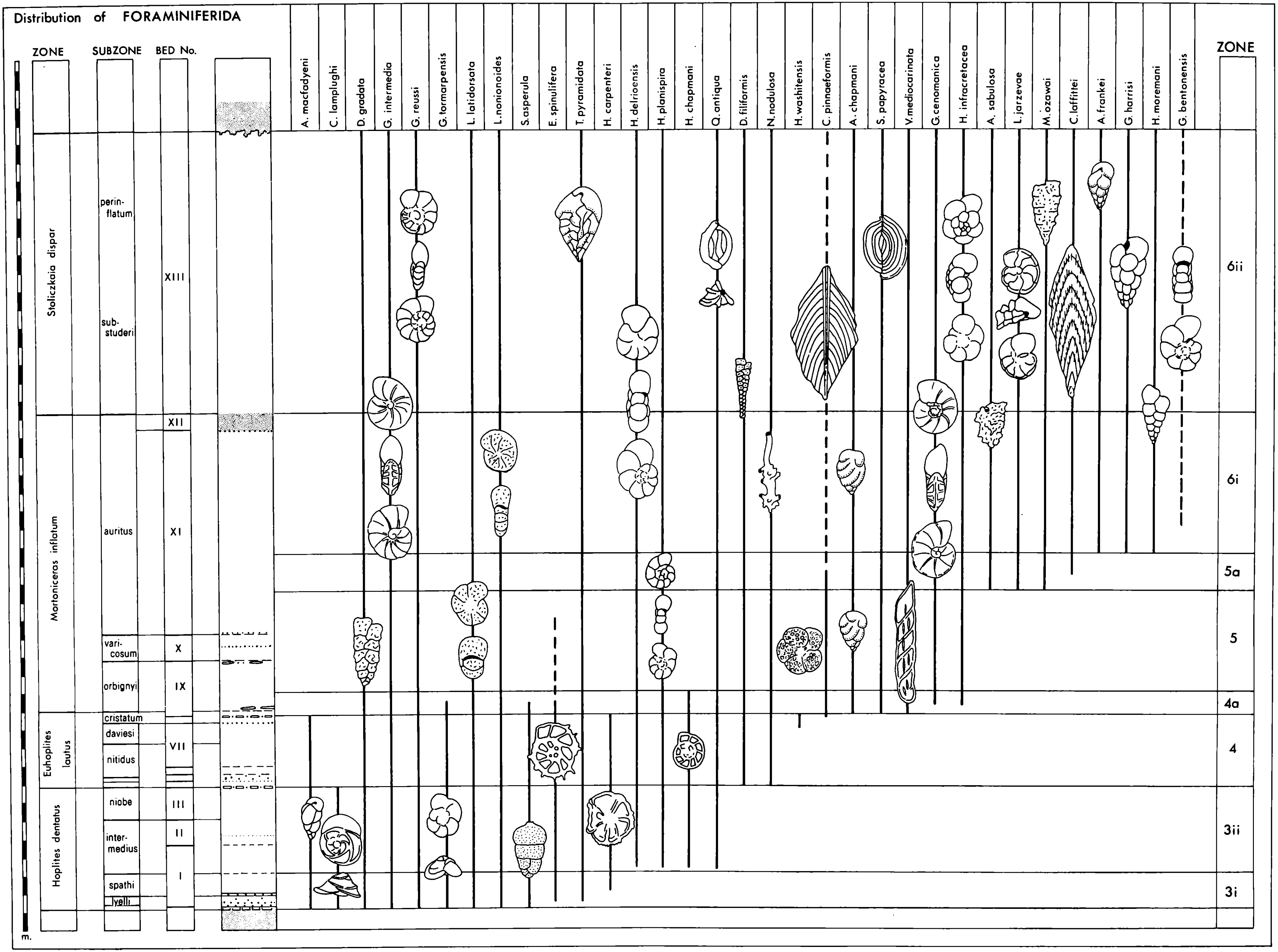

Fig. 3. Distribution of Foraminiferida in the Gault Clay at Copt Point, Folkestone.

disappears. Although *E. spinulifera* dies out within zone 4a, derived, corroded specimens can be found above this level.

Zone 5 Beds IX(upper)-XI(lower) *orbignyi*(upper)-*auritus*(lower).

With the marked reduction of the robertinacean fauna, and the loss of *E. spinulifera,* the fauna from this zone becomes more typically Upper Albian. *A. chapmani* remains the dominant species with *C. pinnaeformis, G. reussi, Tritaxia pyramidata* Reuss (*Verneuillina triquetra* Chapman (*non* Munster) 1892 pl. 6 fig. 24a-b and *Tritaxia tricarinata* Chapman (*non* Reuss) 1892 pl. 1 fig. 1a) and *Dorothia gradata* (Berthelin) (*Gaudryina pupoides* Chapman (*non* d'Orbigny) 1892 pl. 11 fig. 8a-b and *Gaudryina rugosa* Chapman (*non* d'Orbigny) 1892 pl. 11 fig. 9a-b) being less important elements of the fauna.

Transitional zone 5a Bed IX(middle) *auritus*(middle).

As in the case of zone 4 there follows a transitional zone, although the complication in this case is not of a geological nature, being due to the gap in the exposures at Copt Point. A study of borehole material from the Folkestone area indicates that there is a transitional zone at about the level of this gap. The base of the transitional zone is marked by the appearance of three very distinctive species, *A. sabulosa, L. jarzevae,* and *Marssonella ozawai* Cushman. With the appearance of *Citharinella laffittei* Marie in the centre of this transitional zone the fauna almost becomes that which characterizes the remainder of the Upper Gault Clay succession.

Zone 6 Beds XI(upper)-XIII *auritus*(upper)-*perinflatum.*

The appearance of *A. frankei* and the planktonic species *G. bentonensis, Guembilitria harrisi* Tappan, and *Heterohelix moremani* (Cushman), with a complementary reduction in the numbers of *C. pinnaeformis*, identifies this final zone of the Gault Clay. Although the fauna is essentially continuous throughout this interval, two subzones can be recognised and used for correlative purposes.

Subzone 6i Bed XI(upper) *auritus* (upper).

The usual zone 6 fauna with few planktonic individuals in the 30–60 fraction characterizes this subzone, which also contains a fauna rich in large specimens of *G. bentonensis* in its uppermost levels (Bed XII).

Subzone 6ii Bed XIII *substuderi-perinflatum.*

This subzone displays an almost continuous population of planktonic individuals in the 30–60 fraction, as shown in the graph in Figure 1. *A. sabulosa* and *A. chapmani* occur in almost equal numbers in this subzone. *A. frankei* and *C. laffittei* are also more frequently encountered, as are specimens belonging to the Family Polymorphinidae (e.g. *Globulina* spp.), with fistulose variants being concentrated at particular intervals.

Although this completes the succession as it is found at Copt Point there is an added complication which must be discussed here. In some of the boreholes from the English Channel another cycle of sedimentation has been found between Subzone 6ii and the base of the overlying Glauconitic Marl, which forms the base of the Lower Chalk. This cycle is discussed by Carter and Hart (unpublished) in as far as it affects the overall stratigraphy of the mid-Cretaceous, but the fauna (Subzone 6a) is so diagnostic that it can be easily recognised, and has been located in one of the boreholes to be discussed in this account.

Subzone 6a (macrofaunal equivalent unknown).

This subzone is difficult to place in either the Albian or the Cenomanian. The fauna contains the following indicators:

typically Albian species in Britain:—*A. chapmani, A. sabulosa, A. frankei.*

typically Cenomanian species in Britain:—*Arenobulimina advena* (Cushman), *Plectina mariae* (Franke), *Flourensina intermedia* Ten Dam, *Gaudryina austinana* Cushman.

As keeled planktonic species belonging to the genus *Praeglobotruncana* Bermudez appear in the overlying Glauconitic Marl it would seem more correct (Bandy 1967) to place this subzone in the Upper Albian, even though some of the more important Cenomanian benthonic species are present. This problem is made more difficult by the fact that the majority of the species under discussion are evolutionary derivatives of one another. At Folkestone it has been possible to demonstrate that *A. advena* developed from *A. chapmani* with the appearance of the internal partitions which normally characterize the Cenomanian species. In the same interval the triserial *F. intermedia* appears to develop from the quadriserial *A. sabolosa* by the reduction of the number of chambers in each whorl. The fauna of subzone 6a is therefore one of a complete transition. Where this subzone is lacking there is no problem in the identification of the Albian-Cenomanian boundary as the transitional forms of these two evolutionary sequences are not recorded.

3c. The ostracod succession

While recent workers (e.g. Kaye 1964, 1965) have tended to emphasise the taxonomic approach to the study of the Gault Ostracoda the present author has only attempted a schematic approach to the distribution of some of the more commonly encountered species. The Ostracoda are found in large numbers all through the Gault Clay and at several levels they are even more abundant than the Foraminiferida. The twenty-one species included in Figure 4 are the most commonly found, although the rarer species could probably provide a more rigorous zonal scheme. The majority of the species in Figure 4 are long-ranging forms (*Cythereis corrigenda* Kaye, *Cythereis reticulata* Jones and Hinde, *Cythereis thorenensis* Triebel, *Cytherella ovata* (Roemer), *Cytherella parallela* Reuss, *Neocythere* (*Centrocythere*) *denticulata* Mertens, *Neocythere* (*Neocythere*) *vanveeni* Mertens, *Platycythereis gaultina* (Jones), *Protocythere consobrina* Triebel, *Protocythere lineata* (Chapman and Sherborn), *Schuleridea jonesiana* (Bosquet), *Veenia harrisiana* (Jones)) and do not allow any very fine subdivision. Five broad zones are recognised.

Zone A Beds I–II(lower) *eodentatus-intermedius*(lower).

The lowest zone is characterized by a fauna that is poor in comparison to those that are to follow. It is however the most distinctive as its fauna is dominated by the small species *Schuleridea brevis* (Cornuel), together with the much larger *S. jonesiana*.

Zone B Beds II(upper)-VII *intermedius*(upper)-*daviesi*.

The appearance of *Dolocytheridea bosquetiana* (Jones and Hinde), followed closely by *C. thorenensis* and *Monoceratina umbonata* (Williamson), together with the loss of *S. brevis*, marks the base of this zone. It is however the upper limit of the zone which has caused problems similar to those encountered in the foraminiferal succession at the same level.

Zone C Beds VIII-XI(lower) *cristatum-auritus* (lower).

As shown in Figure 4, four species appear at about this level. At the present time however even a sampling interval of 20 cm has not completely—as in the case of the Foraminiferida—solved all the problems. There is still some doubt as to the exact placing of the base of the zone and it may be necessary to adjust

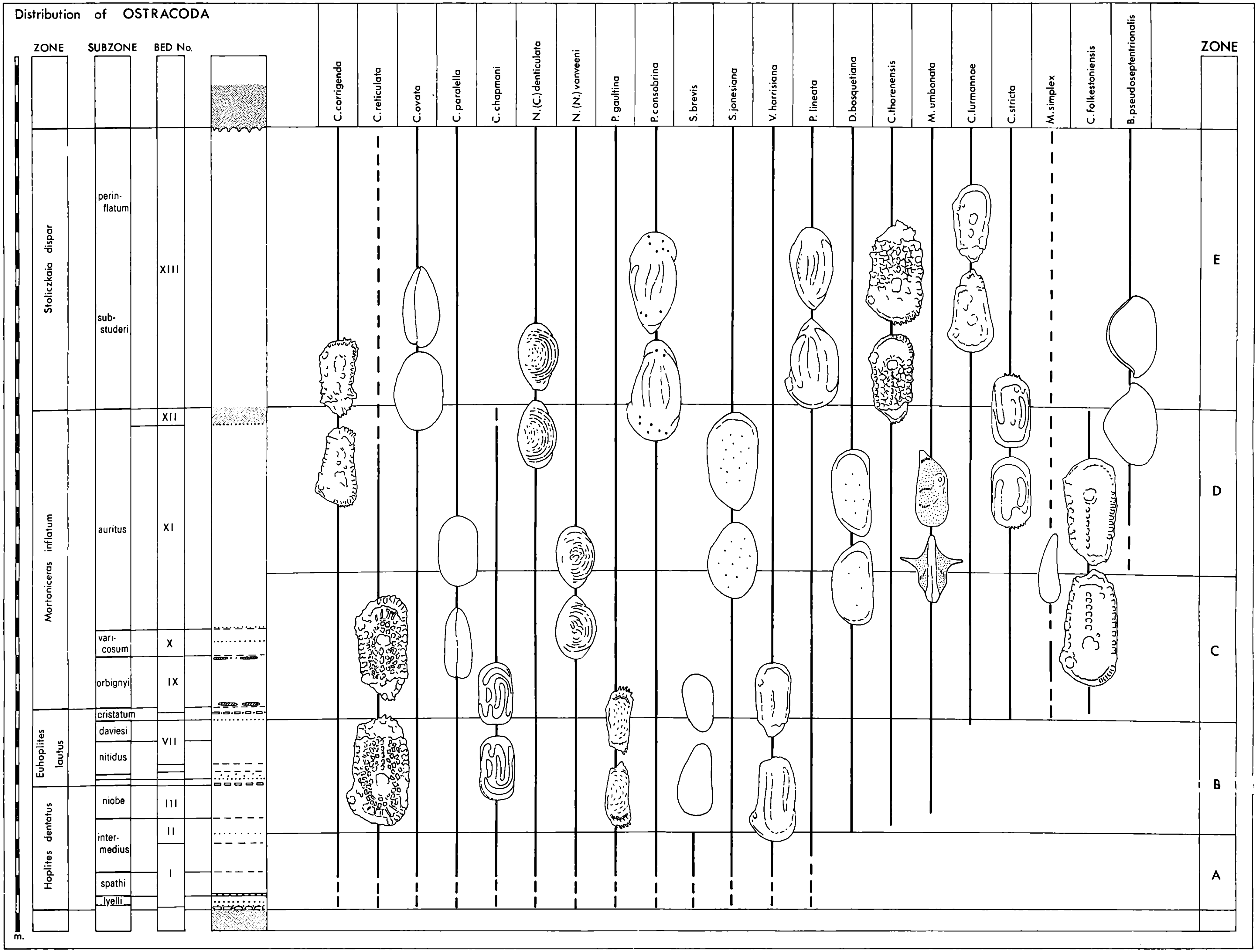

Fig. 4. Distribution of Ostracoda in the Gault Clay at Copt Point, Folkestone.

this in the light of further work. The more reliable species appear to be *Cytherelloidea stricta* (Jones and Hinde), and *Cythereis lurmannae* Triebel, which together with *Macrocypris simplex* Chapman are extremely abundant in this zone.

Zone D Beds XI(upper)-XII *auritus*(lower).

The fauna of zone C continues with little change throughout this zone, but there is a noticeable difference in that *Bairdia pseudoseptentrionalis* (Mertens) appears in considerable numbers. While this species can be found throughout the whole of the Gault Clay succession it is possible to recognise a marked increase in numbers at this level.

Zone E Bed XIII *substuderi-perinflatum*.

This zone is recognised by the reduction of *Cytherelloidea chapmani* (Jones and Hinde) while at the same time there appears to be a corresponding increase in the numbers of *C. stricta*. There is also a marked reduction in numbers of *Cythereis folkestoneiensis* Kaye, although rare specimens have been found in Bed XIII.

It must be emphasised that this is an interim statement on the distribution of the Ostracoda and work is still going into the refining of this scheme. Any modifications will be based on the information being obtained in the study of the borehole material from the west of Kent.

4. Some stratigraphical implications

4a. Lateral changes in the Upper Gault Clay and Upper Greensand

The Dunton Green borehole (TQ 514575), near Sevenoaks, is of particular interest for correlation with the Upper Gault Clay at Copt Point. The borehole was begun in the Lower Chalk and it has therefore been possible to study the fauna across the Glauconitic Marl and into the Gault Clay. Unfortunately, the zonal position of the Glauconitic Marl has changed between Dunton Green and Folkestone, and one cannot use the base of the Lower Chalk as a datum for correlation. It has been decided to correlate the two successions using the fluctuations in the planktonic population. The datum chosen for the present correlation is the marked peak in the percentage of planktonic individuals. Such an increase in the planktonic fauna must be due to a relative increase in the plankton over southern England, and as this would be controlled by water movements in the Gault sea it is expected that over a small area such population fluctuations would be essentially synchronous. Below this datum level in the Dunton Green borehole subzone 6ii, with its rich and distinctive microfauna, is reduced in thickness. It is underlain by what appears to be the equivalent of Bed XII (i.e. of the upper part of subzone 6i) with glauconitic samples being obtained from a thickness of about two metres. The fauna from this level shows the typically large specimens of *G. bentonensis*, although the very high percentage of planktonic individuals recorded at Folkestone is not found at Dunton Green. There is a distinct reduction of the agglutinated fauna, but that is all. This discrepancy between the two graphs suggests that the high percentage of planktonic individuals in Bed XII at Folkestone may be due to preservational differences. The underlying bulk of subzone 6i is also much thinner at Dunton Green. Zone 5 is represented in the lowest levels of the core and transitional zone 5a was also recorded, though it is too thin to be included in Figure 5. It is concluded therefore that at Dunton Green Bed XI

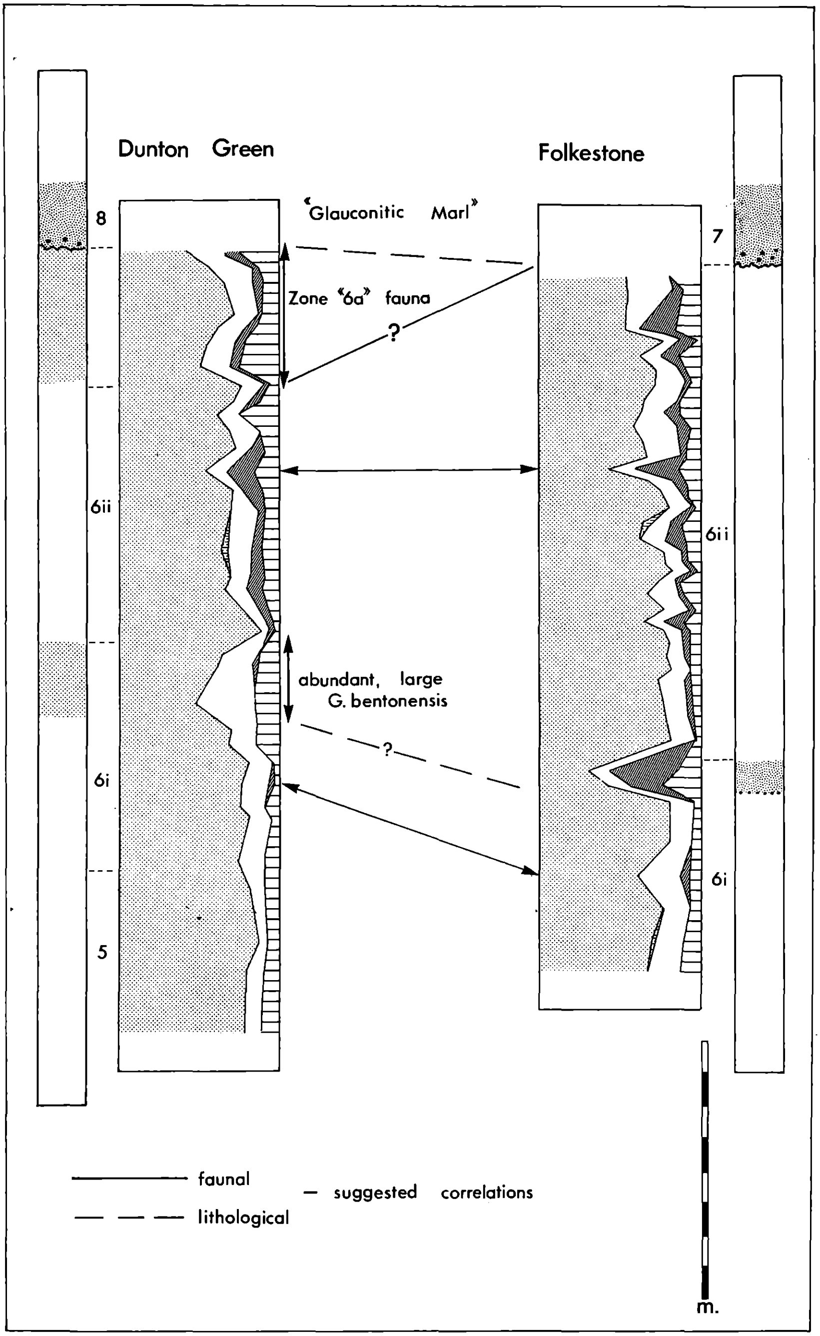

Fig. 5. The suggested correlation of the Dunton Green borehole with the Copt Point succession using a combination of the superfamily percentage graphs and the zonal scheme.

(*auritus* Subzone) has reduced in thickness while there has also been a significant change in Bed XIII (*dispar* Zone). Although there is some reduction in the thickness of subzone 6ii (Bed XIII) at the base, indicating the loss of the basal part of the *substuderi* Subzone, the main reduction has been in the *perinflatum* Subzone, now only 2·75 metres thick. Above this level the slightly arenaceous, mica-rich sediment contains a fauna that can be ascribed to zone 6a. This is the first recorded occurrence of this fauna in southeast England, and how this fits into the regional stratigraphy is largely unknown at the present time.

Thirty-five kilometres to the west of Dunton Green, at Fetcham Mill (Leatherhead), an I.G.S. borehole records a considerable thickness of the Upper Greensand and Gault Clay (Gray *et al.* 1965). The fauna of this borehole (Casey *in* Gray *et al.* 1965 Appendix B) contains elements which make it directly relevant to the present discussion. The first identifiable ammonite of Albian age is *Pleurohoplites* cf. *subvarians* Spath at a depth of 883′ 1″, followed by *Lepthoplites* cf. *pseudoplanus* Spath at 883′ 2″ and *Callihoplites* cf. *tetragonus* (Seeley) at 895′ 2″: the last is remarkably close to the base of the Upper Greensand (894′ 3″). This fauna was ascribed by Casey to the *dispar* Zone, but was taken as being more indicative of the *substuderi* Subzone than of the *perinflatum* Subzone. This indicates that the trend between Folkestone and Dunton Green is continued westwards to Fetcham Mill, and that it seems likely that while the *substuderi* Subzone does persist in a slightly reduced form, the *perinflatum* Subzone is either completely removed, or at best, considerably reduced.

This reduction in thickness of the *dispar* Zone away from the southeast of England would, if continued, mean that in the area north of the Thames and in the southwest of England it would be absent. In the Isle of Purbeck (Dorset) there is a well-exposed series of sections between Swanage, Worbarrow, Lulworth, and Durdle Door, which give a very clear indication of the Albian-Cenomanian stratigraphy of that area. This sequence has been studied in some detail by Wright (*in* Arkell 1947), and that account has provided the following ammonite determinations. Wright has indicated that the *orbignyi, varicosum, auritus* and *aequatorialis* Subzones can be differentiated—all within the Upper Greensand, but below the Exogyra Sandstone. This would appear to agree with the later suggestion of Kennedy (1970 p. 630) that the Exogyra Sandstone belongs to an horizon in either the *aequatorialis* or *auritus* Subzones. The succession above the Exogyra Sandstone is perhaps more interesting in that a few centimetres above the erosion surface which forms the top of this bed, there is a horizon of phosphatised pebbles and fossils. This "ammonite bed" can be traced over the whole of the Purbeck coastline, and it is this horizon that has allowed previous workers to record the presence of the *dispar* Zone in every section. It is interesting however that the *substuderi* Subzone has never been recorded in that area. Wright (*in* Arkell 1947 pp. 184-185) listed the ammonites from this bed and commented " . . . of these some are confined to Dorset, some are members of the semi-derived Cambridge Greensand fauna, and by their occurrence in Dorset can be placed stratigraphically."

The microfauna of the ammonite bed is almost identical to the microfauna of the Cambridge Greensand, and the overall faunal relationships are almost identical with those in Cambridgeshire. While Wright appears to use the Dorset fauna to locate the Cambridge fauna, the author is of the opinion that it would be more correct to regard the "ammonite bed" fauna in the same way as the Cambridge fauna, i.e. totally derived. If this was so then it would mean that there was no *in situ dispar* Zone Upper Greensand in southern Dorset, and that the upper

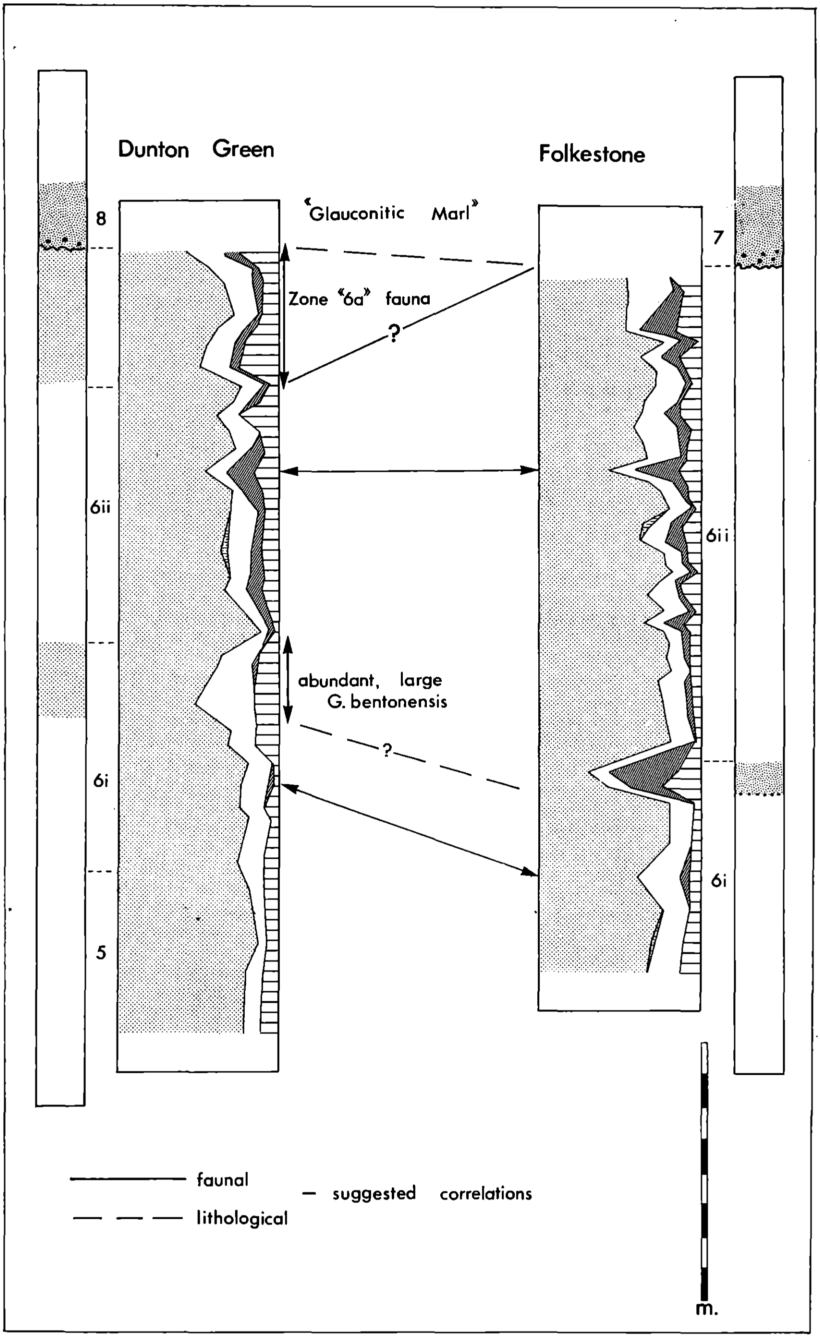

Fig. 5. The suggested correlation of the Dunton Green borehole with the Copt Point succession using a combination of the superfamily percentage graphs and the zonal scheme.

(*auritus* Subzone) has reduced in thickness while there has also been a significant change in Bed XIII (*dispar* Zone). Although there is some reduction in the thickness of subzone 6ii (Bed XIII) at the base, indicating the loss of the basal part of the *substuderi* Subzone, the main reduction has been in the *perinflatum* Subzone, now only 2·75 metres thick. Above this level the slightly arenaceous, mica-rich sediment contains a fauna that can be ascribed to zone 6a. This is the first recorded occurrence of this fauna in southeast England, and how this fits into the regional stratigraphy is largely unknown at the present time.

Thirty-five kilometres to the west of Dunton Green, at Fetcham Mill (Leatherhead), an I.G.S. borehole records a considerable thickness of the Upper Greensand and Gault Clay (Gray *et al.* 1965). The fauna of this borehole (Casey *in* Gray *et al.* 1965 Appendix B) contains elements which make it directly relevant to the present discussion. The first identifiable ammonite of Albian age is *Pleurohoplites* cf. *subvarians* Spath at a depth of 883′ 1″, followed by *Lepthoplites* cf. *pseudoplanus* Spath at 883′ 2″ and *Callihoplites* cf. *tetragonus* (Seeley) at 895′ 2″: the last is remarkably close to the base of the Upper Greensand (894′ 3″). This fauna was ascribed by Casey to the *dispar* Zone, but was taken as being more indicative of the *substuderi* Subzone than of the *perinflatum* Subzone. This indicates that the trend between Folkestone and Dunton Green is continued westwards to Fetcham Mill, and that it seems likely that while the *substuderi* Subzone does persist in a slightly reduced form, the *perinflatum* Subzone is either completely removed, or at best, considerably reduced.

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part of the Upper Greensand (the "Chert Beds") would be better regarded as being of Lower Cenomanian age.

The age of Cambridge Greensand fauna is perhaps one of the best known problems in British stratigraphy. The phosphatised fauna of *dispar* Zone age is enclosed in a glauconitic matrix which contains a foraminiferal fauna (Hart, in press) that can be ascribed to a level well above (upper *H. carcitanensis* Assemblage Zone of Kennedy 1969) the base of the Cenomanian. The Gault Clay immediately below the erosion surface at the base of the greensand contains a fauna indicative of the upper levels of subzone 6i, and at Arlesey the horizon of large specimens of *G. bentonensis* is immediately below the phosphate bed. This would indicate that in Cambridgeshire and Hertfordshire the *in situ dispar* Zone is not represented, and this agrees with the observations on the Dorset coast. The trends recorded in the southeast of England can therefore be shown to continue westwards and northwestwards towards the margins of the basin.

4b. Lateral changes in the Lower Gault Clay

Lateral changes in the Lower Gault Clay can also be traced. To illustrate some of these, the succession at the Sevenoaks Brick works, Greatness Lane (TQ 535576), Sevenoaks, is used, as this is the closest section available to the site of the Dunton Green borehole. The changes described here are therefore operating over the same distances as those already discussed for the Upper Gault Clay. The sequence at Sevenoaks (Fig. 6) is interesting in that there are several recognizable marker horizons within a relatively thin succession, although for the interval covered it is several metres thicker than that at Folkestone. The sequence exposed at the present time includes a clean face which extends from the *lyelli* Subzone to the *cristatum* phosphate bed. The most striking feature of the superfamily percentage graph is the absence of the fauna with a very high percentage of the Robertinacea. This fauna, at Folkestone, occurs within the *nitidus-cristatum* interval and the available microfaunal evidence seems to indicate that these subzones are not represented at Sevenoaks. The ammonite evidence of Owen (1971) agrees with this conclusion, and there is a remarkably close parallel between the microfaunal and macrofaunal distributions. At Sevenoaks there is a high percentage of Robertinacea in the upper *niobe* and *subdelaruei* Subzones, and this again agrees with the Folkestone sequence. The poor robertinacean fauna of the *intermedius* Subzone also occurs at Sevenoaks, even though there has been an increase in the thickness of this subzone at the latter locality. Both the foraminiferal and ostracod zonations show the same distributional patterns at Folkestone and Sevenoaks, and both compare closely with the ammonite succession.

The changes from Folkestone to Sevenoaks are quite striking, with the loss of the *daviesi* and *nitidus* Subzones and a complementary increase in the thickness of the *subdelaruei* and *meandrinus* Subzones. With so much variation within the Gault Clay succession a complete picture will emerge only after a study of all the borehole material from the Folkestone-Reigate (Surrey) section. This research is still in progress, but already it has become apparent that the stratigraphical history of the Gault Clay is not as simple as its essentially uniform appearance would suggest. Owen (1971) has demonstrated some of these variations in the Lower Gault Clay, but it must be emphasised that a complete picture will only become available when the whole succession is studied. While Owen uses the *cristatum* phosphate bed as a datum for many of his correlations, the present author is of the opinion that none of the main stratigraphical markers can be

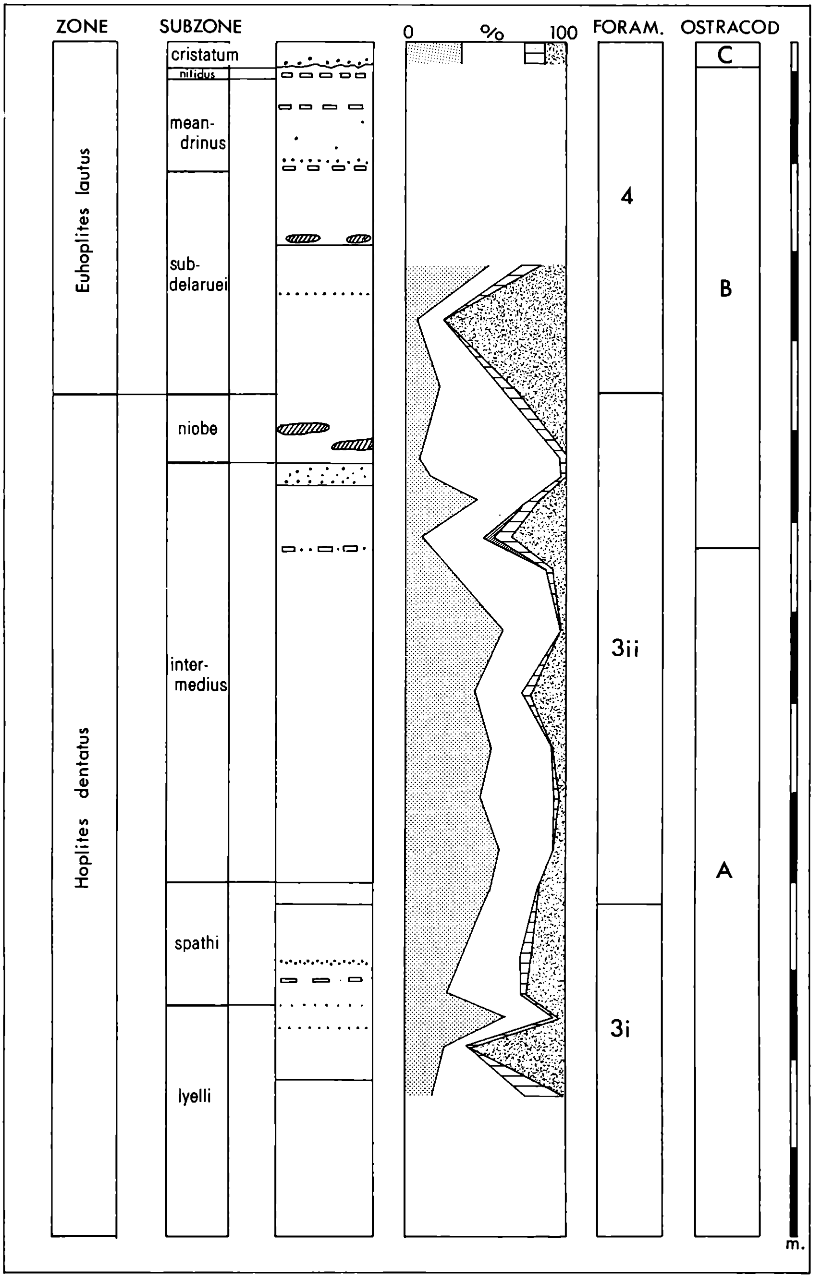

Fig. 6. Zonal sequences and foraminiferal superfamily percentages in the Lower Gault Clay at Sevenoaks, Kent.

used as a datum with any certainty, and one of the problems for any future work is the recognition of some biostratigraphical feature that can be used as a reliable plane of reference.

Acknowledgments. I thank D. J. Carter (Imperial College, London) for his guidance in the study of the microfauna, and Dr. H. G. Owen (British Museum (Natural History), London) for his assistance in the collection of the samples used in the correlation with the ammonite succession at Copt Point, Folkestone. The borehole material from Kent was kindly made available by Dr. A. Weeks, C. J. Foster, and E. Chinsman from the Highways Laboratories of Kent County Council, Maidstone. I am also indebted to Dr. C. G. Adams, Dr. R. H. Bate, Dr. B. Denness, Prof. D. L. Eicher, Mlle. F. Jannin, Mdme. M. Malapris-Bizouard, and Dr. T. Neagu for their help during this research.

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The occurrence and distribution of boreal ammonites from the Neocomian of southeast France (Tethyan Province)

Jean-Pierre Thieuloy

Records of boreal ammonites collected in the Tethyan Province and cited in earlier works are listed. Study of those specimens rediscovered indicates misidentifications which give a false picture of the taxonomy of these forms. A palaeontological study is made of about a hundred specimens, most of which have been collected bed-by-bed by the author from Valanginian and Hauterivian sections. The typically boreal genera *Platylenticeras, Pseudogarnieria, Polyptychites, Dichotomites, Neocraspedites* and *Simbirskites* (*Milanowskia*) are identified. Certain species appear to be valuable markers for precise correlation between the zonal scheme for northwest Europe and that of the Tethyan Province.

In dieser Arbeit werden die borealen Ammoniten-Gattungen aufgezählt und behandelt, die auch in Ablagerungen der Tethys beobachtet wurden oder aus der Tethys-Provinz in älteren Arbeiten erwähnt wurden. Dabei konnten Fehlbestimmungen korrigiert werden, die zu einem falschen Bild der Taxonomie dieser Formen geführt haben. Grundlage dieser paläontologischen Analyse bildeten an die hundert Examplare, die horizontiert gesammelt wurden und die vorwiegend aus Schichten des Valangin und Hauterive stammen. Dabei konnten folgende typisch boreale Gattungen nachgewisen werden: *Platylenticeras, Pseudogarnieria, Polyptychites, Dichotomites, Neocraspedites* und *Simbirskites* (*Milanowskia*). Mit einigen Arten dieser Gattungen scheint eine genaue Koordination borealer und mesogäischer Schichtfolgen möglich zu sein.

L'inventaire des éléments fauniques d'origine boréale, récoltés en province mésogéenne et cités dans les travaux antérieurs, est tout d'abord établi. L'analyse des échantillons retrouvés fait état d'erreurs de déterminations qui tendaient à donner une fausse image de l'évantail taxinomique de ces éléments. L'auteur a pu rassembler une centaine d'individus dont le plus grand nombre provient de coupes valanginennes et hauteriviennes levées banc par banc et l'analyse paléontologique en est faite. Les genres les plus typiquement boréaux *Platylenticeras, Pseudogarnieria, Polyptychites, Dichotomites, Neocraspedites* et *Simbirskites* (*Milanowskia*) sont identifiés. Certaines espèces apparaissent comme de précieux jalons pour l'établissement de corrélations précises entre la zonation valable pour l'Europe du Nord-Ouest et celle de la province mésogéenne.

1. Introduction

The first example of a north European Neocomian ammonite to be recorded from the Tethyan of France was "*Oxynoticeras*" *heteropleurum* (Neumayr and Uhlig), listed by Kilian in 1892. In the twenty years that followed, other species were added to form an apparently important list (Kilian 1910a, 1910b, 1918a, 1918b; Kilian and Reboul 1915; Paquier 1900; Sayn 1896, 1901). Cotillon (1971) has recently contributed to the study of boreal faunal migrations into Tethys in his important paper on the Lower Cretaceous of l'Arc de Castellane.

I have searched the collections at Grenoble for the specimens referred to in these papers, but most have been lost or destroyed. Of those surviving, some had already been examined, such as *Platylenticeras* (Kemper 1961). Careful study of the remainder has shown that they have often been wrongly identified at generic and specific level. These erroneous identifications have contributed to the number of migrant taxa recorded. Table 1 records references to these faunas in the Vocontian and Basses-Alpes facies, their authors, and original and revised identifications. From these original identifications, it appears that 25 boreal taxa are present, the types of which come either from eastern England (Yorkshire and Lincolnshire) or from north Germany (Hils and Teutoburger Wald). Six other species are southern manifestations of a typical boreal genus, *Platylenticeras*. In fact, the whole group are distributed among 14 genera of which only 4 (8 species) are representatives of the fauna of northern Europe.

All the Neocomian ammonites of genuine boreal origin were obtained from the Valanginian and Hauterivian. The Berriasian record listed in Table 1, which to my knowledge is unique to this stage, refers to a specimen which Kilian collected during a trip to the eastern Alps (Tyrol) and which I attribute, without hesitation, to the genus *Spiticeras*. In order to complete the picture, the Barremian reference that authorized Kilian (1896) to note "Il n'est donc plus exact de dire que le Barrémien ne renferme aucune espèce commune au Crétacé inférieur du Nord de l'Europe", an interpretation followed by Cotillon (1971), is also included. However, "*Crioceras*" *roemeri* can under no circumstances be conspecific with the type of Neumayr and Uhlig (1881), and belongs to the strongly trituberculate form *Crioceratites* (*Emericiceras*) *barremensis* (Kilian).

The records of boreal ammonites discussed in the following section are based on material collected bed-by-bed by the author during the last ten years, and in addition on the results of patient research by Breistroffer, Collignon and Mourre, whose collections are in my possession. These collections are invaluable since they come from a limited number of beds and I can confirm the horizons. Compared with the sparse material in old collections, this rich assemblage of about 100 ammonites of boreal affinity constitutes a considerable collection, even taking into account its specific paucity compared with that indicated in the faunal lists of my predecessors.

Some species appear to be important for establishing correlation with the boreal sequence (section 4, below): many of the specimens collected by earlier workers were unique examples and were not really used for such correlation. The few works on this aspect of biostratigraphy include those of Chernova (1951) for the Hauterivian and Kemper (1971) for the Valanginian.

2. The occurrence and stratigraphical assignment of boreal specimens

The discussion is limited here to brief remarks on known boreal species from the point of view of correlation in the European area only: the question of certain common forms will also be examined. These species will be described and figured in a subsequent publication.

Platylenticeras

Platylenticeras of the *heteropleurum* group, recently revised by Kemper (1961), are not rare in the southeast of France; occurrences are as follows:

Isère: Chichilianne (type locality of "*Garnieria paradiscus*" Baumberger = *Platylenticeras* (*P.*) *latum tenue* Koenen).

Drôme: Sainte-Croix, Chamaloc (type locality of *P.* (*P.*) *heteropleurum occidentale* (Sayn)) and col de Prémol (= Jonchères, Bellegarde and La Motte-Chalancon *auct.*) (type locality of *P.* (*P.*) *cardioceroides* (Sayn) and of "*Garnieria angulosa*" Sayn). This last locality was formerly the richest locality for *Platylenticeras* in the Vocontian region.

Hautes-Alpes: Saint-Julien-en-Bochaine (type locality of *P.* (*P.*) *nicolasianum* (d'Orbigny). La Faurie and Piloubeau (= Pomet) near Chateauneuf-de-Chabre.

Analysis of the geographical distribution of the different species is illuminating. Thus, forms conspecific with, or extremely close to, German types are exclusively, or most frequently, represented in the more northerly strata (Chichilianne and Chamaloc), whereas Tethyan manifestations of the genus are more abundant further south (col de Prémol and Piloubeau). The latter locality, where *P.* (*P.*) *cardioceroides* and *P.* (*P.*) *gevrilianum* (d'Orbigny) are quite common (25 specimens), marks the southern limit of the area of distribution of this genus. It has not been found in the southeast district of the Vocontian trough, nor in the semi-pelagic and neritic zones which surround this palaeogeographical area to the south and west.

Old collections are generally not of great help in the stratigraphical assignment of the various species of *Platylenticeras*. Nevertheless, they have enabled me to check the horizon at Piloubeau since the adjoining section at Barret-le-Bas, collected bed-by-bed, has yielded *Platylenticeras* at two horizons. Firstly, a single specimen of *P.* (*P.*) *gevrilianum gevrilianum* is recorded in the upper part of the *Thurmanniceras pertransiens* Zone. The calcareous preservation of this specimen is, to my knowledge, unique. At a slightly higher horizon, an assemblage of pyritic nuclei of *P. cardioceroides* and *P. gevrilianum gevrilianum* occur associated with *Saynoceras hirsutum* and *Kilianella lucensis* in the *Kilianella roubaudi* Zone. This is homologous with the extremely fossiliferous horizon at Piloubeau.

If one refers to the zonation proposed by Kemper (1961), *P.* (*P.*) *latum tenue* occurs in the *P. robustum* Zone. Although the majority of the other species listed above are not recorded from the Lower Saxony Basin, they are related to *P.* (*P.*) *heteropleurum occidentale* and could be placed, at least provisionally, in the *heteropleurum* Subzone. Thus, only the fauna of the lower half of the Platylenticeras Schichten appears to be represented in the Vocontian facies.

Pseudogarnieria

Three small nuclei (two from Chateauneuf-de-Chabre and one from Barret)

Table 1. Published records of boreal species in the French Tethyan area.

SPECIES: original identification	*Author*	*Fossil Localities*	*Revised Identification*	*Original Distribution*
Emericiceras roemeri (N. & Uhl)	Cotillon 1971	Rougon (Alp.-Haute-Prov.)	v *Crioceratites* (*Emericiceras*) gr. *barremensis* (Kil.)	BARREMIAN
Crioceras Roemeri N. & Uhl.	Kil. 1896, 1910	Barrême, Moustiers (Alp.-Haute-Prov.), Lesches (Drôme)	v *Crioceratites* (*Emericiceras*) cf. *barremensis* (Kil.)	
Crioceras Seeleyi N. & Uhl.	Kil. & Reb. 1915	La Bégude (Alp.-Haute-Prov.)	x likely *Crioceratites* (*Cr.*) gr. *quenstedti* (Oost.)	HAUTERIVIAN
Spitidiscus rotula "Phil." var.	"	" "	v *Spitidiscus* gr. *rotula* (Sow.)	
Spitidiscus cf. *rotula* "Phil".	Kil. 1918	La Martre, Bargème (Alp. Haute-Prov.)	v *Spitidiscus* gr. *rotula* (Sow.)	
Lyticoceras corroyi Thomel	Thom. 1961	Falicon (Alp.-maritimes)	*Dichotomites*? *corroyi* (Thom.)	
Acanthodiscus (*Neocomites*) *Frantzi* Kil.	Kil. & Reb. 1915 Kil. 1918	La Bégude, La Martre (Alp.-Haute-Prov.)	v *Leopoldia frantzi* (Kil.)	
Acanthodiscus Vaceki N. & Uhl.	"	" "	v *Acanthodiscus vaceki* N. & Uhl.	
Acanthodiscus Ottmeri N. & Uhl.	"	La Bégude, La Martre, Bargème (Alp.-Haute-Prov.)	v *Acanthodiscus ottmeri* (N. & Uhl.)	
Acanthodiscus hystrix Phil.	Kil. 1918	Brovès, Peyroules (Alp.-Haute-Prov.)	v Neocomitid (*Kilianella*?) n. sp.	
Acanthoplites spiniger Koen.	Kil. & Reb. 1915	La Bégude (Alp.-Haute-Prov.)	v *Eleniceras* aff. *tchechitevi* Bresk.	
Neocomites cf. *amblygonius* N. & Uhl.	"	" "	v *Neocomites* (*Teschenites*) cf. *neocomiensiformis* (Uhl.)	
Neocomites oxygonius N. & Uhl.	"	" "	v *Lyticoceras* gr. *nodosoplicatum* (Kil. & Reb.) *cryptoceras* (d'Orb.)	
Neocomites curvinodus "N. & Uhl."	"	" "		
Neocomites paucinodus N. & Uhl.	"	" "		
Neocomites longinodus N. & Uhl.	Kil. 1918	Peyroules (Alp.-Haute-Prov.)		
Neocomites cf. *longinodus* N. & Uhl.	Kil. & Reb. 1915	La Bégude (Alp.-Haute-Prov.)		
Neocomites cf. *regalis* Pavl.	"	" "	v *Neocomites* (*Teschenites*) cf. *paraplesius* (Uhl.)	
Simbirskites sp. nov. cf. *Iburgensis* Weerth	"	" "	x	
Polyptychites Carteroni d'Orb.	"	" "	x	
Polyptychites bidichotomus Leym.	"	Issarpayes (Alp.-Haute-Prov.)	v *Dichotomites bidichotomus* (Leym.)	
Polyptychites bidichotomus Leym.	Kil. 1910	?	x	
Polyptychites cf. *bidichotomus* Leym.	Paquier 1900	La Charce (Drôme)	v *Olcostephanus* aff. *variegatus* Paquier (*teratos*)	
Polyptychites cf. *biscissus* Koen.	Kil. 1910	Furmeyer (Hautes-Alp.)	x	
Polyptychites quadrifidus Koen.	Kil. & Reb. 1915	La Bégude (Alp.-Haute-Prov.)	v *Polyptychites* cf. *multiplicatus* (Roem.) *in* Koen.	
Subastieria sulcosa Pavl.	Cotillon 1971	?	? *Subastieria sulcosa* (Pavl.)	

Distoloceras hystrix (Phil.)	Cotillon 1971	La Bégude (Alp.-Haute-Prov.)	v *Neocomitid* (*Kilianella* ?) sp. nov.	UPPER VALANGINIAN	VALANGINIAN
Distoloceras aff. *spiniger* (Koen.)	"	" "	v *Eleniceras tchechitevi* Bresk.		
Acanthodiscus cf. *hystrix* (Phil.)	Kil. 1910	?	v *Neocomitid* (*Kilianella* ?) n. sp.		
Hoplites (*Neocomites*) *longinodus* N. & Uhl.	"	?	v *Eleniceras* sp. *Neocomites* (*Teschenites*) sp.		
Hoplites (*Neocomites*) cf. *oxygonius* N. & Uhl.	"	?			
Hoplites (*Neocomites*) curvinodus "N. & Uhl."	"	?			
Hoplites cf. *amblygonius* N. & Uhl.	Paquier 1900	Barret-le-Bas (Hautes-Alp.)	v *Neocomites* (*Teschenites*) sp.		
Simbirskites phillipsi Roem.	Kil. 1918	Gigondas (Vaucluse)	x		
Simbirskites sp. "(sehr selten)"	Kil. 1910	?	x		
Craspedites fissuratus Koen.	"	?	v *Neocraspedites* sp. juv. cf. *fissuratus* (Koen.)		
Craspedites complanatus Koen.	"	?	v *Neocraspedites* sp. juv. cf. *complanatus* (Koen.)		
Dichotomites bidichotomus (Leym.)	Cotillon 1971	La Treille (Var)	v *Polyptychites plicatilis* Koen.		
Polyptchites cf. *diplotomus* Koen.	"	Les Allaves (Alp.-Haute-Prov.)	v *Dichotomites* aff. *biscissus* Koen.		
Polyptychites sp.	Kil. 1910	Noyers (Alp.-Haute-Prov.)	x probably *Olcostephanus* n. sp.	LOWER VALANGINIAN	
Platylenticeras heteropleurum occidentale (Sayn)	Kemper 1961	Ste-Croix (Drôme)	v *Platylenticeras heteropleurum occidentale* (Sayn)		
Platylenticeras cardioceroides (Sayn)	"	Bellegarde, Jonchères, Ste-Croix (Drôme); Chateauneuf-de-Chabre, La Faurie (Hautes-Alp.)	v *Platylenticeras cardioceroides* (Sayn)		
Platylenticeras gevrilianum gevrilianum (d'Orb.)	"	La Faurie, Chateauneuf-de-Chabre, Pomet (Hautes-Alp.)	v *Platylenticeras gevrilianum gevrilianum* (d'Orb.)		
Garnieria paradiscus Baumb.	Baumb. 1928	Chichilianne (Isère)	v *Platylenticeras latum tenue* (Koen.)		
Garnieria angulosa Sayn	Sayn 1901	Jonchères (Drôme)	v *Platylenticeras cardioceroides* (Sayn)		
Garnieria cardioceroides Sayn	"	La Motte-Chalancon (Drôme)	v *Platylenticeras cardioceroides* (Sayn)		
Garnieria heteropleurum var. *occidentalis*	"	Chamaloc, Jonchères (Drôme)	v *Platylenticeras heteropleurum occidentale* (Sayn)		
Garnieria heteropleurum var. *occidentalis* Sayn	Paquier 1900	Chamaloc (Drôme)	v *Platylenticeras heteropleurum occidentale* (Sayn)		
Garnieria angulosa Sayn	"	Col de Prémol (Drôme)	x		
Garnieria cardioceroides Sayn	"	La Motte-Chalancon (Drôme)	v *Platylenticeras cardioceroides* (Sayn)		
Oxynoticeras heteropleurum N. & Uhl.	Kil. 1892	La Faurie, Serres (Hautes-Alp.)	v *Platylenticeras gevrilianum* (d.Orb.)		
Ammonites Nicolasianus d'Orb.	D'Orb. 1850	St-Julien (Hautes-Alp.)	v *Platylenticeras nicolasianum* (d'Orb.)		
Simbirskites gr. Discofalcati	Kil. & Reb. 1915	Sebi near Kufstein (Tyrol)	v. *Spiticeras* (*Negreliceras* ?) sp.	BERRIASIAN	

x specimen lost or destroyed.
? doubtful geographical or stratigraphical position.
v specimen seen by author.

could be examples of the juvenile growth-stage of *Pseudogarnieria undulatoplicatilis* (Stchirowski), a species previously thought to be confined to the Russian Platform. The French nuclei are recorded here as *P.* cf. *undulatoplicatilis.* In addition to their oxycone shape, sharp keel and lateral ribbing, consistent with those of the individual from Pechorka, near Simbirsk (now Ulyanovsk), two characters appear to be even more significant—the corona of small, periumbilical tubercles and the sporadic bifurcation of some of the ribs on the upper third of the whorl flank. These nuclei differ from the Russian type (an ontogenetically more advanced specimen) only in having less flexuous ribs.

