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Proceedings
"Second International Symposium on Cretaceous Stage Boundaries"
Brussels 8 - 16 September 1995

edited by P. F. Rawson, A. V. Dhondt, J. M. Hancock and W. J. Kennedy

BRUXELLES 1996 BRUSSEL

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Dedicated to the memory of TOVE BIRKELUND (1928-1986), chairperson of the Cretaceous Subcommission 1975-1984.

Preface

The Cretaceous Subcommission held its *First International Symposium on Cretaceous Stage Boundaries* at Copenhagen in October 1983, under the Chairmanship of Tove Birkelund, with Finn Surlyk as Secretary. The proceedings were published the following year as volume 33 of the *Bulletin of the Geological Society of Denmark*. The preliminary proposals published in that volume have provided the starting point for all subsequent discussion.

Since 1983 interest in the Cretaceous has developed enormously, aided by several international projects such as the *mid-Cretaceous events programme* (IGCP 67) and more recently Tethyan Cretaceous Correlation (IGCP 262) and the current Tethyan-Boreal Correlation (IGCP 362). It became apparent that our original three working groups (pre Albian Stages, Albian-Turonian Stages and Coniacian-Maastrichtian Stages) were too large in scope to deal effectively with all the new research, so in 1992 the subcommission's structure was reorganised to form a working group for each stage. All active Cretaceous specialists were encouraged to join appropriate groups and over 80 have now done so. We even managed to find volunteers to chair them!

The working groups were strongly encouraged to follow certain guiding principles:

- the selected boundaries should be recognisable over as wide an area as possible and ideally in both Tethyan and Boreal (Temperate) Realms.
- selection should rely on accurate correlation using all available tools, including biostratigraphy, magnetostratigraphy, sequence stratigraphy and isotope stratigraphy.
- the stratigraphic level of the recommended boundary should conform as closely as feasible with current practice.
- the choice of the Global Stratotype Section and Point (GSSP) depends primarily on the chosen boundary marker(s). Although historical precedence should be considered when choosing a stratotype section it should not override the importance of choosing a widely-correlatable boundary in the most appropriate section, in whatever part of the world that may be.

A target of 3 years was set for the production of clear recommendations, to be presented to a second international conference scheduled for 1995. We are immensely grateful to the groups and, in particular, to the group chairmen, for having achieved so much in such a short time. Their conclusions and recommendations were presented to the *Second International Symposium on Cretaceous Stage Boundaries* held in Brussels, Belgium from 8 to 16 September 1995. Over 180 scientists attended the meeting and the working groups' workshops provoked a lively debate.

Inevitably, while this concentrated effort has resolved many problems others have been highlighted. Thus it becomes apparent in the 12 summary papers presented here that although several working groups can now start preparing formal proposals for GSSPs, to be presented to the Commission on Stratigraphy for formal ratification, others have to pursue further research. We intend to complete all this during the next 4 years so that by the time of the International Geological Congress of 2000 our tasks will be completed. In the meantime, readers of this volume who have further information to offer should contact the appropriate Working Group chairmen as soon as possible.

Peter Rawson
Chairman of the Subcommission on Cretaceous Stratigraphy

Annie V. Dhondt
Vice-Chairwoman of the Subcommission on Cretaceous Stratigraphy

Acknowledgements

Between the 1983 and 1995 conferences the Subcommission was chaired by Jake Hancock (1984 - 1989) and Walter Kegel Christensen (1989 - 1994), whose enthusiasm did so much to keep our Subcommission working.

The meeting in Brussels was organised by our Secretary, Annie V. Dhondt, who coped magnificently with everything. The facilities of the Museum were provided by Daniel Cahen, Director of the Institut Royal des Sciences naturelles de Belgique/ Koninklijk Belgisch Instituut voor Natuurwetenschappen. Financial help is gratefully acknowledged from the ''Services Fédéraux des Affaires Scientifiques, Techniques et Culturelles/ Federale Diensten voor Wetenschappelijke, Technische en Culturele Aangelegenheden'' (Brussels), ''Exekutive der Deutschsprachige Gemeinschaft'' (Eupen) and ''Nationaal Fonds voor Wetenschappelijk Onderzoek'' (Brussels).

At the Institut Royal des Sciences naturelles de Belgique/ Koninklijk Belgisch Instituut voor Natuurwetenschappen Annie was helped especially by the staff of the Department of Palaeontology, and the staff connected to the Museum itself. They are too many to mention them all, but we would like to express special thanks to Dirk Anne, Jan Claerbout, René Cremers, Hugo De Potter, Jacques Godefroid, Marcella Haemelinck and Vera Janssens.

The Subcommission is also grateful to the editors of the Bulletin de l'Institut royal des Sciences naturelles de Belgique - Série Sciences de la Terre for allowing us to publish our results as Vol. 66 - Supplement, and to Jake Hancock and Jim Kennedy for their unstinting help with the scientific preparation of the symposium and at the editorial stage. Special thanks go to Alexandra Egorova (Brussels) and Anatoly M. Nikishin (Moscow) for the translation of the abstracts into Russian.

Finally, we would like to thank Jürgen Remane, Chairman of the Stratigraphy Commission, for his continuing support and advice.

Peter Rawson
Chairman, Cretaceous Subcommission.

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SCIENCES DE LA TERRE, 66-SUPP.: 7-10, 1996
AARDWETENSCHAPPEN, 66-SUPP.: 7-10, 1996

The Berriasian Stage and the Jurassic-Cretaceous boundary

by Viktor A. ZAKHAROV, Paul BOWN and Peter F. RAWSON

Abstract

It is recommended that the base of the Berriasian Stage be placed **either** at the base of the *Berriasella jacobi* Zone **or** at the base of the *Tirnovella subalpina* Subzone. The choice of stratotype section will depend on the choice of zone, but will be in SE France or SE Spain. Subdivision of the Berriasian Stage into 2 or 3 substages will again depend on which level is chosen to define the base of the stage.

Key-words: Berriasian, Lower Cretaceous, biostratigraphy, ammonites, calpionellids.

Résumé

Il est recommandé de placer la base de l'étage Berriasien soit à la base de la zone à *Berriasella jacobi*, soit à la base de la sous-zone à *Tirnovella subalpina*. Le choix du stratotype dépendra du choix de la zone, mais il sera situé dans le SE de la France ou dans le SE de l'Espagne. La subdivision de l'étage Berriasien en 2 ou en 3 sous-étages dépendra également du niveau choisi pour définir la base de l'étage.

Mots-clefs: Berriasien, Crétacé inférieur, biostratigraphie, ammonites, calpionellides.

Берриаский ярус и Юрско-меловая граница.

Резюме.
Основание Берриаского яруса рекомендуется определять либо по основанию зоны *Berriasella jacobi*, либо по основанию подзоны *Tirnovella subalpina*. Выбор стратотипа будет зависеть от выбора зоны, но в любом случае стратотип будет расположен на юго-востоке Франции или Испании. Разделение Берриаского яруса на 2 или 3 подъяруса будет также зависеть от уровня, выбранного для определения основания яруса.

Ключевые слова: Берриаский ярус, нижний мел, биостратиграфия, аммониты, *Calpionellida*.

Introduction

Because the base of the Cretaceous is generally placed at the base of the Berriasian stage, definition of the base of the Berriasian has been linked inextricably with the definition of the Jurassic-Cretaceous boundary. Thus the Jurassic-Cretaceous boundary Working Group is responsible for defining the base of the Berriasian stage and of its subdivisions, as well as for determining the base of the Cretaceous. It should be stressed that some authors (e.g. WIEDMANN, 1980; RAWSON, 1990; REMANE, 1990) have indicated that the latter boundary could usefully be placed **above** the Berriasian, at the base of the Valanginian.

As no draft paper had been prepared for Working Group members prior to the Brussels meeting, this short contribution is based on notes from the Brussels meeting compiled by Viktor A. ZAKHAROV (W.G. Chairman 1992-1995) and edited by Paul BOWN (Acting Secretary), with additional material by Peter RAWSON.

The Jurassic-Cretaceous boundary

Definition of the Jurassic-Cretaceous boundary remains an intractable problem despite some 30 years of debate, over a dozen international conferences and a Working Group dedicated to the issue since 1974 (CASEY *et al.*, 1975). The problem hinges on the need to define a boundary that can be correlated over as wide an area as possible and ideally from Tethyan to Boreal realms.

The issues were discussed by Jürgen REMANE, Chairman of the Working Group from 1982 to 1992, in a paper given at an international field meeting on "The Jurassic-Cretaceous Boundary in the Northern Caucasus" in 1987 (REMANE, 1990). An English language version of this paper was circulated to Working Group members with *Newsletter 9* in October 1988, while a modified (English) version was published by *Cretaceous Research* in 1991. REMANE (1990, 1991) pointed out that the problems appear due largely to:

(1) a lack of significant faunal turnovers at the base of the Berriasian, however defined (though some ammonite changes are discussed below);

(2) the effects of the "Purbeckian regression".

The "Purbeckian regression" marked a major global fall in sea-level that led to an interval of high faunal and floral endemism and extreme facies differentiation across the Eurasian region. This in turn renders correlation extremely difficult.

REMANE (1990, 1991) also recalled the recommendations made by the Working Group at the 27th IGC in Moscow in 1984:

(1) The Jurassic/Cretaceous boundary should be defined in the Tethyan Realm.

(2) The first candidate for the boundary is the Tithonian/Berriasian boundary, which corresponds to the base of the combined *jacobi-grandis* Zone [following the recommendation of the 1973 Lyons Colloquium (FLANDRIN *et al.* 1975, p. 392)].

(3) If this boundary level cannot be correlated from the Tethyan to the Boreal realm, a level close to it should be selected [the base of the *occitanica* Zone might be a good solution (HOEDEMAEKER, 1987)].

(4) Until a final decision is made on the Jurassic-Cretaceous boundary, the Berriasian should be placed in the Cretaceous.

Although REMANE concentrated on biochronology, he mentioned the possible role of magnetostratigraphy in future efforts to define the boundary. At the same (1987) conference, RAWSON (1990) suggested the need to consider the applicability of non-biological "events", while at Brussels ERBA (1995) challenged palaeontologists to consider the role of magnetostratigraphy, chemostratigraphy, sequence stratigraphy and cyclostratigraphy

Table 1.
Relationship between the Mediterranean ammonite and calpionellid zones, and possible correlation of the Boreal ammonite zones with the Mediterranean "standard".

Stages	Substages	Mediterranean region			Northern Siberia		Substages	Stages
		ammonites		calpionellids	ammonites			
Berriasian	Upper	*Fauriella boissieri*	*Tirnovella alpillensis*	D3	*Tollia tolli*		Upper	Boreal Berriasian
			Picteticeras picteti	D2	*Bojarkia mesezhnikowi*			
			Malbosiceras paramimounum	D1	*Surites analogus*	*Surites analogus*		
						Surites subquadratus		
	Middle	*Tirnovella occitanica*	*Dalmasiceras dalmasi*	C	*Hectoroceras kochi*	*Surites praeanalogus*	Lower	
						Borealites constans		
			Berriasella privasensis			*Hectoroceras kochi*		
					Chetaites sibiricus	*Chetaites sibiricus*		
			Tirnovella subalpina	B		*Praetollia maynci*		
					?			
	Lower	*Berriasella jacobi*	*Pseudosubplanites grandis*		*Chetaites chetae*		Upper	Volgian
					Craspedites taimyrensis			
			Berriasella jacobi		*Craspedites okensis*	*C. originalis*		
						C. okensis		
						C. exoticus		
					??			
ion.	per			A	*Epivirgatites variabilis*		ddle	

in defining Cretaceous stage boundaries. Despite this, debate has continued to concentrate on the biostratigraphic aspects.

The base of the Berriasian Stage

At the Brussels meeting, the Working Group discussed a number of proposals for boundary points and sections. The conclusions are summarised below.

Boundary Criteria

It was agreed that the base of the Berriasian should be defined on the appearance of a new fossil taxon, and that the stratotype section should be in the Mediterranean region. Two possible faunal events were proposed:

- base of the *jacobi* ammonite Zone
- base of the *subalpina* ammonite Subzone (*occitanica* Ammonite Zone)

base of the *jacobi* Zone

This is essentially the level suggested at the 1973 Lyons Colloquium, as adopted by the Lower Cretaceous Cephalopod Working Group of IGCP Project 262 (Hoedemaeker & Bulot, 1990; Hoedemaeker, Company *et al.*, 1993). According to Hoedemaeker & Bulot (1990), the index species first appears at the base of the zone – a level that corresponds to a major event in ammonite evolution, i.e. at the family level. It is also closely approximated by an important calpionellid event, marking the base of the B Calpionellid Zone (Table 1). However, the *jacobi* Zone is virtually impossible to correlate with boreal areas.

base of the *subalpina* Subzone

The subzone is dominated by the abundance of *Tirnovella subalpina*, which first appears at the base of the subzone (Le Hégarat, 1973, table 12, p. 176). This level marks a significant ammonite turnover, and has good correlation potential. The level is coincident with, or approximates to, the base of the *Praetollia maynci/Runctonia runctoni* ammonite Zone and the *Buchia okensis* buchiid Zone in the Boreal area.

Stratotype Section

The choice of boundary stratotype section is dependent upon the final choice of the defining event. The base of the *jacobi* ammonite Zone is well represented in the Puerto Escano section (Prov. Cordoba, Spain). The base of the *subalpina* ammonite Subzone may be best defined at La Faurie, Ravin de Dreymien (Alpes-de-Provence, France) or Section Z, Berrancode de Tollo (Rio Argos, Caravaca, Prov. Murcia, Spain).

Substage definitions

Substage definitions are dependent on the final stage-boundary event decision. If the base of the *jacobi* Zone is chosen, then the base of the Middle Berriasian may be defined by the base of the *subalpina* Subzone, and the Upper Berriasian by the base of the *boissieri* ammonite Zone. If the base of the *subalpina* Subzone is chosen as the base of the stage, then an Upper Berriasian substage can be defined by the base of the *boissieri* Zone, and no middle substage should be retained.

Recommendations

The working group concluded that further documentation of these potential stratotype sections is required and interdisciplinary teams should investigate the correlation potential of the biostratigraphic events proposed. To improve Tethyan/Boreal correlation, such teams should investigate sections in northern California and northern Siberia.

References

Casey, R., Allen, P., Dörhöfer, G., Gramann, F., Hughes, N. F., Kemper, E., Rawson, P. F. & Surlyk, F., 1975. Stratigraphical subdivision of the Jurassic-Cretaceous boundary beds in NW Germany. *Newsletters on Stratigraphy* **4:** 4-5.

Erba, E., 1995. Cretaceous chronostratigraphy of the third millennium: ammonite-based or something else-based? Second International Symposium on Cretaceous Stage Boundaries: abstracts, 39.

Flandrin, J., Schaer, J. P., Enay, R., Remane, J., Rio, M. M., Kubler, M. B., Le Hégarat, G., Mouterde, R., & Thieuloy, J.-P., 1975. Discussion générale préliminaire au dépôt des motions. *Colloque sur la limite Jurassique-Crétacé. Mémoires du Bureau de Recherches géologiques et minières* **86:** 386-393.

Hoedemaeker, P. J., 1987. Correlation possibilities around the Jurassic-Cretaceous boundary. *Scripta Geologica*, **84**: 1-55.

Hoedemaeker, P. J. & Bulot, L., 1990. Preliminary ammonite zonation for the Lower Cretaceous of the Mediterranean region: report. *Géologie Alpine*, **66:** 123-127.

Hoedemaeker, P. J., Company, M. R. (reporters), Aguirre Urreta, M. B., Avram, E., Bogdanova, T. N., Bujtor, L., Bulot, L., Cecca, F., Delanoy, G., Ettachfini, M., Memmi, L., Owen, H. G., Rawson, P. F., Sandoval, J., Tavera, J. M., Thieuloy, J.-P., Tovbina, S. Z. & Vasicek, Z., 1993. Ammonite zonation for the Lower Cretaceous of the Mediterranean region; basis for the stratigraphic correlation within I.G.C.P. Project 262. *Revista Espanñola de Paleontologia*, **8:** 117-120.

LE HÉGARAT, G., 1971. Le Berriasien du Sud-Est de la France. *Documents du Laboratoire Géolologique de la Faculté des Sciences de Lyon*, **43**, 576 pp.

RAWSON, P. F., 1990. Event stratigraphy and the Jurassic-Cretaceous boundary. *Transactions of the Institute of Geology and Geophysics, Academy Sciences USSR, Siberian branch*, **699:** 48-52 [In Russian with English summary].

REMANE, J., 1990. The Jurassic-Cretaceous boundary: problems of definition and procedure. *Transactions of the Institute of Geology and Geophysics, Academy Sciences USSR, Siberian branch*, **699:** 7-17 [In Russian with English summary]. .

REMANE, J., 1991. The Jurassic-Cretaceous boundary: problems of definition and procedure. *Cretaceous Research*, **12:** 447-453.

WIEDMANN, J., 1980. Paläogeographie und Stratigraphie im Grenzbereich Jura-Kreide Südamerikas. *Münster. Forschung Geologie Paläontologie*, **51:** 27-61.

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The Valanginian Stage

by Luc BULOT (compiler),

with contributions from Eric Blanc, Miguel Company, Silvia Gardin, Susanne Hennig, Philip J. Hoedemaeker, Han Leereveld, Françoise Magniez-Jannin, Jörg Mutterlose, Grigore Pop and Peter F. Rawson

Abstract

The Working Group provisionally recommends that the base of the Valanginian is placed at the base of Calpionellid Zone E, which corresponds almost exactly to the base of the ammonite zone of *''Thurmanniceras'' pertransiens*. The base of the Upper Valanginian as agreed at Copenhagen (1983) is widely used and lies at the base of the ammonite zone of *Saynoceras verrucosum*. No feasible alternative has been proposed but the Working Group still has to document evidence from other fossil groups.
Sections in SE France and the Betic Cordillera (Spain) are under consideration as boundary stratotype sections.

Key-words: Valanginian, Lower Cretaceous, stratotypes, biostratigraphy, ammonites, calpionellids, nannofossils.

Résumé

Le Groupe de Travail recommande provisoirement que la base du Valanginien soit placée à la base de la Zone E à Calpionellides, qui correspond presque exactement à la base de la Zone à ammonites *''Thurmanniceras'' pertransiens*. La base du Valanginien supérieur telle qu'elle a été convenue à Copenhague (1983), est largement utilisée et se situe à la base de la zone à ammonites *Saynoceras verrucosum*. Aucune alternative valable n'a été proposée, mais le Groupe de Travail doit encore s'informer des données sur d'autres groupes fossiles.
Des coupes dans la SE de la France et dans la cordillère bétique (Espagne) sont envisagées comme stratotypes de la limite.

Mots-clefs: Valanginien, Crétacé inférieur, stratotypes, biostratigraphie, ammonites, calpionellides, nannofossiles.

Валанжинский ярус.

Резюме.
Рабочая группа временно рекомендует определять основание Валанжина в основании кальпионельской Зоны E, почти точно совпадающей с основанием аммонитовой Зоны *Thurmanniceras pertransiens*. Основание Верхнего Валанжина, определённое ещё в течение копенгагского Симпозиума 1983 года, широко используется и располагается в основании аммонитовой Зоны *Saynoceras verrucosum*. На данный момент, не существует приемлемой альтернативы для этого основания; тем не менее Рабочая Группа должна еще обработать данные, касающиеся других групп ископаемых.
Разрезы на юго-востоке Франции и в бетической кордильере Испании рассматриваются в качестве прототипа границы.

Ключевые слова: Валанжинский ярус, нижний мел, стратотипы, биостратиграфия, аммониты, Calpionellida, нанофоссилии.

Editors' note: The Working Group chairman, Luc Bulot, had to withdraw from the Brussels meeting at the last minute, but faxed a preliminary report for discussion there. As Luc has not been able to produce an updated version subsequently, the paper published here has been modified from the preliminary report by one of the editors (PFR). It incorporates the provisional recommendations made at Brussels, but because of time constraints it has not been circulated to members of the Valanginian Working Group. Hence the paper must be regarded simply as a working document that illustrates the progress made and indicates what further research the Working Group will be undertaking.

In addition to the contributors listed above, we are grateful to other Working Group Members who have supplied information cited in the text.

Introduction

The historical type area of the Valanginian Stage is the Seyon Gorge, near Valangin in the Swiss Jura (see BARBIER & THIEULOY, 1965; RAWSON, 1983). Recognition of the inadequacy of this section for correlation purposes led to the proposal for two ''hypostratotype'' sections at Angles (Alpes-de-Haute-Provence) and Barret-le-Bas (Hautes-Alpes) in the south-east of France (BUSNARDO *et al.*, 1979). The ranges of ammonites, belemnites, ostracods, foraminifera, calpionellids and nannofossils were documented for the two sections. The base of the Valanginian was placed at the base of the *''Thurmanniceras'' otopeta* Zone and the Lower/Upper Valanginian boundary at the base of the *Saynoceras verrucosum* Zone. Subsequently, the Copenhagen Symposium **provisionally** recommended that the base of the Valanginian be placed at the base of the *otopeta* Zone (BIRKELUND *et al.*, 1984, p. 6). It suggested that candidate boundary stratotypes ''should be investigated in southeast Spain, southeast France, the Crimea and Caucasus.''

The Lower/Upper Valanginian boundary was not considered at Copenhagen.

The base of the Valanginian Stage

AMMONITE SCALES

Since BUSNARDO *et al.*'s (1979) work was published there has been much discussion of the Berriasian-Valanginian boundary among ammonite workers. The biostratigraphy at this level is affected by four main problems that limit its resolution and are at the base of the disputes mentioned below:

- Subdivisions of the various zonal schemes were defined after different biostratigraphic concepts and therefore correlations between the different types of biozones are sometimes difficult to achieve

- Collection failure restricts the biostratigraphic value of some reference sections

- Lack of suitable monographs misleads biostratigraphers in the taxonomic interpretation of most key species

- Important provincialism (Tethyan and Boreal) reduces the significance of the regional zonal scheme

The debate has centred on evidence from the French (Subalpine Range) and Spanish (Betic Cordillera) successions (e.g. HOEDEMAEKER, 1982; RAWSON, 1983; COMPANY, 1987; BULOT, BLANC, *et al.*, 1993; BULOT *et al.*, 1994; BULOT, 1995; HOEDEMAEKER & LEEREVELD, 1995). These sequences have provided a biostratigraphic framework for the whole Valanginian Stage that the successive Cephalopod working groups of IGCP projects 262 and 362 have applied to the rest of the Mediterranean Province (HOEDEMAEKER & BULOT, 1990; HOEDEMAEKER, COMPANY *et al.*, 1993). For the sake of stability, the working groups retained the base of the *otopeta* Zone as the Berriasian/Valanginian boundary for the standard Mediterranean succession. However, **this proposition was considered as a workable consensus and not as a definitive solution.** It is one of four candidate boundaries that have been put forward so far:

- the base of the *pertransiens* Subzone *sensu* LE HÉGARAT (1971);

- the base of the *otopeta* Zone *sensu* BUSNARDO & THIEULOY (1979), a solution provisionally recommended by the Cretaceous Subcommission at Copenhagen (BIRKELUND *et al.*, 1984);

- the base of the *alpillensis* Subzone *sensu* HOEDEMAEKER (1982), a solution so far rejected by many Cretaceous stratigraphers;

- the base of the *pertransiens* Zone *sensu* BULOT (1995).

Three important points should be mentioned:

1. Correlation between the *alpillensis* Zone *sensu* HOEDEMAEKER, *alpillensis* Zone *sensu* BULOT and *callisto* Zone *sensu* LE HÉGARAT is still problematic.

2. Since reinvestigation of the Los Miravetes section (Caravaca, Spain) by AGUADO, COMPANY, TAVERA and SANDOVAL (1995, poster in Brussels) it is now clear that the differences between the ammonite distributions documented by HOEDEMAKER (1982) on the one side and THIEULOY (1979), COMPANY (1987), BULOT *et al.* (1993) and BULOT (1995) are essentially linked to different taxonomic interpretations. According to all the authors except HOEDEMAKER, the *alpillensis* assemblage is almost equivalent to the *callisto* assemblage.

3. In addition, *"Thurmanniceras" pertransiens sensu* THIEULOY, COMPANY and BULOT is interpreted in a much more restricted sense than *"T." pertransiens sensu* HOEDEMAEKER. According to the French and Spanish workers, the *pertransiens*-like forms associated with *"T." otopeta* are *Tirnovella* n. sp. close to the *alpillensis* group. This taxon ranges high in the *otopeta* Subzone but disappears below the first occurrence of the calpionellid *Calpionellites darderi*. According to BULOT (1995), the *"Thurmanniceras" pertransiens* figured by LE HÉGARAT & REMANE (1968) from Ginestou is a *Tirnovella* nov. sp.

In BULOT's (1995) opinion, as the *alpillensis* Subzone *sensu* HOEDEMAEKER roughly corresponds to the interval between the FO (first occurrence) of *Lorenziella hungarica* and the LO (last occurrence) of *"T." otopeta* (see HOEDEMAEKER & LEEREVELD, 1995), the *alpillensis* Subzone and the *callisto* Subzone correspond to the approximately same time interval.

CALPIONELLIDS

Since the early work by REMANE (1963), an almost complete agreement has been reached for the Late Berriasian and Early Valanginian calpionellid zonation. Four different events are considered as biostratigraphic markers:

- base of D Zone and of D1 Subzone, marked by the first occurrence of *Calpionellopsis simplex* (ALLEMANN & REMANE, 1979; REMANE, 1985; POP, 1994; BLANC, 1995).

- base of D2 Subzone, characterised by the progressive domination of *C. oblongata* over *C. simplex* (ALLEMANN & REMANE, 1979; REMANE, 1985)

- base of D3 Subzone, defined by the first occurrence of *Lorenziella hungarica* (ALLEMANN & REMANE, 1979; REMANE, 1985; POP, 1994; BLANC, 1995).

- base of E Zone, marked by the first occurrence of

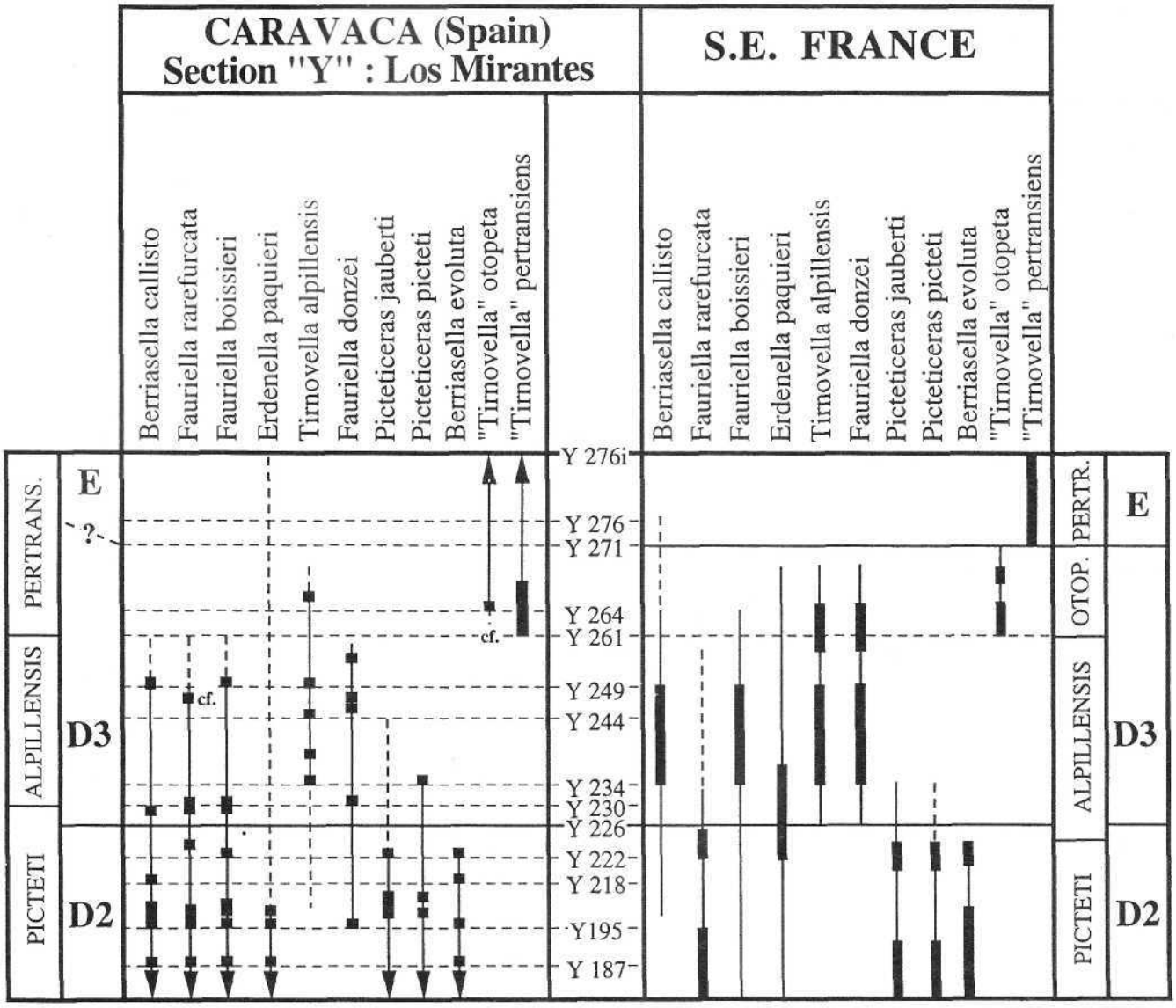

Fig. 1 — Biostratigraphy (calpionellids and ammonites) of the top Berriasian and basal Valanginian, and comparison of ammonite distributions in SE France and Los Miravetes, SE Spain (modified from BULOT, 1995, fig. 9).
For ''Section Y: Los Mirantes'' read ''Section Y: Los Miravetes''.

Calpionellites darderi (ALLEMANN & REMANE, 1979; REMANE, 1985; POP, 1994; BLANC, 1995).

More recently, POP (1994) and BLANC (1995) have shown that the first occurrence of *Praecalpionellites murgeanui* is a significant event in Rumania, Cuba and SE France. Nevertheless, it must be stressed that there is no major turnover in the evolution of calpionellids around the Berriasian-Valanginian transition beds:

- all species of the D2 Zone cross the D2/D3 boundary and *L. hungarica*, whose first appearance defines the base of D3, always remains rare. The same is true for *Calpionellites darderi* (base of Zone E).

- the only spectacular event is the sudden disappearance of *Calpionellopsis oblonga* in the upper D3 Zone in SE France. However, elsewhere this species or at least very similar forms continue upwards well into the E Zone.

The calibration between the calpionellid and ammonite zones is synthesised in Figure 1, based on bed by bed sampling in SE France (LE HÉGARAT & REMANE, 1968; ALLEMANN & REMANE, 1979; synthesis in BLANC, 1995). Furthermore, the typical uppermost D3 calpionellid assemblage (*murgeanui* Subzone *sensu* POP, 1994) can be correlated with the upper *otopeta* Subzone (*thieuloyi* Biohorizon) (BULOT, 1995; BLANC, 1995).

Even if the ammonite zonal scheme based on the French Valanginian standard sections indicates the high correlation value of the *otopeta* Subzone, ALLEMANN & REMANE (1979) have shown that no important changes are observed in calpionellid populations at that level.

Therefore calpionellids can hardly be used to characterise a Berriasian-Valanginian boundary drawn at the base of the *otopeta* Subzone. So far, this boundary has been estimated by placing it between the FOs of *L. hungarica* and *C. darderi*. Over most of the Vocontian Basin, a level where *C. oblonga* reaches up to 30% of the calpionellid association has been recognised in the lower part of the *otopeta* Subzone. Above, *C. oblonga* seems to disappear. Unfortunately, this observation does not apply to the rest of Tethys (the Balearics and Mexico, for example) because there *C. oblonga* or very similar forms coexist with *Calpionellites* species.

Recently, BLANC *et al.* (1994), BULOT (1995) and BLANC (1995) have recorded *C.* aff. *oblongata* associated with *C. darderi*. Therefore, ALLEMANN & REMANE's ((1979) proposal to define the Berriasian-Valanginian boundary by using the last appearance of *C. oblonga* does not seem to be workable. It is easier to recognise BULOT, BLANC, *et al.*'s (1993) suggested boundary (base of the *pertransiens* Zone) using calpionellids because the FO of *''T.'' pertransiens* and *C. darderi* are almost synchronous (BLANC, POP and REMANE, *personal communications*).

CALCAREOUS NANNOFOSSILS

In this section, special emphasis is given to SE France, because this region (together with SE Spain: AGUADO, 1994) is the only one where nannofossil events have been calibrated directly with ammonite successions.

Calcareous nannofossil studies of the Vocontian Basin originate in works by THIERSTEIN (1971, 1973, 1976) and MANIVIT (1979). More recent investigations by BRALOWER *et al.* (1989), GARDIN & MANIVIT (1993), BERGEN (1994) and BULOT & GARDIN (*in prep.*) have allowed a refined understanding of the calcareous nannofossil biostratigraphy for the Berriasian-Valanginian time interval owing to the exceptional preservation and recovery of the nannofloras.

Four sections [Angles (Alpes-de-Haute Provence), Barret-le-Bas (Hautes-Alpes), Majastres (Alpes-de-Haute-Provence) and Montbrun-les-Bains (Drôme)] have been sampled bed by bed by BULOT & GARDIN (*in prep.*). Preparation of slides was made using the standard technique of MONECHI & THIERSTEIN (1985). No centrifuging was made to eliminate ''spottiness'' because the intermittent occurrence of taxa are here considered and interpreted as the expression of significant changing factors. At least 500 fields of view per slide were analysed for biostratigraphic purposes. Samples from Barret, Angles and Montbrun yield abundant, diverse and well preserved nannofloras, while at Majastres the assemblages are less diverse and preservation is poorer.

Main nannofossil events

Tubodiscus verenae has been considered as a Lower Valanginian marker by ROTH (1978), BRALOWER (1987), ERBA & QUADRIO (1987), APPLEGATE & BERGEN (1988), BRALOWER *et al.* (1989) and BERGEN (1994). According to our data, its FO is at the base of the *otopeta* Subzone (bed 175 at Angles; bed 71b at Montbrun-les-Bains). Similar results were published by MANIVIT (1979). BERGEN (1994) recorded an earlier occurrence of this taxon at Angles in the transitional beds between the *picteti* and *alpillensis* subzones. In SE France, the occurrence of *T. verenae* is not continuous and shows a ''false'' extinction at the top of the *O. nicklesi* biohorizon (*trinodosum* Zone). In fact, it then reappears sporadically from the uppermost Valanginian (*callidiscus* Zone) throughout the Hauterivian. It should be noted that at ODP Site 638B, *T. verenae* shows a continuous distribution throughout the whole upper Valanginian (APPLEGATE & BERGEN, 1988 and GARDIN, unpublished data). This pattern invalidates the LO of *T. verenae* as a reliable marker.

In addition, BERGEN (1994) and BULOT & GARDIN (*in prep.*), outlined some other events. The LO of *Rhagodiscus nebulosus* was near the top of the *alpillensis* Subzone (*otopeta* biohorizon) at Majastres (bed PG 166). According to BERGEN (1994), this event occurs a little lower in the *alpillensis* Subzone. Overlap between *R. nebulosus, T. verenae* and *N. silvaradion* at Angles will be discussed below. Preliminary results at Angles (bed 200) and Montbrun-les-Bains (bed 208b) suggest that *Cyclagelosphera* sp. 4 disappears in the uppermost part of the *otopeta* Subzone. More detailed work is needed to determine the value of this taxon as a biostratigraphic marker.

A significant change in the nannofossil assemblage occurs in the *pertransiens* Zone. In all sections, the first biostratigraphic event recorded in this zone is the FO of *Calcicalathina oblongata.* A precursor form, here referred to as *C.* aff. *oblongata* (= *Calcicalathina* sp. A *in* BERGEN, 1994) has been recorded in all the studied sections. In agreement with BERGEN's observations, this form seems transitional between the genus *Rhagodiscus* and the genus *Calcicalathina*. The bed-by-bed sampling at Montbrun-les-Bains allows us to draw an evolutionary lineage. *C.* aff. *oblongata* ranges through the entire *pertransiens* Zone and its FO has been observed within the *alpillensis* Subzone at both Angles and Montbrun.

A new genus, *Bulotinus*, appears in the lower part of the *pertransiens* Zone at Angles (bed 236), Majastres (bed PRY 150) and Barret-le-Bas (bed 47). BERGEN (1994) records the stratigraphic range of *Pickelhaube umbellatus* (*Bulotinus umbellatus* in BULOT and GARDIN, *in prep.*) as restricted to the lowermost *pertransiens* Zone to the base of the *inostranzewi* Zone (bed 300).

One of the most significant records within the upper part of the *pertransiens* Zone is the occurrence of *Micrantholithus speetonensis*, a taxon supposedly restricted to the Boreal Realm (TAYLOR, 1978; PERCH-NIELSEN, 1979; CRUX, 1989; MUTTERLOSE, 1991). *M. speetonensis*

is very rare in the studied sections but seems to always occur at the same stratigraphic level at Angles, Majastres and Barret-le-Bas. The presence of this boreal species in a North Western Tethyan basin is a useful datum for interregional correlations and could be a further witness of the pertinence of the Vocontian basin as an intermediate area between the Boreal and Tethyan Realms (see discussion below).

The FO of *Rhagodiscus dekaeneli* and *Eiffellithus windii* are also recorded within the upper *pertransiens* Zone at Angles (bed 255), Barret-le-Bas (bed 42) and Majastres (bed PRY 153b). These findings are consistent with those of BERGEN (1994).

Problems

A recent report by ERBA *et al.*, (1995) has proposed an integrated stratigraphic framework for the Lower Cretaceous using ammonites, nannofossils, calpionellids, magnetostratigraphy and carbon stable isotopes. Raw data were mainly obtained from the Italian Maiolica succession and the Rio Argos section in SE Spain.