As with *Platylenticeras* of the *gevrilianum-cardioceroides* group, these specimens come from the horizon with *Saynoceras hirsutum,* which clearly may be placed in the Lower Valanginian. This agrees with the dating of the Russian *P. undulatoplicatilis* zone as Lower Valanginian (Sazanova 1971).

Polyptychites

A single ammonite from Baou (Alpes-Haute-Provence) is identified as *Polypychites* aff. *keyserlingi* (Pavlow *non* Neumayr and Uhlig). The depressed whorl-section and the arrangement of the remarkably coarse ribs are closely comparable to those of the specimen from Kachpour (near Simbirsk), figured by Pavlow (1892 pl. 8 fig. 13). The stratigraphical horizon of the French specimen is unknown.

A unique example of *Polyptychites plicatilis* Koenen, discovered by Cotillon in the "Petite Lumachelle" (horizon 9) at la Treille (Var) and recorded (Cotillon 1971) as *Dichotomites bidichotomus* (Leymerie) obviously belongs to the group of *Polyptychites ascendens* Koenen and exhibits all the distinctive characteristics of *P. plicatilis:* flattened outline, number of umbilical bullae, dense, forwardly-curving "astieriform" ribs. Its shape, moreover, is close to that of the type figured by Koenen (1909 pl. 22 figs 1, 4). This specimen is of special value in the stratigraphical scale established by Cotillon (1971); in fact, it contributes to conferring a high Upper Valanginian age on this "Petite Lumachelle". Subsequently, I have discovered a thin, constant horizon with *Saynoceras verrucosum,* the exact homologue of beds which yield *S. verrucosum* in the pelagic Vocontian facies, immediately above the "Petite Lumachelle", at the base of the marly horizon 10 of Cotillon. It therefore follows that *P. plicatilis,* which is an element of the *Polyptychites clarkei* Zone at Hanover, occurs here in an identical position, at the top of the *campylotoxus* Zone (*sensu* Thieuloy). This specimen is thus of remarkable interest in establishing correlation.

Two splendid ammonites from the neritic facies of l'Arc de Castellane are ascribed to the species described and figured by Koenen (1902 pl. 13 figs 4, 5, 9) under the name *Polyptychites multiplicatus* (Roemer). One, from the locality of la Bégude, was attributed by Kilian and Reboul (1915) to *P. quadrifidus* Koenen; the other was discovered by M. Collignon in the adjoining section at Allaves. The ontogenetic development of the former and of the German type specimen are similar and their morphological characters and parameters closely comparable. The specimen from Allaves is better preserved and illustrates the development of coarsened ribbing, which in the specimen figured by Koenen begins on the adapertural third of the shell.

The exact stratigraphical horizon of these two specimens is not known. The collectors recorded a Lower Hauterivian age on the original labels, but the lithology would suggest an Upper Valanginian horizon. I favour the marly, bi-coloured limestone that forms the base of the "Grande Lumachelle" of Cotillon (top of horizon 10 or base of 11) as their probable source. The German type specimen was from the *verrucosum* Zone (*sensu* Koenen).

Dichotomites

Several species of *Dichotomites* occur in southeast France. *D. ramulosus* (Koenen) is represented by an example from Barret-le-Haut (Hautes-Alpes), bed 151 (Thieuloy collection). This calcareous specimen, an adult 120 millimetres in diameter, is unfortunately crushed laterally but the branching and irregularly dichotomous arrangement of the ribbing is identical with that of the German form. The exact stratigraphical horizon of this specimen is known: it is from the Upper Valanginian *Himantoceras trinodosum* Zone.

A single ammonite from Issarpayes, near Allaves (Alpes-Haute-Provence) (collected by Reboul and identified by Kilian and Reboul (1915) as *Polyptychites bidichotomus*) approaches the holotype of *D. bidichotomus* (Leymerie) in its general dimensions and in its mode of ribbing: regular dichotomy and occasional trifurcation. The stratigraphical horizon of this specimen was not specified, but its preservation in hard, rough, marly limestone, rich in small fragments, is that of the uppermost beds of the "Grande Lumachelle". These are the beds which have yielded the *Dichotomites* described below, associated with *Neocomites teschenensis* (Uhlig), *N.* (*Teschenites*) sp., *Eleniceras* sp. and *Dicostella* sp. (Cotillon collection). This horizon, therefore, is homologous with the *N.* (*T.*) *callidiscus* Zone of the Vocontian province.

Dichotomites aff. *biscissus* (Koenen) is known by three incomplete outer whorls from Allaves—one determined by Cotillon (1971) as *Polyptychites* cf. *diplotomus*, one from the Collignon collection, and one from the author's collection. These specimens have in common a marked degree of evolution which exposes a third of the previous whorl, a subquadrate whorl-section with slightly convex flanks, and bidichotomous ribbing. The specimen collected by Cotillon differs from the other two in its coarser ribs, and is similar in ornament to "*Lyticoceras*" *corroyi* Thomel (= *Dichotomites lateumbilicatus* Thomel), on which the disappearance of the ribs on the venter is only a consequence of the weathering of the ventral region. This species is a *Dichotomites* with evolute whorls and a subquadrate whorl-section, as originally suggested by Thomel (1961).

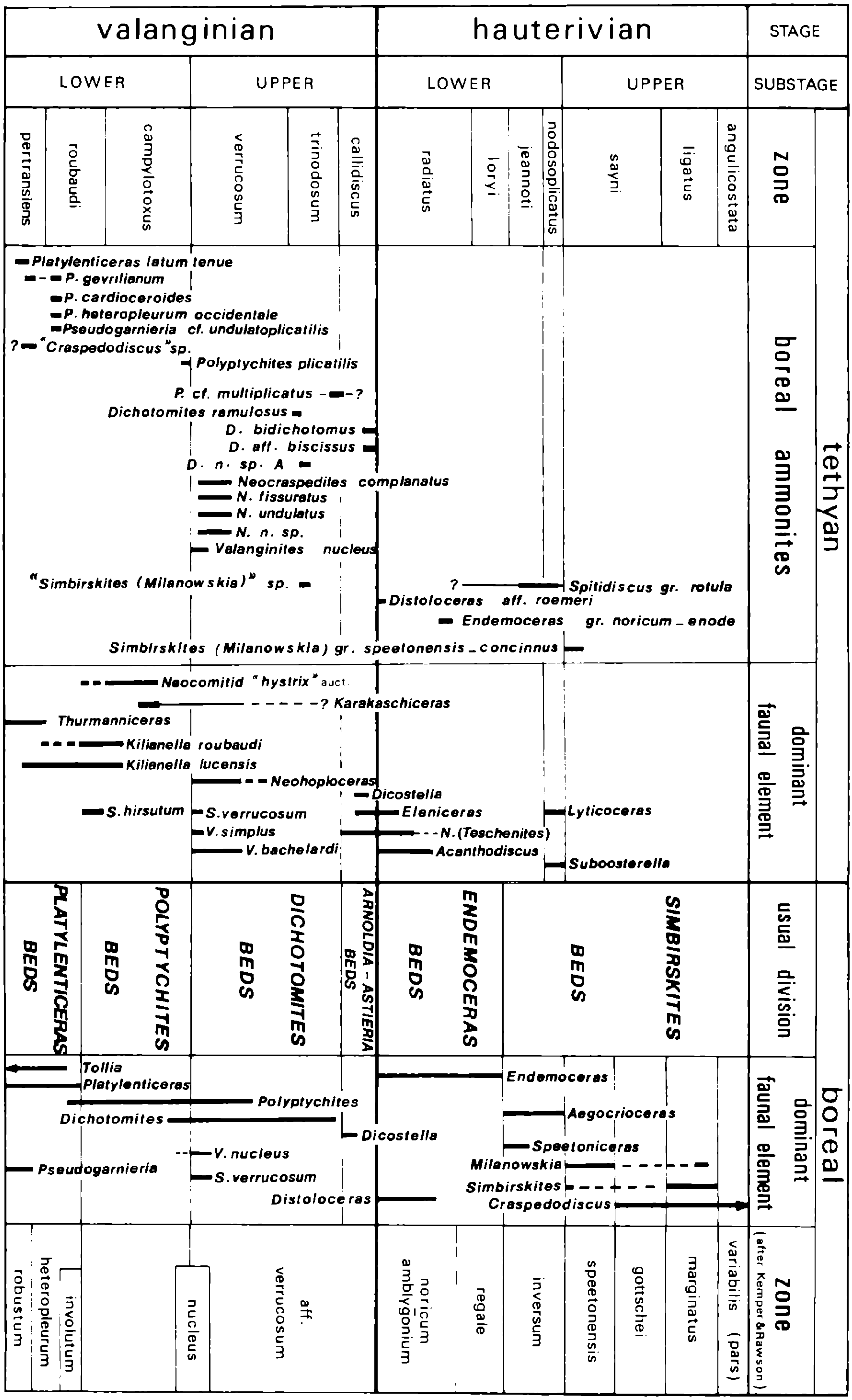
All three specimens were collected from the top of the "Grande Lumachelle"—*N.* (*T.*) *callidiscus* Zone. *D. biscissus* was dated by Koenen (1902) as Upper Valanginian ("*terscissus* Zone"), a large unit of only limited use in correlation.

Dichotomites sp. nov. A is represented by 12 septate, pyritised nuclei (10 from the author's collection: 2 from the Collignon collection) collected at Angles and St-Firmin (Alpes-Haute-Provence). The shell is involute and compressed with feebly convex, slightly converging flanks and a vertical umbilical wall. The fine, dense, prorsiradiate ribbing curves strongly forward on the venter. Because of their juvenile nature these *Dichotomites* cannot be attributed to a previously described species. For this reason they are interpreted here as a new form, in which the stratigraphical value is all-important. They occur associated with a population of *Himantoceras trinodosum* Thieuloy and "*Simbirskites*" *auct.* from a horizon a little way up in the *trinodosum* Zone (Upper Valanginian).

Neocraspedites

Several species of *Neocraspedites* are relatively common in the Vocontian province: 45 septate nuclei (Breistroffer, Collignon and the author's collections) have

Table 2. Valanginian and Hauterivian zonations in the Boreal and Tethyan Provinces, with the distribution of selected dominant ammonites and the immigrant fauna.



been collected from the Col de Lazarier, near Arnayon (Drôme), Barret-le-Bas (Hautes-Alpes) and St-Firmin (Alpes-Haute-Provence). Their taxonomic position is not perfectly defined. However, juvenile stages of *N. complanatus* (Koenen), *N. undulatus* (Koenen) and *N. fissuratus* (Koenen) are identified. Furthermore, a new morphological type may be present, in which the ribbing is less dense and stronger on the flanks.

The distribution of these French representatives of the genus *Neocraspedites* is limited to the base of the Upper Valanginian (the *verrucosum* Zone).

Valanginites

Valanginites nucleus (Roemer), which characterises the basal part of the German Dichotomiten Schichten, is common in some localities in the French neritic facies. Two sections (Les Allaves and Carajuan, Alpes-Haute-Provence) have yielded about 10 stratigraphically localised specimens that in all respects correspond with Roemer's and Koenen's figures, and also with *Ammonites utriculus* Matheron, a junior subjective synonym of *V. nucleus*. All come from a moderately thick marly sequence (Horizon 10 of Cotillon 1971) which contains only *Saynoceras verrucosum* at its base. The fauna of these beds also contains a variety of *Valanginites* with more prominent, denser ribs (*V.* cf. *psaephoides* (Mayer-Eymar) = *V. bachelardi* (Sayn)), and, as Kemper (1971) has supposed, *Dobrodgeiceras wilfridi wilfridi* (Karakasch) and *D. wilfridi ventrotuberculatum* Nikolov, the distribution of which is specified here. In a previous paper (Thieuloy and Gazay 1967) these *Dobrodgeiceras* were placed at a higher stratigraphical level. This genus can most easily be distinguished from *Valanginites* by the appearance of primary ribs and the greater development of periumbilical tubercles.

In the pelagic Vocontian province, *V. simplus* (d'Orbigny) (? = *V. nucleus* juv.) is recorded only from the base of the *verrucosum* Zone, in association with the index species, whereas *V. bachelardi* extends a little higher in the zone.

Simbirskites

A partially deformed specimen in the author's collection appears to be a *Simbirskites* close to *S.* (*Milanowskia*) of the *speetonensis-concinnus* group. Dr. P. F. Rawson confirmed this identification from a cast. The primary ribs divide into two secondary ribs and other secondary ribs appear sporadically. The ribbing is moderately prorsiradiate, curving forwards over the venter. The outer whorls show that starting at a diameter of 70 millimetres the lateral tubercle diminishes and turns into a feeble radial swelling of the primary rib.

The specimen was collected from bed 46 (author's number) from Allaves, associated with the first representatives of *Subsaynella sayni* (Paquier) from the lower part of the *S. sayni* Zone.

Many authors have recorded "*Simbirskites*" in the Vocontian Valanginian. I have traced the material referred to and have distinguished two morphological types—one in the Lower Valanginian and one in the Upper Valanginian. The first type is represented by only four specimens: one from Brune (Ardèche) (Gevrey collection), one from the Col de Prémol (Drôme) (Collignon collection) and 2 from Chateauneuf-de-Chabre (Hautes-Alpes) (Breistroffer collection). I have not found this form in a stratigraphically localised bed, but its horizon is beyond question: in fact, these localities have yielded a well-known fauna exclusively of Lower Valanginian age. This type is here placed at the top of the *pertransiens* Zone or the base of the *roubaudi* Zone because the fauna from Brune is an association of

Thurmanniceras and *Kilianella* without *Neocomites*. These "*Simbirskites*" forms have been referred to *Craspedodiscus* in the collections, for in certain features they recall the specimen of *C. phillipsi* (Roemer) figured by Neumayr and Uhlig (1881 pl. 15 fig. 7) and more particularly *C. carinatus* (Koenen). In fact, their ribbing closely resembles that of the Tolliinae, but the ventral region is very distinctive. The whorl flanks, which are initially sub-parallel, rapidly converge towards the venter. The venter itself is angular and surmounted by a ridge formed by the enlargement of the secondary ribs. These specimens do not have real affinity with the Simbirskitinae and must be considered as a new genus, the phylogenetic interpretation of which remains difficult.

The second type of "*Simbirskites*" is more common and is represented by 15 septate nuclei from Angles and Les Sources de l'Asse (Alpes-Haute-Provence) in the Collignon and Thieuloy collections. These specimens call to mind the juvenile stages of *Simbirskites* (*Milanowskia*) of the *concinnus* group. However, many characters separate them: a lesser degree of involution, the absence of true adapertural curvature of the ribs on the venter, "astieriform" umbilical tubercles and the presence of deep, prorsiradiate constrictions. Here again, commonplace morphological convergence accounts for the simbirskitid appearance, but they probably belong to a new, very evolute olcostephanid genus. I have found them with *Dichotomites* sp. nov. A from the *trinodosum* Zone of the Upper Valanginian.

Endemoceras

Various species of *Endemoceras* (Thiermann 1963), a genus very abundant in Germany and England where certain species are used as zonal indices for the Lower Hauterivian, have been cited in old papers or identified in the collections. After examining the material I did not find a single specimen which could be conspecific with boreal forms. All must be assigned to the genera *Neocomites* (*Teschenites*) and *Eleniceras*. However, I have collected one incomplete specimen from the section at l'Ire-du-Claux, near Chabrières (Alpes-Haute-Provence), which seems to me to belong to the group of *Endemoceras noricum-E. enode*. The falcoid ribbing, which continues over the venter in the form of chevrons, and the aperture of the body-chamber are closely comparable to those figured by Thiermann (1963 pls 24–25). This specimen came from a glauconitic bed in which the Lower Hauterivian fauna (*radiatus* Zone) is condensed. Although this condensed succession is not of any great stratigraphical value, the *radiatus* Zone of France is probably the equivalent of the *amblygonium* and *noricum* Zones and, at least in part, of the *regale* Zone.

Distoloceras

The neocomitid genus *Distoloceras,* with more-or-less uncoiled whorls, is not very common. The majority of the French specimens referred to *D. hystrix* (Phillips) *D. curvinodum* (Phillips) or *D. spiniger* (Koenen) must be assigned to the genus *Eleniceras* of Upper Valanginian age or to a "kilianellid" with *Distoloceras*-like appearance from the Lower Valanginian (*campylotoxus* Zone).

I have collected a strongly trituberculate form from Angles (Alpes-Haute-Provence) which I have called *D.* aff. *roemeri* (Neumayr and Uhlig). The stratigraphical position of this specimen (above the first *Acanthodiscus*—i.e. Lower Hauterivian) would therefore agree with the English distribution of this genus (Speeton Clay Beds D2D, *amblygonium* Zone and D1, the condensed *amblygonium-noricum* horizon (Rawson 1971b)). On the other hand, "*Acanthodiscus*" *lamberti*

Sayn, which is probably a juvenile stage of an early *Distoloceras,* occurs in the upper part of the *verrucosum* Zone and perhaps slightly above, in the *trinodosum* Zone.

Spitidiscus

Spitidiscus of the *S. rotula* (J. de C. Sowerby) group is widely represented in the Tethyan Province. I have collected a number of specimens of related or different species (Thieuloy 1972) from the upper part of the Lower Hauterivian (*Olcostephanus jeannoti* and *Lyticoceras nodosoplicatum* Zones).

4. Tentative correlation with northwest Europe

In general, the French material is too poorly known to establish accurate, continuous correlations between the zonal schemes of the Tethyan and Boreal Provinces. However, some of the specimens form good horizon markers which have enabled me to make some remarks on particular problems of correlation.

Kemper (1961) has drawn attention to the value of *Platylenticeras* in establishing a Lower Valanginian zonation, potentially of international value. Most certainly, the Tethyan Province was sporadically "invaded" by individuals of this genus, the distribution of which I have specified, but their rarity in the Vocontian province and their total absence in the neritic facies form too serious a handicap for the use of *Platylenticeras* in an international correlation. Be that as it may, the French specimens suggest that the Platylenticeras Schichten include the *pertransiens* Zone and part of the *roubaudi* Zone.

If the above identification of *Pseudogarnieria* cf. *undulatoplicatilis* is correct, the base of the *roubaudi* Zone could be compared with the *undulatoplicatilis* Zone of the Russian Platform and the *posterum* Zone of Kemper (1961).

The various individuals of the genus *Polyptychites* cannot easily be used. However, their stratigraphical position in southeast France is not inconsistent with the distributions that Koenen (1909) and Seitz (1949) published for the north German species. Thus the *campylotoxus* Zone must contain Koenen's (1909) *clarkei* Zone.

The "*nucleus* Zone" of Germany is a well-marked chronostratigraphical unit and many of its macrofaunal elements have been collected in the Tethyan Province. *Saynoceras verrucosum* (? = *S. germanicum* (Koenen)), which is very rare in Germany, is, on the other hand, the fundamental element of the exactly homologous horizon, the *verrucosum* Zone (*sensu* Thieuloy). This index-species occurs in a thin, very characteristic horizon from the pelagic vocontian basin to its neritic margin. It is also in this zone that many juvenile representatives of *Neocraspedites* together with *Valanginites nucleus* and its related forms have been collected. On referring to the German works which deal with the latter taxon, I was surprised to discover that it was found by Struckmann and Koenen only in very limited numbers. I am convinced that this plexus is at least as widespread in the Tethyan Province as in its type-area. Also, I cannot follow Kemper's (1971) proposal that *V. nucleus* should replace *S. verrucosum* as an index-fossil. These two taxa have an apparently identical distribution and *V. nucleus,* in my opinion, has no advantages which would allow it to supplant the priority and customary use of *S. verrucosum.* As formerly conceived, the *S. verrucosum* Zone was too broad, but now that the index-species is known to have a limited vertical range the zone is of value in international correlation.

Dichotomites, which is absent in the *verrucosum* Zone, appears at two horizons in the Tethyan Province: *D. ramulosus* (and *D.* sp. nov. A (juv.)) occurs in the *trinodosum* Zone, which is in complete agreement with its German distribution (Mittleren Dichotomiten Schichten), while *D. bidichotomus* and a *Dichotomites* species with coarse ribbing appear in the uppermost Valanginian (*callidiscus* Zone) associated with rare specimens of *Dicostella.* However, Kemper (1971) believes that the latter morphological type resembles the "Arnoldien" of Stolley, which he identifies as the genus *Neohoploceras* Spath. I do not have a complete knowledge of these German forms but I suspect that they are conspecific with forms of the *N. submartini* group, which I commonly come across in the *verrucosum* Zone. With regard to *Dicostella,* it is advisable to point out that the type-species comes from a condensed faunal horizon and that this genus up to now is known only from very rare examples mostly from the neritic facies. They occur in a continuous sequence near the Valanginian-Hauterivian boundary. I would therefore be inclined to consider the Arnoldien Schichten and my *callidiscus* Zone as homologous, while the overlying Astierien Schichten is as yet not recognised in the Tethyan Province.

In the Hauterivian, comparative evidence becomes rare and the only specimen of particular interest in correlation is the *Simbirskites* (*Milanowskia*) gr. *speetonensis-concinnus* from Allaves. Its association with the first representatives of *Subsaynella sayni* enables one to correlate the base of the *sayni* Zone with the base of the *Simbirskites speetonensis* Zone, these levels corresponding in each province to an important faunal change.

The list compiled here confirms all previous work on faunal exchanges between the Tethyan and Boreal Provinces (Chernova 1951; Marek 1968; Rawson 1971a, 1971b, and see also this volume).

In the Berriasian, faunas were mutually exclusive. It is only in the Lower Valanginian that a regime of faunal exchange was established between the two provinces. This is affirmed in the Upper Valanginian for it was during this period that the number of migrant elements and their specific variety were greatest. Communications were made in both directions, but it appears that the Tethyan area was clearly the richer from the exchanges.

In the Hauterivian, connections were maintained, but the list demonstrates rapid impoverishment and the *Simbirskites* of the *sayni* Zone may have been the last boreal element to reach the seas of southeast France. Isolation of the province is complete in the Barremian, at least as far as this western sector of Tethys is concerned.

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Boreal influences in the Upper Aptian-Lower Albian beds of Normandy, northwest France

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A detailed stratigraphical study has been made of the Aptian-Albian clastic deposits of the coastal cliffs north of Le Havre, Normandy. Direction of cross-bedding, heavy mineral suites of the Sables ferrugineux and ammonite assemblages of the "Argiles a *Bucaillella*" provide evidence of boreal influences during the Upper Aptian (*jacobi* Zone) in the Normandy region. Coarse and condensed sedimentation in the Poudingue ferrugineux testify to drastic regional palaeogeographical modifications during the Lower and Middle Albian. The western margin of the Anglo-Paris Basin tilted progressively eastwards: at the same time, erosion and a profound palaeoclimatic change gave rise to a deposit forshadowing those of the Upper Cretaceous. From the beginning of the Upper Aptian to the end of the Middle Albian, Normandy and the Isle of Wight belonged to neighbouring parts of the northern Anglo-Paris Basin and probably had restricted connections with the southern half of the basin, which remained under Tethyan influence.

Klastische Sedimente von Apt-Alb-Alter, die bei Küstenprofilen nördlich von Le Havre (Normandie) aufgeschlossen sind, wurden sehr intensiv untersucht. Wie aus Messungen der Schrägschichtung und Schwermineral-Analysen an den "Sables ferrugineux", aber auch aus den Ammoniten-Faunen der "Argiles à *Bucaillella*" hervorgeht, bestanden boreale Einflüsse zur Zeit des Oberapt (*jacobi* Zone) im Gebiet der Normandie. Grobkörnige Sedimente und kondensierte Folgen verweisen bei dem "Poudingue ferrugineux" auf drastische Veränderungen der regionalen Paläogeographie im Unter- und Mittelalb. Der Westrand des Anglo-Paris-Beckens wanderte ständig ostwärts. Gleichzeitig verursachte ein tiefgreifender Wechsel der paläoklimatischen Verhältnisse die Ablagerung von Gesteinen, die denen der Oberkreide ähnelten. Vom Beginn des Oberapt an bis zum Ende des Mittelalb gehörten die Normandie und die Insel Wight zu benachbarten Sedimentationsräumen des nördlichen Teiles des Anglo-Paris-Beckens. Dieser Beckenteil hatte nur begrenzte Verbindungen zum Südteil des Beckens, der im Einflußbereich der Tethys lag.

L'étude stratigraphique détaillée des dépôts détritiques aptiens et albiens a été faite dans les falaises côtières situées au N du Havre, Normandie. Les mesures de stratification oblique, les cortèges de minéraux lourds des Sables ferrugineux et l'assemblage d'ammonites des Argiles à *Bucaillella* fournissent les preuves d'influences boréales dans la région normande durant l'Aptien supérieur (Jacobi). La sédimentation grossière et condensée du Poudingue ferrugineux témoigne de modifications paléogéographiques régionales intervenant brutalement pendant l'Albien inférieur et moyen. La bordure occidentale du bassin anglo-parisien bascule progressivement vers l'est; dans le même temps, l'érosion et un profond changement paléoclimatique donnent naissance à un dépôt original annonçant ceux du Crétacé supérieur. Du début de l'Aptien supérieur à la fin de l'Albien moyen, la Normandie et l'île de Wight appartenaient à des régions trés voisines de la partie septentionale du bassin anglo-parisien relativement indépendante de la moitié méridionale restant sous l'influence mésogéenne.

1. Introduction

Lower Cretaceous detrital formations crop out on both sides of the Seine estuary (Normandy); the Upper Aptian-Albian sandy beds rest unconformably on the weathered, eroded and gently folded Upper Jurassic rocks. These first Cretaceous marine deposits show sedimentological and palaeontological characters which allow us to link them to the boreal transgression, the Upper Aptian sediments filling continental depressions in the northeastern part of the Normandy area. At the end of this phase of active sedimentation began a main phase of disturbance, erosion and reworking of the sea-bottom and adjacent land, related to major epeirogenic movements which profoundly modified the western basin shore-line during the Lower and Middle Albian, introducing new sedimentary environments and new biological conditions that foreshadowed those of the Cenomanian.

During the last fifteen years, stratigraphical researches combined with careful sampling and systematic revision of the palaeontological collections have led us to continue the early work of Lennier (1867), first independently, then in collaboration (Destombes 1958; Rioult 1962; Juignet 1971; Destombes, Juignet and Rioult 1973). The present paper aims to describe and interpret the main lithostratigraphical and chronostratigraphical units of the Lower Cretaceous in the Pays de Caux cliffs. A monograph on the Middle Albian stratigraphy of the Anglo-Paris Basin has been published recently: in his description of some Pays de Caux cliff sections, Owen (1971a) pointed to various affinities and differences of sedimentation and ammonite fauna compared with those of the Isle of Wight.

We propose to describe successively the stratigraphy, palaeontology and lithology of the Lower Cretaceous arenaceous formations of Normandy and to discuss the main hydrodynamic relations with the boreal transgression before proceeding to conclusions about the palaeogeographical evolution of the Pays de Caux area during Upper Aptian-Albian times.

The lithostratigraphical succession in the Pays de Caux is as follows:

Upper Cretaceous		Base of Cenomanian: Craie glauconieuse	
		Erosion surface	
Lower Cretaceous	V:	Gaize supérieure	UPPER ALBIAN
	IV:	Gaize inférieure	
	III:	Gault	
		Erosion surface	
	II:	Poudingue ferrugineux	LOWER AND MIDDLE ALBIAN
		Erosion surface	
	Ib:	“Argiles à *Bucaillella* de Cauville”	UPPER APTIAN
	Ia:	Sables ferrugineux	
		unconformity	
Upper Jurassic		Top of Kimmeridgian clays and limestones	

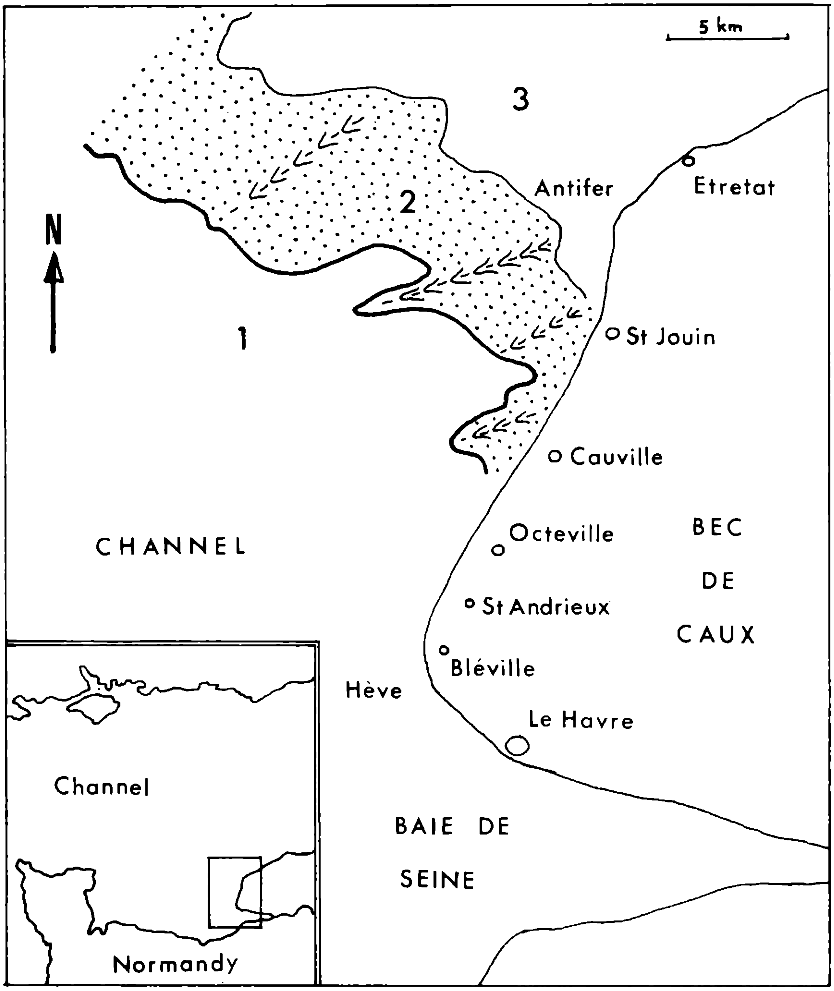

Fig. 1. Sketch-map showing the position of the sections studied in the cliffs and the geology of the adjacent Channel floor.

1. Kimmeridgian limestone.
2. Sables ferrugineux and Poudingue ferrugineux.
3. Gault, Gaize and Cenomanian chalk.

Geophysical studies (Guyader and Lapierre 1972) show four "palaeovalleys" filled with Sables ferrugineux in the erosion surface at the top of the Kimmeridgian.

2. Stratigraphy of the Sables ferrugineux and Poudingue ferrugineux between Le Havre and St Jouin

The Poudingue ferrugineux is seen to be intercalated between the Sables ferrugineux and the Gault clays. Contacts with these two formations are in fact erosion surfaces. We shall describe briefly the Sables ferrugineux and the Gault, and a detailed stratigraphy will be given for the Poudingue ferrugineux (Fig. 2); the different beds are numbered as in the general lithostratigraphical sections of the cliffs, which begin above the beach or at the lower part of the accessible outcrops. The bed-numbers are preceded by the first letter of the locality: they do not correspond from one section to another.

2a. Cap de la Hève (H)

Bed		*Thickness (metres)*
Gault:	black, glauconitic, burrowed marls with quartz pebbles and phosphatised nodules at base.	3·00
	— erosion surface —	
Poudingue ferrugineux:		3·30
H6	abundant quartz gravels and pebbles in a ferruginous, more-or-less hardened, buff, clayey, sandy matrix (2 m). *Isohoplites eodentatus* (Casey), *Otohoplites normanniae* Destombes, Juignet and Rioult.	
H5	abundant quartz gravels with hard, ferruginous, brown and grey, clayey, sandy matrix: basal conglomeratic bed with pebbles and ferruginous or phosphatized nodules (1·30 m). Sandstone nodules with *Leymeriella* aff. *regularis* (Bruguière) and *Hypacanthoplites* sp.	
	— burrowed erosion surface —	
Sables ferrugineux:		about 12·00 visible
H1–4	sands, cross-bedded in middle, clayey, glauconitic and burrowed in upper part.	

2b. Bléville (B)

Gault:	black, glauconitic marl with phosphatic nodules and reworked pebbles and gravels.	3·60
Poudingue ferrugineux:		4·20
B6	abundant gravels and pebbles in a brown, clayey, sandy matrix; fragments of wood and ferruginous concretions at the base (0·60 m).	
B5	abundant gravels and pebbles in a buff, clayey, sandy matrix; purple sandy clay with gravels at the top (1·10 m).	
B4	ferruginous gravels and sand; grey, clayey sand towards the top (0·60 m).	
	— erosion surface —	
B3	clayey, burrowed, brown, ferruginous, poorly-bedded sand with dark grey clay and glauconitic patches; the lower part is conglomeratic with quartz pebbles, ferruginous and phosphatized nodules, and channels and pipes the Sables ferrugineux. Beds of buff and purple clays at the top (1·90 m).	
	— erosion surface —	
Sables ferrugineux:		25·00
B1–2	sands, lower and middle parts cross-bedded, upper part more glauconitic and micaceous with lignite. Base rests on Kimmeridgian.	

2c. Saint Andrieux (A)

Gault:	black, glauconitic marl with phosphatic pebbles.	5·00
Poudingue ferrugineux:		3·00
A12	blackish marl with gravels and pebbles at top (1·40 m).	
A11	abundant quartz gravels and pebbles in buff, ferruginous sand (0·80 m).	
A10	scattered gravels in a brown, sandy, clayey matrix (0·50 m).	
A9	coarse, buff, ferruginous sands with ferruginous sheets and nodules (0·30 m). *Hypacanthoplites* sp.	
Sables ferrugineux:		about 25·00 visible
A1–8	fine, cross-bedded sands with ferruginous, argillaceous pebbles and lignite; the top is more clayey and burrowed.	

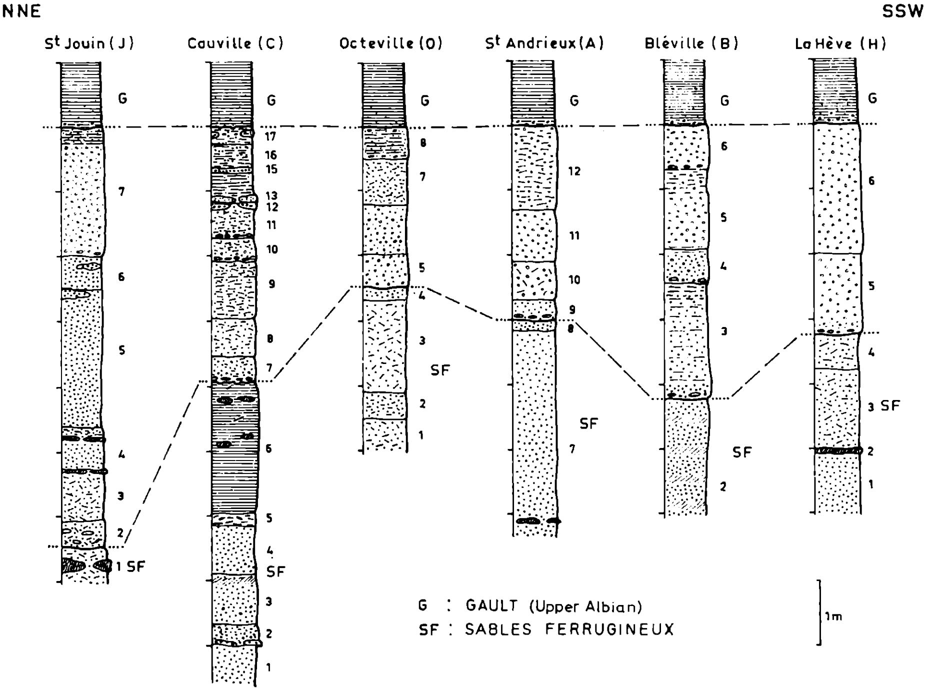

Fig. 2. Lithological variation of the Poudingue ferrugineux between Le Havre and Etretat.

2d. Octeville (O)

		Thickness (metres)
Gault:		4·40
Poudingue ferrugineux:		2·40
08	glauconitic, sandy clay with phosphatic nodules and wood (0·60 m).	
07	yellow and black, burrowed, glauconitic, clayey sand (0·70 m).	
06	soft, glauconitic sand with gravels, passing into fine, yellow sand (0·60 m). *Isohoplites* sp., *Hoplites* sp.	
05	abundant gravels in a hardened sandy matrix (0·50 m).	
Sables ferrugineux:		3·40 visible
01–4	(upper beds only) glauconitic, clayey ferruginous, burrowed sands.	

2e. Cauville (C)

This locality shows the most fossiliferous section of the Poudingue ferrugineux; in addition, the upper part of the Sables ferrugineux shows facies unknown to the south.

		Thickness (metres)
Gault:	clays, very glauconitic	4·00
	— erosion surface —	
Poudingue ferrugineux:		4·20
C17	fine, clayey, glauconitic sand with gravels, phosphatized nodules and wood (0·40 m). Fossiliferous glauconitic sandstone nodules contain *Anahoplites planus* (Mantell), numerous bivalves (*Inoceramus concentricus*) and gastropods. Owen (1971a) reported *Anahoplites splendens* (J. Sowerby) and *Dimorphoplites niobe* Spath from this bed.	
C16	fine, very glauconitic, burrowed sand; black clayey sheet at the bottom (0·50 m).	
C15	yellow, coarse sand (0·05 m).	
C14	glauconitic, sandy marl (0·30 m).	
C13	glauconitic sand and sandstone nodules (0·20 m).	
C12	discontinuous band: iron-coated gravels and phosphatized pebbles in a glauconitic, sandy, hardened matrix (0 to 0·20 m). Fragments of wood, bivalves (*Exogyra latissima*), *Hoplites* aff. *dentatus* (J. Sowerby) and crustacean fragments.	
	— erosion surface —	
C11	grey and buff, coarse, clayey sand with basal conglomerate (0·50 m). *Beudanticeras albense* Breistroffer, *B.* aff. *dupinianum* (d'Orbigny), *B. sanctaecrucis* (Bonarelli and Nagera), *Cleoniceras* (*Neosaynella*) *inornatum* Casey, *Douvilleiceras* sp., *Isohoplites eodentatus*, *I. steinmanni* (Jacob), *Hoplites caletanus* Destombes, Juignet and Rioult, *Lyelliceras vaasti* Destombes, Juignet and Rioult and *Exogyra latissima* in the lower part.	
	— erosion surface —	
C10	grey, clayey, glauconitic sands with gravels; basal conglomerate with large pebbles (up to 30 cm); phosphatized, ferruginous, pyritic nodules and rare ammonites (0·40 m). *Douvilleiceras* aff. *aequinodum* (Quenstedt) at the base.	
	— erosion surface —	
C9	grey and yellow, glauconitic, clayey, burrowed sand (0·80 m).	
C8	pale yellow, coarse sand with grey clayey patches; very glauconitic sand at the bottom (0·60 m).	
C7	gravels in a clayey, sandy, glauconitic, purple matrix; ferruginous nodules and reworked ammonites in the lower bed (0·40 m). *Acanthohoplites* aff. *bigoureti* (Seunes), "*A.*" *pachys* Destombes, Juignet and Rioult, *Hypacanthoplites anglicus* Casey, *H.* cf. *jacobi* (Collet). (Several *Leymeriella* aff. *regularis* probably originate from this level.)	
	— bored erosion surface —	
Sables ferrugineux:		5·20
C6	"Argiles à *Bucaillella* de Cauville": dark grey, sandy, glauconitic clay with scattered gravels, wood, and crustacean remains; two lines of yellow, ferruginous and pyritic, septarian nodules (2·10 m). *Acanthohoplites* aff. *bigoureti*, *Hypacanthoplites rubricosus* Casey, *H.* cf. *jacobi*, *Bucaillella cayeuxi* Destombes, Juignet and Rioult, numerous bivalves (*Longinuculana* sp.), gastropods and fragments of wood in the nodules.	
C5	clayey, burrowed sand with fragments of wood (0·20 m).	
C4	yellow sand with gravels; lenticular beds with clay and glauconite (0·70 m).	
C3	clayey, burrowed, grey and yellow sand; glauconitic patches and gravels at the bottom, cross-bedding and black, clayey sheet at the top (0·80 m).	
C2	quartz gravels and grey sand, ferruginous nodules at the bottom (0·40 m). *Hypacanthoplites* aff. *jacobi.*	
C1	light yellow, glauconitic, coarse sand (1·00 m).	

2f. Saint Jouin (J)

South of St. Jouin the Poudingue ferrugineux crops out above the high beach.

		Thickness (*metres*)
Gault:		about 4·00
	— erosion surface —	
Poudingue ferrugineux:		6·30
J7	coloured quartz gravels and pebbles in dark grey, glauconitic, sandy marl (1·80 m). *Hoplites* aff. *dentatus*, *H.* aff. *bullatus*, *Anahoplites* aff. *intermedius* Spath, *Inoceramus concentricus*, numerous other bivalves and gastropods, fragments of wood.	
J6	fine, yellow sand and ferruginous sandstone (0·60 m). *Douvilleiceras* sp., *Isohoplites eodentatus*, *Hoplites* aff. *paronai* Spath.	
J5	buff, ferruginous sand with gravels and sandstone (2·10 m).	
J4	yellow sand, ferruginous sandstone and black clayey sheets (0·60 m).	
J3	buff and grey, clayey, burrowed sand with ferruginous sandstone at the top (0·90 m).	
J2	dark grey, clayey sand with quartz gravels, phosphatized nodules, ferruginous concretions and wood (0·30 m). *Hypacanthoplites subelegans* Breistroffer.	
J1	dark grey, glauconitic, burrowed sand with sandstone and ferruginous nodules and pieces of wood (0·50 m).	

2g. Stratigraphical discussion

Comparison of the different sections between Le Havre and St. Jouin shows the main lateral facies variations of the Poudingue ferrugineux (Fig. 2). Nevertheless, correlation of the different levels from one section to another is difficult on account of the lenticular nature of the different units and the numerous erosion and channelled surfaces. However, it is possible to distinguish two different areas: southwards, at La Hève, Bléville, St. Andrieux and Octeville, the formation is homogeneous, with reduced thickness and abundant gravels; on the other hand, northwards, from Cauville to St. Jouin, the thickness increases and the clayey fraction is more and more important.

In that area, below the Poudingue the Sables ferrugineux end with the "Argiles à *Bucaillella* de Cauville" and the facies-break is less evident than towards the south. These clays represent the top of the formation fortuitously preserved from erosion: in other places they were eroded away before the deposition of the Poudingue ferrugineux. Palaeontological evidence corroborates this interpretation.

The cliffs near Cauville, north of Le Havre, show the most complete succession, and the following stratigraphical discussion will be based mainly on this locality (Fig. 3).

Macrofossils are absent in the lower half of the Sables ferrugineux and it is impossible at present to be precise about the age of these basal sands. However, several specimens of *Hypacanthoplites* aff. *jacobi* originating in the sandy and ferruginous beds immediately below the "Argiles à *Bucaillella*" indicate the top beds of the Upper Aptian (*jacobi* Zone).

The "Argiles à *Bucaillella* de Cauville" with its fossiliferous septarian concretions, is revealed as an important biostratigraphical unit. The first pebble-bed with derived fossils appears above the eroded top of these clays. Among its ammonite fauna, the primitive hoplitid *Bucaillella* (type-species: *B. cayeuxi* Destombes, Juignet and Rioult), shows close affinities with the boreal genus *Arcthoplites* Spath. *Bucaillella* is a new genus and therefore cannot be used to date the "Argiles de Cauville". It is only possible to establish our conclusions on the associated ammonite fauna. In the Cauville area, *Bucaillella* is always mixed with *Hypacanthoplites* and incomplete ammonites with strong tuberculate costation on inner whorls referred provisionally to "*Acanthohoplites*". The genus *Hypacanthoplites* appears in the *rubricosus* Subzone, near the end of Aptian times, and ranges up

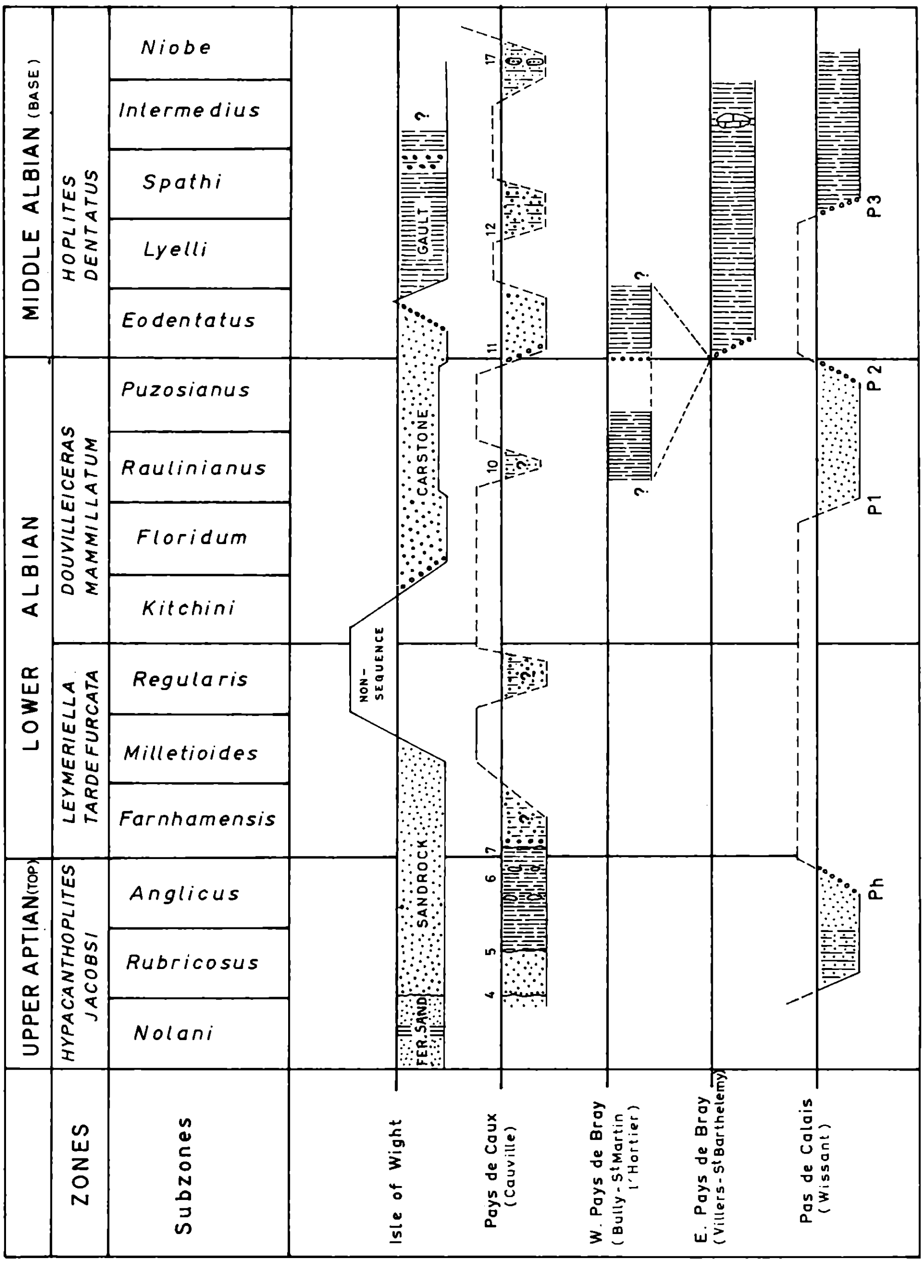

Fig. 3. Age and correlation of the Aptian-Albian beds of Normandy and southern England.

through the whole of the Lower Albian (Casey 1965), but it reaches its acme only in the upper part of the *jacobi* Zone (*anglicus* Subzone) and in the lower part of the *tardefurcata* Zone (*farnhamensis* Subzone). Old records of "*Acanthohoplites*" in Upper Aptian-Lower Albian rocks of southern England relate to the inner whorls of *Hypacanthoplites* according to the recent revision of these genera by Casey (1965). By comparison with the adjacent areas of the Paris Basin, the presence of *Hypacanthoplites* and the absence of *Douvilleiceras* would lead us to consider the age of these clays as post-*rubricosus* and pre-*kitchini*, that is to say earlier than the *mammillatum* Zone. The association of *Hypacanthoplites* cf. *jacobi*, *H. rubricosus* and "*Acanthohoplites*" aff. *bigoureti* in septarian nodules is known in Breistroffer's Clansayesian or in Casey's *anglicus* Subzone. But allied specimens of both *H. jacobi* and *H. anglicus* are also reworked in the first remanié-bed, beside rolled and bored *Bucaillella*, body chambers assigned to "*Acanthohoplites*" aff. *seunesi*, and "*A*". *pachys*, with advanced type of sculpture recalling the costation of *Hypacanthoplites peroni* (Jacob). The type of the last species was collected in the same locality as the phragmocone of *H. milletioides* figured by Casey (1965 p. 432 fig. 159), at the Bois-des-Loges, near Grandpré (Ardennes). No other ammonite genus, and especially neither *Douvilleiceras* nor *Leymeriella*, have been found with these two late *Hypacanthoplites*. Casey chose *H. milletioides* as index of his middle subzone of the *tardefurcata* Zone: in this subzone, the group of *H. trivialis*, of which *H. peroni* is probably a tuberculate offshoot, reaches its acme. Thus, the morphology of the Acanthohoplitinae associated with *Bucaillella* in the pebble-bed suggests a later date than those in the septarian concretions and may be younger than the *anglicus* Subzone. Two small fragments of *Leymeriella* aff. *regularis* may have originated in the same remanié and condensed bed. In this connection we have to remember that several *L.* aff. *regularis* and a nucleus of *Hypacanthoplites* were found in the same derived pebble of ferruginous sandstone at the Cap de la Hève. In consequence, the horizon of the "Argiles à *Bucaillella*" may be restricted to the post-*rubricosus*—pre-*regularis* interval.

The closest comparable fauna is the ammonite assemblage from the *farnhamensis* Subzone of Surrey, which is composed mainly of late *Hypacanthoplites* (groups of *H. anglicus* and *H. milletioides*) together with the ancestral hoplitinid *Farnhamia*, whose apparent endemism is comparable to that of *Bucaillella*; but *Leymeriella* is absent. To conclude, the "Argiles à *Bucaillella*" *s. str.* belong to the *anglicus* Subzone and the terminal condensed pebble-bed should be referred to a time-interval spanning the *anglicus* Subzone (*jacobi* Zone, Upper Aptian) and the *farnhamensis* (? *milletioides* or even *regularis*) Subzones (basal part or the whole of the *tardefurcata* Zone of the Lower Albian).

The genus *Bucaillella* is therefore considered as one of the earlier members of the Hoplitinae, penecontemporaneous with *Farnhamia*, perhaps slightly earlier because of its appearance in the *anglicus* Subzone. The beds containing *Bucaillella* may represent a local subzone in the biostratigraphic scale based on the evolution of the Hoplitidae.

Above this first pebble-bed with *Leymeriella* aff. *regularis*, the Poudingue ferrugineux includes several fossiliferous condensed layers (Fig. 3).

The *mammillatum* Zone seems very poorly represented in the lower part of the formation (bed 10). The assemblage found in bed 11 undoubtedly marks the basal part of the *dentatus* Zone of the Middle Albian: it is equivalent to the lower subzone with *Isohoplites eodentatus* and perhaps of part of the *lyelli* Subzone. A higher position in the *dentatus* Zone is indicated by large specimens of *Hoplites* in bed 12. Lastly, the various *Anahoplites* and *Dimorphoplites niobe* in bed 17 are respectively characteristic of the *intermedius* and *niobe* Subzones, at the top of the *dentatus* Zone (basal part of *loricatus* Zone of Owen). The upper zone of the Middle Albian with *Euhoplites lautus* is not known in our sections, though Lennier (1867 p. 163) recorded "*Ammonites lautus* (Parkinson)", testifying to the presence of the genus *Euhoplites* in the lower glauconitic beds of the Cretaceous cliffs at the Cap de la Hève. Finally, the biochronological boundaries of the Poudingue Ferrugineux are the *regularis* Subzone at the base and the *niobe* Subzone at the top, and its horizon spans the Lower/Middle Albian junction.

Above the eroded surface truncating the Poudingue ferrugineux, the Argiles du Gault (*varicosum* Subzone) and the Gaize (*auritus* Subzone to *dispar* Subzone) represent the Upper Albian (including "Vraconian").

3. Petrology of the Poudingue ferrugineux

Petrological study of the phenoclasts enclosed in the rudaceous seams of the Poudingue ferrugineux shows that the clastic sediments deposited in Normandy during the early Albian originated from an Armorican source nearby. Other sedimentary features of the formation give evidence of its conditions of deposition and of the diagenetic environment.

3a. Nature of phenoclasts—origin of clastic sediments

Siliceous rocks (quartz, sandstones and quartzites, silicified rocks) form the bulk of the reworked material in the conglomerates. Igneous, ferruginous and phosphatic rocks are of secondary importance.

Quartz predominates in gravels and five types have been distinguished in the formation:

(i) Vein quartz, milky white, translucent or dirty green with microscopic sinuous piling of polygonal chloritic spangles: these quartzs are well known in numerous veins cutting the Brioverian shales and greywackes of Manche and Calvados;

(ii) common quartz with solid inclusions (biotite, tourmaline, rutile, zircon with polychroic halos);

(iii) rarer quartz with lines of fluid inclusions or negative crystals;

(iv) pegmatitic phenocrystals of quartz associated with perthitic microcline.

The last three types of quartz are highly characteristic of the Barfleur granites, which occur in both continental and submarine outcrops north-east of the Cotentin peninsula.

(v) pink or reddish quartz with haematitic pitting or crust, very common in the "Couches d'Eroudeville" (Upper Triassic of western Normandy): but this type of quartz, being linked to lateritic pedogenesis, could have acquired its characteristics during one of the Wealden weathering phases.

One cobble of vein quartz injecting sericitic phyllites similar to the Cherbourg-la-Glacerie beds, has been collected in the Poudingue ferrugineux at La Hève.

Among the sandstone suite, Lower Palaeozoic quartzites were the main contributors to the coarse sediments during the Albian, either directly (broken blocks with angular edges) or by reworking of ancient conglomerates such as the thick, uncemented, widespread Upper Triassic fanglomerates (Couches d'Eroudeville). Several derived pebbles and cobbles of "Grès armoricain" (Arenig) or "Grès de

May" (Llandeilo-Caradoc) have been recorded from La Hève and Cauville cliffs, and pebbles of black micaceous sandstones of Armorican Silurian or Devonian pattern from Octeville cliff.

Among the silicified rocks, subsequent weathering has often altered the original characteristics of the mother-rocks. Four types are separated:

(i) sponge-spicule rocks varying from calcarenite with numerous sponge-spicules to pure monaxone, triactine, dichotriaene sponge-spicules felting (spongolith) in chalcedonic cement, with scattered foraminifera (sponge-bottom commensals such as *Spirophthalmidium*, "*Valvulina*", *Paalzowella*, *Nubeculinella* and rare Nodosariidae, *Lenticulina* sp.), mixed with echinoderm ossicles, plates and spines, or thin-shelled bivalvia (such as *Bositra*) (see Fig. 4f, g, h): these various constituents and textures are present in the rocks inaccurately named "Grès du Planet" found in a restricted area of the Bessin (an area between Isigny, Bayeux and Arromanches) at the top of coastal cliffs and offshore.

(ii) a ferruginous and silicified dolomite showing large rhombs zoned with haematite, and with solution cavities filled with silica (peripheral chalcedony and central quartz mosaic) in a distinctive pattern recorded only in the Upper Triassic ("Couches de Neuilly-la-Forêt", Lestre facies) has been found at the Cap de la Hève in association with the following type.

(iii) a silicified argillite with numerous pollen grains and spores in chalcedonic matrix of a type recorded in the Rhaetic Beds outcropping on the land and the Channel floor around the Barfleur granites, in the neighbourhood of silicified magnesium carbonates (Larsonneur and Rioult 1969).

(iv) a silicified calcarenite with ghosts of unsorted oolites and bioclasts, glauconitic or limonitic pellets, shows affinities with a Lower Hettangian limestone, locally silicified, occurring on the plateau southwest of Barfleur (Hommeril and Pareyn 1966) and off-shore from this small harbour.

On the other hand, several erratic cobbles of granite and microcline phenocrysts have been collected at the Cap de la Hève and compared with the Cotentin granites. Constituents of the Barfleur granitic sands are commonly encountered in the Poudingue ferrugineux: quartz, microcline, muscovite and tourmaline from the pegmatitic margins of the massif are highly characteristic.

Ferruginous gravels and pebbles are always deeply oxidized and opaque in thin-section; some of them are weathered glauconitic or pyritic rocks. Phosphatic pebbles are relatively rare and often found in the basal part of the sequences, especially, for example, above bed 7 in Cauville cliffs.

To sum up, the petrological study of phenoclasts in the Poudingue ferrugineux leads one to look for the main source of the clastic sediments deposited in the Pays de Caux during the Lower and Middle Albian in the area of the Barfleur granitic massif and its Mesozoic cover-rocks (Upper Triassic-Jurassic), i.e. in the northeast part of the Cotentin peninsula and adjacent offshore areas. Palaeogeographically, this conclusion appears the most logical on account of the following data:

(i) the rapid diminution of sediment thickness towards this area;

(ii) the shore-line variations and subsequently the direction of littoral currents controlling the distribution of clastic materials;

(iii) the permanent tectonic trends of the northeast margin of the Armorican massif: structural units of Palaeozoic rocks, epeirogeny and subsidence of the northeast margin of the Lower Cretaceous Armorican mainland;

(iv) the grouping of the possible sources in a limited area of Normandy and the adjacent Channel floor.

(v) the relative freshness of many clastic components apparently linked with rapid transportation and the burial of mechanically eroded debris or the clasts reworked from Upper Triassic fanglomerates in this area.

But some of the phenoclasts found in the Poudingue ferrugineux, namely poorly sorted ferruginous and glauconitic sandstones with abundant plant debris, belong either to the formation itself (intraformational erosion) or are derived from indurated, slightly older (Lower Cretaceous) rocks which cropped out nearby. Pebbles of the latter sometimes contain *Leymeriella*, Nuculidae and Pseudomelaniidae. The presence of such reworked pebbles of penecontemporaneous sandstones indicate both the existence of conditions favouring early lithification and strong currents to rework the indurated bottoms during the coarse clastic floods.

3b. Petrological study of consolidated beds in the Poudingue ferrugineux

The salient petrological features of the beds, lenses and concretions of indurated sandstones or conglomerates observed in this formation are:

(i) an obvious heterogeneity of all beds resulting from the mixing of three main classes of clastics: firstly an argillaceous matrix, probably the "normal" deposit, secondly, silt to fine sands with angular grains and thirdly, coarse, more or less gravelly sands with all grades of roundness up to well-rounded grains with a glossy or polished surface.

(ii) comminuted or macroscopic plant remains are abundant and contrast with a faunal scarcity, except for shells of large oysters, some crustacean tests, rare casts of molluscs or echinoids, and occasional vertebrate bones or teeth.

(iii) although invertebrates are often absent the bulk of the beds is, nevertheless, strongly bioturbated.

(iv) glauconite is present, more or less concentrated in layers or seams in the upper part of the formation.

(v) pyrite is sometimes highly developed as a cement.

From these observations it is possible to conclude that:

(i) the Poudingue ferrugineux results from the deposition of periodic discharges of coarse, mechanically-eroded rock-debris with concomitant reworking of the bottoms between more or less long decantation phases, with rare and short winnowing of sediments.

(ii) the depositional environment was marine, but strongly influenced by alluvial deposits in the neighbourhood of the shore-line and close to a land under "rhexistatic" conditions (Erhart 1967).

The proximity of land is confirmed by the abundance of plant remains (Fig. 4i, l), varying from millimetric or centimetric fragments of vegetable tissue, to fragments of roots, stems, branches, fronds, fruits or drift woods bored by teredinids (such tree-trunks drifting along the shores were able to transport stones). The bulk of the wood belongs to the gymnosperms (many abietinean remains, with cones and pebbles of resin); arborescent-ferns and cycadophyta are rarer. The abundance of conifers argues rather in favour of a temperate climate. The importance of the bioturbation is controlled by the richness of organic material, mainly of vegetable origin, in the terrigenous sediments. According to the morphology of the burrows, endofauna, especially crustacean scavengers, played an important part in bioturba-

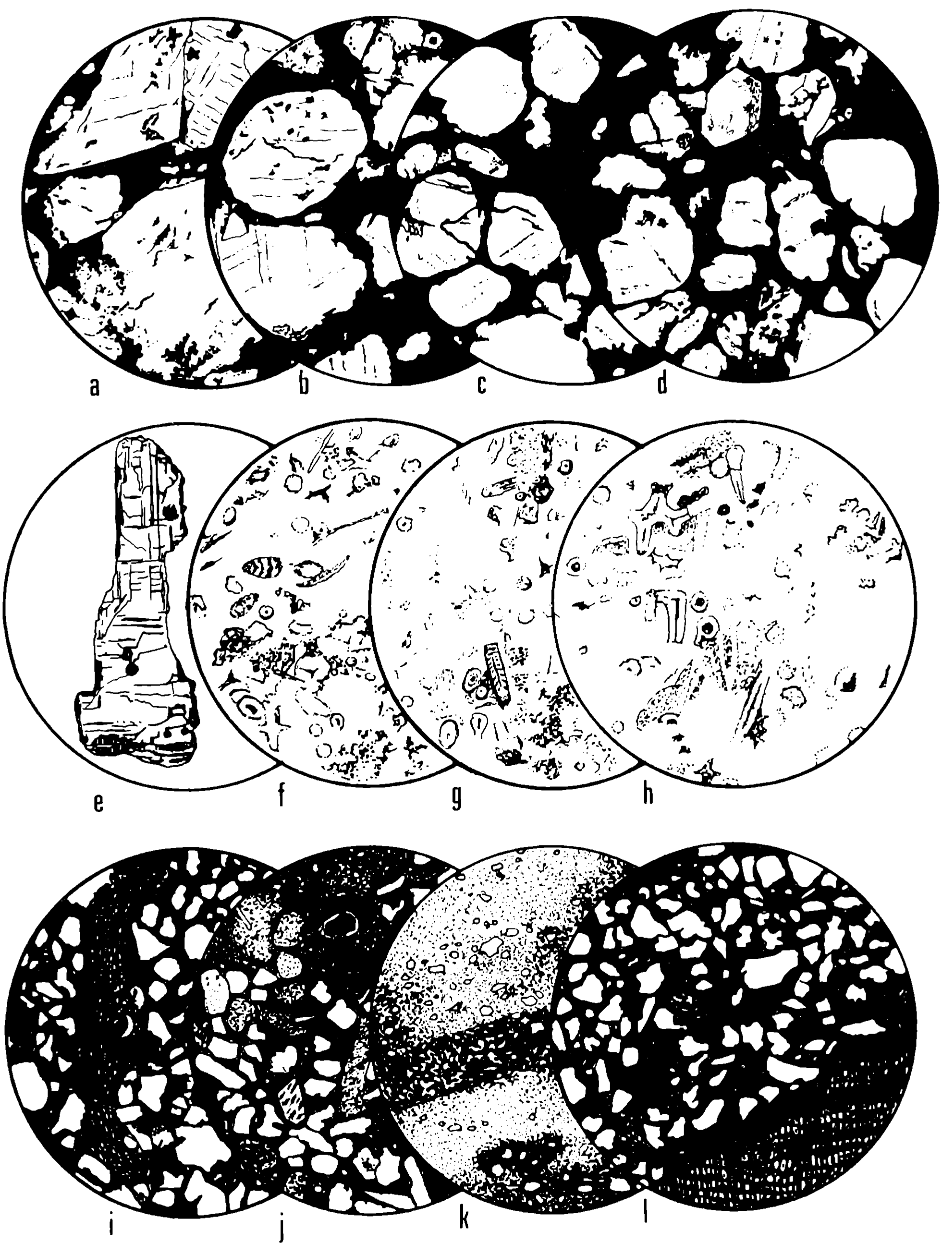

Fig. 4. Petrological and mineralogical studies of the Sables ferrugineux and the Poudingue ferrugineux.

a,b very coarse facies of pyritic sandstone with fresh (a) and rounded (b) quartz grains. Poudingue ferrugineux, La Hève (bed 6).

c, d coarse facies of pyritic sandstone with euhedral (d) or well-rounded (c) grains. Poudingue ferrugineux, Cauville (bed 10).

e typical kyanite grain from Sables ferrugineux, La Hève (bed 1) (compare with Rastall 1919).

f-h three facies of silicified spongolithic pebbles. Poudingue ferrugineux, La Hève (bed 5–6).

i ferruginous sandstone with well-preserved plant remains and *Leymeriella*. Poudingue ferrugineux, La Hève (bed 5).

j glauconitic sandstone. Poudingue ferrugineux, Cauville (bed 10).

k bioturbated glauconitic mudstone. Poudingue ferrugineux, Cauville (bed 6).

l ferruginous sandstone with sideritized wood. Poudingue ferrugineux, La Hève (bed 5).

All drawings: x 20, except 4e: x 15.

tion. Epifauna occurs on oysters, and numerous thick shells, often bivalve, are bored by the sponge *Cliona*. Both are good indicators of the upper part of the infralittoral zone, i.e. of very shallow littoral waters, during deposition.

The poverty of the fauna is related to the peculiar living environment and to diagenesis. Because of the rich organic content of the sediments interstitial water would be relatively acid. Such conditions were only favourable to a small number of species, albeit represented by numerous populations. During burial, solution of $CaCO_3$ took place in the skeletons and tests lying in acid waters and this could partially explain the rarity of fossils.

Pyrite formed in optimum conditions in these iron-rich clastic deposits containing organic matter decaying under anaerobic conditions. Rapid burial prevented oxidation, but during diagenesis the pyrite became segregated. Now, pyritized plant remains are restricted to the clayey or silty seams. Pyrite is common in argillaceous or sandstone slabs and in septarian concretions, in which it constitutes the heart and lines all cracks. Often it gives to the pyritic rocks the aspect, density and hardness of cast-iron, especially in the lower half of the formation in the Cauville and St. Jouin cliffs. Lastly, pyrite cements many coarse sandstone lenses, encasing every clast, filling all anfractuosities and slits in quartz or felspar grains (Fig. 4a–b): this pyritic sandstone is more frequent at the top of the Poudingue ferrugineux at the Cap de la Hève and at Cauville (bed C11). However, wood and other plant remains (Fig. 41) were sometimes fossilized by siderite, which also locally cemented the mudstone concretions: the siderite is now partially altered to limonite.

Green glauconitic minerals are represented by lobate or cracked grains, some with a strongly limonitised brown surface and others showing sections with fibrous, radial and yellowish aureole and with an aggregate-pattern under polarized light (Fig. 4j). Variations of pH and Eh on marine bottoms were propitious to the formation of glauconite in the presence of the rich iron, argillaceous and organic contents of the deposits. But chamosite also probably formed in conglomeratic lenses at the top of the Poudingue ferrugineux (bed C12) in the Cauville cliffs, where argillaceous, phosphatic invertebrate (crustacean? molluscan?) faecal pellets, ovoid or in a flattened ribbon bearing axial swelling, show all tinges from light bluish-grey to dark bluish-green. A mineralogical study of these is in progress.

These data complement the previous conclusions based on the petrological study of the phenoclasts and give more details about the conditions of deposition and the diagenesis of the Poudingue ferrugineux: in particular, the proximity of land, shallow water and rapid burial of sediments are confirmed.

Palaeontological assemblages and geochemical palaeotemperature measurements suggest that after a cooler climate through the Upper Aptian, there was a subtropical climate during the Albian in the Anglo-Paris Basin.

4. Sedimentological study of the Sables ferrugineux and Poudingue ferrugineux.

4a. Grain-size analysis

Near La Hève and Octeville, in the southern area, the Sables ferrugineux are usually fine-grained and well sorted; on the other hand the Poudingue ferrugineux is coarse and gravelly (38 % rudites, 54 % arenites, 8 % lutites) throughout, and very badly sorted; blocks and pebbles occur at the base and the top.

In the northern area, at Cauville, the upper part of the Sables ferrugineux (beds

1, 2, 3, 4) is coarser and less well sorted than at La Hève; the upper part (bed 6: Argile à *Bucaillella*) shows a clayey facies unknown towards the south where it has probably been eroded. In the Poudingue ferrugineux of the northern area, the coarse detrital material is scattered in an abundant clayey matrix foreshadowing the Gault facies.

In both areas, the overlying Gault is a clayey, glauconitic, bioturbated deposit with a more or less important reworked horizon of the Poudingue at the base.

Table 2. Grain size analysis parameters

		Mdmm	Mdφ	x	P84	P16	σ68	αP
PF	La Hève	0·1	−0·2	+0·05	+1·8	−1·7	17·5	−0·3
	Octeville	0·15	+2·8	+2·5	+3·0	+2·0	0·5	−1·8
	Cauville	0·67	+0·6	+1·3	+2·8	−0·2	1·5	+1·4
	St. Jouin	0·38	+1·4	+0·75	+3·3	−1·8	2·55	−0·8
	St. Jouin	0·34	+1·6	+1·35	+2·0	+0·7	0·65	−1·0
SF	La Hève	0·22	+2·2	+2·0	+2·6	+1·4	0·6	−1·0
	Octeville	0·22	+2·2	+2·05	+2·2	+1·9	0·15	−3·0
	Cauville	0·70	+0·5	+0·8	+1·8	−0·2	1·0	+0·9

SF: Sables ferrugineux. PF: Poudingue ferrugineux. Md mm: Median in mm. Mdφ: Median in φ unit. x: Mean. P 84 and P 16: Percentiles 84 and 16. σ 68: Dispersion for 68% of the sediment. α P: Asymmetry index of Pearson (all these parameters in φ unit.)

4b. Morphoscopy

At La Hève, the Poudingue contains many pebbles. Morphoscopical study applied to the quartz pebble fraction between 21 and 30 mm shows a blunt index $\frac{2r}{L}$ varying between 77 and 381 with a median of 235, and a flattening index $\frac{(L+1)}{2e}$ varying between 118 and 300 with a median of 182. According to the diagrams of Tricart, these values characterise a fluviatile facies.

The morphoscopical study of the sandy fraction of the Poudingue ferrugineux was made on three grain-size classes; the grain erosion was estimated by comparison with the visual chart of Krumbein and Sloss, and the state of the surfaces was examined. The results are summarized in Table 3.

Table 3. Sand morphoscopical analysis of the "Poudingue ferrugineux"

	Size in mm	0·2—0·5	0·5—1	1–2
shape %	spherical	1	0	3
	ovoid	3	5	14
	round	23	38	45
	rounded corners	51	55	37
	non-eroded	22	2	1
surface aspect %	mat glazed	50	75	56
	mat	6	13	43
	shiny	16	7	0
	pricked	20	3	1
	without patina	8	2	0

Interpretation of these results shows that the grains were weakly or moderately eroded, the erosion increasing with the size.

For most of the material, the erosion features were acquired in a continental environment (frequent wind patina) with superimposed marks of fluviatile and marine reworking.

4c. Calcimetry

Parts of the Poudingue ferrugineux are hardened and cemented by iron oxide, and others by calcium carbonate which may be present for 15% to 20%. Even in soft clayey beds calcium carbonate is present and at La Hève there is 30% in the lutite fraction (less than 50 microns).

So, the Albian Poudingue appears to represent a mixing of two phases: the clayey, glauconitic, carbonate phase represents fine marine sedimentation related to the characteristic features of the Albian basin; the coarse detrital phase with coarse sands, gravels and pebbles corresponds to an overflow of continental material unloaded from the west and related to an epeirogenic uplift movement of the northern part of the Armorican land mass; during its deposition this formation channelled and reworked the underlying Aptian beds decreasingly towards the open sea.

4d. Mineralogy

(i) *Sables ferrugineux.* This formation locally contains beds with white, grey or black quartz gravels and pebbles (see Cauville, bed 2). The usual facies is a fine quartzose sand with a variable percentage of glauconite emphasizing the bedding. Felspar are not common but muscovite is frequent and associated with more or less altered biotite.

Table 4. Heavy minerals from the "Sables ferrugineux"

	1	2	3	4	5	6	7	8	9	10	grain size microns
Hève	3	14	50	1	15	15	1	—	1	—	50–500
Hève	tr.	62	tr.	15·6	8	13·2	tr.	—	—	—	160–500
Bléville	10	10	51	1	14	13	1	—	—	—	50–500
Bléville	5	17	42	—	22	12	1	—	—	—	50–500
Bléville	1	60·5	2	5	16	15	—	—	—	—	160–500
St. Andrieux	11	8	56	—	15	7	—	—	1	—	50–160
St. Andrieux	—	42	2	5·5	28	22	—	—	tr.	—	160–500
Octeville	10	9	60	0·3	13	4	2	0·5	—	0·3	50–500
Cauville	10	9·1	62	tr.	12·3	4	1·5	0·5	—	0·5	50–500
Cauville	—	65	5·7	15	10·7	2·9	tr.	—	—	tr.	160–500
Cauville	2	64	8·7	16	2·7	4·7	tr.	—	1·3	—	50–500

1: rutile. 2: tourmaline. 3: zircon. 4: andalusite. 5: kyanite. 6: staurolite. 7: garnet. 8: amphibole. 9: anatase. 10: brookite.

Heavy mineral suites contain 25% to 50% of metamorphic minerals. Ubiquitous minerals are always prevalent (zircon and rutile between 50 and 160 microns, tourmaline between 160 and 500 microns).

In the metamorphic mineral assemblages, kyanite is often the commonest (mean 14·2%) and is represented by large, elongate, angular, little-worn plates with well defined cleavages (Fig. 4e); some distinctive varieties may be fibrous or bent and some are light green. Staurolite (mean 10·2%) is less frequent than kyanite and shows heterogeneous varieties: dark orange colour with marked pleochroism, light yellow with numerous black inclusions, well-rounded or tooth-edged (Pomerol 1965) and some vermiculate species (Vatan 1950).

Andalusite grains (mean 5·4%) are large and weakly pleochroic with carbonaceous inclusions. Garnet is not frequent (mean 0·6%) but occurs as colourless and angular grains. Significant horizontal and vertical variations are not evident but the prevalence of kyanite over staurolite increases in the upper part of the formation.

(ii) *Poudingue ferrugineux.* At La Hève, the gravel fraction of the Poudingue contains 75% quartz and 25% of the same petrographical varieties as those described in the pebble analyses.

The sandy fraction, mainly quartzose, contains a variable percentage of glauconite (up to 5%). Muscovite is often abundant and biotite not rare; felspars are not common. The heavy mineral suites are dominated by ubiquitous species (zircon and rutile or tourmaline). Several varieties of tourmaline may be distinguished, particularly an iron tourmaline (schorlite) with blue-pink pleochroism closely resembling the tourmaline of parts of the Barfleur granite (Cotentin) and of associated pegmatites. Angular and cracked, corroded kyanite grains are common; staurolite shows numerous varieties; andalusite grains are large. Table 5 shows the heterogeneity of the Poudingue and the variability of the heavy mineral suite.

Table 5. Heavy minerals from the "Poudingue ferrugineux"

	1	2	3	4	5	6	7	8	9	10	grain size μm
Hève	—	91·5	tr.	5	1	1·5	1	—	—	—	160–500
Octeville	13·5	13·1	50·5	0·4	4·5	1·9	13·8	0·2	0·7	1·4	50–500
Cauville	—	86·5	1	6·5	—	5	1	tr.	—	—	160–500
Cauville	6·8	14	50	0·2	14	11·6	2·8	0·5	0·2	—	50–500
St. Jouin	6·3	14·4	32	—	10·4	0·8	32·8	0·8	0·8	1·6	50–200

(symbols as in Table 4.)

Montmorillonite is dominant over illite in the clay fraction of the Poudingue as in the Gault.

4e. Cross-bedding

The Poudingue ferrugineux is poorly stratified and shows no cross-bedding.

On the other hand, cross-stratification is common in the Sables ferrugineux, either planar or trough cross-stratification. Thickness of the cosets varies between 0·10 and 1·00 metres in the Bec de Caux; southwards in the Pays d'Auge, cosets are locally more than 2 metres thick. In both areas, the orientation of hundreds of cosets has been measured (Juignet 1971). Around Le Havre, two main current directions occur: 170° and 230° with a mean 210°, a value which also appears in the orientation of trough channels. In the Pays d'Auge, mean current direction is 70° in the lower part and 140° in the upper part. Herring-bone cross-stratification is rare near Le Havre but common in the Pays d'Auge.

5. Depositional environment and source of the Upper Aptian—Lower Albian detrital formations of Normandy and eastern England

5a. Current directions

In England, orientation of cross-bedding has been measured in the Woburn Sands north of London, and in the Folkestone Beds to the south. In East Anglia, between Hunstanton and Leighton Buzzard, currents came from the north (Schwarzacher 1953). In the Weald, currents from the northwest have a mean orientation of 144° (Wells, Taylor and Gossling 1947, Middlemiss 1959, 1962a, Narayan 1963). In the Boulonnais (France), Narayan (1963) found two main directions: 133° and 330°.

These data are summarised on Figure 5 (map c). It appears that the London Platform, which separated a northern and a southern basin during the Lower Aptian, did not influence current directions at the end of the Aptian period. Owen (1971b) showed that in borings near the Thames estuary, on the southern part of the London Platform, the Lower Greensand is present between the Palaeozoic or Jurassic basement and the Gault: the sands are 1·5 to 10 metres thick and are correlated with some part of the Folkestone Beds: the erosion surface at the top of these sands may explain their local disappearance. Therefore, on our palaeogeographical sketch of the *jacobi* Zone (Fig. 5c), we suppose that the western part of the London Platform was submerged. It appears that the general current direction extended southwards and affected Normandy.

5b. Source of heavy minerals

There have been numerous heavy mineral studies of the Aptian/Albian detrital formations in England (Rastall 1919, 1930; Versey and Carter 1926; Boswell 1928; Wood 1956; Pomerol 1965) and France (Pomerol 1961, 1965; Juignet 1965, 1971; Juignet *et al.* 1966, 1967; Okhravi 1965). All the authors have underlined the high percentage of kyanite and staurolite and the prevalence of the former mineral in the Folkestone Beds and the Carstone and their equivalents in France. The kyanite content reaches a maximum of 36% in the Folkestone Beds of the Weald, 37% in the Pays de Bray, 28% in the Bec de Caux, 28% near Pont Audemer, 24% near Villequier, 18% near Lisieux; such high ratios also occur in the Carstone of Norfolk and Lincolnshire. In all these places, kyanite grains are large, angular and little worn. It seems that they represent a rapid arrival of new material with a limited inheritance. The staurolite group is very heterogeneous with freshly eroded angular minerals (dark orange variety) and others which seem to have been reworked from underlying formations.

The mineralogical studies have always associated the two mineral species and concluded that the couple kyanite+staurolite came from the Armorican Massif (Vatan 1938; Wood 1956; Pomerol 1965). We think it is better to consider the two minerals separately. It appears that the formations in direct dependance of the Armorican Massif (e.g. Wealden of Bray and the Isle of Wight, Cenomanian of Maine) contain a high ratio of staurolite but little kyanite. The widespread sands of the Upper Aptian in Normandy and the sands and grits of the Upper Aptian/Lower Albian in eastern England contain an abundance of kyanite that gives evidence of the intervention of a new source of material. We think, as already suggested by Allen (1967), that a Scoto-Scandinavian province (Caledonian area) fed the *jacobi* Zone transgression (Juignet 1971). The sudden increase in kyanite

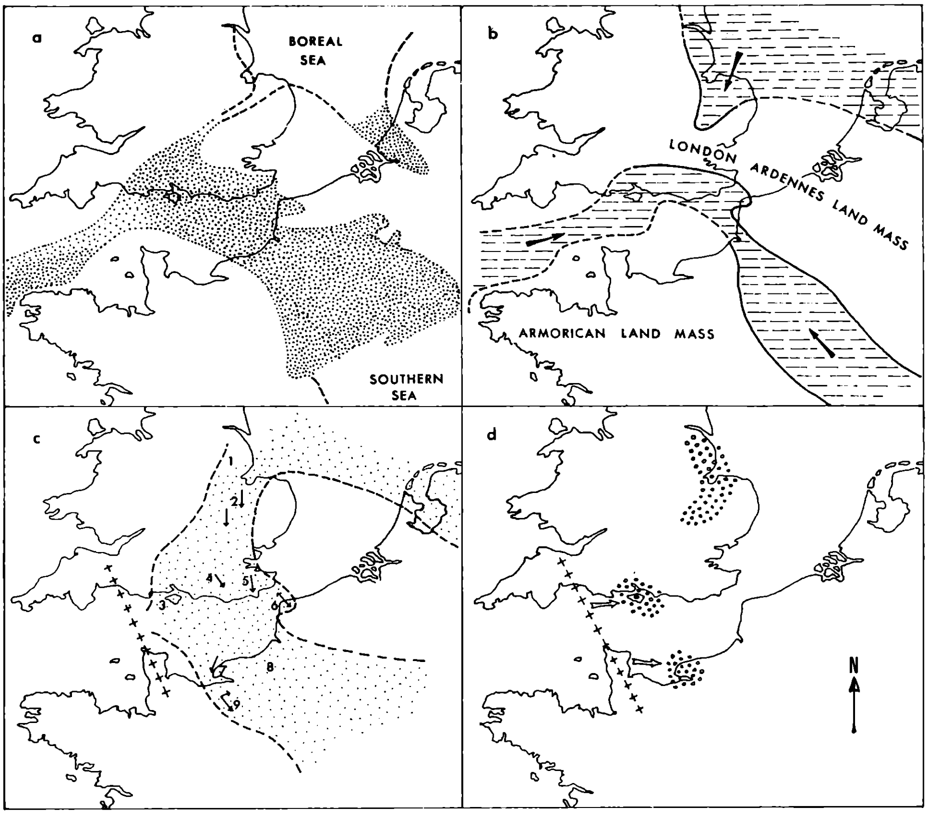

Fig. 5. Lower Cretaceous paleogeography.

a. Wealden deposits (Hastings facies)
(after Allen 1967; Boillot *et al.* 1972; Andreieff *et al.* 1972).

b. Lower Aptian (*Deshayesites deshayesi* Zone)
(after Middlemiss 1962b).

c. Upper Aptian (*Hypacanthoplites jacobi* Zone)
Upper part of Lower Greensand and Sables ferrugineux. Mean current direction indicated by arrows; the "London platform" is partly submerged. Localities: 1 Lincolnshire; 2 East Anglia; 3 Isle of Wight; 4 Western Weald; 5 Eastern Weald; 6 Boulonnais; 7 Bec de Caux; 8 Pays de Bray; 9 Pays d'Auge.

d. Carstone facies and Poudingue ferrugineux
Uplift of a Cotentin-Devon ridge indicated by line of crosses; the arrows indicate the sources of pebbles.

content would be ascribed to the overflow of a barrier (London-Ardennes landmass, Fig. 5b, c) by the advancing boreal transgression.

The mineralogical composition of the Lower-Middle Albian Poudingue ferrugineux is more difficult to interpret; the reworking of underlying sands is important and, besides, there is locally a high garnet ratio. The coarse fraction proves a feeding from the western continental areas, more probably around the Cotentin. The clay fraction foreshadows the Gault. In many places, in England as well as in France, condensed deposits occur during this period.

This sedimentological analysis shows that both the general current directions and the heavy mineral suites confirm the extension of boreal influences towards Normandy during the Upper Aptian. The spread of a transgressive shallow sea covering part of the London Platform and Normandy contrasts with the earlier partition of the basins (Fig. 5b, c).

The local facies of the Poudingue ferrugineux and of the Carstone of the Isle of Wight indicate a different environment in the south during the Lower Albian; this resulted from an increase of erosion of the northern part of the Armorican Massif due to the uplift of a southeast-northwest Cotentin-Devon axis (Fig. 5c, d).

6. Palaeogeographical evolution of the Normandy region during the Aptian and Albian

During the Lower Cretaceous the palaeogeography of the northeastern margin of the Armorican continental area was profoundly modified. As part of the mainland which emerged during the Portlandian regression, it was progressively invaded by marine waters in Upper Aptian and Albian times.

The distribution of land and sea during the Lower Aptian is outlined below and the palaeogeographical evolution of the Normandy region within the framework of the Anglo-Paris Basin is then summarized.

6a. Regional palaeogeography at the beginning of the Aptian

At the end of the Portlandian the sea receded from the Anglo-Paris Basin to a northeasterly position between England and Scandinavia. New areas of dry land were chemically and mechanically eroded under rather warm climatic conditions. Non-marine deposits of Wealden facies (Hastings Beds type) were then laid down in depressions of the continental surface, especially in the western Channel area, the north-central Channel, the south of England, the eastern Channel and the Boulonnais, the Pays de Bray and the southeast part of the Paris Basin (Fig. 5a).

At the beginning of the Aptian (Fig. 5b) the now emergent Normandy area was bordered on the north and northwest by a marine tongue which protruded from the primitive North Atlantic Basin and crossed the western Channel, flooding southern England. This hypothesis is supported by the appearance above the Wealden in this last area (Atherfield Clay) of marine faunas which probably came by this route (Middlemiss 1962b). Eastwards an arm of the Tethys advanced and retreated across the Paris Basin; during the Hauterivian it covered the Pays de Bray for a short time and later, towards the end of the Lower Aptian, it invaded the areas of subsidence. The Normandy land drainage was linked with these two arms of the sea, newly established over two areas characterized by a high post-Hercynian tectonic sensitivity.

The seas progressively penetrated the ancient river system. According to recent seismic researches made along the coast (Fig. 1) (Guyader and Lapierre 1972) palaeovalleys in the Pays de Caux, cut in the Kimmeridgian clays and limestones and filled with Aptian arenaceous formations, are orientated perpendicularly to the marine strait of the Pays de Bray. On the other hand, the Lower Cretaceous deposits quickly thicken eastwards, from a sharp change of slope, a kind of palaeoflexure, situated approximately under the present valley of the River Risle (Juignet 1971). During this time, the boreal sea reached northeast England and a wide gulf skirting the London Platform advanced towards the convergence area of the two other seas towards Normandy.

6b. The Upper Aptian transgression in the Normandy region

In Normandy the Lower Cretaceous deposits are clearly uncomformable on the Jurassic rocks. Westwards, the Aptian-Albian clastic deposits lapped on to progressively older outcrops of the post-Jurassic continental surface: Kimmeridgian in the Pays de Caux, Callovian-Oxfordian in the Pays d'Auge, Bathonian-Bajocian in the Campagne de Caen. Arenaceous beds of presumed Albian age, underlying the silicified sandstones and limestones with *Orbitolina concava*, were deposited on Liassic or directly on Palaeozoic rocks in the Cotentin peninsula. In the estuary of the River Seine the Upper Jurassic rocks are thrown into large parallel folds; their eroded surface beneath the Lower Cretaceous sands seems locally undulating. It is difficult at present to date these local deformations: initially a phase of folding took place in pre-Upper Aptian times and this was followed by a phase of warping, probably related to epeirogenic movements known to have occurred during the passage from Lower to Middle Albian and to the abrupt coarsening of sedimentation (Rioult 1962).

During the Upper Aptian the confluence of the boreal gulf with the two sea-arms linked to the proto-North Atlantic and the Tethys led to wide flooding of the adjacent lands. The western part of the London Platform was probably submerged. This transgression appears to have been slow and placid and is not marked by a basal conglomerate in Normandy. Marine currents distributed fine arenaceous deposits on the weathered post-Jurassic peneplain. Cross-bedding measurements in the Upper Aptian sands of Normandy show a dominant southwards pattern of currents. The heavy-mineral suites prove northern sources of supply of sediments: among the metamorphic constituents, kyanite is typical in the Upper Aptian (and Lower Albian) sediments from southern England to Normandy, and picks out the line of littoral drift. After periodic winnowing of the sands, decantation began and argillaceous deposits appear in the depositional environment.

The major lithostratigraphical units were thus formed: at the base the sands of the Sables ferrugineux, cross-bedded, generally well-washed and sorted, light-coloured sands with various grain sizes; above, the clay facies, the "Argiles à *Bucaillella*", grey clays with silty or sandy seams, revealing quiet local conditions favourable to fossilization and the formation of septarian nodules. The poor benthonic fauna is usually preserved as numerous small specimens of a few species (crustaceans, nuculids and mytilids, pseudomelaniids); ammonites are rare. Plant remains are mainly gymnosperms, abietinean woods and cones, indicators of climatic conditions that were temperate rather than subtropical, that is to say of relative cooling of the atmospheric temperature.

This first Cretaceous sedimentary sequence is truncated abruptly by an erosion surface marking the beginning of the Albian.

6c. Palaeogeographical interpretation of the Poudingue ferrugineux (and of the Carstone)

The sharp interruption of the quiet depositional conditions shown by the "Argiles à *Bucaillella*" and the strong erosion of its upper surface marked the start of epeirogenic movements which maintained instability during the whole of the period of deposition of the Poudingue ferrugineux, up to the end of the Middle Albian. The beds show evidence of reworking, condensation and non-sequences. The palaeogeographical distribution of coarse clastic sediments, the Poudingue ferrugineux and its lateral equivalent in England, the Carstone, was clearly restricted to the Pays de Caux, the Isle of Wight and the northeast of England

(Yorkshire, Lincolnshire, Norfolk) in the northern part of the Anglo-Paris Basin (Fig. 5d). This localisation of such a coarse formation bear evidence of drastic modifications in pedogenesis and hydrodynamics. Strong currents charged with coarse materials (sands, gravels, pebbles, cobbles and blocks) torn from the land and from the sea bottom reached some parts of the marine basin. This rock debris was brought mainly from the western coast: from the Cotentin peninsula and the Baie de Seine to the Pays de Caux and from the Western Channel bottoms, Cornwall and Devon to southern England (Isle of Wight). These coarse clastic supplies arrived subsequent to the boreal transgression and its cooling of temperature, but are related to epeirogenic movements which affected mainly the western margin of the basin along an axis approximately orientated northwest-southeast and joining the Cotentin to Devon.

Eastwards, subsidence increased towards the long axis of the Anglo-Paris Basin; westwards the opening and deepening of the North Atlantic Basin was in progress. A general eastwards rocking motion of the western margin of Anglo-Paris Basin took place during the Lower and Middle Albian. On account of the size of the phenoclasts, a spasm may be adduced as having taken place in the *dentatus* Zone (between *eodentatus* and *spathi* Subzones), but the disturbance began earlier, in the *tardefurcata* Zone, and was again quite strong during the *mammillatum* Zone according to the fossil fauna and sedimentation. The folds observed in the south of England are considered to be of *tardefurcata* Zone age (Casey 1961). During these times, connections between the Anglo-Paris Basin, the proto-North Atlantic and the boreal sea were reduced and those between the Anglo-Paris Basin and the Tethys increased. The uplift of the western margin gave a new relief and brought large areas under erosion, providing new sources of coarse materials. Active "rhexistasis" (Erhart 1967), resulting from important climatic changes following the boreal transgression, brought profound modifications in vegetation and abundant plant remains to the sediments. Step by step, the shore-line advanced and open sea influences reached the Normandy region. The Poudingue ferrugineux, as also the Carstone, presents intermediate characteristics of sedimentation, extending the Lower Cretaceous pattern and yet announcing certain Upper Cretaceous types of deposits. Following the Upper Aptian cooling of the climate, new ecological niches opened during the Lower and Middle Albian steps of the transgression with new evolutionary trends being expressed among the marine fauna. Thus, in the top beds of the Poudingue ferrugineux inoceramid and pectinid associations appear which evolve through the whole of the regional Upper Cretaceous formations.

A general westwards flooding in the direction of Dorset-Devon area or the Cotentin peninsula was initiated during the eastwards rocking motion of the western margin of the Anglo-Paris Basin. During Aptian and Albian times the Normandy region always remained within the province which included the Isle of Wight and south Dorset, while the Pays de Bray showed closer affinities with the southeast part of the Paris Basin, and the Boulonnais with the southeast of England (Fig. 5c). But a constant diachronism existed between the two sides of the present English Channel, sharp depositional changes always appearing earlier in the Isle of Wight succession and its echoes reaching the Pays de Caux generally one or more zones later. The first post-Wealden marine deposits appear in the Upper Aptian of the Pays de Caux. In the southern part of the Isle of Wight the Carstone begins with the *kitchini* Subzone and ends with the *eodentatus* Subzone; the Gault facies starts with the *lyelli* Subzone. In the Pays de Caux the Poudingue ferrugineux facies appeared late in the *regularis* Subzone and disappeared after the *niobe* Subzone;

the clay facies of the Gault commenced with the *varicosum* Subzone (Fig. 3). The apparent absence of the *loricatus* and *lautus* Zones in the Pays de Caux marks an important erosion phase at the end of the Middle Albian, already recorded in southern England and the Anglo-Paris Basin (Spath 1943; Owen 1971a). The Middle Albian subzones are more easily recognisable in the Isle of Wight than in the Pays de Caux, where the beds are condensed, but during this time the argillaceous Gault facies was well developed in the Pays de Bray, as also southwards over most of the Albian stratotype region. Beginning with the Upper Albian, marine conditions became more uniform over the northern part of the Anglo-Paris Basin.

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The Valanginian and Hauterivian stages in northwest Germany

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The first part of this paper gives a brief description and definition of the Lower Saxony Basin. The basin had only relatively narrow connections with neighbouring seas of the boreal basin system, which at times resulted in limited water and faunal exchanges. In the more strongly subsiding parts of the basin over 2,000 metres of Lower Cretaceous sediments were deposited. However, most of these strata were denuded after the "inversion" of the basin during the subhercynian orogeny. The second part of the paper deals with the Valanginian and Hauterivian strata, their subdivision, palaeoecology and facies. Special attention is paid to regions where these strata crop out.

Im ersten Teil der Arbeit wird eine Kurzbeschreibung und Definition des Niedersächsischen Unterkreide-Beckens gegeben. Das Becken hatte nur relativ schmale Verbindungsstraßen zu den benachbarten Becken des borealen Beckensystems. Das führte zu einigen Besonderheiten: zu zeitweilig begrenztem Wasser- und Faunen-Austausch. In den stärker absinkenden Teilen des Beckens kamen mehr als 2,000 meter Sedimente der Unterkreide zur Ablagerung. Der größte Teil der Beckenfüllung wurde jedoch nach der subhercynen Inversion des Beckens wieder abgetragen. Im zweiten Teil werden Abgrenzung, Unterteilung, Oekologie und Fazies von Valangin und Hauterive geschildert.

La première partie de ce travail est une description rapide et une définition du Bassin de Basse-Saxe au Crétacé inférieur. Les connections de ce bassin avec les mers environnantes du domaine boréal n'étaient que relativement étroites et en conséquence leurs échanges marins et fauniques étaient parfois limités. Dans les secteurs les plus fortement subsidents de ce bassin, plus de 2 000 mètres de sédiments se sont déposés; toutefois, la plus grande partie de ce remplissage fut déblayée au cours de l'inversion orogénique subhercynienne. La seconde partie traite des limites, des subdivisions, de la paléoécologie et du faciès des couches valanginiennes et hauteriviennes. Les régions où affleurent ces couches sont l'objet d'une attention toute particulière.

1. Introduction

Lower Cretaceous sediments are widely distributed in northwest Germany, though generally covered by younger strata. The Lower Cretaceous rocks are of considerable economic importance as they contain the largest known oil-accumulations of the country. The sediments have therefore been penetrated by many boreholes during oil exploration. The results of the study of these occurrences have been published by the Geological Survey of the Federal Republic of Germany (Bundesanstalt für Bodenforschung) in a comprehensive atlas (Paläogeographischer Atlas der Unterkreide Nordwestdeutschlands: Schott *et al.* 1967, 1969), which will be cited in the text as "Atlas". In this paper only the Valanginian and Hauterivian sediments will be treated in detail. Aptian and Albian sediments are discussed separately (Kemper, this volume).

The "Atlas" deals primarily with the subsurface Lower Cretaceous sediments encountered during oil drilling. Therefore in the following pages, attention is concentrated on the surface occurrence of Lower Cretaceous rocks, in an attempt to complete the picture regarding the distribution, biostratigraphy, and ecology of the Valanginian-Hauterivian sediments.

The regional distribution of outcrops of the Lower Cretaceous sediments in Germany is restricted to two different areas: the hill region of Lower Saxony (Sackwald, Hils, Deister, Osning etc.) and the north German lowland. In the north German lowland, the Lower Cretaceous sediments are usually covered by a few metres of Holocene and/or Pleistocene sediments. Therefore they are exposed only in brickyards. The number of such exposures has rapidly dwindled in the last few years, and in future the only way to study these sediments will be by shallow boring or in chance exposures. Because the study of the Lower Cretaceous sediments is almost entirely dependent on borehole information, and because megafossils are usually poorly represented in these sediments, this study is made fruitful only through the evaluation of both megafossils and microfossils.

During the last 40 years, micropalaeontologists have created problems through their biostratigraphical method—by giving ammonite zonal names to microfossil assemblages without finding the nominate ammonites, instead of proposing an autonomous classification. It is therefore necessary now to attempt a synthesis and coordination of microfossil and megafossil data and to re-examine and correct the traditional biostratigraphical classification of the German Lower Cretaceous. Such studies are urgent because in the last few years the study of these Lower Cretaceous rocks has been neglected in comparison with that of other geological systems. This is in spite of the numerous borings and the unusually thick (2000 metres) continuous sequence in northwest Germany, a thickness not attained in adjacent regions of the Boreal Realm. Stolley published the last comprehensive report in 1937.

It is especially difficult to apply the existing biostratigraphical division to all facies types. The microfossil subdivision (Bartenstein and Bettenstaedt 1962) is applicable only in the shallow-water deposits of the oil-field region at the northern margin of the basin, where the distribution charts for microfossils were developed. The facies of the central part of the basin cannot be satisfactorily subdivided with the help of these charts.

2. The Lower Saxony Basin

The main region of sedimentation in north Germany during the Lower Cretaceous was the Lower Saxony Basin. It belongs to a basin system which included large parts of the North Sea region (from eastern England to the Netherlands, North Jutland and further northwards), and which was connected through the Baltic Sea and Poland with eastern and southern seas, at least intermittently (Atlas).

The Lower Saxony Basin formed a relatively narrow, elongated and subsiding basin with an average breadth of 80 kilometres and a length of about 280 kilometres (Figs 1–4). It extended from the German/Netherlands frontier in the west to east of Brunswick (Atlas). Its southern margin was near Rheine and Bielefeld, and its

Fig. 1. The western, central and eastern regions of the Lower Saxony Basin, and the marginal areas. The position of major towns is shown ("Atlas", modified). Abbreviations: Ch = Channel; E = Embayment. Presumed land is shown in colour.

northern margin lay north of Celle. The basin is of epeirogenic origin and was formed in the Upper Jurassic. In it about 4000–5000 metres of Upper Jurassic and Lower Cretaceous sediments accumulated. The characteristic features of the basin (regardless of the local conditions related to salt stocks) are great thicknesses of strata and concordant sequences free from any hiatus or condensation. These features are a result of continuous subsidence and accumulation.

On the other hand, the massifs and swells bordering this basin are characterized by the absence of Lower Cretaceous sediments or by thin, condensed sediments with non-sequences and occasional overlap. The bordering swells with uprising tendency are of a different nature. The Rhenanian Massif as well as the East Netherlands Triassic High (belonging to the middle European continent) were land masses throughout Valanginian-Hauterivian time. They were first covered by the sea during the Middle Albian and especially in the Cenomanian. On the other hand, the Pompeckj's Swell had the nature of an archipelago with sedimentation in sea straits and shallow bays.

The main part of the basin can be regarded, following Voigt (1963), as the "Randtrog" (i.e. bordering trough or foredeep) of the Rhenanian Massif. In front of this massif the areas of deepest subsidence undoubtedly occurred and therefore at least in some periods also the greatest depths of water. Subsequently, this very part of the basin experienced the strongest uplift during the inversion of the subhercynian orogeny. Today it is the "ostwestfälisch-lippische Keuperbergland". The southern boundary had the character of a flexure zone (Atlas). The northern boundary of the basin is considered also as a synsedimentary flexure zone lying on the margin of a regionally important swell, i.e. a major tectonic hinge, which appears to be fractured in the region of the Aller river (Atlas). Marginal troughs with greater thicknesses of sediment are here small in size and of limited extent.

The basin asymmetry is due partly to the rapid and strong subsidence in front of the Rhenanian Massif compared with the broad areas of shallow water on the other margins, and partly to the dissimilarity of the northern and southern borderlands. This asymmetry is reflected in the sedimentation. The Lower Cretaceous along the southern margin of the basin is composed mainly of sandstones, the quartz fragments of which were derived from the Carboniferous of the Rhenanian Massif. On or around the Pompeckj's Swell sandstones are either missing or unimportant. In this region sands and silts are found only in the neighbourhood of Dogger outcrops. This was the case in the Valanginian and especially in the Berriasian.

The central parts of the basin were characterized by continuous and rather regular subsidence, whereas irregular subsidence related to a variety of structures occurred in the marginal regions. In the eastern region sedimentation was influenced by salt movements. True tectonic movements occurred particularly in the marginal zones, as witnessed by dislocations, unconformities and transgression horizons. In the Neocomian these movements were only weak, getting stronger in late Lower Cretaceous time. The western marginal region was divided into well-marked troughs, separated by synsedimentary swells. These swells strike east-west and are characterized by generally thin sediments, with or without non-sequences. Individual zones may be only a few centimetres or a few metres thick on the swells. A less prominent but similar pattern of alternating swells and troughs parallels the northern margin in places.