Comparison between the chart proposed by ERBA *et al.* (1995) and data provided in this report suggests that either the nannofossil workers have not reached full agreement on the taxonomy of such key species as *T. verenae* or *C. oblongata* or that preservation problems and/or hiatuses have been overlooked in the study of the nannofossils.

As an example, according to ERBA *et al.* (1995), the range of *T. verenae* is restricted to the Upper Valanginian, while all the data collected separately in SE France by MANIVIT, BERGEN and GARDIN shows that this species first appears in the *otopeta* Subzone and disappears high in the Hauterivian.

OTHER FOSSIL GROUPS

Recent work on dinoflagellates, ostracods and foraminifera does not appear to have reached the same degree of resolution as the fossil groups discussed so far. However, points to consider include:

ostracods: BULOT (1995) presented a table of the ostracod markers of the French Berriasian and Valanginian, showing that several taxa first appear in the *otopeta* Subzone or the *pertransiens* Zone.

dinoflagellates: after comparison between the ranges proposed by MONTEIL (1992) and LEEREVELD *in* HOEDEMAEKER & LEEREVELD (1995), it is difficult to see how far the dinoflagellates can help in defining the Berriasian-Valanginian boundary.

foraminifera: MOULLADE (1979) and MAGNIEZ-JANNIN (*personal communication*) show that in our present state of knowledge the small benthic foraminifera are of little help in characterising the boundary.

NON-BIOLOGICAL EVENTS

magnetostratigraphy: because of the problems discussed in the nannofossil section, it should be stressed that the calibration of magnetostratigraphic reversals against biostratigraphic scales needs much improvement. Unfortunately, the sampling at Montbrun-les-Bains has not allowed a direct calibration for the Berriasian-Valanginian boundary beds. So far, for the Berriasian-Valanginian boundary, the only section where a direct correlation between ammonite zonation and magnetostratigraphy has succeeded is at Cehegin in SE Spain (OGG *et al.*, 1988).

sea level changes: these have been investigated at length in recent years, but for the Valanginian there is still no general agreement on their significance and correlation potential at a very large scale (except perhaps for the "Mid Valanginian" event). Additionally, sequence stratigraphy analysis *sensu* Vail is a method not a finality of itself.

TETHYAN-BOREAL CORRELATIONS

While Aptian and Albian ammonites show only limited geographical differentiation, during Berriasian to Barremian times the Boreal and Tethyan Realms were characterised by two distinct faunas. This pattern of ammonite distribution necessitates the construction of two different ammonite scales (RAWSON, 1981, 1995). Generally, discussion on patterns of migration of boreal faunas to NW Tethys has been based on data from SE France even though Boreal occurrences are recorded from the Helvetic domain, the Carpathian belt and the Swiss Jura.

The first detailed account of the biostratigraphic distribution of boreal ammonites in SE France was by THIEULOY (1973, 1977), while KEMPER *et al.* (1981), THIEULOY *et al.* (1990) and BULOT, THIEULOY, *et al.* (1993) have provided further information. The occurrence of boreal species in SE France is sporadic and all specimens recorded belong to the fauna described from the West European Province of RAWSON (1981). For the interval considered herein, two successive periods can be distinguished:

- **Late Berriasian**: no boreal species have ever been recorded from SE France.

- Early Valanginian: boreal species occur scarcely in SE France. The West European genus *Platylenticeras* provides a good link with the Boreal Realm even though this taxon is rare outside North Germany (RAWSON, 1993).

It should be noted that the origin of *Platylenticeras* is still under discussion. KEMPER *et al.* (1981) and RAWSON (1993) favour a Tethyan ancestry but BULOT (1990) considers *Platylenticeras* as a Northern European offshoot of the boreal Craspeditinae. In SE France, *Platylenticeras* is

rare at the base of the *pertransiens* Zone but evolved to produce two successive populations that include endemic species. Even where *Platylenticeras* reached its maximum abundance (base of the *stephanophorus* Zone), the genus represents less than 1% of the assemblage in SE France.

In addition, two dubious *Paratollia* and a single *Polyptychites* were recorded from the Lower Valanginian by THIEULOY (1977). The biostratigraphic position of this record has been revised since. The *''Paratollia''* come from the lower part of the *pertransiens* Zone while the *Polyptychites* was found in the middle part of the *stephanophorus* Zone (probably from the upper part of the *subcampylotoxus* biohorizon).

In contrast to the difference in the ammonite faunas, calcareous nannofloras had a much more cosmopolitan distribution during Early Cretaceous times. For the north European Boreal area, nannofossil events were calibrated against the ammonite succession at the Speeton section (Yorkshire, UK). There the Late Berriasian and Early Valanginian D beds represent the *albidum, Paratollia* and *Polyptychites* zones that correlate roughly with the upper part of the *boissieri* Zone to the top of the *stephanophorus* Zone. Comparison of the assemblages described by PERCH-NIELSEN (1979), TAYLOR (1982) and CRUX (1989) with data from SE France shows that most of the species are common to the two provinces. The following species, usually considered as ''boreal'', are recorded for the first time in SE France:

S. silvaradion - lowest occurrence at Angles is at bed 172 (uppermost part of the *alpillensis* Subzone)

S. horticus and *C. salebrosum* - known from the base of the *pertransiens* Zone (Angles and Majastres)

M. speetonensis - a ''spot'' species that occurs in the upper part of the *pertransiens* Zone.

According to CRUX (1989), *C. salebrosum* and *S. horticus* appear in bed D7B (lower part of the *albidum* Zone), while *S. silvaradion* appears a little higher, in bed D7A. The lowest occurrence of *M. speetonensis* is in bed D4B (*Paratollia* Zone). According to the known correlations, this distribution implies that the FO of *S. silvaradion* and *M. speetonensis* is at the same level at Speeton and SE France, while *C. salebrosum* and *S. horticus* appear earlier in NW Europe than in SE France.

If the LO of *S. silvaradion* is synchronous in the two realms the base of the *albidum* Zone should be correlated with the transitional beds between the *alpillensis* and *otopeta* subzones. This is an improvement for inter-realm correlations that were speculative at this level.

C. salebrosum is rare in SE France and very common in offshore Norway and at Speeton (CRUX, 1989). This suggests that this species is a true boreal taxon that appeared first in NW Europe and reached NW Tethys by the beginning of the Valanginian just like the first occurrence of *Platylenticeras*. This would confirm that a migration event occurred at the base of the *pertransiens* Zone. A similar pattern of distribution is shown by *S. horticus* but this species is rare in both provinces.

M. speetonensis suggests a very different problem. In SE France, a taxon that shows affinities with *M. speetonensis* (*M.* sp. in GARDIN & MANIVIT, 1993) is known from the Late Berriasian (*picteti* Subzone) and ranges up into the *inostranzewi* Zone. This form does not show as regular a shape as *M. hoschulzi* nor does it bear the distinct ''spines'' as *M. speetonensis*. It is considered as a possible ancestor of *M. speetonensis*. In SE France, *M. speetonensis* is very rare (1 specimen in 500 fields of view!) and its distribution is limited to some beds in the upper part of the *pertransiens* Zone. In the West European Province, its range is longer but the form is rare there as well. Such a pattern suggests two possible hypotheses:

- *M. speetonensis* is of Tethyan ancestry but became established as a permanent ''population'' in the southern part of the Boreal Realm due to better conditions.

- there is no phyletic link between *M.* aff *speetonensis* and *M. speetonensis*, in which case the ''spotty'' occurrence of the latter in SE France is indicative of a brief connection between the two realms.

POSSIBLE BOUNDARY STRATOTYPES

Since Copenhagen, sections have been investigated in detail at several localities in SE France and the Betic Cordillera of SE Spain. Provisionally, Montbrun-les-Bains (SE France) appears to be the most promising section.

PROVISIONAL RECOMMENDATION

A majority of participants at Brussels voted to place the boundary at the base of Calpionellid Zone E, which corresponds almost exactly to the base of the ammonite zone of *Thurmanniceras pertransiens*. A minority voted for the latter. The calpionellid index was preferred because it can be recognised over a broader geographic area, as far west as Mexico. This provisional decision awaits ratification after the whole Working Group has been consulted.

The Lower/Upper Valanginian boundary

This boundary is much less contentious. Over the last 25 years it has been widely accepted to lie at the base of the *Saynoceras verrucosum* ammonite Zone *sensu* THIEULOY, 1979. Since then, ammonite sequences have been logged in numerous sections in SE France (BULOT, THIEULOY, *et al.*, 1993; BULOT & THIEULOY, 1993; BULOT,

1995) and the Betic Cordillera (COMPANY, 1987). These have shown that the major faunal turnover occurs a little lower in the stratigraphic column (base of the *inostranzewi* Zone *sensu* BULOT, 1995 = uppermost part of the *campylotoxus* zone *sensu* THIEULOY, 1979). However, the base of the *verrucosum* Zone is distinctive and can be recognised also in the West European Province of the Boreal Realm.

Other faunal/floral markers still await documentation by the Working Group, and only then will a stratotype section be recommended. Sections in both SE France and the Betic Cordillera are under consideration.

References

AGUADO, R., 1994. Nannofossiles del Cretacico de la Cordillera Betica (sur de España). Bioestratigrafia. Tesis Doctoral, Universidad de Granada, 413 pp. .

AGUADO, R., COMPANY, M. & TAVERA, J.M., 1995. Considerations about the Berriasian-Valanginian boundary in SE Spain. Second International Symposium on Cretaceous Stage Boundaries - Abstracts: 5.

ALLEMANN, F. & REMANE, J., 1979. Les faunes de calpionelles du Berriasien supérieur - Valanginien. *Les Stratotypes Français*, **6**, Editions du C.N.R.S., 99-109.

APPLEGATE, J. & BERGEN, J. A., 1988. Cretaceous calcareous nannofossil biostratigraphy of sediments recovered from the Galicia Margin, ODP Leg 103. *Proceedings ODP Scientific Results*, **103**: 293-348.

BARBIER, R. & THIEULOY, J.-P., 1965. Étage Valanginien. *Mémoires du Bureau de Recherches Géologiques et Minières*, **34**: 79-84.

BERGEN, J. A., 1994. Berriasian to early Aptian calcareous nannofossils from the Vocontian trough (SE France) and Deep Sea Drilling Site 534: new nannofossil taxa and a summary of low-latitude biostratigraphic events. *Journal of Nannoplankton Research*, **16:** 59-69.

BIRKELUND, T., HANCOCK, J.M., HART, M.B., RAWSON, P. F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F., 1984. Cretaceous stage boundaries - proposals. *Bulletin of the Geological Society of Denmark*, **33:** 3-20.

BLANC, E., 1995. Transect plateforme-bassin dans les séries carbonatées du Berriasien supérieur et du Valanginien inférieur (domaines jurassien et nord-vocontien). Thèse Doctorale Université de Grenoble I, 324 pp.

BLANC, E., BULOT, L. & PAICHELER, J.-C., 1994. La coupe de référence de Montbrun-les-Bains (Drôme, SE France): un stratotype potentiel pour la limite Berriasien-Valanginien. *Comptes rendus de l'Académie des Sciences, Paris*, **318/II:** 101-108.

BRALOWER, T. J., 1987. Valanginian to Aptian calcareous nannofossil stratigraphy and correlation with the Upper M-sequence magnetic anomalies. *Marine Micropaleontology*, **11:** 293-310.

BRALOWER, T. J., MONECHI, S. & THIERSTEIN, H., 1989. Calcareous nannofossil zonation of the Jurassic-Cretaceous interval and correlation with the geomagnetic polarity time-scale. *Marine Micropalaeontology*, **14:** 153-235.

BULOT, L. G., 1990. Évolution des Olcostephaninae (Ammonitina, Cephalopoda) dans le contexte paléo-biogéographique du Crétacé Inférieur (Valanginien-Hauterivien) du Sud-Est de la France. Thèse, Université de Bourgogne, 178 pp.

BULOT, L. G., 1995. Les formations à ammonites du Crétacé inférieur dans le SE de la France (Berriasien-Hauterivien): biostratigraphie, paléontologie et cycles sédimentaires. *Thèse Muséum National d'Histoire Naturelle*, 374 pp.

BULOT, L. G., BLANC, E., THIEULOY, J.-P. & REMANE, J., 1993. La limite Berriasien-Valanginien dans le Sud-Est de la France: données biostratigraphiques nouvelles. *Comptes rendus de l'Académie des Sciences, Paris*, **316:** 1771-1778.

BULOT, L. & THIEULOY, J.-P., 1993. Implications chronostratigraphiques de la révision de l'échelle biostratigraphique du Valanginien supérieur et de l'Hauterivien du Sud-Est de la France. *Comptes rendus de l'Académie des Sciences, Paris*, **317:** 387-394.

BULOT, L. G., THIEULOY, J.-P., ARNAUD, H. & DELANOY, G., 1994. The Lower Cretaceous of the South Vocontian basin and margins. *Géologie Alpine*, Mémoire Hors Série, **20:** 383-399.

BULOT, L. G., THIEULOY, J.-P., BLANC, E. & KLEIN, J., 1993. Le cadre stratigraphique du Valanginien supérieur et de l'Hauterivien du Sud-Est de la France: définition des biochronozones et caractérisation de nouveaux biohorizons. *Géologie Alpine*, **68:** 13-56.

BUSNARDO, R. & THIEULOY, J.-P., 1979. Les zones d'ammonites du Valanginien. *Les Stratotypes Français*, **6**, Editions du C.N.R.S., 58-68.

BUSNARDO, R., THIEULOY, J.-P. & MOULLADE, M., 1979. Hypostratotype Mesogéen de l'Étage Valanginien (sud-est de la France). *Les Stratotypes Français* **6**, Editions du C.N.R.S., 143 pp.

COMPANY, M., 1987. Los Ammonites del Valanginiense del sector oriental de las Cordilleras Beticas (SE de España). Tesis Doctoral, Universidad de Granada, 294 pp.

CRUX, J., 1989. Biostratigraphy and palaeogeographical applications of Lower Cretaceous nannofossils from north-west Europe. *In*: CRUX, J. & HEXK, S. (eds) Nannofossils and their applications, 143-211. Ellis Horwood, Chichester.

ERBA, E., CECCA, F. & HOEDEMAEKER, P., 1995. Report on early Cretaceous stratigraphy (IGCP 262 - Pelagic Working Group). *TBC-Newsletter*, **5:** 7-8.

ERBA, E. & QUADRIO, B., 1987. Biostratigrafia a nannofossili calcarei, calpionellidi e foraminiferi planctonici della Maiolica (Titoniano superiore - Aptiano) nelle Prealpi Bresciane (Italia settentrionale). *Rivista Italiana di Paleontologia e Stratigrafia*, **93:** 3-108.

GARDIN, S. & MANIVIT, H., 1993. Upper Tithonian and Berriasian calcareous nannofossils from the Vocontian Trough (SE France): biostratigraphy and sequence stratigraphy. *Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine*, **17:** 277-289.

HOEDEMAEKER, P.J., 1982. Ammonite biostratigraphy of the uppermost Tithonian, Berriasian and Lower Valanginian along the Rio Argos (Caravaca, SE Spain). *Scripta Geologica*, **65**, 81 pp.

HOEDEMAEKER, P. J. & BULOT, L., 1990. Preliminary ammonite

zonation for the Lower Cretaceous of the Mediterranean region: report. *Géologie Alpine*, **66:** 123-127.

HOEDEMAEKER, Ph. J., COMPANY, M. R. (reporters), AGUIRRE URRETA, M.B., AVRAM, E., BOGDANOVA, T. N., BUJTOR, L., BULOT, L., CECCA, F., DELANOY, G., ETTACHFINI, M., MEMMI, L., OWEN, H. G., RAWSON, P. F., SANDOVAL, J., TAVERA, J. M., THIEULOY, J.-P., TOVBINA, S. Z. & VASICEK, Z., 1993. Ammonite zonation for the Lower Cretaceous of the Mediterranean region; basis for the stratigraphic correlation within I.G.C.P. Project 262. *Revista Española de Paleontologia*, **8**: 117-120.

HOEDEMAEKER, P. J. & LEEREVELD, H., 1995. Biostratigraphy and sequence stratigraphy of the Berriasian-lowest Aptian (Lower Cretaceous) of the Rio Argos succession, Caravaca, SE Spain. *Cretaceous Research*, **16:** 195-230.

KEMPER, E., RAWSON, P. F. & THIEULOY, J.-P., 1981. Ammonites of Tethyan ancestry in the early Lower Cretaceous of north-west Europe. *Palaeontology*, **24**: 251-311.

LE HÉGARAT, G., 1971. Le Berriasien du Sud-Est de la France. *Documents du Laboratoire de Géologie de la Faculté des Sciences de Lyon*, **43**, 576 pp.

LE HÉGARAT, G. & REMANE, J., 1968. Tithonique supérieur et Berriasien de la bordure cévenole. Corrélation des Ammonites et des Calpionelles. *Geobios*, **1**: 1-69.

MANIVIT, H., 1979. Les nannofossils. *Les Stratotypes Français* **6**, Editions du C.N.R.S., 87-98.

MONECHI, S. & THIERSTEIN, H. R., 1985. Late Cretaceous-Eocene nannofossil and magnetostratigraphic correlations near Gubbio, Italy. *Marine Micropalaeontology*, **9:** 419-440.

MONTEIL, E., 1992. Kystes de dinoflagellés index (Tithonique-Valanginien) du sud-est de la France. Proposition d'une nouvelle zonation palynologique. *Revue de Paléobiologie*, **11:** 299-306.

MOULLADE, M., 1979. Les foraminifères du Valanginien hypostratotypique. *Les Stratotypes Français*, **6**, Editions du C.N.R.S. 110-126.

MUTTERLOSE, J., 1991. Das Verteilungs- und Migrations-muster des kalkigen Nannoplanktons in der Unterkreide (Valangin-Apt) NW-Deutschlands. *Palaeontographica*, **B 221**: 27-152.

OGG, J. G., STEINER, M. B., COMPANY, M. & TAVERA, J. M., 1988. Magnetostratigraphy across the Berriasian-Valanginian boundary (Early Cretaceous), at Cehegin (Murcia Province, southern Spain). *Earth and Planetary Science Letters*, **87:** 205-215.

PERCH-NIELSEN, K., 1979. Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. *In:* WIEDMANN, J. (ed) Aspekte de Kreide Europas. IUGS Series A **6:** 223-272.

POP, G., 1994. Calpionellid evolutive events and their use in biostratigraphy. *Romanian Journal of Stratigraphy*, **76:** 7-24.

RAWSON, P. F., 1981. Early Cretaceous ammonite biostratigraphy and biogeography. *In:* HOUSE, M. R. & SENIOR, J. R. (Eds) The Ammonoidea. Systematics Association Special Volume **18:** 499-529.

RAWSON, P. F., 1983. The Valanginian to Aptian stages - current definitions and outstanding problems. *Zitteliana*, **10:** 493-500.

RAWSON, P. F., 1993. The influence of sea level changes on the migration and evolution of Lower Cretaceous (pre-Aptian) ammonites. *In:* HOUSE, M. R. (Ed) The Ammonoidea: environment, ecology and evolutionary change. Systematics Association, Special Volume **47**: 227-242.

RAWSON, P. F., 1995. The "Boreal" Early Cretaceous (Pre-Aptian) ammonite sequences of NW Europe and their correlation with the Western Mediterranean faunas. *Memorie Descrittive della Carta Geologica d'Italia*, **51**: 121-130.

REMANE, J., 1963. Les Calpionelles dans les couches de passage Jurassique-Crétacé de la fosse vocontienne. *Travaux du Laboratoire de Géologie de la Faculté des Sciences de Grenoble*, **39**: 25-82.

REMANE, J., 1985. Calpionellids. *In:* BOLLI, H. M., SAUNDERS, J. B. & PERCH-NIELSEN, K. Plankton Stratigraphy. 555-572. Cambridge University Press.

ROTH, P. H., 1978. Cretaceous nannofossil biostratigraphy and oceanography of the northwestern Atlantic Ocean. *Initial Reports of the Deep Sea Drilling Project* **44**: 731-759.

TAYLOR, R. J., 1978. The distribution of calcareous nannofossils in the Speeton Clay (Lower Cretaceous) of Yorkshire. *Proceedings of the Yorkshire Geological Society*, **42:** 195-209.

TAYLOR, R. J., 1982. Lower Cretaceous (Ryazanian to Albian) calcareous nannofossils. *In:* LORD, A. R. (Ed) A stratigraphical index of calcareous nannofossils, 40-80. Ellis Horwood, Chichester.

THIERSTEIN, H., 1971. Tentative Lower Cretaceous calcareous nannoplankton zonation. *Eclogae Geologicae Helvetiae*, **64:** 459-488.

THIERSTEIN, H., 1973. Lower Cretaceous calcareous nannoplankton biostratigraphy. *Abhandlungen der Geologischen Bundesanstalt*, Wien, **29:** 1-52.

THIERSTEIN, H., 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Marine Micropalaeontology*, **1**: 325-362.

THIEULOY, J.-P., 1973. The occurrence and distribution of boreal ammonites from the Neocomian of southeast France (Tethyan Province). *In:* CASEY, R. & RAWSON, P. F. (Eds). The Boreal Lower Cretaceous. Geological Journal Special Issue **5:** 289-302.

THIEULOY, J.-P., 1977. Les ammonites boréales des formations néocomiennes du sud-est Français (Province Subméditerranéenne). *Geobios*, **10:** 395-461.

THIEULOY, J.-P., 1979. Les ammonites. *Les Stratotypes Français*, **6**, Editions du C.N.R.S., 38-57.

THIEULOY, J.-P., FUHR, M. & BULOT, L., 1990. Biostratigraphie du Crétacé inférieur de l'Arc de Castellane (S.E. de la France). 1: Faunes d'ammonites du Valanginien supérieur et âge de l'horizon dit de "La Grande Lumachelle". *Géologie Méditerranéenne*, **17:** 55-99.

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The Hauterivian Stage

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Abstract

The base of the Hauterivian is recommended to be drawn at the first appearance of the ammonite genus *Acanthodiscus*. This is known from shallow-water facies in both Tethyan and Boreal areas of Europe. The section at La Charce, Drôme, SE France, is recommended as the boundary stratotype. The same section is also appropriate as boundary stratotype for the base of the Upper Hauterivian, which is here defined by the last occurrence of the nannofossil *Cruciellipsis cuvillieri*.

Key-words:
Hauterivian, Lower Cretaceous, biostratigraphy, magnetostratigraphy, isotope stratigraphy, stratotypes.

Résumé

Il est recommandé de placer la base de l'Hauterivien à la première apparition du genre d'ammonite *Acanthodiscus*. Ce genre est présent dans les faciès peu profonds des dépôts téthysiens et boréaux d'Europe. La coupe à La Charce, Drôme, S.E. France, est recommandée comme stratotype de la limite. La même coupe peut être utilisée comme stratotype pour la base de l'Hauterivien supérieur, qui coïncide avec la disparition du nannofossile *Cruciellipsis cuvillieri*.

Mots-clefs
Hauterivien, Crétacé inférieur, biostratigraphie, magnétostratigraphie, stratigraphie isotopique, stratotypes.

Готеривский ярус.

Резюме.
Рекомендуется определять основание Готерива по первому появлению аммонита рода *Acanthodiscus*. Последний присутствует в неглубоких фациях тетиских и бореальных отложений Европы. В качестве стратотипа границы рекомендуется использовать разрез в поселке La Charce, департамент Drôme на юго-востоке Франции. Тот же разрез может быть использован как стратотип для основания верхнего Готерива, совпадающего с исчезновением нанофоссилия *Cruciellipsis cuvillieri*.

Ключевые слова: Готеривский ярус, нижний мел, биостратиграфия, магнитостратиграфия, изотопическая стратиграфия, стратотипы.

Introduction

In 1874 RENEVIER defined the Hauterivian stage, based on the type area of Hauterive (Neuchâtel, Switzerland). The ''marnes à *Astieria*'', the ''marnes bleues d'Hauterive'' and the ''Pierre Jaune de Neuchâtel'' were included in the Hauterivian. More recent studies, however, follow BAUMBERGER (1901), who transferred the ''marnes à *Astieria*'' to the Valanginian stage (for detailed discussion see RAWSON, 1983).

As for other Cretaceous stages, a distinctive provincialism is recognizable for the Hauterivian, resulting in two different zonation schemes: a Boreal and a Tethyan standard zonation. The Hauterivan stage is, however, marked by a pronounced exchange of marine floras and faunas between Tethyan and Boreal Realms, while the Berriasian, Valanginian and Barremian stages are characterised by more endemic taxa. Thus, within Europe, some markers are present both in the Tethys and in the Boreal realm, allowing an inter-regional correlation.

The base of the Hauterivian

Traditionally the base of the Hauterivian is defined by the first appearance of the ammonite *Acanthodiscus radiatus* and allied species, and that was the boundary recommended at Copenhagen (BIRKELUND *et al.*, 1984, p. 7). The value of *Acanthodiscus* lies in its presence in shallow water facies both in the Tethys and the Boreal Realm, though it is rare in the deeper-water facies.

The Hauterivian Working Group has considered other possible boundary criteria too, and these are discussed below.

DINOFLAGELLATES

Recently, LEEREVELD (1995) compiled the first and last occurrences of dinoflagellates for the European Hauterivian in both the Tethys and the Boreal realms. The FO (first occurrence) of *Muderongia staurota*, an earliest Hauterivian event, is a possible candidate for defining the Valanginian/Hauterivan boundary. In the Mediterranean area *M. staurota* occurs in the upper part of the *Acanthodiscus radiatus* ammonite Zone, in NW Germany

at the top of the *Endemoceras amblygonium* ammonite Zone. Thus the FO of *M. staurota* is an important event, allowing direct inter-regional correlation.

Calcareous Nannofossils

Various species of calcareous nannofossils have their first and last occurrences (FO, LO) in the early Hauterivian: FO of *Nannoconus bucheri* (Tethys only), LO of *Eiffelithus windii*, FO and LO of *Eprolithus antiquus* (Boreal Realm only).

The LO of *Eiffelithus windii* has been observed within the early Hauterivian *Acanthodiscus radiatus* Zone in France (Bergen, 1994; Gardin, *in prep.*). *E. windii* is, however, rare or absent in the Boreal Realm. Furthermore it is a taxonomically problematic form.

The LO of *Tubodiscus verenae* has often been recorded as a latest Valanginian event in the Mediterranean sections (Bralower, 1987; Bergen, 1994; Channell *et al.*, 1995; Erba *et al.*, 1995).

However, although it is usually very rare and discontinuous in range, it appears to extend through the Hauterivian too (Bulot *et al.*, this volume). *T. verenae* has not been observed in expanded sections in the Boreal Realm covering the Valanginian/Hauterivian boundary interval.

Foraminifera and Ostracods

Benthic foraminifera and ostracods have been used quite successfully in the Boreal Realm for a zonation and regional correlation (e.g. Bartenstein & Bettenstaedt, 1962; Bartenstein, 1978; Meyn & Vespermann, 1994). However, the fairly detailed zonal scheme, based on benthic foraminifera, cannot be used for inter-regional correlation.

The FO of the ostracod *Protocythere triplicata* has been observed by many authors in the Boreal Realm (Bartenstein & Bettenstaedt, 1962); this event occurs in the *Astieria* beds (*Eleniceras paucinodum* ammonite Zone of Quensel, 1988) in the latest Valanginian of NW Germany (Niedziolka, 1988). In France (Alpes-de-Haute-Provence) the FO of *P. triplicata* seems to equate to the base of the *furcillata* Subzone (Donze, 1976). Consequently the FO of *P. triplicata* is time transgressive, having its FO in NW Europe later than in France. Planktonic foraminifera are of no help as although they first appear in the late Valanginian in the Mediterranean area [*Globigerinelloides gottisi* (Coccioni & Premoli Silva, 1994)], they not occur before the earliest Aptian in the Boreal Realm.

Ammonites

The Hauterivian ammonites show a distinctive provin-

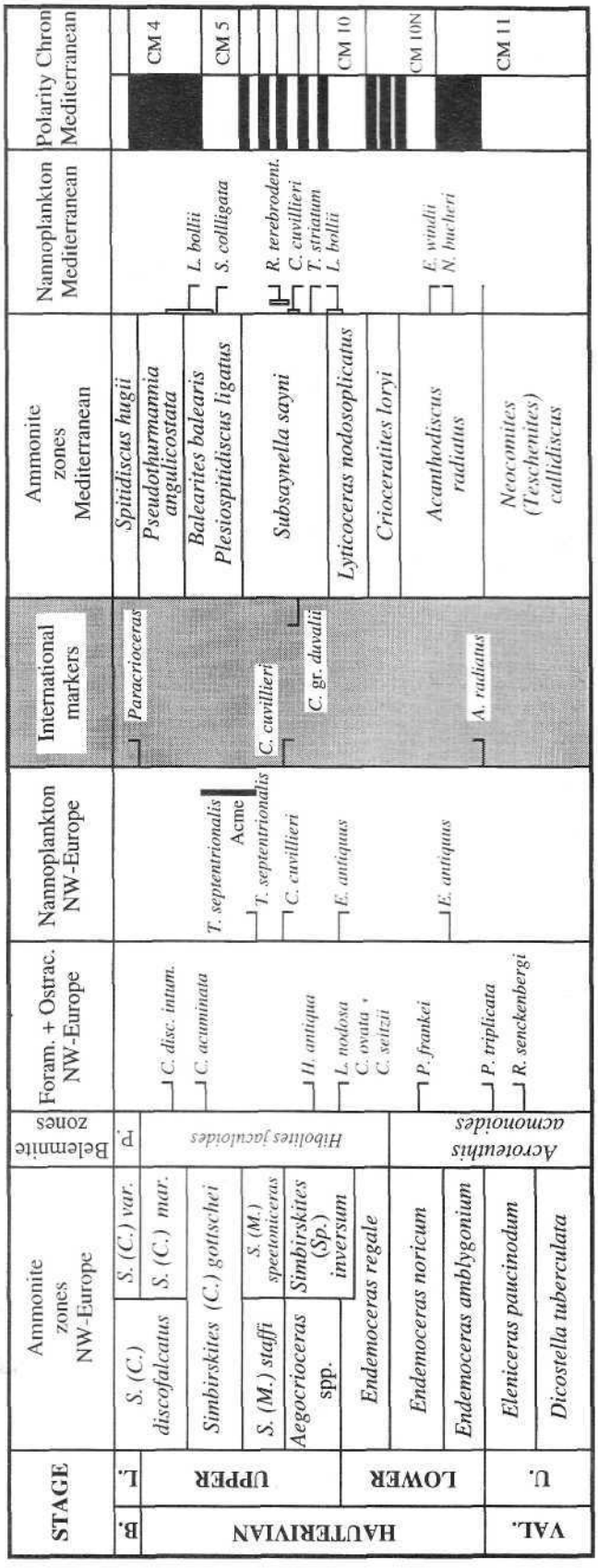

Fig. 1 — Integrated stratigraphy of the Hauterivian for the Boreal and Tethyan areas. Compiled from numerous sources (see text).

cialism, allowing two different biostratigraphic zonation schemes to be used for the Tethys and the Boreal Realm. In the Tethys the base of the Hauterivian is traditionally defined by the first appearance of the ammonite genus *Acanthodiscus*, in the Boreal Realm by the FO of the ammonite *Endemoceras amblygonium*. In the Boreal Realm the first *Acanthodiscus* (*A. bivirgatus*) has been observed in the upper part of the *E. amblygonium* Zone. This might give the basal *E. amblygonium* Zone of the Boreal Realm a latest Valanginian age. Since, however, the first Boreal *Acanthodiscus* is a phylogenetically advanced form it is believed here that the base of the Tethyan *A. radiatus* Zone and the base of the Boreal *E. amblygonium* Zone correlate.

In NW Germany, QUENSEL (1988) placed the *Astieria* beds (beds with *Olcostephanus*), which underlie the *E. amblygonium* Zone, into the *Eleniceras paucinodum* Zone and defined the Valanginian/ Hauterivian boundary at the base of this unit. This suggestion has not been followed subsequently, since the FO of the overlying *E. amblygonium* is quite distinctive throughout NW Europe. HOEDEMAEKER (1984) and HOEDEMAEKER & LEEREVELD (1995) have proposed that the base of the Hauterivian be drawn much lower, at the base of the *Karakaschiceras pronecostatum* horizon, i.e. the second horizon within the *Saynoceras verrucosum* Zone. This level is marked by a faunal turnover of the ammonites and a change in the dinoflagellate assemblages. It correlates approximately with the level in which true *Dichotomites* and *Juddiceras* appear in NW Germany. This would alter the Hauterivian/Valanginian boundary radically and most of what presently is part of the Upper Valanginian would be included in the Hauterivian. Another problem is the correlation with the Boreal succession. However, both *Saynoceras verrucosum* and rare *Karakaschiceras* are known from the lowermost Upper Valanginian of NW Germany, where they co-occur.

MAGNETOSTRATIGRAPHY

No direct correlation between ammonites and polarity chrons has been established so far. BESSE *et al.* (1986) described a magnetostratigraphy for the Angles section (Alpes-de-Provence, France), which cannot be correlated to the standard magnetic polarity chrons. The traditional Valanginian/Hauterivian boundary is probably correlatable with the base of magnetic polarity chron CM 11n (CHANNELL *et al.*, 1995; ERBA *et al.*, 1995). Indirect correlation is indicated by correlations via calcareous nannofossils and dinoflagellates. No magnetic zonation exists for the Boreal Realm. This is partly due to a different lithology, not allowing palaeomagnetic data to be collected.

ISOTOPE STRATIGRAPHY

LINI *et al.* (1992) published a δ^{13} C isotope curve for the Valanginian to Aptian of northern Italy. This curve shows a distinctive latest Valanginian isotope shift correlated to magnetostratigraphy and a nannofossil zone, but not to ammonite zones. This isotopic excursion has been calibrated with bio-magnetostratigraphy in several sections (CHANNELL *et al.*, 1993) and has been observed from various ODP sites. The peak value correlates with magnetic chron M11 and may well be a good proxy for the Valanginian/Hauterivian boundary. The mudstone facies of the Boreal realm does not allow any isotope analyses due to its low calcium carbonate content.

RECOMMENDATIONS

Following the discussions in Brussels it is suggested that the base of the Hauterivian is defined by the first occurrence of the ammonite genus *Acanthodiscus*. Using *Acanthodiscus* for the definition of the Valanginian/Hauterivian boundary, the base of the Tethyan *A. radiatus* ammonite Zone and the base of the Boreal *Edemoceras amblygonium* ammonite Zone may correlate (see above). The reasons for using *Acanthodiscus* are as follows:

- the genus is present in the shallow-water facies in both the Tethyan and Boreal Realms.
- the boundary is defined by a genus, not a species.
- there are no taxonomic problems with *Acanthodiscus*.
- this definition follows the traditional boundary.

Disadvantages in using *Acanthodiscus* are:

- its rarity in the deep-water facies of both the Tethyan and Boreal Realms.
- in the deep-water facies of the Boreal Realm the first *Acanthodiscus* spp. (including *A. radiatus*) appear at the base of the *Endemoceras noricum* Zone (QUENSEL, 1988).

BOUNDARY STRATOTYPE

Originally the Hauterivian stage was defined at Hauterive (Neuchâtel, Switzerland) (RENEVIER, 1874). Because of the condensed nature of some units, poor exposure and the general rarity of ammonites the type area has long been regarded as unsatisfactory. Thus from the time of KILIAN onward, French workers have preferred to use the expanded sequences in SE France as a standard for reference. Of these, that at La Charce (Drôme) is the best documented exposure across the Valanginian/ Hauteri-

vian boundary (THIEULOY, 1977; BULOT *et al.*, 1993) and was proposed as the boundary stratotype by THIEULOY (1977, p. 125). Here, the first *Acanthodiscus* appear in bed 254 of BULOT *et al.* (1993).

As no alternative section in Spain or the Caucasus/Crimea areas has been put forward, the Hauterivian Working Group follow THIEULOY's (1977) recommendation to use the La Charce section as the boundary stratotype for the Valanginian/Hauterivian boundary.

The base of the Upper Hauterivian

In the Mediterranean the Lower/Upper Hauterivian boundary has traditionally been placed at the base of the *Subsaynella sayni* ammonite Zone. Other possible criteria have been considered by the Working Group.

DINOFLAGELLATES

The basal Upper Hauterivian in the Tethyan Realm is characterised by three successive FOs of dinocyst taxa. Two of these species (*Aprobolocysta eilema, Canningia pistica/grandis*) are typical boreal elements. *A. eilema* has its FO in SE France in the *S. sayni* ammonite Zone. A best fit of the FOs of these three species suggests the position of the traditional boundary somewhere in the *Simbirskites inversum* ammonite Zone.

CALCAREOUS NANNOFOSSILS

The FOs and LOs of the following nannofossil species have been observed in the Upper Hauterivian: FO and LO of *Lithraphidites bollii* (Tethys only), LO of *Tegumentum striatum*, LO of *Cruciellipsis cuvillieri*, FO of *Rucinolithus terebrodentarius* (Tethys only), LO and acme of *Tegulalithus septentrionalis* (Boreal Realm mainly) and LO of *Speetonia colligata*.

Tegumentum striatum has its last occurrence in the basal part of the *S. sayni* ammonite Zone in France (GARDIN, *in prep.*). This species is rare to common in the Mediterranean sections and common in the Boreal sections. Its disappearance seems to be time transgressive, since it has its LO in NW Europe in the late Hauterivian *Simbirskites discofalcatus* ammonite Zone.

In SE France *Cruciellipsis cuvillieri* has its LO in the upper part of the *S. sayni* Zone (BERGEN, 1994; GARDIN, *in prep.*). In Italy, the LO of *C. cuvillieri* is correlated to magnetic chrons M7-M8 and therefore is Late Hauterivian in age (CHANNELL *et al.*, 1995; ERBA *et al.*, 1995). In the Boreal Realm *C. cuvillieri* has its LO just above the top of the *Aegocrioceras* beds in NW Germany (KEMPER *et al.*, 1987), but somewhat lower (top of *E. regale* ammonite Zone) at Speeton (CRUX, 1989). Its absence in the Speeton *Aegocrioceras* beds probably reflects the extremely condensed nature of the beds there, leading to poor preservation and a generally impoverished flora. Since *C. cuvillieri* is a quite distinctive species it may be a good candidate for defining the Lower/Upper Hauterivian boundary.