The accompanying palaeogeographical maps (Figs 1–4) clearly demonstrate that from Valanginian to middle Albian time only narrow connections existed with neighbouring basins of the great boreal basin system. The eastern seaway was the most important. The three sea straits of the Pompeckj's archipelago (Ems, Hoya and Gifhorn Channels) were also constant and important. It is not certain whether there were connections to the southwest, between the Alstätte embayment and the West Netherlands Basin. Such a short connection could have existed in the Berriasian as is evidenced by some faunal elements.

All these seaways were relatively narrow, so that they either hindered or prevented the spreading of some species, all the more so as the influence of sea currents must also be considered. These narrow sea connections worked partially as ventiles

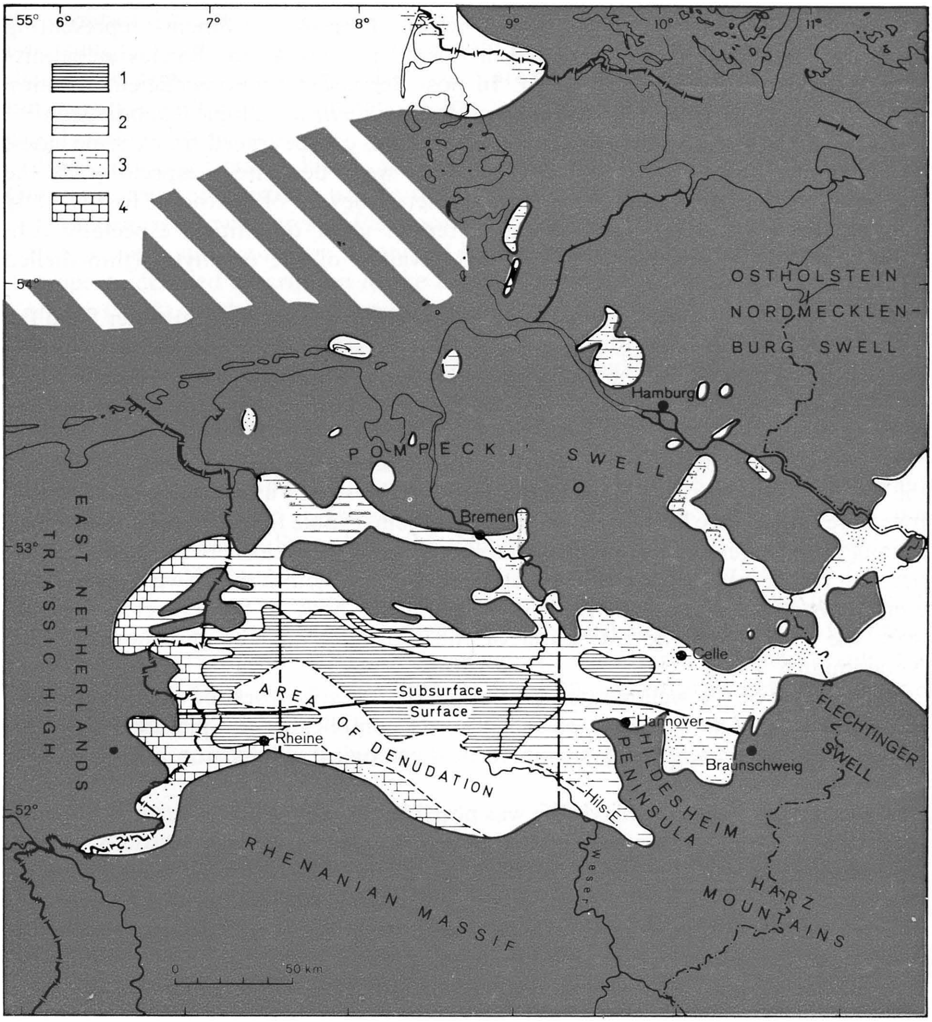

Fig. 2. Distribution of sediments in the Lower Saxony Basin in the late Berriasian (German "Wealden") ("Atlas", modified). Presumed land is shown in colour.

1. Shales and mudstones more than 400 m thick
2. Shales and mudstones less than 400 m thick
3. Sandstones preponderant or important
4. Calcareous marginal deposits (*Neomiodon* limestones)

and partially they had a sorting effect on the distribution of animals. Whereas some genera and species failed to penetrate these seaways, others (for example *Platylenticeras, Dichotomites, Aegocrioceras*) succeeded in immigrating and found biotopes in which they could evolve spontaneously or "explosively", without competitors.

In many periods (especially in the Valanginian) the Lower Saxony Basin had a certain degree of independence as is indicated by endemic faunal components. In other periods (for example the Aptian) cosmopolitan elements prevailed and endemic elements were lacking or infrequent.

Another result of the marked separation from the world seas was the intermittent restriction in circulation of the deeper water. Therefore sediments representing anaerobic environments accumulated in various periods. In the Berriasian salinity was the important ecological factor. In post-Berriasian time insufficient aeration was the critical factor which was responsible for a *vertical* ecological subdivision.

All gradations in conditions of reduced aeration can be traced. In extreme cases, bituminous "paper shales" or "fish shales" were deposited, especially in the Barremian and early Aptian. They are completely devoid of benthonic fossils. Only nectonic or planktonic fossils occur, often in great quantities, especially fish, planktonic foraminifera and thin-shelled bivalves of the epiphytal (thin-shelled *Inoceramus*).

In periods of extremely reduced circulation badly aerated bottom water filled the whole basin and not only its central part. Thus dark and finely laminated sediments are widely distributed in the basin. The benthonic fauna adapted to deeper water either disappeared completely or was compelled to emigrate to marginal and usually isolated biotopes.

After the return of better ecological conditions, new species appeared, occupying the biotopes of the extinct or emigrant faunas. The severe anaerobic periods therefore were responsible for some prominent and remarkable faunal breaks best known among foraminifera and ostracods. The most important breaks or "Faunenschnitte" occur at the Lower-/Middle Barremian boundary and within the Lower Aptian. The conditions of deposition of the "Blätterton-Ton" beds of the Lower Barremian were the reason for the extinction of the typical bivalve-benthos-fauna of the Neocomian.

The species of the well aerated shallow neritic to sublittoral environments were not influenced. The existence of such faunas complicates the picture and is the reason why the presence of a strong vertical ecological subdivision has been overlooked hitherto.

In moderately aerated periods life was possible for eurybiontic benthonic animals, such as arenaceous foraminifera. The poorly aerated water was restricted in this case more-or-less to the deeper parts of the basin: "Zentral-oder Beckenfazies". During the different Lower Cretaceous stages, this *lateral* ecological differentiation into the poorly aerated central "Beckenfazies" and better aerated marginal areas was the rule. This naturally is also reflected in the faunal distribution pattern. In the Upper Valanginian, early Upper Hauterivian, the Lower Barremian as well as in the early Albian, sediments characteristic of moderately aerated environments were widely distributed.

The lateral faunal distribution is also reflected in the collections of museums and institutes. This provincialism is accentuated through the present limited preservation of the Lower Cretaceous rocks. The present-day distribution of Lower Cretaceous rocks in the surface region is a result of the great "inversion" of the basin in the subhercynian orogeny and subsequent denudation. Just that part of the basin lying in front of the Rhenanian Massif in which the thickest sequences were deposited suffered the strongest uplifting during the subhercynian inversion and therefore was completely denuded (white areas on Figs 1–4). The fact that a half to three-quarters of the original Lower Cretaceous sediments and especially most of the central basin sediments were removed must be taken into consideration in all evaluations of the Lower Cretaceous in Germany.

In the following descriptions, western, central and eastern regions of the basin are distinguished. The western and eastern regions with numerous bays are characterized by the wide distribution of sediments and faunas of the shallow neritic to the sublittoral zones. In the eastern region, the influence of salt domes is characteristic, causing rapid changes of thickness and facies. The central part comprises (if the coastal regions in the north and south are not regarded) the particularly thick, but poorly fossiliferous sediments of the 'central facies', which on the maps is closely hatched (Figs 2–4).

The surface/subsurface line is another natural boundary of some significance. Only the outcropping strata will be treated here in detail. In most places they are only hidden by a few metres of Pleistocene/Holocene sediments.

The western surface-region is marked by the towns of Rheine-Bentheim-Ahaus. A modern, detailed description of the Lower Cretaceous of this region is given by Kemper (1968). In the central region two different facies of the Lower Cretaceous can be distinguished, the Osning with its near-shore sand facies (Osnabrück, Bielefeld), and the dark shales of the Neocomian (Berriasian-Hauterivian) of the "Schaumburg-lippische Kreidemulde" north of Minden and north of the Weser and Wiehen hills, including the Bückeberg. In the eastern region there are surface occurrences of Lower Cretaceous rocks in the area around Hanover, Peine, Brunswick, Salzgitter, and Hildesheim and in the Hils, Deister, Süntel and Osterwald hills. This is the classical region of the German Lower Cretaceous of authors like F. A. Roemer, A. Von Strombeck, M. Neumayr and V. Uhlig, A. Von Koenen, E. Stolley, G. Maas, A. Wollemann and others. Here are situated the famous localities of the "Hilston", the "Hilskonglomerat", and the "Gault", the last a term which was used by the early German workers for the Aptian and Albian. Comprehensive modern studies on the central and eastern regions are still lacking (the last work is Stolley 1937), if the explanations of the "Atlas" with its emphasis on the sub-surface part are not included here.

3. The late Berriasian

The complex problem of the Jurassic/Cretaceous boundary and the definition of the Berriasian stage in Germany is beyond the scope of this paper and will not be treated here. Until now, the strata overlain by the Platylenticeras Beds of the Lower Valanginian have been called "Wealden", although "Wealden" here is not a stage name but a term for a special facies. Now that it is certain that at least the major part of the "Wealden" facies in Germany is equivalent to part of the English Purbeckian, a new name for the "German Wealden" is necessary. As explained elsewhere (Kemper, in preparation), it is recommended that the term "Bückeberg Sequence" should be used for these sediments. The name is derived from a hill-chain in southern Lower Saxony.

The Lower and Middle Bückeberg Sequence consists mainly of fresh-water sediments, but it includes also intercalations of brackish-water or even marine origin. In the Upper Bückeberg Sequence (hitherto "Wealden 5–6"), sediments of pliohaline to brachyhaline water predominate.

In this report the Upper Bückeberg Beds are considered to be late Berriasian. If my suggestion to take the base of the Platylenticeras Beds—i.e. the first appearance of *Platylenticeras*—as the base of the Valanginian is not accepted, the Upper Bückeberg Beds would be lowermost Valanginian and should be called the "Osterwald-Schichten", redefined but following Riedel 1941.

A subdivision of the Upper Bückeberg Sequence is only possible by species of the ostracod genus *Pachycytheridea.* In contrast to the faunas of the limnic environment of the Lower and Middle Bückeberg Sequence, the fauna is now composed of euryhaline species. In addition to the persistent *Neomiodon* species, Corbulidae, Bakevellidae and gastropods belonging to the Procerithiidae and Rissoidae are very common. This fauna appears in the succeeding Platylenticeras Beds together with cephalopods but without other stenohaline species. These peculiar layers in the Platylenticeras Beds are known as "mixed fauna beds". The facies of the Upper Bückeberg Sequence is rather uniform and reveals no lateral changes. The grey mudstones contain intercalations of clay-ironstone. The basin was rather narrow (Fig. 2) and had no seaways to the north: marine incursions came from the east.

4. The Valanginian stage

4a. Definition and subdivision

The Valanginian (hitherto called "Valendis" in Germany) is here defined as the period of time between the first appearance of the ammonite genus *Platylenticeras* and the appearance of the ammonite genus *Endemoceras.* For biostratigraphical subdivision ammonites are of the utmost importance.

In the Lower Valanginian (formerly "Mittel-Valendis") the genus *Platylenticeras* provides good marker fossils. The genus (monographically studied by Kemper 1961) can be considered as an acute-whorled descendant of the Craspeditidae. It begins with rather small, widely umbilicate forms and its evolutionary development terminates with large, narrowly umbilicate and disc-shaped species with high whorls. Some species have umbilical nodes, but there are many transitions between specimens with and without nodes. Thus the separation of individuals with umbilical nodes into an independent genus, *Tolypeceras* Hyatt, is impossible and the name unnecessary.

Specimens of *Platylenticeras* are always abundant and it is therefore one of the best index fossils in the German Lower Cretaceous. Three zones can be distinguished. Some species seem to be endemic, probably because *Platylenticeras* was the first ammonite to enter the new biotope formed after the Wealden environment and was able therefore to evolve rapidly with little competition. In spite of these endemic forms the genus had a wide and interregional distribution in Europe (Kemper 1961; Thieuloy, this volume) and is the best possible index fossil for the base of the Valanginian (Kemper 1971a).

During the Lower Valanginian, other ammonite genera also invaded the Lower Saxony Basin, namely *Euryptychites* and finely ribbed descendants of the Craspeditidae. The latter group seem to belong partially to the *Tollia* and partially to the *Chandomirovia* line of evolution. Some of the *Tollia*-like species were described and figured by Kemper (1964). However, they do not have a craspeditid suture line. All

Table 1. Subdivision of the Valanginian stage.

		Zone	Subzone	Old Subdivision	
Hauterivian					
Upper Valanginian		"Astierien-Schichten"			Ober Valendis
		Dicostella pitrei		Arnoldien-Beds	
	Dichotomites	*Neocraspedites complanatus* and *Neocraspedites undulatus*		Dichotomites - Beds	
		Dichotomites bidichotomus	*Dichotomites tardescissus*		
		Dichotomites biscissoides			
	Prodichotomites	*Prodichotomites polytomus*	*Valanginites nucleus*		
			Neocraspedites flexicosta		
Lower Valanginian	*Polyptychites*	*Polyptychites middendorfi* and *Polyptychites clarkei*		Polyptychites-Beds	Mittel Valendis
		Polyptychites brancoi and *Polyptychites euomphalus*	*Costamenjaites pumilio*		
	Platylenticeras	*Platylenticeras involutum*		Platylenticeras-Beds	
		Platylenticeras heteropleurum			
		Platylenticeras robustum			
Berriasian	Bückeberg Sequence			German "Wealden"	

these species are extremely rare (in contrast with *Platylenticeras*) and have not yet been studied in detail.

Comparison with Russian faunas is rather difficult, since representatives of the genera mentioned or lately described from there, such as *Bogoslovskia, Stchirowskiceras, Proleopoldia, Temnoptychites, Russanovia, Menjaites* and *Bodylevskyiceras* appear to be absent in the Lower Saxony Basin, or at least have not yet been found at outcrop. Possibly they failed to immigrate through the narrow sea channels. On the other hand, it is possible that some species will be found in the future, since the abundant material from numerous oil wells has not yet been studied. Thin-shelled fossils, not represented in collections from outcrops, are often preserved compressed or as fragments in cores.

Species of the genus *Polyptychites* first appear in the uppermost part of the Platylenticeras Beds, including *P. keyserlingi* (Neumayr and Uhlig), *P.* aff. *michalskii* (Bogoslowsky) and *P. quadrifidus* Koenen. Following the disappearance of *Platylenticeras*, species of the genus *Polyptychites* are used as zone fossils for the overlying Polyptychites Beds. Identification of the various species is very difficult because only the body chamber is usually preserved. A subdivision into two zones is possible (see Table 1). The lowermost part of the sequence is also characterized by the presence of *Costamenjaites pumilio* (Vogel). As with *Platylenticeras,* there appear to be some endemic species of *Polyptychites.*

The lowermost three-quarters of the Upper Valanginian sequence are characterized by the presence of the genus *Dichotomites,* which gave its name to the Dichotomites Beds. The early species, for which Kemper (1971a) introduced the new generic name *Prodichotomites* (type species *P. polytomus* (Koenen) are thick-whorled and coarsely-ribbed, and show transitions to their polyptychitid ancestors. They are typical of the "Lower Dichotomites Beds" of earlier authors. The accompanying species of the *polytomus* fauna are very conspicuous: *Neocraspedites flexicosta* (Koenen), "*Polyptychites*" *orbitatum* (Koenen)) and especially *Valanginites nucleus* (Roemer). *V. nucleus* is a very important marker fossil for inter-regional correlation (Kemper 1971a). In the future, subzones may be distinguished based on ammonites related to *Astieriptychites* but with narrower whorls and wider umbilicus. True *Astieriptychites* (to which "*Polyptychites*" *orbitatum* (Koenen), as well as "*P.*" *sphaericus* and "*P*" *gradatus* Koenen, obviously belongs) are rare in Germany. Their first appearance is not known exactly, but there is some evidence that they are confined to the *polytomus* Zone.

The sediments overlying the *polytomus* beds ("Middle Dichotomites Beds" of earlier authors) are characterized by *Dichotomites* species which have very strong, coarse ribs which bifurcate in the *biscissus* pattern. In another paper I am naming the main group *D. biscissoides* sp. nov.; they are much thicker and have a much wider umbilicus than *D. biscissus* Koenen. In the upper part of these *biscissoides* beds, the index species is joined by *D. terscissus* (Koenen) and *D. tardescissus* (Koenen).

The succeeding strata are the *bidichotomus* beds. The marker fossil, however, is not the true *Dichotomites bidichotomus* (Leymerie) but a related form which only has the bidichotomous rib-pattern in common with Leymerie's species, all other features being different.

Throughout the Dichotomites Beds species of "*Neocraspedites*" occur. Without doubt they are an offshoot of the *Dichotomites* stock, and there seems to be no relationship with the earlier *Neocraspedites* of the Lower Valanginian, which are convergent offshoots of the Craspeditidae. The "*Neocraspedites*" of the Dichotomites Beds are subjected to two orthogenetic changes: the size increases and the ribbing becomes weaker and denser. In "*Neocraspedites*" *complanatus* (Koenen) and "*N.*" *undulatus* (Koenen) the genus provides two guide fossils for the uppermost Dichotomites Beds.

Other accompanying ammonite species are important. The first crioceratitid ammonites of the German Lower Cretaceous appear in the Middle Dichotomites Beds. Two forms occur: *Juddiceras curvicosta* (Koenen) with *Aegocrioceras* habit, and another species of *nolani* habit, having spinose main ribs. These forms are related either to *Protancyloceras* or *Himantoceras*; or they may be considered to be descendants of the Neocomitinae. The Neocomitinae are also represented by forms with *Distoloceras*-like ornament and species of the *Kilianella* line, such as *Luppovella longi* (Sayn) and *L. dubisiensis* (Baumberger). Another related species, *Dicostella pitrei* (= *Arnoldia* Stolley: *pitrei* Zone = "Arnoldien-Schichten" in Germany) is of special importance in inter-regional stratigraphy.

All these Neocomitinae were immigrants from the Tethys, which allows the assumption that suitable sea connections must have existed. This is also strengthened by the presence of *Choffatella* in the eastern seaway (Michael and Pape 1971). Furthermore, rare representatives of the Tethyan index genus *Saynoceras* are found in Germany.

The uppermost beds considered to belong to the Valanginian are the "Astierien-Schichten", so-called because of the presence of *Olcostephanus* (= *Astieria*) alone. However, this genus appeared much earlier and vanished much later, in the Hauterivian. There is no other index fossil available.

4b. Facies and ecology

Remarkably constant conditions existed during the deposition of the Platylenticeras Beds, whereas a strong facies differentiation is the predominant feature of the late Lower and early Upper Valanginian. The differentiation is due to the subsidence of the central part of the basin. Here, dark, ammonite-rich clay-stones (preserved particularly in Schaumburg-Lippe) accumulated, especially in the *biscissoides* and *bidichotomus* Zones. As a result of the poor aeration the benthonic biotopes are poorly fossiliferous, nearly without megafossils and mainly with arenaceous foraminifera.

In the marginal regions there are several different biotopes and facies-units equivalent to the central facies. The Bentheim Sandstone (late lower Valanginian), a marine shelf sand-body covering a broad shelf area in the west of the basin, is well known. Nearshore sands are also known from the Upper Valanginian of this region as well as from the northern margin of the basin. The shallow-water clay bottom biotopes of the western region are crowded with ostracods (*Valendocythere, Costacythere*, *Schuleridea*), crinoids and gastropods, which have not yet been studied.

Species of *Platylenticeras, Polyptychites* and *Dichotomites* are recorded from the near-shore sand facies of the southern region (Osning Sandstone, low horizons). Fossiliferous nodules from there contain species of *Lingula, Thetis, Spondylus, Bakevellia,* pectinids, Procerithiidae and crinoids. In the Valanginian of the eastern part of the basin only a few well-dated horizons are known. In many places the Upper Valanginian lies transgressively on older horizons. In this rather narrow part of the basin the sequences are arenaceous and thin; in contrast, about 200–300 metres of Valanginian sediment were deposited in the centre of the basin.

In post-*bidichotomus* time there was an increase in areal extent of shallow water over the Lower Saxony basin, with consequent amelioration of the living conditions. At this time new benthonic faunas conquered the old biotopes to a certain extent.

5. The Hauterivian stage

5a. Definition and subdivision

The Hauterivian is defined here as the period of time between the first appearance of the ammonite genus *Endemoceras* and the extinction of *Simbirskites* and/or the appearance of *Hoplocrioceras*. The genus *Endemoceras* has been studied recently by Thiermann (1963) in Germany and Rawson (1971b) in England. Thus we have good opportunities for comparison between the Endemoceras Beds of the two countries. The zonal sequence is similar in both England and Germany in spite of the fact that the index fossil of the youngest zone, *E. regale,* is yet to be found *in situ* in Germany. However, the existence of this species is documented by specimens in museum collections, and the presence of *Hibolites,* which is absent in both the *E. amblygonium* and *E. noricum* Zones, is an indirect proof of the existence of the *regale* Zone in Germany (Rawson 1971b). Specimens of *Endemoceras* are very common in the *amblygonium* Zone and *noricum* Zone and are therefore good index fossils. They are usually accompanied by various species of *Acanthodiscus, Distoloceras, Olcostephanus* and, rarely, *Eleniceras.*

In the succeeding beds representatives of the genus *Aegocrioceras,* hitherto in Germany called *Aegocrioceras capricornu* (Roemer), are even more common. It is clear that we are dealing with more than one species. Rawson (unpublished Ph.D. thesis 1966) reviewed English occurrences of this genus and distinguished several species, among which *A. quadratum* (Crick) seems to be the most dominant. However, further researches are still necessary in Germany to find their stratigraphical sequence here. The "Aegocrioceras Beds" in Germany form such a characteristic horizon that it is not wise to replace the name with a *Simbirskites* zonal name. The Upper Hauterivian begins with these Aegocrioceras Beds, which as defined here represent only the lower part of the *capricornu* Zone of some previous authors. They are overlain by beds with abundant *Simbirskites* of the *staffi* group, which were often included in the upper *capricornu* Zone. The sudden appearance of these earliest *Simbirskites,* together with *Crioceratites,* indicates an important immigration horizon which forms a very characteristic marker in the Lower Saxony Basin.

Species of *Aegocrioceras* were the first crioceratitid ammonites to appear in the Hauterivian. *Crioceratites,* with differentiation into primary and secondary ribs and with three spines on the main ribs on each flank (*C. hildesiense, C. wermbteri* etc.) appeared, as noted above, with the first *Simbirskites,* just above the Aegocrioceras Beds. They are closely related to the Tethyan *C. nolani,* and all probably appeared at approximately the same time. *Crioceratites* with this general aspect occur through the rest of the Hauterivian and have been utilized for zonal purposes. However, although they are locally abundant, they are usually flattened and difficult to identify at specific level. Thus a subdivision of the sediments above the Aegocrioceras Beds based on *Simbirskites* alone appears necessary, as indicated by Bähr (1964). The zonation proposed here (Table 2) is based on species ranges listed by Bähr (1964) supplemented by further field observations in northwest Germany by Dr. P. F. Rawson and the author. This zonation can be compared closely with the English scheme recently proposed by Rawson (1971a), though the abundance of species in the two countries is different so that a generalized northwest European subdivision based on *Simbirskites* cannot be made at present.

The recent discovery of *Spitidiscus* in the *hildesiense* beds of the Gildehauser Sandstone is also of importance. *Spitidiscus rotula* (J. de C. Sowerby) (as a result of its poor preservation previously misidentified in Germany as *Valdedorsella*) is restricted in England and Germany to a very limited level. This ammonite seems to be an important index fossil for inter-regional correlation, since the main distribution of *Spitidiscus* is in the Tethys, from where several species are known.

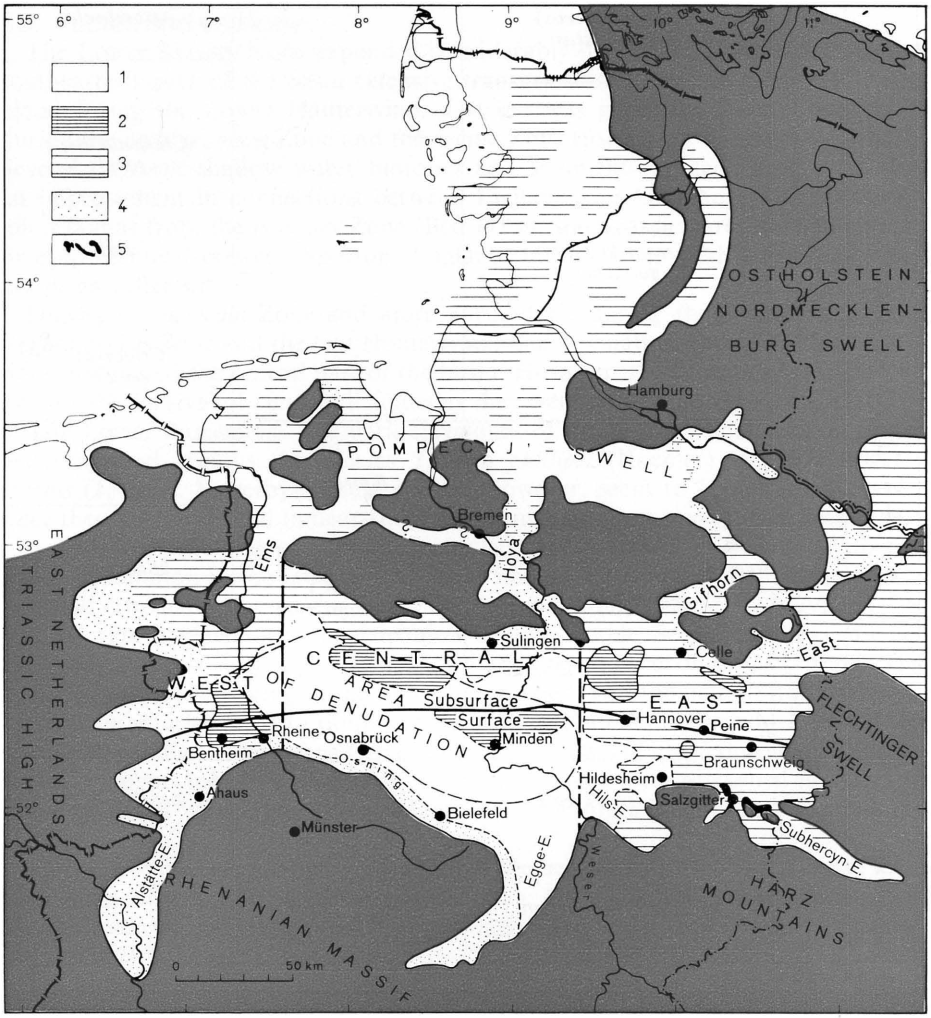

Fig. 3. Distribution of sediments and basin outline in the Hauterivian ("Atlas", modified). Presumed land is shown in colour.

1. Deposits not known
2. Shales and mudstones more than 400 m thick
3. Shales and mudstones less than 400 m thick
4. Sandstones preponderant or important
5. Iron ore

Table 2. Subdivision of the Hauterivian stage.

		Zone	Subzone	Old Subdivision
Barremian				
Upper Hauterivian	*Simbirskites Crioceratites*	*Simbirskites* (*Craspedodiscus*) *discofalcatus*		"*Crioceras*" *strombecki*
		Simbirskites (*Craspedodiscus*) *gottschei*		*Craspedodiscus tenuis* and "*Crioceras*" *seeleyi*
		Simbirskites (*Milanowskia*) *staffi*	*S.* (*M.*) *ihmensis*	
	Spitidiscus		*S.* (*M.*) *staffi*	*Crioceratites hildesiensis*
	Aego-crioceras	*Aegocrioceras* spp.		*Aegocrioceras capricornu*
Lower Hauterivian	*Endemoceras*	*Endemoceras regale*		*Acanthodiscus bivirgatus*
		Endemoceras noricum		"*Lyticoceras*" *noricum*
		Endemoceras amblygonium	*Endemoceras longinodum*	
Upper Valanginian				

The Hautervian/Barremian boundary is still unsatisfactorily defined, because *Simbirskites* are very rare in the uppermost part of the Upper Hauterivian. Putting the boundary within the *rarocinctum* Zone as suggested by Bähr (1964) cannot be recommended. Probably the only possibility left is to regard the Barremian as beginning with the first appearance of the ammonite genus *Hoplocrioceras*. In this case the boundary will be located at the base of the *rarocinctum* Zone. Other useful criteria are expected as a result of work now in progress on the belemnite family Oxyteuthidae.

5b. Facies and ecology

The Lower Saxony basin expanded considerably during the Hauterivian. In the southeastern part of the basin extensive transgressions ("Hilskonglomerat") took place during the Lower Hauterivian. The sea was generally shallow, especially during the *amblygonium* Zone and the *regale* Zone (formerly: "Bivirgaten-Zone"). Several different shallow water biotopes and sediments existed. There was also an improvement in connections between England and Germany. The benthonic microfaunas from the *noricum* Zone (Bed D1 at Speeton) upward are very similar or even identical between Speeton (England) and Germany, while earlier faunas are often different.

During the *noricum* Zone and more particularly during the deposition of the *Aegocrioceras* Zone and the late Hauterivian, bad circulation and anaerobic conditions dominated the central part of the basin. However, the conditions were not as bad for the survival of benthonic fauna as they were during the Upper Valanginian or late Lower Barremian. The dark claystones of the central facies contain in the better aerated regions the species *Thracia phillipsi* (Roemer) and *Boreionectes cinctus* (J. de C. Sowerby). These species, however, seem to be easily adaptable, since they are also found in near-shore sediments. *Exogyra couloni* Defrance is also very widely distributed as well as the crustacean *Mecochirus ornatus* (Phillips), which is common in the late *noricum* Zone and in the *regale* Zone. Furthermore, isocrinid crinoids of the genera *Isocrinus, Neocrinus* and *Nielsenicrinus* lived in this biotope. These genera are accompanied by remarkable Serpulidae (Regenhardt 1961) which show during the Hauterivian an interesting evolutionary trend. The genus *Rotularia,* belonging to the Spirorbinae, tried with the help of its gastropod-like highly whorled shell to dominate the clay bottom. This serpulid lived till the Middle-Barremian. The genus *Genicularia* (Ditrupinae) is also conspicuous for its keeled, straight, tube-like shell, open at both ends and with thickened nodes. The spherical genus *Glomerula* which belongs to the Filograninae is characteristic of agitated water.

The gastropods, especially Procerithiinae, Metacerithiinae and Mathildinae have their main distribution in shallow water seas. Only one *Procerithium* species is characteristic of the oxygen-poor, deep water. Trochidae and Pleurotomariidae were restricted to near shore areas.

The biotopes and facies, especially of the Lower Hauterivian, are variable. To the west, limestones were deposited during the *noricum* Zone. The fauna of the *noricum* Zone sandy limestones was described by Kemper (1968). The presence of *Buchia, Eleniceras tchechitevi* Breskowski and *Trocholina* is characteristic of this fauna. Limestones were also deposited in the eastern regions. Rich, shallow water faunas in limited biotopes occur in these limestones, which contain here iron ore and other coarse clastic material ("Hilskonglomerat"). The fauna of these beds consists, beside the oysters (*Exogyra, Lopha*), of the well known Pharetrone and brachiopod biostromes with terebratulids and rhychonellids. These elements as well as others, like *Trocholina*, *Cytherelloidea* etc., denote a well aerated, shallow-water environment with hard bottoms. The microfauna of these regions was described by Michael and Pape (1971) and Kemper (1971b), and the bryozoan fauna by Hillmer (1971). In the region of Salzgitter iron ore was deposited.

During the Upper Hauterivian the deposition of clayey sediments dominated almost everywhere: "Hilston", which reaches, however, to the Aptian at its strato-

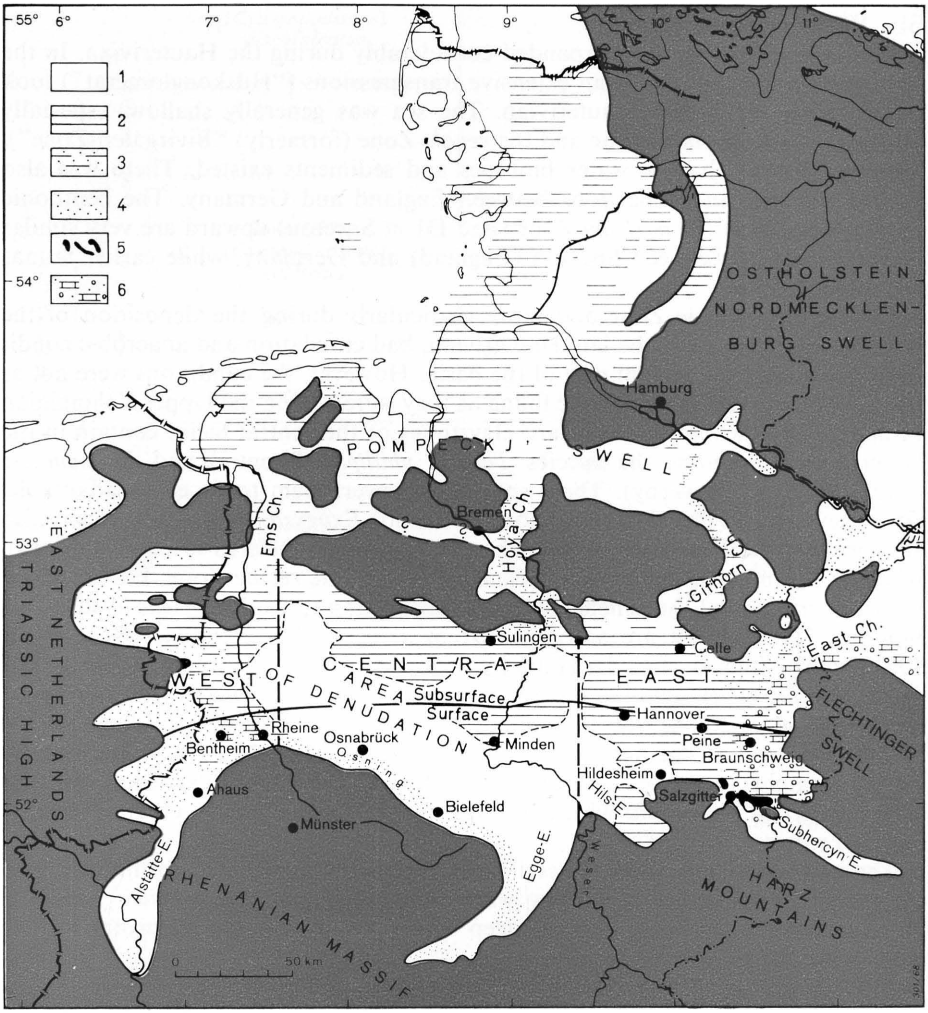

Fig. 4. Facies in late Lower Hauterivian time. Presumed land is shown in colour.

1. Deposits not known
2. Open sea facies: grey or dark calcareous shales with sideritic nodules, passing into lighter coloured rocks with calcareous nodules in nearshore and shallow neritic areas ("Hilston")
3. Sandy clays
4. Sandstones
5. Iron ore
6. Calcareous shallow-water deposits ("Hilskonglomerat")

type. Sandy sediments accumulated only in the southern and western regions (Osning and Gildehauser Sandstone respectively).

The fauna of the Osning Sandstone was studied by Weerth (1884). The greatest part of this fauna comes from the Hauterivian stage. The *Simbirskites* are of especial interest. The benthonic fauna of this sandstone consists of echinoids (Toxasteridae and Conulidae), burrowing bivalves (*Pholadomya, Panopea*), as well as species of *Pinna, Lima*, *Thetis* and brachiopods.

Kemper (1968) studied in detail the Gildehauser Sandstone which occurs near Bentheim. This spiculitic sandstone includes faunas of the Aegocrioceras Beds and at least part of the old *Crioceratites hildesiense* Zone. Its *Simbirskites* fauna has recently been summarized. It consists mainly of the following species: *Simbirskites* (*Speetoniceras*) *inversum* (M. Pavlow), *S.* (*S.*) *subbipliciforme* (Spath) and *S.* (*S.*) *versicolor* (Trautschold). The accompanying fauna is rich (Kemper 1968). The dominating rich sponge fauna is indicated by the abundance of spicules.

The clayey sediments of the western, shallow water areas are exceptionally fossiliferous and include foraminifera, ostracoda, gastropoda and crinoids. Most of these species are not yet described.

The typical benthonic fauna of the Neocomian disappeared in the *fissicostatum* Zone of the Lower Barremian. During this time unsuitable, anaerobic conditions prevailed which destroyed deep water benthonic assemblages. The following species became extinct in the lower Saxony Basin: *Thracia phillipsi, Exogyra couloni* and *Camptonectes* (*Boreionectes*) *cinctus*. These species are characteristic of sediments of Valanginian and Hauterivian age.

The 500 metres thick Hauterivian sediments of Germany, together with those of the Albian stage, contain the richest faunas and rock types known from the German Lower Cretaceous. During both stages, good sea connections with neighbouring regions existed. Furthermore, the presence of widely distributed good index fossils allows inter-regional correlations.

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The Aptian and Albian stages in northwest Germany

E. Kemper

The Aptian and Albian strata of northwest Germany are described with emphasis on boundaries, subdivision, palaeoecology and facies. The Aptian and Albian have much in common but differ greatly from older Lower Cretaceous strata of the same region. Movements belonging to several (pre-Austrian) phases led to local deepening or shallowing of the sea and to non-sequences, discordances and transgressions. The result is a profusion of different facies, which, because of the dearth of ammonites, can be correlated only with difficulty. In addition to lateral facies-changes, there are also vertical changes. Dark sediments accumulated in Lower Aptian and Lower Albian times in waters of reduced circulation. In the Upper Aptian and Middle and Upper Albian pale marls were deposited.

In dieser Arbeit werden die Schichten des Apt und Alb, ihre Abgrenzung, Unterteilung, Palaeoökologie und Fazies beschrieben. Apt und Alb haben viele Gemeinsamkeiten. Gegenüber den älteren Schichten der Unterkreide bestehen beträchtliche Unterschiede. Eine Analyse von Apt und Alb ist aus verschiedenen Gründen schwierig. Bewegungen von mehreren tektonischen Phasen führten teils zu Wasser-Vertiefungen und teils zu Verflachungen, zu Lücken, Diskordanzen und Transgressionen. Das Ergebnis ist eine Fülle von unterschiedlichen Fazieskörpern, die aus Mangel an leitenden Ammoniten nur schwer parallelisiert werden können. Neben einem lateralen Fazieswechel ist auch ein vertikaler vorhanden. Dunkle Sedimente kamen im Unter-Apt und Unter-Alb zur Ablagerung. Im Ober-Apt sowie im Mittel-und Ober-Alb bildeten sich helle Mergel.

Les couches aptiens et albiens du Nord-Ouest de l'Allemagne sont décrits dans leurs limites, leur subdivision, leur paléoécologie et leurs faciès. L'Aptien et l'Albien ont beaucoup de points communs, mais des différences considérables les distinguent des couches éocrétacés plus âgés de la même région. Des mouvements tectoniques répartis en plusieurs phases (préaustriennes) sont responsables d'approfondissements ou de hauts-fonds marins localisés et de lacunes, discordances et transgressions. Il en résulte une profusion de formations différentes dont les corrélations ne peuvent être faites qu'avec difficulté, en raison de la rareté des ammonites. En plus des variations latérales de faciès, il en existe aussi de verticales. A l'Aptien inférieur et à l'Albien inférieur, se déposèrent des sédiments sombres de mer peu aérée, tandis que l'Aptien supérieur et l'Albien moyen et supérieur sont représentés par des marnes plus claires.

1. Introduction

Early German authors often bracketed Aptian and Albian together as "Gault", apparently in order to bring out the similarities between these stages and to emphasize the contrast with the Neocomian (in which they included the Barremian). Indeed, there is a remarkable contrast with the Neocomian and Barremian which had its origins in external factors such as climate, tectonics and epirogenesis.

As in Neocomian times, the main area of sedimentation in the Aptian and Albian was the Lower Saxony Basin (Figs 1, 2). Although by Aptian times the shape and size of the basin had not changed much since the Neocomian, there were great differences in the development of the basin and in sedimentation.

In the Berriasian-Barremian period medium to dark grey mudstones with low carbonate content were deposited in the main. They commonly contain layers of clay-ironstone, and glauconite is absent or extremely rare. Subsidence was more or less continuous everywhere and even in the thin veneer of strata covering the swells major non-sequences are rare. Tectonic movements were unimportant and confined to the margins of the basin. Epirogenic processes, however, resulted in a widening of the basin in the Upper Valanginian.

In contrast to this, the Aptian-Albian period was characterized by tectonic instability. Movements reached their climax in six phases[1]—pre-Aptian, middle Lower Albian, late Lower and early Middle Albian, late Middle Albian, late Upper Albian and early Cenomanian—and had a considerable effect in the marginal areas, producing non-sequences, discordances, erosion and transgressions. Additional transgressions (Upper Aptian and lowermost Lower Albian) in marginal districts and over salt stocks are of local importance only.

Another feature, perhaps a result of more distant disturbances, was the deposition of volcanic ashes in the Upper Aptian, which appear today as beds of montmorillonite clay, as, for example, near Sarstedt (Lutze 1968). They seem to be equivalent to the layers of Fuller's Earth in the Sandgate Beds of the English Aptian.

These processes influenced sedimentation. In episodes of poor aeration dark mudstones and marls formed, as in the Neocomian, though with different faunas; for example, in the Lower Aptian as anaerobic "Fish Shales". During periods of favourable living conditions variegated marls accumulated in shallow-water areas in the north and east of the basin and on the Pompeckj's Swell. These are the "Gargas-" or "Ewaldi-Mergel" in the Aptian and the "Concentricus-" and "Sulcatus-Schichten" in the Albian.

In general, the carbonate content of the rocks, even of the dark rocks, is higher than in the Neocomian and glauconite and phosphorite are important components, particularly in front of the northern margin of the Rhenanian massif, where glauconite and siderite form the "glauconite-siderite" facies. The abundance of glauconite and phosphatic nodules in rocks of the southern part of the basin is a very characteristic feature of the Aptian-Albian. The pale marls are characterized by rich benthonic faunas (foraminifera, ostracods, inoceramids) and by a marked reduction in ammonites. In practice, a usable subdivision is possible only by using phylogenetic lineages of ostracods and species of *Neohibolites*.

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[1] Perhaps the use of the term "tectonic phase" should be avoided, because the movements were more epeirogenic in nature.

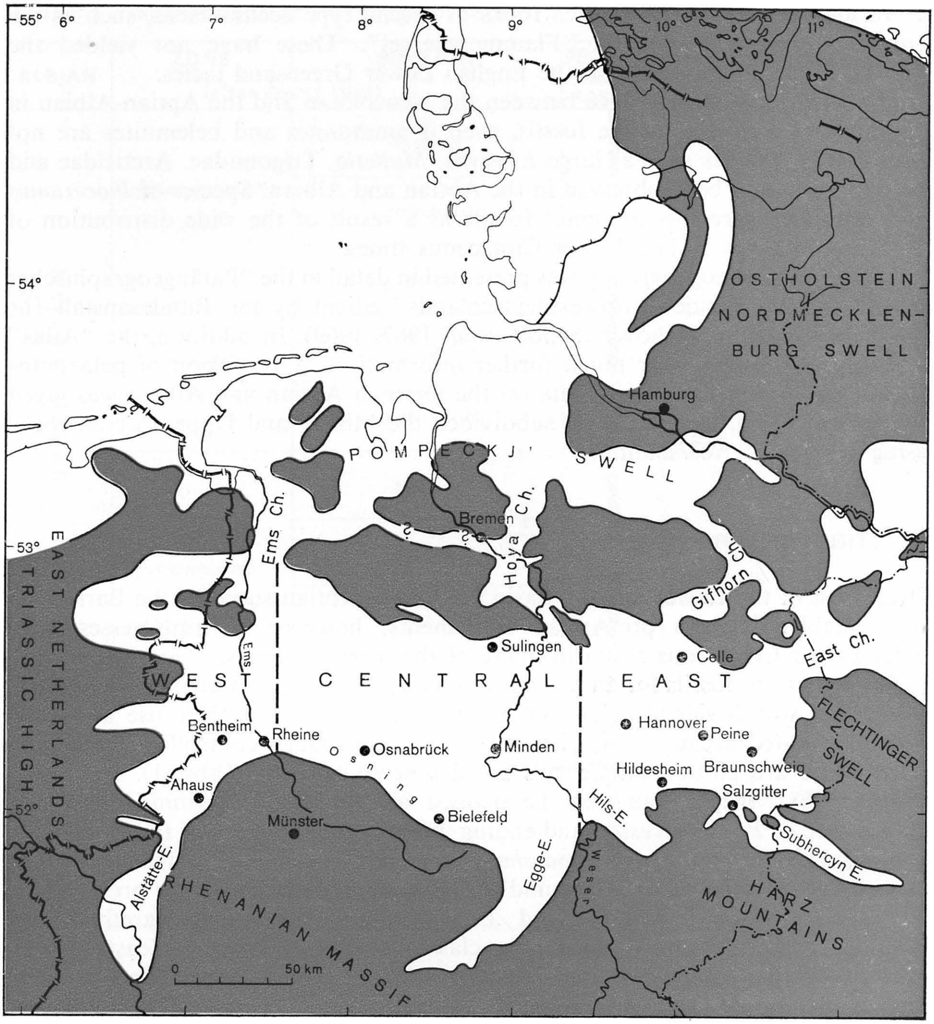

Fig. 1. The western, central and eastern regions of the Lower Saxony Basin (basin outline in Hauterivian times) with adjacent areas. The position of major towns is shown ("Atlas", modified). Presumed land is shown in colour.

The dark sediments of the phases of poor circulation have either no benthonic fauna (middle Lower Aptian) or yield only unimportant fossils such as arenaceous foraminifera (Lower Albian). Many beds, however, are rich in ammonites (nekton).

In addition to the vertical subdivision into pale and dark facies-units, there are great lateral changes of facies, much more than in the Neocomian. Especially obvious is the contrast between the northern and southern regions of the basin. In the central part, and particularly in the shallow areas of the northern part of the basin and on the gradually submerging Pompeckj's Swell (or Archipelago) pale marls were deposited predominantly. In the foreland of the Rhenanian massif and over parts of the massif itself, however, strongly glauconitic sandstones of various origins or sponge-rich rocks of special type accumulated, such as the Osning Greensand and the "Flammenmergel". These have not yielded the littorial fauna characteristic of the English Lower Greensand facies.

The most striking difference between the Neocomian and the Aptian-Albian in Germany is provided by the fossils, even if ammonites and belemnites are not considered. Bivalves such as large *Exogyra, Mulletia,* Trigoniidae, Arcticidae and others have never been observed in the Aptian and Albian. Species of *Inoceramus* and *Aucellina* were the dominant fossils as a result of the wide distribution of open sea biotopes in late Lower Cretaceous times.

In 1967 the palaeogeography was presented in detail in the "Paläogeographischer Atlas der Unterkreide Nordwestdeutschlands" edited by the Bundesanstalt für Bodenforschung in Hanover (Schott *et al.* 1967, 1969). In addition, the "Atlas" and its commentary offer much further information. A profusion of palaeontological and biostratigraphical data on the German Aptian and Albian was given by Stolley (1937). Spaeth (1971) subdivided the Middle and Upper Albian rocks using species of *Neohibolites.*

2. The Aptian stage

Over most of the Lower Saxony Basin the Lower Aptian succeeds the Barremian conformably. Due to pre-Aptian movements, however, it transgresses onto older Lower Cretaceous strata in many of the marginal areas.

The important fossils for an orthostratigraphy of the Aptian are the ammonites. Genera of world-wide distribution occur in Germany, but their use as index-fossils is limited because their distribution is in part facies-controlled. Ammonite occurrences are plotted on Casey's zonal scheme of 1961 (Table 1). Following Casey (1961), the Aptian may be defined as the period beginning with the appearance of *Prodeshayesites* and ending with the introduction of *Proleymeriella.* Some species of the genus *Prodeshayesites* are guide-fossils in the lowermost Lower Aptian. They have been found in Germany in particularly fine preservation in various regions: Alstätte and Lambertimark (west), Margarethen-Egge (Osning Sandstone, south), and at the classic locality of Timmern (east). Today only two exposures survive, near Alstätte (Kemper 1967, 1968). The sediments are light-coloured and accumulated in well-aerated waters. Of the fauna associated with the prodeshayesitids, paradeshayesitids (especially *P. laeviusculus* Koenen sp.), *Ancyloceras* cf. *urbani* (Neumayr and Uhlig), *Pictetia astieriana* (d'Orbigny) and *Protanisoceras* are noteworthy. Some of these species indicate good sea connections with neighbouring basins and with the south, as do also the scarce occurrences of *Aucellina* and *Duvalia. Neohibolites* appears to be missing still.

The succeeding zone was always called the "Zone of *Hoplites weissi*" by early German authors. This horizon has not been exposed for many decades and no statement on its position can be made here.

Lithologically, the most uniform member of the Aptian is the thinly laminated "Fisch-Schiefer" (or Fish Shales) of middle Lower Aptian time. These shales developed as a result of the anaerobic relationship of the near-bottom waters, not only in the Lower Saxony Basin, but also in the waters of the Pompeckj's Swell and even near Heligoland and on parts of the Russian Platform. They occur even in marginal embayments (Alstätte and Subhercynian Embayments).

Table 1. Subdivision of the Aptian stage

ALBIAN	**ZONE** (after Casey 1961)	**SUBZONE**	**PROOF OF INDEX FOSSILS**	**OLD STRATIGRAPHICAL UNITS**
UPPER APTIAN	*Hypacanthoplites jacobi*	*anglicus*	▮	milletianus and nolani Clays
		rubricosus		Hils and Rothenberg Sandstones
		nolani	▮	
	Parahoplites nutfieldensis	*cunningtoni*	▮	schmidti and trautscholdi Beds
		subarcticum		
	Cheloniceras martinioides	*buxtorfi*	▮	? ?
		gracile	▮	
		debile	▮	? ?
LOWER APTIAN	*Tropaeum bowerbanki*	*meyendorffi*		ewaldi or Gargas Marl
		transitoria	▮	
	Deshayesites deshayesi	*grandis*	▮	? ?
		parinodum		Fish Shales
	Deshayesites forbesi	*callidiscus*		
		kiliani		
		fittoni		? ?
	Prodeshayesites fissicostatus	*obsoletus*	▮	bodei Clays
		bodei	▮	
BARREMIAN				

Due to the absence of bottom life the Fish Shales are characterized by paper-thin bedding and by the sole presence of nektonic and planktonic fossils. Fish remains and planktonic foraminifera are very abundant. The bivalve *Inoceramus* cf. *ewaldi* Schlüter is found as a thin-shelled representative of the floating phytal. The similarly rich ammonite fauna is composed of species of *Deshayesites, Aconeceras* and *Sanmartinoceras,* and *Ancyloceras elatum* Koenen. As the specimens are always crushed flat, specific determinations of the deshayesitids and aconeceratids are not possible. It is uncertain, therefore, which deshayesitid zones and subzones are represented by the Fish Shale facies and in which place in the zonal sequence the facies terminates. It may be surmised that at least part of the *Deshayesites deshayesi* Zone is present in the pale marl facies, namely the pale to variegated ewaldi Marl, as, for example, was described by Ernst (1927) from Heligoland and Rethmar.