The LO of rare *Tegulalithus septentrionalis* has been reported from the *Plesiospitidiscus ligatus* ammonite Zone in France (GARDIN, *in prep.*), while it is common in the Boreal *Simbirskites staffi* and *S. gottschei* ammonite zones.

Speetonia colligata occurs too high in the Upper Hauterivian to be considered as a marker for the Lower/Upper Hauterivian boundary. Furthermore it is a rare species in both the Boreal Realm and the Tethys.

AMMONITES

In the Mediterranean the Lower/Upper Hauterivian boundary is currently defined by the disappearance of the Neocomitinae and the first appearance of *Subsaynella sayni* (BULOT *et al.*, 1993). It is placed at the base of the *Subsaynella sayni* Zone (*Cruasiceras cruasense* horizon). The Boreal Upper Hauterivian is characterised by the ammonite *Simbirskites*, which occurs from California and Arctic Canada to NW-Europe and the former Soviet Union. Ammonites typical of the *Lyticoceras nodosoplicatus* and *Subsaynella sayni* zones occurring in the Speeton Clay (eastern England) succession show that there the base of the *sayni* Zone equates with the middle part of the boreal *Simbirskites inversum* Zone. In NW Germany *S. inversum* is very rare; the heteromorph ammonite genus *Aegocrioceras* is extremely common in this interval. Consequently the base of the *Aegocrioceras* beds has been taken to approximate to the Lower/Upper Hauterivian boundary.

RECOMMENDATIONS

For defining the boundary of the Lower/Upper Hauterivian substages the LO of the nannofossil *Cruciellipsis cuvillieri* in the Mediterranean area is suggested. This event lies in the upper part of the *Subsaynella sayni* ammonite Zone (*sensu* HOEDEMAEKER & BULOT, 1990) in the Tethys and just above the top of the *Aegocrioceras* beds in NW Europe. Using *C. cuvillieri* has the following advantages:

- the species is present in the Boreal Realm, in the Tethys and in the Indian Ocean. It thus has a really world-wide distribution.
- the species is easily recognised.

- there are no taxonomic problems with *C. cuvillieri.*

- the current definition compares closely with the traditional boundary.

The disadvantage of using *C. cuvillieri* is that it splits the Tethyan *S. sayni* Zone, placing the lower part in the Lower Hauterivian.

BOUNDARY STRATOTYPE

As no alternative section in Spain or the Caucasus/Crimea areas has been put forward, the Hauterivian Working Group agreed to recommend the La Charce section as the boundary stratotype for the Lower/Upper Hauterivian boundary.

References

BARTENSTEIN, H., 1978. Worldwide zonation of the Lower Cretaceous using benthic foraminifera. *Newsletters on Stratigraphy*, **6:** 30-41.

BARTENSTEIN, H. & BETTENSTAEDT, F., 1962. Leitfossilien der Mikropaläontologie. Arbeitskreis Deutscher Mikropaläontologen (Editor) **B7:** 225-297.

BAUMBERGER, E., 1901. Über Facies und Transgressionen der unteren Kreide am Nordrande der Mediterrano-helvetischen Bucht. *Wissenschaftliche Beilagen Berichte Töchterschule*, Basel, 1900/1901.

BERGEN, J. A., 1994. Berriasian to early Aptian calcareous nannofossils from the Vocontian trough (SE France) and Deep Sea Drilling Site 534: new nannofossil taxa and a summary of low-latitude biostratigraphic events. *Journal of Nannoplankton Research*, **16:** 59-69.

BESSE J., BOISSEAU T., ARNAUD-VANNEAU, A., ARNAUD H., MASCLE G. & THIEULOY J.-P. 1986. Modifications sédimentaires, renouvellements des faunes et inversions magnétiques dans le Valanginien de l'hypostratotype d'Angles. *Bulletin Centre Recherches Exploration-Production Elf-Aquitaine*, **10:** 365-368.

BIRKELUND, T., HANCOCK, J.M., HART, M.B., RAWSON, P. F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F. 1984. Cretaceous stage boundaries - proposals. *Bulletin of the Geological Society of Denmark*, **33:** 3-20.

BRALOWER, T. J., 1987. Valanginian to Aptian calcareous nannofossil stratigraphy and correlation with the Upper M-sequence magnetic anomalies. *Marine Micropaleontology*, **11:** 293-310.

BULOT, L., THIEULOY, J.-P., BLANC, E. & KLEIN, J. 1993. Le cadre stratigraphique du Valanginien supérieur et de l'Hauterivien du Sud-Est de la France: définition des biochronozones et caractérisation de nouveaux biohorizons. *Géologie Alpine*, **68:** 13-56.

CECCA, F. & ERBA, E. 1995. Correlations of Hauterivian and Barremian (Early Cretaceous) stage boundaries to polarity chrons. *Earth and Planetary Science Letters*, **134:** 125-140.

CHANNELL, J. E. T., ERBA, E. & LINI, A. 1993. Magnetostratigraphic calibration of the Late Valanginian carbon isotope event in pelagic limestones from Northern Italy and Switzerland. *Earth and Planetary Science Letters*, **118:** 145-166.

CHANNELL, J. E. T., CECCA, F. & ERBA, E., 1995. Correlations of Hauterivian and Barremian (Early Cretaceous) to polarity chrons. *Earth and Planetary Science Letters*, **134**: 125-140.

COCCIONI, R. & PREMOLI SILVA, I. 1994. Planctonic foraminifera from the Lower Cretaceous of Rio Argos sections (southern Spain) and biostratigraphic implications. *Cretaceous Research*, **15:** 645-687.

CRUX, J. A., 1989. Biostratigraphy and palaeogeographical applications of Lower Cretaceous nannofossils from the north-western Europe. *In*: Nannofossils and their applications, 143 - 211.

DONZE, P., 1976. Répartition stratigraphique des espèces du genre *Protocythere* TRIEBEL 1938 (Ostracode), dans le Valanginien de la région de Chabrières (Alpes-de-Haute-Provence). *Revue de Micropaléontologie*, **19:** 19-26.

ERBA, E., CECCA, F. & HOEDEMAEKER, P,. 1995. Report on early Cretaceous stratigraphy (IGCP 262 - Pelagic Working Group). *TBC-Newsletter*, **5:** 7-8.

HOEDEMAEKER, P. J., 1984. Proposals for the stratigraphic positions of the Berriasian - Valanginian and the Valanginian - Hauterivian boundaries. *Bulletin of the Geological Society of Denmark*, **33:** 139-146.

HOEDEMAEKER, P. J. & BULOT, L. 1990. Preliminary ammonite zonation for the Lower Cretaceous of the Mediterranean region: report. *Géologie Alpine*, **66:** 123-127.

HOEDEMAEKER, P. & LEEREVELD, H., 1995. Integrated stratigraphy and sequence stratigraphy of the Lower Cretaceous along the Rio Argos (Caravaca, SE Spain). *Cretaceous Research*, **16:** 195-230.

KEMPER, E., MUTTERLOSE, J. & WIEDENROTH, K. 1987. Die Grenze Unter-/Ober-Hauterive in Nordwestdeutschland, Beispiel eines stratigraphisch zu nutzenden Klima-Umschwunges. *Geologisches Jahrbuch*, **A 96:** 209-218.

LEEREVELD, H., 1995. Dinoflagellate cysts from the Lower Cretaceous Rio Argos succession (SE Spain). *LPP Contribution Series* **2**, 175 pp.

LINI, A., WEISSERT, H. & ERBA, E., 1992. The Valanginian carbon isotope event: a first episode of greenhouse climate conditions during the Cretaceous. *Terra Nova*, **4:** 374-384.

MEYN, H. & VESPERMANN, J., 1994. Taxonomische Revision von Foraminiferen der Unterkreide SE-Niedersachsens nach ROEMER (1839, 1841, 1842), KOCH (1851) und REUSS (1863). *Senckenbergiana Lethaea*, **74** (1-2): 49-272.

NIEDZIOLKA, K., 1988. Die Mikrofauna im Valangin-Hauterive-Grenzbereich des zentralen niedersächsischen Beckens (Pollhagen, Wiedensahl II). *Berliner geowissenschaftliche Abhandlungen*, **A 94**: 89-173.

QUENSEL, P., 1988. Die Ammonitenfauna im Valangin-Hauterive Grenzbereich vom Mittellandkanal bei Pollhagen. *Berliner geowissenschaftliche Abhandlungen*, **A 94**, 15-71.

RAWSON, P. F., 1983. The Valanginian to Aptian stages - current definitions and outstanding problems. *Zitteliana*, **10:** 493-500.

RENEVIER, E., 1874. Tableau des terrains sédimentaires. *Bulletin de la Société vaudoise des Sciences naturelles*, **13:** 218-252.

THIEULOY, J.-P. 1977. La zone à Callidiscus du Valanginien supérieur vocontien (Sud-Est de la France). Lithostratigraphie, ammonitofaune, limite Valanginien-Hauterivien, corrélations. *Géologie Alpine*, **53:** 83-143.

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The Barremian Stage

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Abstract

Inter-regional correlation in the Barremian is impossible because of strong biotic differentiation between realms coupled with a lack of obvious non-biostratigraphic markers to provide good boundaries. Thus we have chosen the best of the limited options available to define boundaries within the Tethyan Realm.

We recommend that the base of the Barremian be placed at the base of the *Spitidiscus hugii* ammonite Zone in the Río Argos section, SE Spain. Supplementary information will be compiled to fully document this choice before formal submission via the Cretaceous Subcommission to the Commission on Stratigraphy.

The base of the Upper Barremian should be defined by the first appearance of the ammonite *Ancyloceras vandenheckei* in one of the Subbetic sections in SE Spain, probably section X.KV (Barrano de Cavila, Caravaca). Other sections in the region require further documentation before the final recommendation can be made.

Key-words:
Barremian, Lower Cretaceous, biostratigraphy, magnetostratigraphy, stratotypes.

Résumé:

Pour le Barrémien, toute corrélation interrégionale est impossible à cause d'une forte différentiation biotique entre les différents domaines combinée à un manque évident de marqueurs non biostratigraphiques pour indiquer de bonnes limites. C'est pourquoi nous avons choisi les meilleures parmi les options limitées existantes pour définir les limites dans le domaine téthysien.

Nous recommandons de placer la base du Barrémien à la base de la Zone de l'ammonite *Spitidiscus hugii*, dans la section du Rio Argos, Espagne du S.-E. Des informations supplémentaires seront rassemblées pour documenter ce choix avant de le soumettre formellement par l'intermédiaire de la Sous-commission du Crétacé à la Commission de Stratigraphie.

La base du Barrémien supérieur devrait être définie par la première apparition de l'ammonite *Ancyloceras vandenheckei* dans une des sections subbétiques (S.-E. de l'Espagne), probablement la section X.KV (Barrano de Cavila, Caravaca). D'autres sections dans la région doivent être étudiées de façon plus approfondie avant que l'on puisse faire de recommandation définitive.

Mots-clefs:
Barrémien, Crétacé inférieur, biostratigraphie, magnétostraigraphie, stratotypes.

Барремский ярус.

Резюме.
Для Барремского яруса межрегиональная корреляция не представляется возможной в связи с сильной биотической дифференциацией, существующей между разными областями, а также в связи с очевидным недостатком биостратиграфических знаков, необходимых для правильного обозначения границ. По этой причине мы выбрали наилучшую из существующих ограниченных возможностей для определения границ области Тетис.
Мы рекомендуем определять основание Баррема по основанию аммонитовой зоны *Spitidiscus hugii*, в разрезе Rio Argos на юго-востоке Испании. Дополнительная информация будет предоставлена для документации данного выбора до его формального представления Стратиграфической Комиссии, при посредничестве Меловой Подкомиссии.
Основание верхнего Баррема должно быть определено при первом появлении аммонита *Ancyloceras vandenheckei* в одной из предбетских секций на юго-востоке Испании, вероятно в разрезе X.KV (Barrano de Cavila, Caravaca). Другие разрезы данного района требуют дополнительного изучения для формулировки конечных рекомендаций.

Ключевые слова: Барремский ярус, нижний мел, биостратиграфия, магнитостратиграфия, стратотипы.

Introduction

The Barremian Working Group has continued the work initiated by its predecessor, the pre-Albian Stages Working Group, whose conclusions were presented at Munich in 1982 (RAWSON, 1983) and Copenhagen in 1983 (BIRKELUND *et al.*, 1984). The preliminary proposals made at the Subcommission's 1983 Copenhagen conference are a necessary starting point for defining the base of the Barremian. The Lower/Upper Barremian boundary was not considered at Copenhagen, but had been discussed briefly at Munich. At both meetings debate centred mainly on the ammonite sequence and little information was offered on possible microfossil or other boundary markers (BIRKELUND *et al.*, 1984, pp. 7-8). The main obstacles to making firm recommendations for stage and substage boundaries were recognised as:

- a lack of detailed lithological, palaeontological, magnetostratigraphic and chronostratigraphic logs for many key sections around the world (RAWSON, 1983, p. 499).

- provincialism in many fossil groups, rendering long-distance correlation very difficult (BIRKELUND *et al.*, 1984).

Since the Copenhagen meeting much new information has been published, especially on various European sequences. Some important palaeomagnetic data are now available and sequence stratigraphy has given new insights. However, this new information has highlighted the difficulty of correlating the better-known West Tethyan (Spain to the Caucasus) sequences with Barremian successions elsewhere. Even within Europe, the increasing endemicity of many fossil taxa by the beginning of the Barremian makes it difficult to correlate the West Tethyan faunas/floras with those of the NW European "Boreal" area. Conversely, the stratigraphy of some of the rich ammonite faunas of the Americas is poorly known.

We are therefore taking the pragmatic view that as a truly global correlation of Barremian rocks is still an unachieved ideal which may never be fully satisfied, it is better not to delay making our recommendations on the boundary levels. Although there are differences of opinion and emphasis within our working group, which will be elaborated upon below, the consensus is that the boundaries should be defined in the Western Tethys and based primarily on the ammonite sequence there. It proved impossible to find good, reliable microfossil markers of any wide applicability, but we have indicated those useful biological (and non-biological) events that coincide closely with the ammonite boundaries.

Definition of the Barremian Stage

BUSNARDO (1965) noted that although COQUAND's (1861) original definition of the Barremian was not very precise, it embraced both the Upper Hauterivian and Barremian of current usage. The pre-Albian Stages Working Group agreed with BUSNARDO that "despite historical priority it is best in the interests of stability" to follow KILIAN's (1888) more limited interpretation of the Barremian (RAWSON, 1983, p. 497). KILIAN had included the zone of *Pseudothurmannia angulicostata* in the Hauterivian, and that is the view taken by the majority of, though not all, workers since (see discussion below).

The base of the Barremian

During the preliminary exchange of ideas among Working Group members, it became apparent that there were no obvious microfossil or non-biostratigraphic markers that could convincingly supplant the ammonites as a primary tool for defining the base of the Barremian. Thus debate has centred primarily on which ammonite level would provide the best boundary.

At Copenhagen is was noted that while some workers placed the base of the Barremian at the base of the *Pseudothurmannia angulicostata* Zone (i.e. base of the *Pseudothurmannia* beds) others put it above that zone while BUSNARDO (*in* RAWSON, 1983, p. 498) drew it high *within* the *angulicostata* Zone based on the first appearance of the desmoceratid ammonites *Raspailiceras* and *Barremites*. The Copenhagen meeting recommended that the Hauterivian/Barremian boundary should be placed

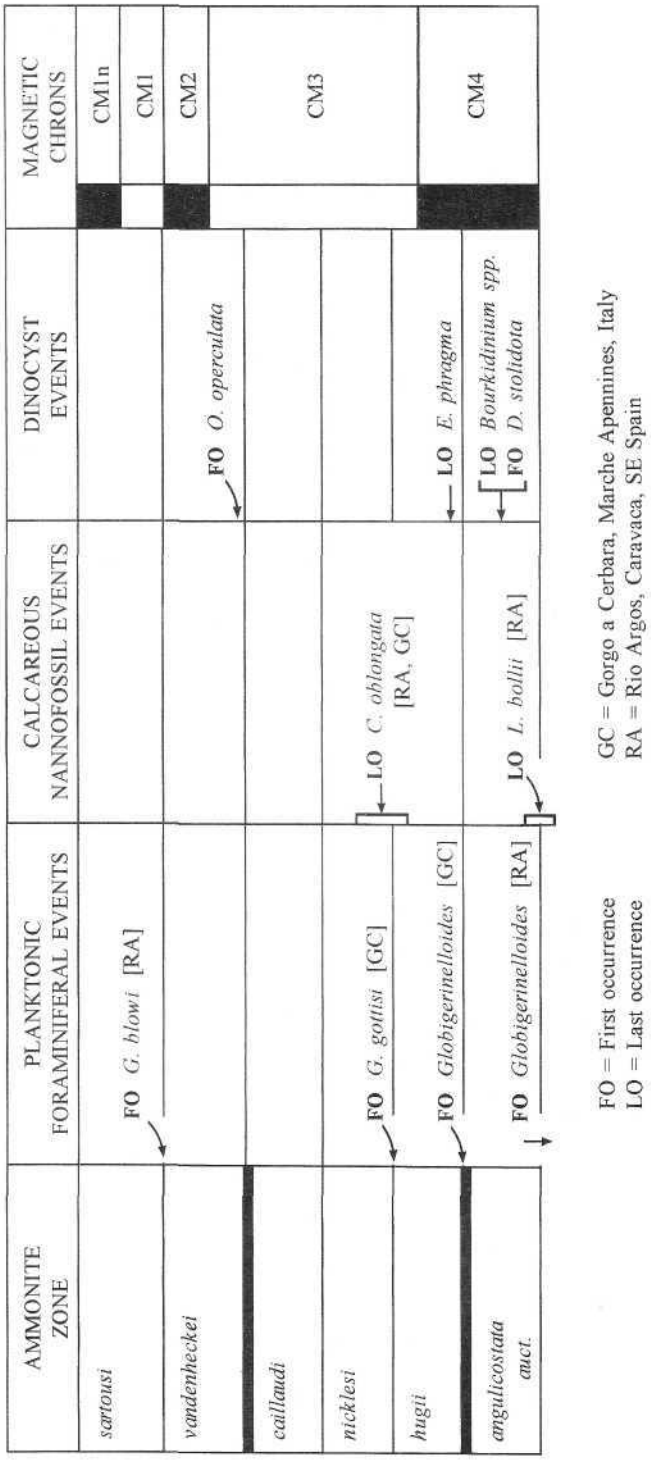

Fig. 1 — Lower Barremian and lower Upper Barremian Tethyan (Mediterranean) ammonite zones, microfossil events and magnetic polarity chrons.
The solid line beneath the *hugii* Zone represents the recommended base of the Barremian and that beneath the *vandenheckei* Zone the recommended base of the Upper Barremian.

either below or above the *Pseudothurmannia* beds and that a boundary **within** them should be avoided (BIRKELUND *et al.*, 1984, p. 8).

Three possible horizons for the base of the Barremian were discussed at Brussels:

- base of the *Spitidiscus hugii* Zone (i.e. above the *Pseudothurmannia* beds)
- middle of the *Pseudothurmannia* beds
- base of the *Pseudothurmannia* beds

BASE OF THE *SPITIDISCUS HUGII* ZONE

The Lower Cretaceous Cephalopod Team of IGCP Project **262** (now transferred to Project **362**) suggested that the boundary could be placed at the base of the *Spitidiscus hugii* Zone, immediately **above** the *Pseudothurmannia* beds (HOEDEMAEKER & BULOT, 1990, fig. 1).

The *Spitidiscus hugii* Zone was first named by BUSNARDO (*in* ROGER, 1980, table). The index species first appears in Bed 73 of the Angles section in SE France (BUSNARDO & VERMEULEN, 1986), about 4 m above the last *Pseudothurmannia*, and it occupies a similar position in sections in SE Spain through France eastwards to the Caucasus.

In the Subbetic Domain (Betic Cordillera, southern Spain) the base of the zone is defined by the first appearance of specimens of the *Spitidiscus hugii* (OOSTER) - *Spitidiscus vandeckii* (d'ORBIGNY) group, but no one ammonite species is restricted to the zone (COMPANY *et al.*, 1995).

In the Carpathians exposure is poor and consequently there is a lack of suitable sections and faunas. This is especially true for the Silesian Unit of the Outer West Carpathians, well known for ammonite occurrences in the last century (UHLIG, 1883). However, the base of the *S. hugii* Zone is clearly marked, especially by a strong reduction to sudden disappearance of crioceratids and *Pseudothurmannia*, while the spitidiscids appear anew but sporadically. *Hamulinites parvulus* (UHLIG) appears as a new element but extends through the whole Lower Barremian (VASICEK *et al.*, 1994; VASICEK, *in press*). However, in Italy CECCA (*unpublished*) has found the latter species lower down, in the Faraoni Level (*catulloi* Subzone).

In the Khidikari section of western Georgia the highest Hauterivian beds with *Pseudothurmannia* are overlain by Lower Barremian limestones with *Spitidiscus* spp. According to new, preliminary data, very rare *S. hugii* occur at the base of these limestones (KVANTALIANI & SAKHELASHVILI, *in preparation*).

DELANOY (*personal communication*) notes that it does not seem possible to use any other truly characteristic form between the last *Pseudothurmannia* and the first *S. hugii*. In the Barrême region of SE France these species are separated by some levels very rich in Desmoceratidae (*Barremites, Raspailiceras*). These desmoceratids do not appear to be of a very refined stratigraphic usage, and their local abundance is perhaps due to particular ecological conditions. VASICEK (*personal communication*) also points out that as desmoceratids are rather difficult to determine and are mostly not very well preserved, it is unrealistic to use them for defining the boundary.

CECCA *et al.* (1994) suggest that the base of the *hugii* Zone lies somewhat above the last occurrence of the nannofossil *Lithraphidites bollii*. However, von SALIS (*personal communication*) notes that in general the nannofossils show little change in the vicinity of the Hauterivian/Barremian boundary. CECCA *et al.* (1994) also indicate that planktonic foraminifera are of little help in broad regional correlation as the first and last occurrences appear to fluctuate considerably from one area to another (see Table 1).

The base of the *hugii* zone falls high in magnetochron M4 (BARTOLOCCI *et al.*, 1992).

MIDDLE OF THE *PSEUDOTHURMANNIA* BEDS

HOEDEMAEKER (*in* HOEDEMAEKER, COMPANY *et al.*, 1993, and *personal communication*) proposes that in the Río Argos (SE Spain) section the old *Pseudothurmannia angulicostata* Zone at the top of the Hauterivian can be split into two, a lower subzone of *P. ohmi* and an upper subzone of *P. catulloi*. He prefers to lower the base of the Barremian stage to the base of the *P. catulloi* Subzone. In terms of sequence stratigraphy, HOEDEMAEKER notes that the *catulloi* Subzone corresponds to a lowstand systems tract which "is commonly missing, especially in rather shallow seas. It is fortunately well represented along the Río Argos where the sea was rather deep."

LEEREVELD (*personal communication*) has examined the dinoflagellate data. He points out that the base of the *S. hugii* Zone is difficult to characterise but that the middle of the *P. angulicostata* auct. Zone can be identified quite easily in SE France and SE Spain. This level approximates to that suggested as a boundary by HOEDEMAEKER. It is characterised by:

- the last consistent and frequent presence of *Cymososphaeridium validum*
- the last occurrence of *Bourkidinium* spp.
- the first occurrence of *Diphasiosphaera stolidota.*

BASE OF THE *PSEUDOTHURMANNIA* BEDS

AVRAM (*personal communication*) recommends this level, following, for example, BRESKOWSKI (1975), AVRAM (1983), VASICEK *et al.* (1983) and, indirectly, COQUAND (1861) in his original definition of the Barremian. His

argument is based on ammonite ranges at the Svinita section in Romania. Here the Cheloniceratinae (*Paraspiticeras*) first appear just beneath the *Pseudothurmannia* beds, followed by the first Hemihoplitidae (*Pseudothurmannia*) and then the Pulchelliidae (*Psilotissotia*). AVRAM regards the assemblage as much more related to the Barremian than to the Hauterivian.

POSSIBLE BOUNDARY STRATOTYPE SECTIONS

At Copenhagen it was recommended that sections in southeast France, southeast Spain, the Carpathians, the Crimea and the Caucasus should be considered as candidates for the Hauterivian/Barremian boundary stratotype. The WG meeting at Brussels considered several possible candidates. At Angles (the Barremian "stratotype section"), the boundary seems to occur at the base of bed 72, where *S. hugii* first appears (data of BUSNARDO & VERMEULEN, 1986). Ammonites are scarce around this level, and there are problems of exposure. Conversely, COMPANY, HOEDEMAEKER, SANDOVAL and TAVERA considered that the Río Argos section in SE Spain would make a very good boundary stratotype as it is well exposed and ammonites are abundant.

AVRAM (*personal communication*) suggested that there are two possible candidate localities in Romania. At Svinita (western end of the Southern Carpathians) the *Pseudothurmannia* beds are well represented, while several metres above the *Spitidiscus hugii* group appears, well below the *caillaudianus* Zone assemblage. Unfortunately there is not yet a good and completely studied section.

In Dambovicioara (eastern end of the Southern Carpathians) the beds with *Pseudothurmannia* are rich in individuals but poorly exposed (because of their structural setting). They are obviously followed by beds with *Spitidiscus vandeckii*, *Pulchellia changarnieri* and, 1 m above, the first *Holcodiscus* ex. gr. *caillaudianus-perezianus*.

The Crimean sections are too condensed to be considered for a boundary stratotype (BARABOSHKIN, *personal communication*) but the base of the *angulicostata* Zone is well marked. Sections in the Northern Caucasus, Mangyshlak and Turkmenia contain only very rare ammonites across the boundary interval, and most are boreal forms.

RECOMMENDATIONS

By a majority view the Brussels meeting of our Working Group recommended drawing the base of the Barremian at the base of the *Spitidiscus hugii* Zone. In a subsequent postal vote, 13 members replied; 11 supported this proposal while the other two alternatives received one vote each. The alternative of lowering the boundary to the base of the *catulloi* Zone was rejected because this zone is of limited applicability — it is apparently missing in many of the shallower water areas as it represents an interval of low sea level. This at least partially explains why some other contributors could not recognise a twofold division of the widespread *Pseudothurmannia*-rich beds at the top of the Hauterivian. Conversely the deposits of the overlying *hugii* Zone are much more widespread and are now recognised from SE Spain eastwards to the Western Caucasus, the index species occurring at least sparsely over most of that area.

Such a distribution goes some way towards meeting the need to establish a correlation of relevant strata and define a boundary "that will be recognisable over as wide an area as possible". But we have no evidence whether the *hugii* Zone can be traced further to the west, to Mexico or Columbia. And it is probably impossible to correlate the horizon very closely with boreal sequences, at least by using ammonites alone. However, dinoflagellates may provide a useful guideline.

The meeting also recommended that the Río Argos section would make an appropriate boundary stratotype section. In the subsequent postal vote, 12 members supported this proposal and one abstained. Information on the ranges of other fossil groups in this section is now documented (HOEDEMAEKER & LEEREVELD, 1995).

The Lower/Upper Barremian boundary

DEFINITION OF THE BOUNDARY

For the Pre-Albian Stages Working Group, BUSNARDO (*in* RAWSON, 1983, p. 498) defined the base of the Upper Barremian "by the appearance of *Heinzia* and of "*Emericiceras*" of the *barremense* Group. Table 1 in RAWSON (1983) showed an "*Emericiceras*" *barremense* Zone at the base of the Upper Barremian, following BUSNARDO (*in* ROGER, 1980).

The Cephalopod Working Group of IGCP Project 262 rejected the "*Emericiceras*" *barremense* Zone because of the ambiguous interpretation of "*E.*" *barremense*. They replaced it with the *Ancyloceras vandenheckei* and overlying *S. sartousiana* Zones, taking the base of the *vandenheckei* Zone to mark the base of the Upper Barremian. This position has been followed in several subsequent publications (e.g. BARTOLOCCI *et al.*, 1992; CECCA *et al.*, 1994; COMPANY *et al.*, 1995; VASICEK *et al.*, 1994).

DELANOY (*personal communication*) notes that in France there is a significant but progressive change of the ammonite faunas from this level upward, which ushers in the great faunal renewal of the *sartousiana, feraudianus* and *giraudi* Zones. He also points out that *E. barremense* occupies higher levels than *A. vandenheckei*.

The base of the *vandenheckei* Zone was the only boundary suggested by members of the WG prior to the Brussels meeting and no other boundary was put forward at Brussels. LEEREVELD (*personal communica-*

tion) points out that the first occurrence of the dinoflagellate *Odontochitina operculata* approximates to the base of this zone. BARTOLOCCI *et al.* (1992, pp. 63-68) show that the boundary lies high in magnetochron M3.

POSSIBLE BOUNDARY STRATOTYPE SECTIONS

COMPANY, SANDOVAL and TAVERA (*personal communication*) suggest that section X.KV (Barrano de Cavila, Caravaca) of the Subbetic Zone of SE Spain may be a suitable candidate. Studies of the distribution of calcareous nannofossils, planktonic foraminifers, palynomorphs and sequence stratigraphy are being carried out on this and other Subbetic sections.

AVRAM (*personal communication*) notes that in the Carpathian localities mentioned above the boundary beds are not exposed but could be excavated artificially; the lack of exposure does not reflect a structural problem.

RECOMMENDATIONS

We recommend that the base of the upper Barremian is defined by the base of the *vandenheckei* Zone. In the postal vote, 11 members supported this view, one abstained and one disagreed. The zonal species is widely distributed in western Tethys, being recorded from SE Spain eastwards as far as the Tvishi section of western Georgia (KAKABADZE & KOTETISHVILI, 1995).

The meeting also agreed that a boundary stratotype should be chosen from one of the Subbetic sections of SE Spain, and this was supported in the subsequent postal vote by 12 members (with one abstention). Further documentation of the most appropriate sections is awaited.

Correlation with the Boreal Realm

The recommended boundaries are based on Tethyan taxa belong to the Mediterranean faunal province. The nearest boreal area to this is the West European Province *sensu* RAWSON (1981), embracing the North Sea and North German basins. This region was open to considerable Tethyan influence during the Valanginian and Hauterivian but less so during much of the Barremian (e.g. MUTTERLOSE, 1988; RAWSON, 1994). There are no records of the *Spitidiscus hugii* group or of other distinctively basal Barremian ammonites. However, dinoflagellate ''tops'' in the lower part of the *variabilis* Zone indicate that this interval correlates with the top of the *balearis* Zone to the base of the *angulicostata* Zone and not, as currently suggested, with the base of the Barremian (LEEREVELD, *personal communication*). This may indicate that the appearance of the belemnite *Praeoxyteuthis pugio* high in the *variabilis* Zone gives a reasonable approximation to the base of the Barremian.

RAWSON (1995) has provisionally drawn the base of the Upper Barremian at the base of the *denckmanni* Zone, while suggesting that the boundary could be a little lower, ''in or at the base of the *elegans* Zone. The latter position would be supported by KAKABADZE's (1981) Georgian record of *P.* cf. *elegans* (which is from the Upper Barremian *Heinzia matura* Zone) and of *P. denckmanni* in the overlying *Hemihoplites feraudianus* Zone. Furthermore, LEEREVELD (*personal communication*) points out that the dinoflagellate *Odontochitina operculata*, whose first occurrence is at about the base of the Upper Barremian in western Tethys, first appears in the lower part of the *P. elegans* Zone in the West European Province (Speeton). The base of this zone also coincides with the LO of the belemnite genus *Aulacoteuthis* and the FO of its successor, *Oxyteuthis*.

References

AVRAM, E., 1983. Barremian ammonite zonation in the Carpathian area. *Zitteliana*, **10:** 509-514.

BARTOLOCCI, P., BERALDINI, M., CECCA, F., FARAONI, P., MARINI, A. & PALLINI, G., 1992. Preliminary results on correlation between Barremian ammonites and magnetic stratigraphy in Umbria-Marche Apennines (Central Italy). *Palaeopelagos*, **2:** 63-68.

BIRKELUND, T., HANCOCK, J.M., HART, M.B., RAWSON, P. F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F. 1984. Cretaceous stage boundaries - proposals. *Bulletin of the Geological Society of Denmark*, **33:** 3-20.

BRESKOWSKI, S., 1975. Les zones et sous-zones ammonitiques dans l'étage Barrémien en Bulgarie du Nord-Est. *Geologica Balcanica*, **5:** 47-66.

BUSNARDO, R., 1965. Le Stratotype du Barrémien. 1. - Lithologie et Macrofaune. *Mémoires du Bureau de Recherches Géologiques et Minières*, **34:** 101-116.

BUSNARDO, R. & VERMEULEN, J., 1986. La limite Hauterivien-Barrémien dans la région stratotypique d'Angles (Sud-Est de la France). *Comptes Rendus de l'Académie des Sciences, Paris*, **302**, II: 457-459.

CECCA, F., PALLINI, G., ERBA, E., PREMOLI-SILVA, I. & COCCIONI, R., 1994. Hauterivian-Barremian chronostratigraphy based on ammonites, nannofossils, planktonic foraminifera and magnetic chrons from the Mediterranean domain. *Cretaceous Research*, **15:** 457-467.

COMPANY, M., SANDOVAL, J. & TAVERA, J. M., 1995. Lower Barremian ammonite biostratigraphy in the Subbetic Domain (Betic Cordillera, southern Spain). *Cretaceous Research*, **16:** 243-256.

COQUAND, H., 1861. Sur la convenance d'établir dans le groupe

inférieur de la formation cretacée un nouvel étage entre le Néocomien proprement dit (couches à *Toxaster complanatus* et à *Ostrea couloni*) et le Néocomien supérieur (étage Urgonien de d'ORBIGNY). *Mémoires de la Société d'Emulation de Provence*, **1:** 127-139.

HOEDEMAEKER, P. J. & BULOT, L., 1990. Preliminary ammonite zonation for the Lower Cretaceous of the Mediterranean region: report. *Géologie Alpine*, **66:** 123-127.

HOEDEMAEKER, P. J., COMPANY, M. (reporters), AGUIRRE-URRETA, M. B., AVRAM, E., BOGDANOVA, T. N., BUJTOR, L., BULOT, L., CECCA, F., DELANOY, G., ETTACHFINI, M., MEMMI, L., OWEN, H. G., RAWSON, P. F., SANDOVAL, J., TAVERA, J. M., THIEULOY, J.-P., TOVBINA, S. Z. & VASICEK, Z., 1993. Ammonite zonation for the Lower Cretaceous of the Mediterranean Region; basis for the stratigraphic correlations within IGCP-Project 262. *Revista Española de Paleontologia*, **8:** 117-120.

HOEDEMAEKER, Ph. J. & LEEREVELD, H., 1995. Biostratigraphy and sequence stratigraphy of the Berriasian-lowest Aptian (lower Cretaceous) of the Rio Argos succession, Caravaca, SE Spain. *Cretaceous Research*, **16:** 195-230.

KAKABADZE, M. V., 1981. The ancyloceratids of the south of the USSR and their stratigraphical significance. *Trudy Geologicheskovo Instituta Tbilisi*, **71:** 1-196 [in Russian, with English summary].

KAKABADZE, M. V. & KOTETISHVILI, E., 1995. New data on the Upper Barremian biostratigraphy of the Georgian region (Caucasus). *Memorie Descrittive della Carta Geologica d'Italia*, **51:** 103-108.

KILIAN, W., 1888. Description géologique de la Montagne de Lure (Basses-Alpes). *Annales des Sciences Géologiques*, **19-20:** 458 pp.

MUTTERLOSE, J., 1988. Migration and evolution patterns in Upper Jurassic and Lower Cretaceous belemnites. *In*: WIEDMANN, J. & KULLMANN, J. (eds), Cephalopods - Present and Past. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 525-537.

RAWSON, P. F., 1981. Early Cretaceous ammonite biostratigraphy and biogeography. *In:* HOUSE, M. R. & SENIOR, J. R. (Eds) *The Ammonoidea. Systematics Association Special Volume*, **18:** 499-529, Academic Press, London.

RAWSON, P. F., 1983. The Valanginian to Aptian stages - current definitions and outstanding problems. *Zitteliana*, **10:** 493-500.

RAWSON, P. F., 1994. Sea level changes and their influence on ammonite biogeography in the European Early Cretaceous. *Palaeopelagos, Special Publication 1* [Proceedings of the 3rd Pegola International Symposium ''Fossili, Evoluzione, Ambiente'']: 317-326.

RAWSON, P. F., 1995. The ''Boreal'' Early Cretaceous (Pre-Aptian) ammonite sequences of NW Europe and their correlation with the Western Mediterranean faunas. *Memorie Descrittive della Carta Geologica d'Italia*, **51**: 121-130.

ROGER, J., 1980. Barrémien. *Mémoires Bureau de Recherches Géologiques et Minières*,**109**: 106-111.

UHLIG, V., 1883. Die Cephalopodenfauna der Wernsdorferschichten. *Denckschriften der Oesterreichische Akademie der Wissenschaften, math.-naturwiss. Kl.*, **46:** 127-290.

VASICEK, Z., *in press*. Lower Cretaceous ammonite biostratigraphy in the Western Carpathians (Czechoslovakia). *Géologie Alpine*.

VASICEK, Z., MICHALIK, J. & BORZA, K., 1983. To the ''Neocomian'' biostratigraphy in the Krizna-Nappe of the Strazovske Vrchy Mountains (Northwestern Central Carpathians). *Zitteliana*, **10:** 467-483.

VASICEK, Z., MICHALIK, J. & REHAKOVA, D. 1994. Early Cretaceous stratigraphy, palaeogeography and life in Western Carpathians. *Beringeria*, **10:** 169 pp.

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The Aptian Stage

by Elisabetta ERBA,

with contributions by Roque Aguado, Emil Avram, Evgenii J. Baraboschkin, James A. Bergen, Timothy J. Bralower, Fabrizio Cecca, James E. T. Channell, Rodolfo Coccioni, Miguel Company, Gérard Delanoy, Jochen Erbacher, Timothy D. Herbert, Philip Hoedemaeker, Mikhail Kakabadze, Han Leereveld, Andrea Lini, Irina A. Mikhailova, Jörg Mutterlose, James G. Ogg, Isabella Premoli Silva, Peter F. Rawson, Katharina von Salis, Helmut Weissert.

Abstract

Detailed multidisciplinary analyses of several sections through the Barremian-Aptian interval resulted in the revision of the Aptian stage, including the Barremian-Aptian boundary. The Aptian Working Group (= AWG) established an integrated stratigraphy based on biostratigraphy (ammonites, belemnites, calcareous nannofossils, planktonic and benthic foraminifera, dinoflagellates, radiolarians), magnetostratigraphy, isotope stratigraphy ($\delta^{13}C$ and $^{86}Sr/^{87}Sr$), event stratigraphy, sequence stratigraphy, and cyclostratigraphy.

Historical precedence was considered and the preliminary proposals made at the Copenhagen Symposium in 1983 were considered as starting point. The new information highlighted the difficulty of using the first appearance of *Prodeshayesites* for the definition of the base of the Aptian, and revealed the importance of biostratigraphy based on other fossil groups, especially micro- and nannofossils, as well as physical and chemical tools such as magnetostratigraphy, chemostratigraphy, sequence stratigraphy and cyclostratigraphy in global correlations.

Following the discussions at and after the Second International Symposium on Cretaceous Stage Boundaries (Brussels, 8-16 September 1995), the majority of the AWG selected the base of magnetic chron MO as the event for the definition of the base of the Aptian stage. It must be emphasised that magnetostratigraphy must always be integrated with biostratigraphy and magnetic chron MO must be identified in relation to palaeontological events.

After accepting the base of magnetic chron MO as the base of the Aptian stage, the AWG identified the Gorgo a Cerbara section (Umbria-Marche Basin, Central Italy) as possible GSSP for the base of the Aptian Stage. This section represents an excellent exposure of Barremian to Aptian pelagic carbonates, and offers a wide range of available stratigraphies including magnetostratigraphy, calcareous nannofossil and planktonic foraminiferal biostratigraphy, radiolarian biostratigraphy, dinoflagellate biostratigraphy, chemostratigraphy ($\delta^{13}C$) and cyclostratigraphy. Moreover, the Oceanic Anoxic Event 1a is represented by the black shales of the Selli level. The record of ammonites is not continuous; however, a few diagnostic layers have been detected.

The Aptian substage subdivision was also discussed, but the AWG has not yet provided recommendations. While a two-fold subdivision is adopted for the Boreal Aptian, a three-fold subdivision is often applied to low-latitude sequences. The integrated stratigraphy elaborated by the AWG for the stage is still under revision and Aptian subdivisions will be the subject of further work.

Key-words:
Aptian, Lower Cretaceous, biostratigraphy, magnetostratigraphy, chemostratigraphy, cyclostratigraphy, anoxic events, GSSP, stratotypes.

Résumé

Des analyses détaillées et multidisciplinaires de plusieurs sections de l'intervalle Barrémien-Aptien ont permis la révision de l'étage Aptien et de la limite Barrémien-Aptien. Le Groupe de Travail Aptien (= AWG) a établi une stratigraphie intégrée, basée sur la biostratigraphie (ammonites, bélemnites, nannofossiles calcaires, foraminifères planctoniques et benthiques, dinoflagellés, radiolaires), la magnétostratigraphie, la stratigraphie isotopique ($\delta^{13}C$ et $^{86}Sr/^{87}Sr$), la stratigraphie événementielle, la stratigraphie séquentielle, et la cyclostratigraphie.

L'historique de la question a été pris en considération et les propositions préliminaires faites au Symposium de Copenhague en 1983 ont servi de point de départ. Des nouvelles données ont mis en lumière la difficulté que présente la première apparition de *Prodeshayesites* pour la définition de la base de l'Aptien, et démontrés l'importance de la biostratigraphie fondée sur d'autres groupes fossiles, particulièrement les micro- et nanno-fossiles, ainsi que des outils physiques et chimiques tels que la magnétostratigraphie, la chimiostratigraphie, la stratigraphie séquentielle et la cyclostratigraphie pour des corrélations globales.

Pendant et après les discussions du Second Symposium sur les Limites d'Etages du Crétacé (Bruxelles, 8 - 16 Septembre 1995), la majorité de l' AWG a sélecté la base du chron magnétique MO comme l'événement pour la définition de la base de l'Aptien. L'attention a été attirée sur le fait que la magnétostratigraphie devait être intégrée à la biostratigraphie et que le chron magnétique devait être défini en relation avec des événements paléontologiques.

Après avoir accepté le chron magnétique MO comme la base de l'étage Aptien, l'AWG a indiqué la coupe de Gorgo a Cerbara (le Bassin d'Ombrie-Marche, Italie centrale) comme GSSP possible pour la base de l'Aptien. Cette coupe représente un excellent affleurement de carbonates pélagiques d'âge Barrémien à Aptien, et permet de nombreuses aplications stratigraphiques, entre autres la magnétostratigraphie, la biostratigraphie des nannofossiles calcaires et des foraminifères planctoniques, des radiolaires, des dinoflagellés, la chimiostratigraphie ($\delta^{13}C$) et la cyclostratigraphie. En plus l''"Oceanic Anoxic Event 1a" est représenté par les "black shales" du niveau Selli. Les ammonites ne s'y retrouvent pas de façon continue, mais certains niveaux diagnostiques ont été découverts.

La division de l'Aptien en sous-étages a aussi été discutée, mais l'AWG n'a pas encore fait de recommandations. L'Aptien boréal est en général divisé en deux, mais l'Aptien des basses latitudes est souvent divisé en trois. La stratigraphie intégrée élaborée par l'AWG est encore en révision et les subdivisions aptiennes feront l'objet de travaux ultérieurs.

Mots-clefs:
Aptien, Crétacé inférieur, biostratigraphie, magnétostratigraphie, chimiostratigraphie, cyclostratigraphie, événements anoxiques, GSSP, stratotypes.

Аптский ярус.

Резюме.
Благодаря подробному и многопредметному изучению ряда разрезов Барремско-Аптского интервала ученым удалось пересмотреть понятия Аптского яруса и Барремско-Аптской границы. Рабочая группа Аптского яруса установила, что интегрированная стратиграфия базируется на биостратиграфии, включающей аммониты, белемниты,

известковые нанофоссилии, планктонические и бентические фораминиферы, динофлагеллаты и радиолярии, а также на магнитостратиграфии, циклостратиграфии, изотопической ($\delta^{13}C$ и $^{86}Sr/^{87}Sr$) событийной и секвентной стратиграфиях.
Предыстория данного вопроса была принята во внимание, а предварительные предложения, прозвучавшие на копенгагском Симпозиуме 1983 года, послужили точкой отсчёта. Новые данные подробно осветили то препятствие, которое представляет собой первое появление *Prodeshayesites* для определения основания Аптского яруса и продемонстрировали важную роль биостратиграфии, основанной на изучении других групп ископаемых, в частности, микро- и нанофоссилий, а также физических и химических технологий, таких как магнитостратиграфия, хемостратиграфия, циклостратиграфия и секвентная стратиграфия, в глобальных корреляциях.
Обсуждения, проведённые в течение и после Второго Симпозиума, посвящённого Границам Меловых Ярусов (Брюссель, 8-16 сентября 1995), позволили большинству участников Рабочей Группы Аптского Яруса определить основание магнитного хрона (M0) как главного элемента для определения основания Аптского яруса. Учёные обратили особое внимание на тот факт, что магнитостратиграфия должна всегда составлять единое целое с биостратиграфией, и что магнитный хрон должен быть определён неразрывно от палеонтологических событий.
Приняв магнитный хрон M0 за основание Аптского яруса, Рабочая Группа Аптского Яруса указала разрез Gorgo a Cerbara (бассейн Umbria-Marche, Центральная Италия) как вероятный GSSP для основания Аптского яруса. Этот разрез является идеальным примером отложений пелагических карбонатов от барремского до аптского возрастов и отличным объектом для применения многочисленных существующих стратиграфий, включающих магнитостратиграфию, биостратиграфию известковых нанофоссилий и планктонических фораминифер, биостратиграфию радиолярий и динофлягеллатов, хемостратиграфию (δ^{13} C) и циклостратиграфию. Кроме того, «Oceanic Anoxic Event 1a» представлен «black shales» уровня Selli, где аммониты присутствуют неравномерно. Тем не менее, было раскрыто несколько диагностиеских слоёв.
Разделение Аптского яруса на подъярусы также стало объектом дискуссий, но Рабочая Группа Аптского Яруса не вынесла каких-либо рекомендаций. Бореальный Апт обычно делится на 2 части, в то время как Апт «lower latitudes» часто делится на 3 части. Интегрированная стратиграфия, разработанная Рабочей Группой Аптского Яруса, находится в процессе ревизии, а подъярусы Апта будут подробнее рассмотрены в последующих работах.

Ключевые слова: Аптский ярус, нижний мел, биостратиграфия, магнитостратиграфия, хемостратиграфия, циклостратиграфия, безкислородные события, GSSP, стратотипы.

Introduction

Revision of the Aptian stage, including the Barremian/Aptian (B/A) boundary interval, has been carried out by the Aptian Working Group in the past three years. The aims of the Aptian Working Group are to nominate an internationally acceptable boundary for the base of the stage and substage boundaries where appropriate, and propose candidate stratotype sections.

The recommended boundary must be recognisable over as wide an area as possible and ideally in both Tethyan and Boreal Realms. The selection of the boundary is determined by good correlation based on all available tools including (quantitative) biostratigraphy, magnetostratigraphy, isotope stratigraphy, event stratigraphy, sequence stratigraphy, and cyclostratigraphy. The strati-

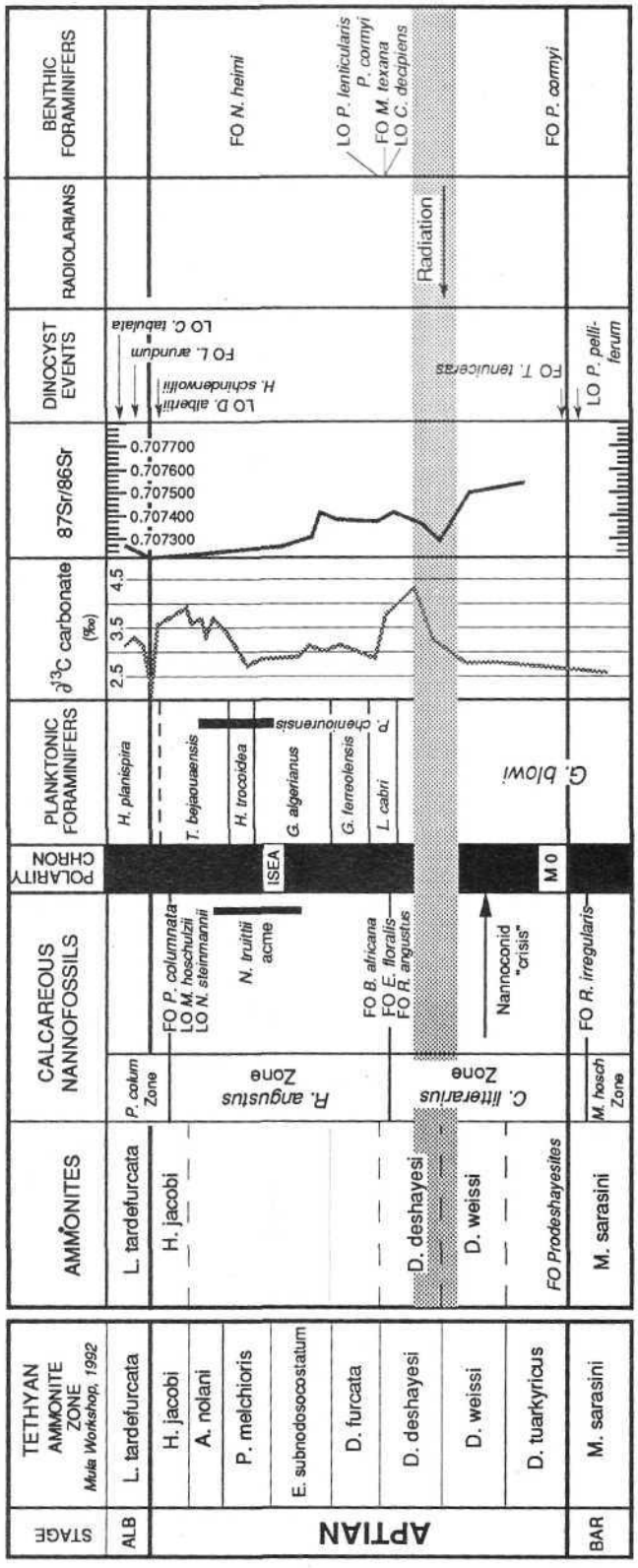

Fig. 1 — Integrated stratigraphy of the Aptian for the Tethyan area and low latitudes.

Table 1 – Sections studied and/or revised for the discussion of the Barremian/Aptian boundary

Area	Section	Studied Interval	Type of Investigation	Reference
SE France	Angles (Route d'Angles)	Barremian/Aptian boundary	Ammonites, Calcareous nannofossils, Dinoflagellates	Delanoy, 1991, 1995 Erba, in prep. Thierstein, 1973 Leereveld, 1995
SE France	Le Combe Lambert	Lower Aptian	Ammonites	Delanoy, 1995
SE France	Méouilles	Lower Aptian	Ammonites	Delanoy, 1995
SE France	La Colle gully	Lower Aptian	Ammonites	Delanoy, 1995
SE France	Vignon's gully	Lower Aptian	Ammonites	Delanoy, 1995
England	Speeton	Barremian-Aptian	Ammonites	Rawson, pers. com. 95
S Spain	Campillo de Arenas	Barremian-Aptian	Ammonites, Calcareous nannofossils, Planktonic foraminifers, Radiolarians	Aguado et al., 1992 Aguado et al., 1995
S Spain	Huéscar	Barremian-Aptian	Ammonites, Calcareous nannofossils	Aguado et al., 1995
S Spain	Barranco de Cabila	Barremian-Aptian	Ammonites, Calcareous nannofossils	Aguado et al., 1995
S Spain	Caprés	Barremian-Aptian	Ammonites, Calcareous nannofossils	Aguado et al., 1995
S Spain	Foncalet	Barremian-Aptian	Ammonites, Calcareous nannofossils	Aguado et al., 1995
S Spain	Busot	Barremian-Aptian	Ammonites, Calcareous nannofossils	Aguado et al., 1995
S Spain	Sierra del Corque	Barremian-Aptian	Ammonites, Sequence stratigraphy	Company et al., 1992
S Spain	Rio Argos	Barremian-Aptian	Ammonites, Dinoflagellates, Calcareous nannofossils, Planktonic foraminifers, Sequence stratigraphy	Hoedemaeker & Leereveld, 1995 Coccioni & Premoli Silva, 1994
Central Italy	Gorgo a Cerbara	Upper Hauterivian-Aptian	Ammonites, Planktonic foraminifers, Calcareous nannofossils, Magnetostratigraphy, Cyclostratigraphy, Radiolarians, $\delta^{13}C$, $\delta^{18}O$	Lowrie & Alvarez, 1984 Coccioni et al., 1992 Bralower, 1987 Herbert, 1992 Cecca et al., 1994 Erba, 1994 Erbacher, 1995
Central Italy	S.S. Apecchiese	Upper Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers	Erba et al., 1989
Central Italy	Piobbico core	Aptian-Albian	Calcareous nannofossils, Planktonic foraminifers, Trace fossils, Cyclostratigraphy	Erba, 1988, 1992, 1994 Tornaghi et al., 1989 Herbert & Fischer, 1986 Fischer et al., 1991 Erba & Premoli Silva, 1994 Herbert et al., 1995
N Italy	Polaveno	Berriasian-Barremian	Calcareous nannofossils, Planktonic foraminifers, Magnetostratigraphy, Radiolarians	Erba & Quadrio, 1987 Channell & Erba, 1992 Jud, 1995 Channell et al., 1995
N Italy	Pié del Dosso	Upper Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, Magnetostratigraphy	Erba & Quadrio, 1987 Channell & Erba, 1992 Erba, 1994
N Italy	Capriolo	Berrasian-Aptian	Calcareous nannofossils, Planktonic foraminifers, Magnetostratigraphy, Carbon isotope stratigr., Radiolarians	Channell et al., 1987, 1993 Channell & Erba, 1992 Weissert & Lini, 1991 Lini et al., 1992 Jud, 1995

Continuation of Table 1

N Italy	Cismon	Hauterivian-Aptian	Calcareous nannofossils, Planktonic foraminifers, Magnetostratigraphy, Carbon isotope stratigr., Cyclostratigraphy	Channell et al., 1979 Weissert et al., 1985 Bralower, 1987 Weissert, 1989 Erba, 1994 Herbert, 1992
N Italy	Alpetto-Laghetto	Upper Barremian-Aptian	Ammonites, Calcareous nannofossils, Magnetostratigraphy, Sequence stratigraphy	Cecca & Landra, 1994 Channell et al., 1995 Bersezio, 1994
Georgia	Tvishi	Upper Barremian	Ammonites	Kakabadze & Kotetishvili, 1995
Carpathians	Medziholie	Lower Aptian	Ammonites	Vasicek & Rakùs, 1995
Transcapian	Tuarkyr Anticline	Barremian/Aptian boundary	Ammonites	Bogdanova & Lobacheva, 1995
Pacific Ocean	DSDP 463	Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, Magnetostratigraphy, T.O.C.	Tarduno et al., 1989 Sliter, 1992 Erba, 1994 Bralower et al., 1993
Pacific Ocean	DSDP 167	U. Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, Magnetostratigraphy, T.O.C.	Tarduno et al., 1989 Sliter, 1992 Bralower et al., 1993
Pacific Ocean	DSDP 317	Aptian-Albian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Pacific Ocean	DSDP 305	Aptian-Albian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993 Sliter, 1992
Pacific Ocean	DSDP 306	Aptian-Albian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993 Sliter, 1992
Atlantic Ocean	DSDP 364	Lower Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Atlantic Ocean	DSDP 370	Aptian-Albian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Atlantic Ocean	DSDP 398	U. Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Atlantic Ocean	DSDP 402	Aptian-Albian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Atlantic Ocean	DSDP 417	Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Atlantic Ocean	DSDP 511	U. Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993
Atlantic Ocean	DSDP 534	Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993 Ogg, 1987 Roth, 1978
Atlantic Ocean	ODP 641	U. Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993 Applegate & Bergen, 1988 Ogg, 1988
Indian Ocean	ODP 763	U. Barremian-Aptian	Calcareous nannofossils, Planktonic foraminifers, T.O.C.	Bralower et al., 1993

graphic level of the recommended boundary should conform as closely as feasible with current practice and the proposed boundary stratotype section depends primarily on the chosen boundary.

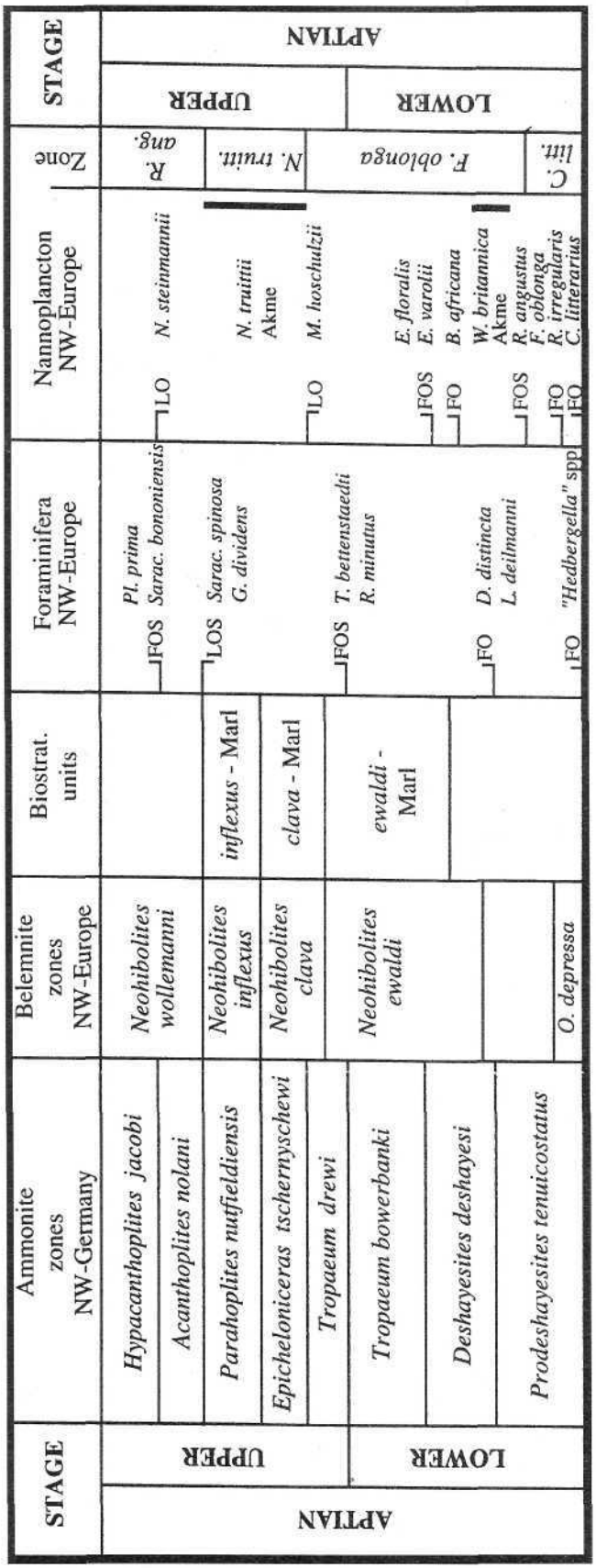

Fig. 2 — Integrated stratigraphy of the Aptian for Boreal realm and high latitudes (Mutterlose, pers. comm., 1995).

Although historical precedence was considered it has not over-ridden the importance of choosing a widely correlatable boundary. As recommended by the Subcommission on Cretaceous Stratigraphy, the preliminary proposals made at the Subcommission's 1983 Copenhagen conference (BIRKELUND *et al.*, 1984) were considered as starting point. At the Copenhagen conference, the discussion of the Aptian stage was focussed on the ammonite sequence, whereas other (micro)fossil groups as well as other stratigraphic tools were disregarded. In the past decade, detailed multidisciplinary analyses have been carried out on several sections through the Barremian-Aptian interval (Table 1). Studies were conducted also within the framework of the IGCP 262 - Tethyan Cretaceous Correlations, Pelagic Working Group and IGCP 362-Tethyan Boreal Cretaceous. The new information highlighted the difficulty of using ammonite sequences, and revealed the importance of biostratigraphy based on various fossil groups, especially micro- and nannofossils, magnetostratigraphy, chemostratigraphy, sequence stratigraphy and cyclostratigraphy in global correlations.

The Aptian Working group elaborated an integrated stratigraphy for the stage (Figures 1 and 2) that is the base for recommendations on the boundary level.

Definition of the Aptian stage

The Aptian stage was originally defined by d'ORBIGNY (1840) and Apt (Vaucluse) in southeast France was indicated as type area. La Bedoule, Gargas (near Apt) and Clansayes are all reference sections for subdivisions of the Aptian though not all satisfactory for correlation purposes (see RAWSON, 1983).

At the Copenhagen conference, it was recommended (1) to place the base of the Aptian at the first appearance of *Prodeshayesites* and (2) to consider sections in southeast France, Turkmenia, England and north Germany for selection of the boundary stratotype. The discussion of regional correlation pointed out that there was less faunal differentiation across Europe during the Aptian than during earlier periods, though the proportion of Tethyan genera increases southwards. The French ammonite sequence was inadequately documented (see MOULLADE *et al.*, 1980), but "*Prodeshayesites*" / *Deshayesites* occurs there with more typically Tethyan genera and thus provides a link between Boreal and Tethyan faunas. *Deshayesites* may be widespread geographically, but there has been dispute as to whether the Venezuelan faunas, for example, really belong to this genus.

The base of the Aptian

The IUGS Subcommission on Cretaceous Stratigraphy

(BIRKELUND *et al.*, 1984) recommended to place the Barremian/Aptian boundary at the chronostratigraphic level coinciding with the appearance of the subgenus *Deshayesites (Prodeshayesites)*. No alternative boundaries have been proposed since then. Most ammonite palaeontologists of the Aptian working group prefer to maintain the Barremian/Aptian boundary at the first occurrence of *Prodeshayesites*, and potential stratotype sections have been studied in various areas. In addition, DSDP (Deep Sea Drilling Project) and ODP (Ocean Drilling Program) sites drilled in the Pacific, Atlantic and Indian oceans have been investigated (Table 1). These studies revealed that virtually no ammonite-dated sections represent a continuous and complete Barremian/Aptian boundary. Thus the working group considered the possibility of placing the base of the Aptian (= the Barremian/Aptian boundary) at other events.

Due to absence or uneven distribution of ammonite faunas in several Aptian sequences from continents or ocean drilling sites, chronostratigraphy is routinely derived from calcareous nannofossil and planktonic foraminiferal biostratigraphy. Calcareous plankton (nannofossils and planktonic foraminifers) were exhaustively studied in several sections, but no events were detected at the Barremian/Aptian boundary as defined by ammonites. A few dinoflagellate cyst events occur close to this boundary, but they are restricted to the Tethyan area.

Stable isotopes are now currently used in stratigraphy and constitute a powerful tool for correlations across different basins. In particular, the $\delta^{13}C$ curve established for the Barremian-Aptian interval is reproducible in pelagic and shallow-water sequences across various basins and can be used for global correlations. The strontium isotopic curve also shows significant fluctuations and constitutes a reliable correlation tool.

For several sections, magnetostratigraphy combined with biostratigraphy provides a high resolution stratigraphy. The youngest reversal of the Lower Cretaceous to Upper Jurassic M-sequence, namely magnetic chron M0, represents a potential chronozone which is detectable at all latitudes and in various settings, both in marine and terrestrial sequences.
We report below a synthesis of the discussion of the various events.

	CECCA, 1993 pers.comm.			*Rawson, 1983*		
STAGE	TETHYAN *Mula Workshop, 1992*	South-East France *Lyon Colloquium, 1963*	STAGE	Southern England *Rawson, 1983* *Hancock, 1991*	Northern Germany *Rawson, 1983*	STAGE
upper = *Clansayesian*	H. jacobi	D. nodoso-costatum	upper	H. jacobi	H. jacobi	upper
	A. nolani				A. nolani	
middle = *Gargasian*	P. melchioris	C. subnodoso-costatum		P. nutfieldiensis	P. nutfieldiensis	
	E. subnodosocostatum	A. nisus	APTIAN	C. martinoides	E. tschernyschewi	APTIAN
APTIAN					T. drewi	
	D. furcata	D. deshayesi		T. bowerbanki	T. bowerbanki	
	D. deshayesi		lower	D. deshayesi	D. deshayesi	lower
lower = *Bedoulian*	D. weissi			D. forbesi		
	D. tuarkyricus			P. fissicostatus	P. tenuicostatus	
BAR	M. sarasini	S. seranonis	BAR	P. bidentatum	P. bidentatum	BAR

CORRELATION OF TETHYAN AND BOREAL AMMONITE ZONATIONS
(Ammonite zones not in scale)

Fig. 3 — Correlations of Aptian ammonite zonations.

Ammonites

If the first appearance of *Prodeshayesites* is taken to mark the base of the Aptian, as recommended at Copenhagen, problems arise. The type species of *Prodeshayesites*, *P. fissicostatum*, is from Speeton in England. The genus is common in the basal Aptian of eastern England and North Germany, and appears to have spread southward from this region to southern England as transgression spread into the Anglo-Paris Basin, where it gave rise to *Deshayesites*. Thus, using this criterion, a type section should be defined in the North Sea- North German area (Rawson, pers. comm., 1995).

The type section of the Speeton Clay at Speeton (England) shows an ammonite sequence across the Barremian/Aptian boundary which is under study (Rawson, pers. comm. 1995). Heteroceratid ammonites occur with *Aconeceras* just below the lowest record of *Prodeshayesites*. The exposure at Speeton is in the foreshore and often covered. However, if an artificial excavation were to be dug inland, where *Prodeshayesites* is documented from a borehole, a more permanent exposure could be made.

The rare "*Prodeshayesites*" so far recorded from SE France and other Tethyan areas belong to late *Deshayesites* and true *Prodeshayesites* have yet to be documented in those regions. Thus, if the first Tethyan "*Prodeshayesites*" is taken to mark the base of the Aptian, this boundary will be at a higher level than understood in the Anglo-Paris, North Sea and German basins.

In SE France, the base of the Aptian has been taken at the base of the *deshayesi* Zone. The Barremian/Aptian boundary interval of the Angles-Barrême area has been thoroughly investigated for ammonite distribution (Delanoy, 1995). Several specimens have been collected, but significant ammonites have not been found in the lowermost Aptian. Busnardo (1965) placed the base of the Aptian at the base of bed 197 of the Route d'Angles section because he found the first *Pseudohaploceras matheroni* in that bed. This species is now known to appear in the latest Barremian. Its level at Angles is marked by a "non-characterised zone" with few ammonites. Nevertheless, this boundary, which is a transgressive surface, is not in conflict with later discoveries. The first deshayesitids appear only 2 metres above, where "*Prodeshayesites*" is recorded in bed 200 (Delanoy, 1991).

Several sections spanning the Barremian/Aptian boundary have been investigated in Southern Spain, but significant ammonites are extremely rare, especially *Deshayesites* (Aguado *et al.*, 1995). The scanty ammonite record does not allow the recognition of the base of the Aptian.

In the Rio Argos sections (Caravaca, Murcia, Spain) the first Aptian ammonites (*Prochelonicera*s and *Deshayesites*) occur just above a global transgressive surface, whereas *Colchidites* disappears just below it. It is possible that a hiatus marks the Barremian/Aptian boundary at Rio Argos (Hoedemaeker & Leereveld, 1995).

The Cephalopod Working Group of IGCP Project 262 adopted the Georgian Aptian ammonite sequence as a "standard" for the Mediterranean Region because a detailed zonation of the French succession was still not available (Hoedemaeker & Bulot, 1990). Pelagic sections in Georgia (Kakabadze & Kotetishvili, 1995) provide a virtually complete sequence of ammonites across the Barremian/Aptian boundary. Here the base of the Aptian is taken to be the base of the *D. tuarkyricus* Zone; *Prodeshayesites* is not recorded. However, palaeontological data are still insufficient to resolve the Barremian/Aptian boundary in Georgia or correlate with other regions.

Bogdanova & Lobacheva (1995) studied Barremian-Aptian sections in the Transcaspian area, where the base of the Aptian is characterized by rare and non-significant ammonites.

Calcareous Nannofossils

None of the nannofossil events proposed by Thierstein (1973) to place the Barremian/Aptian boundary at low latitudes was proved reliable. In fact, the FO of *Chiastozygus litterarius* is a Barremian event, the FO of *Rucinolithus irregularis* is dated as latest Barremian and *Nannoconus colomii* disappears in the late Aptian. At low latitudes, the FO of *Rucinolithus irregularis* is the most reliable nannofossil event, and the closest to the Barremian/Aptian boundary (Channell & Erba, 1992; Coccioni *et al.*, 1992; Erba, 1994; Channell *et al.*, 1995; Aguado *et al.*, 1995). It occurs in the upper part of the *M. sarasini* ammonite Zone and precedes magnetic polarity zone CM0. The FO of *Flabellites oblongus* is older than the FO of *R. irregularis* and correlates with the lower part of the *M. sarasini* ammonite zone (Aguado *et al.*, 1995).

In the Boreal Realm, the FO of *C. litterarius* is used to place the base of the Aptian (Mutterlose, 1991), but direct correlations with ammonites are not available. The FOs of *R. irregularis* and *F. oblongus* are younger than the FO of *C. litterarius* (Figure 2).

Recently, a distinctive nannofossil event has been documented on a global scale in the Early Aptian (Erba, 1994). Nannofossil assemblages are marked by a "nannoconid crisis" that occurred some 0.28 Ma after the end of magnetic Chron CM0. This "nannoconid crisis" precedes the black shales of the Oceanic Anoxic subEvent 1a of late early Aptian age (Figure 1).

Planktonic Foraminifers

The FO of *Globigerinelloides blowi* was detected in the Upper Barremian, within the Giraudi Zone and magnetic Chron CM1n and, therefore, predates the Barremian/Aptian boundary (Cecca *et al.*, 1994; Coccioni & Premoli Silva, 1994).

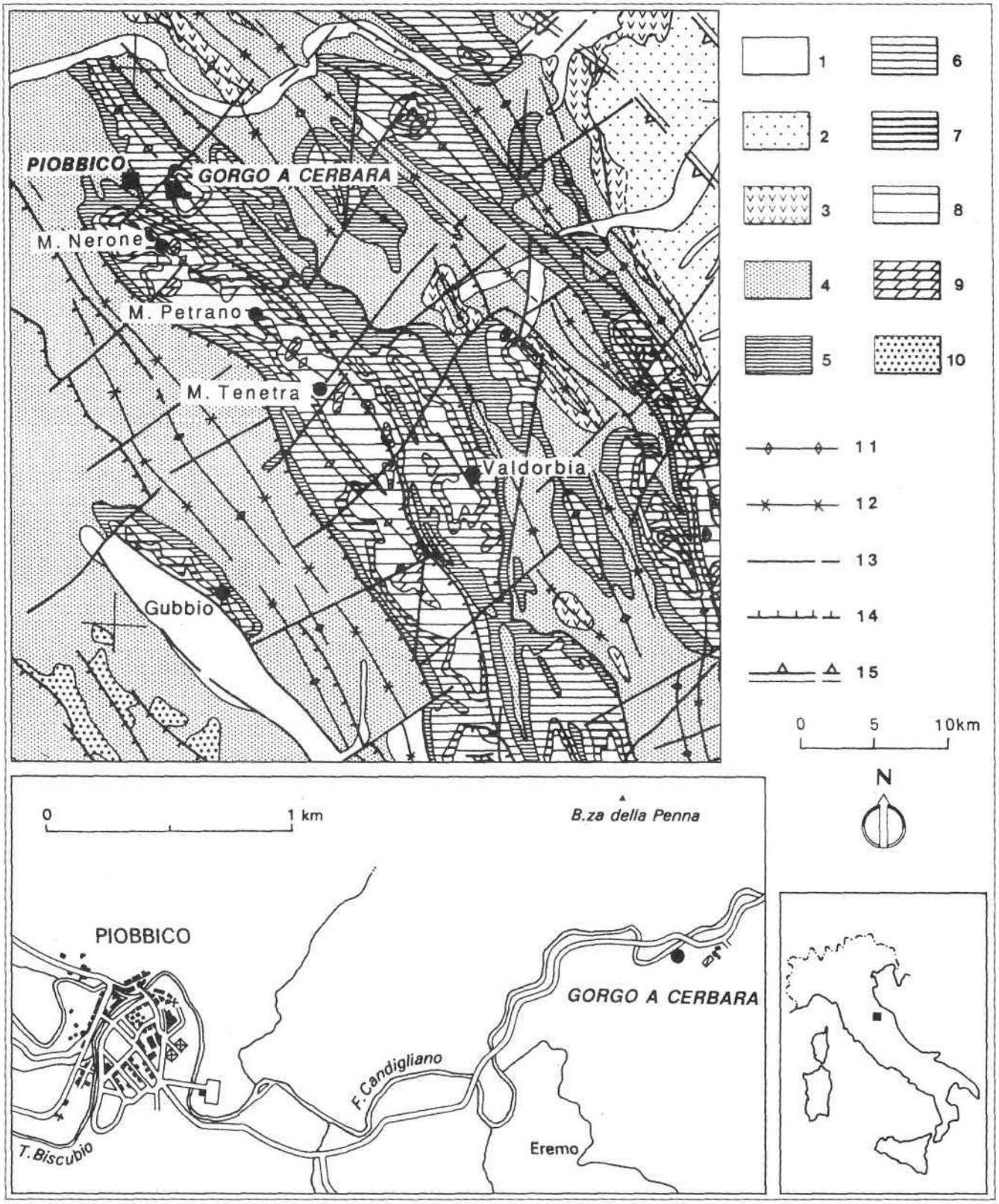

Fig. 4 — Geological map and location of the Gorgo a Cerbara section in the central Apennines (central Italy) (after ERBA, 1988). 1) Quaternary-Pliocene continental facies; 2) Quaternary-Pliocene marine terrigenous facies; 3) Messinian evaporitic facies; 4) Miocene marine terrigenous facies; 5) Oligocene-Paleocene pelagic facies; 6) Upper Cretaceous pelagic facies; 7) mid-Cretaceous pelagic facies (= Scisti a Fucoidi Formation); 8) Lower Cretaceous-Lower Jurassic pp. pelagic facies; 9) Lower Jurassic pp. -Upper Triassic carbonate platform facies; 10) alloctonous units; 11) anticline; 12) syncline; 13) fault; 14) thrust; 15) buried inverse fault.

Dinoflagellate Cysts

Dinoflagellate cyst events have been derived from ammonite calibrated sections from both Tethyan and Boreal areas (Leereveld, 1995). In general, there is a tendency to more extended ranges in the Boreal Realm. In the Tethyan area, the LO of *P. pelliferum* is slightly before the Barremian/Aptian boundary and the FO of *T. tenuiceras* shortly postdates the boundary. In the Boreal Realm, no dinoflagellate cyst events were observed at or close to the base of the Aptian.

Magnetostratigraphy

Direct calibration of magnetic polarity zones with ammonite biozones in the Barremian/Aptian boundary interval are not available yet. A single specimen of "*Prodeshayesites*" was found in the upper part of magnetic chron M0 at the Gorgo a Cerbara section (Channell *et al.*, 1995) (Figure 4).