The top of the *deshayesi* Fish Shales is the one easily recognizable boundary in the German Aptian and in the past was commonly misused as the Lower Aptian/Upper Aptian boundary. After the destruction of the benthonic biotopes at the time of the Fish Shale environment, there followed in the younger Lower Aptian a gradual influx of old and new benthonic species. The following were new: *Saracenaria spinosa* (Eichenberg), *Lenticulina* (*L.*) *gaultina* (Berth.), *L.* (*Astacolus*) *schloenbachi* (Reuss), *Gavelinella* cf. *barremiana* Bettenstaedt, *Gaudryina dividens* Grabert, *Valvulineria gracillima* Dam and *Saxocythere* of the *tricostata* group. Following the accumulation of the Fish Shales, at least four different facies-regions have to be distinguished in the late Lower Aptian and the Upper Aptian until the end of the *Parahoplites nutfieldensis* Zone:

1. The northern basin and the Pompeckj's Swell, in the shallow-water areas of which were deposited pale and variegated marls, the ewaldi and the Gargas Marls, essentially in the late Lower Aptian and early Upper Aptian.
2. The central facies of the Hanover-Brunswick (Braunschweig) area, with rocks of medium grey colour.
3. The northwestern margin of the Rhenanian massif near Ochtrup and Rheine and the "martini Tone" (mudstones) of the southeast (Salzgitter). (The latter name is derived from the occurrence of rare specimens of *Cheloniceras* of uncertain species, now lost).
4. The Osning Sandstone region, of barren near-shore facies without limestones. Shallow-water deposits with limestone intercalations (the Hythe Beds facies) have never been observed in Germany.

Both the pale marls of the northern basin and the rocks of the central basin facies are devoid of large ammonite guide-species of the genera *Epicheloniceras, Tropaeum, Ammonitoceras, Parahoplites,* etc. Small *Parahoplites* of the *melchioris* group and *Tropaeum subarticum* Casey occur rarely, though Aconeceratidae (*Sanmartinoceras-Sinzovia*) are frequent and widely distributed. Especially typical of the late *Cheloniceras martinioides* and the *nutfieldensis* Zones is *Sinzovia stolleyi* Casey, which Stolley called "*Oppelia trautscholdi*"—hence his "trautscholdi Beds". Stolley (1911) introduced a subdivision based on occurrences of species of the genus *Neohibolites,* though this subdivision has proved problematic. The Lower Aptian/Upper Aptian boundary runs through the middle of his "*ewaldi* Zone".

The pale marls, the central basin facies and the Ochtrup facies all have different benthonic microfaunas. The central facies, for example at Haimar, Hohenhameln and the Deisterbucht, is characterized by a preponderance of arenaceous

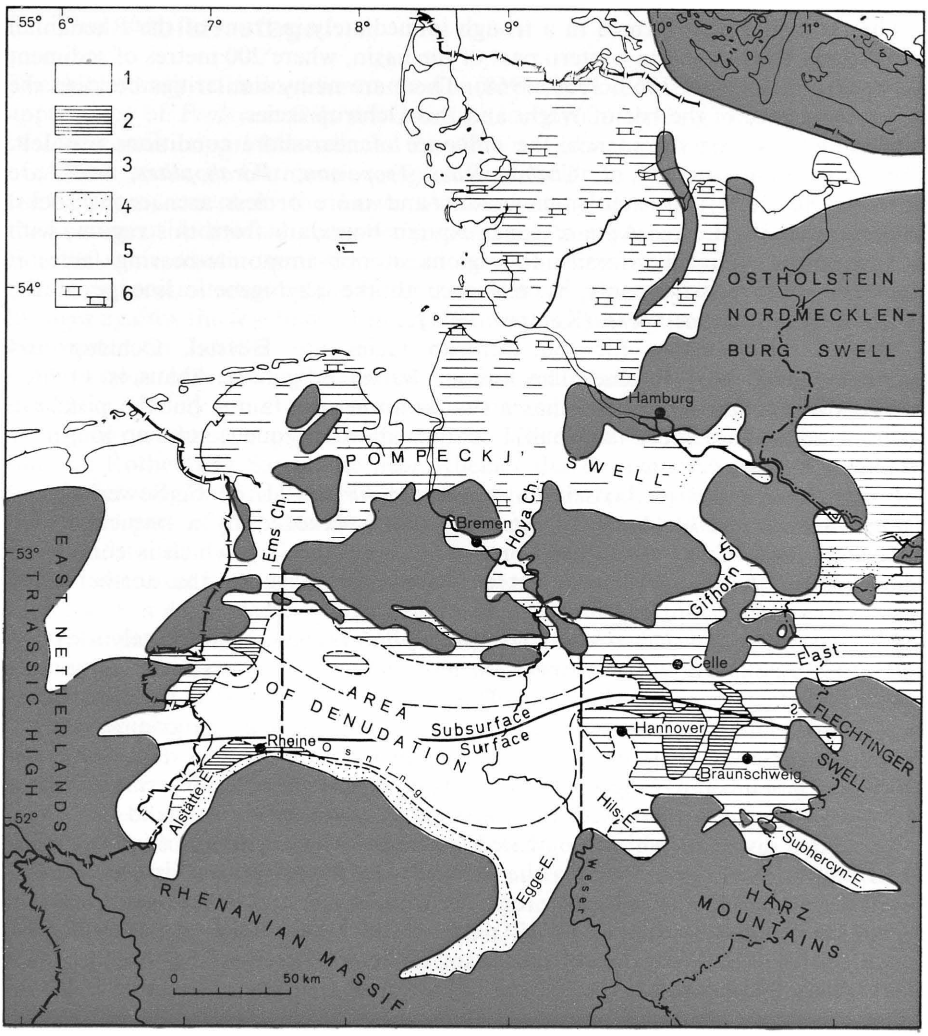

Fig. 2. Distribution of sediments (facies and thicknesses) and basin outline in Aptian times ("Atlas", modified). Presumed land is shown in colour.
1. Deposits not known
2. Calcareous shales and mudstones more than 100 m thick (Central facies and dark facies in front of Rhenanian Massif)
3. Calcareous shales and mudstones less than 100 m thick (ewaldi—or Gargas—Marl).
4. Arenaceous near-shore deposits, particularly the Osning Sandstone
5. Denuded areas
6. More calcareous sediments.

foraminifera (*Rhizammina-Haplophragmoides-Ammodiscus-Glomospira* associations). In the pale marls (Heligoland, Hanover, Wettbergen, Sarstedt) calcareous-shelled forms such as globigerinids (*Hedbergella*) and gavelinellids are the prominent microfossils, together with the megafossils *Inoceramus* cf. *ewaldi* Schlüter, *Aucellina aptiensis* d'Orbigny, "*Terebratula*" *moutoniana* d'Orbigny, *Terebrirostra neocomiensis* d'Orbigny and rare Cancellothyrididae. These ewaldi Marls correspond to the Sutterby Marl of eastern England.

The Ochtrup facies formed in a trough immediately in front of the Rhenanian massif near Rheine, in the western part of the basin, where 200 metres of sediment accumulated (Kemper 1963, 1964, 1968). There are many similarities between the Aptian sequence of the Isle of Wight and this Ochtrup facies.

In spite of strong subsidence, the influence of near-shore conditions was felt. The large guide-species of *Cheloniceras, Tropaeum, Parahoplites,* etc. are restricted to these consistently glauconitic and more or less arenaceous rocks. Projection of the Lower Aptian/Upper Aptian boundary from this region, with its occurrence of marker-fossils, to regions of non-ammonite-bearing facies is therefore made possible only by reference to the phylogenetic lineage of the ostracod genus *Saxocythere* (Kemper 1971).

Well-known localities for the Ochtrup facies are Hörstel, Ochtrup and Rothenberg, all near Rheine. The famous Barler Berg near Ahaus is situated in the Alstätte Embayment and has a similar ammonite fauna, but the pits have been abandoned for more than half a century and the sequence can no longer be reconstructed for certain.

In the Rheine district beds with *Dufrenoyia furcata* (J. de C. Sowerby) and *Tropaeum bowerbanki* (J. de C. Sowerby) are succeeded by a sequence with *Tropaeum drewi* Casey (including some spinose subspecies), which is considered as equivalent to the uppermost part of the ewaldi Marls of the northern and eastern areas.

The succeeding *Epicheloniceras* and *Parahoplites* faunas are absolutely identical with the Russian and English ones. *Sinzovia stolleyi* Casey has some value as a marker-fossil, as mentioned above. This ammonite appears in different facies in the *nutfieldensis* Zone of the Rheine district (in the glauconitic-sideritic Rothenberg Sandstone) as well as at equivalent horizons in the east. The Rothenberg Sandstone ranges from the Upper Aptian into the lowermost Albian and has strong similarities with the Carstone of Hunstanton, England.

The facies diversity, which originated in shallow-water conditions in important areas of the north, ended within the *nutfieldiensis* Zone. In the *Hypacanthoplites jacobi* Zone stronger subsidence, together with reduced circulation, caused the deposition of dark sediments in all parts of the basin. Sandstones are known only from the southern rim of the basin: Hils, Osning (part), Dörenther and Rothenberg Sandstones.

The benthonic fauna of the dark mudstones of the highest Upper Aptian comprises predominantly arenaceous foraminifera which were adapted to this poorly oxygenated environment. The same is true of the impoverished ostracod fauna, consisting of *Protocythere nodigera* Triebel, *Saxocythere dividera* (Gruendel), *Clithrocytheridea decumana* Triebel, *Dolocythere rara* Mertens and *Pseudobythocythere goerlichi* Mertens, which are typical of these rocks. Sediments of the *nolani* Subzone exposed at Stedum and Sarstedt-Kipphut are almost devoid of ammonites. On the other hand, the rest of the *jacob*i Zone has yielded rich and well-preserved faunas of *Hypacanthoplites* and *Callizoniceras,* made famous by the former pits of Algermissen and Vöhrum and now exposed at Schwiecheldt, and in new pits at Immensen and Arpke. In Germany the *jacobi* Zone (including the *nolani* Subzone) was formerly put in the Lower Albian.

Thicknesses of Aptian strata vary widely. From a few metres at the margins of the basin and in the Pompeckj's Swell they pass into sequences of 200 metres (near Rheine) and 300 metres (west of Peine) in the central part of the basin and in the troughs in front of the Rhenanian massif.

3. The Albian stage

The Albian may be defined for our region as the period of time beginning with the appearance of *Proleymeriella schrammeni* (Jacob) and ending with the incoming of *Inoceramus crippsi* Mantell and *Neohibolites ultimus* (d'Orbigny). An analysis of Albian strata in Germany is especially difficult because of facies variations. Furthermore, except in the Lower Albian, ammonites are extremely rare and thicknesses of individual zones vary greatly as a result of tectonic movements. For the same reason there are several non-sequences at different horizons. The following account relies on the calibration of fixed points in the evolving ostracod lineages against the few finds of index-ammonites. Ammonite records (up to 1971) are plotted on Table 2.

The Lower Albian was the time when dark sediments prevailed over wide areas, though a variety of arenaceous and glauconitic equivalents were laid down along the southern margin of the basin. The sandstones are: the glauconitic-sideritic Rothenberg Sandstone near Rheine, the Dörenther Sandstone west of Osnabrück (region where the Osning Sandstone is split by shaly intercalations), the upper part of the Osning Sandstone and the glauconitic and spiculiferous Hils Sandstone.

The lowermost beds, the *Proleymeriella schrammeni* and *Leymeriella tardefurcata* Zones, are in a clay facies which cannot be distinguished lithologically from that of the underlying *jacobi* Zone of the uppermost Aptian. However, the index-ammonites are always abundant. Their derivation from the Desmocerataceae (*Callizoniceras*) was demonstrated by Brinkmann (1937) and rich collections illustrating this phylogeny still exist. *Hypacanthoplites* (especially *H. anglicus* Casey and forms of the *elegans-hanovrensis* group) persist into the Albian; some examples are non-tuberculate already at 10 mm diameter. The enriched benthonic fauna indicates improved circulation (which had begun already in late *jacobi* times), though arenaceous foraminifera continued to prevail.

Regarding the ecology, the occurrence of superbly preserved molluscan faunas, especially gastropods, in the *schrammeni* Zone of Algermissen (old abandoned pit), described by Wollemann (1903, 1909, 1912) is remarkable. Small tooth-like corals of the genus *Ceratotrochus* also occur. Many of these fossils, notably the pleurotomariids, naticids and corals, are usually seen in shallow-water or near-shore deposits; hence phases of good aeration may be postulated for the *schrammeni* Zone. Today there are only two exposures of this zone—the claypit west of Vöhrum (new pit: lowermost *schrammeni* Zone) and Algermissen (new pit: uppermost *schrammeni* Zone). Several exposures still exist of the succeeding *tardefurcata* Zone—Altwarmbüchen, Algermissen (new pit), Immensen (new pit) and Thiede. In this zone the fauna consists of abundant *Leymeriella,* rare *Hypacanthoplites* and thin-shelled *Aucellina* (especially *A. quaasi* Wollemann) which are abundant in some beds. Probably beginning already in the *schrammeni* Zone, but chiefly in the *tardefurcata* Zone, the basin was enlarged. Transgressive *tardefurcata* beds are known from the west, northwest and especially from the southeast (Brunswick-Salzgitter district) of the basin. Early authors called this transgressive horizon "Gaultkonglomerat". It has many phosphorite pebbles. Near Brunswick these beds are variegated and contain sideritic sandstone horizons.

The upper part of the *tardefurcata* Zone and the overlying Zone of *Leymeriella regularis* have not been exposed for several decades. Limited observations from

Table 2. Subdivision of the Albian stage

CENOMANIAN	ZONE	SUBZONE	PROOF OF INDEX FOSSILS & GAPS	OLD STRATIGRAPHICAL UNITS	
UPPER ALBIAN	*Stoliczkaia dispar*	*dispar-perinflatum*			
		substuderi	non sequence		
	Mortoniceras inflatum	*aequatorialis*	█	gryphaeoides Beds	Flammenmergel
		auritus	█		
		varicosum		sulcatus Beds	
	Dipoloceras cristatum	*orbignyi*			
		cristatum			
MIDDLE ALBIAN	*Hoplites lautus*	*daviesi* *nitidus*	█	concentricus Beds	minimus Clay and Greensand
	Hoplites loricatus	*meandrinus* *subdelaruei* *niobe* *intermedius*	█		
	Hoplites dentatus	*spathi* *lyelli* *eodentatus*	regional non sequence		
LOWER ALBIAN	*Douvilleiceras mammillatum*				
	Leymeriella regularis		█	regularis Clays	Hils and Rothenberg Sandstones
	Leymeriella tardefurcata		█ non sequence	tardefurcata Clays	
	Proleymeriella schrammeni		█		

borehole samples suggest that this was a time of increasing amelioration of conditions for benthonic species. Layers with intensive bioturbation increase and the previously monotonous dark grey colour of the rocks is relieved by faint brownish and greenish tints.

Perhaps beginning late in the *regularis* Zone, but more probably in the succeeding period, shallowing took place. *Inoceramus concentricus* Parkinson and *Neohibolites minimus* (Lister) appear in these shallow-water biotopes for the first time. Locally, the sediments are variegated (greenish or olive-grey) though dark colours prevail. The microfauna is still of Aptian type; typical Gault species are lacking and ancestral variants of *Gaudryina dividens* Grabert still persist.

As there are no surface exposures and thousands of boreholes have yielded only very poor megafossils, the age of these beds may never be determined with precision. They may in part belong to the Zone of *Douvilleiceras mammillatum:* representatives of *Douvilleiceras* are extremely rare in Germany (Seitz 1956). The basal part of the *Hoplites dentatus* Zone may be represented here, too.

Accumulation of Lower Albian sediments ended at most places with a lithological change which had its origin in tectonic movements more widespread than those of *tardefurcata* time. The pre-Austrian movements during the passage from Lower to Middle Albian time were the most important of the German Lower Cretaceous and fundamentally altered the Lower Saxony Basin. On the one hand uplift and shallowing took place in the northern half of the basin, while on the other hand the bounding massifs of the basin subsided, particularly the Rhenanian massif and the Pompeckj Swell, so that they were completely or partially inundated by the Middle Albian trangression. The few index-fossils that have been found show that unbroken sequences exist only in the central parts of the basin, from Georgsdorf in the west to Brunswick in the east. To the north and south, gaps, condensed beds and attenuated sequences are widespread.

Near Bielefeld, *Dimorphoplites* cf. *doris* Spath (*fide* H. G. Owen) and *Hoplites dentatus* (J. Sowerby) were found only a few metres above *Leymeriella* (Althoff and Seitz 1934). In the Alstätte Embayment dark Lower Albian is overlain by argillaceous greensands with *Hoplites* of the *spathi* Subzone, so that the *mammillatum* and early *dentatus* sediments seem to be absent here as well. Therefore a *spathi* Subzone transgression may be suggested, though in all these places there are some metres of undated sediments below. The immediate appearance of *Anahoplites* in the overlying "splendens Clays" supports this interpretation of a late Lower and early Middle Albian non-sequence. The same is true in general for the appearance of *Anahoplites* in a low position in the German Middle Albian and for the preponderance of *Dimorphoplites* in former exposures of this substage.

Further evidence of the importance of the Middle Albian transgression and for a *mammillatum*-early *dentatus* non-sequence in the marginal areas of the Lower Saxony Basin is given by the Emsbett section near Rheine (Müller 1896), where greensands with *Neohibolites* lap against a swell. At the base of this transgressive horizon remanié specimens of *Leymeriella* and *Hypacanthoplites* are said to have been found. The succeeding marls contain ammonites of late Middle and Upper Albian age. In boreholes west of Rheine 300 metres of strata intervene between this transgressive horizon and the Cenomanian.

Despite many uplifts, movements in the late Lower and early Middle Albian led to a widening of the seaways, resulting in the influx of new benthonic faunas. This produced the typical Gault fauna, which was able to evolve optimally in the now widespread shallow-water biotopes. This Gault faunal change was of unprecedented extent in the German Lower Cretaceous. Naturally, it is especially sharp in those areas where the *mammillatum*-early *dentatus* non-sequence occurs: but everywhere there is a great contrast with the faunas of arenaceous foraminifera of the relatively poorly aerated environments of the Lower Albian.

In the area of continuous sedimentation and thick sequences west of Peine and Brunswick (Dollbergen, Wendezelle) a microfauna occurs which is characteristically absent from most other areas. This is apparently the fauna of the *mammillatum* and early *dentatus* Zones. Although numerous microfossil species immigrated with the Gault faunal change, at first there were still considerable differences between the microfauna of the Anglo-Paris Basin and that of the Lower Saxony Basin. It was only gradually, mainly in the Upper Albian, that both basins acquired more and more species in common; even so, endemic species occurred in each basin. Ammonites prove to be the best fossils for inter-regional correlation.

Most of the Middle Albian sediments were deposited in *spathi* and *intermedius* Subzone times, and thus equivalents of both subzones are well represented, especially in the northern and central facies. Sediments of younger Middle Albian age are less well-known. There are indications that sediments of the *Hoplites lautus* Zone are thin, condensed and with non-sequences, at least in some marginal districts. According to H. G. Owen (unpublished) the Middle/Upper Albian boundary in Germany is much lower than German workers have so far suggested: thus the Middle Albian is rather thin (at most places much less than 50 metres) in contrast to the very thick and important Upper Albian (up to 300 metres).

As in the Upper Aptian, different facies must be distinguished in the Middle Albian, i.e. in the *loricatus* and *lautus* Zones. All facies have in common a higher carbonate content than the Lower Albian rocks and a wide distribution of shallow-water biotopes. The benthonic microfauna is therefore rich and is represented by large individuals. Even more characteristic is the abundance of *Inoceramus concentricus* in these marls—hence the "Concentricus Schichten" of early authors. These beds are easily recognizable by the large numbers of *Inoceramus*-prisms present in washed residues; *Neohibolites minimus,* with three subspecies, is another important fossil (Spaeth 1971).

The Northern facies (Staffhorst, Thoeren, Lüneburg), of small thickness, has the highest carbonate content. It covered the whole of the Pompeckj's Swell. The rocks are pale and variegated with frequent reddish intercalations. This facies continued to the early Upper Albian. In the Pompeckj's Swell and in the north (Lüneberg, Hamburg, Schleswig), however, prisms and red coloration may range higher into the Upper Albian. Typical brachiopods of this facies are *Kingena lima* (Defrance) (Ernst 1927) and *Terebrirostra neocomiensis* (d'Orbigny).

The strata of the central facies (Georgsdorf, north and east of Hanover and near Peine) are medium grey in colour and much thicker. Their benthonic microfauna (foraminifera and ostracoda) is relatively rich. West of Rheine dark sediments with impoverished faunas accumulated; this may be called the Rheine facies, best interpreted as a special development of the central facies. To the southeast the central facies passes into the lithologically similar "minimus Clay" (or southeast facies), which overlies the Hils Sandstone in the Hils, Sackwald and Harz Foreland. The minimus Clay—named after the belemnite *N. minimus*—marks the transgressive phase of the Middle Albian.

The microfauna is not uniformly rich. An abundance of *Arenobulimina* and radiolaria is typical of the southern region of the minimus Clay. *Inoceramus concentricus* is generally not common and is completely missing in the deposits of the more deeply subsiding areas in front of the Rhenanian massif. In the shallow-water areas of the east it may be frequent (Konrad 1 shaft). Silt, fine quartz grains and glauconite commonly occur and phosphorite is an important local component.

Compared with those of the central and northern facies, sediments of the south differ critically in the possession of sponge remains and glauconite. The sponges become more numerous in the Upper Albian. The presence of this sponge-glauconite facies in the south throughout almost the whole of the Albian is a remarkable and unexplained feature. Ecological analysis is difficult because only isolated spicules are preserved. The comparable abundance of radiolaria in the Middle Albian of the southern regions of the basin indicates another marine chemical regime. Presumably several factors contributed to this unusual environment.

Similar conditions occurred in the southwest, where the Osning Greensand or southwest facies appears in the Alstätte Embayment. Here again, typical constituents are *Neohibolites minimus,* glauconite, phosphorite, *Inoceramus*-prisms and sponge-spicules (Ölbach, south of Ahaus). The lithology oscillates between argillaceous greensands and glauconitic-arenaceous shales and mudstones, the bottom beds having the highest quartz and glauconite contents.

Everywhere in the south these argillaceous-glauconitic sediments with incomplete and partly condensed sequences are typical of the transgressive Middle Albian. They cover the northern part of the Rhenanian massif (Schuster and Wolburg 1962; Ellermann 1962). The following fauna was reported from these rocks near Bielefeld by Althoff and Seitz (1934): *Ostrea vesicularis* Lamarck, *Exogyra* sp., *Lima* sp., *Pecten behrensi* Wollemann, *P. orbicularis* J. Sowerby, *Pteria* cf. *rauliniana* (d'Orbigny), *Neithea morrisi* (Pictet and Roux), *Plicatula* sp., *Pholodomya* sp., *Dentalium* sp., *Pleurotomaria* sp., and *Terebratula dutempleana* d'Orbigny.

There are suggestions (though it is not completely clear) that the Upper Albian may transgress in places (Konrad 1 shaft, Staffhorst, Thoeren 30 and Hanover (?)), as in the Anglo-Paris Basin. However, if this transgression really does exist (and in Schlumberger logs it cannot be distinguished from condensed horizons), it is much less important than the succeeding transgression of the *Stoliczkaia dispar* Zone.

A very significant marker-horizon in Germany is provided by the entry of *Inoceramus sulcatus* Parkinson, which was derived from *I. concentricus* approximately at the passage from Middle to Upper Albian (Woods 1912; Owen 1971). Another marker-horizon in the Upper Albian is provided by the sudden appearance of large numbers of *Aucellina coquandiana* (d'Orbigny) (=*gryphaeoides* J. de C. Sowerby), which remains abundant through the rest of the Albian and into the Cenomanian. In Germany the name *A. gryphaeoides* has been used up till now, but it is possible that other species also occur; further research is required. At Folkestone (England) the sudden appearance of *Aucellina* took place in the *auritus* Subzone of the *Mortoniceras inflatum* Zone and there are strong indications that it was synchronous elsewhere. *A. coquandiana* is distributed in all facies and is therefore a guide-fossil of great value.

As in the Middle Albian, different facies-regions have to be distinguished in the Upper Albian. These are the Flammenmergel, Hanover facies, and Rheine facies, all being open-sea sediments equivalent to the Upper Greensand of England. Only in the highest Upper Albian did uniform sedimentary conditions prevail with the onset of the Bemerode facies (after Bemerode, near Hanover (see also Bertram and Kemper 1971). In the region of the Hanover facies, i.e. the middle and northern part of the basin and the Pompeckj's Swell, lithology is similar to that of the Middle Albian. Rich *Inoceramus* faunas and variegated colours characterize the lowermost Upper Albian sediments of the Pompeckj's Swell. In the region of Rheine and Burgsteinfurt dark sediments with impoverished benthonic faunas were deposited (Rheine facies). Foraminifera of the genus *Arenobulimina* prevail and radiolaria are typical. This facies has been encountered only in boreholes and is therefore poorly known.

Better known is the facies of the south and southeast, the so-called "Flammenmergel", which is well exposed and forms geomorphological features (see Jordan and Schmid 1968; Jordan 1968). The Flammenmergel is a spiculiferous carbonate showing strong bioturbation. The silica of the spicules has been mobilized in different degrees to form siliceous limestones ("Kieselkalke"). The Flammenmergel is thus comparable with the "malmstone" of England. It yielded a fine ammonite fauna, with species of *Mortoniceras* and *Puzosia,* near Salzgitter at the Hillenberg (in the collection of the Niedersächsisches Landesamt für Bodenforschung, Hanover). *Aucellina coquandiana* is also common in this facies; in addition Jordan and Schmid (1968) reported Rhychonellidae, *Pleurotomaria* sp., *Gastrochaena* sp., *Ostrea* sp., *Anomia* sp., *Lima gaultina* Woods, *Crenella orbicularis* (J. de C. Sowerby) and *Plicatula gurgitis* Pictet and Roux.

Presumably the Flammenmergel accumulated in warm shallow water some distance off the shore. Interfingering with the minimus Clay facies has been observed in several places. At different localities the Flammenmergel facies begins at different horizons. In the southeast (Bielefeld, Sackwald, Hohensassel) it begins in the Middle Albian (*lautus* Zone?). Further north (Konrad 1) it begins later, in the *cristatum* or even in the early *inflatum* Zone.

It is uncertain when the Flammenmergel facies ended. Fossils found by Jordan and Schmid (1968) may have originated in the *substuderi* Subzone of the *dispar* Zone. In the *dispar-perinflatum* Subzone (and perhaps a little earlier in the west) uplift, followed by denudation, took place in the course of the pre-Austrian movements, affecting essentially the margins and areas adjacent to the old massifs. The youngest strata of the Upper Albian, presumably corresponding to the "Vraconian", therefore succeed with more or less strong disconformity in the marginal regions. Sandstones are known only from the Rhenanian massif—the Altenbeken and Rüthen Greensands.

Apart from these greensands, the strata are very uniform in contrast to the preceding and are here called the Bemerode facies. Of all Albian sequences this facies has the greatest areal distribution, covering vast areas of the bordering massifs. The Bemerode beds are readily recognisable in boreholes because of their low resistivity values and the profile of the potential curve on electrical logs, for the clay content of the earlier beds is here partly replaced by silt. The rocks are darker than previously in the lower part but become paler upwards. The ostracod and foraminifera fauna is rich; radiolaria are often abundant, but not present everywhere.

To these beds must be attributed presumably the thin clay-marl observed between the Flammenmergel and the Cenomanian near Salzgitter (Gitter-Berg and Flöteberg), as well as the corresponding dark-grey to black marls of Altenbeken, Iburg and of the boreholes near Rheine. The higher "Glauconitmergel" (Müller 1896) near Rheine could be interpreted as the transgressive horizon of the Bemerode beds.

As the discordance shows, the tectonic processes in this phase of the Austrian orogeny must have been considerable. After this phase an expansion of the sea took place in the Upper Albian (*dispar* Zone) which did not fall significantly short of that of the Cenomanian. The upper surface of the Bemerode beds was itself eroded during a renewed transgression that carried the Cenomanian beyond the earlier margins of the Lower Saxony Basin. Each phase of movement resulted in the denudation of several metres of earlier sediments in the marginal regions, as is best known from the west. Valid statements on the thicknesses of Albian beds in Germany are scarcely possible. The Lower Albian may reach up to 200 metres and the Upper Albian 300 metres. Normally the Middle Albian is considerably less than 50 metres. In the environs of Hanover the Upper Albian is especially thick.

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Neohibolites ernsti and its occurrence in the Upper Albian of northwest Germany and England

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The belemnite *Neohibolites ernsti* Spaeth is briefly defined and its stratigraphical horizon (upper *cristatum* and *inflatum* Zone) shown in the Upper Albian of Lüneburg and Salzgitter, northwest Germany. In England the species has been found in similar horizons in Kent, Norfolk, Lincolnshire and Yorkshire. Further study of the English occurrences, which are subject to a rigid ammonite zonal control, should increase the usefulness of *N. ernsti* as a means of correlation with the northwest German Upper Albian basin-facies, in which ammonites are lacking.

Die Belemnitenart *Neohibolites ernsti* Spaeth sowie ihr stratigraphisches Auftreten im nordwestdeutschen Ober-Albium (Ober *cristatum* Zone und *inflatum* Zone) von Lüneburg und Salzgitter wird kurz charakterisiert. In England konnte das Auftreten dieser Art in entsprechender stratigraphischer Position in den untersuchten Profilen von Kent, Norfolk, Lincolnshire und Yorkshire festgestellt werden. Weitere Untersuchungen der englischen Vorkommen mit ihrer gut definierten Gliederung in Ammonitenzonen dürften den Wert von *N. ernsti* als Leitform für die extrem ammonitenarme Beckenfazies des nordwestdeutschen Ober-Albium unterstreichen.

La Bélemnite *Neohibolites ernsti* Spaeth est brièvement définie et son horizon stratigraphique (sommet de la zone à *Cristatum* et zone à *Inflatum*) est précisé dans l'Albien supérieur de Lüneburg et de Salzgitter (N-W de l'Allemagne). En Angleterre, cette espèce a été rencontrée à des niveaux identiques dans le Kent, le Norfolk, le Lincolnshire et le Yorkshire. Une étude supplémentaire des récoltes anglaises, soumises au strict contrôle zonal des Ammonites, devrait accroître l'utilité de *N. ernsti* comme outil de corrélation avec les faciès néoalbiens d'Allemagne du Nord-Ouest où les Ammonites font défaut.

1. Introduction

The Tethyan belemnite genus *Neohibolites* is quite abundant, with many species, subspecies and local variants, in the Aptian and Albian strata of northwest Europe, Poland and the western part of the Soviet Union, as well as in Bulgaria, Rumania, and Sardinia. In regions where ammonite faunas of this age are rare or absent the succession of *Neohibolites* species can be used for indirectly determining the ammonite zones, as was first pointed out by Stolley (1937).

As a result of a recent revision of *Neohibolites minimus* (Miller 1826) and allied forms from the northwest German Middle and Upper Albian, two significant new species were delimited in the Upper Albian (Spaeth 1971). Though statistical studies have not yielded clear-cut distinctions, the species *Neohibolites oxycaudatus* Spaeth and *Neohibolites ernsti* Spaeth can easily be distinguished from each other by particular differences in the shape of their guards.

2. *Neohibolites ernsti* Spaeth

As in the whole group of Middle and Upper Albian *Neohibolites,* at least 60 per cent of all adult stages of *N. ernsti* developed an epirostrum (*sensu* Müller-Stoll 1936) which overgrows the characteristic shape of the elongated posterior end of the orthorostrum. Because of this only sections can be used for exact specific determination. Sometimes also natural weathering of at least parts of the epirostrum might expose the posterior end of the orthorostrum (Fig. 1a).

For easier determination of *N. ernsti,* breaking the posterior part of the epirostrum often helps one observe the typical rectangular shape of the dorsoventrally flattened apical end of the orthorostrum; this is seen in cross-sections of orthorostra. The tip is entirely enclosed in the subsequent growth lamellae of the epirostrum which mostly show a tendency to a circular outline in cross-section. Adult epirostra may even tend to a lateral flattening in their final growth stages (Fig. 1c). On the other hand adult specimens of the ancestral species *Neohibolites oxycaudatus* (though linked by some transitional forms), can clearly be identified by the entirely circular posterior portion of the guard, which has an acutely rounded tip in both ortho- and epirostra (Fig. 1d).

3. Stratigraphical occurrence

The delimitation of the two upper Albian *Neohibolites* species was based on some two hundred specimens, carefully recorded in bed-by-bed collections from a section at Lüneburg, south of Hamburg, and two sections in the Salzgitter region, south of Brunswick, in West Germany (Fig. 2). The limits of the beds containing *N. ernsti* are rather distinct in these sections, although the exact stratigraphical position of the horizons is still difficult to define in accordance with ammonite zones. Occasional broken pieces of ammonites, e.g. *Euhoplites alphalautus* Spath, suggest that the occurrence of *N. ernsti* is restricted to the *orbignyi, varicosum,* and *auritus* Subzones of the higher *Dipoloceras cristatum* and lower *Mortoniceras inflatum* Zones of the Upper Albian (the zones are after Collignon 1965, and the subzones after Spath 1941). Milbourne (1963) pointed out the increase in numbers of individuals of *Neohibolites* in the *inflatum* Zone (apparently with

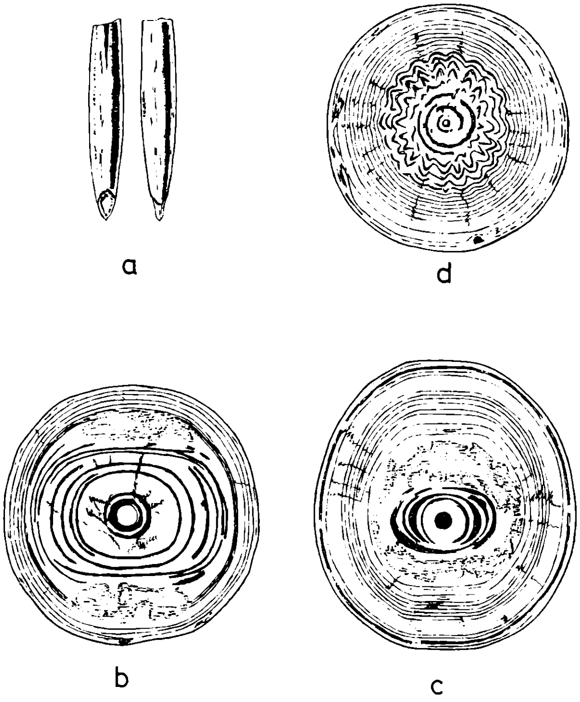

Fig. 1. *Neohibolites ernsti* Spaeth and *N. oxycaudatus* Spaeth.

a *N. ernsti* (left, ventral view: right, lateral view) from the Upper Albian, lower *inflatum* Zone, of Lüneburg, northwest Germany. Because of the partial corrosion of the epirostrum the apical end of the orthorostrum is clearly visible and shows the difference in shape in ventral and (flattened) lateral aspect (x 0·7).

b Cross-section through the apical region of *N. ernsti*, showing the inner dorsoventrally flattened orthorostrum, overgrown by epirostral lamellae with circular outline in the outer part (x 10).

c Cross-section through the apical region, near the tip, of an adult *N. ernsti*. The inner part shows the dorsoventrally flattened apical end of the orthorostrum. The middle part, which is the first growth-stage of the epirostrum, is disordered by corrosion. The outer part shows the lamellae of the epirostrum with slight lateral compression (x 10).

d Cross-section through the apical part of an adult *N. oxycaudatus* from the Upper Albian, *cristatum* Zone, of Lüneburg, northwest Germany. In contrast with *N. ernsti*, *N. oxycaudatus* constantly shows a rounded apical part and tip of the orthorostrum. The inner part of the epirostrum shows the zig-zag outline of the lamellae in cross-section, while the outer part shows concentric growth lamellae (x 10).

some new species not listed by Swinnerton 1955) in several Albian sections in southeast England. It is therefore of great interest to compare some of the British belemnite records (located according to the well-defined ammonite zones) with northwest German Upper Albian forms.

3a Germany

In the shaly marls of the basin facies of the Lüneburg succession (Fig. 2 loc. 8) *Neohibolites ernsti* is common from beds 28 to 38. This stratigraphical range can be considered to represent the lower part of the *inflatum* Zone, and possibly includes the highest part of the *cristatum* Zone. No ammonites have been found during recent collecting: however, Ernst (1922 p. 318) described small pyritized individuals of *Mortoniceras inflatum* (J. Sowerby) from these beds (see also Schmid 1962).

In the Salzgitter region, the Upper Albian of the margins of the Lower Saxony Basin is predominantly developed as a gaize, a spongilitic marl ("Flammenmergel": see Kemper, this volume). The spongilite beds, with poorly preserved fauna, are intercalated with thin shaly layers, which in the lower part contain a very few belemnites.

In the two sections at Salzgitter (Fig. 2 locs 9 and 10) *N. ernsti* is rare and only found in a very limited succession. In section 10 (Fig. 2) the occurrence of this species is restricted to bed 6. This, consisting of marly shale and containing irregularly distributed phosphatic nodules, is enriched with glauconite and can be regarded as a reworked and extremely condensed bed. Bed 6 of section 10, and bed 0 of section 9 are considered to represent at least part of the *inflatum* Zone. This is suggested by some broken and badly preserved ammonite fragments from the underlying beds which are provisionally determined as *Dimorphoplites* sp. and *Euhoplites* sp., which might indicate the *cristatum* Zone.

Additional evidence that the zonal distribution of *N. ernsti* is from the upper *cristatum* Zone to the lower or middle *inflatum* Zone was obtained from the Upper Albian outcrops of the Sackwald, about 70 kilometres south of Hanover. Jordan and Schmid (1968 pp. 63, 64) pointed out that *N. minimus* "*stolleyi* Ernst" appears in the *varicosum* Subzone, followed in the overlying beds by *N. minimus* "*intermedius* Ernst". This part of the section is assumed to represent the lower *inflatum* Zone, in part the *auritus* Subzone. Since it was possible in 1969 to collect distinct specimens of *N. ernsti* in these overlying beds (Spaeth 1971 pl. 8 fig. 2) it is obvious that at least some of the young and fragmentary individuals of *N. minimus* "*intermedius* Ernst" collected by Jordan and Schmid (1968) belong to *N. ernsti*. This allows indirectly the assumption of a lower *inflatum* range, which is supported (Spaeth 1971) by the fact that *N. minimus* "*stolleyi* Ernst" of the underlying beds is synonymous with *N. oxycaudatus* of middle and upper *cristatum* age.

3b England

In 1971 and 1972 the author collected *Neohibolites ernsti* from the well-defined ammonite zones and subzones exposed in the English Upper Albian outcrops at Wrotham, Kent (Fig. 2 loc. 7; section described by Milbourne 1963) and Ashford, Kent (Fig. 2 loc. 6; section from H. G. Owen, unpublished). In the Ashford Brickworks clay-pit the *cristatum* and *orbignyi* Subzones and part of the *varicosum* Subzone were well exposed in September 1972. The succession of *N. minimus minimus* (Miller), *N. oxycaudatus,* and *N. ernsti* was clearly observed

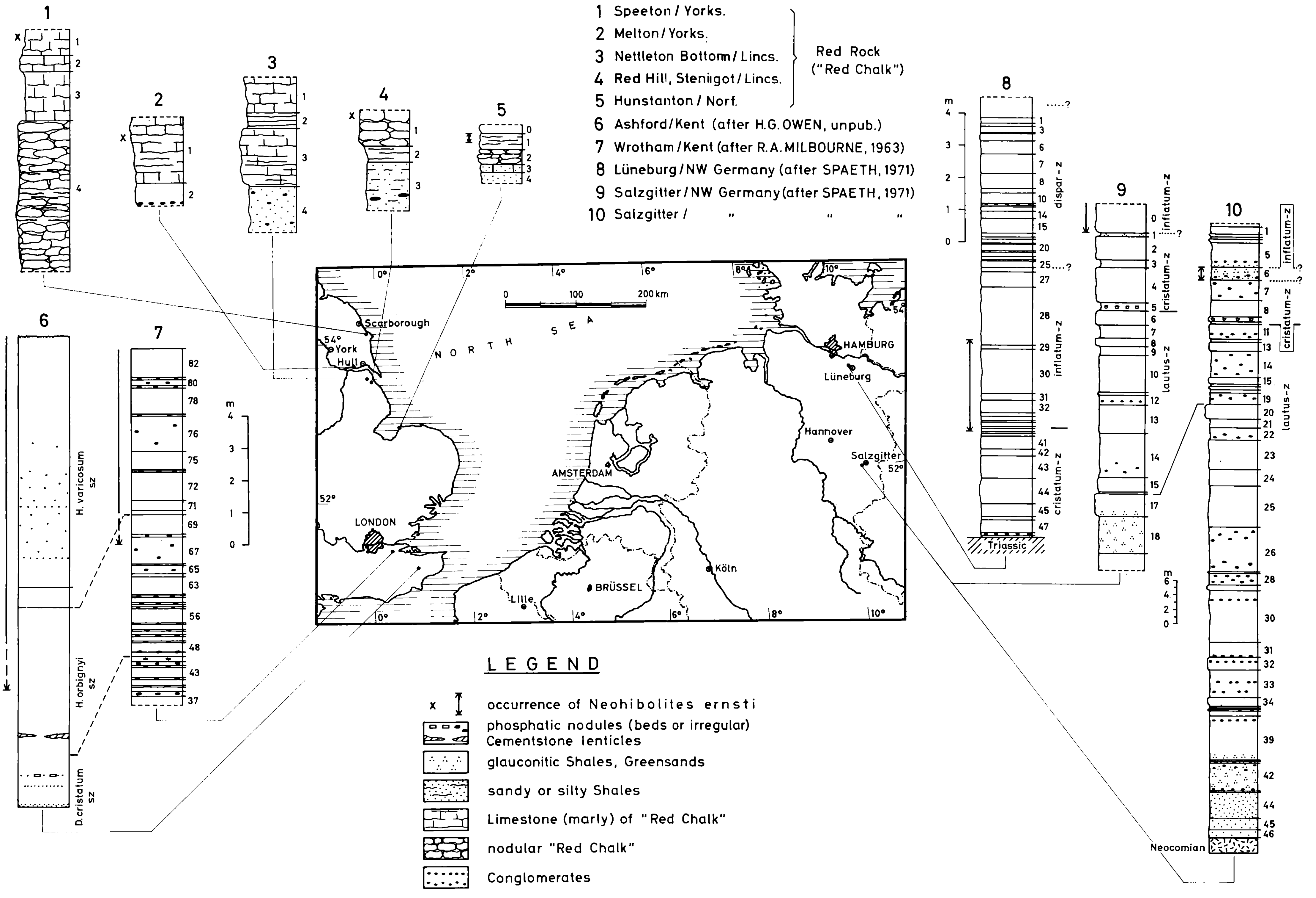

Fig. 2. Middle and Upper Albian sections in northwest Germany (right) and eastern and southeastern England (left). (Ammonite zones after Collignon 1965, subzones after Spath 1941, p. 668).

during the collecting in these subzones. Belemnites could be recorded together with a considerable number of characteristic ammonites. The results of collecting proved to be in absolute accordance with the vertical distribution of *Neohibolites* species in the main German section of Lüneburg.

The Ashford section yielded numerous *N. minimus minimus* in the basal part of the *cristatum* Subzone, together with *Inoceramus sulcatus* Parkinson. In the overlying clays of the *orbignyi* Subzone the beds contain numerous individuals of *N. oxycaudatus*, increasing in abundance upwards, together with *Hysteroceras orbignyi* (Spath) and other characteristic ammonite species. In the overlying beds of the upper *cristatum* Zone *N. ernsti* predominates, but *N. oxycaudatus* also occurs, its numbers decreasing upwards. *Hysteroceras varicosum* (J. de C. Sowerby) and *Euhoplites alphalautus* Spath are abundant, and it appears that the uppermost part of the clay-pit ends within the middle part of the *varicosum* Subzone.

Although the Upper Albian beds of the Wrotham clay-pit were not well enough exposed for bed-by-bed collecting in 1971, it was still possible to identify the upper *cristatum* Zone and the lower *inflatum* Zone. Many individuals of *N. ernsti* were found together with *Hysteroceras varicosum* (J. de C. Sowerby) and *Euhoplites alphalautus* Spath, indicating the *varicosum* Subzone. The topmost beds of the pit still yielded *N. ernsti* in association with small specimens of *Mortoniceras inflatum* (J. Sowerby).

With one exception the Red Chalk ("Hunstanton Red Rock") outcrops of eastern England (Fig. 2 locs 1–5) were found also to contain *N. ernsti* in their higher levels. Even in the most condensed section at Hunstanton, Norfolk (described by Larwood 1961) the occurrence of *N. oxycaudatus* and especially of *N. ernsti* is obviously restricted to the upper bed (see Fig. 2 loc. 5).

Because ammonites are in general very rare or even absent in the Red Chalk* it is impossible to zone the beds accurately. However, the fact that *Neohibolites ernsti* is not found lower stratigraphically than the upper *cristatum* Zone suggests the possible indirect indication of this horizon in the Red Chalk section.

Generally *N. minmus minimus* (Miller) is abundant in the lower part of these sections. The author has also found a few examples of *N. oxycaudatus*.

The Red Chalk sections are described briefly:

1. *Speeton Cliff, Yorkshire*

Bed No.	metres	Lithology
(1)	0·80	Dark brick-red marly limestone with sparsely scattered *Neohibolites minimus* and very rare *N. ernsti* in the uppermost part.
(2)	0.50	Light-red hard marly limestone, sparsely fossiliferous, with *N. minimus minimus.*
(3)	1.50	Dark brick-red marly limestone with white patches.
(4)	5·00	Red nodular marly limestone beds with several white bands (up to 0·05 m thickness) and thin marl bands. Lower part obscured by beach-pebbles.

2. *Melton, Yorkshire*

Bed No.	metres	Lithology
(1)	2·00	Pale brick-red marly limestone, upper part more calcareous, lower part more shaly. Numerous *N. minimus minimus* and very sparse *N. ernsti* in the higher part. The bottom grades into
(2)	0·60	Carstone sands with brachiopods (Owen, Rawson and Whitham 1968) and corroded *N. minimus minimus* in the topmost bed.

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* In the collection of Albian fossils in the Institute of Geological Sciences a specimen of *Mortoniceras* (*Deiradoceras*) *cunningtoni* Spath is the only ammonite indicating the *auritus* Subzone of the upper *inflatum* Zone.

3. *Nettleton Bottom, Lincolnshire*

Bed No.	metres	Lithology
(1)	2·00	White marly chalk (Cenomanian).
(2)	0·40	Pale yellow-weathering calcareous marl with Lebensspuren (Cenomanian?).
(3)	1·70	Brick-red hard limestone, partly nodular with abundant *N. minimus minimus* in the lowest 0·50 m, and scattered small pebbles, increasing in diameter and numbers towards bottom.
(4)	5·00	Carstone sands, enriched in pebbles. Base not exposed.

4. *Red Hill, Stenigot, Lincolnshire*

Bed No.	metres	Lithology
(1)	1·15	Pink nodular limestone with thin marl bands, at the base darker red, with quartz grains, *Inoceramus* fragments and terebratuloid brachiopods. *N. minimus minimus* is abundant, *N. ernsti* rare.[1]
(2)	ca. 0·50	Red marly bed with numerous *N. minimus minimus.*
(3)	ca. 1·50 exposed	Green-brownish weathering, slightly calcareous and ferruginous sands with burrows and concretions. Uppermost part coloured red (by infiltration) (Carstone). Base not exposed.

5. *Hunstanton Cliff, Norfolk*

Bed No.	metres	Lithology (Larwood 1961, modified)
(1)	0·30	Mottled pale or dark pink hard nodular limestone with abundant *N. minimus minimus* and rare *N. ernsti.*
(2)	0·60	Darker pink, partly nodular limestone with many small pebbles and a high proportion of quartz grains; *N. minimus minimus* abundant.
(3)	0·25	Pale pink sandy and soft, marly calcareous bed with scattered small pebbles and limonite-coated quartz grains; sparsely scattered *N. minimus minimus* and *N. minimus pinguis* Stolley. Towards bottom grading into
(4)	3·00	Carstone, fine, brown, sandy.

4. Conclusions

As a result of bed-by-bed collecting in the Upper Albian of northwest Germany and southeastern and eastern England, it is clear that *Neohibolites ernsti* first appears in the higher part of the *cristatum* Zone. Though there is some evidence that this species reaches the higher *inflatum* Zone (up to the "*aequatorialis*" Subzone of Spath), it is so far impossible to relate the highest stratigraphical occurrence to an exact ammonite zonation in the studied sections. Because of the general rarity of ammonites in the Middle and Upper Albian of northwest Germany the ammonite zonation here can be established only indirectly, with the help of *N. oxycaudatus* and *N. ernsti.* (In the northwest German basin facies [Lüneburg] the latter belemnite is followed by the species *N. praeultimus* Spaeth, which doubtless extends to the *Stoliczkaia dispar* Zone [Spaeth 1971]).

More detailed studies of the stratigraphical distribution of English Upper Albian *Neohibolites* species in relation to the well-defined ammonite zones might yield a useful correlation scheme, possibly transferable in detail to northern France (Boulonnais) and northwest Germany.

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[1] *Neohibolites ultimus* (d'Orbigny), listed by Larwood (1961) after Whitaker and Jukes-Brown (1889), has not been found here and does not occur in the Upper Albian (Spaeth 1971).

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The stratigraphy and palaeogeography of the Lower Cretaceous deposits of the Polish Lowland area

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In the Polish Lowland area the Lower Cretaceous deposits are limited mainly to a sedimentary furrow situated between the East European Platform and the Fore-Sudetic Variscan platform. These deposits, up to 600 metres in thickness, are represented by clayey-arenaceous formations of a shallow epicontinental marine basin. The younger stages of the Lower Cretaceous as a rule overlap the older ones. The Berriasian, Valanginian and Hauterivian are evidenced by ammonites and microfauna. In its lowermost part, the Berriasian is developed in a brackish-marine facies yielding ostracods of Serpulite age. A group of azoic, principally arenaceous, deposits overlying the Hauterivian is tentatively referred to the Barremian, Aptian, and Lower and Middle Albian.

Im Raum des polnischen Flachlandes sind Ablagerungen der Unterkreide hauptsächlich an einen Sedimentationstrog gebunden, der im Osten von der Osteuropäischen Plattform und im Westen von der Vor-Sudetisch-Variskischen Plattform begrenzt war. Die bis zu 600 m mächtigen Ablagerungen sind tonig bis sandig entwickelt und bildeten sich in einem flachen, epikontinentalen Meeresbecken. Die jüngeren Stufen der Unterkreide greifen generell über die älteren hinweg. Berrias, Valangin und Hauterive wurden durch Ammoniten und Mikrofaunen nachgewiesen. Die ältesten Schichten des Berrias entstanden zum Teil im brackischen Milieu und lieferten Serpulit-Ostrakoden. Fossilfreie und überwiegend sandige Sedimente im Hangenden des Hauterive werden vorerst dem Abschnitt Barreme bis Mittelalb zugeordnet.

En Basse-Pologne, les dépôts de Crétacé inférieur sont limitées principalement à un sillon sédimentaire compris entre la plateforme Est-européenne et la plateforme avant-sudète d'origine varisque. Ces dépôts, atteignant 600 m d'épaisseur, sont des formations argilo-sableuses d'un bassin marin épicontinental et peu profond. Les étages les plus récents du Crétacé inférieur reposent en règle générale sur les plus anciens. La présence de Berriasien, de Valanginien et d'Hauterivien est prouvée par des Ammonites et des microfaunes. Dans sa partie basale, le Berriasien est représenté par un faciès saumâtre qui fournit des Ostracodes d'un âge contemporain du banc à Serpulite. Un ensemble de dépôts azoïques, essentiellement arénacés, qui repose sur l'Hauterivien est attribué, sous réserve, au Barrémien, à l'Aptien et à l'Albien inférieur et moyen.