The FO of the nannofossil species *Rucinolithus irregularis* correlates with the upper part of the uppermost Barremian *M. sarasini* ammonite Zone and precedes magnetic polarity zone CM0. Magnetic chron M0 has been identified in several low-latitude sections from the Tethys, Atlantic, Pacific and Indian oceans as well as in the Boreal Realm in the Isle of Wight (Keith & Hailwood, 1988). Moreover, it is recognisable in pelagic/hemipelagic and neritic facies and in terrestrial sequences as well.

Chemostratigraphy

Stable carbon isotope stratigraphy of the Barremian-Aptian has been established in several sections with calcareous plankton biostratigraphy and magnetostratigraphy. A major positive excursion correlates with the Oceanic Anoxic Event 1a (Lower Aptian) and a second excursion marks the upper Aptian (Weissert & Lini, 1991; Weissert & Lini, pers. com. 1994) (Figure 1).

The Strontium isotope curve ($^{86}Sr/^{87}Sr$) is still to be improved for the Barremian-Aptian. However, distinctive variations have been detected in the Aptian (Jones *et al.*, 1994) (Figure 1).

Correlations

For Early Cretaceous chronostratigraphy, time scales of the past decade (Harland *et al.*, 1982; Kent & Gradstein, 1985; Harland *et al.*, 1990; Gradstein *et al.*, 1994; Channell *et al.*, 1995 b) used magnetostratigraphy integrated with calcareous plankton biostratigraphy. Ammonite control of magnetic chron is available only for a few polarity chrons. In recent time scales, the base of the Aptian is placed at the base of magnetic chron M0.

Recommendations

At the Brussels Symposium (September, 1995), the majority of the Aptian Working Group recommended to equate the Barremian/Aptian boundary, and therefore the base of the Aptian, with the base of magnetic chron M0. It must be emphasised that magnetostratigraphy must be always integrated with biostratigraphy (Figure 1) and magnetic chron M0 must be identified in relation to the FO of *Prodeshayesites*, and/or FO of *Rucinolithus irregularis* and or FO of *Flabellites oblongus* and/or the "nannoconid crisis", and/or the FO of *Globigerinelloides blowi*. Black shales of the OAE 1a, the $\delta^{13}C$ and the strontium curves can also provide litho- and chemostratigraphic calibrations of magnetic chron M0.

We report here that most ammonite palaeontologists of the Aptian Working Group prefer to maintain the Barremian/Aptian boundary at the first occurrence of *Prodeshayesites* or "*Prodeshayesites*", but virtually no ammonite-dated sections represent a continuous and complete Barremian/Aptian boundary.

Proposed boundary stratotype section

Accepting the base of magnetic chron M0 as base of the Aptian stage, then the Gorgo a Cerbara section (Umbria-Marche Basin, central Italy) (Figures 4 and 5), with an excellent exposure of Barremian to Aptian pelagic carbonates, is proposed as the boundary stratotype section. The section has magnetostratigraphy (Lowrie & Alvarez, 1984; Channell, in prep.), calcareous nannofossil (Bralower, 1987; Coccioni *et al.*, 1992; Erba, 1994) and planktonic foraminiferal biostratigraphy (Coccioni *et al.*, 1992), radiolarian biostratigraphy (Erbacher, 1994), dinoflagellate biostratigraphy (Coccioni *et al.*, 1993), and chemostratigraphy ($\delta^{13}C$) (Hadji, 1991; Erbacher, 1994). The Upper Barremian-Lower Aptian portion of the Gorgo a Cerbara section is shown in Figure 5.

The record of ammonites is not continuous; however, a few diagnostic layers have been detected. In particular, a specimen of "*Prodeshayesites*" was found at 894.70 m and indicates that magnetic chron M0 correlates with the *D. tuarkyricus* Zone (Channell *et al.*, 1995).

Magnetostratigraphy was originally provided by Lowrie & Alvarez (1984), but the section was sampled in great detail across magnetic chron M0 to increase the stratigraphic resolution of the boundaries (Channell, pers. comm., 1994). Samples up to 893.00 m show normal polarity and indicate magnetic chron M1n. Magnetisation of samples 893.10 and 893.20 is very weak and therefore this short interval is indeterminate. The first reversed sample is at 893.32 m, where we place the base of magnetic chron M0 and, consequently the base of the Aptian.

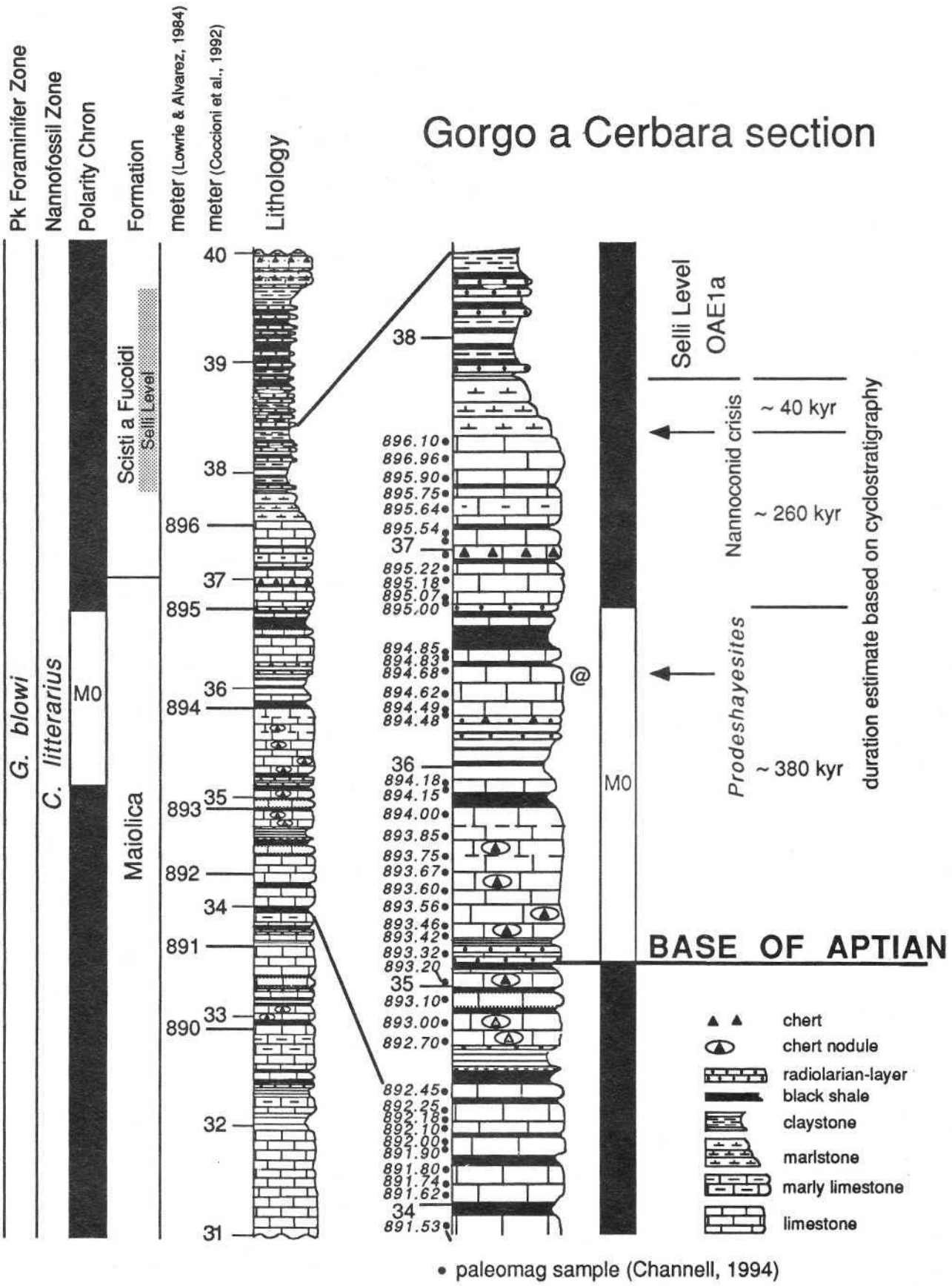

Fig. 5 — Stratigraphy of the Upper Barremian-Lower Aptian interval of the Gorgo a Cerbara section. Calcareous plankton biostratigraphy after COCCIONI *et al.* (1992) and ERBA (1994); magnetostratigraphy after CHANNELL (in prep.); cyclostratigraphy after HERBERT (1992).

Cyclostratigraphy was completed across the Barremian/Aptian boundary and provides a resolution of 10k years (HERBERT, 1992). Based on Milankovitch-type cycles, the duration of magnetic chron M0 is 380 kyrs (Figure 5).

Aptian substage boundaries

Recent revisions of Cretaceous ammonite zonations (HANCOCK, 1991; HOEDEMAEKER, *et al.*, 1993; RAWSON, 1993) point out that two different ammonite zonations are used for the Boreal and the Tethyan Realms (Figure 3). While a two-fold subdivision (Lower and Upper) is adopted for the Boreal Aptian, a three-fold subdivision (Lower, Middle, Upper) is often proposed for the Tethyan Aptian following the French division into Bedoulian, Gargasian and Clansayesian. RAWSON (1983) discussed at length the Aptian substage subdivisions. The matter was also discussed during the Lower Cretaceous Cephalopod Meeting held in Piobbico (Italy) in 1994, but no final decision was taken.

Stratigraphers using calcareous plankton biostratigraphy, usually subdivide the Aptian into Lower and Upper. This substage boundary is equated to the base of the *L. cabri* foraminiferal Zone and the base of the *R. angustus* (=FO *E. floralis*) nannofossil Zone.
The Aptian Working Group established direct correlations between calcareous plankton stratigraphy, benthic foraminifers, dinocysts, radiolarians, magnetostratigraphy, chemostratigraphy ($\delta^{13}C$ and Strontium) (Figures 1 and 2), but no substage subdivision(s) were proposed. This will be the subject of further work.

References

AGUADO, R., COMPANY, M., O'DOGHERTY, L., SANDOVAL, J. & TAVERA, J. M., 1992. Biostratigraphic analysis of the pelagic Barremian/Aptian in the Betic Cordillera (southern Spain): preliminary data. *Cretaceous Research* **13**, 445-452.

AGUADO, R., COMPANY, M., SANDOVAL, J. & TAVERA, J. M., 1995. Biostratigraphic events around the Barremian-Aptian boundary in the Betic Cordillera (Southern Spain). *Second International Symposium on Cretaceous Stage Boundaries, Abstract Volume*, p. 6.

APPLEGATE, J. L. & BERGEN, J. A., 1988. Cretaceous calcareous nannofossil biostratigraphy of sediments recovered from the Galicia Margin, ODP Leg 103. In *Proceedings of Ocean Drilling Program, Scientific Results* (eds. BOILLOT, G., WINTERER, E. L., *et al.*) **103**, 293-348 (College Station, TX Ocean Drilling Program).

BERSEZIO, R., 1994. Stratigraphic framework and sedimentary features of the Lower Aptian ''Livello Selli'' in the Lombardian basin (Southern Alps, Northern Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, **99**, 569-589.

BIRKELUND, T., HANCOCK, J. M., HART, M. B., RAWSON, P. F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F., 1984. Cretaceous stage boundaries-proposals. *Bulletin of the Geological Society of Denmark* **33**, 3-20.

BOGDANOVA, T. N. & LOBACHEVA, S. V., 1995. The Barremian/Aptian boundary in the Transcaspian area (ammonites, bivalves, brachiopods, echinoids). *Second International Symposium on Cretaceous Stage Boundaries, Abstract Volume*, p. 24.

BRALOWER, T. J., 1987. Valanginian to Aptian Calcareous Nannofossil Stratigraphy and correlation with the upper M-Sequence magnetic anomalies. *Marine Micropaleontology* **11**, 293-310.

BRALOWER, T. J., SLITER, W. V., ARTHUR, M. A., LECKIE, R. M., ALLARD D. & SCHLANGER, S. O., 1993. Dysoxic/anoxic episodes in the Aptian-Albian (Early Cretaceous). In *The Mesozoic Pacific: Geology, Tectonics, and Volcanism, Geophys. Monogr. Ser.*, vol. 77, edited by M. Pringle, W. W. Sager, W. V. Sliter, and S. Stein, pp. 5-37, AGU, Washington, D. C., 1993.

BUSNARDO, R. 1965. Le stratotype du Barrémien. Lithologie et macrofaune. *Mémoires du Bureau de Recherches Géologiques et Minières*, **34**, 101-116.

CECCA, F.,& LANDRA, G., 1994. Late Barremian-Early Aptian ammonites from the Maiolica Formation near Cesana Brianza (Lombardy Basin, Northern Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, **99**, 395-422.

CECCA, F., PALLINI, G., ERBA, E., PREMOLI SILVA, I. & COCCIONI, R., 1994. Hauterivian-Barremian chronostratigraphy based on ammonites, nannofossils, planktonic foraminifera, and magnetic chrons from Mediterranean Domain. *Cretaceous Research*, **15**, 457-467.

CHANNELL, J. E. T. & ERBA, E. 1992. Early Cretaceous polarity chrons CM0 to CM11 recorded in Northern Italian land sections near Brescia (Northern Italy). *Earth and Planetary Science Letters* **108**, 161-179.

CHANNELL, J. E. T., BRALOWER, T. J.. & GRANDESSO, P., 1987. Biostratigraphic correlation of Mesozoic polarity chrons CM1 to CM23 at Capriolo and Xausa (Southern Alps, Italy). *Earth and Planetary Science Letters* **85**, 203-221.

CHANNELL, J. E. T, CECCA, F. & ERBA, E., 1995. Correlations of Hauterivian and Barremian (Early Cretaceous) stage boundaries to polarity chrons. *Earth and Planetary Science Letters* **134**, 125-140.

CHANNELL, J. E. T., LOWRIE, W. & MEDIZZA, F. 1979. Middle and Early Cretaceous magnetic stratigraphy from the Cismon section, Northern Italy. *Earth and Planetary Science Letters* **42**, 153-166.

CHANNELL, J. E. T., ERBA, E., NAKANISHI, M. & TAMAKI, K., 1995 b. Late Jurassic -Early Cretaceous timescales and oceanic magnetic anomaly block models. *SEPM Special Publications*, **54**, 51-63.

COCCIONI, R., ERBA, E., & PREMOLI SILVA, I. 1992. Barremian-Aptian calcareous plankton biostratigraphy from the Gorgo Cerbara section (Marche, central Italy) and implications for plankton evolution. *Cretaceous Research*, **13**, 517-537.

COCCIONI, R., GALEOTTI, S. & SANTARELLI, A., 1993. Preliminary palynological analysis of the Maiolica-Scisti a Fucoidi transition (Barremian-Aptian) in the Gorgo a Cerbara section (central Italy). *Paleopelagos*, **3**, 199-205.

COCCIONI, R. & PREMOLI SILVA, I., 1994. Planktonic foraminifera from the Lower Cretaceous of the Rio Argos section (southern Spain) and biostratigraphic implications. *Cretaceous Research*, **15**, 645-687.

DELANOY, G. 1991. Sur la présence du genre *Prodeshayesites* Casey, 1961 (Ammonoidea) dans l'Aptien inférieur du bassin Vocontien. *Cretaceous Research* **12**, 437-441.

DELANOY, G. 1995. About some significant ammonites from the Lower Aptian (Bedoulian) of the Angles- Barreme area (South-East France). *Memorie Descrittive della Carta Geologica d'Italia*, **51**, 65-101.

ERBA, E., 1988. Aptian-Albian calcareous nannofossil biostratigraphy of the Scisti a Fucoidi cored at Piobbico (central Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, **94**, 249-284.

ERBA, E., 1992. Calcareous nannofossil distribution in pelagic rhythmic sediments (Aptian-Albian Piobbico core, Central Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, **97**, 455-484.

ERBA, E., 1994. Nannofossils and superplumes: the Early Aptian nannoconid crisis. *Paleoceanography*, **9**, 483-501.

ERBA, E., COCCIONI, R. & PREMOLI SILVA, I., 1989. The "Scisti a Fucoidi" in the Umbria-Marche area: The Apecchiese road sections. *Memorie Descrittive Carta Geologica d'Italia*, **39**, 146-164.

ERBA, E. & PREMOLI SILVA, I., 1993. Orbitally driven cycles in trace fossil distribution from the Piobbico core (Late Albian, Central Italy). *IAS Special Publication*, **19**, 211-225.

ERBA, E. & QUADRIO, B., 1987. Biostratigrafia a Nannofossili calcarei, Calpionellidi e Foraminiferi planctonici della Maiolica (Titoniano superiore-Aptiano) nelle Prealpi Bresciane (Italia Settentrionale), *Rivista Italiana di Paleontologia e Stratigrafia*, **93**, 3-108.

ERBACHER, J., 1994. Entwicklung und Paläozeanographie mittelkretazischer Radiolarien der westlichen Tethys (Italien) und des Nordatlantiks. Ph. D. Thesis, Univ. Tübingen, 119 pp.

FISCHER, A. G., HERBERT, T. D., NAPOLEONE, G., PREMOLI SILVA, I. & RIPEPE, M., 1991. Albian pelagic rhythms (Piobbico core). *Journal of Sedimentary Petrology*, **61**, 1164-1172.

GRADSTEIN, F. M., AGTERBERG, F. P., OGG, J. G., HARDENBOL, J., VAN VEEN, P., THIERRY, J. & HUANG, Z., 1994. A Mesozoic time scale. *Journal Geophysical Research*, **99**, 24051-24074.

HADJI, S. 1991. Stratigraphie isotopique des carbonates pelagiques (Jurassique supérieur-Crétacé inférieur) du Bassin d'Ombrie-Marches (Italie). Ph. D. Thesis, Univ. Pierre et Marie Curie, Paris, 118 pp.

HANCOCK, J.M. 1991. Ammonite scales for the Cretaceous System. *Cretaceous Research*, **12**, 259-291.

HARLAND, W. B., ARMSTRONG, R. L., COX, A. V., CRAIG, L. E., SMITH, A. G. & SMITH, D. G. 1990. *A geologic time scale 1989*, 263 pp. (Cambridge University Press, Cambridge).

HARLAND, W.B., COX, A.V., LLEWELLYN, P.G., PICKTON, C.A.G., SMITH, A.G. & WALTERS, R. 1982. *A geologic time scale*, 131 pp. (Cambridge University Press, Cambridge).

HERBERT, T. D. 1992. Paleomagnetic calibration of Milankovitch cyclicity in Lower Cretaceous sediments. *Earth and Planetary Science Letters*, **112**, 15-28.

HERBERT, T. & FISCHER, A. G., 1986. Milankovitch climatic origin of mid-Cretaceous black shale rhythms in central Italy. *Nature*, **321**, 739-743.

HERBERT, T., PREMOLI SILVA, I., ERBA, E., & FISCHER, A. G., 1995. Orbital chronology of Cretaceous-Paleocene marine sediments. *SEPM Special Publication.*, **54**, 81-93

HOEDEMAEKER, P.J., & BULOT, J.L., 1990. Preliminary ammonite zonation for the Lower Cretaceous of the Mediterranean region. *Géologie Alpine*, **66**, 123-127.

HOEDEMAEKER, P. & COMPANY, M. (Reporters) *et al.* 1993. Ammonite zonation for the Lower Cretaceous of the Mediterranean region: basis for the stratigraphic correlations within IGCP-Project 262. *Revista Española de Paleontologia*, **8**, 117-120.

HOEDEMAEKER, P.J., & LEEREVELD, H., 1995. Biostratigraphy and sequence stratigraphy of the Berriasian-lowest Aptian (Lower Cretaceous) of the Rio Argos succession, Caravaca, SE Spain. *Cretaceous Research*, **16**, 195-230.

JONES, C. E., JENKYNS, H. C., COE, A. L., & HESSELBO, S. P., 1994. Strontium isotopic variations in Jurassic and Cretaceous seawater. *Geochimica et Cosmochimica Acta*, **14**: 3061-3074.

JUD, R. D., 1995. Early Cretaceous radiolarian biostratigraphy of Umbria-Marche Apennines (Italy), Southern Alps (Italy and Switzerland) and Hawasina Nappes (Oman). *In* BAUMGARTNER *et al.* (Eds.) Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: occurrences, systematics, biochronology. Mémoire Géologie Lausanne, 751-797.

KAKABADZE, M., & KOTETISHVILI, E., 1995. New data on the Upper Barremian biostratigraphy of the Georgian region (Caucasus). *Memorie Descrittive della Carta Geologica d' Italia*, **51**, 103-108.

KEITH, M., & HAILWOOD, E.A., 1988. Magnetostratigraphy of the Lower Cretaceous Vectis Formation (Wealden Group) on the Isle of Wight, Southern England. *Journal of the Geological Society, London*, **145**, 351-360.

KENT, D.V. & GRADSTEIN, F.M. 1985. A Cretaceous and Jurassic geochronology. *Geological Society of America Bulletin*, **96**, 1419-1427.

LEEREVELD, H., 1995. Dinoflagellate cysts from the Lower Cretaceous Rio Argos succession (SE Spain). *LLP Contribution Series*, **2**, 173 pp.

LOWRIE, W. & ALVAREZ, W. 1984. Lower Cretaceous magnetic stratigraphy in Umbrian pelagic limestone sections. *Earth and Planetary Science Letters* **71**, 315-328.

MOULLADE, M., TAXY, S. & TRONCHETTI, G., 1980. Aptien. *Mémoires Bureau Recherches Géologiques et Minières*, **109**, 112-115.

MUTTERLOSE, J. 1991. Das Verteilungs- und Migrations-Muster des kalkigen Nannoplanktons in der Unterkreide (Valangin-Apt) NW-Deutschland. *Palaeontographica Abt. B*, **221**, 27-152.

OGG, J. G., 1987. Early Cretaceous magnetic polarity time scale and the magnetostratigraphy of Deep Sea Drilling project Sites 603 and 534, western central Atlantic. *In*: *Initial Reports of DSDP* (eds. van HINTE, J. E., WISE, S. W. Jr., *et al.*), **93**, 849-879.

OGG, J.G., 1988. Early Cretaceous and Tithonian magnetostratigraphy of the Galicia Margin (Ocean Drilling program Leg 103). *In*: *Initial Reports of ODP* (eds. BOILLOT, G., WINTERER, E.L., *et al.*), **103**, 650-682.

ORBIGNY, A. de, 1840. Paléontologie francaise. Terrains crétacés. I. Céphalopodes. 662 pp.

RAWSON, P. 1983. The Valanginian to Aptian stages. Current definitions and outstanding problems. *Zitteliana*, **10**, 493-500.

ROTH, P. H., 1978. Cretaceous nannoplankton biostratigraphy

and oceanography of the northwestern Atlantic Ocean. *In*: *Initial Reports of DSDP* (eds. BENSON, W. E., SHERIDAN, R.E. *et al.*), **44**, 731-759.

SLITER, W. V. 1992. Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section. *Journal of Foraminiferal Research,* **19**, 1-19.

TARDUNO, J. A., SLITER, W. V., BRALOWER, T. J., MCWILLIAMS, M., PREMOLI SILVA, I. & OGG, J. G. 1989. M-sequence reversals recorded in DSDP sediment cores from the western Mid-Pacific Mountains and Magellan Rise. *Geological Society of America Bulletin*, **101**, 1306-1316.

TARDUNO, J. A., SLITER, W. V., KROENKE, L., LECKIE, M., MAYER, H., MAHONEY, J. J., MUSGRAVE, R., STOREY, M., & WINTERER, E. L. 1991. Rapid formation of Ontong Java Plateau by Aptian mantle plume volcanism. *Science,* **254,** 399-403.

THIERSTEIN, H. R. 1973. Lower Cretaceous calcareous nannoplankton biostratigraphy. *Abhandlungen der Geologischen Bundesanstalt A,* **29**, 1-52.

TORNAGHI, M. E., PREMOLI SILVA, I. & RIPEPE, M. 1989. Lithostratigraphy and planktonic foraminiferal biostratigraphy of the Aptian-Albian ''Scisti a Fucoidi'' in the Piobbico core, Marche, Italy: background for cyclostratigraphy, *Rivista Italiana di Paleontologia e Stratigrafia,* **95**, 223-264.

VASICEK, Z. & RAKUS, M., 1995. Lower Aptian ammonites from the Medziholie locality (the Malà Tatra Mountains, Slovakia). *Memorie Descrittive della Carta Geologica d'Italia*, **51**, 173-183.

WEISSERT, H. 1989. C-isotope stratigraphy, a monitor of paleoenvironmental changes: a case study from the Early Cretaceous. *Survey in Geophysics.*, **10**, 1-61.

WEISSERT, H., & LINI, A. 1991. Ice Age interludes during the time of Cretaceous greenhouse climate?, in *Controversies in modern Geology*, edited by D. W. MULLER, J. A. MCKENZIE & H. WEISSERT, pp. 173-191, Academic Press, London.

WEISSERT, H., MCKENZIE, J. A. & CHANNELL, J. E. T. 1985. Natural variations in the carbon cycle during the Early Cretaceous. *In*: The Carbon Cycle and Atmospheric CO_2: Natural variations Archaean to Present (eds. SUNDQUIST, E. T. & BROECKER, W. S.), pp. 531-545 (*Geophysic Monograph* **32**).

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The Albian stage and substage boundaries

by Malcolm HART [compiler], Francis AMÉDRO and Hugh OWEN

with contributions by Emil Avram, Evgenij J. Baraboschkin, Peter Bengtson, Geza Czaszar, Dimas Dias-Brito, Elisabetta Erba, Andrew S. Gale, Agnes Görög, Erle G. Kauffman, Ludmila F. Kopaevich, Elisso Kotetishvili, Han Leereveld, Ignacio Machado Brito, Ricardo Martinez, Mihaela C. Melinte, Irina A. Mikhailova, Jörg Mutterlose, John D. Obradovich, Jose Maria Pons, Isabella Premoli Silva, Archana Tewari, Karl.-Armin Tröger and R. Venkatachalapathy

Abstract

Following discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995, the Working Group has identified two possible GSSP's (Global Boundary Stratotype Sections and Points) for the base of the Albian Stage. One of these, located at Vohrum (North Germany), was fully discussed at the Copenhagen Symposium in 1983 and, if selected, would use the appearance of *Leymeriella schrammeni* for the definition of the base of the Albian Stage. Unfortunately, apart from the ammonite information, there appears to be few other biostratigraphic data available for that succession. An alternative stratotype section, in the Vocontian Trough of S.E. France, offers a wider range of descriptors, including ammonites, calcareous nannofossils, planktonic foraminifera, dinoflagellate cysts and oceanic anoxic events [e.g., the Paquier Event]. Once data for both sections are fully compiled a boundary is clearly definable.

The bases of the Middle Albian and Upper Albian were also discussed, the decision having been taken to retain the tripartite subdivision of the Albian Stage. A possible GSSP for the base of the Middle Albian is the Côtes Noires succession on the River Marne near St-Dizier [Haute-Marne, France]. While the boundary may be identified by the appearance of *Lyelliceras lyelli* further work on the proposed GSSP needs to be done [possibly by the GFC]. The base of the Upper Albian is probably best defined by the appearance of *Dipoloceras cristatum*. There are two potential GSSP's; Wissant [Pas-de-Calais, France] and Folkestone [Kent, England] — both listed by d'ORBIGNY in the initial definition of the Stage. Either of these sections could act as the GSSP, although it is recognised that the succession at Folkestone is very condensed. An alternative locality, in the Vocontian Trough [S.E.France] may prove more suitable and information on all three locations will be gathered before a final decision is taken.

Key words: Albian, Lower Cretaceous, biostratigraphy, ammonites, inoceramids, foraminiferids, nannofossils, stratotypes, oceanic anoxic events, GSSP.

Résumé

A la suite des discussions du ''Second International Symposium on Cretaceous Stage Boundaries'' tenu à Bruxelles (8-16 Septembre 1995), le Groupe de Travail a identifié deux GSSP (Global Boundary Stratotype Sections and Points) possibles. L'une des deux sections, située à Vohrum (Allemagne du Nord) a été discutée en détail au symposium de Copenhague (1983); si elle était choisie, l'apparition de *Leymeriella schrammeni* définirait la base de l'Albien. Malheureusement, peu de données biostratigraphiques, à part celles fournies des ammonites, existent pour cette section. L'autre section considérée se trouve dans la fosse vocontienne (S.- E. de la France); elle offre une série plus étendue de fossiles étudiés tels que les ammonites, les nannofossiles calcaires, les foraminifères planctoniques, les cystes de dinoflagellés, et des niveaux anoxiques océaniques (comme par exemple le niveau Paquier). Après compilation des données pour les deux sections, une limite sera clairement définissable.

Les bases de l'Albien Moyen et de l'Albien Supérieur ont aussi été discutées, la décision ayant été prise de garder une subdivision tripartite pour l'étage Albien. Un GSSP possible pour la base de l'Albien Moyen est la section des Côtes-Noires sur la Marne, près de Saint-Dizier (Haute-Marne, France). La limite peut-être placée à l'apparition de *Lyelliceras lyelli*, mais des recherches supplémentaires sont nécessaires sur ce GSSP proposé (peut-être par le GFC).

La base de l'Albien Supérieur est probablement le mieux définie par l'apparition de *Dipoloceras cristatum*. Il y a deux GSSP possibles: Wissant (Pas-de-Calais, France) et Folkestone (Kent, Angleterre), tous deux mentionnés par d'ORBIGNY dans la définition de l'étage Albien. L'une et l'autre de ces sections pourraient être choisies comme GSSP, bien qu'il soit admis que la section à Folkestone est très condensée. Une localité alternative, dans la fosse vocontienne (S.-E. France) pourrait être plus indiquée. Ces trois localités seront étudiées avant de prendre une décision finale.

Mots-clefs: Albien, Crétacé inférieur, biostratigraphie, ammonites, inocérames, foraminifères, nannofossiles, stratotypes, évènements océaniques anoxiques, ''GSSP''.

Альбский ярус и границы подъярусов: предложения Рабочей Группы Альбского Яруса Субкомиссии Меловой Стратиграфии.

Резюме.

В результате обсуждений, прошедших в течение «Второго Международного Симпозиума по вопросам Границ Мелового Яруса» в Брюсселе (8-16 сентября 1995 года), Рабочая Группа определила два возможных GSSP «Global boundary Stratotype Sections and Points» для основания Альбского яруса. Один из них, расположенный в Vohrum, (северная Германия), стал объектом горячих обсуждений на копенгагском Симпозиуме 1983 года; в случае его выбора в качестве стратотипа, основание Альбского яруса будет определяться по появлению *Leymeriella schrammeni*. К сожалению, за исключением аммонитовых данных, существует лишь незначительное количество информации биостратиграфического характера, необходимой для такого выбора. Альтернативный разрез для стратотипа, расположенный в Воконтской впадине, на юго-востоке Франции, предлагает более широкий выбор изученных ископаемых, таких как аммониты, известковые нанофоссилии, планктонические фораминиферы, цисты динофлагеллат, а также океанические безкислородные уровни (как например уровень Paquier). После того как информация по каждой из двух секций будет собрана полностью, возможно будет чётко определить границу. Обсуждения коснулись также Среднего и Верхнего Альба; было принято решение сохранить разделение Альбского яруса на 3 части. Возможным GSSP для Среднего Альба представляется разрез Les Côtes-Noires, на реке Marne недалеко от Saint-Dizier (Haute Marne, Франция).

Границу можно определить при появлении *Lyelliceras lyelli*; тем не менее, необходимо провести дополнительные исследования по данному GSSP (вероятно GFC, Groupe Français du Crétacé). Основание Верхнего Альба вероятно определено наилучшим образом при появлении *Dipoloceras cristatum*. Здесь также возможны 2 GSSP, Wissant (Па-де-Кале, Франция) и Folkestone (Кент, Англия); оба указаны d'ORBIGNY при определении Альбского яруса. В качестве GSSP может быть выбран любой из этих разрезов, хотя допускается, что разрез в Folkestone очень сильно сконденсирован. Воконтская впадина является третьей, наиболее подходящей альтернативой.

Ключевые слова: Альбский ярус, нижний мел, биостратиграфия, аммониты, иноцерамы, фораминиферы, нанофоссилии, стратотипы, безкислородные океанические события, GSSP.

Introduction

The Albian Stage was proposed by d'ORBIGNY (1842-1843) for the interval between the Aptian and what is now called the Cenomanian. The name was originally derived from the Roman name for the Aube (Alba). The localities (Figure 1) initially cited by d'ORBIGNY include Wissant (Pas-de-Calais), Côtes-Noires (Haute-Marne), Gaty, Maurepaire, Dienville, Ervy (Aube), Saint-Florentin (Yonne), Perte-du-Rhône (Ain), Machéroménil (Ardennes) and Varennes (Meuse) in France and Folkestone (Kent) in England.

Following the work of BREISTROFFER (1947) the Albian Stage was generally accepted as beginning with the *Leymeriella tardefurcata* Zone, including at the base a level with *Leymeriella schrammeni* (*op. cit.*, p. 38). At the meeting in Copenhagen in 1983 it was agreed that the base of the Stage would be better drawn at the base of the *Leymeriella schrammeni* Zone (BIRKELUND *et al.*, 1984). Unfortunately this nominate species is restricted to the N. W. European faunal province (''Boreal'') and is not known from the classic areas of the Paris Basin.

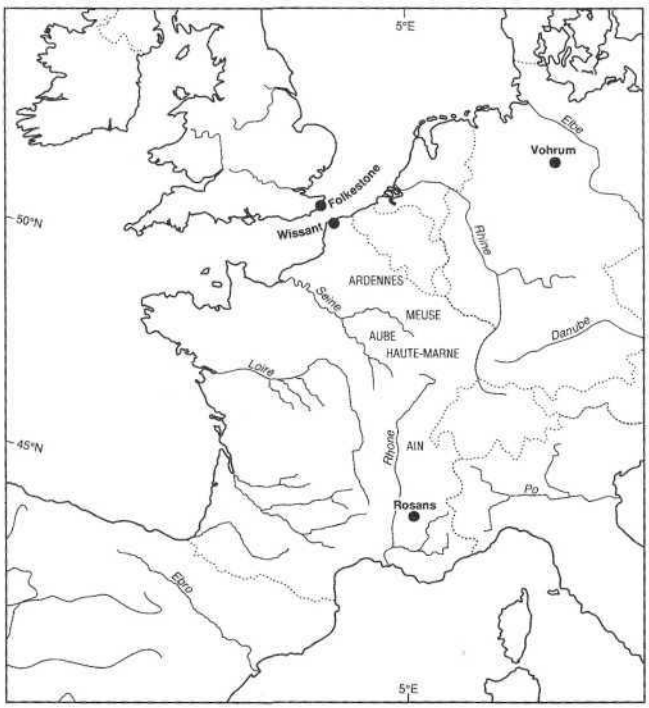


Fig. 1 — Albian localities discussed in the text or mentioned in the initial definition of d'ORBIGNY (1842-43).

The internal subdivisions of the Albian Stage are equally problematical, with the base of the Middle Albian and the base of the Upper Albian yet to be agreed. At the present time *Lyelliceras lyelli* can be used to define the base of the Middle Albian and *Dipoloceras cristatum* to define the base of the Upper Albian.

Stratigraphic terms such as the Selbornian (JUKES-BROWNE, 1900) and Vraconian (RENEVIER, 1867) have gained little general acceptance, although the latter is often used in the French literature.

Traditionally the Albian Stage has been subdivided on ammonites and there is established a well-known zonal and subzonal scheme for the European area, although it does have wider application. More recently a number of workers have described the foraminifera, ostracoda, dinoflagellate cysts and calcareous nannofossils (*s.l.*). In many of the areas described as being ''typical'' of the Stage the lithology is predominantly a dark blue-grey clay, deposited in mid-palaeolatitudes. This rather restricts the faunas and floras and has somewhat limited the international correlation of the Stage.

The Albian Stage occupies a part of the mid-Cretaceous ''magnetic quiet zone'' and the majority of workers have little magnetostratigraphic data from this interval. Recently E. J. Baraboschkin (Moscow, Russia) has indicated that a magnetic zonation may be possible but this has yet to be tested internationally. While there have been isolated attempts to use stable isotopes there is not yet a generally accepted data base for the Albian Stage that could be used for stratigraphical purposes (unlike for some higher parts of the Cretaceous succession).

The Albian Stage

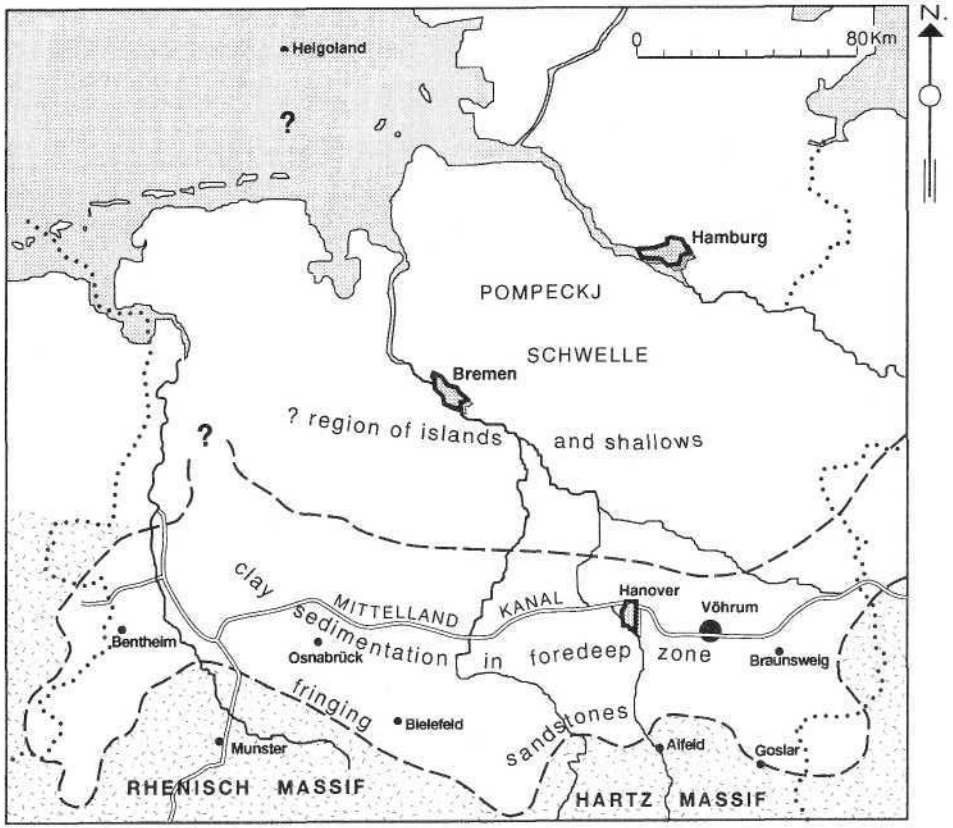
At the Brussels Symposium the Working Group resolved that it would follow the spirit of the initial definition of the base of the Albian and its tripartite division. These decisions reflect both the total duration of the Albian Stage (one of the longest in the Cretaceous) and the well-established ammonite zonation.

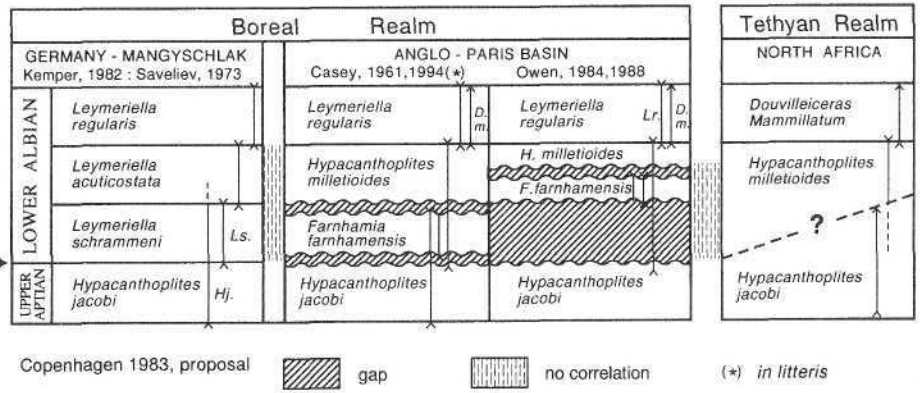
The Base of the [Lower] Albian

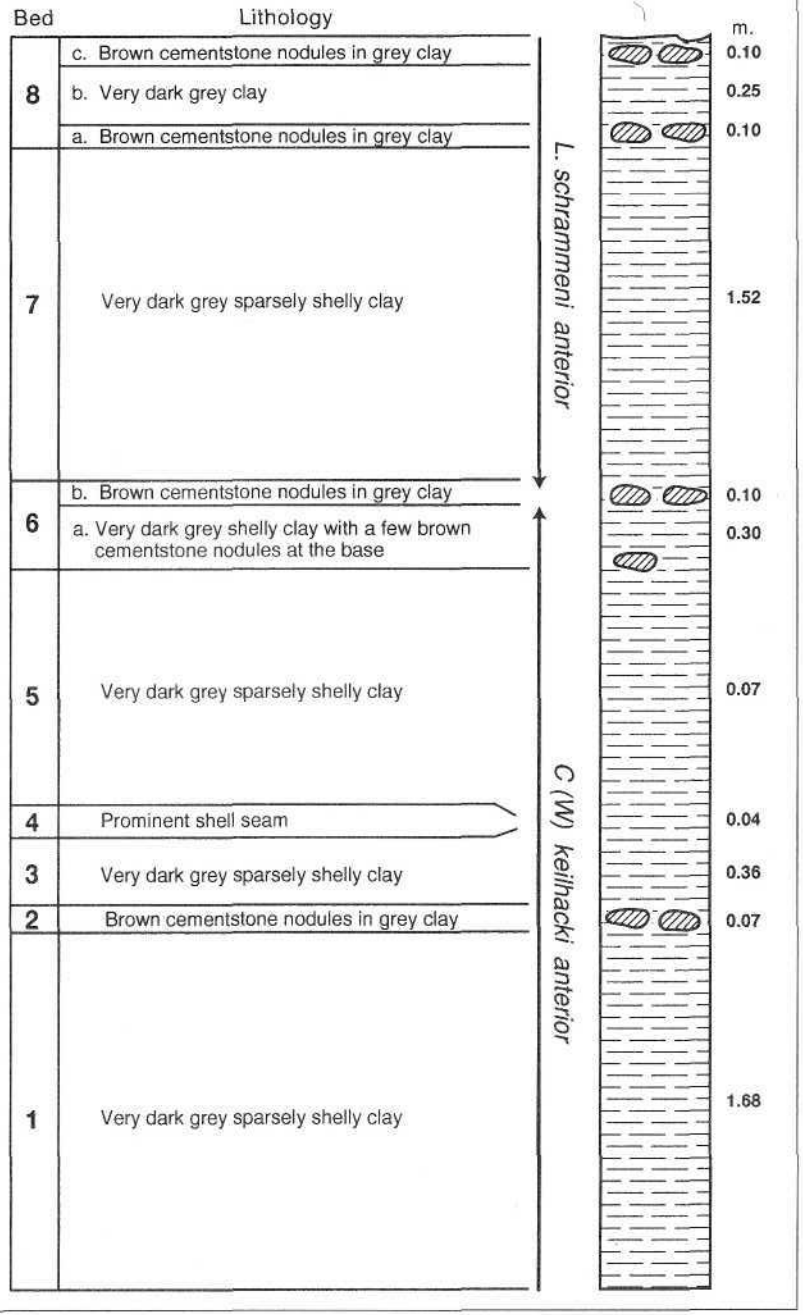
At the Copenhagen Symposium in 1983 (BIRKELUND *et*

→

Fig. 2 — Locality map for Vohrum and the succession in the section described by OWEN (1979). The correlation diagram is based on unpublished data supplied by F. AMÉDRO.


Helgoland
0
80Km
N.
?
Hamburg
POMPECKJ
SCHWELLE
Bremen
? region of islands
and shallows
?
clay
sedimentation
MITTELLAND
KANAL
Hanover
Vöhrum
in foredeep zone
Bentheim
Osnabrück
Braunsweig
fringing
sandstones
Bielefeld
Munster
Alfeld
Goslar
RHENISCH MASSIF
HARTZ MASSIF


Boreal Realm
Tethyan Realm
GERMANY - MANGYSCHLAK
Kemper, 1982 : Saveliev, 1973
ANGLO - PARIS BASIN
Casey, 1961,1994(*)
Owen, 1984,1988
NORTH AFRICA
LOWER ALBIAN
UPPER APTIAN
Leymeriella regularis
Leymeriella acuticostata
Leymeriella schrammeni
Hypacanthoplites jacobi
Ls.
Hj.
D. m.
Lr.
H. milletioides
F. farnhamensis
Hypacanthoplites milletioides
Farnhamia farnhamensis
Douvilleiceras Mammillatum
?
Copenhagen 1983, proposal
gap
no correlation
(*) in litteris


Bed
Lithology
m.
8
c. Brown cementstone nodules in grey clay
0.10
b. Very dark grey clay
0.25
a. Brown cementstone nodules in grey clay
0.10
7
Very dark grey sparsely shelly clay
1.52
L. schrammeni anterior
b. Brown cementstone nodules in grey clay
0.10
6
a. Very dark grey shelly clay with a few brown cementstone nodules at the base
0.30
5
Very dark grey sparsely shelly clay
0.07
C (W) keilhacki anterior
4
Prominent shell seam
0.04
3
Very dark grey sparsely shelly clay
0.36
2
Brown cementstone nodules in grey clay
0.07
1
Very dark grey sparsely shelly clay
1.68

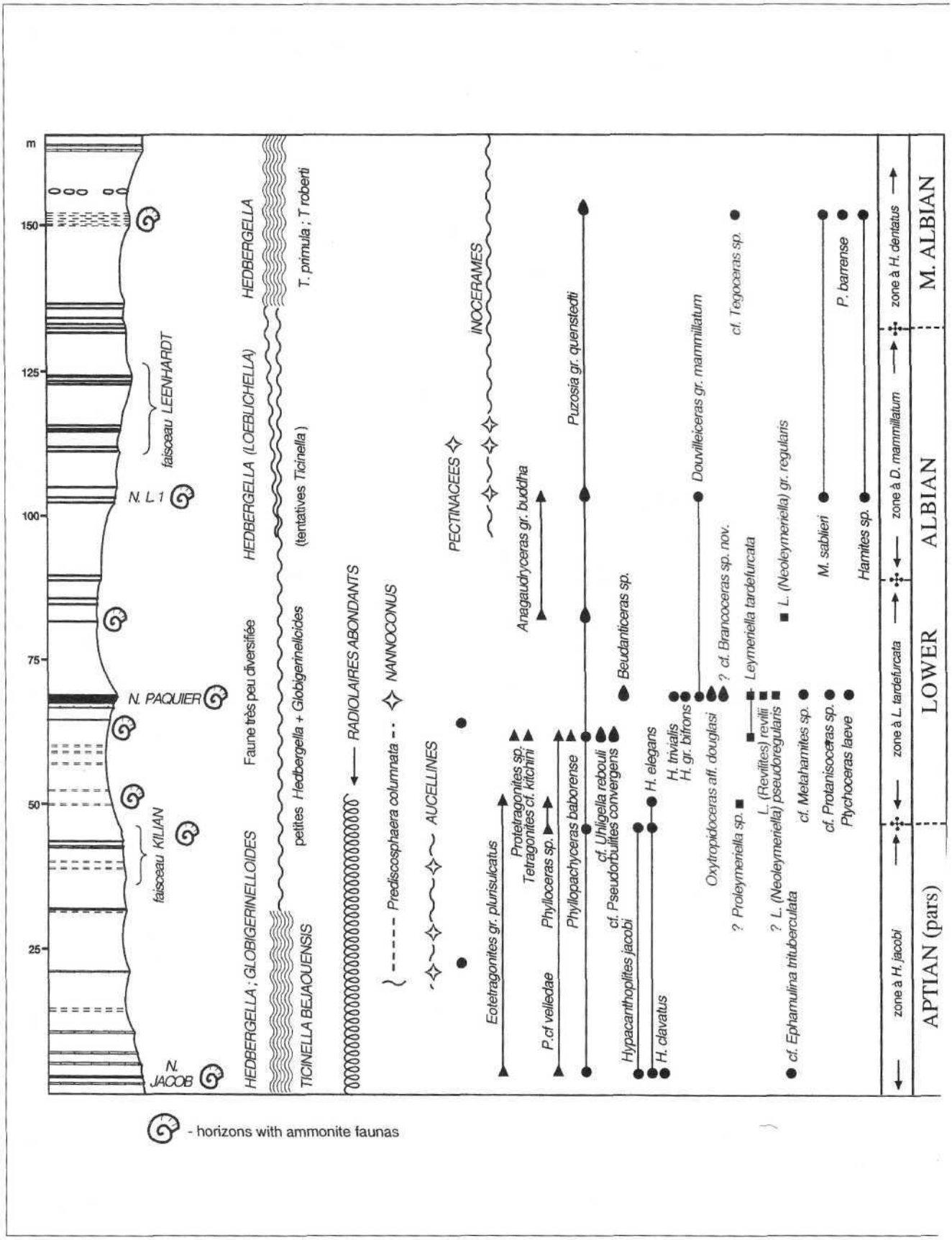


Fig. 3 — The succession of the Col de Pré-Guittard (Drôme); based on data in BRÉHERET *et al.* (1986). N.B. the placing of Aptian/Albian boundary - as indicated in the text - is not precisely known. [filled triangles = Mediterranean forms; fil circles = cosmopolitan forms; filled squares = European forms; filled droplets' = cosmopolitan forms with Mediterran affinities].

al., 1984) the discussion focused on the ammonite faunas that could be used to identify the base of the Albian. Few data were forthcoming on any other fossil groups, although it was suggested that the calcareous nannofossil, *Prediscosphaera columnata*, might be a possible alternative. It was recommended that the boundary might continue to be placed at the base of the *Leymeriella schrammeni* Subzone which is well-documented in the N. W. European succession. If that subzone is to be used OWEN (1979) has proposed that the best exposed section is that near Vorhum, in the Hannover-Braunschweig area of North Germany (Figures 1 and 2). Following that decision there has been considerable interest in the Lower Cretaceous successions of the Vocontian Trough (BRÉHERET *et al.*, 1986 and references therein).

Both of the above locations were discussed at the Brussels Symposium and it was resolved that a more complete database for the Vocontian Trough would be obtained prior to making any decision on the GSSP. Information from North America was lacking from the discussions in Brussels and nothing else has come to light since that time. Some information is available from the Cauvery Basin (South India), the Mesozoic Basins of Eastern Brazil and successions in the south of Russia (N. Caucasus), but there appears to be little support for using any of these areas as alternatives.

Vohrum, North Germany

OWEN (1979, 1984), accepting the base of the *Leymeriella schrammeni* Subzone as the base of the Albian stage, recommended that the succession at Vohrum (Figs 1 and 2) be identified as the boundary stratotype. The boundary would, therefore be located (Figure 2) at the level between Beds 6a and 6b, in a succession of clays spanning the Aptian-Albian boundary interval. *L. schrammeni* was assumed to mark the base of the Albian by KEMPER (1973) and the same author (KEMPER, 1982 a, b) has provided further data on the North Germany successions, including information on the ostracod faunas.

There are problems with this definition and the selection of Vohrum as the stratotype section.

1. Interprovincial correlation of the *schrammeni* Subzone is difficult and this is summarised in BIRKELUND *et al.* (1984) and OWEN (1984).

2. CASEY (1961) correlated the subzone of *L. schrammeni* with his subzone of *Farnhamia farnhamensis*, apparently despite that species not having been found outside S. E. England (OWEN, 1984). During the writing of this report CASEY (1996) has highlighted what he considers to be problems over the correlation of the ammonite subzones between S. E. England and N. Germany (OWEN, 1988, 1992). This, CASEY (*op. cit.*) claims, caused AMÉDRO (1992) to postulate a gap in the succession at the base of the Albian. OWEN (1996), in a direct reply to CASEY's comments, attempts to explain his position, outlining the difficulties involved in correlating ammonite data from isolated collections with a well-determined succession where *in-situ* material can be collected. Clearly there should be a resolution of these difficulties before a decision is taken on the base of the *L. schrammeni* Subzone at Vohrum as the definition of the GSSP for the base of the Albian stage.

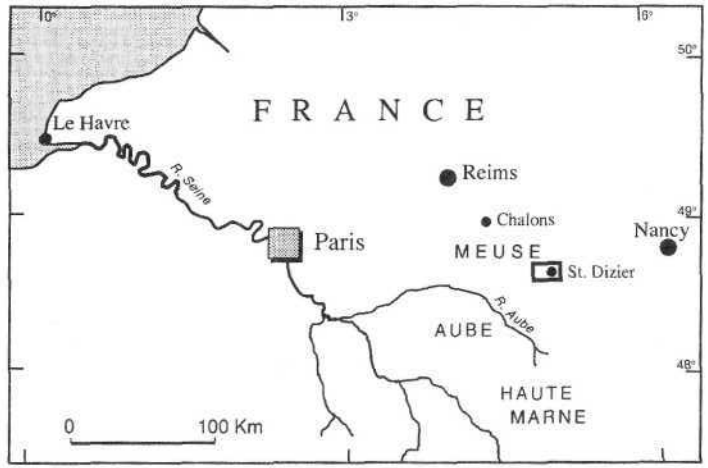
3. As far as can be determined there is relatively little new work on the Vohrum section in terms of belemnites, inoceramids, foraminifera, ostracods, calcareous nannofossils and dinoflagellate cysts. If the Vohrum succession is to be the GSSP for the base of the Albian stage some of this information will be required so that correlations away from the reference section can be performed as accurately as possible. There has been a considerable amount of work on the foraminifera of North Germany (eg. BARTENSTEIN, 1976 a, b, c, 1977; BARTENSTEIN & BETTENSTAEDT, 1962; BARTENSTEIN & BRAND, 1949; GRABERT, 1959) but none of this appears to specifically relate to Vohrum. The published information indicates that several taxa may appear at, or about, the base of the *schrammeni* Subzone. These are *Pleurostomella obtusa, Pl. subnodosa, Arenobulimina macfadyeni,* members of the *Gaudryina dividens* lineage, *Dorothia filiformis* and *Vaginulina gaultina*. MUTTERLOSE (1992) has indicated that the calcareous nannofossil, *Prediscosphaera columnata* appears within the *tardefurcata* Subzone, but the flora — in general — is rather poor in the N. W. German Basin. The belemnites are very important in N. W. Europe and a considerable amount of work has been done by SPAETH (1973), MUTTERLOSE (1990) and MUTTERLOSE *et al.* (1983). It is generally accepted (MUTTERLOSE, 1992) that the base of the *schrammeni* Subzone equates to the base of the *Neohibolites strombecki* Zone. If this is true, then it should be confirmed with collections made at Vohrum (if it is to be selected as the GSSP). Such collections could also be used to confirm the distributions of other microfossil groups.

There are significant problems over the use of the first appearance of *L. schrammeni* as the marker for the base of the Albian. As indicated in Figure 2 there are problems of inter-regional correlation, especially in parts of Southern Europe and North Africa. In the Kuma section of the North Caucasus DRUSHCHITS & MIKHAILOVA (1966) have described the biostratigraphy, although Baraboschkin (*pers. comm.*) has been unable to find the index fossil either in the field or in museum collections. In every section in the area there is a hiatus/phosphorite horizon. The situation is the same in Turkmenia, Crimea, Mangyshlak and the whole of the Russian Platform (SAVELIEV, 1973; BARABOSCHKIN, *in press*).

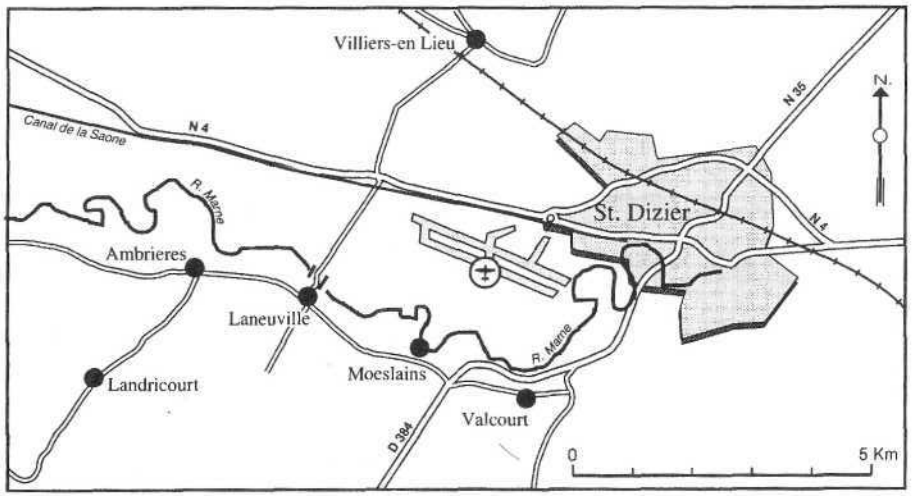
The Vocontian Trough

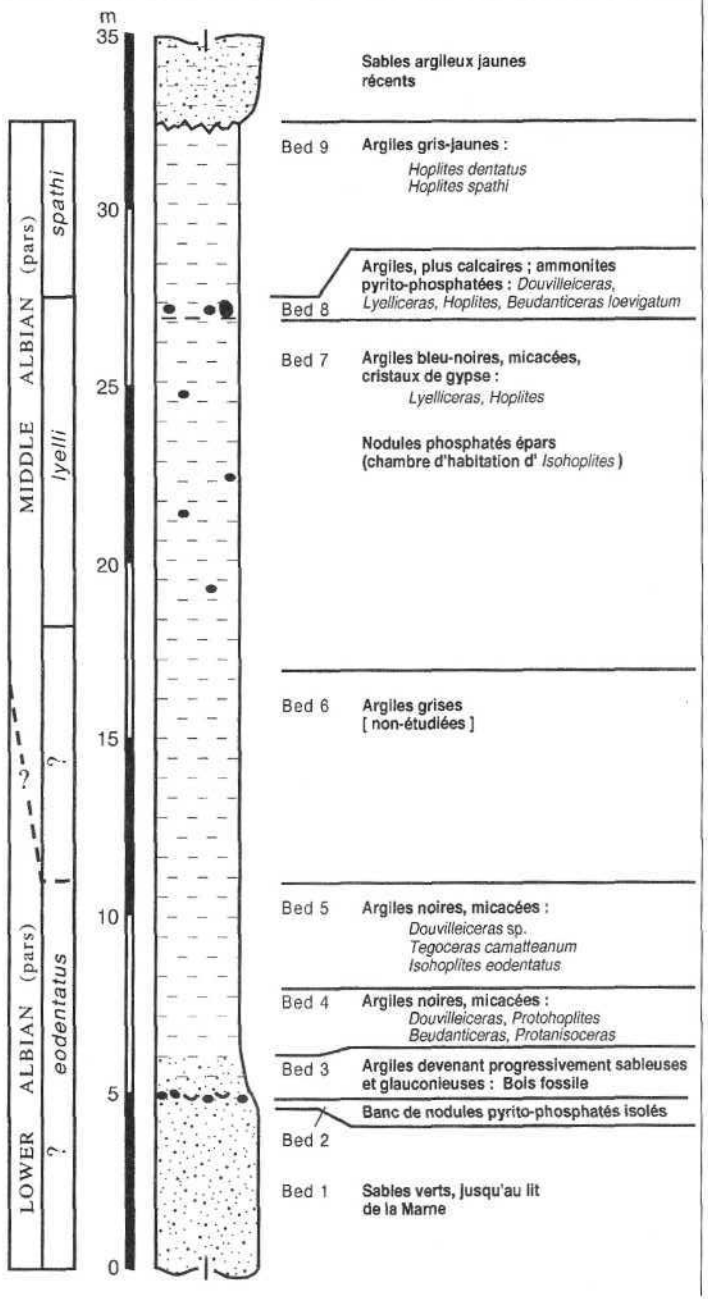
BRÉHERET *et al.* (1986) have described an integrated sedimentological, geochemical and palaeontological study of the Aptian-Albian succession in the Vocontian Trough. In particular, the succession on the Col de Pré-Guittard (Drôme) may be:

— the most complete succession across the boundary;
— one of the best studied sections currently available;
— well-exposed and unlikely to disappear over time;
— readily accessible;


10°
3°
6°
50°
49°
48°
FRANCE
Le Havre
R. Seine
Reims
Chalons
Paris
Nancy
MEUSE
St. Dizier
R. Aube
AUBE
HAUTE
MARNE
0
100 Km

Legend
Dark Clays
Sands
Exogyra
pyrite - phosphate nodules
pyrite - phosphate ammonites


Villiers-en Lieu
Canal de la Saone
N 4
R. Marne
Ambrieres
Laneuville
Landricourt
Moeslains
Valcourt
D 384
St. Dizier
N 35
N 4
N
0
5 Km


m
35
30
25
20
15
10
5
0
LOWER ALBIAN (pars)
? eodentatus
MIDDLE ALBIAN (pars)
lyelli
spathi
Sables argileux jaunes récents
Bed 9 Argiles gris-jaunes :
Hoplites dentatus
Hoplites spathi
Argiles, plus calcaires ; ammonites pyrito-phosphatées : Douvilleiceras, Lyelliceras, Hoplites, Beudanticeras laevigatum
Bed 8
Bed 7 Argiles bleu-noires, micacées, cristaux de gypse :
Lyelliceras, Hoplites
Nodules phosphatés épars (chambre d'habitation d' Isohoplites)
Bed 6 Argiles grises [non-étudiées]
Bed 5 Argiles noires, micacées :
Douvilleiceras sp.
Tegoceras camatteanum
Isohoplites eodentatus
Bed 4 Argiles noires, micacées :
Douvilleiceras, Protohoplites
Beudanticeras, Protanisoceras
Bed 3 Argiles devenant progressivement sableuses et glauconieuses : Bois fossile
Banc de nodules pyrito-phosphatés isolés
Bed 2
Bed 1 Sables verts, jusqu'au lit de la Marne

It contains a range of faunal and floral groups together with the Paquier and Jacob "oceanic anoxic events". Using data from BRÉHERET *et al.* (1986) it has been possible to construct a summary chart (Figure 3) which shows a range of geological, sedimentological and palaeontological features that could be used to define the boundary. Options appear to be:

— FO of *Leymeriella tardefurcata*
— FO of *Douvilleiceras* ex. gp. *mammillatum*
— FO of *Prediscosphaera columnata*
— LO of *Hypacanthoplites jacobi*
— the Paquier "oceanic anoxic event" [top or bottom]
— the topmost organic-rich bed of the "faisceau Kilian".
— any other datum

While there are a number of gaps in our knowledge, the dinoflagellate cysts have recently been described by VINK (1995). These data show a number of possible datums between 50 m. and 80 m. (Figure 3), with the most suitable horizon being located slightly above the boundary indicated in the figure. Bréheret (*pers. comm.* to Han Leereveld) has indicated that the full data on the ammonite succession has yet to be published and that the boundary should be taken as lying between 42 m. and 54 m. Bréheret and Delamette have also suggested that there may even be an hiatus at, or about, the potential boundary. Important extinctions of dinoflagellate cysts at, or about, the boundary include *Hystrichosphaerina schindewolfii* and *Cerbia tabulata* while *N. singularis, P. securigerum, Systematophora penicillata, Litosphaeridium arundum* and *P. eisenackii* have their first appearance within the same interval. The planktonic foraminifera are very abundant in this succession but, unfortunately, cannot offer a suitable LAD or FAD at this level. CARON (as a co-author in BRÉHERET *et al.*, 1986) has shown that the planktonic foraminifera responded to the Paquier (and other) oceanic anoxic events in by adjusting their position in the water column and often excluding those that lived in deeper-water environments. Ticinellids, and other stratigraphically important taxa, disappear at the critical level (Figure 3), being replaced by a population of small, shallow-water, hedbergellids (BRÉHERET *et al.*, 1986, figs 3, 11, 13, 14).

Substage Boundaries

The Base of the Middle Albian

At the Copenhagen Symposium it was agreed (BIRKELUND *et al.*, 1984) that the base of the Middle Albian should be drawn at the base of the *Lyelliceras lyelli* Subzone. It was noted that the best sequences across the boundary are located in the Aube (see Figure 1) and it was recommended that, following the work of OWEN (1971) and DESTOMBES (1979), a suitable GSSP might be identified.

OWEN (1971, 1984) has given detailed accounts of the possible definitions for the base of the Middle Albian, together with a resume of previous work. After a full discussion of the ammonite faunas from many localities in the Anglo-Paris Basin, OWEN (1984, p. 186) concluded that the base of the *L. lyelli* Subzone be regarded as the base of the Middle Albian. This largely follows the revisions of the stratigraphy proposed by DESTOMBES & DESTOMBES (1965, pp. 265-267). Both DESTOMBES & DESTOMBES (1965) and OWEN (1971) regard the section at Les-Côtes-Noires-de-Moëslains near St-Dizier (Haute-Marne) as being a potential stratotype (Figure 4). Sedimentologically it is relatively complete and there are good ammonite faunas. It has the advantage of being a natural exposure; a riverbank on a meander of the River Marne that is accessible from a minor road that runs parallel to the river on the southern bank.

There are, unfortunately, two problems with this otherwise straightforward solution.

1. Despite a quite exhaustive search it has been impossible to track down any other detailed palaeontological work on the Côtes-Noires succession. This means that data on the foraminifera, ostracods, calcareous nannofossils, etc., is lacking. DESTOMBES & DESTOMBES" (1963) description of the lithology of Bed 7 (the critical level) as "argiles bleu-noires, micacées, cristaux de gypse" is very worrying. Gypsum (or selenite) crystals are a product of modern weathering that usually indicate that the carbonate microfauna may have been leached out of the sediments. Clearly work needs to be done on the succession if it is to be proposed as a GSSP in order that the other fossil groups can be investigated. HART (1973) has shown that the *eodentatus-spathi* interval is represented by his Zone 3(i) with, appearing at — or about — the base of the *lyelli* Subzone, the distinctive foraminiferal species *Epistomina spinulifera.* Associated with this taxon in UK successions (HART, 1973; PRICE, 1977; HART *et al.*, 1989) are *Conorboides lamplughi* and *Gavelinella tormarpensis.* MAGNIEZ-JANNIN (1983), working on the successions of the Aube has compared her micropalaeontological zonation with that of the ammonite faunas and located the base of the Middle Albian (AMÉDRO *et al.*, 1995, fig. 6) in the middle of her Zone 2 (based on the appearance of *Valvulineria parva rotunda*). Using material from the same localities as HART in S. E. England, TAYLOR (1982) has identified a number of calcareous nannofossils (*Prediscosphaera cretacea, Dictyococcites parvidentatus, Gaarderella granulifera* and *Braarudosphaera regularis*) that appear at, or about, the boundary. HART (1973) also described the ostracod fauna and while a number of taxa are present (especially *Schuleridea brevis* and *S. jonesiana*) the fauna is relatively poor in comparison to the remainder of the Gault Clay succes-

←

Fig. 4 — Locality map for the section at Les Côtes-Noires-de-Moëslains near St-Dizier, France. The succession shown is based on the work of DESTOMBES & DESTOMBES (1965) and OWEN (1971). N.B. the lack of specific information in Beds 6 and 7 and the report of gypsum crystals (see text for significance) in the latter.

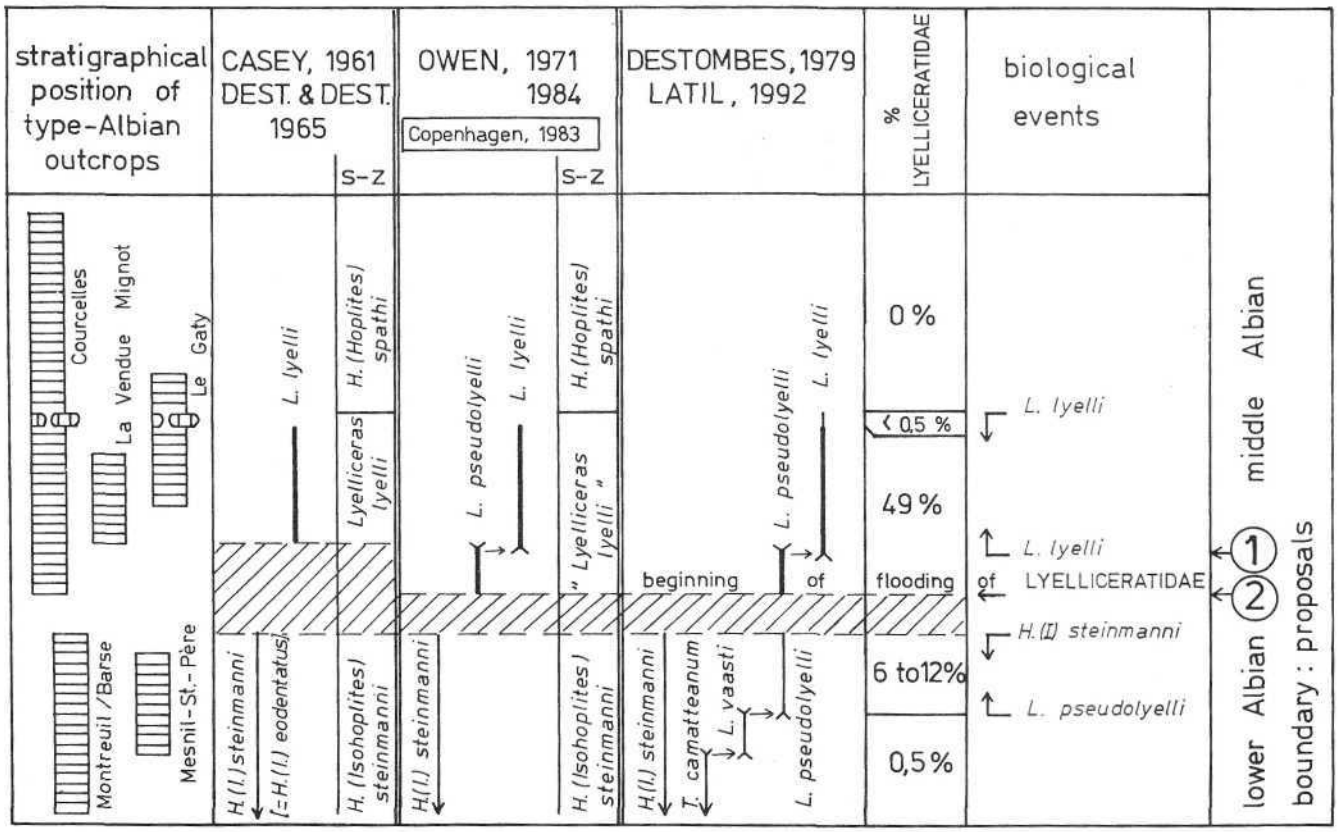


Fig. 5 — Stratigraphical details of the Lower-Middle Albian boundary provided by F. AMÉDRO.

sion. Unfortunately, the major facies change at the base of the Gault Clay does not allow the documentation of a full Lower - Middle Albian transition in any work based on the succession at Folkestone. In the successions in North Germany *Neohibolites minimus* appears just before the base of the Middle Albian (as defined in that area; base of the Zone of *H. dentatus*). As this belemnite is well-known right across Europe and into Russia it is important that its precise appearance in relation to the sub-stage boundary is determined.

2. The second problem concerns the *precise* definition of the base of the *lyelli* Subzone. AMÉDRO (manuscript) has shown that *L. lyelli s. s.* appears slightly above the influx of *Lyelliceras* in the succession (Figure 5) and that one has to decide whether to use:-

— the appearance of a flood of *Lyelliceras,* including *L. pseudolyelli*; or

— the appearance of *L. lyelli s. s.*

The Working Group in Brussels suggested that all the above issues should be investigated, especially as they apply to the succession of the Côtes-Noires. It was suggested that an international group, possibly co-ordinated by the GFC, might take this on board and that, until that work is completed, we adhere to the decisions of the Copenhagen Symposium and record that the appearance of *Lyelliceras lyelli* should be used to define the base of the Middle Albian.

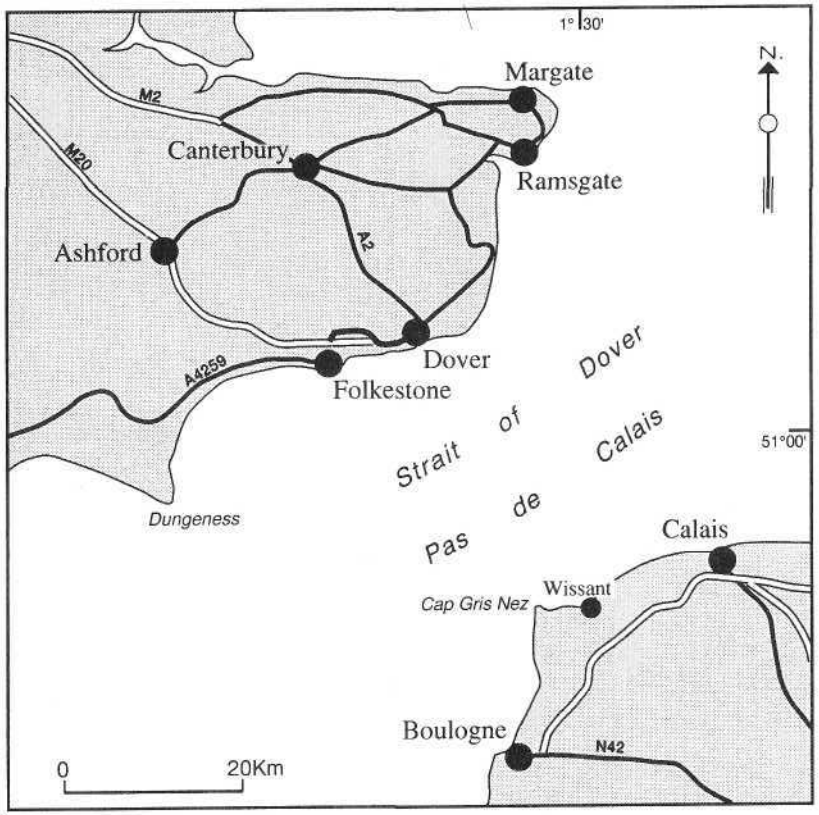
In Russia (MIKHAILOVA & SAVELIEV, 1989) the base of the Middle Albian is taken at the base of the *Isohoplites eodentatus* Zone. This is based on a view of *Isohoplites/Hoplites* evolution, the "European" nature of the taxon, a basin-wide sea level rise in the *eodentatus* Zone and a significant change in the inoceramid fauna immediately below the base of the zone (SAVELIEV, 1962; BARABOSCHKIN, *in press*).

The Base of the Upper Albian

BREISTROFFER (1947) proposed that the base of the Upper Albian should be drawn at the appearance of the ammonite *Dipoloceras cristatum* and related species of *Dipoloceras*. This view was upheld in Copenhagen (BIRKELUND *et al.*, 1984; OWEN, 1984) especially since *D. cristatum* is quite widely known (eg. Texas — see YOUNG 1966) and, even where it is absent, the horizon can be determined adequately by other faunas (OWEN, 1984).