1. Introduction

In the Polish Lowland area Lower Cretaceous deposits are limited essentially to a large sedimentary unit called the Danish-Polish furrow, which is situated between the East European platform on the one side and the Variscan platform of the Fore-Sudetic area on the other. Accordingly, the major Lower Cretaceous deposits are restricted to the Kujavian-Pomeranian swell and the adjacent troughs. However, in the north and in parts of the southwestern area, small patches of Lower Cretaceous deposits are found also on the adjacent platform areas (Figs 1 and 2).

Except in the Carpathians, natural exposures of Lower Cretaceous rocks are found in Poland only along the margins of the Holy Cross Mountains. The best-known Neocomian exposure occurs in a brick yard at Wawal, south of Tomaszow Mazowiecki. On the northeastern margin of the Holy Cross Mountains

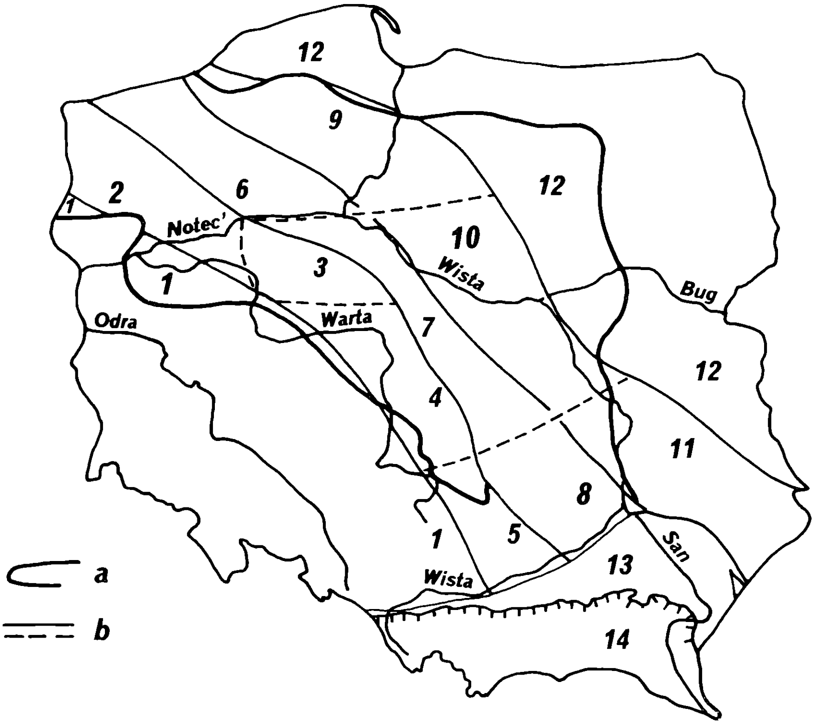

Fig. 1. Map of tectonic units.
(a) Present limit of Lower Cretaceous deposits.
(b) Boundary of tectonic units.

1—Sudetes, Fore-Sudetic monocline and Silesian-Cracow monocline

2—5. Szczecin-Miechów trough: 2—Szczecin trough, 3—Mogilno trough, 4—Łódź trough, 5 Miechów trough

6—8. Middle Polish swell: 6—Pomeranian swell, 7—Kujavian swell, 8—Gielniów swell and the Holy Cross Mountains

9-11. Marginal trough: 9—Pomeranian trough, 10—Warsaw trough, 11—Lublin trough

12. Precambrian platform

13. Carpathian foredeep

14. Carpathian Mountains.

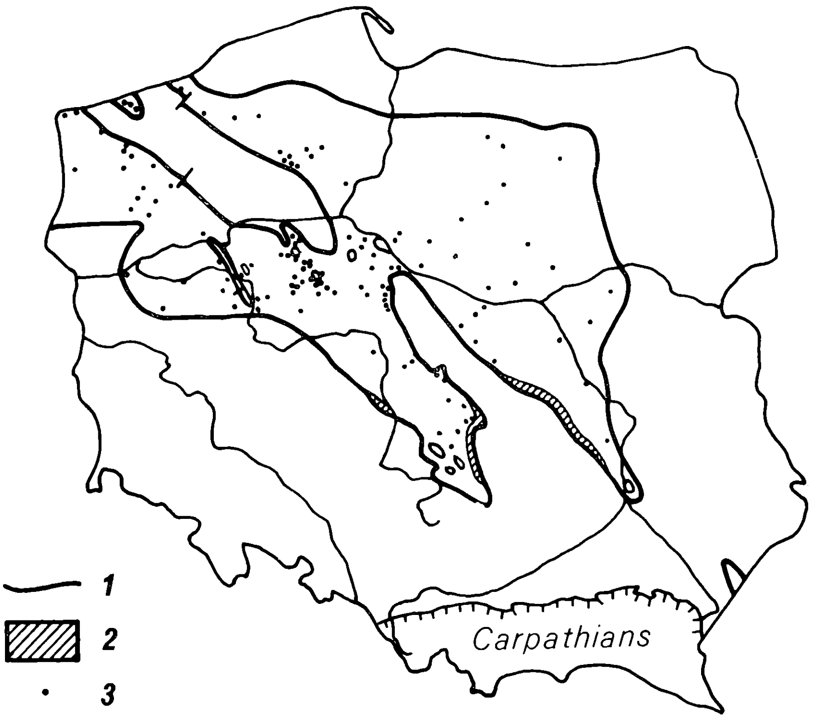

Fig. 2. Occurrence of the Lower Cretaceous (Carpathians excluded).
1. Present limits of Lower Cretaceous deposits
2. Lower Cretaceous outcrops
3. Important boreholes penetrating the Lower Cretaceous.

massif, Neocomian sediments lie beneath a thin overburden of Quaternary deposits in the vicinity of Ilza and Radom, where they can be observed in trial pits. A somewhat wider belt of exposures round the Holy Cross Mountains shows post-Hauterivian Lower Cretaceous deposits, tentatively referred to the Barremian, Aptian, and Lower and Middle Albian. Deposits of late Lower Cretaceous age are found also in the vicinity of Burzenin, near Sieradz, within the southwestern part of the Lodz trough.

Outside these areas, Lower Cretaceous deposits can be reached by drilling either through the Tertiary and Quaternary overburden, which varies from several dozen metres to two hundred metres in thickness (the Kujavian-Pomeranian swell: Fig. 1) or through a more-or-less thick cover, locally up to 3,000 metres, of Upper Cretaceous calcareous-marly deposits in the Mogilno trough region.

A complete sequence through the Lower Cretaceous occurs mainly in the area of the Kujavian-Pomeranian swell and within the adjacent parts of the Szczecin-Mogilno-Lodz trough and the Pomeranian-Warsaw trough. Here, sedimentary continuity can be observed in the Lower Cretaceous and Jurassic deposits, the thickness of the former locally reaching 600 metres (Fig. 3).

Thus, the Kujawy area marks the centre of the epicontinental Lower Cretaceous basin, its longitudinal axis being roughly in line with the southwestern part of the

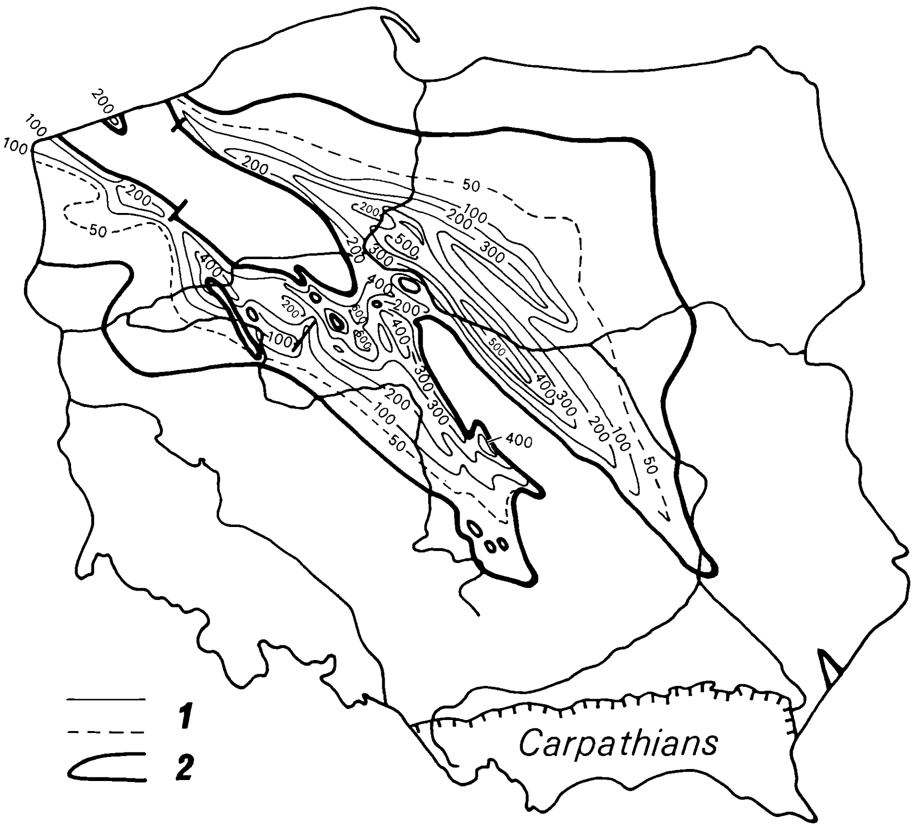

Fig. 3. Thickness of the Lower Cretaceous deposits (Carpathians excluded).
1. Isopachytes at 50, 100, or 200 metres intervals
2. Boundaries of sub-Tertiary outcrops of the Lower Cretaceous.

Kujavian-Pomeranian swell. The axis gradually rises in a northwestern direction in the Baltic areas, and in a southeastern direction towards the Holy Cross Mountains. In consequence of this, the northern Baltic areas reveal an incomplete section of the marine Berriasian (Ryazanian) deposits resting unconformably on various members of the early Portlandian, or Kimmeridgian (Dadlez and Dembowska 1965). Along the margins of the Holy Cross Mountains, marine deposits of Berriasian age immediately overlie Lower Portlandian formations (Witkowski 1969), and a series of Barremian-Middle Albian age also rests unconformably on the early Upper Jurassic formations. The latter series occurs mainly in the south of this region and overlaps the older Lower Cretaceous deposits.

Passing from this central area of the Lower Cretaceous sedimentary basin towards the northeastern and southeastern peripheral areas, beyond the Kujavian swell and the narrow adjacent zones of troughs, one observes a gradual reduction in thickness, increasing sedimentary and erosional gaps, and some facies changes related to the near-shore zone. Here the upper stages of the Lower Cretaceous overlap the lower members of this system, and rest unconformably on various

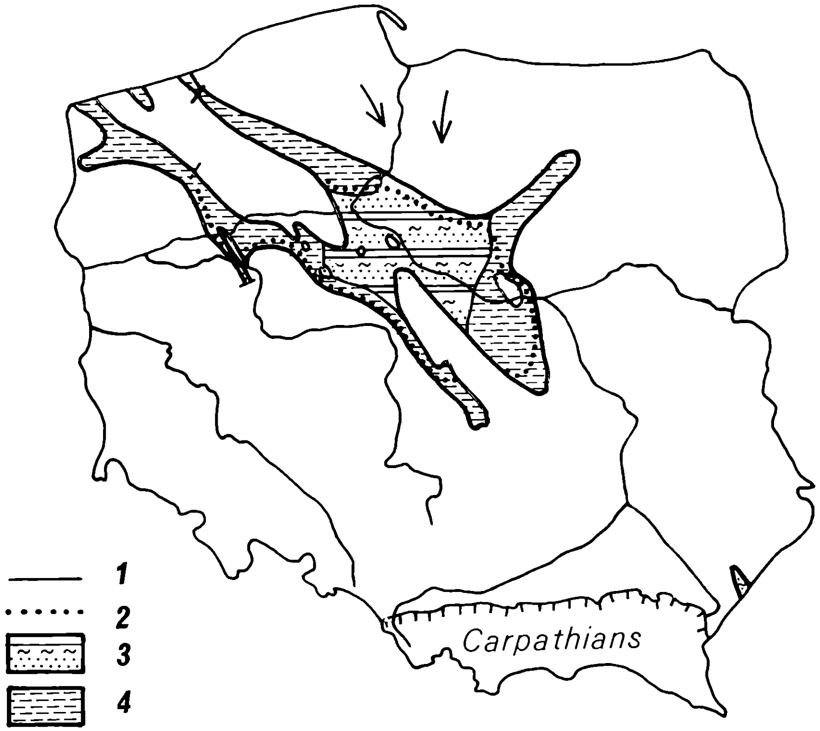

Fig. 4. Distribution of the main Berriasian and Lower Valanginian facies (Carpathians excluded).

1. Limit of marine Berriasian and Lower Valanginian deposits
2. Limit of brackish-marine Berriasian deposits
3. Claystones and siltstones, with calcareous sandstones at the base
4. Claystones and siltstones, locally arenaceous.

horizons of the Upper Jurassic, or, as in the southwestern part of the Szczecin trough and in the adjacent monocline, on Middle or Lower Jurassic (Raczyńska 1967).

2. Berriasian sediments

The Berriasian can be observed within a relatively small area of the Polish Lowland. From the northwestern margin of the Holy Cross Mountains its deposits extend along the Kujavian-Pomeranian swell and the narrow zones of the adjacent troughs, and continue as far as the Baltic Sea (Figs 4 and 5).

The lowermost brackish-marine deposits of Berriasian age are characterized by their limited extent. They continue here the brackish and Purbeckian conditions of the Upper Jurassic. However, the presence of glauconite, agglutinated foraminifers and isolated marine pelecypods indicates the influence of the Lower Cretaceous transgression (Marek 1967). The age of these formations is proved by *Cypridea* cf. *posticalis* Jones and other ostracods (Bielecka and Sztejn 1966;

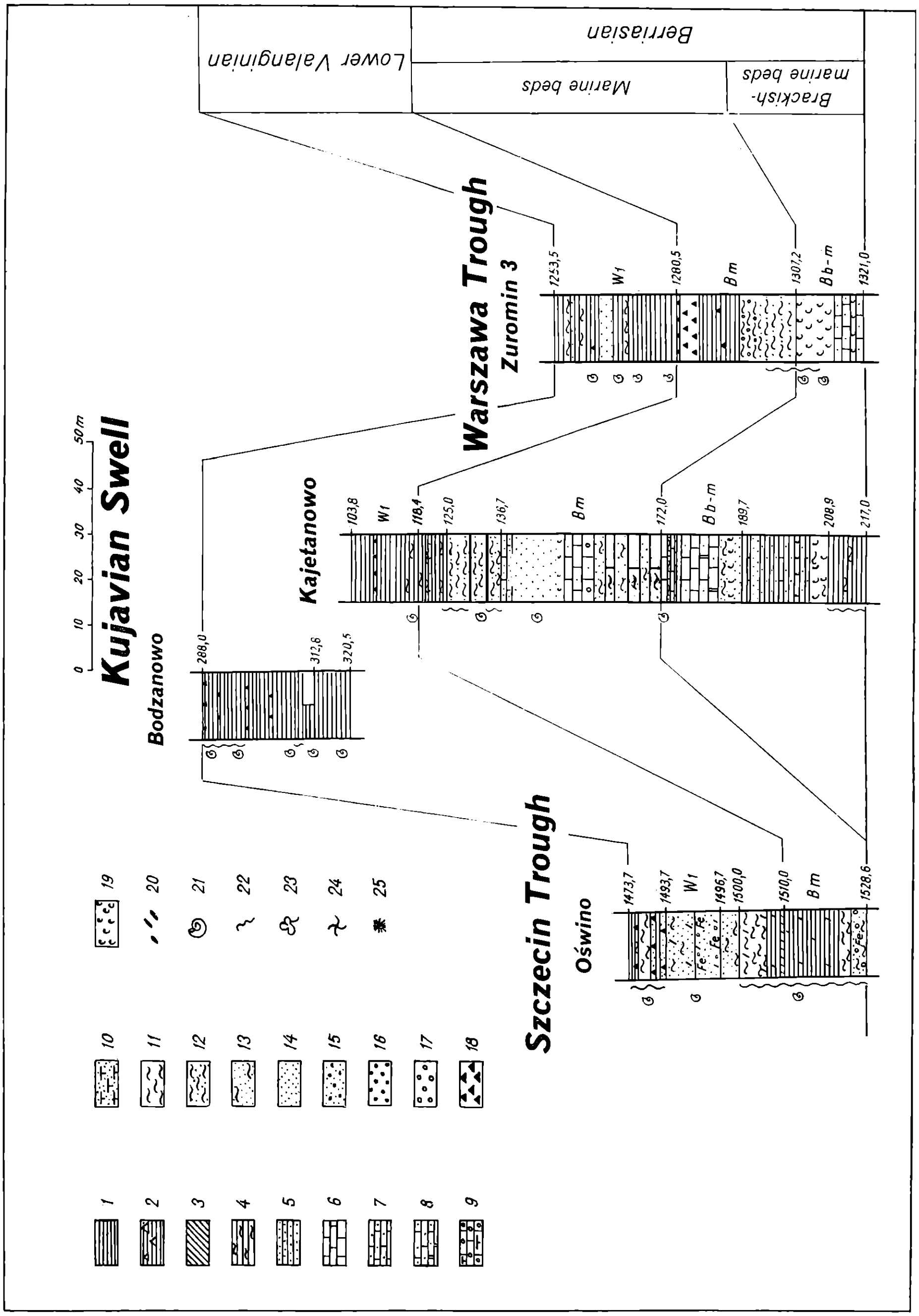

Fig. 5. Selected Berriasian and Lower Valanginian lithostratigraphical sections in the Polish Lowland.

Explanation of Figs 5, 7, 9 and 11.

1—Claystones and shales. 2—Claystones with sideritic intercalations. 3—Ash-grey claystones. 4—Silty claystones. 5—Arenaceous claystones, or claystones laminated by fine-grained sandstones. 6—Limestones. 7—Arenaceous limestones, or calcareous sandstones. 8—Arenaceous-dolomitic limestones. 9—Oolitic marly limestones. 10—Arenaceous marls. 11—Siltstones. 12—Arenaceous siltstones. 13—Silty sandstones. 14—Fine-and medium-grained sandstones. 15—Variously grained sandstones, locally with fine gravels. 16—Coarse-grained sandstones and grits. 17—Ferruginous oolites. 18—Siderite. 19—*Cyrena* shell-deposits. 20—comminuted fossils. 21—Pelecypods, locally with ammonites. 22—Microfauna. 23—Fragments of carbonized wood. 24—Rhizoids. 25—Glauconite.

Marek, Bielecka and Sztejn 1969; Anderson, this volume). In similar basins in Western Europe this fauna is typical of the Upper Serpulit. The same age is proved also by palynological studies (Mamczar 1966). As far as lithofacial development is concerned, this series is represented by marly claystones with intercalations of *Cyrena* shell-marls, and, in the Kujawy region, with intercalations of arenaceous limestones. Its thickness does not exceed 30 metres.

The marine Berriasian (Ryazanian) is relatively well established by ammonites, the guiding character of which allows this stage to be divided into two horizons: a lower horizon with *Riasanites rjasanensis*, and an upper horizon with *Surites spasskensis*. As a rule, the marine beds are argillaceous, always with interbedded ferruginous rocks in the Kujawy region, and with sandstone intercalations in the Warsaw trough, a fact suggesting a northern or northeastern source of detrital material (Marek 1968, 1969). The maximum thicknesses of the Berriasian deposits are recorded from the area of the Kujawy swell in the northeastern part of the Mogilno trough, and in the Oborniki anticline, where they amount to 90-140 metres (Marek 1969; Raczyńska 1971). Towards the periphery the thicknesses gradually decrease. In the Berriasian, the sedimentary basin gradually expanded and deepened. A transition can be observed here from the first marine ingressions in the fresh-water basin of the Purbeckian, to a typical marine sedimentary environment with ammonites, marine pelecypods and foraminifera.

A fairly rich ammonite fauna, represented within the Polish Lowland area by Mediterranean genera (*Berriasella, Neocosmoceras, Himalayites,* and others) and the Central Russian genus *Riasanites,* points to the ingression of the Berriasian sea from the south, most probably along the eastern border of the Holy Cross Mountains. This route seems to be indicated by the Berriasian deposits of Mediterranean type encountered in the vicinity of Lubaczow. The possibility of a connection between the Berriasian basin in the Lowland area and the Central-European sea through the Danish furrow cannot, however, be dismissed.

3. Lower and Middle Valanginian deposits

The Lower Valanginian deposits reflect the persistence of the marine conditions established in the Berriasian, and the two stages generally occur together. In the west, near Szczytno, the Lower Valanginian deposits are found in a distinctly overlapping position, forming a narrow wedge within the East European platform (Fig. 4). Throughout the Polish Lowland deposition was fairly uniform; the sediments are dominantly argillaceous, becoming slightly arenaceous eastwards, and with intercalations of sideritic concretions; the supply of coarse-grained materials was limited.

The sparse ammonite fauna comprises the genera *Platylenticeras* and *Neocomites* (Table 1), which indicate a connection between the Polish Lower Valanginian sea and the Anglo-German basin (*Platylenticeras*) and possibly also with the southern seas (*Neocomites*).

The Middle Valanginian was deposited over a greater area than the earlier formations of Lower Cretaceous age (Fig. 6). This was a period of marked shallowing and of a freshening of the sedimentary basin. This is proved by the considerable increase in sand content in the deposits and by the intercalations of rhizoid sandstones (characteristic of West Poland) which provide evidence of lacustrine sedimentation (Figs 6 and 7).

Table 1. Distribution of ammonites in the Polish Lowland

Species	Berriasian		Valanginian			Hauterivian	
	Lower	Upper	Lower	Middle	Upper	Lower	Upper
Riasanites rjasanensis (Wenetzky) (Lahusen)	———						
Subthurmannia sp. (cf. *boissieri* Pictet)	- - - -	- - - - -					
Himalayites cf. *cortazari* (Retowski)	- - - - -						
Himalayites cf. *breveti* (Pomel)	- -	- - -					
Berriasella cf. *pontica* (Retowski)	- - - - -						
Berriasella lorioli (Zittel)	- - - - -						
Berriasella euxina (Retowski)	- - - -						
Berriasella cf. *jauberti* Mazenot	- -	- - -					
Neocomites sp. (cf. *occitanicus* Pictet)	- - - - -						
Neocosmoceras cf. *sayni* (Simionescu)		———					
Euthymiceras cf. *euthymi* (Pictet)		———					
Surites **subtzikwinianus* (Bogoslovsky)		- - - -					
Surites cf. *spasskensis* (Nikitin)		- - - -					
Surites cf. *kozakowianus* (Bogoslovsky)		- - - -					
Surites sp.		———					
Platylenticeras (*Tolypeceras*) cf. *marcousianum* (d'Orbigny)			———				
Platylenticeras (*T.*) cf. *marcousianum inflatum* (Koenen)			- - - -				
Platylenticeras (*P.*) *heteropleurum posturum* (Koenen)			- - - -				
Platylenticeras (*P.*) *gevrilianum gevrilianum* (d'Orbigny)			———				
Neocomites neocomiensis (d'Orbigny)			———		———		
Neocomites neocomiensis var. *premolica* (Sayn)			- - - -				
Polyptychites sp./cf. *gravidus* (Roemer)			- - - -				
Oxyteuthis sp.			- - - -	- - - -			
Polyptychites nucleus (Roemer)					———		
Polyptychites cf. *petschorensis* (Bogoslovsky)					- - - -		
Polyptychites sp. f. juv. (cf. *gradatus* Koenen)					———		
Polyptychites cf. *ascendens* Koenen					- - - -		
Polyptychites cf. *latissimus* (Neumayr and Uhlig)					- - - -		
Polyptychites cf. *michalskii* (Bogoslovsky)					———		
Polyptychites cf. *ramulicostatus* (Pavlow)					- - - -		
Polyptychites cf. *rectangulatus* (Bogoslovsky)					- - - -		
Polyptychites cf. *keyserlingi* (Neumayr and Uhlig)					- - - -		
Dichotomites cf. *bidichotomus* (Leymerie)					———		
Dichotomites cf. *terscissus* (Koenen)					- - - -		
Dichotomites cf. *biscissus* (Koenen)					- - - -		
Neocraspedites complanatus (Koenen)					———		
Saynoceras verrucosum (d'Orbigny)					———		
Leopoldia provincialis Sayn					———		
Leopoldia quadristriangulata Sayn					- - - -		
Leopoldia sp. (cf. *biassalensis* Karakasch)					- - - -		
Astieria bachelardi Sayn					- - - -		
Astieria cf. *sayni* Sayn					- - - -		
Neocomites biformis Sayn					- - - -		
Bochianites neocomiensis (d'Orbigny)					———		
Endemoceras noricum (Roemer)						- - - - -	
Neocraspedites cf. *carteroni* (d'Orbigny)						- -	
Ammonites sp.							- -

* The ammonites recorded here as species of *Surites* require a more detailed revision. They may belong to the Berriasellidae rather than to the Craspeditidae: there are discordant opinions between workers interested in the Boreal and in the Tethyan Realms.

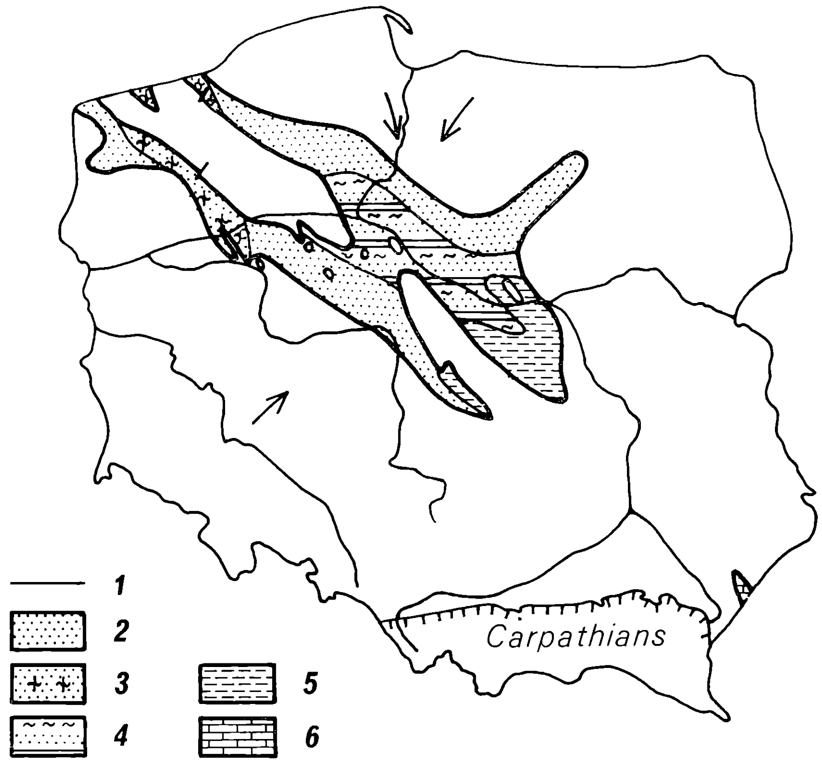

Fig. 6. Distribution of the main Middle Valanginian facies (Carpathians excluded).
1. Limit of deposits
2. Fine-grained and subordinate coarse-grained sandstones
3. Sandstones with intercalations of rhizoid siltstones
4. Sandstones, with clay-silt intercalations at the top and base
5. Claystones and arenaceous siltstones
6. Arenaceous limestones.

In the central part of the basin, in the Kujawy region, the Middle Valanginian deposits show the influence of marine sedimentation of siltstone-clay type (with agglutinated foraminifera) adjacent to the Lower Valanginian and Upper Valanginian boundaries. The middle portion of the complex is arenaceous and shows features characteristic of near-shore sedimentation, perhaps of a fluvial nature, with abundant plant debris and mostly without glauconite. Towards the margins of the basin, the marine siltstone-clay intercalations disappear, whereas intercalations of rhizoid sandstones appear in the west (Fig. 6).

As in the case of the Berriasian deposits, the facies distribution points to a generally northern area of supply (Fig 6) during the Middle Valanginian. The basin was partly isolated, and periodically subject to marine influence, both in the northwest and in the southeast. The maximum thickness of the Middle Valanginian deposits (120–170 metres) occurs in the area of the Kujawy swell and in the adjacent zone of troughs. Absence of these deposits in the Lublin region is the result of subsequent erosion.

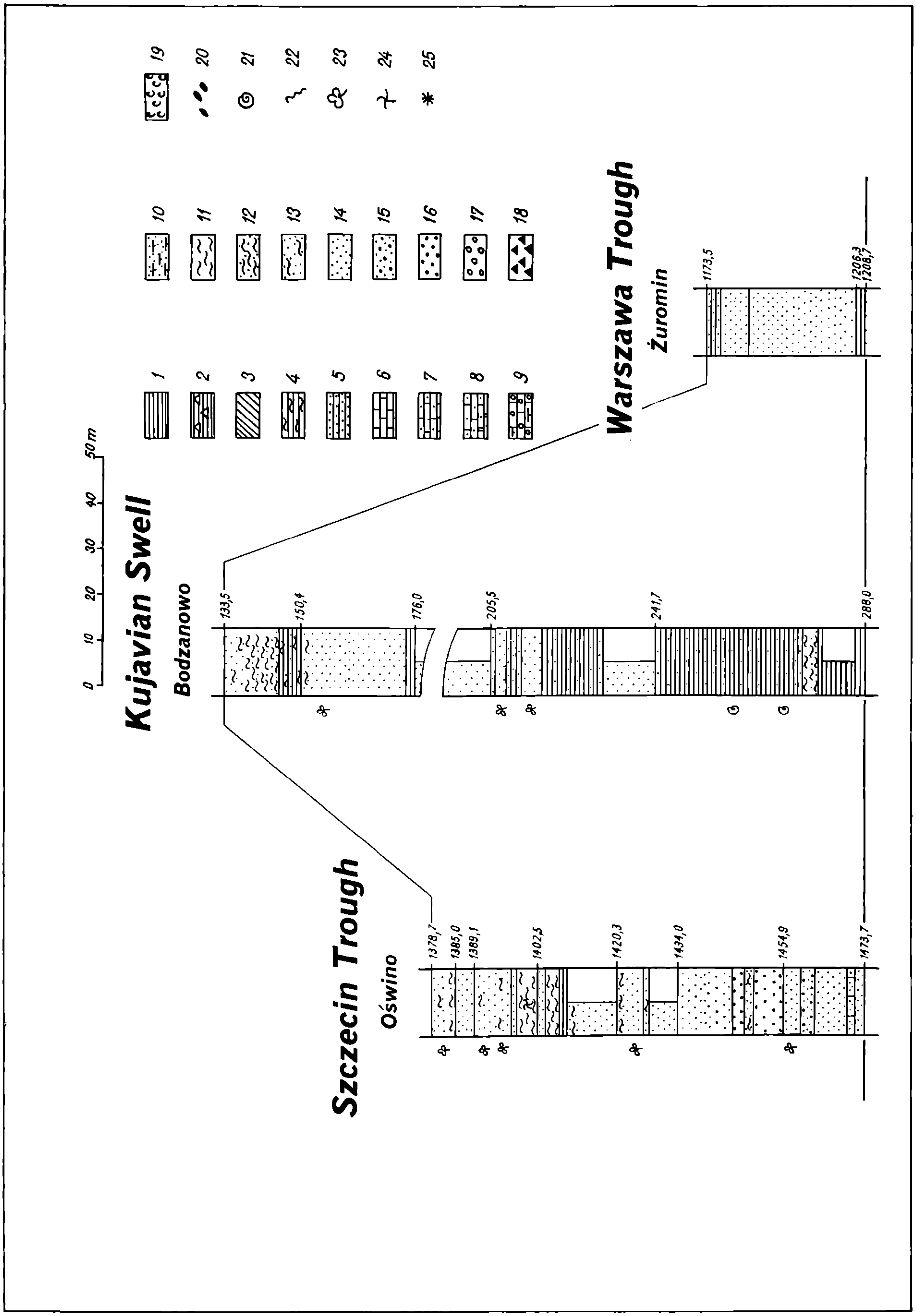

Fig. 7. Selected Middle Valanginian lithostratigraphical sections in the Polish Lowland (for explanation see Fig. 5).

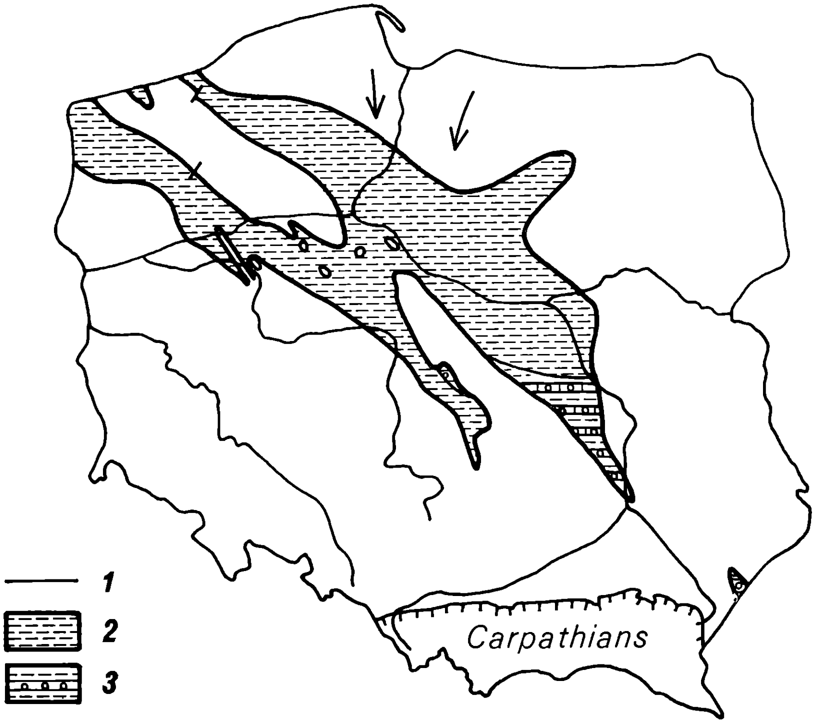

Fig. 8. Distribution of the main Upper Valanginian facies (Carpathians excluded).

1. Limit of deposits
2. Claystones and siltstones, locally arenaceous
3. Claystones and siltstones with intercalations of marly, organo-detrital and oolitic limestones.

4. Upper Valanginian deposits

After the period of regression in the Middle Valanginian, a new transgressive cycle commenced, accompanied simultaneously by deepening and widening of the sedimentary basin. In the southeastern area the Upper Valanginian deposits extend as far as Zawichost (Fig. 8).

The Upper Valanginian deposits are characterized by a feeble facial differentiation. For the most part they are composed of claystones (commonly arenaceous) and siltstones, the increased sand content being particularly noticeable on the anticlinal structures (Fig. 9). In the southeastern part of the area, an important role is played marly-calcareous and oolitic deposits, somewhat related to the Mediterranean facies that are found in the area of Lubaczow within the Carpathian foredeep.

As with the earlier part of the Lower Cretaceous the maximum known thicknesses of the Upper Valanginian deposits (30–55 metres) occur in the area of the Kujavian swell and within the adjacent zones.

The Upper Valanginian ammonite fauna, namely the genera *Dichotomites, Polyptychites, Astieria, Leopoldia* and *Neocomites,* represents a mixed boreal

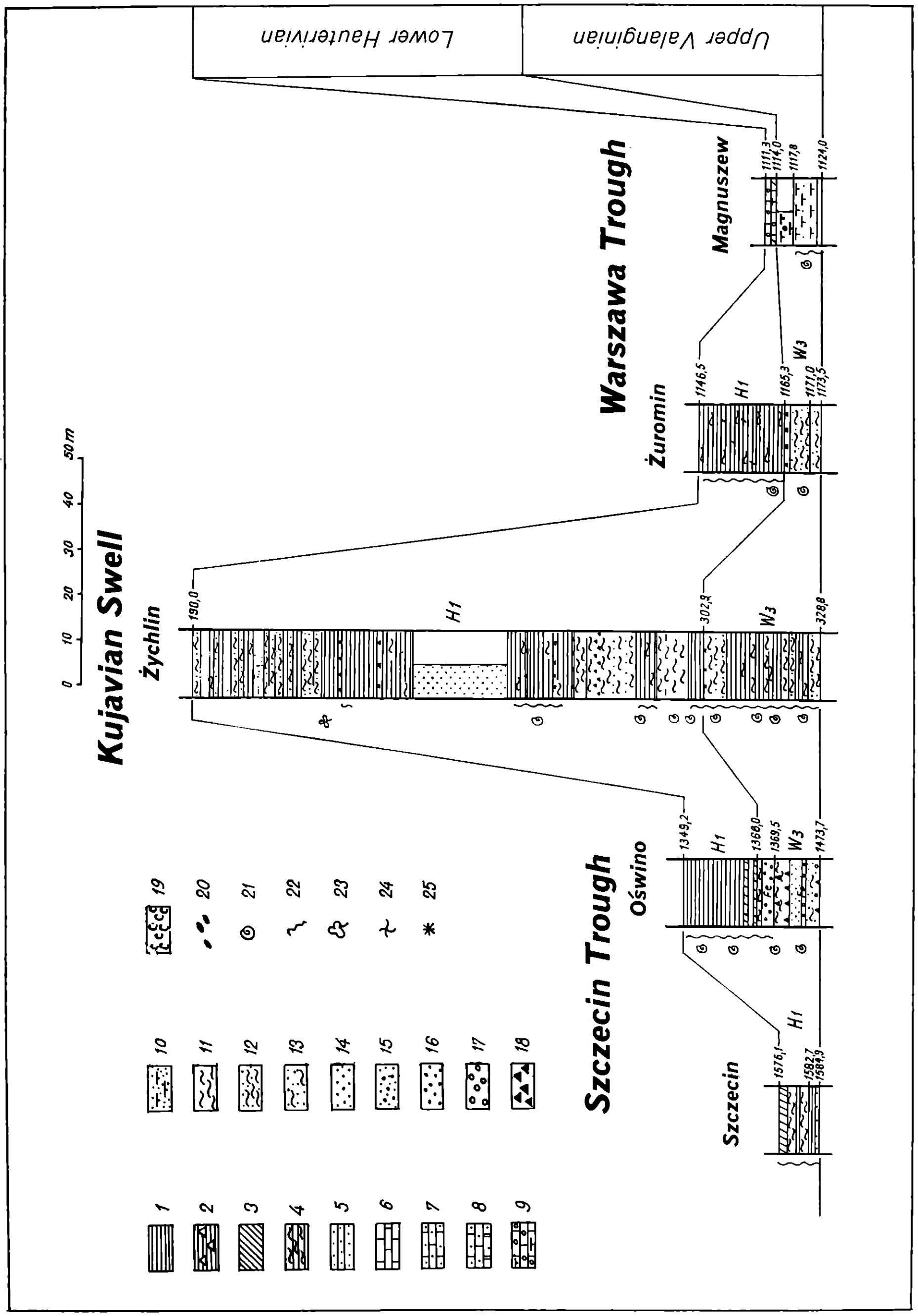

Fig. 9. Selected Upper Valanginian and Lower Hauterivian lithostratigraphical sections in the Polish Lowland (for explanations see Fig. 5).

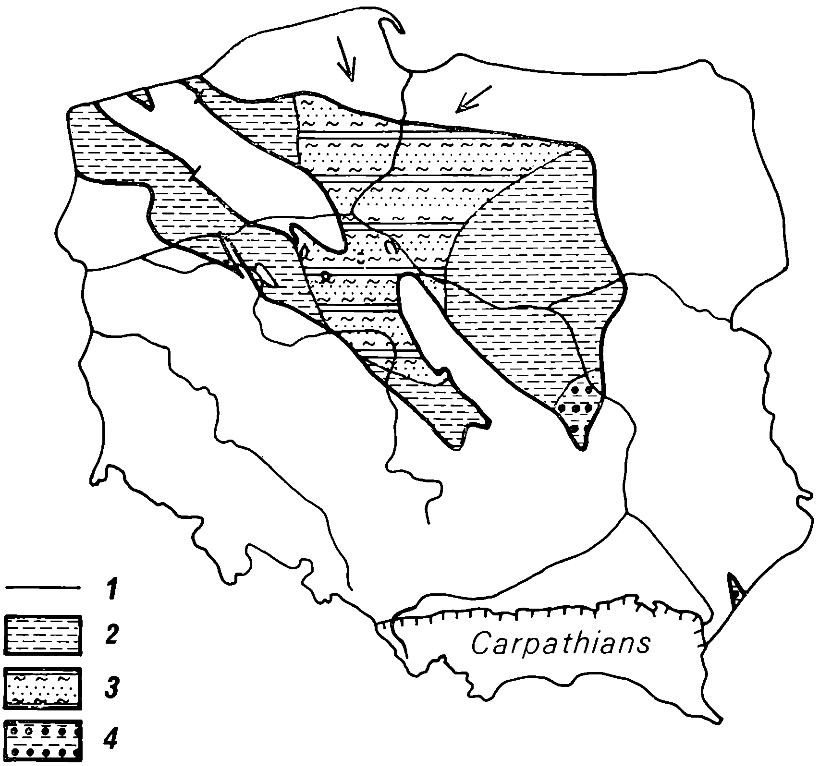

Fig. 10. Distribution of the main Lower Hauterivian facies (Carpathians excluded).
1. Limit of deposits
2. Claystones and siltstones
3. Claystones and siltstones with sandstone intercalations in the middle
4. Claystones, arenaceous marls and oolitic limestones.

and Mediterranean type (Table 1). Species known from the Russian Platform area are abundant. The character of the fauna points to a connection of the Polish Lowland basin with the boreal and the Mediterranean basins.

5. Hauterivian deposits

The Lower Hauterivian witnessed a continuation of the marine conditions that prevailed in the Upper Valanginian. The sea spread further than it had earlier in the Lower Cretaceous, in the northeastern area reaching as far as the line Miastko-Olsztyn-Chociwel-Choszczno-Wrzesnia-Turek-Belchatow (Fig. 10). Within the northeastern margin of the Holy Cross Mountains it advanced only to Przytyk.

In the siltstone-claystone facies prevailing during the Lower Hauterivian (Fig. 9), the greatest accumulations of coarse-grained material may be observed within the Mogilno trough, the Kujavian swell, and in the areas of the Pomeranian and Warsaw troughs. The facies distribution resembles that of the Berriasian and Middle Valanginian, suggesting a northern source of detrital material. The

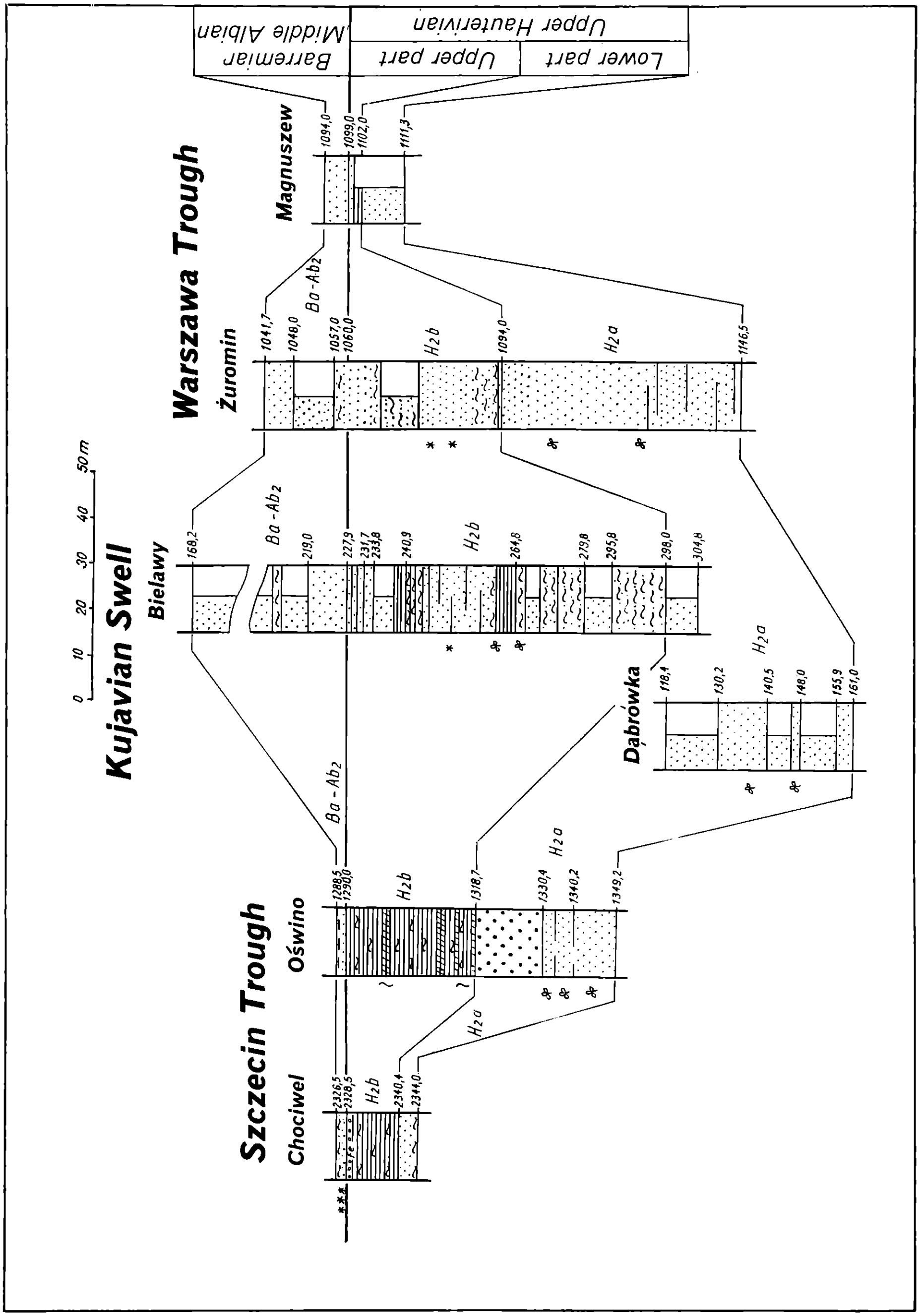

Fig. 11. Selected Upper Hauterivian and Barremian-Middle Albian lithostratigraphical sections in the Polish Lowland (for explanation see Fig. 5).

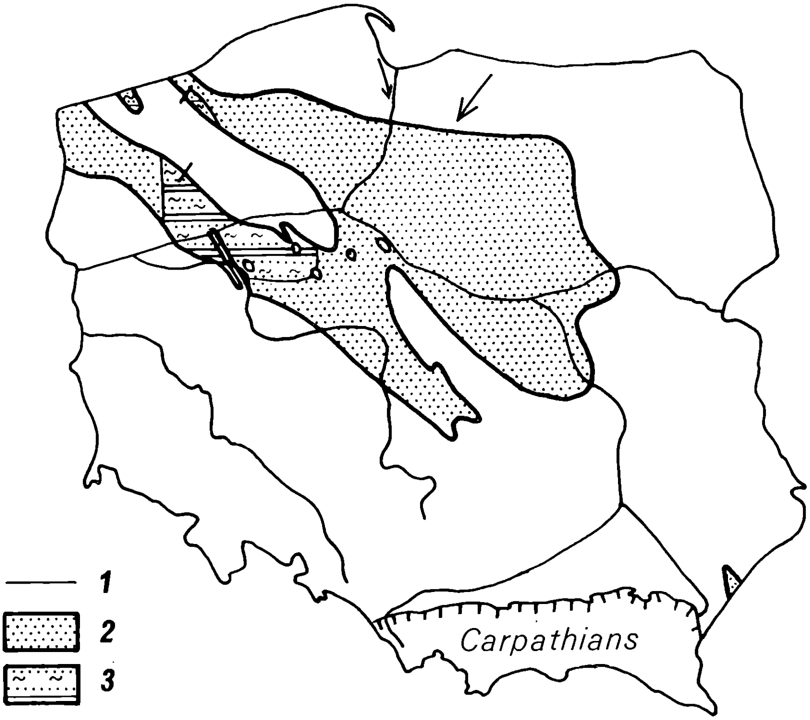

Fig. 12. Distribution of the main facies in the lower complex of the Upper Hauterivian (Carpathians excluded).

1. Limit of deposits
2. Fine-grained sandstones with subordinate variously-grained sandstones and carbonized wood-debris
3. Sandstones, generally silty at the base, with intercalations of loamy claystones (West Poland).

maximum thicknesses noted in the central part of the basin (Oborniki) range from 100 to 170 metres.

The ammonite fauna, particularly the form *Endemoceras noricum* (Roemer), suggests that the sedimentary basin was connected with the West European sea. A connection with the Mediterranean basin probably also existed; this may be inferred from palaeogeographical and faunal data (such as the Cretaceous at Lubaczow). The ammonite form *Leopoldia* of the group *biassalensis* Karakasch indicates a link with the Lower Hauterivian of the Central Russian basin.

Within the Lowland area the Neocomian ammonite record ends in the Lower Hauterivian. The overlying deposits, tentatively referred to the Upper Hauterivian (Fig. 11) are represented in their lower part mainly by sandstones with fragments of carbonized wood; in the west there are intercalations of loamy claystones, typical of isolated inland basins (Fig. 12).

In the upper part of the sequence a recurrence of marine sedimentary conditions is indicated. The deposits are mainly glauconitic sandstones with argillaceous intercalations in the central part of the basin, and claystones (Fig. 13). An

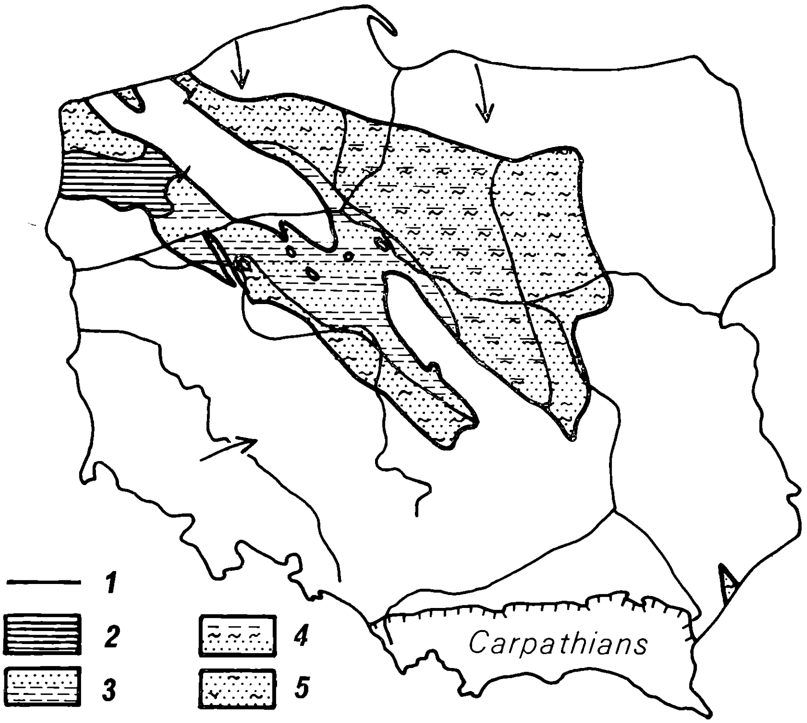

Fig. 13. Distribution of the main facies in the upper complex of the Upper Hauterivian (Carpathians excluded).

1. Limit of deposits
2. Claystones laminated with siltstones
3. Siltstones and claystones; intercalations of sandstone with glauconite in the upper part
4. Fine- and variously-grained sandstones; intercalations of siltstones and claystones at the base and locally at the top
5. Fine-grained sandstones, locally silty, with glauconite.

agglutinated foraminiferal fauna occurs, represented by *Haplophragmoides* sp., *Ammodiscus gaultinus* Berthelin, *Trochammina inflata* (Montagu) and *Reophax scorpiurus* Montfort (Sztejn 1960, 1967).

The areal extent of the upper marine complex of the Upper Hauterivian generally coincides with that of the Lower Hauterivian. On the other hand, a diminished area of the lower complex in the Upper Hauterivian may be observed locally, particularly along the margins of the Holy Cross Mountains (Zarzecin and Przytyk), and in the Szczecin trough (Choszczno region).

The distribution of facies in the Upper Hauterivian points to both the northern and the Sudetic supply areas; in addition, the Holy Cross Mountains are thought to have been an active source of sediment. The greatest thicknesses of the presumed Upper Hauterivian deposits (90 to 140 metres) occur within the areas of the Kujawy swell and the adjacent zones of troughs.

The Upper Hauterivian sedimentary basin of the Lowland area probably lessened its connection with the southern sea. Its poor fauna of pelecypods and

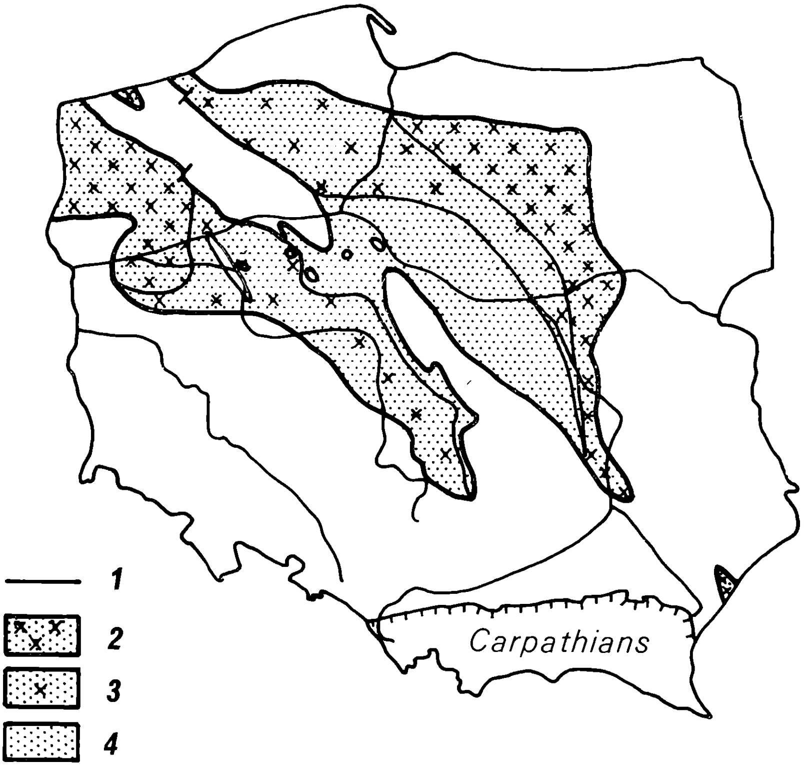

Fig. 14. Distribution of the Barremian-Middle Albian facies (Carpathians excluded).
1. Limit of deposits
2. Quartz-glauconite sandstones
3. Sandstones with more-or-less abundant glauconite
4. Sandstones, generally with little glauconite.

foraminifera reflects a restricted connection with the West European basin, as shown by the more positive influence of the marine conditions in West Poland, compared with that prevailing elsewhere in the Lowland area.

6. Younger Lower Cretaceous sediments

The youngest arenaceous-glauconitic series of the Lower Cretaceous is tentatively referred to the Barremian-Middle Albian period. It marked a new transgressive cycle of Lower Cretaceous sedimentation (Figs 11 and 14), the transgressive character of which is generally emphasized by a basal bed of coarse-grained material, locally conglomeratic. The sands are unfossiliferous through almost the entire Lowland area but are overlain by sandy-marly deposits of Upper Albian age, which yield phosphorites with *Aucellina gryphaeoides* (J. Sowerby) and *Neohibolites ultimus* (d'Orbigny). The latter deposits foreshadow the carbonate sedimentary cycle of the Upper Cretaceous.

Thus, the age of this sandy series is suggested only by its stratigraphical position between proven Upper Albian sediments and presumed Upper Hauterivian deposits. Only within the northeastern marginal area of the Holy Cross Mountains do the greatly reduced arenaceous deposits yield a Middle Albian fauna, represented by *Hoplites dentatus* (J. Sowerby), *Anahoplites* cf. *praecox* Spath and others (Cieśliński 1960; Cieśliński and Pożaryski 1970).

The thickness of this sandy series amounts to 140 metres at the most. Whether any part of it should be referred to the time interval Barremian-Middle Albian is questionable.

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Correlation of the Jurassic-Cretaceous boundary beds in the Boreal Realm

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The Volgian/Berriasian junction separates two ammonite assemblages of different generic composition and provides the boundary of the Jurassic and Cretaceous Systems in the Boreal Realm. Extinction of the subfamily Virgatosphinctinae coincides with this boundary in both Boreal and Tethyan Realms. The boundary beds are fully represented in Siberia, the Urals and Spitsbergen, but marine Lower Berriasian is missing on the Russian Platform and in Poland. Valanginian faunas in the U.S.S.R. may be correlated with those of southeast France and northwest Germany by means of the ammonites *Polyptychites* and *Platylenticeras*.

Durch die Wolga-Berrias-Grenze werden zwei Ammoniten-Faunen getrennt, die aus unterschiedlichen Gattungen bestehen. Diese Grenze bietet sich daher als Jura-Kreide-Grenze im Borealgebiet an. Das Erlöschen der Unterfamilie Virgatosphinctinae fällt mit dieser Grenze zusammen und zwar sowohl im Boreal- als auch im Tethys-Gebiet. Die Grenzschichten sind in Sibirien, im Ural und auf Spitzbergen voll entwickelt. Auf der russischen Plattform und in Polen fehlt marines Unter Berrias. Die Faunen des Valangin der USSR können mit Hilfe der Ammoniten-Gattungen *Polyptychites* und *Platylenticeras* mit denjenigen von SE Frankreich und NW Deutschland korreliert werden.

Le passage Volgien-Berriasien est marqué par la succession de deux associations d'Ammonites de composition générique différente et concrétise la limite Jurassique-Crétacé dans le Domaine boréal. L'extinction de la sous-famille des *Virgatosphinctinae* coincide avec cette limite tant dans la province boréale que la mésogéenne. Les niveaux de passage sont amplement représentés en Sibérie, en Oural et au Spitzberg, mais le Berriasien inférieur de faciès marin fait défaut sur la Plateforme russe et en Pologne. Les faunes valanginiennes d'U.R.S.S. peuvent être corrélées avec celle du Sud-Est français et celles d'Allamagne du Nord-Ouest à l'aide des genres *Polyptychites* et *Platylenticeras* (Ammonoìdes).

1. Introduction

The boreal marine faunas of the Volgian, Berriasian and Valanginian have much in common; the Berriasian faunas are very similar to those of the Volgian, though in the course of their evolution new forms appeared to link them closely with the Valanginian. It should be stressed that transformation of individual groups of the marine faunas within the Boreal Realm, especially in the benthos, was not synchronous: there was a time-shift with respect to different facial environments within a given province. Time-shifts of this sort were manifested to a lesser extent in the nektonic groups such as belemnites, and in the case of the ammonites it is difficult, if not impossible, to establish their existence at all, since these fossils are themselves the criteria of age-determination.

This paper is essentially a summary of recent Soviet work published in a volume edited by Saks (1972).

2. The Upper Volgian substage

The Upper Volgian deposits of the Boreal Realm are characterized in general by the evolution of the ammonite genus *Craspedites,* which is joined by *Garniericeras* and *Kachpurites* in the lower part of the substage (Zone of *Kachpurites fulgens*) in the Russian Platform and the Urals. Discovery of *Virgatosphinctes* in Siberia (with *Craspedites*, *Aulacosphinctes* and *Lementia*), in the Urals, Spitsbergen and, supposedly, in Greenland deserves special attention, for this ammonite permits us to correlate with some confidence the Upper Volgian substage of the Boreal Realm with the Upper Tithonian of the Tethyan Realm (Table 1).

The upper part of the Upper Volgian, from the *Craspedites originalis* Subzone of the *C. okensis* Zone through the *C. taimyrensis* Zone to the *Chetaites chetae* Zone, contains ammonites which Bodylevsky (1956) recognized as a special genus, *Taimyroceras*, being very similar to *Craspedites* of the group of *C. okensis* (d'Orbigny) and especially to the group of *C. nodiger* (Eichwald). This ammonite genus and its allies are known from Siberia, the Urals, Spitsbergen, the Canadian Arctic Archipelago (*C. canadensis* Jeletzky) and the Russian Platform (*C. nodiger*). Furthermore, at the top of the substage (Zone of *Ch. chetae*) the ammonite genus *Chetaites* appears (Shulgina 1962) in Siberia, northeastern Asia, the Urals, Spitsbergen, the Far East and, supposedly, on the Lofoten Islands ("*Virgatosphinctes*", Sokolov 1912).

The Upper Volgian beds of eastern England were identified by R. Casey (1962, 1971), though published descriptions of ammonites are lacking.

3. The Jurassic-Cretaceous boundary

The boundary between the Tithonian and the Berriasian of the Tethyan Realm is placed at the top of the Zone of *Berriasella chaperi* and hence below the Zone of *Berriasella grandis.* Among the ammonites, the extinction of the subfamily Virgatosphinctinae coincides with this boundary and provides a criterion for both the Tethyan and Boreal Realms.

In Siberia, the Urals and Spitsbergen the Jurassic-Cretaceous border beds are continuous and here the boundary between the Volgian and the Berriasian must

		South-Eastern France	**Spitsbergen**	**Russian Platform**	**Northern Urals**	**Siberia**	
Lower Cretaceous (pars)	Lower Valanginian	*Kilianella roubaudi*	*Polyptychites* spp.	*Polyptychites michalskii*	*Polyptychites michalskii*	*Polyptychites stubendorffi*	*Polyptychites michalskii*
		Kilianella lucensis		*Temnoptychites hoplitoides*	*Temnoptychites insolutus*		*Temnoptychites syzranicus*
				Pseudogarnieria undulatoplicatilis		*Neotollia klimovskiensis*	
	Berriasian	*Berriasella boissieri*	*Tollia* sp.	*Surites spasskensis*	*Bojarkia payeri*	*Bojarkia mesezhnikowi*	
			Surites sp. *Subcraspedites* sp.		*Surites analogus*	*Surites analogus*	
				Riasanites rjasanensis	*Hectoroceras kochi*	*Hectoroceras kochi*	
		Berriasella grandis	*Chetaites* cf. *sibiricus*		*Chetaites* cf. *sibiricus*	*Chetaites sibiricus*	
Upper Jurassic (pars)	Upper Tithonian (Upper Volgian)	*Berriasella chaperi*	*Chetaites?* sp.		*Chetaites?* cf. *chetae*	*Chetaites chetae*	
			Craspedites ex.gr. *nodiger*	*Craspedites nodiger*	*Craspedites* cf. *taimyrensis*	*Craspedites taimyrensis*	
		Berriasella delphinensis	*Craspedites* *Virgatosphinctes*	*Craspedites subditus*	*Craspedites subditus*	*Craspedites okensis*	*Craspedites originalis*
				Kachpurites fulgens	*Kachpurites fulgens*		*Craspedites okensis*
							Virgatosphinctes exoticus

be placed naturally at the top of the Zone of *Chetaites chetae,* where *Virgatosphinctes, Craspedites* and *Garniericeras* disappear. The next zone (*Chetaites sibiricus*) is characterized by a typical Berriasian ammonite assemblage with *Paracraspedites, Subcraspedites, Surites, Praetollia* and *Hectoroceras.* Only one ammonite genus (*Chetaites*) seems to be common to the *Ch. chetae* and *Ch. sibiricus* Zones. Ammonites of Tethyan type are present also in the *sibiricus* Zone of Siberia and are most similar to the Lower Berriasian *Argentiniceras* of South America.

In eastern Europe the boundary between the Volgian and Berriasian stages may be placed above the *Craspedites nodiger* Zone, beyond which no genus of Volgian ammonites ranges. Unfortunately, the presence of a regional disconformity at the top of the Volgian on the Russian Platform deprives this boundary of precise definition. A typical Berriasian ammonite assemblage, with Berriasian Craspeditidae and a number of forms of Tethyan affinities (*Riasanites, Euthymiceras, Neocomites,* etc.), is present in the *Riasanites rjasanensis* Zone overlying the disconformity.

Certain Berriasian Craspeditidae, notably *Surites,* are encountered in the Upper Volgian (*Craspedites subditus* Zone) of the Russian Platform (River Unzha).

So far as can be judged from the available data, the ammonite and *Buchia* assemblages of North America (Alaska, northern and western Canada) resemble those of Siberia. Indo-Pacific forms of ammonites appear in western Canada and dominate in the U.S.A., providing additional evidence for correlation of the Boreal and Tethyan Realms.

It may be concluded that in the Boreal Realm the boundary between the Volgian and Berriasian stages splits two ammonite assemblages of essentially different generic composition. However, these changes are but feebly reflected at higher taxonomic levels. The late Jurassic family Perisphinctidae is represented in the Lower Berriasian only by the genus *Chetaites.* Nevertheless, changes at this level are more pronounced than those within the Volgian and the Berriasian or between the Berriasian and the Valanginian. The placing of the boundary between the Jurassic and Cretaceous Systems between the Volgian and Berriasian stages based on boreal ammonites therefore seems amply justified.

4. The Berriasian stage

The Berriasian stage of the Boreal Realm is characterized by the ammonite genera *Surites, Paracraspedites, Subcraspedites, Praetollia, Externiceras* and *Hectoroceras;* also by *Chetaites* in the lowermost horizons and by *Bojarkia* and *Tollia* in the uppermost horizons. This assemblage is represented in Siberia, the Urals, the Russian Platform (accompanied by Tethyan elements), Spitsbergen and Greenland, and in the impoverished faunas of Canada (together with typical Berriasian *Buchia*). Ammonites of the genus *Hectoroceras* are typical of the middle part of the Berriasian (*Hectoroceras kochi* Zone) and occur in Siberia as isolated examples in the *sibiricus* Zone. Beds with *Hectoroceras* may be regarded as firm markers for the middle part of the boreal Berriasian.

In eastern England this ammonite assemblage is found in the basal beds of the Spilsby Sandstone (Swinnerton 1935), which permits these sandstones to be assigned entirely to the Berriasian (but see Casey, this volume). This conclusion is consistent with the presence of a belemnite assemblage with *Acroteuthis* s.s. in the basal beds of the Spilsby Sandstone (Swinnerton 1936–55). However, it must be noted that on the Russian Platform elements of the belemnite assemblage and the first representatives of typically Berriasian Craspeditidae are found already in the Upper Volgian. It is quite likely that the same holds for England.

The eastern European Berriasian begins with the *Riasanites rjasanensis* Zone. The presence in this zone of *Euthymiceras*, and also *Berriasella* cf. *boissieri* in Poland, permits its correlation with the upper zone of the western European Berriasian, the *B. boissieri* Zone. It may be concluded, therefore, that on the Russian Platform and in Poland the lower part of the Berriasian is missing in the marine facies.

The Upper Berriasian horizons of Siberia (*Bojarkia mesezhnikowi* Zone), the Urals, England and Greenland contain ammonites of the genus *Bojarkia* (especially *B. payeri* Toula sp.) and *Tollia*, though the *Buchia* assemblage maintains a typical Berriasian aspect.

5. The Valanginian stage

Higher in the sequence, in the *Neotollia klimovskiensis* Zone, the genus *Neotollia* appears, accompanied by *Tollia* and a Valanginian assemblage of *Buchia*. Ammonites of the genus *Neotollia* are widespread in the Boreal Realm (Siberia, Urals, Petchora and Volga basins, northwest Germany, Canada, western U.S.A., and possibly Greenland). Perhaps the species *mutabilis* Stanton and *paucicostata* Donovan belong to this genus. Beds with *Neotollia* should be regarded as firm marker-horizons for the base of the boreal Valanginian. On the Russian Platform the base of the Valanginian is formed by the *Pseudogarnieria undulatoplicatilis* Zone according to I. G. Sazonova, with the endemic ammonites *Pseudogarnieria, Proleopoldia, Menjaites* and *Stchirowskiceras*. Here *Temnoptychites* and *Neotollia?* are typical of the Valanginian, while *Surites, Subcraspedites* and *Bojarkia* are confined to the Berriasian. The *Buchia* assemblage of the *undulatoplicatilis* Zone is already Valanginian.

The *undulatoplicatilis* and *klimovskiensis* Zones may be correlated with the lower part of the Lower Valanginian of northwest Germany (beds with *Platylenticeras, Tollia* and *Neotollia*), Switzerland and southeast France, where *Platylenticeras* is also present.

Higher in the sequence, in the *Temnoptychites syzranicus* Zone, the dominant ammonite is *Temnoptychites; Neotollia* persists and *Polyptychites, Euryptychites, Astieriptychites* and *Virgatoptychites* appear. Strata with *Temnoptychites* are widespread over the Boreal Realm (Siberia, the Urals, Petchora and Volga basins, Greenland, northern Canada, and possibly Poland). The overlying *Polyptychites michalskii* Zone of the Lower Valanginian is characterized by species of *Polyptychites* and similar beds extend over the whole Boreal Realm. The Lower Valanginian belemnite assemblage with *Acroteuthis* s.s. has the same distribution.

The *Polyptychites* beds may be reliably correlated with the *Kilianella roubaudi* Zone of the Valanginian stratotype sections in Switzerland and southeast France because of the discovery there of *Polyptychites*.

In conclusion, it may be assumed that the Jurassic-Cretaceous boundary beds are quite well correlated within the Boreal Realm, where it is possible to trace not only stages but numerous zones. Thanks to the presence of certain ammonites in common, the boreal sequence may be correlated with the stages and zones of the Tethyan Realm, though with less confidence.

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Belemnite assemblages from the Jurassic-Cretaceous boundary beds in the Boreal Realm

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The Boreal-Atlantic region, perhaps the Central Russian Sea, was the centre of origin of new groups of boreal belemnites at the end of the Jurassic and the beginning of the Cretaceous. During the Middle and Upper Volgian *Pachyteuthis* s.s., *Simobelus* and *Lagonibelus* s.s. here gave way to *Microbelus*, while *Acroteuthis* s.s. appeared in the Spilsby Sandstone (Berriasian) of eastern England and *Boreioteuthis* in the Upper Berriasian of eastern Europe. *Cylindroteuthis* (*Arctoteuthis*) appeared and evolved in the Berriasian of the Arctic region, becoming dominant in the Valanginian of the western U.S.A. and Canada.

Das boreal-atlantische Reich und vielleicht auch das zentralrussische Meer waren zur Zeit des späten Jura und der frühen Kreide Ursprungsgebiet von neuen Gruppen borealer Belemniten. Während des Mittel und Ober Wolga wurden die Gattungen *Pachyteuthis* s.s., *Simobelus* und *Lagonibelus* s.s. in diesen Gebieten durch *Microbelus* ersetzt. *Acroteuthis* s.s. tritt im Spilsby Sandstein (Berrias) von Ost England und *Boreioteuthis* im Ober Berrias von Ost Europa auf. *Cylindroteuthis* (*Arctoteuthis*) erschien und entfaltete sich im Berrias des arktischen Gebietes und wurde die dominierende Komponente im Valangin der westlichen USA und von Kanada.

La région boréale atlantique, peut être le bassin marin de Russie centrale, était le centre d'émergence de nouveaux groupes de Bélemnites boréales à la fin du Jurassique et au début du Crétacé. Durant le Volgien moyen et supérieur, *Pachyteuthis* s.s., *Simobelus* et *Lagonibelus s.s.* y cédaient la place à *Microbelus*, tandis qu'*Acroteuthis s.s.* apparaissait dans les Grès de Spilsby (Berriasien) en Angleterre orientale et *Boreieteuthis* au Berriasien supérieur en Europe de l'Est. *Cylindroteuthis* (*Arctoteuthis*) faisait son apparition et se développait dans le Berriasien de la région arctique, en devenant dominant dans la Valanginien de l'Ouest des Etats-Unis et du Canada.

1. Introduction

At the end of the Jurassic and the beginning of the Cretaceous the boreal seas were populated by belemnites of the family Cylindroteuthidae, which was very widely dispersed. The families Duvaliidae and Belemnopsidae (except for the genus *Belemnopsis*) were distributed over the Mediterranean area of the Tethyan Realm and Belemnopsidae and rare Duvaliidae over the Indo-Pacific Region. Among the belemnite assemblages of the Boreal Realm one may observe radical changes during the late Jurassic-early Cretaceous, though these changes were not strictly contemporaneous in the various zoogeographical regions and provinces. We begin our review with the Boreal-Atlantic Region—the centre of origin of certain taxonomic groups of belemnites which spread through the whole Boreal Realm during the Neocomian.

2. Belemnites of the Boreal—Atlantic Region

A belemnite assemblage containing *Acroteuthis* s.s. appears at the base of the Spilsby Sandstone of eastern England, together with the ammonites *Paracraspedites* and *Subcraspedites* (Swinnerton 1936–1955). The latter are of early Berriasian age according to the majority of publications, though Casey (1962, 1971) believes them to belong to the late Middle Volgian and the Upper Volgian. If the general trends in the evolution of the boreal faunas of the late Jurassic-early Cretaceous are taken into account, then it seems probable that certain genera and subgenera first appeared in the Western European Province and later spread to other parts of the Boreal Realm.

Small rostra found at the base of the Spilsby Sandstone with *Acroteuthis* s.s. were considered by Swinnerton to belong to *Acroteuthis subquadratus* (Roemer). It is probable that these are representatives of the subgenus *Microbelus*, which is extremely abundant in the Upper Volgian and Lower Berriasian of the Boreal-Atlantic Region. Specific belemnite assemblages vary in the higher Berriasian horizons, though the subgenus *Acroteuthis* s.s. (and possibly *Microbelus*) is still present. *Acroteuthis* is replaced by the Oxyteuthidae in the Hauterivian of England.

In northwest Germany marine Berriasian is lacking but only *Acroteuthis* s.s. is found at the base of the Valanginian. In Denmark, on the other hand, belemnites are present in deposits of Upper Volgian or Berriasian age, judging by the associated *Buchia*. From the illustrations given by Sorgenfrei and Buch (1964) these belemnites appear to be juvenile *Lagonibelus* and *Acroteuthis* (*Microbelus*). No belemnites have been reported from the Berriasian of Poland.

As for the Eastern European Province of the Russian Platform, according to the data of Gustomesov (1964), Gerasimov (1969) and Saks and Nalnyaeva (1966, 1968, *in* Saks *et al.* 1972) the top of the Middle Volgian (*Epivirgatites nikitini* Zone) contains *Lagonibelus* (*Holcobeloides*) *volgensis* (d'Orbigny) and representatives of the subgenus *Microbelus*. Higher in the sequence are present both *Microbelus* (predominant in the Upper Volgian) and *Boreioteuthis* (which appears in the *Craspedites subditus* Zone) and also *Acroteuthis* s.s., which appears in the *Craspedites nodiger* Zone. The belemnite assemblage of the Berriasian Zone of *Riasanites rjasanensis* is similar to that of the Volgian, with *Microbelus* usually dominant.

A sudden change in the belemnite composition takes place in the overlying *Surites spasskensis* Zone; *Acroteuthis* s.s. becomes dominant and *Boreioteuthis* acquires the common occurrence typical of the Eastern European Province—a feature which distinguishes this province from that of western Europe. Finally, in the Lower Valanginian *Pseudogarnieria undulatoplicatilis* Zone, *Acroteuthis* s.s. and *Boreioteuthis* are especially numerous and solitary *Cylindroteuthis* (*Arctoteuthis*) appear as immigrants from Siberia. This belemnite assemblage is not known in higher beds of the Valanginian.

3. Belemnites of the Arctic Region

On the River Izhma, in the Petchora Basin, the Middle Volgian (*nikitini* Zone) yields a belemnite assemblage typical of the Russian Platform; from the presumed Upper Volgian only one central Russian Upper Volgian species has been obtained. From the base of the exposed Berriasian section species typical of the Upper Jurassic and Lower Cretaceous of Siberia have been recovered. Higher in the sequence, species of European *Acroteuthis* predominate in the *Surites analogus* Zone, together with Siberian forms such as *Pachyteuthis* (*Simobelus*) *curvula* Saks and Nalnyaeva. In Siberia and the Urals the latter species characterizes the *analogus* Zone and the bottom part of the overlying *Bojarkia mesezhnikowi* Zone. *Acroteuthis* continues to dominate the belemnite assemblages of later horizons, including the bottom part of the Lower Valanginian.

Blüthgen (1936) reported a rich belemnite assemblage from Spitsbergen (King Charles Land) in Berriasian-Valanginian beds: 33 species and subspecies, belonging mainly to *Acroteuthis* s.s., some to *Boreioteuthis*, *Lagonibelus* s.s., *Pachyteuthis* s.s., *Simobelus* and *Pseudohibolites*. The specimens were collected from scree and without stratigraphical data; not all the described species have an adequate taxonomic basis and we have no information with which to compare the fauna with that of late Jurassic times in the same area. However, of special importance is the presence of representatives of the Tethyan Belemnopsidae (*Pseudohibolites*) that might have been carried round northwest Europe to Spitsbergen by warm Atlantic currents.

Evidence concerning the belemnite composition of the Upper Jurassic-Lower Cretaceous of East Greenland is very poor. Species that survived at the same time in the Petchora Basin and Siberia are known by isolated finds in the Middle Volgian. *Acroteuthis* s.s. has been reported from the *Hectoroceras kochi* Zone of the Berriasian and from undifferentiated Berriasian (Spath 1947; Donovan 1953).

In West Siberia, near the eastern foot of the pre-Arctic Urals, an assemblage similar to that of the Russian Platform, with predominant *Pachyteuthis* s.s. and *Simobelus*, survived during the Middle Volgian. The Upper Volgian deposits of the *Kachpurites fulgens* Zone, as in the Eastern European Province, are characterized by a dominance of *Microbelus*. However, in the topmost beds of the Volgian there appears an entirely different assemblage, with *Cylindroteuthis* s.s., *Acroteuthis* and *Lagonibelus* ex gr. *elongatus*, which contains many of the species that appear in northern Central Siberia. This assemblage persists into the Berriasian. An assemblage in which Siberian species occur together with eastern European species of *Microbelus* is apparently restricted to the Lower Berriasian; it disappears in the *kochi* Zone and it is the Siberian species of belemnites that persist.

Higher in the sequence, in the *Bojarkia payeri* Zone of the foothills of the Urals, *Acroteuthis* s.s. occurs. Finally, in the lower Valanginian Zone of *Temnoptychites insolutus*, *Acroteuthis* s.s. occupies the dominant position among the assemblages.

Belemnites of northern Central Siberia (North Siberian zoogeographical Province) have been studied in greater detail; they were dispersed throughout the seas of the Yenisey-Lena and Priverkhoyansk depressions. Here a peculiar assemblage comprising members of the subgenera *Cylindroteuthis* s.s., *Arctoteuthis*, *Lagonibelus* s.s., *Holcobeloides*, *Pachyteuthis* s.s., *Simobelus*, rare *Boreioteuthis* and *Microbelus* existed during the Volgian. A fauna of 19 species has been collected from the top of the Middle Volgian. The assemblage was reduced to 15 species in the Upper Volgian, the subgenus *Microbelus* disappearing. Up to the base of the *analogus* Zone variations in composition of the belemnite assemblages consist essentially of impoverishment of the surviving Volgian fauna. Seven species have been collected from the *Chetaites sibiricus* Zone, seven from the *kochi* Zone, and 12 from the *analogus* Zone, where *Acroteuthis* s.s. appears for the first time. Eleven species have been found in the *mesezhnikowi* Zone, of which five belong to *Acroteuthis* s.s.

At the boundary of the Berriasian and Valanginian, between the Zones of *Bojarkia mesezhnikowi* and *Neotollia klimovskiensis*, the predominant element in the assemblage is the subgenus *Acroteuthis* s.s. (10 out of 15 species) instead of the earlier dominating subgenera *Lagonibelus* s.s. and *Arctoteuthis*.

The Upper Jurassic and Lower Cretaceous belemnites of Alaska and Canada are poorly known. Imlay (1961) described a rostrum from the Berriasian-Valanginian of northern Alaska which we identify as *Lagonibelus* (*Lagonibelus*) *sibiricus* Saks and Nalnyaeva. From the Valanginian of the Canadian Archipelago (Ellef Ringnes Island) a peculiar subconical rostrum was found by Jeletzky (1964) and described as *Acroteuthis* sp. nov. A; in fact it seems to belong to *Cylindroteuthis* (*Cylindroteuthis*) sp. nov. ex gr. *subporrecta* Bodylevsky.

The upper Middle Volgian deposits of Vancouver Island yielded (Jeletzky 1965) a rostrum that belongs rather to the species *Cylindroteuthis* (*C.*) *jacutica* Saks and Nalnyaeva, widespread in the Volgian of Siberia.

Crickmay (1930) described *Cylindroteuthis* (*Arctoteuthis*) *baculus* Crickmay and *Pachyteuthis* (*Simobelus*) *cretacea* Crickmay from the Berriasian of British Columbia. The former species is known also from the Berriasian of Siberia and according to Jeletzky and Tipper (1968) is confined to the upper part of the Canadian Berriasian. The latter is close to species from the Volgian of Siberia. The occurrences of these two species indicate a similarity between the Volgian-Berriasian belemnite assemblages of western Canada and northern Siberia. Valanginian rostra from British Columbia recorded by Jeletzky (1965) as *Acroteuthis* sp. nov. A belong in fact to *Cylindroteuthis* (*Arctoteuthis*) cf. *harabylensis* Saks and Nalnyaeva.

The Upper Volgian (Upper Tithonian) and Neocomian belemnites of California and Oregon were described by Anderson (1938, 1945). The original specimens are preserved in the Museum of the Californian Academy of Sciences and were examined by Stevens (1965) and by Saks in 1971. At the end of the Jurassic the western U.S.A. was populated by Siberian-like representatives of *Cylindroteuthis* s.s. and *Arctoteuthis*, together with forms having a fusiform rostrum without furrows, perhaps *Hibolites*. Stevens (1965) rightly noted that the species assigned by Anderson to *Belemnopsis* (except for the species *berrysae*), belong to the Cylindroteuthidae, i.e. to *Cylindroteuthis* with moderately extended rostra or possibly to *Lagonibelus* ex gr. *elongatus* (it is impossible to identify the genus without knowing the inner structure of the rostrum). Stevens doubted whether Anderson was right in identifying the genus *Hibolites*, though the rostra assigned to this genus differ from

Table 1. Boreal belemnite assemblages in the Jurassic-Cretaceous boundary beds.

		Western Europe	Eastern Europe	Siberia	North America
Lower Cretaceous	Upper Valanginian	*Acroteuthis* s. str.	*Acroteuthis* s.l.	*Acroteuthis* s.l. *Arctoteuthis*	*Acroteuthis* s.l. *Arctoteuthis*
	Lower Valanginian				
	Berriasian		*Microbelus-Acroteuthis* s. str.	*Cylindroteuthis* s.l.	*Cylindroteuthis* s.l.
		Microbelus-Acroteuthis s. str.			
Upper Jurassic	Upper Volgian	?	*Microbelus-Acroteuthis* s. str.		
	Middle Volgian	*Lagonibelus* s. str. *Pachyteuthis* s.l.	*Lagonibelus* s.l. *Pachyteuthis* s.l.		

those of the Cylindroteuthidae in having a fusiform shape. Following Stevens and Saks, many of the species reported by Anderson should be merged, though a full revision cannot be made without examination of all available material.

It should be noted that *Cylindroteuthis* (*Lagonibelus*?) and *Hibolites* are present also in the Lower Tithonian (Portlandian) beds of California.

None of the belemnite species assigned by Anderson to the Upper Tithonian of California survived to the Cretaceous. This sharp difference between the Jurassic and Cretaceous belemnite assemblages of the Pacific coast of the U.S.A. may be explained by the presence of a significant gap in the belemnite record. Imlay and Jones (1970) have confirmed the presence of Berriasian rocks in the western U.S.A., though the species of *Acroteuthis* described by Anderson (1938) from the Lower Cretaceous (Paskenta Group) are not tied to the Berriasian by ammonite finds and may well belong to the Lower Valanginian. An assemblage containing *Acroteuthis* (*Boreioteuthis*) and, more rarely, *Arctoteuthis* becomes dominant in the Valanginian of the western U.S.A. and Canada.

Because of the well-developed ventral furrow on the rostrum, Stevens (1965) assigned Anderson's Neocomian *Acroteuthis* to *Aulocoteuthis*. We cannot agree with this, since ventral furrows are present on the rostra of *Acroteuthis* also, especially in the subgenus *Boreioteuthis*. The genus *Aulocoteuthis* belongs to the family Oxyteuthidae and differs from *Acroteuthis* in its lateral furrows, which are lacking in the Californian *Acroteuthis*.

4. Conclusions

In the Boreal-Atlantic Region the Middle Volgian belemnite assemblage with *Pachyteuthis* s.s., *Simobelus* and *Lagonibelus* s.s. changed during Middle and Upper Volgian and Lower Berriasian times into the assemblage with *Microbelus*; the latter spread eastwards as far as the western part of the West Siberian sea. *Acroteuthis* s.s. appeared in this assemblage in the later part of the Upper Volgian and gained a dominant position everywhere west of the meridian of the Urals. Beginning with the Volgian, we observe at the same time the role played by *Boreioteuthis* in the Eastern European Province.

As for the Arctic Region (including the Boreal-Pacific Province), a belemnite assemblage with *Cylindroteuthis* s.s., *Arctoteuthis*, *Lagonibelus* ex gr. *elongatus*, *Pachyteuthis* s.s. and *Simobelus* existed during the Volgian and became gradually impoverished but still survived to the end of the Berriasian. This assemblage was spread over the Boreal-Pacific Province as far as California and the Soviet Far East; at the end of the Volgian it penetrated westwards to the Urals. It was at the end of the Berriasian that *Acroteuthis* s.s. and *Boreioteuthis* spread throughout the Arctic region. By the Valanginian the belemnite assemblage with *Acroteuthis* s.s. had occupied the whole of the Boreal Realm. Only *Boreioteuthis* is unknown in western Europe.

The above evidence permits the conclusion that the centre of origin of new groups of boreal belemnites in late Volgian time (*Microbelus* ex gr. *russiensis*, *Acroteuthis* s.s., Neocomian *Boreioteuthis*) was the Boreal-Atlantic Region, perhaps the Central Russian sea. It was Neocomian *Arctoteuthis* that appeared and evolved in the Arctic Region.

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Foraminifera from the Jurassic-Cretaceous boundary beds in the U.S.S.R. (Boreal Realm)

V. A. Basov, S. P Bulynnikova and K. I. Kuznetsova

Volgian-Neocomian foraminifera of the Boreal Realm belong to benthonic groups, whose distributions were facies-controlled. Evolution proceeded at differing rates in different environments and regions, and faunal composition also varied from one zoogeographical region to another. Faunas representing both the Arctic and Boreal Atlantic Regions occur in the Volgian-Berriasian sediments of the U.S.S.R. In Siberia, distinctive new faunas appear not at the Jurassic/Cretaceous boundary but in the *Hectoroceras kochi* Zone and particularly in the *Surites analogus* Zone.

Wolgisch-neokome Foraminiferen des Borealgebietes gehören zu benthonischen Gruppen, deren Verbreitung von der Fazies abhängig war. Die Evolution verlief in den verschiedenen Lebensräumen und Gebieten unterschiedlich schnell. Auch ist die Zusammensetzung der Faunen in den verschiedenen zoogeographischen Regionen unterschiedlich. In den Wolga- und Berrias-Ablagerungen der USSR sind Faunen sowohl der arktischen als auch der boreal-atlantischen Region beobachtet worden. In Sibirien treten neue Faunen nicht an der Jura-Kreide-Grenze, sondern in der *Hectoroceras kochi* Zone und besonders in der *Surites analogus* Zone auf.

Les Foraminifères volgiens et néocomiens du Domaine boréal sont des benthoniques dont la distribution dépendait du faciès. Leur évolution s'effectuait à des taux divers dans des environnements et des contrées différentes et la composition faunique variait aussi d'une province à l'autre. Des faunes représentatives à la fois de la région Arctique et de la région boréale atlantique se rencontrent dans les sédiments volgiens et berriasiens d'U.R.S.S. En Sibérie, des faunes nouvelles et caractéristiques apparaissent non point à la limite Jurassique-Crétacé mais dans la zone à *Hectoroceras kochi* et surtout dans la zone à *Surites analogus*.

1. Introduction

During the final phases of Jurassic history in the Boreal Realm there appeared a new type of foraminiferal fauna in which the Nodosariidae predominated and the Polymorphinidae, Lituolidae and Ammodiscidae were also well represented. Compared with previous faunas, the Epistominidae, Ophthalmidiidae and Spirillinidae became less important. From the predominant Nodosariidae there evolved new polygenetic branches of the genera *Lenticulina, Marginulina, Astacolus* and *Saracenaria*, which gave rise to the main elements of the Lower Cretaceous fauna that became widely developed in the Neocomian. This phase was characterized by the appearance of genera unknown in older faunas: *Arenoturrispirillina* (Ammodiscidae), *Ammobaculoides* (Lituolidae), *Dentalinopsis* (Nodosariidae), *Paradentalina*, *Tentifrons* and *Spirofrondicularia* (Polymorphinidae).

Though a common pattern of evolution may be discerned among the foraminifera of the Boreal Realm as a whole, faunal composition and peculiarities of development varied from area to area, according to position in the various zoogeographical regions. The *Arctic Region,* located north and northeastwards from the line passing through the northern Urals and north Scandinavia and covering the marine basins of the Petchora depression, the Arctic Islands, West Siberia, the Yenisey-Lena area, the northeastern part of the U.S.S.R., Alaska and north Canada (Saks *et al.* 1971), was characterised by widely distributed groups of agglutinated foraminifera (Ammodiscidae, Lituolidae, Textularidae, Ataxophragmiidae, Trochamminidae) along with Nodosariidae. There was a prevalence of members of the genera *Recurvoides, Evolutinella, Trochammina, Ammodiscus* and *Dorothia; Lenticulina* and *Marginulina* were the most diverse among the secretory foraminifera.

In the *Boreal-Atlantic Region,* stretching south and southwestwards from the line passing through the northern Urals and north Scandinavia, secretory foraminifera were predominant, especially the Nodosariidae. The Polymorphinidae and Epistominidae were also important, as was the Lituolidae among the agglutinating foraminifera. The genera most frequent in the Protozoan assemblages were *Haplophragmoides, Lenticulina, Marginulina, Citharina, Vagulininopsis?, Guttulina, Ramulina, Hoeglundina* and *Mironovella* (Kuznetsova 1965).

Because the foraminifera are represented exclusively by benthonic groups dependent on facies-environment, stratigraphical subdivisions (zones and beds) based on them are related to ammonite zones. This enables us to carry out interregional correlation with confidence. The composition of faunal assemblages in the various structural-facies zones is very diverse and widely distributed species are found to a greater extent among the eurybionites. These species allow us to correlate sections in different facies. For comparison it is desirable to use assemblages of similar facies type or a series of assemblages characterizing various contemporaneous environments (e.g. from coastal-shoal to moderately abyssal). The latest studies carried out on the Taimyr Peninsula (Basov *et al.* 1965) show that the Middle Volgian foraminiferal assemblages of the Arctic Region from the coastal-shoal facies are very similar at generic and specific levels to Middle Volgian assemblages from the coastal-shoal facies of the Russian Platform. The great differences between the foraminiferal faunas of the Siberian and Russian Platforms is due to the fact that relatively deep basins were widespread in Siberia during the Volgian but absent on the Russian Platform (Basov 1968).

2. Volgian-Neocomian foraminiferal assemblages

Difficulties in using foraminifera for long-range correlation can be overcome by comparing faunas of adjacent areas where they have elements in common. We shall analyse the Volgian-Neocomian phase of foraminiferal development beginning with the Middle Volgian, when the features of this phase were best expressed, and which can be correlated with the English Portlandian and the "Middle Bononian" of Poland.

2a. Middle Volgian assemblages

In the Middle Volgian substage of the Arctic Region two successive foraminiferal assemblages can be distinguished: (1) *Spiroplectamina vicinalis* and *Saracenaria pravoslavlevi*, and (2) *Spiroplectamina vicinalis* and *Dorothia tertuosa*. Both assemblages have a similar systematic composition, but differ in the quantitative ratio of certain groups. Ten species among seven genera are common to both assemblages. The most characteristic are *Ammobaculites haplophragmoides* Fursenko and Polenova, *Spiroplectamina vicinalis* Dain, *Saracenaria pravoslavlevi* Furs. and Pol., *Marginulina formosa* Mjatliuk, *M. striatocostata* Reuss, *Marginulinata pyramidalis* (Koch), *Guttulina dogieli* Dain and *Spirofrondicularia rhabdogonoides* (Chapman).

Some species in the Middle Volgian fauna gave rise to phylogenetic branches traceable in the Lower Cretaceous.

The Middle Volgian substage of the Boreal-Atlantic Region is characterized by very rich assemblages of foraminifera. Three phases can be clearly distinguished in their evolution, each corresponding to an ammonite zone and providing in turn the basis for a foraminiferal zone. The first phase corresponds to the *Lenticulina ornatissima* and *Saracenaria kazanzeni* Zone, the second to the *Lenticulina ponderosa* Zone and the third to the *Astacolus mosquensis* and *Lenticulina oligostegia* Zone (Dain and Kuznetsova 1971). The last two zones are considerably poorer in foraminifera in northwest Europe (particularly England) than in eastern Europe, this being related to shallowing of the north European basin and great changes in living conditions of the benthos (Kuznetsova 1969).

2b. Upper Volgian assemblages

Upper Volgian time on the Russian Platform was characterized by shallowing of the sea basin, which resulted in impoverishment of foraminiferal assemblages: this began somewhat earlier in the northwestern part of the area. *Lenticulina, Marginulina, Dentalina, Nodosaria* and *Saracenaria* were predominant and sedentary *Ramulina* and *Placopsilina* were also present. Purbeckian continental deposits were formed in England and Poland at this time. In Siberia, on the contrary, the Upper Volgian was characterized by a widespread marine transgression that submerged almost the whole of the West Siberian lowland and the Yenisey-Lena depression. Evidence of this sea basin can be seen also in the northeastern U.S.S.R. Upper Volgian foraminiferal assemblages of Central and West Siberia are similar in composition. They are characterized by the predominance of Ammodiscidae (*Ammodiscus, Arenoturrispirillina*), Lituolidae (*Schleiferella emaljanzevi, S. volossatovi, Recurvoides obskiensis*), some Haplophragmoidae and, to a lesser extent, by Trochamminidae (Basov 1968). In Volgian time Ammodiscidae (*Arenoturrispirillina*) were widely distributed also in the Canadian Arctic, where on the basis of their disappearance the Jurassic-Cretaceous boundary is drawn (Chamney 1971). Secretory forms were in a subordinate position and are found mostly in the relatively shallow parts of the basin. A peculiar group of Lituolidae originating in the genus *Evolutinella* developed through most of the Neocomian (Bulynnikova 1967).

The Upper Volgian assemblages in the Siberian successions changed with time. While assemblages of the *Craspedites okensis—Ammodiscus veteranus* and *Schleiferella emeljanzevi* Zones are clearly of Volgian type, beginning with the *Craspedites taimyrensis* Zone (correlated with the *C. nodiger* Zone of the Russian Platform) there appears a number of species well represented in the Berriasian: *Marginulina zaspelovae* Romanova, *Schleiferella fimbriata* (Schar.), *Orientalia*? *baccula* Schl., *Recurvoides paucus* Dubr., *Haplophragmoides infracretaceous* Mjatliuk, *Trochammina* ex. gr. *rosaceaformis* Romanova, etc.

Species and species-groups common to the Upper Volgian of the Boreal-Atlantic and Arctic Regions are: *Haplophragmoides* ex gr. *inconstans* Bartenstein and Brand, *Geinitzinita arctocretacea* Gerke, *Marginulinata pyramidalis* (Koch), *Marginulina striatocostata* Reuss, *M. glabroides* Gerke, *M. impropria* Basov, *Citharina* aff. *brevis* (Furs. and Pol.), *Nodosaria* ex gr. *paupercula* Reuss, *Astacolus suspectus* Basov, *A? trigonius* Basov, and *Saracenaria valanginiana* Bartenstein and Brand (about 15 species among 10 genera).

2c. Berriasian assemblages

When analysing the stratigraphical boundary of the Jurassic and Cretaceous Systems, we can see a discrepancy between the rank accorded this boundary and the scale of faunal changes. Moreover, in Siberia the boundary established by means of ammonites (between the *Chetaites chetae* and *Ch. sibiricus* Zones) does not coincide with the level where the systematic composition of the foraminifera changes. The Berriasian stage contains all the species appearing in the upper two zones of the Volgian (*C. taimyrensis* and *Ch. chetae* Zones) besides a number of older Volgian species. New elements of the assemblages of the lower part of the Berriasian stage in the near-shore shallow zone are merely subspecies of the Volgian-Berriasian species (*Marginulinopsis borealis mjametchensis, Globulina chetaensis berriassica, Geinitzinita arctocretacea arctocretacea*) (Basov 1969); in the relatively deep zone the differences in foraminiferal assemblages of the uppermost Volgian and the lowermost Berriasian are in the quantitative ratios between species.

When evaluating the stratigraphical importance of foraminifera, one should always bear in mind their facies association, since coeval assemblages from different facies vary in composition and their development proceeded at different rates. Thorough study of the Khatanga basin shows that the process of renewal of faunal composition proceeded more rapidly in the coastal zone, whereas in the relatively deep zone many Volgian species persisted almost throughout the Berriasian.

Distinctly new Berriasian elements appear in Siberia in the *Hectoroceras kochi* Zone and particularly in the *Surites analogus* Zone. The latter interval witnessed the flourishing of specific groups that were either poorly developed in the Volgian or appeared for the first time in the Berriasian: *Trochammina* ex gr. *neocomiana* Mjatliuk, *T. rosaceaformis* Romanova, *Gaudryina gerkei* Vassil, *Ammobaculites praegoodlandensis* Bulynnikova, *A. gerkei* Scharov., *Haplophragmium scabrum* Bulynnikova, etc. Here for the first time appear representatives of the genus *Ammobaculoides* (*A. sibiricus*): some species belonging to groups widely distributed in the Upper Volgian, however, persist: *Ammodiscus veteranus, Schleiferella emeljanzevi, Verneuilinoides* ex gr. *perexiguus, Trochammina* ex gr. *rosaceaformis,* *Marginulina zaspelovae,* costate marginulines, *Lenticulina* ex gr. *muensteri* Roemer, etc.

At the end of the Berriasian (*Tollia payeri* Zone) in North Siberia the basin became increasingly shallow and ceratobuliminides (*Pseudolamarckina tatarica*) became widespread. Along the southern and eastern periphery of the West Siberian lowland there were also distributed Nodosariidae (*Lenticulina multicus* Zaspel., *L. lideri* Roman., etc.).

In the deeper western part of the basin a peculiar assemblage existed, represented by abundant populations of *Trochammina polymera* Dubr. Here persisted the earlier species *Verneuilinoides perexiguus, Recurvoides paucus* and small *Ammodiscus.* Species and species-groups found also in the Neocomian of the Boreal-Atlantic region were present at this time: *Haplophragmium* ex gr. *inconstans, Geinitzinita arctocretacea, Marginulinata pyramidalis, Marginulina striatocostata, M. glabroides, M. impropria, Citharina* aff. *brevis, Nodosaria* ex gr. *paupercula, Astacolus suspectus, A? trigonius, Saracenaria valanginiana,* etc.

During the latter half of the Valanginian and the Hauterivian a further regression of the sea took place on Siberian territory, causing the formation of peculiar brackish foraminiferal assemblages in which the above groups did not play any significant role (Bulynnikova *et al.* 1971). The further development of the foraminiferal fauna of the Volgian-Neocomian can be traced in the Cretaceous basins of western Europe, where one may observe a great number of species similar to, and perhaps conspecific with, those of Siberia and to some extent with those of eastern Europe.

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A comparison of the austral and boreal Lower Cretaceous foraminiferal and ostracodal assemblages

Viera Scheibnerová

Recognition of an Austral Biogeoprovince in the southern hemisphere, equivalent to the Boreal Biogeoprovince, is ratified by the study of the foraminifera. The striking homogeneity of the Lower Cretaceous microfaunas (ostracods and foraminifera) in each province was a result of the extra-tropical position of the relevant parts of the southern and northern continents and the geographical proximity of these parts within each province. The extent of similarity of the austral and boreal foraminiferal faunas was determined by episodic south-north migrations. Such migrations influence the study of evolutionary lineages and must be taken into account in biostratigraphy.

Aus Studien an Foraminiferen ergab sich, daß auf der südlichen Hemisphäre eine "australe Biogeoprovinz" existiert, die der "borealen Biogeoprovinz" äquivalent ist. Die erstaunliche Gleichförmigkeit der Mikrofaunen der Unterkreide (Ostrakoden und Foraminiferen) in jeder Provinz hatte zwei Ursachen. Einmal war es die Lage außerhalb des Tropengürtels und zum anderen die geographische Nähe der größeren Kontinentgebiete in jeder Provinz. Ursache der großen Ähnlichkeit der borealen und australen Foraminiferen-Faunen waren episodische Süd-Nord-Wanderungen. Der Einfluß solcher Migrationen muß bei Untersuchung phylogenetischer Reihen berücksichtigt werden.

La mise en évidence d'une biogéoprovince australe dans l'hémisphère Sud, homologue de la biogéoprovince boréale, est confirmée par l'étude des foraminifères. La remarquable homogénéité des microfaunes éocrétacées (ostracodes et foraminifères) de ces deux provinces provenait de la localisation extra-tropicale des secteurs concernés des continents boréal et austral et de leur proximité géographique à l'intérieur de chacune des deux provinces. Le degré de similitude des faunes boréale et australe de foraminifères dépendait de migrations Sud-Nord épisodiques. De telles migrations conditionnent l'étude des lignées évolutives et la biostratigraphie doit en tenir compte.

1. Introduction

The classical beginnings of Cretaceous micropalaeontology in Europe and in North America were connected with the study of non-tropical benthonic foraminiferal faunas, especially with those inhabiting the environments which fall under the broad scope of the Boreal Biogeoprovince. Later, a shift in the interest of micropalaeontologists appeared towards tropical foraminifera (reflected in some neglect of the benthonic forms) most typically those of Upper Cretaceous (and Tertiary) age, for which international biostratigraphy tended to be based on planktonic foraminifera.

However, Lower Cretaceous seas were inhabited by very few planktonic forms. These are not well suited for biostratigraphy because of their scarcity, low specific diversity and extended vertical ranges.

While the non-tropical Lower Cretaceous foraminiferal assemblages of the northern hemisphere have been studied in great detail since the beginnings of micropalaeontology, this is not true of their equivalents in the southern hemisphere, mainly because of paucity of data on the occurrence there of the marine Lower Cretaceous. The typical occurrences are those of Australia (Great Artesian Basin) described by Irene Crespin. Recently more data have accumulated, not only in Australia and New Zealand, but also in South Africa and South America, through studies by Herm (1966), Bertels (1969, 1970), Hillebrandt (1970, 1971), Malumián (1968), Webb (1966, 1968, in press) and Scheibnerová (1970, 1971 a-f, 1972a, 1972b, in press a).

Recent studies in Australia have revealed the Lower Cretaceous foraminiferal faunas to be composed of several species similar to or identical with those of the Boreal Biogeoprovince in the northern hemisphere (Scheibnerová 1971c, 1972a, in press b). The existence of the Austral Biogeoprovince as distinguished by the author (Scheibnerová 1970) proved to be justified. It represents a non-tropical climatic zone of the southern hemisphere during the Cretaceous with the Great Artesian Basin as a type area (Scheibnerová 1971 f).

With the existence of the Austral Biogeoprovince several questions arise concerning the character and taxonomy of austral foraminifera as well as their biostratigraphical value, all those being closely allied to the questions of dispersal pattern and palaeogeography during the Mesozoic. Some of these questions have been dealt with in detail elsewhere (Scheibnerová 1971b). In this paper the following specific problems are discussed:

(a) Similarities and differences between the boreal and austral foraminiferal faunas, and migration between the two regions.