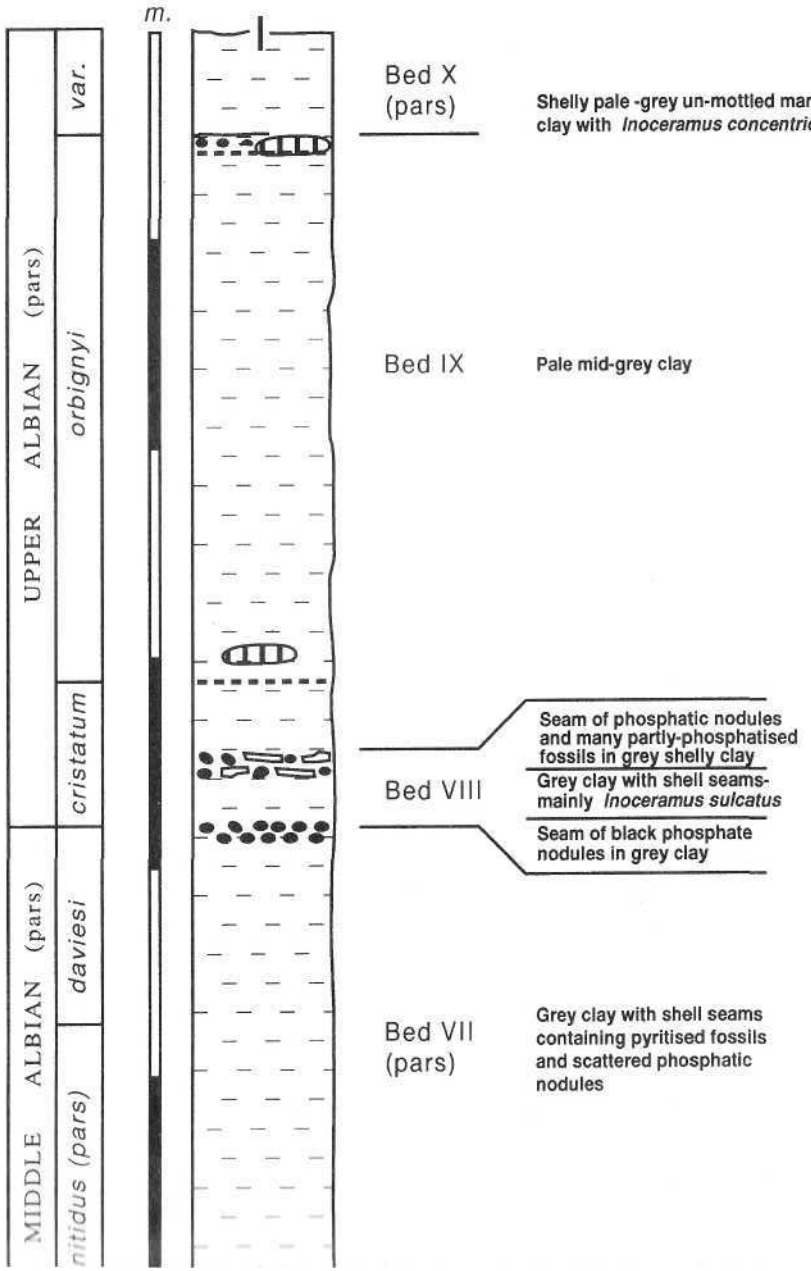
AMÉDRO (manuscript) has indicated, however, that there are large areas of the world (Western USA and Japan) where the *D. cristatum* fauna is unknown. AMÉDRO

Fig. 6 — Locality map for the sections at Folkestone and Wissant. The succession at Copt Point, Folkestone is based on the work of OWEN (1976). Information on the Boulonnais successions can be found in ROBASZYNSKI *et al.* (1980).



Legend

- Dark clays
- phosphatic nodules
- shell debris
- cementstone nodules



& DESTOMBES (1978) have shown that, even in the North European Province of the Boreal realm, *Dipoloceras* is usually a very minor component of any ammonite fauna. An alternative marker, favoured by AMÉDRO, would be the first appearance of *Mortoniceras (Mortoniceras) pricei* as this taxon appears to be recognised over a much wider geographical area. In two of the key sections (Wissant, Pas-de-Calais, France and Folkestone, Kent, United Kingdom - see Figure 6) the successions are quite condensed and there are disadvantages to both. Micropalaeontological work (HART, 1973; PRICE, 1977; ROBASZYNSKI *et al.*, 1980; TAYLOR, 1982; HART *et al.*, 1989) has been based largely on a sample interval too crude for these condensed successions (despite being at intervals of 1 m. or even 0.50 m.). In the Aube succession AMÉDRO *et al.* (1995, fig. 6) indicate that *D. cristatum* is not yet known in the area as there are no suitable exposures but, as far as it can be identified, the base of the *cristatum* Subzone is located in the middle of MAGNIEZ-JANNIN's (1983) zone 8, which is based on the appearance of *Citharinella* aff. *pinnaeformis*. The base of her zone 9 (which coincides with the base of the *Mortoniceras (M.) pricei* Zone) is characterised by the appearance of *C. pinnaeformis s. s.*. In the succession at Folkestone both HART (1973, fig. 3) and PRICE (1977) indicate that *C. pinnaeformis* appears within the *cristatum* Subzone (middle of Bed VIII) with *Arenobulimina chapmani* appearing a few centimetres above in the base of Bed IX (and probably just below the appearance of *Mortoniceras (M.) pricei*. Just before the appearance of *C. pinnaeformis*, in the Folkestone succession, there is a flood of *Hedbergella washitensis*, a highly distinctive planktonic species which is known from many parts of the world (eg. Brazil - see KOUTSOUKOS *et al.*, 1989).

MUTTERLOSE (1992) indicates that the base of the *D. cristatum* Subzone equates with the base of the *Neohibolites oxycaudatus* Zone in the North German successions and this important correlation requires confirmation. The appearance of *D. cristatum* is used to define the base of the Upper Albian in large areas of the North Caucasus (BARABOSCHKIN, *in press*) and Turkmenia (MIKHAILOVA & SAVELIEV, 1989). In these areas *Actinoceramus sulcatus* appears together with *D. cristatum*.

In order to progress towards a decision, the Working Group suggested that information on as many faunal/floral groups be obtained from:

1. Wissant (Pas-de-Calais, France) where the base of the *D. cristatum* Subzone can be located 0.20 m. below the top of "Bed r" of AMÉDRO & DESTOMBES (1978).

2. Folkestone (Kent, UK) where the base of the *M. (M.) pricei* Zone of AMÉDRO (1992), equivalent to the top of the *D. cristatum* Subzone, can be drawn 0.70 m. above the base of "Bed IX" (OWEN, 1976).

3. Dallas (Texas, USA) where successions with *D. cristatum* might prove to be a valuable reference point for correlation into the USA and (perhaps) the Pacific Region.

4. Localities in the area around Rosans (Drôme, France) where, in an expanded succession (Gale, *pers. comm.*), it may be possible to investigate ammonite, inoceramid, calcareous nannofossil, foraminiferal and dinoflagellate cyst distributions. These expanded successions may provide better resolution of the palaeontological data than is possible in the relatively condensed successions of Folkestone and Wissant.

For the present the Working Group recommends that the base of the *D. cristatum* Subzone continues to be used to define the base of the Upper Albian.

Summary

The Working Group has identified two possible stratotype sections for the base of the Albian Stage. These are the sections at Vohrum (North Germany) and the Col de Pré-Guittard (Drôme, France). If the former is used then the appearance of *L. schrammeni* will almost certainly be used as the marker. The succession of the Col de Pré-Guittard offers a range of possibilities and these were not fully discussed in Brussels.

The base of the Middle Albian may be located at the appearance of *Lyelliceras lyelli* in the section at "Les-Côtes-Noires-de-Moëslains" near St-Dizier (Haute-Marne, France) although this remains to be fully investigated.

The base of the Upper Albian may be drawn at the base of the *D. cristatum* Subzone, although a suitable succession is still being sought. A number of possibilities have been identified; Folkestone, Wissant or a locality in the Vocontian Trough.

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References

AMÉDRO, F., 1992. L'Albien du bassin anglo-parisien: Ammonites, zonation phylétique, séquences. *Bulletin Centre de Recherches, Exploration-Production Elf-Aquitaine,* **16**: 187-233.

AMÉDRO, F., (*manuscript*). Albian Substage Boundaries: Presentation, Discussion and Proposals. (Circulated at the Brussels Meeting).

AMÉDRO, F. & DESTOMBES, P., 1978. Répartition des ammonites dans l'Albien moyen et supérieur, argileux, de Wissant (Bou-

lonnais). *Bulletin d'Information des Géologues du Bassin de Paris*, **15**: 9-15.

AMÉDRO, F., MAGNIEZ-JANNIN, F., COLLETÉ, C. & FRICOT, C., 1995. L'Albien-type de l'Aube, France: une revision nécessaire. *Géologie de la France*, **2**: 25-42.

BARABOSCHKIN, E. J., (*in press*). Russian Platform as a controller of the Albian Tethyan/Boreal ammonite migration. *Geologica Carpathica.*

BARTENSTEIN, H., 1976 a. Foraminiferal zonation of the Lower Cretaceous in North West Germany and Trinidad, West Indes - an attempt. *Neues Jahrbuch für Geologie und Paläontologie* **1976, 3**: 187-191.

BARTENSTEIN, H., 1976 b. Practical applicability of a zonation with benthonic foraminifera in the worldwide Lower Cretaceous. *Geologie en Mijnbouw*, **55**: 83-86.

BARTENSTEIN, H., 1976 c. Benthonic index foraminifera in the Lower Cretaceous of the northern hemisphere between East Canada and North West Germany. *Erdöl, Kohle, Erdgas, Petrochemie*, **29**: 254-256.

BARTENSTEIN, H., 1977. Stratigraphic parallelism of the Lower Cretaceous in the northern hemisphere. *Newsletters on Stratigraphy*, **6**: 30-41.

BARTENSTEIN, H. & BETTENSTAEDT, F., 1962. Marine Unterkreide (Boreal und Tethys). *In: Leitfossilien der Mikropalaontologie*, **B7**: 225-297.

BARTENSTEIN, H. & BRAND, E., 1949. New genera of Foraminifera from the Lower Cretaceous of Germany and England. *Journal of Paleontology*, **23**: 669-672.

BIRKELUND, T., HANCOCK, J.M., HART, M.B., RAWSON, P.F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F., 1984. Cretaceous stage boundaries - Proposals. *Bulletin of the Geological Society of Denmark*, **33**: 3-20.

BRÉHERET, J. G., CARON, M. & DELAMETTE, M., 1986. Niveaux Riches en Matière Organique dans l'Albien Vocontien; Quelques Caractères du Paléoenvironnement; Essai d'Interprétation génétique. *Documents Bureau Recherches Géologiques et Minières*, **110**: 141-191.

BREISTROFFER, M., 1947. Sur les Zones d'Ammonites dans l'Albien de France et d'Angleterre. *Travaux du Laboratoire de Géologie de l' Université de Grenoble*, **26**: 17-104.

CASEY, R., 1961. The stratigraphical palaeontology of the Lower greensand. *Palaeontology*, **3**: 487-621.

CASEY, R., 1996. Lower Greensand ammonites and ammonite zonation. *Proceedings of the Geologists' Association*, **107**: 69-74.

DESTOMBES, P., 1979. Les Ammonites de l'Albien inférieur et moyen dans le stratotype de l'Albien: Gisements, Paléontologie, Biozonation. *In: Les Stratotypes Français,* Editions du CNRS, **5**: 51-194.

DESTOMBES, P. & DESTOMBES, J. P., 1965. Distribution zonale des ammonites dans l'Albien du bassin de Paris. [Colloque sur le Crétacé Inférieur, 1963]. *Mémoire Bureau de Recherches Géologiques et Minières*, **34**: 255-270.

DRUSHCHITS, V. V. & MIKHAILOVA, I. A., 1966. Lower Cretaceous biostratigraphy of the North Caucasus. Moscow State University Publication, Moscow, 190 pp. [in Russian].

GRABERT, B., 1959. Phylogenetische Untersuchungen an *Gaudryina* und *Spiroplectinata* (Foram.) besonders aus dem nordwestdeutschen Apt und Alb. *Abhandlungen der senckenbergischen naturforschenden Gesellschaft*, **498**: 1-71.

HART, M. B., 1973. A correlation of the macrofaunal and microfaunal zonations of the Gault Clay in SE England. *In:* CASEY, R. & RAWSON, P. F. [eds], The Boreal Lower Cretaceous, *Geological Journal Special Issue,* **5**: 267-288.

HART, M. B., BAILEY, H. W., CRITTENDEN, S., FLETCHER, B. N., PRICE, R.J. & SWIECICKI, A., 1989. Cretaceous. *In:* JENKINS, D. G. & MURRAY, J. W. [eds], Stratigraphical Atlas of Fossil Foraminifera, Ellis Horwood, Chichester, UK, British Micropalaeontological Society Series, 273-371.

JUKES-BROWNE, A.J., 1900. The Cretaceous Rocks of Britain. 1 The Gault and Upper Greesand of England. *Memoirs Geological Survey UK, London*, 499 pp.

KEMPER, E., 1973. The Aptian and Albian stages in northwest Germany. *In:* CASEY, R. & RAWSON, P. F. [eds], The Boreal Lower Cretaceous, *Geological Journal Special Issue*, **5**: 345-360.

KEMPER, E. [Ed.]., 1982 a. Das späte Apt und frühe Alb Nordwestdeutschlands. *Geologisches Jahrbuch*, **A65**: 1-703.

KEMPER, E., 1982 b. 7. Die Mikrofossilien des späten Apt und frühen Alb in Nordwestdeutschland. 7.1. Die Ostrakoden des Apt und frühen Alb des Niedersächsischen Beckens. *Geologisches Jahrbuch*, **A65**: 413-439.

KOUTSOUKOS, E.A.M., LEARY, P.N. & HART, M.B., 1989. *Favusella* Michael (1972): Evidence of ecophenotypic adaption of a planktonic foraminifer to shallow-water carbonate environments during the mid-Cretaceous. *Journal of Foraminiferal Research*, **19**: 324-336.

LATIL, J. L., 1992. Évolution des Lyelliceratinae Spath, 1921 (Ammonitina, Ammonoidea) de l'Albien inférieur et moyen: perspectives ontogénétiques et phylogénétiques. *Mémoires École pratique des Hautes Études, Paris* 128 pp.

MAGNIEZ-JANNIN, F., 1983. Essai de correlation des zones foraminifères de l'Albien stratotypique (Aube, France) avec les zones d'ammonites. *Geobios*, **16**: 405-418.

MIKHAILOVA, I. A. & SAVELIEV, A. A., 1989. The Albian Stage. *In*: Cretaceous Zones in the USSR. The Lower Series. *Transactions Interdepartemental stratigraphic Committee of the USSR*, **20**: 141-217 *Leningrad, Nauka Publishing House* [in Russian].

MUTTERLOSE, J., 1990. A belemnite scale for the Lower Cretaceous. *Cretaceous Research*, **11:** 1-15.

MUTTERLOSE, J., 1992. Biostratigraphy and palaeobiogeography of Early Cretaceous calcareous nannofossils. *Cretaceous Research*, **13**: 167-189.

MUTTERLOSE, J., SCHMID, F. & SPAETH, Ch., 1983. Zur Paläobiogeographie von Belemniten der Unter-Kreide in NW-Europa. *Zitteliana*, **10**: 293-307.

ORBIGNY, A. d', 1842. Paléontologie française. Terrains Crétacés, t. 2 Gastéropodes. Editions Masson, Paris, 456 pp.

OWEN, H.G., 1971. Middle Albian Stratigraphy in the Anglo-Paris Basin. *Bulletin of the British Museum, Natural History (Geology), Supplement*, **8**, 164 pp.

OWEN, H.G., 1976. The stratigraphy of the Gault and Upper Greensand of the Weald. *Proceedings of the Geologists' Association*, **86**: 475-498.

OWEN, H.G., 1979. Ammonite Zonal Stratigraphy in the Albian of North Germany and its setting in the Hoplitinid Faunal Province. *In:* WIEDMANN, J. [Ed.], Aspekte der Kreide Europas, IUGS **A6**: 563-588.

OWEN, H.G., 1984. Albian Stage and Substage boundaries. *Bulletin of the Geological Society of Denmark*, **33**: 183-189.

OWEN, H.G., 1988. Correlation of Ammonite Faunal Provinces

in the Lower Albian (mid-Cretaceous). *In*: WIEDMANN, J. & KULLMANN, J. [eds], Cephalopods - Present and Past, Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 477-489.

OWEN, H.G., 1992. The Gault - Lower Greensand junction beds in the northern Weald (England) and Wissant (France). *Proceedings of the Geologists' Association*, **103**: 83-110.

OWEN, H.G., 1996. ''Uppermost Wealden facies and Lower Greensand Group (Lower Cretaceous) in Dorset, southern England: correlation and palaeoenvironment'' by Ruffell & Batten (1994) *and* ''The Sandgate Formation of the M20 Motorway near Ashford, Kent and its correlation'' by Ruffell & Owen (1995)'': reply. *Proceedings of the Geologists' Association*, **107**: 74-76.

PRICE, R.J., 1977. The stratigraphical zonation of the Albian sediments of north-west Europe, as based on foraminifera. *Proceedings of the Geologists' Association*, **88**: 65-91.

RENEVIER, E., 1867. Notices géologiques et paléontologiques sur les Alpes vaudoises et les régions environnantes. V. Complément de la faune de Cheville. *Bulletin de la Société vaudoise des Sciences naturelles*, **13**: 218-252.

ROBASZYNSKI, F., AMÉDRO, F., FOUCHER, J.C., GASPARD, D., MAGNIEZ-JANNIN, F., MANIVIT, H. & SORNAY, J., 1980. Synthèse biostratigraphique de l'Aptien au Santonien du Boulonnais à partir de sept groupes paléontologiques: Foraminifères, Nannoplancton, Dinoflagellés et Macrofaunes. *Revue de Micropaléontologie*, **22**: 195-321.

SAVELIEV, A. A., 1962. Albian inoceramids of Mangyshlak. *Palaeontological Collection 3, Transactions VNIGRI*, **196**: 219-276 [in Russian].

SAVELIEV, A. A. 1973., Lower Albian stratigraphy and ammonites of Mangyshlak (*Leymeriella tardefurcata* and *Leymeriella regularis* Zones). *Transactions VNIGRI*, **323**: 340 pp. [in Russian].

SPAETH, Ch. 1973. Untersuchungen an Belemniten des Formenkreises um *Neohibolites minimus* (Miller, 1826) aus dem Mittel- und Ober-Alb Nordwestdeutschlands. *Beihefte zum Geologischen Jahrbuch*, **100**: 127 pp.

TAYLOR, R. J. 1982. Lower Cretaceous (Ryazanian to Albian) calcareous nannofossils. *In:* LORD, A. R. [Ed.], *A Stratigraphical Index of Calcareous Nannofossils*, Ellis Horwood, Chichester, UK, 40-80.

VINK, A., 1995. Biostratigraphy and palaeoenvironmental modelling of the latest Aptian-Middle Albian in the Vocontian Basin (S.E. France); a palynological approach with emphasis on dinoflagellate cysts. Unpublished M.Sc. Report, Utrecht University.

YOUNG, K. 1966. Texas Mojsisovicziinae (Ammonoidea) and the Zonation of the Fredericksburg. *Memoir, Geological Society of America*, **100:** 1-225.

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The Cenomanian stage

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Abstract

Following discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995, the Cenomanian Working Group, identified as marker for the base of the Cenomanian the first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides*. As GSSP (Global Boundary Stratotype Section and Point) for the base of the Cenomanian Stage, it proposed in the Mont Risou section (Rosans, Hautes-Alpes, France) the point of the first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides*, 36 m from the top of the Marnes Bleues Fm. For the Mont Risou section biostratigraphic data on calcareous nannofossils, planktonic foraminifera, ammonites, bivalves and carbon and oxygen isotopes have been studied.

The base of the Middle Cenomanian substage is the first appearance of the ammonite *Cunningtoniceras inerme* with the entry of *Inoceramus schoendorfi* and *Rotalipora reicheli* as secondary markers, with the Southerham Grey Quarry section at Lewes in Sussex (England) as stratotype for the Lower-Middle Cenomanian boundary.

For the base of the Upper Cenomanian no agreement was reached.

Key-words: Cenomanian, Upper Cretaceous, biostratigraphy, ammonites, inoceramids, foraminiferids, nannofossils, isotope stratigraphy, GSSP.

Résumé

A la suite des discussions au cours du "Second International Symposium on Cretaceous Stage Boundaries" tenu à Bruxelles (8-16 Septembre 1995), le Groupe de Travail du Cénomanien a choisi comme marqueur pour la base du Cénomanien l'apparition du foraminifère planctonique *Rotalipora globotruncanoides*. Comme "GSSP" (Global Boundary Stratotype Section and Point) pour la base du Cénomanien, le Groupe de Travail propose dans la coupe du Mont Risou (Rosans, Hautes-Alpes, France) la première apparition de ce foraminifère à 36 m sous le sommet de la Formation des Marnes Bleues. Pour la section de Mont Risou existent des données biostratigraphiques concernant les nannofossiles calcaires, les foraminifères planctoniques, les ammonites et les bivalves; les isotopes du carbone et de l'oxygène ont été étudiés.

La base du Cénomanien moyen a été placée à l'apparition de l'ammonite *Cunningtoniceras inerme* et, comme marqueurs secondaires, on a désigné *Inoceramus schoendorfi* et *Rotalipora reicheli*; comme stratotype pour la limite Cénomanien inférieur-moyen, on propose la carrière Southerham Grey, à Lewes (Sussex, Angleterre).

Pour la base du Cénomanien supérieur aucune décision n'a encore été prise.

Mots-clefs: Cénomanien, Crétacé supérieur, biostratigraphie, ammonites, inocéramidés, foraminifères, nannofossiles, stratigraphie isotopique, "GSSP".

Отчёт по Сеноманскому ярусу.

Резюме.
В результате обсуждений, прошедших в течение «Второго Международного Симпозиума по вопросам Границ Мелового Яруса» в Брюсселе (8-16 сентября 1995 года), Рабочая Группа Сеноманского яруса выбрала в качестве индекс-вида для основания Сеноманского яруса появление планктонического фораминифера *Rotalipora globotruncanoides*. В качестве «GSSP» (Global Boundary Stratotype Section and Point) для основания Сеноманского яруса Рабочая Группа предлагает первое появление данного фораминифера на глубине 36 метров от вершины отложения Marnes Bleues, в разрезе Mont Risou (Rosans, Hautes Alpes, Франция). Для разреза Mont Risou существуют биостратиграфические данные, касающиеся меловых нанофоссилий, планктонических фораминифер, аммонитов и двустворчатых моллюсков; изотопы углерода и кислорода также были изучены.
Основание подъяруса среднего Сеномана определяется при появлении аммонита *Cunningtoniceras inerme*; в качестве вторичных индекс-видов выбраны *Inoceramus schoendorfi* и *Rotalipora reicheli*. В качестве стратотипа для границы нижнего и среднего Сеномана учёные предлагают Карьер Southerham Grey, в Lewes (Sussex, Англия).
Что касается основания верхнего Сеномана, то на данный момент не было принято никакого решения.

Ключевые слова: Сеноманский ярус, верхний мел, биостратиграфия, аммониты, иноцерамы, фораминиферы, нанофоссилии, изотопическая стратиграфия, «GSSP».

HISTORICAL SUMMARY

The Cenomanian stage was proposed by D'ORBIGNY (1847) for the strata seen at Le Mans (lat.: Cenomanum-Paléontologie Française, Terrains Cretacés, **4:** 270) in the Paris Basin.

HANCOCK (1960) recognised three ammonite zones in the Cenomanian sequences of the Sarthe region, including the stratotype of D'ORBIGNY:

Upper Cenomanian - *Calycoceras naviculare* Zone

Middle Cenomanian - *Acanthoceras rhotomagense* Zone

Lower Cenomanian - *Mantelliceras mantelli* Zone

JUIGNET (1974, 1980), KENNEDY (1984) gave a more detailed subdivision with at least two standard zones in each substage.

Albian-Cenomanian boundary

Boundary criteria for the Albian-Cenomanian boundary which were under discussion in the first International Symposium on Cretaceous Stage Boundaries (BIRKELUND *et al.* 1984, HANCOCK, 1984) in Copenhagen.

Ammonite-based zonation

- Base of the *Hypoturrilites schneegansi* Zone established by DUBOURDIEU (1956) on the basis of Cenomanian sections in Tunisia and Algeria.
- Base of the *Graysonites adkinsi* Zone, first defined in Texas (MANCINI, 1979), but widely distributed in Tethyan and Pacific regions.
- Base of the *Neostlingoceras carcitanense* Zone in the Cenomanian of Europe.

[In many areas of the Northern Lower Temperate Realm (Boreal) there is a more or less important sedimentological hiatus between the Albian and Cenomanian].

- Base of the *Mariella (Wintonia) brazoensis* Zone underlying the *Graysonites adkinsi* Zone in Texas (YOUNG, 1957). This zone was not recognised outside of Texas till now and was not recommended.

Microfossil-based zonation

- LO of the planktonic foraminiferan *Planomalina buxtorfi* happens slightly earlier than the FO of the ammonite

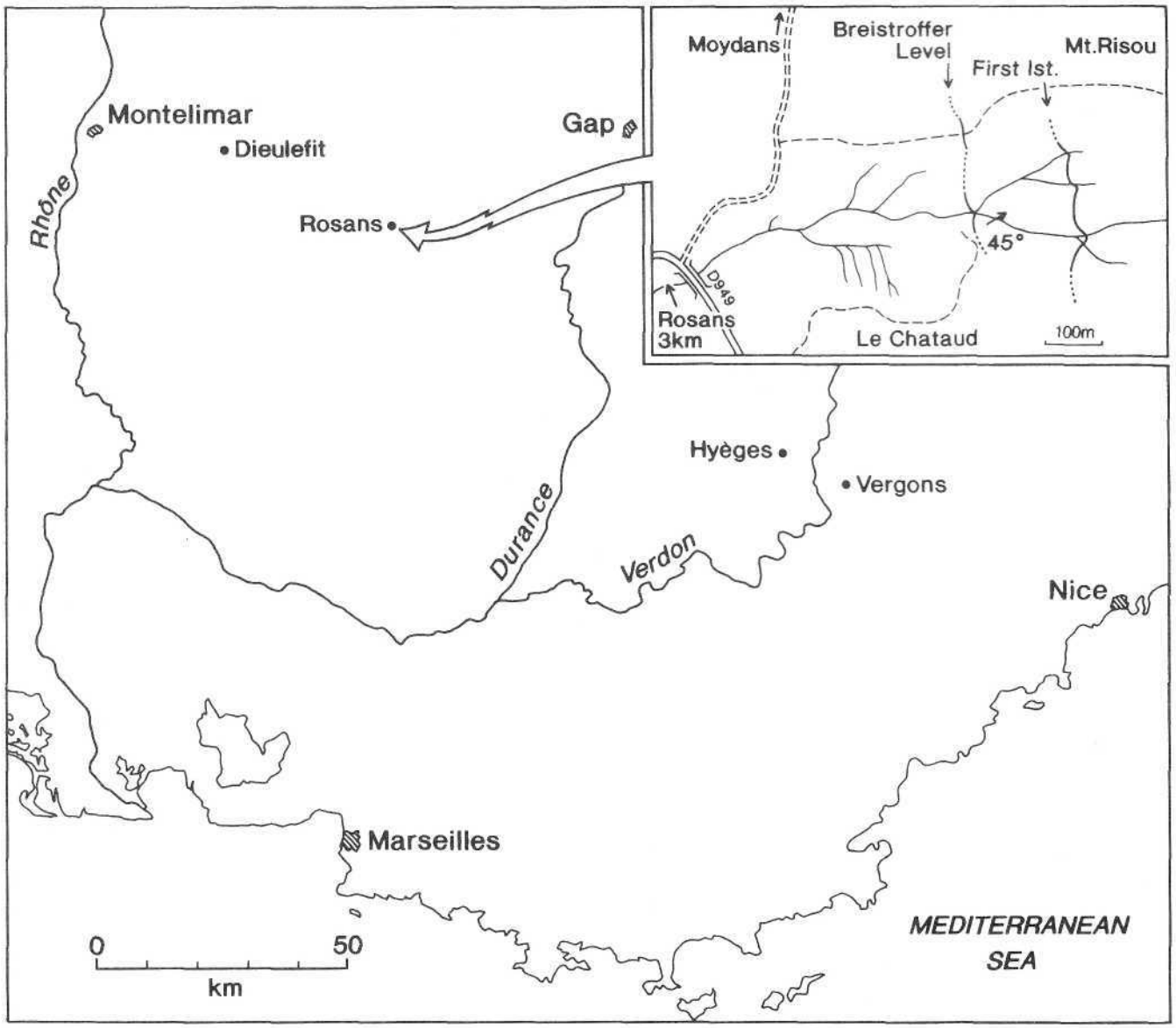


Fig. 1 — Locality map showing the position of the Mont Risou outcrops (from GALE *et al.*, 1996).

Hypoturrilites schneegansi. The occurrence of *Pl. buxtorfi* just below the Cenomanian is coincident with a flood occurrence of *Globigerinelloides bentonensis* (Morrow) used as Albian-Cenomanian boundary over the North Sea Basin (HART *et al.*, 1981).

- In Tethyan shelf carbonate successions the foraminiferal genus *Orbitolina* is useful: FOs of *O. (Orbitolina) concava concava* and *O. (O.) conica* are used at this level.
- The FO of the coccolith *Eiffelithus turriseiffellii* below the base of *Hypoturrilites schneegansi* can be traced in Tethyan and Boreal Realms.

Suggested stratotype

GALE *et al.* (1995, 1996) presented a proposal for a potential Albian-Cenomanian boundary stratotype at Mont Risou near Rosans (Hautes-Alpes, France) with boundary criteria. The base of the Cenomanian stage corresponds to the base of the widely recognised *Mantelliceras mantelli* Zone at Mont Risou. If *Mantelliceras mantelli* is absent, *Neostlingoceras* is a proxy ammonite.

Using a *planktonic foraminiferal succession* in the Mont Risou section GALE *et al.* explain:

"There are two possible planktonic foraminiferan proxy markers for the Albian-Cenomanian boundary, defined by the ammonite fauna at -30 m:
The first occurrence of *Rotalipora globotruncanoides* at -36 m, and its common occurrence at -27 m. The latter is a more reliable datum. It should be noted, that these planktonic foraminifera datums are only 6 m below and 3 m above the ammonite datum in what is a highly expanded section, while the first occurrence of *Rotalipora globotruncanoides* in the Kalaat Senan region of Central Tunisia (ROBASZYNSKI *et al.* 1993, 1994) is also just below the base of the Cenomanian as defined by ammonites".

Bivalve succession

Not mentioned in Copenhagen, but useful for zonation at Mont Risou is the bivalve succession. *Aucellina* is common in the Upper Albian and extends into the basal Cenomanian strata in England, France, Germany, Poland and Russia (*Aucellina/ultimus* event). Two inoceramid species are overlapping in one bed at Mont Risou. In the basal layers *Inoceramus anglicus* (WOODS, 1912, pl. 45, figs. 8-10, text-fig. 29), extending from the Upper Albian to the Lower Cenomanian, were observed. In the hanging wall (upper part of the *Neostlingoceras carcitanense* Zone) *Inoceramus crippsii crippsii* Mantell is common. The Lower Cenomanian begins with *Inoceramus crippsii crippsii* Mantell in the case of a sedimentological hiatus. This is typical for many sections in Germany, Poland and Russia.

Substage boundaries

LOWER / MIDDLE CENOMANIAN BOUNDARY

Ammonite succession

KENNEDY (1995) defines this boundary with the first appearance of the genera *Acanthoceras* and *Cunningtoniceras* above beds with *Mantelliceras*. The lowest ammonite fauna of Middle Cenomanian age is characterised by *Cunningtoniceras* (Sarthe: KENNEDY & JUIGNET, 1993; Boulonnais: ROBASZYNSKI *et al.*, 1994; S. England: PAUL *et al.*, 1994; Tunisia: ROBASZYNSKI *et al.* 1993, 1994; Turkmenia: ATABEKIAN, 1985; Texas: KENNEDY & COBBAN, 1990).

According to KENNEDY (1995) the lowest Middle Cenomanian faunas are characterised by different species of the genus *Cunningtoniceras* (*C. inerme, C. cunningtoni*) rather than *Acanthoceras rhotomagense* in the Northern Lower Temperate Realm and Tethyan Realm.

Bivalve succession

The proposed boundary agrees with the first rare appearance of *Inoceramus schoendorfi* Heinz together with *I. crippsii hoppenstedtensis* Tröger, rare *I. crippsii crippsii* Mantell, *I. virgatus virgatus* Schlüter and *I. virgatus scalprum* J. Böhm.

MIDDLE/UPPER CENOMANIAN BOUNDARY

Ammonite succession

Referring to the ammonites there is a disagreement in the position of the *Acanthoceras jukesbrownei*-Zone. This zone is placed in the Middle Cenomanian by many authors but in the Upper Cenomanian by others. KENNEDY (1995) explains:

"There is thus a need for a decision on the principle of where to place the *Ac. jukesbrownei*-Zone, in the Middle versus Upper Cenomanian. My own view is that the base of the *jukesbrownei*, marked by the first appearance of the index species, is not a good datum for the base of the Upper Cenomanian substage. *Ac. jukesbrownei* has a very limited geographic distribution with records from southern England, the Boulonnais south to Sarthe, Provence, Ariège in France, Germany, Poland and Turkmenia only. A better datum, likely to be more widely recognised, is the top of the *jukesbrownei* Zone, marked by the replacement of *Acanthoceras* by *Calycoceras (Calycoceras)* and *Cal. (Proeucalycoceras)*, a boundary in keeping with HANCOCK's original faunal concepts, reiterated subsequently (HANCOCK 1960, 1991; HANCOCK *et al.*, 1993). The name of the zone above the *jukesbrownei*-Zone is, however, a matter of contention.

Cal. (Calycoceras) naviculare (Mantell) originally used as index species, is absent from the lower part of

the zone, and extends into the succeeding *Metoiococeras geslinianum*-Zone and correlatives. Indeed it is the commonest in this zone in the United States Western Interior, and the holotype comes from this level in Sussex, England.

Eucalycoceras pentagonum (Jukes-Browne) was proposed as a substitute index by JUIGNET & KENNEDY (1976), but it too first appears well above the extinction point of *Acanthoceras jukesbrownei* and extends into the succeeding *geslinianum/gracile*-Zone in Sarthe and Alpes-Maritimes in France, South Dakota and Colorado in the USA.

A third substitute index species, *Calycoceras (Proeucalycoceras) guerangeri* (Spath) was proposed by WRIGHT *et al.* (1984). The first occurrence of this species is significantly lower than that of both *Calycoceras (Calycoceras) naviculare* (Mantell) and *Eucalycoceras pentagonum* (Jukes-Browne) while its geographic distribution from southern England to Sarthe, Alpes-Maritimes and Alpes-de-Haute-Provence in France, Portugal(?), Tunisia and New Mexico (USA) spans Boreal and Tethyan Realms''.

Bivalve succession

The top of the *jukesbrownei* Zone nearly agrees with the first appearance of *Inoceramus pictus pictus* Sowerby, widely distributed in the Boreal and Pacific realms. The *jukesbrownei* Zone is characterized by *I. atlanticus* Heinz.

PROPOSALS PRESENTED AT THE BRUSSELS SYMPOSIUM (11-14 September 1995)

After intensive and extensive discussions concerning biostratigraphic, lithostratigraphic, taxonomic problems and problems of preservation the working group presented the following proposals:

• **The basal boundary criterion for the Cenomanian stage should be the first appearance of the planktonic foraminiferan *Rotalipora globotruncanoides* SIGAL, 1948.**

Votes were unanimously in favour (17 yes, no abstentions).

• **Possible basal boundary stratotypes for the Cenomanian Stage:**
Mont Risou near Rosans in southeastern France (proposed by A. S. Gale, W. J. Kennedy, J. A. Burnett, M. Caron & J. D. Marshall)

Section in the Kalaat Senan region, N. of Kef el Azreg, Tunisia (proposed by F. Robaszynski, F. Amédro, C. Dupuis, J. Hardenbol)

[Section described by ROBASZYNSKI *et al.* (1993, 1994) from near Kef el Azreg, Tunisia, as a candidate for the official Albian-Cenomanian boundary stratotype. This section was discussed at length at the Brussels meeting, and a preliminary decision taken to designate it as a subsidiary reference section. As at Mont Risou, *Rotalipora globotruncanoides* first occurs a short distance below the first record of the ammonite *Mantelliceras*, and there is an interval of 18.5 m between the last *Cantabrigites* and the first *Mantelliceras*, but *Mortoniceras (Durnovarites)* extends to within 1 m of the first *Mantelliceras*. (ROBASZYNSKI *et al.*, 1994, fig. 12) rather than the 98 m interval present at Mont Risou].

After intensive discussions a vote was taken for the **acceptance of the Mont Risou section as a stratotype (GSSP) for the Cenomanian basal boundary**.

Votes: 17 yes, 6 no, 4 abstentions.

In the light of this vote in favour of the Mont Risou section, it was decided that **the proposed section in Tunisia was proposed as reference section in the Tethyan Realm.**

The evidence from nannofloral occurrences, phosphatisation of ammonites and other fossils and channelling of the basal contact suggested, that there was condensation or even a non sequence in the basal Lower Cenomanian part of the Tunisian section.

• **The basal boundary criterion for the Middle Cenomanian substage should be situated at the first appearance of the ammonite *Cunningtoniceras inerme* with the entry of *Inoceramus schoendorfi* and *Rotalipora reicheli* as secondary markers.**

Votes: 17 yes, 3 abstentions.

Three potential basal boundary stratotypes for the Middle Cenomanian substage were discussed:
• Southerham Grey Quarry, Lewes, Sussex, England.

• The coastal section between Folkestone and Dover, Kent, England.

• The coastal section at Cap Blanc Nez, Boulonnais, Northern France.

According to the postal vote (extended deadline till 15.01.96) the **Cenomanian W.G. proposed the Southerham Grey Quarry section at Lewes in Sussex (England) as stratotype for the Lower-Middle Cenomanian boundary**.