(b) Implications of the existence of an austral equivalent of the Boreal Biogeoprovince for biostratigraphy, with special reference to the Lower Cretaceous.

Close affinities are recognised among austral ostracodal faunas.

2. Foraminiferal assemblages

2a. Austral foraminiferal assemblages

A comparison of the Australian (Great Artesian Basin) Lower Cretaceous foraminifera with those of South Africa (Lambert and Scheibnerová, in preparation), New Zealand, South America or peninsular India reveals striking similarities. The most important reason for this essentially homogeneous fauna is seen in the extra-tropical position of the southern continents and their geographical proximity at that time, i.e. before the accelerated separation of the southern continents after the Albian. The faunal similarity continued in the Upper Cretaceous because there were no major obstacles to the dispersal of these marine faunas, except where increasing distance prevented direct dispersal of certain species. Because of a temperature controlled dispersal and distribution of these austral faunas, clear evidence for the post-Albian drift to the north of certain parts of Gondwanaland is provided. This is so especially in the case of peninsular India, where Lower Cretaceous foraminifera are clearly austral while post-Albian ones are of a Tethyan aspect (Scheibnerová 1970, 1971a, 1971b).

2b. Affinities between the austral and boreal assemblages

Early Mesozoic foraminiferal faunas seem to show quite strong cosmopolitanism. Jurassic and Cretaceous foraminiferal faunas can be regarded as relicts of the faunas which inhabited epicontinental seas when the northern and southern continents were much closer together than they are today (see especially Stevens 1971; Stevens and Clayton 1971). However, already during the Jurassic we can see a latitudinally restricted, i.e. circumglobal, distribution of faunas within the climatic zones, with an obvious differentiation into tropical and non-tropical faunas. The non-tropical faunas are represented by the boreal and austral assemblages.

The degree of similarity within the Lower Cretaceous Boreal or Austral Biogeoprovinces respectively is very high: one can find identical composition at the species level in different parts of these biogeoprovinces and the differences are purely quantitative. On the other hand the similarities between the two provinces are basically at the generic level, though there are also a number of closely similar or identical species, specially species of *Lingulogavelinella, Gavelinella, Bilingulogavelinella, Orithostella, Neobulimina, Praebulimina, Discorbis, Valvulineria, Gyroidinoides, Pseudolamarckina, Reinholdella, Hoeglundina*, some miliolids (*Scutuloris*), several nodosariids, *Hedbergella planispira, H. infracretacea*, and numerous aggultinated forms (Scheibnerová 1971c, 1971e, 1972a, in press b).

While the faunal affinities within the Austral (or within the Boreal) Biogeoprovince can be relatively easily explained, the faunal similarities between the two provinces are a result of complex factors, the most important of which appears to have been a south-north migration of some elements of the fauna, most probably via cold currents or cooler, deeper waters (Scheibnerová 1971b, in press a, and section 2c below). Despite these bipolar elements, faunal development within the two provinces was more or less independent, though many species have retained a very similar general character due to similar (i.e. non-tropical) temperature conditions and can often be classified as geographical species or varieties.

2c. South-north migrations

Darwin was aware of the fact that more continental plants have migrated from the north to the south than *vice versa*. He explained this by reference to the larger extent of dry land in the northern hemisphere at present. Due to evolutionary pressure they became more advanced and more numerous and had more chance to survive than did the less advanced southern forms when migrations occurred owing to climatic changes. Following the same reasoning, because of a greater extent of sea cover in the southern hemisphere one can expect the main stream of marine organisms to have come from the south to the north, especially in the Mesozoic. Marine environments in the northern hemisphere, however, were more varied, due to constant fluctuations in the extent of sea cover. Consequently, during the Cretaceous evolutionary pressure caused the development of more varied assemblages composed of more advanced species in the northern than in the southern hemisphere seas, where conditions were more conservative during Phanerozoic time.

The south-north migrations were episodic. Both warm and cold currents reflect the general climatic pattern and hence migrations were strongly affected by temperature fluctuations. Therefore there was a greater similarity between the Tethyan and extra-Tethyan faunal assemblages during the Lower Cretaceous than in the Upper Cretaceous because of a climatic amelioration during the latter, accompanied by a weakening of current activity. Oceanic currents played a very important role in faunal dispersal. This has been discussed in detail in a study of the distribution of Lower and Upper Cretaceous austral foraminiferal faunas in Australia, New Zealand, peninsular India, Africa and South America (Scheibnerová 1971b, in press a). In the Lower Cretaceous, before the opening of the Atlantic Ocean and especially before the establishing of the connection between the North and South Atlantic Ocean, a very important role in the south-north migration was probably played by a cold Lower Cretaceous analogue of the Humboldt Current in the eastern South Pacific Ocean. This current might have accounted for the strong austral aspect of Lower Cretaceous foraminiferal faunas from some parts of northern South America, such as Peru, Ecuador, northern and central Columbia, Venezuela and even Trinidad. It is well-known that in these areas the foraminiferal faunas were rather peculiar in their generic and specific composition. As seen from the publications by Thalmann (1946), Stone (1949), Petters (1954, 1955) and especially by Guillaume, Bolli and Beckmann (1969) and as confirmed by Bolli (personal communications 1972), the planktonic component in these areas is unlike the "typical" Cretaceous assemblages in adjacent areas to the north. Apart from Radiolaria, numerous small, simple *Globigerina*-like forms, *Hedbergella*, *Globigerinelloides* and Heterohelicidae are the most frequent forms. At the same time the predominating benthos is composed of simple agglutinated forms and some calcareous species showing remarkable similarity with those known to occur further south, in areas belonging to the Austral Biogeoprovince. These faunas are especially interesting if compared with coeval faunas of the present western equatorial Africa (Scheibnerová, in press b). The influx of southern (austral) forms continued and was even strengthened later through the activity of the Upper Cretaceous analogue of the Benguala Current in the eastern South Atlantic. The influence of this current, together with that of a cool current in the eastern South Pacific, might account also for many elements in the Cretaceous sediments of the Gulf Coast Region being similar to those of the South Atlantic, South America and New Zealand (Scheibnerová, in press a).

The analysis of the character and distribution of the Lower and Upper Cretaceous foraminiferal assemblages (Scheibnerová 1971b, in press a) also shows that while most calcareous and aggultinated forms were possibly temperate in origin and migrated from the south to the north via cool currents and during the cooling of the world climate, planktonic Cretaceous foraminifera were originally typically tropical and only some of the species spread to the north and south via warm currents and during the periods of warming of the climate (Scheibnerová 1971b; Frerichs 1971).

2d. Biostratigraphical considerations

The intermittent migration of new elements affects quite strongly the study of evolutionary lineages. The incomplete geological record and the subjective element in the taxonomy sometimes make it difficult to determine whether new taxonomic elements in the fauna were local members of an evolutionary lineage or immigrants. This problem is especially important since evolutionary lineages have become a basis for biostratigraphy. Recent studies have shown that the distribution pattern of Cretaceous foraminifera, both planktonic and benthonic, is a reflection of climatic differentiation. It has also been shown that temperature changes were the direct reason for often abrupt changes in the evolution of some species (see especially Olsson 1972). The problems of the existing tropical biostratigraphy based on the planktonic foraminifera have been discussed elsewhere (Scheibnerová 1971d): it is clear that the local appearance of certain species, in both tropical and extra-tropical areas, does not necessarily coincide with their appearance in the area of origin, but may be purely a reflection of climatic warming or cooling.

While planktonic foraminifera reflect mainly the world-wide climatic zonation and palaeo-oceanographic pattern (warm and cold currents and changes in their distribution), benthonic foraminifera reflect also local changes of palaeoenvironment and sedimentary basins. Therefore, a Lower Cretaceous biostratigraphy based on benthonic foraminifera should be closely associated with environmental analysis. There are problems in biostratigraphy caused by particular aspects of the mode of life of benthonic foraminifera, especially in relation to patchiness in areal distribution. Discontinuous distribution is a basic feature of the occurrence of all animals, including planktonic forms. All animals live in groups of sufficient size to ensure their survival and tend to live in the most favourable areas. Hence we can see different faunal profiles or partial profiles from localities which may be very close both geographically and in time, but are rich in different species or even genera. Thus a zonal scheme which utilizes several guide-species is to be preferred to one in which there is only one zonal index.

A compilation of possible new Cretaceous biostratigraphical schemes based on foraminifera has recently been published (Scheibnerová 1972c). This shows that not only the principal tropical and non-tropical schemes are necessary, but even within the same biogeoprovinces, both tropical and non-tropical, biostratigraphical zonations must be compiled for different marine environments. This principle has previously been applied successfully in the Upper Cretaceous of the Boreal Biogeoprovince in northern Europe. It is being applied at present in the Lower Cretaceous of the type area of the Austral Biogeoprovince.

3. Ostracodal assemblages

Special attention has been devoted to a comparison of the Australian ostracods with those of South Africa, New Zealand, Madagascar and South America and to some extent with those of the Boreal Biogeoprovince. Faunal affinities within the Austral Biogeoprovince have been recognized (Scheibnerová 1970, 1971a, 1971b) despite earlier published data claiming their endemic nature (Grekoff 1963; Dingle 1969). Recently, interesting affinities have been recognised by Krömmelbein (in press) who concluded that close palaeobiogeographical relationships must have existed between eastern Brazil and western Africa during the Aptian and Albian when ostracods can be compared at the species level. Later, during the Upper Cretaceous, relationships were at a generic level: this applies also to other areas studied (southern Africa and Australia (Great Artesian Basin)). *Brachycythere* and *Manjugaella* were regarded as the genera most useful in inter-regional correlations (for more detail see Krömmelbein, in press).

The Lower Cretaceous austral ostracods have been studied so far only sporadically (Grekoff 1963; Dingle 1969). In the present author's opinion they represent a rather ancient group of ostracods, very important in following the links between the early and late Mesozoic types. Because of their comparative simplicity and smaller diversity when compared with those of the Boreal Biogeoprovince they might prove to be an excellent group for the study of morphological response to environmental changes. In view of the palaeogeographical development of the Gondwana continents they might also prove to be useful in the study of the migration capability of ostracods. At present, it seems that the response of ostracodal morphology to palaeoenvironmental and palaeogeographical changes was much faster and more intensive than that observed in foraminifera.

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A review of the boreal Lower Cretaceous

R. Casey and P. F. Rawson

1. Introduction

This review is essentially a commentary on the preceding papers. It aims to give coherence and perspective to the biostratigraphical and related information provided on the various parts of the Lower Cretaceous Boreal Realm. Full-name citation of authors without year of publication refers to contributors to this volume.

The evolution of the Tethyan and Boreal faunal Realms during the Jurassic and Cretaceous was perhaps the most striking event of Mesozoic marine zoogeography. Knowledge of this faunal differentiation is derived almost exclusively from the inhabitants of shallow seas, perhaps with depths not exceeding 200 metres (Basov *et al.* 1972). It affected many life-forms, both benthonic and pelagic, but is particularly well-documented for the Ammonoidea. Belemnites show a similar distributional pattern but, as for the Jurassic (Hallam 1969, 1971), knowledge of the distribution of other faunas is generally sparse. Brachiopod distributions are detailed by F. A. Middlemiss and E. F. Owen; some distinctively boreal genera and species occur, while others were restricted to Tethys or the Jura region and a number occur in both realms, at least within Europe. Dilley (1971) has shown that many of the Lower Cretaceous genera of benthonic foraminifera, especially the smaller forms, had a wide distribution within their ecological niches.

Provincialism among the cephalopod faunas was most pronounced at the end of the Jurassic and the beginning of the Cretaceous, and coincided with the formation of an arid subtropical belt on land (Vakhrameev 1972) and the retreat of the seas from many marginal areas in the northern hemisphere. The Lower Cretaceous of this region thus inherited a complex biogeographical situation from the Jurassic, with land barriers and areas of brackish or continental deposition blocking the old seaways. The pattern of semi-isolated basins continued till the end of the Barremian, with minor modifications reflecting transgressive and regressive pulses. Then a series of transgressions, commencing early in the Aptian and continuing through the Albian, resulted in the flooding of extensive areas of former land-masses and the broadening of connections between the earlier basins. These palaeogeographical changes considerably affected the patterns of faunal distribution.

In so far as it has a present-day analogue, the Mesozoic Boreal Realm probably corresponds to the combined Arctic and Boreal Provinces, though palaeobotany, oxygen-isotope analyses and other evidence suggest that it had a relatively equable climate approaching the Warm-temperate of today. Its geographical setting was different, though it was during the Lower Cretaceous that the distribution of oceans and landmasses began to evolve towards the present-day pattern of north-south orientation. The dating of initial rifting in the North Atlantic is still difficult to establish. Geophysical evidence generally indicates a late Lower Cretaceous/early Upper Cretaceous date, while faunal evidence suggests at least narrow marine connections through this area during the Lower Cretaceous (e.g. F. A. Middlemiss; E. F. Owen; P. F. Rawson), and the occurrence of phosphatic nodules from mid-Kimmeridgian times onwards could indicate the earlier development of an oceanic circulatory system (Casey 1971). P. Juignet *et al.*, H. G. Owen and R. Casey have speculated on a link between changes in both fauna and physiography with phases in the opening of the North Atlantic.

2. The Lower Cretaceous Boreal Realm

2a. Faunal migrations and limits of the Boreal Realm

Arkell (1956) recognized Boreal and Tethyan "spreads"—periods when boreal Jurassic ammonites extended southwards or Tethyan ones northwards beyond their normal limits, to temporarily displace previously established faunas. These spreads have their counterparts in the Lower Cretaceous, and indicate that the boundary between the two realms oscillated with time.

P. F. Rawson reviewed the migration of Ryazanian—Barremian cephalopod faunas. In Europe, northward spread of Tethyan or Tethyan-derived ammonites occurred in the Lower Ryazanian, when *Riasanites* and *Euthymiceras* occupied the Russian Platform, in the Lower Hauterivian (*Endemoceras* in northwest Europe) and in the Upper Barremian (*Matheronites* on the Russian Platform). Along the Pacific Coast of North America, boreal spreads occurred during the Upper Valanginian and Hauterivian, Tethyan spreads during the Berriasian, Lower Valanginian and probably Barremian. Such generalizations rely to some extent on subjective taxonomy. For example, ideas on the source of *Platylenticeras* in the northwest European Lower Valanginian depend largely on whether it is regarded as a craspeditid of northern domicile (E. Kemper; J. P. Thieuloy) or as a berriasellid derived from the south (R. Casey).

Superimposed on these spreads or temporary changes in the boundary between realms, is a complex picture of more localised migration of faunas from one realm to the other along connecting seaways. A pattern of migration is apparent in northwest Europe, where faunal movements are becoming well-documented. Migration of Tethyan forms northwards occurred particularly during the Valanginian and Hauterivian, and is known among ostracods (P. Donze; J. W. Neale), brachiopods (F. A. Middlemiss; E. F. Owen), ammonites (E. Kemper; P. F. Rawson) and belemnites (P. F. Rawson). The ammonite migrations are most closely dated, and indicate a peak during the Upper Valanginian and Lower Hauterivian, when some boreal forms also migrated southwards to Switzerland and southeast France (e.g. J. P. Thieuloy).

Throughout the northern hemisphere the Aptian-Albian transgressions saw a considerable modification of the earlier faunal distribution patterns. With the broadened marine connections and submergence of land-masses, the boundary between the two realms often became blurred and extensive areas of faunal overlap may occur. In Europe, a northward migration of some brachiopods during the Lower Aptian (F. A. Middlemiss; E. F. Owen) took place within a relatively uniform ammonite province. Aptian ammonites such as *Deshayesites*, *Cheloniceras* and many of the Ancyloceratidae are widely distributed from the Mediterranean area to northern Europe, and strictly boreal genera are few.

Similarly, although some ammonite provinces may still be discerned in the Albian of the northern hemisphere (e.g. Jeletzky 1971; H. G. Owen), by Middle Albian times a fairly homogeneous assemblage of hoplitinid genera extended southwards from Spitsbergen to the Mediterranean shores of France and eastwards to Transcaspia (H. G. Owen); gastroplinitinids had common ground with the hoplitinids in the far north and seldom strayed south. The dominant belemnite in this broad region was *Neohibolites,* regarded by C. Spaeth as a Tethyan form. Possibly most of Europe was at this time an area of overlap of boreal and Tethyan faunas, no clear line of demarcation being possible for the two realms. There is a comparable overlap of the Lower Albian Tethyan and Boreal Realms for about 950 kilometres along the Pacific Coast of North America (D. L. Jones). By Upper Albian times the southern incursion of boreal faunas had ceased here, probably as a result of tectonic movements creating physical barriers, so that the realms were once again sharply separated and boreal ammonites confined to Arctic Canada and the Canadian Western Interior (Jeletzky 1971).

2b. Subdivision of the Boreal Realm

The faunas and floras of the Boreal Realm were by no means homogeneous, but show differences at family, subfamily and generic levels in different areas. Soviet workers have introduced an elaborate classification of the boreal Upper Jurassic for the territory of the U.S.S.R. and adjoining regions (Krimgolts *et al.* 1968), subsequently projected, with modifications, into the early Lower Cretaceous (e.g. V. N. Saks and T. I. Nalnyaeva). Two main divisions of the marine faunas are recognized—the Boreal-Atlantic and the Arctic Regions—each with a number of provinces and subprovinces. There is a separate classification for the flora.

A provincial classification in line with the Soviet scheme has been adopted for other regions by J. A. Jeletzky, who has distinguished a North American Boreal Province and a North Pacific Province applicable throughout the Lower Cretaceous (see Jeletzky 1971), by R. Casey in his description of the faunas of the Spilsby Province of the English Ryazanian, and by H. G. Owen with his recognition of an Albian European Province.

A different scheme of regional and provincial classification is required for each stage (or even zone), reflecting the changing pattern of faunal distribution and limits of the Boreal Realm. The reality of some of these provinces requires reassessment as our knowledge of faunas increases.

2c. Development of the Lower Cretaceous Boreal Realm

The origin and development of the Mesozoic Boreal Realm has provided material for extensive discussion since the pioneer work of Neumayr (1883): there has been renewed interest in recent years, though much of the discussion is based on inadequate faunal evidence. Although some "boreal" and "Tethyan" distributions can be recognized in the Lower Jurassic the sharp separation of the two faunas became apparent during the Middle Jurassic, during a period of marked regression when the Boreal Ocean was a partially land-locked inland sea (Hallam 1969). Thus the pattern of Lower Cretaceous Realms had a long pre-Cretaceous history of development.

The concensus of opinion in the present volume is that the Lower Cretaceous Boreal and Tethyan Realms show a latitudinal arrangement reflecting the disposition of climatic belts. Palaeogeographical control is also apparent, especially in pre-Aptian times.

Differences in water temperature (coupled with salinity) are considered to be the main climatic factor, though most authors accept that in comparison with the present day, temperature gradients during the Lower Cretaceous were slight. J. W. Neale finds that a simple temperature gradient appears sufficient to account for the differences between Tethyan and boreal ostracod faunas. The northward spread of certain ostracod genera from southeast France to the Valanginian of Poland and Germany and the Hauterivian of England is believed to reflect a levelling of temperatures consequent on an increase in temperature in northern Europe and a decrease further south (P. Donze). This accords with E. F. Owen's study of brachiopod distributions and their limiting factors. F. A. Middlemiss shows how closely the distribution of terebratulacean brachipods in Europe follows latitudes once the effects of the Tertiary orogeny are allowed for: he regards temperature/salinity as the primary climatic factor but indicates the importance of palaeogeographical configuration, especially on boreal faunas. P. F. Rawson stresses the same factors when discussing cephalopod migrations. D. L. Jones recognizes a relationship between temperature and faunal distributions along the Pacific Coast of North America, noting evidence of an increasing temperature gradient during the late Albian and into the Upper Cretaceous, related to a northern cooling of temperature. Among non-marine faunas, F. W. Anderson suggests that the distribution of cypridean ostracods was at least in part climatically controlled.

A significant aspect of temperature control is its importance at the reproductive period as a factor in the distribution of marine organisms (Ekman 1953). At the present day, the wide range of temperature in extra-tropical regions consequent upon seasonal changes gives scope for a diversity of life-forms in this respect. Assuming that the tilt of the Earth's axis was more or less the same as today, then the Mesozoic Boreal Realm must have experienced analagous seasonal changes of temperature and illumination, though overall temperature changes were doubtless less severe in this period of more equable climate. Adaptation of this reproductive cycle to northern seasons would probably have caused genetic isolation from Tethyan parent stocks as well as resulting in the evolution of new northern forms having temperature-controlled southern limits (Reid 1973). These factors alone could explain the continuing Tethyan/Boreal dichotomy among the Cephalopoda and the diversity of some boreal faunas compared with contemporary Tethyan ones.

In summary, the Lower Cretaceous Boreal Realm may be regarded as a latitudinal, temperature-controlled climatic belt whose faunal peculiarities were at times heightened by restricted communication with southern seas, especially during the Jurassic-Cretaceous transition. If this is so, then an Austral Realm should be discernible in the southern hemisphere. The apparent absence of such a realm coupled with the presumed slight temperature gradient in Mesozoic times have been used to disclaim a temperature control on the Boreal Realm (e.g. Hallam 1969). However, evidence is accumulating to suggest that an Austral Realm does indeed exist (e.g. V. Scheibnerovà). P. F. Rawson suggests that the relatively low taxonomic level at which this is distinguished may reflect the open nature of the southern seas, which were subject to a slight temperature gradient but did not suffer geographical isolation.

3. Lower Cretaceous stratigraphy

Refinement of chronostratigraphical classification, leading to an improved standard time-scale, depends on elaboration of local detail, such as full documentation of faunal and floral successions and facies, and the recognition of similar sequences, individual faunas, genera, or even a single species in other areas. At one end of the symposium spectrum are the syntheses of reconnaissance data from large territories like southern Alaska (D. L. Jones) and Arctic Canada (J. A. Jeletzky); at the other, reassessment of some of the better known areas of Europe, such as E. Kemper's reviews of northwest Germany. Despite over 150 years of effort, crucial information on the faunal succession in Europe is still forthcoming, such as R. Casey's description of the Volgian/Ryazanian ammonite sequence of eastern England.

The absence of contributions on the macroflora was disappointing considering that the Lower Cretaceous was such an eventful time in the history of the plants. Sharp changes from Mesophyte to Cenophyte flora took place in the northern hemisphere at the end of the Lower Cretaceous; a Mesozoic floral belt at middle latitudes was displaced polewards as world climate warmed towards an Albian peak (Vakhrameev 1964; Smiley 1967).

Analysing the symposium contributions on a stratigraphical basis, it is evident that the lower limit of the Cretaceous was a focal point of interest and several authors were concerned with local and/or regional aspects of the Berriasian/Ryazanian and the Valanginian. The upper limit of the Lower Cretaceous, the Albian, was a secondary peak of interest; it was the middle stages of the Lower Cretaceous which attracted least attention. Though to some extent the results of this simple analysis are patently fortuitous, we believe that the general picture obtained reflects current trends in Lower Cretaceous research. Renewed attacks on the perennial problem of the Jurassic-Cretaceous boundary, encouraged by the colloquium on this topic at Lyon in September 1973, were, perhaps, predictable; the widespread occurrence of fossiliferous deposits of Albian age, foreshadowing the great transgressions of the Upper Cretaceous, may account for the concentration of effort at that level.

3a. Stratigraphically useful fossil groups

Although ammonites have traditionally provided the main tools of Lower Cretaceous time-correlation, other fossil groups are being utilized to an increasing degree. In this volume reference has been made particularly to belemnites, bivalves, foraminifera, ostracoda and the microflora.

Ammonites

Throughout the Mesozoic successions ammonites are still the mainstay of zonation and correlation in marine sediments. No other group of organisms combines such wide dispersal and rapidity of evolution with relative independence of facies. For these reasons the acquisition of new data on the vertical and horizontal distribution of ammonites continues to spearhead research on the chronostratigraphy of the boreal Lower Cretaceous. Here, as in the literature of other regions and series, there is a tacit assumption that evolutionary/migratory faunal changes in the Ammonoidea took place simultaneously in all areas, though in many other fossil-groups there is evidence of geographical time-shifts in such changes. V. N. Saks and N. I. Shulgina observe that as ammonites are themselves the criteria of age-determination, time-shifts are difficult, if not impossible, to establish in the history of this group. The Tethyan/Boreal taxonomic dichotomy, whether or not directly attributable to climatic factors, itself suggests that ammonites were to some extent facies-bound. Thus R. Casey describes the Siberian Upper Volgian "*Virgatosphinctes*" as facies-ammonites and points out the fallability of assuming that they were contemporaneous with supposed congeneric Tethyan forms. Because ammonite names so frequently carry critical implications of age, subjectivity of identification and nomenclature in the Ammonoidea probably creates more problems of communication in chronostratigraphy than does any other Mesozoic fossil group.

Belemnites

The role of belemnites in Lower Cretaceous chronostratigraphy has always been that of subordinate zonal fossils—suitable for coarse subdivision and correlation where ammonites are rare or lacking. This is in contrast to the situation in parts of the Upper Cretaceous, where belemnites provide a fine zonal subdivision recognizable over large areas of Europe and beyond. At the beginning of the Cretaceous provincialism among this group of cephalopods was as marked as that among the ammonites at this level, and only broad inter-regional comparisons and correlations may be achieved at present by their use. Moreover, V. N. Saks and T. I. Nalnyaeva believe that certain genera and subgenera first appeared in western Europe and only later spread to other parts of the Boreal Realm. Though radical changes occurred in the composition of belemnite assemblages during the Jurassic-Cretaceous transition, such changes were not strictly contemporaneous in the various zoogeographical regions and provinces (V. N. Saks and T. I. Nalnyaeva). These assertions would appear to diminish the potential value of belemnites for long-range time-correlation in the Lower Cretaceous. Against this must be set the fact that stratigraphical records of belemnite assemblages in the boreal Lower Cretaceous are currently expressed in terms of ammonite sequences whose correlation from region to region is not infrequently subjective. Evolution of belemnite species was apparently quite rapid and provision of an independent belemnite chronology in the Lower Cretaceous comparable to that established in the European Campanian-Maestrichtian may yet prove feasible. This possibility is foreshadowed by the work of Spaeth (1971 and this volume) and Rawson (1972) on *Neohibolites* and *Aulacoteuthis* respectively.

Bivalves

Certain bivalves evolved fairly rapidly in the Lower Cretaceous and were sufficiently widely distributed to allow their use for regional zonation. Chief among these in the Boreal Realm is the genus *Buchia*. In North America, where ammonites of early Lower Cretaceous age are often very rare, *Buchia* zonations have been proposed for both the North American Boreal Province and the Pacific Province (see D. L. Jones; J. A. Jeletzky). The zones are relatively long-ranging (two per stage) but appear to be of considerable value for correlation at a regional level. Thus the presence of Berriasian and Valanginian strata in southern Alaska is recognized purely on *Buchia* species (D. L. Jones). Problems arise in long-distance correlation of North American *Buchia* faunas with those in Greenland (see F. Surlyk) and the U.S.S.R., and at this scale ammonites are more reliable (J. A. Jeletzky).

Species of *Inoceramus* are used for zonal purposes in the Upper Cretaceous of both Europe and North America. In the Lower Cretaceous, the *Inoceramus coptensis-salomoni* lineage is useful for dating in the Lower Albian (Casey 1961) of Europe and the *Inoceramus concentricus—sulcatus* transition marks the Middle/Upper Albian boundary over even wider areas.

In the non-marine sequence, the neomiodontid *Myrene* is associated with the "Cinder Beds" and contemporaneous quasi-marine invasions (Casey 1956) and constitutes a marker facies-fossil for the base of the European Ryazanian.

Ostracods

The use of ostracods for stratigraphical subdivision in non-marine Lower Cretaceous deposits was clearly demonstrated by the classic work by Forbes (1855) and Jones (1885) on the Purbeck-Wealden, carried on by F. W. Anderson and others. Despite the ever-increasing volume of data on their taxonomy and distribution, ostracods feature very little in zonal schemes for the marine Lower Cretaceous, though M. B. Hart provides a tentative zonal scheme for the Gault Clay (Middle-Upper Albian) of southeast England. E. Kemper notes that in Germany micropalaeontologists have customarily recorded microfossil assemblages (both ostracods and foraminifera) in terms of ammonite chronozones. J. W. Neale tabulates all British marine records and recognizes broad assemblages whose ranges roughly coincide with the standard stages. In his detailed study of the ostracods of the Speeton Clay D Beds (Ryazanian—early Hauterivian) Neale (1962) recognized several discrete assemblages, some of which permit close correlation with German occurrences, though they are clearly facies-controlled (see Neale 1968). Facies-control limits the value of ostracod assemblages even in relatively local correlation (E. Kemper).

The best hope for establishing an ostracod zonal sequence of regional application lies in the study of evolutionary lineages. It seems that the evolution of Lower Cretaceous ostracoda was generally more rapid than that of contemporaneous foraminifera. J. W. Neale discusses the prospects of such zonations and puts forward as an example a tentative phylogeny for *Cytherelloidea*. Successive assemblage zones based on occurrences of a single genus (*Cytheridea*), and therefore corresponding broadly to phylogenetic stages, have been proposed for the Purbeck-Wealden of southern England and provide the basis for detailed correlation with sequences in widely separated areas of Europe (F. W. Anderson).

Foraminifera

The majority of Lower Cretaceous foraminifera were benthonic forms, and hence were facies-dependent. Faunas varied considerably on both local and regional scales, and their development proceeded at different rates in different environments (V. A. Basov *et al.*). Thus the tendency of north German micropalaeontologists to calibrate foraminiferal (and ostracodal) assemblages to ammonite zones is repeated also in, for example, the Canadian (T. P. Chamney) and Soviet (V. A. Basov *et al.*) work. Both E. Kemper and V. A. Basov *et al.* further note that different rates of change (evolutionary and migratory) may occur in faunas of different parts of the same basin, all of which further hinders attempts at time-correlation.

Agglutinated foraminifera appear particularly difficult to use for regional correlation (T. P. Chamney), whereas other forms may be more widely distributed and of value in inter-regional correlation (B. N. Fletcher). V. A. Basov *et al.* suggest that long-distance correlation can be attempted in a series of steps, by comparing elements in common in faunas of adjacent areas.

The relationship between facies and faunas in a single section is shown in B. N. Fletcher's study of the Speeton Clay of England. The major faunal changes occur in the D Beds (Ryazanian—early Hauterivian) and are closely related to facies changes. Where the overall facies is more constant, in the Hauterivian and early Barremian, faunal changes take place slowly and consist of a steady series of appearances and extinctions, some of which are significant in regional correlation.

M. B. Hart proposes foraminiferal assemblage zones for the Gault Clay (Middle-Upper Albian) of southeastern England but points out that the sequence is only of local application. T. P. Chamney's assemblage zones of agglutinated foraminifera are of value for inter-basin correlation within the Canadian boreal region but of limited international significance, though V. A. Basov *et al.* recognize a broadly similar sequence in Siberia.

It appears, therefore, that foraminiferal assemblages may be very valuable in regional correlation, but that their use over wide areas is much more doubtful.

Palynology, plant megafossils

Palynological analysis is a relatively new field of palaeontology and its application to problems of correlation in the boreal Lower Cretaceous should be regarded as in the nature of promising pilot-studies. The potential usefulness of microflora in establishing marine—non-marine ties is of great importance in such areas as the Wealden of southeast England, where, with the exception of a few euryhaline ostracods and acritarchs, precise time-correlation with the marine facies must rely on fossil plant data, principally miospores (N. F. Hughes). Similarly, Smiley's (1972) studies of the Alaskan Albian-Maestrichtian interval has demonstrated how bed-by-bed sampling of plant megafossils, concentrating on areas of marine—non-marine transition, could lead to the integration of floral zones into the world time-scale currently based on marine faunal zonation. The sequence of floral zones in the non-marine Albian of northern Alaska established by Smiley suggests that where plant megafossil remains and floral horizons are adequate a finer zonation can be obtained from floral assemblages than from marine faunas. This is thought to result from the quicker vegetational response to the relatively rapid and severe changes of climate on land compared with the more moderate conditions of the open sea and slower rates of change in the marine situation. Batten (1972), also working on the Lower Cretaceous, stresses that effective use of spores, pollen and other palynomorphs for fine stratigraphical subdivision and correlation requires understanding of the relationship between lithological and palynological facies, thus indicating an area of collaboration open to palaeontologists and sedimentologists investigating the vast areas of continental deposits spread through the boreal Lower Cretaceous.

3b. The base of the Lower Cretaceous and the Ryazanian stage

Six of the papers published here are concerned with biochronological aspects of the Jurassic-Cretaceous boundary. Each author, working from his own ground, has produced a different zonal scheme and a different correlation table—J. A. Jeletzky on Arctic Canada, F. Surlyk on East Greenland, R. Casey on eastern England, and V. N. Saks and co-authors on Siberia and the Russian Platform. These differences reflect not merely provincial variations in the fauna but also conflicting ideas on the identity and stratigraphical horizons of ammonite genera in common. For example, in his description of the English sequence, R. Casey substantiates his assertion (Casey 1962) that *Paracraspedites* and *Subcraspedites* of the Spilsby Sandstone are Jurassic (Volgian) forms and considers that records of these genera in the Lower Cretaceous (Ryazanian) of Siberia, the Russian Platform and Arctic Canada refer properly to *Surites, Borealites* and other homoeomorphs. V. N. Saks and N. I. Shulgina, however, in conformity with recent Soviet publications revert to the opinion of Spath (1924) and Swinnerton (1935) that the Lower Spilsby Sandstone ammonites provide a basis for correlation with the Lower Cretaceous of the U.S.S.R. The use of belemnites to support this correlation (see V. N. Saks and T. I. Nalnyaeva) is considered by R. Casey to be invalidated by out-of-date stratigraphical information.

J. A. Jeletzky places the base of the Lower Cretaceous of Arctic Canada above beds yielding *Praetollia antiqua* Jeletzky and has identified the same species or a close ally in the Hesteelv Formation of East Greenland (F. Surlyk Pl. 1, fig. 1) where it occurs together with *Hectoroceras kochi* and above a *Buchia* assemblage of generally Cretaceous aspect (Jeletzky *in* F. Surlyk). F. Surlyk dates the Hesteelv horizon as Ryazanian in agreement with the placing of the *H. kochi* Zone well up in the Ryazanian by Russian and West European authors. J. A. Jeletzky, however, concludes (p. 52) that "like *Praetollia, Hectoroceras* may possibly range down into the uppermost Jurassic beds in East Greenland and elsewhere". R. Casey regards *Praetollia antiqua* as a Canadian representative of *Borealites,* characteristic of the *H. kochi* Zone and not even of earliest Cretaceous age. Jeletzky supports a Jurassic age for *P. antiqua* by his assessment of the accompanying *Buchia* fauna in Canada, which he correlates with ammonite-bearing Upper Volgian/Upper Tithonian *Buchia* sequences in British Columbia and California (North Pacific Province). Thus the dating of the Canadian *P. antiqua* fauna and its presumed analogues in East Greenland as either Jurassic (J. A. Jeletzky) or Cretaceous (R. Casey) would seem to hinge on the relative values placed on ammonites or *Buchia* for long-distance correlation (see section 3a, above).

Aside from subjective taxonomy, a fundamental dichotomy of view emerged concerning correlation between boreal and Tethyan occurrences at this level and the stage nomenclature that should be used in such correlation. R. Casey considers that until the base of the Berriasian stage has been firmly fixed by international consent and its boreal correlative identified two terminologies must be used:

Tithonian/Berriasian for the Tethyan Realm and Volgian/Ryazanian for the boreal. The provisional base of the Berriasian (*grandis* Zone) is thought by R. Casey to fall near the Middle/Upper Volgian boundary, Berriasian and Volgian thus overlapping. J. A. Jeletzky and V. N. Saks and his Soviet co-workers, on the other hand, regard the Volgian and the Berriasian as consecutive stages, with the Lower Berriasian occupying a stratigraphical hiatus between the Volgian and the Ryazan Beds on the Russian Platform. These authors believe that correlation is sufficiently advanced to dispense with such regional, non-standard terms as Ryazanian.[1]

The Ryazanian is highly condensed in its stratotype region and this, combined with its transgressive and non-sequential base,[2] has been a deterrent to general acceptance of this stage name. Nevertheless, the post-Volgian/pre-Valanginian boreal ammonite sequences "have a community of character that requires expression in stratigraphical terms" (R. Casey p. 228) and the name Ryazanian is available for this role. We prefer therefore to retain the Volgian/Ryazanian terminology as a temporary measure until stratigraphical correlation has reached the point where Tithonian/Berriasian, Portlandian/Berriasian, or some other agreed standard can be applied on a global scale.

Correlation between the Ryazanian of the Russian Platform and the Siberian sequences varies from one author to another; the varying conclusions are summarised in Table 1.

Table 1.

Northern Siberia (Jeletzky)		Siberia (Casey)		Siberia (Saks and Shulgina)		Russian Platform	
klimovskiensis	Val. (pars)	*klimovskiensis*	Val. (pars)	*klimovskiensis*	Val. (pars)	*undulatoplicatilis*	Val. (pars)
mesezhnikowi							
analogus	Berriasian	*mesezhnikowi*	Ryazanian	*mesezhnikowi*	Berriasian	*spasskensis*	Ryazanian
		analogus		*analogus*			
		kochi		*kochi*		*rjasanensis*	
		sibiricus					
kochi		*chetae*	Volgian (pars)	*sibiricus*		(hiatus)	
sibiricus	?						
chetae	Tithonian (pars)			*chetae*	Tith./Volg.		
taimyrensis		*taimyrensis*		*taimyrensis*		*nodiger*	Volg. (pars)

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[1] To avoid confusion it should be pointed out that the term Berriasian as used by Anderson, Neale, Fletcher and Marek and Raczyńska relates entirely to strata of Ryazanian age. The Tithonian/Berriasian or Portlandian/Berriasian boundary cannot yet be fixed either in England or in Poland.

[2] The initial Ryazanian transgression was so widespread—from the Russian Platform to southern England—as to suggest that its origin was eustatic and hence that it is an excellent time-marker.

3c. The Valanginian stage

Usage of substage terminology has varied and is a source of some confusion regarding the exact age of faunas. While many past authors have used a bipartite division of Lower and Upper Valanginian, others have recognized a Middle Valanginian too. This sometimes resulted from a misunderstanding of the German terms "Mittel-" and "Ober-Valendis": E. Kemper abolishes the former and recognizes Lower and Upper divisions, thus according with French and Soviet practice. In the present volume, J. A. Jeletzky still prefers a tripartite scheme; his Middle Valanginian coincides with the upper part of the Lower Valanginian of other authors, and correlates with the main *Polyptychites* horizons of western Europe and the Soviet Union. J. A. Jeletzky's usage of Upper Valanginian (Fig. 3, pp. 48–49) agrees with that of other workers.

Over most of the Boreal Realm the characteristic Valanginian ammonites belong to the Craspeditidae (Tolliinae) and Polyptychitinae, but in the earlier part of the Lower Valanginian of northwest Europe *Platylenticeras* is the dominant genus, while *Pseudogarnieria* typifies the lowest horizons on the Russian Platform. The occurrence of *Platylenticeras* and polyptychitids in the south of France (J. P. Thieuloy) and of occasional Tethyan genera in northwest Europe provide sufficient inter-regional markers (Kemper 1971b and this volume) for reasonable correlation within Europe, but the correlation between Tethys and other parts of the Boreal Realm is more difficult, particularly around the limits of the Valanginian, which are therefore difficult to define. The Siberian (and Canadian) sequences yield a series of tolliinids (including *Tollia*) crossing the Ryazanian/Valanginian boundary: Sazanova (1971) places the *Bojarkia mesezhnikowi* Zone at the base of the Valanginian, a procedure followed by J. A. Jeletzky, while V. N. Saks and N. I. Shulgina and R. Casey include this zone in the Ryazanian (Berriasian) and place the boundary at the base of the overlying *Neotollia klimovskiensis* Zone.

The later Lower Valanginian *Polyptychites* and allies have been subjected to so much monographic description that it is almost impossible to unravel a natural sequence through the taxonomic confusion. However, there is some evidence of a comparable series of forms from Canada, through Greenland and northwest Europe to the Russian Platform, Siberia and the Soviet Far East.

The polyptychitid *Dichotomites* characterises the lower part of the Upper Valanginian in most regions. However, tolliinids living along the Pacific Coast of North America during the later Lower Valanginian ("*Tollia*" *mutabilis* group) gave rise to the late tolliinid *Homolsomites*, species of which migrated to Arctic Canada at the beginning of the Upper Valanginian and reached Siberia and the Russian Platform during the latest Valanginian (J. A. Jeletzky). These are not known from northwest Europe, which was at this time open to considerable Tethyan influence (E. Kemper; P. F. Rawson).

3d. The Hauterivian stage

The relative lack of comment on this stage partly reflects its absence or limited development in some regions. In many areas there is an erosional break of varying degrees of magnitude above the Valanginian, which may represent a period of early Hauterivian folding (Vereshchagin 1962).[1]

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[1] Dated as Hauterivian by Vereshchagin, who followed the then standard Soviet view that the *Simbirksites* beds of the Russian Platform and parts of Siberia were Barremian. Reassignment of these to the Hauterivian (e.g. Drushchits 1962; Rawson 1971) suggests that the main movements may have been Lower Hauterivian.

Above this break, the first ammonites to appear are *Simbirskites* (subgenus *Speetoniceras*); various subgenera of this genus form the characteristic boreal fauna till the end of the Hauterivian. The zonal scheme which E. Kemper puts forward here for the northwest German Simbirskites Beds correlates well with schemes for northeast England (Rawson 1971) and the Russian Platform and Siberia (Pavlow 1901; Chernova 1951). The genus is also known from the Pacific Coast of North America, Alaska (D. L. Jones), Arctic Canada, and the Caucasus and Crimea, while J. P. Thieuloy records a single specimen from southeast France.

The best-known "boreal" Hauterivian ammonite successions are in northwest Europe (E. Kemper; P. F. Rawson), though as a standard of comparison the Lower Hauterivian fauna is of limited value. At this level the zonal form is an endemic but Tethyan-derived neocomitid, *Endemoceras* (Thiermann 1963); its absence in other regions has been interpreted, wrongly, as indicating a faunal break (e.g. Chernova 1951). In fact, there is evidence of a time overlap between the younger *Endemoceras* of the west European *regale* Zone and the earliest *Speetoniceras* of the Russian Platform (Rawson 1971). The only other known faunas that may be of early Hauterivian age are those of the Pacific Coast of North America and possibly some Siberian forms. In both cases the faunas have been assigned to *Homolsomites* (Jeletzky 1971; Shulgina 1965); the Pacific Coast forms are dated as Lower Hauterivian because of their position beneath *Simbirskites* and above presumed Valanginian ammonites, while the Siberian species were only tentatively dated as Hauterivian by Shulgina (1965) and are regarded as late Valanginian by J. A. Jeletzky.

3e. The Barremian stage

There was little discussion on this stage, but D. L. Jones records *Acrioceras* and *Shasticrioceras* from southern Alaska and P. F. Rawson comments on the dominance of heteromorph ammonites in both the northwest European and North American sequences. The Barremian stands out as a period of proliferation of heteromorphs, which often dominate the ammonite faunas. Often fragmentary, and with homoeomorphs in both the Upper Hauterivian and the Lower Aptian, these uncoiled ammonites pose acute problems of identification. This fact, combined with the doubtful value of existing ammonite zonal schemes, has doubtless contributed to the neglect of the Barremian stage. Evidence for the biostratigraphical value of Barremian belemnites in northwest Europe (Stolley 1925; Rawson 1972) requires testing in other parts of the Boreal Realm.

3f. The Aptian stage

In Europe the Aptian was primarily a phase of transgression. E. Kemper points out that in northwest Germany climatic changes and epeirogenic movements ushered in this stage. In southeast England the Aptian marked the return of the sea after a long interval of non-marine deposition, coinciding with the transgression observed in the marginal areas of the Lower Saxony Basin. In Normandy, it was the Upper Aptian transgression that brought the first post-Wealden sediments (P. Juignet *et al.*); this event was preceded by a phase of folding which may be correlated with inter-Aptian folding and faulting in the western Weald of southern England (Casey 1961). Though possessing distinctive features due to its special geographical environment, the Aptian of northwest Germany is more closely linked with that of England in respect of its ammonite sequence (Kemper 1971a) than previously realised. A common base is provided by the entry of the primitive deshayesitid *Prodeshayesites*, with many species interchangeable in the two regions.

Specific identity of ammonites occurs at many higher horizons in the Aptian (*Dufrenoyia furcata, Tropaeum bowerbanki, T. drewi T. subarcticum, Hypacanthoplites jacobi,* etc.) and the *Epicheloniceras* and *Parahoplites* faunas are also strikingly similar, thus enabling the main horizons in the English zonal scheme to be recognized in Germany (E. Kemper). For correlation within the non-ammonitiferous facies in northwest Germany the ostracod *Saxocythere* has proved invaluable.

In the Polish Lowland area a new transgressive cycle occurred during the Barremian-Albian (S. Marek and A. Raczyńska), leaving mostly coarse clastic, shallow-water, unfossiliferous sediments, some of which may represent the Aptian.

F. A. Middlemiss notes northward migrations of Tethyan faunas during both the Lower and Upper Aptian, citing in particular the abundance of "*Terebratula*" *moutoniana* in northwest Germany, *Sulcirhynchia* and corals, etc. in the English Lower Aptian, and the rudist *Toucasia* in the English Upper Aptian. Juignet *et al.*, however, see the Upper Aptian as a period of climatic cooling following the confluence of the seas over northern France with the boreal gulf centred on the present-day North Sea. Possibly there were two directions of transgression, from both the south and the north, the latter being responsible for an influx of boreal brachiopods to southern England during the Upper Aptian (F. A. Middlemiss).

In western and Arctic Canada the Aptian was also a period of very active epeirogenesis (T. P. Chamney), which agrees with the drastic palaeogeographical changes inferred by Jeletzky (1971); in neighbouring southern Alaska, the apparent absence of Aptian strata may simply reflect moderate vertical movements (D. L. Jones). Even where marine Aptian strata are present (as in Arctic Canada where transgression occurred) ammonites are very scarce (Jeletzky 1971) and microfaunas poorly known (T. P. Chamney).

3g. The Albian stage

In northwest Europe, the Albian situation is analogous to that of the Aptian; amid the complexity of local detail, more and more connecting threads are being picked out. Lower Albian movements first detected in southern England (mid-*tardefurcata* break of Casey 1961) have their sedimentary expression also in northern France (Juignet *et al.*), where the Poudingue ferrugineux is the lithological counterpart of the Carstone of the Isle of Wight. This in turn may be correlated broadly with the Carstone of eastern England, which is mirrored in the Rothenburg Sandstone of the southern rim of the Lower Saxony Basin (E. Kemper). Here, however, the most widespread tectonic movements occurred during the passage from Lower to Middle Albian, which E. Kemper describes as the most important of the German Lower Cretaceous. In England and northern France this event is represented by the Lower Greensand/Gault junction, which for many years had been taken in England as the boundary of the Lower and Upper Cretaceous.

There appears to be general agreement that the European Albian commences with the *tardefurcata* Zone and that the "Clansayes" horizon (*jacobi* Zone), included in the Albian by Spath and others, is more appropriately assigned to the Aptian. There is, however, no common ammonite fauna that defines this base throughout Europe, the earliest leymeriellids of Germany (*Proleymeriella schrammeni* and allies) being replaced in southern England by the hoplitid *Farnhamia* and in northern France perhaps by *Bucaillella.* The last occurs at the top of the Sables ferrugineux of Cauville, Normandy, and its precise position at the Aptian/Albian boundary is uncertain. The hoplitid sequences of northern France, the Anglo-Paris Basin and northwest Germany run to a similar pattern and enable us to trace an important regional phase of erosion at the end of the Middle Albian, first detected by Spath (1943).

Compared with that of England, the German sequence (E. Kemper) is broken by more numerous non-sequences and subject to rapid changes of facies, especially in the Middle Albian, though the English sequence of ammonite faunas for the Middle and Upper Albian may be followed, at least in outline. In the Upper Albian the well-known Flammenmergel may be recognized as the German equivalent of the English malmstone and the French Gaize, and the glauconitic marginal sandstones as comparable to the various local Upper Greensands of England. The use of the bivalves *Aucellina coquandiana* and *Inoceramus sulcatus* for correlation should be noted, and C. Spaeth shows the value of the belemnite *Neohibolites ernsti* in correlating the English succession with the German Upper Albian basin-facies, in which ammonites are lacking. In the Pays de Caux the apparent absence of the upper part of the Middle Albian (P. Juignet *et al.*) marks an important phase of erosion already recorded in southern England and the Anglo-Paris Basin.

The rich Albian faunas in the Pacific Coast region of North America are referred to by D. L. Jones. These include ammonite genera found also in Europe (*Douvilleiceras, Cleoniceras, Mortoniceras, Arcthoplites*), together with a number of endemic forms (*Brewericeras, Hulenites*). Middle and Upper Albian faunal provinces and palaeogeography are discussed by H. G. Owen in the light of continental displacement. He believes that the Arctic-North American Boreal Province was isolated from the European Province during the Middle Albian, but from the occurrence of the Arctic ammonite *Gastroplites* at the base of the Upper Albian in Europe infers a later sea-connection between the two provinces. A similar connection with the North Pacific region and the Arctic-North American Boreal Province, "an almost land-locked epicontinental sea" with "an impoverished fauna", is postulated by H. G. Owen. D. L. Jones could find no sharp boundary between the boreal Lower Albian ammonite occurrences along the Pacific Coast and their North Pacific contemporaries, but provincial segregation took place in the Upper Albian, possibly resulting from physical barriers to migration.

Probably the best documented faunal sequence through the Middle and Upper Albian is provided by the Gault Clay of southeast England, where a fine zonation on ammonites is supported by a wealth of data on the distribution of other organisms. M. B. Hart's contribution on the microfauna is indicative of the revival of interest in a long-neglected aspect of Gault palaeontology.

4. Correlation between the Boreal and Tethyan Realms

The problem of correlating particular parts of the boreal successions with the "standard" Tethyan stage and zonal schemes is touched upon by many contributors. Discussion of the correlation of stage boundaries is really meaningless until these are ratified by the I.U.G.S. Stratigraphy Commission (N. F. Hughes). However, correlation between faunas is an important step which can be made where faunas overlap or where "stray" elements are recorded outside their normal geographical range. The latter may provide inter-regional markers of considerable value, though their importance may be obscured by artificial taxonomy. The Hauterivian-Barremian crioceratitid ammonites of northwest Europe provide an interesting example of the problems involved. Many forms were originally recorded as conspecific with broadly-defined Tethyan species, until taxonomic splitting (e.g. Koenen 1902) resulted in the recognition of apparently discrete boreal assemblages, sometimes separated at generic level. Now it is becoming apparent that there *are* species in common. During the symposium, Dr. S. S. Sarkar examined many of the Speeton Clay crioceratitids in museums and in the Rawson collection, and writes:

> "although Spath (1924) noted that the Speeton crioceratitids do not include forms identical with the well-known *Crioceratites duvali* and *C. astierianum* of Tethys, I have examined a number of specimens which are close to French species. They include examples which are probably conspecific with *Crioceratites duvali* Leveille, *C. duvali* d'Orbigny *non* Lev., *Emericiceras* (*Emericiceras*) *thiollierei* (Astier), *Acrioceras tabarelli* (Astier) and '*Crioceras*' *binelli* Astier. In addition, some of the many crioceratitids from north Germany figured by Koenen (1902) look very much like Tethyan forms, though this can be confirmed only after thorough palaeontological revision."

Some of these crioceratitids therefore appear valuable for inter-realm correlation, as also are the typically "boreal" ammonites which J. P. Thieuloy records from southern France. It is probable that re-examination of other faunas and floras in both realms will reveal further examples of "taxonomic" obstacles to correlation.

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Generic and zonal index

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