Votes: in favour of the Southerham Grey Quarry: 12; in favour of the Folkestone-Dover coastal section: 1, in favour of the Cap Blanc Nez, Boulonnais coastal section: none; abstentions: 2

• **Basal Upper Cenomanian boundary**

In the case of the lower boundary criterion for the Upper Cenomanian substage no agreement was reached. The following possible boundary criteria were discussed:

a. The entry of *Acanthoceras jukesbrownei*

b. The upper limit of *Acanthoceras jukesbrownei*

c. The entry of *Calycoceras (Proeucalycoceras) guerangeri*

d. The entry of *Calycoceras naviculare*

e. The entry of *Eucalycoceras pentagonum*

f. The entry of the *Inoceramus pictus* - group

It was considered that criteria **d** and **e** were currently unsatisfactory in view of insufficient data on these taxa. The discussion then concentrated on the criteria **a, b, c,** and **f.**

It was recommended, that a working party chaired by F. Robaszynski should investigate these criteria in more detail in sections in southern France, which may well prove the best potential substage boundary stratotype. F. Robaszynski accepted this proposal.

DESCRIPTION OF THE CANDIDATE GLOBAL REFERENCE SECTION FOR THE BASAL CENOMANIAN AT MONT RISOU, SE FRANCE

The Albian-Cenomanian boundary succession at Mont Risou, 5 km E of Rosans, Hautes-Alpes, France (Figure 1, p. 58) is described in detail in GALE *et al.* (1996). In this succession, the Albian-Cenomanian boundary falls in an expanded, continuous sequence, deposited in the rapidly subsiding Vocontian Basin.

Macrofaunas are of mixed Boreal and Tethyan affinities, and the sequence yields ammonites, inoceramid bivalves, nannofossils and planktonic foraminifera, and preserves an original stable isotope record. The outcrops cover many thousands of square metres, the sequence is rapidly eroding with good access.

The base of the Cenomanian was defined in Brussels by the first occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides* SIGAL, 1948 with the Mont Risou section as the global reference section, where the datum level lies 36 m below the top of the Marnes Bleues Formation as defined by a zero datum limestone at the base of the succeeding limestone.

The Vocontian Basin underwent rapid subsidence from the Middle Jurassic (Callovian) to the Late Cretaceous, and thick successions of deep-water pelagic limestones and hemipelagic marls accumulated. In this region, the Aptian, Albian and earliest Cenomanian stages are represented by up to 750 m of **the Marnes Bleues Formation**, comprising rhythmically bedded dark marls, with distinctive horizons of laminated organic-rich black shales, rare marly limestones, clastic turbidites and slumps. Condensed horizons are infrequent, and represented by glauconitic beds.

In the upper part of **the Marnes Bleues** (Figure 2), a distinct and widely traceable horizon (Br: **Breistroffer Level** of BRÉHÉRET, 1988a) is about 10 m in thickness and includes beds of laminated, dark grey marls. From these BRÉHÉRET (1988b) recorded a ''Vraconian'' (Late Albian) fauna. Above, the uppermost 100 m of the Marnes Bleues comprise grey marls containing infrequent barytes-cemented concretions, small pyritised fossils and concretions, and prominent-weathering thin (10-30 cm) units containing more carbonate. Pyritised ammonites are locally common and are well-known for the presence of a rich Tethyan ammonite assemblage (JACOB 1907; THOMEL 1987, 1992) regarded as both Upper Albian and Lower Cenomanian by previous authors.

1-2 m beneath the top of the formation is a thin (< 0.3 m), dark marl containing small concretions of iron pyrites, abundant small pectinids (*Syncyclonema*) and ammonites, especially *Idiohamites, Algerites* and *Sciponoceras.*

The base of the overlying **un-named formation** of marly limestones and marls of Cenomanian age is marked everywhere in the basin by a bundle of 4-5 thin (0.1-0.2 m) limestones which locally form a low scarp near the top of the badlands cut in the Marnes Bleues. The base of the lowest limestone provides a distinctive zero datum against which faunas in the underlying marls can be located. A succession of weaker limestone bundles are overlain by some 20 m of marls which display few bedding features. Above, thick bundles containing up to 15 thin marly limestones alternate with dark marls. The bivalve *Inoceramus crippsii crippsii* Mantell, is abundant from +52 to +62 m.

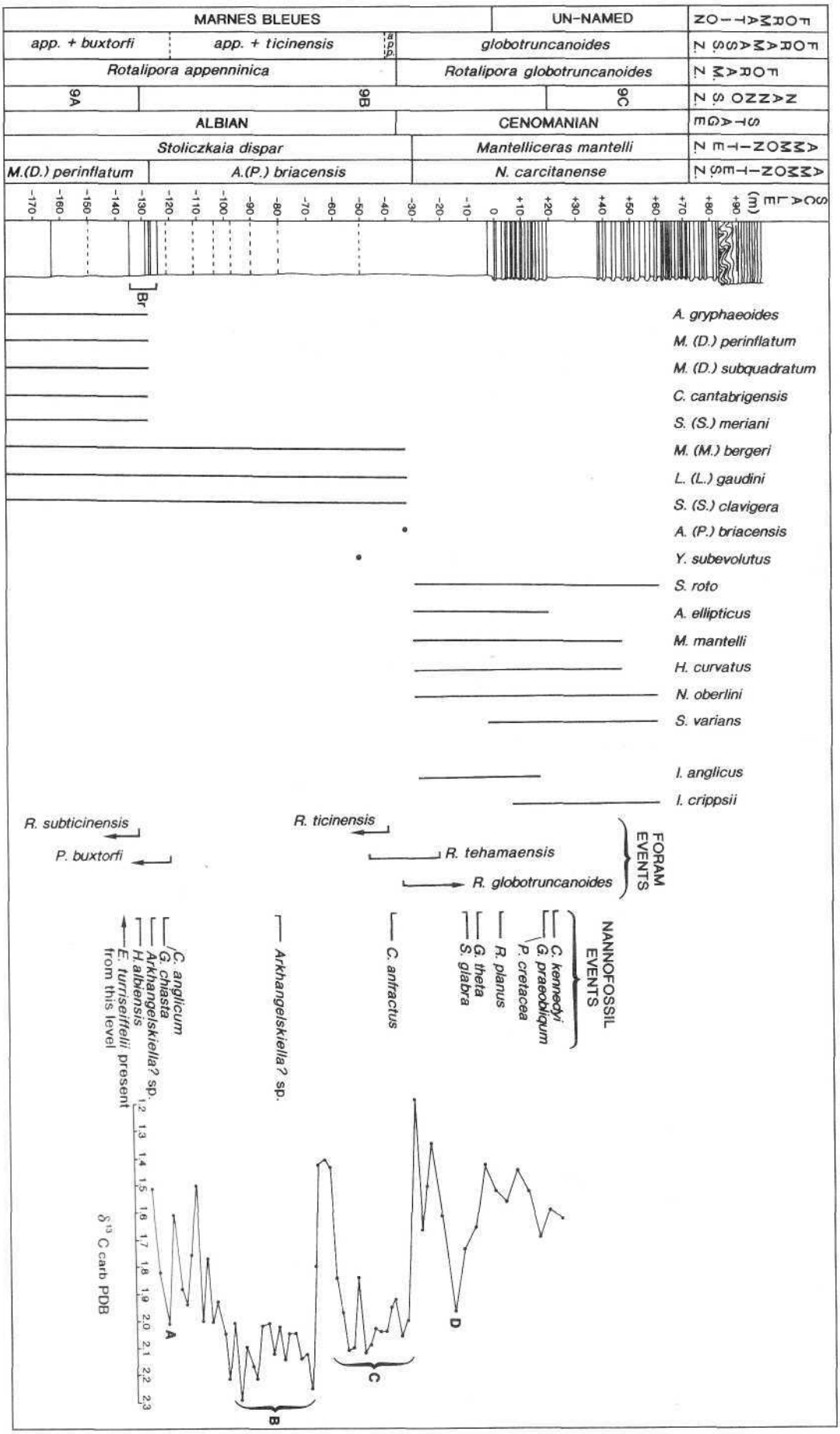
The best Albian/Cenomanian transition is visible on the west side of Mont Risou, north of Le Chataud, where a continuously accessible succession of nearly 250 m, from the Breistroffer Level in the Marnes Bleues to a horizon 85 m above the base of the overlying Cenomanian marly limestones and marls (Figure 2).

The planktonic foraminiferal succession

CARON *in* GALE *et al.* (1996) examined planktonic foraminifera from the Marnes Bleues Formation spanning levels -136 to -15 m (Figure 3).

The following bioevents were recognised:

(1). Abundant *Planomalina buxtorfi* to -120 m and its absence above -116 m.
(2). *Costellagerina libyca* from -112 m to -136 m (base of the sampled interval).
(3). Diverse *Rotalipora* association, with *R. ticinensis*


MARNES BLEUES
UN-NAMED
app. + buxtorfi
app. + ticinensis
globotruncanoides
Rotalipora appenninica
Rotalipora globotruncanoides
9A
9B
9C
ALBIAN
CENOMANIAN
Stoliczkaia dispar
Mantelliceras mantelli
M.(D.) perinflatum
A.(P.) briacensis
N. carcitanense
(m)
Br
A. gryphaeoides
M. (D.) perinflatum
M. (D.) subquadratum
C. cantabrigensis
S. (S.) meriani
M. (M.) bergeri
L. (L.) gaudini
S. (S.) clavigera
A. (P.) briacensis
Y. subevolutus
S. roto
A. ellipticus
M. mantelli
H. curvatus
N. oberlini
S. varians
I. anglicus
I. crippsii
R. subticinensis
P. buxtorfi
R. ticinensis
R. tehamaensis
R. globotruncanoides
FORAM EVENTS
NANNOFOSSIL EVENTS
C. anglicum
G. chiasta
Arkhangelskiella? sp.
H. albiensis
E. turriseiffelii present from this level
Arkhangelskiella? sp.
C. anfractus
G. theta
S. glabra
R. planus
P. cretacea
C. kennedyi
G. praeobliquum
δ13C carb PDB
A
B
C
D

and *R. appenninica* from -40 m to the base of the sampled interval.
(4). Simultaneous appearance of *R. gandolfii* and *R. tehamaensis* at the -40 m level.
(5). First appearance of *R. globotruncanoides* at -36 m, which defines the base of the Cenomanian stage, following the preliminary conclusions of the Brussels meeting.
(6). Common *R. globotruncanoides* at -27 m.

The planktonic foraminiferal zonation of ROBASZYNSKI & CARON (*in* press) can be applied to the sequence, with the *Rotalipora appenninica* Zone extending from the base of the sampled interval to the first appearance of *R. globotruncanoides* at -36 m. The base of the succeeding *R. globotruncanoides* Zone is marked by the appearance of the index species. The *R. appenninica* Zone can be divided into three assemblage subzones in the Mont Risou section, the *R. appenninica* and *Planomalina buxtorfi* Subzone extends from the base of the sampled interval to -116 m, the *R. appenninica* and *R. ticinensis* Subzone from -116 to -40 m and the third Subzone corresponds to the interval from -40 to -36 m, where *R. appenninica* is present and *R. ticinensis* absent.

The ammonite succession
KENNEDY *in* GALE *et al.* (1996) presented the following scheme of assemblage Zones and Subzones:

SUBSTAGE	ZONE	SUBZONE
LOWER CENOMANIAN	*Mantelliceras mantelli*	*(Mantelliceras saxbii* *(Sharpeiceras schlueteri* *(Neostlingoceras carcitanense*
UPPER ALBIAN (part)	*Stoliczkaia dispar*	*(Arrhaphoceras (Praeschloenbachia) (briacensis* ((*(Mortoniceras (Durnovarites) (perinflatum* (*(Mortoniceras (Mortoniceras) (rostratum*

The lowest faunas from that part of the Mont Risou sequence (Figures 2) extend through more than 50 m of section. The range of *Mortoniceras (Durnovarites) perinflatum* defines the upper limit of its subzone at -126 m. Above, an interval of 96 m (-126 to -30 m) in which *Mortoniceras (Durnovarites)* and *Cantabrigites* are absent but *Stoliczkaia (S.) clavigera* present and represents SCHOLZ's (1973) *briacensis* Subzone (a specimen of the index species was found at -32 m).

The base of the overlying *Mantelliceras mantelli* Zone is marked by the appearance of the index species 2 m higher at -30 m. *Neostlingoceras oberlini* (DUBOURDIEU, 1953), a typical species of the *N. carcitanense* Subzone occurs at the same level and defines the base of the *carcitanense* Subzone, exactly coincident with the base of the *mantelli* Zone.

In ammonite terms the base of the Cenomanian at Mont Risou is the first occurrence of *Mantelliceras mantelli*, or *Neostlingoceras oberlini* at the -30 m level, that is to say 30 m below the first limestone bed in the sequence, the base of which defines the top of the Marnes Bleues, and 6 m above the boundary datum, the first occurrence of *Rotalipora globotruncanoides* at -36 m, in the uppermost part of the *briacensis* Subzone.

The bivalve succession
Although of low diversity, the inoceramid and *Aucellina* faunas from Mont Risou are important because they demonstrate the range of species in an expanded Albian-Cenomanian boundary sequence where they can be placed in relation to ammonite Subzones.

Aucellina are common but poorly preserved in the *perinflatum* Subzone at Mont Risou. The genus is absent above the Breistroffer Level (-135 to -126 m). [In England and Germany *Aucellina* species extends into the Early Cenomanian and can be a good markers for the base of the stage (MORTER & WOOD, 1983)].

A distinctive, undescribed *Inoceramus* is common throughout the Albian part of the succession at Mont Risou (see GALE *in* GALE *et al.*, 1996, figs. 21 f, j; 31, g? h).

Two *Inoceramus* species occur in the Cenomanian at Mont Risou, overlapping in a single bed only. *Inoceramus anglicus* Woods occurs infrequently in the *carcitanense* Subzone from -30 to +4 m. [Elsewhere the main occurrence of this species is in the Late Albian, although it also occurs in the *carcitanense* Subzone in Southern England, Germany and elsewhere in Europe].
Inoceramus crippsii crippsii Mantell is common in the upper part of the *carcitanense* Subzone at Mont Risou. *I. crippsii crippsii* is uncommon in the lower part of its range at Mont Risou (+4 m) but becomes abundant and attains large sizes in the 5 bundles of thin limestones between +52 and +62 m.

The nannofossil succession
BURNETT *in* GALE *et al.* (1996) recognised 153 nannofossil taxa from the samples at Mont Risou.

In nannofossil terms, the Albian-Cenomanian boundary falls within SISSINGH's (1977) NF Biozone CC9, as defined from the FO of *Eiffellithus turriseiffelii* to the FO of *Microrhabdulus decoratus*. This zone was originally

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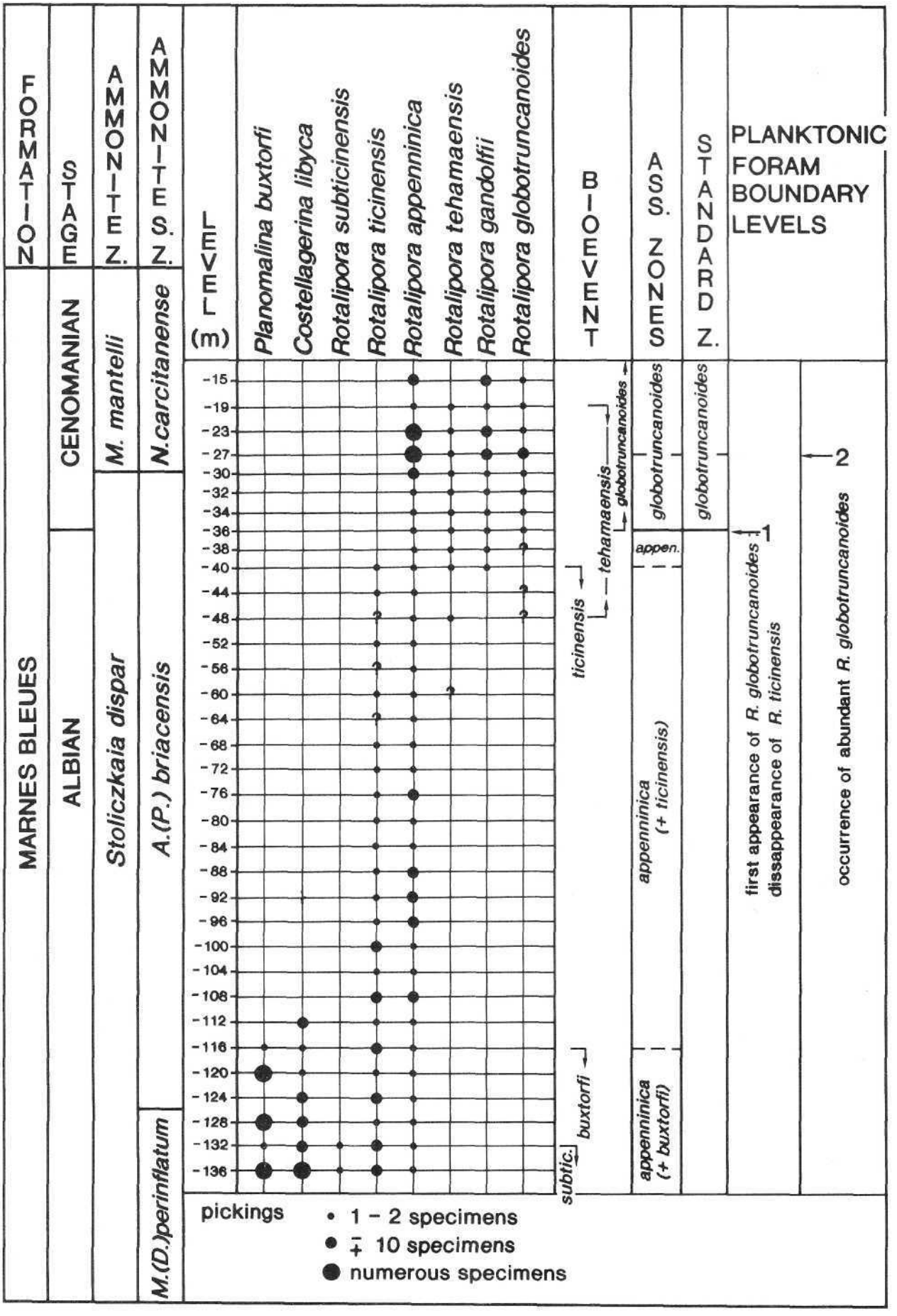
Fig. 2 — Integrated litho- and biostratigraphy across the Albian-Cenomanian boundary at Mont Risou. Selected macrofossil ranges, planktonic foraminiferan and nannofossil events, and the $\delta^{13}C$ curve are shown. A - D are specific peaks in the $\delta^{13}C$ curve mentioned in the text. Br = Breistroffer level (from GALE *et al.*, 1996).


FORMATION
MARNES BLEUES
STAGE
CENOMANIAN
ALBIAN
AMMONITE ZONE
M. mantelli
Stoliczkaia dispar
AMMONITE SUBZONE
N.carcitanense
A.(P.) briacensis
M.(D.)perinflatum
DEPTH (m)
-15
-19
-23
-27
-30
-32
-34
-36
-38
-40
-44
-48
-52
-56
-60
-64
-68
-72
-76
-80
-84
-88
-92
-96
-100
-104
-108
-112
-116
-120
-124
-128
-132
-136
Planomalina buxtorfi
Costellagerina libyca
Rotalipora subticinensis
Rotalipora ticinensis
Rotalipora appenninica
Rotalipora tehamaensis
Rotalipora gandolfii
Rotalipora globotruncanoides
BIOZONES
subtic.
buxtorfi
ticinensis
tehamaensis
globotruncanoides
appenninica (+ buxtorfi)
appenninica (+ ticinensis)
appen.
globotruncanoides
globotruncanoides
STANDARD Z.
globotruncanoides
PLANKTONIC FORAM BOUNDARY LEVELS
first appearance of R. globotruncanoides 1
dissappearance of R. ticinensis
occurrence of abundant R. globotruncanoides 2
pickings
• 1 – 2 specimens
● ∓ 10 specimens
● numerous specimens

lescribed from the Col de Palluel (Hautes-Alpes, SE France), based on the work of THIERSTEIN (1973), and has subsequently been subdivided by PERCH-NIELSEN (1979, summarised in 1985), using the LO of *Hayesites albiensis* and the FO of *Corollithion kennedyi*/LOs of *Watznaueria britannica* and *Braarudosphaera africana*. Thus, the boundary more precisely falls within NF Biosubzone CC9B, since the LO of *Hayesites albiensis* and the FO of *Corollithion kennedyi* were both recognised in the Mont Risou section (although only one specimen of each was found) (Figure 2).

The low nannofossil biostratigraphical resolution is not insurmountable. The Late Albian and Early Cenomanian encompassed a period of rapid and diverse evolution within the nannofossil family Arkhangelskiellaceae, specifically within the genera *Broinsonia, Crucicribrum* and *Gartnerago*.

The FO of *Corollithion kennedyi* was used by PERCH-NIELSEN, at the same level as the LOs of *Braarudosphaera africana* and *Watznaueria britannica*, as the first post-boundary marker. This easily-recognisable taxon was first described in 1981 and, therefore, has only rarely been cited in the literature, which mainly predates this.

Preservation of the nannoflora assemblages at the Mont Risou section is moderate throughout the sequence.

Examination of the complete and expanded Albian-Cenomanian sequence at Mont Risou has allowed a tentative sequence of events (including many from the Arkhangelskiellaceae) to be determined in relation to the established ones. These events are summarised in Figure 2.

Although the use of FOs which occur close to the base of the sequence studied may be suspect, since preservation or low abundances may have precluded their identification in the lower two samples, one was identified immediately above the LO of *Hayesites albiensis* (-132 m): the FO of *Arkhangelskiella*? sp. (-128 m). This is followed by the FOs of *Crucicribrum anglicum* and *Gartnerago chiasta* at -124 m. (N.B. PERCH-NIELSEN (1985) has the LO of the former taxon coinciding with the LO of *Hayesites albiensis*). All of these taxa are arkhangelskiellids. None are common (i.e. they occur in abundances of <1 specimen per field of view) but their stratigraphical ranges are reasonably consistent.

No apparently reliable events occur over the following 40 m. *Calculites anfractus* has its FO at -40 m, 4 m below the Albian-Cenomanian boundary, followed by the LO of *Staurolithites glabra* 24 m above the boundary at -12 m. Higher up the section, *Gartnerago theta* and *Radiolithus planus* have their FOs at -8 m and 0 m respectively. Four metres below the FO of *Corollithion kennedyi* (+20 m), are the apparently coincident FOs of *Gartnerago praeobliquum* and *Prediscosphaera cretacea sensu stricto*, at +16 m. The LOs of *Braarudo*sphaera *africana*, *Crucicribrum anglicum* and *Watznaueria britannica* occur stratigraphically higher.

If the FO of *Calculites anfractus* and the LO of *Staurolithites glabra* prove to be correlatable elsewhere, then these two taxa could define a nannofossil subzone around the boundary.

Carbon and oxygen isotope stratigraphy

Discussed in detail by GALE & KIDD *in* GALE *et al.* (1996).

– **Oxygen isotope record**

The $\delta^{18}O$ curve for the Risou section (Figure 4) shows small scale variance in the order of 0.3 for much of the lower, Albian, part of the succession, values mostly falling between -3.8 and -4.1. In the Cenomanian part of the section above (-30 m up to + 20 m) values rise to a maximum value of -3.5. The possibility that these values are altered by the addition of isotopically light cement during burial diagenesis has to be considered, because the Marnes Bleues in the Vocontian Basin have been buried up to several kilometres.

– **Carbon isotopes**

$\delta^{13}C$ in carbonate sediments is relatively stable and more likely to survive the effects of burial diagenesis than are oxygen isotopes.

Additional evidence for a primary $\delta^{13}C$ signal in the Mont Risou section comes from the lack of correlation between lithologies and carbon isotope values.

The carbon curve (Figure 4) registers a broad overall peak (maximum values of 2.3 at -104 m) through much of the Mont Risou section, broken into four discrete peaks (lettered A, B, C, D in Figures 2 and 4) by sharp, short-lived falls of $\delta^{13}C$ of up to 0.8. These peaks and troughs do not correspond to lithological changes, are defined by numerous points, and thus probably represent secular change. Peak B registers the highest values which progressively fall through C and D. However, to demonstrate convincingly the primary nature of the Mont Risou $\delta^{13}C$ signature, it is necessary to find similar coeval curves in other localities (cf. SCHOLLE & ARTHUR, 1980).

Carbon curves based on bulk carbonate analyses across Albian-Cenomanian boundary sections have been published previously by JENKYNS *et al.* (1994, fig 10) for Gubbio, Marche, Italy, and by MITCHELL & PAUL (1994, fig. 1) for the section at Speeton in Yorkshire, England, both based on whole-rock analyses.

The sequence of biostratigraphic and lithological marker events in the Mont Risou sequence

Figure 2 summarizes the distribution of selected key lithological, isotopic, faunal and floral events across the Albian-Cenomanian boundary in the Marnes Bleues succession at Mont Risou: from oldest to youngest:

←

Fig. 3 — Planktonic foraminiferan occurrences across the Albian-Cenomanian boundary in the Mont Risou section (from GALE *et al.*, 1996).

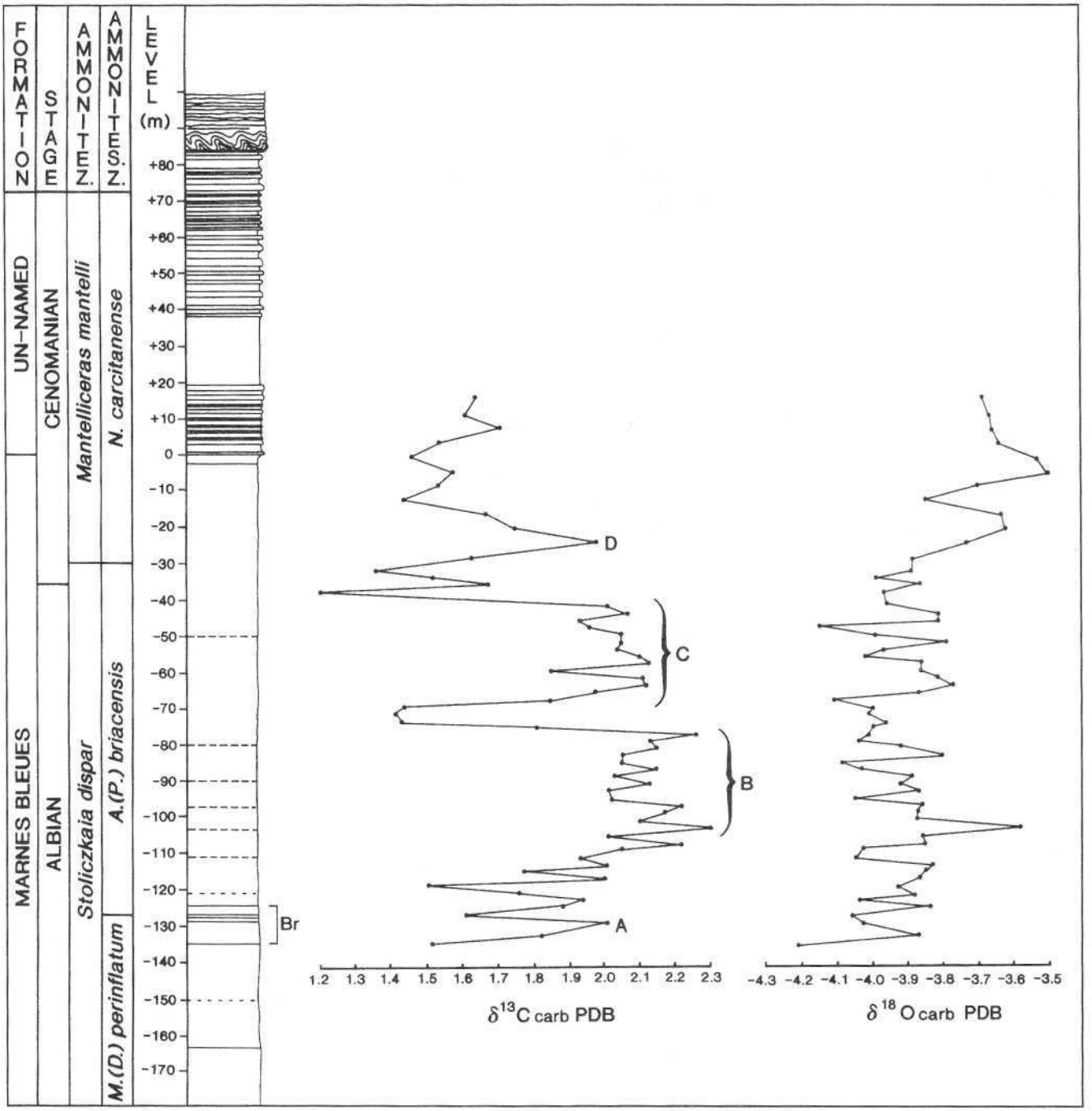


Fig. 4 — The $\delta^{13}C$ and $\delta^{18}O$ curves across the Albian-Cenomanian boundary in the Mont Risou section. A - D are specific peaks mentioned in the text. Br = Breistroffer level (from GALE *et al.*, 1996).

(1). Base of the Breistroffer Level at -135 m.
(2). LO of the planktonic foraminiferan *Rotalipora subticinensis* at -132 m.
(3). LO of the nannofossil *Hayesites albiensis*, also at -132 m.
(4). LO of the ammonites *Durnovarites* and *Cantabrigites*, also at -132 m.
(5). FO of the nannofossil *Arkhangelskiella*? sp. at -128 m.
(6). Top of the Breistroffer Level at -124 m.
(7). FO of the nannofossils *Gartnerago chiasta* and *Crucicribrum anglicum* at -124 m.
(8). LO of the planktonic foraminiferan *Planomalina buxtorfi* at -116 m.
(9). LO of the planktonic foraminiferan *Costellagerina libyca* at -112 m.
(10). LO of the nannofossil *Arkhangelskiella*? sp. at -80 m.
(11). FO of the planktonic foraminiferan *Rotalipora tehamaensis* at -48 m.
(12). LO of the planktonic foraminiferan *Rotalipora ticinensis* at -40 m.
(13). FO of the planktonic foraminiferan *Rotalipora gandolfii*, also at -40 m.

(14). FO of the nannofossil *Calculites anfractus*, also at -40 m.
(15). FO of the planktonic foraminiferan *Rotalipora globotruncanoides* at -36 m, which defines the base of the Cenomanian stage.
(16). LO of the predominantly Albian ammonites *Lechites gaudini*, *Stoliczkaia clavigera*, *Mariella miliaris* and *Hemiptychoceras subgaultinum* at -32 m.
(17). FO of the classic Cenomanian ammonite markers *Neostlingoceras oberlini*, *Mantelliceras mantelli*, *Hyphoplites curvatus* and *Sciponoceras roto* at -30 m.
(18). Common occurrence of the planktonic foraminiferan *Rotalipora globotruncanoides* at -27 m.
(19). LO of the nannofossil *Staurolithites glabra* at -12 m.
(20). FO of the nannofossil *Gartnerago theta* at -8 m.
(21). The zero datum, the first limestone in the sequence.
(22). FO of the nannofossil *Radiolithus planus* at the zero datum.
(23). FO of the nannofossils *Gartnerago praeobliquum* and *Prediscosphaera cretacea sensu stricto* at +16 m.
(24). FO of the nannofossil *Corollithion kennedyi* at +20 m.

The major faunal change in the ammonite fauna occurs between -30 and -32 m, with the disappearance of typical Albian taxa at -32 m and the appearance of typical Cenomanian taxa at -30 m, a short distance above the base of the Cenomanian as defined by the first appearance of *Rotalipora globotruncanoides* at -36 m.

At Mont Risou, a typical *N. carcitanense* Subzone fauna is found from -30 to +20 m, with elements ranging higher. Between +52 and +62 m five bundles of thin limestones yield abundant large *I. crippsii crippsii* and numerous inflated *Mantelliceras*.

The Albian-Cenomanian boundary in the eastern Anglo-Paris Basin can be shown by faunal correlation with Mont Risou to be marked by hiatus and condensation of a greater magnitude than hitherto suspected. This comprises two discrete parts: a gap represented by the terminal Albian surface, equivalent to 100-150 m of marls at Mont Risou, with part of the *perinflatum* Subzone and all of the *briacensis* Subzone missing, and the highly condensed Glauconitic Marl, which is represented by some 60-100 m of *carcitanense* Subzone marls and limestone at Mont Risou.

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References

ATABEKIAN, A. A., 1985. [Turrilitids of the late Albian and Cenomanian of the southern part of the USSR]. *Trudy Medved. Stratigrafii SSSR*, **14**, 112 pp. [in Russian]

BIRKELUND, T., HANCOCK, J. M., RAWSON, P.F., REMANE, J., ROBASZYNSKI, F.,SCHMID, F., SURLYK, F., 1984. Cretaceous Stage Boundaries-Proposals. *Bulletin Geological Society Denmark*, **33**: 3-20.

BRÉHÉRET, J.-G. 1988a. Episodes de sédimentation riche en matière organique dans les marnes bleues d'âge aptien et albien de la partie pélagique du bassin vocontien. *Bulletin de la Société Géologique de France*, (8) **4**: 349-386.

BRÉHÉRET, J.-G. 1988b. Organic-rich beds in the Aptian-Albian Marnes Bleues Formation of the Vocontian Basin. Pp. 203-227 *In:* BEAUDOIN, B. & GINSBURG, R. (Eds.). Cretaceous resources, events and rhythms. (Nato Advanced Workshop, Global Sedimentary Geology Programme. A commission of the International Union of Geological Sciences).

DUBOURDIEU, G. 1953. Ammonites nouvelles des Monts du Mellègue. *Bulletin du Service de la Carte Géologique de l'Algérie*. (1), Paléontologie, **16**: 76 pp.

DUBOURDIEU, G., 1956. Étude géologique de la région de l'Ouenza (confins algéro-tunisiens). *Bulletin du Service de la Carte géologique d'Algérie* NS **10**: 659 pp.

GALE, A. S., KENNEDY, W. J., BURNETT, J. A., CARON, M., MARSHALL, J. D., 1995. Mont Risou near Rosans (Hautes-Alpes, SE France); a potential Albian-Cenomanian boundary stratotype.- 19 pp. ,6 figs.

GALE, A. S., KENNEDY, W. J., BURNETT, J. A., CARON, M., KIDD, B.E.., 1996. The Late Albian to Early Cenomanian succession at Mont Risou near Rosans (Hautes-Alpes, S E France); an integrated study (ammonites, inoceramids, planktonic foraminifera, nannofossils, oxygen and carbon isotopes). *Cretaceous Research*, 17 (5): 515- 606.

HANCOCK, J. M., 1960. Les ammonites de la Sarthe. Comptes rendus Congrès Sociétés Savantes - Dijon 1959.- Colloque sur le Crétacé supérieur français: 249-252 (misdated 1959).

HANCOCK, J. M., 1984. Some possible boundary-stratotypes for the base of the Cenomanian and Turonian Stages. *Bulletin Geological Society Denmark*, **33**: 123-128.

HANCOCK, J. M., 1991. Ammonite scales for the Cretaceous system. *Cretaceous Research*, **12**: 259-291.

HANCOCK, J. M., KENNEDY, W. J. & COBBAN, W. A., 1993. A correlation of the Upper Albian to basal Coniacian sequences of Northwest Europe, Texas and the United States Western Interior. *Geological Association of Canada. Special Paper*, **39**: 453-476

HART, M. B., BAILEY, H. W., FLETCHER, B., PRICE, R. & SWIECICKI, A., 1981. Cretaceous. *In*: JENKINS, D. G. & MURRAY, J. W., Eds., Stratigraphical Atlas of Fossil Foraminifera. British Micropalaeontological Society. pp. 149-227; Ellis Horwood Ltd.

JACOB, C., 1907. Études paléontologiques et stratigraphiques sur la partie moyenne des terrains crétacés dans les Alpes françaises et les régions voisines. *Annales de l'Université de Grenoble*, **19:** 221-534 (published also in 1908 in *Travaux du*

Laboratoire de Géologie de l'Université de Grenoble, **8**: 280-590 and later in 1908 in *Bulletin de la Société de Statistique des Sciences Naturelles et des Arts Industriels du Département de l'Isère (Grenoble)*, (4), **10**: 201-514).

JENKYNS, H. C., GALE, A. S. & CORFIELD, R. M., 1994. Carbon- and oxygen- isotope stratigraphy of the English chalk and Italian scaglia and its palaeoclimatic significance. *Geological Magazine*, **131**: 1-34.

JUIGNET, P., 1974. La transgression crétacée sur la bordure orientale du Massif armoricain. Aptien, Albien, Cénomanien de Normandie et du Maine. Le stratotype du Cénomanien. Thèse Univ. Caen, 810 pp.

JUIGNET, P., 1980. Cénomanien. Pp. 130-138. *In:* CAVELIER, C. & ROGER, J., Les étages français et leurs stratotypes. *Mémoires du Bureau de Recherches géologiques et minières*, **139**: 295 pp.

JUIGNET, P. & KENNEDY, W. J., 1976. Faunes d'ammonites et biostratigraphie comparée du Cénomanien du nord-ouest de la France (Normandie) et du sud de l'Angleterre. *Bulletin trimestriel de la Société géologique de Normandie et Amis du Muséum du Havre*, **63**: 193 pp.

KENNEDY, W. J., 1984. Ammonite faunas and the 'standard zones' of the Cenomanian to Maastrichtian stages in their type areas, with some proposals for the definition of stage boundaries by ammonites. *Bulletin of the geological Society of Denmark*, **33**: 147-161.

KENNEDY, W. J., 1995. Ammonite definitions of Cenomanian substages. 9 pp. , 5 figs. (unpublished report)

KENNEDY, W. J. & COBBAN, W. A., 1990. Cenomanian Ammonite faunas from the Woodbine Formation and lower part of the Eagle Ford Group, Texas. *Palaeontology*, **33**: 75-154.

KENNEDY, W. J. & JUIGNET, P., 1993. A revision of the ammonite faunas of the Type Cenomanian, 4. Acanthoceratinae (*Acompsoceras, Acanthoceras, Protacanthoceras, Cunningtoniceras* and *Thomelites*). *Cretaceous Research*, **14**: 145 - 190.

KENNEDY, W. J. & JUIGNET, P., 1994. A revision of the ammonite faunas of the type Cenomanian, 6. Acanthoceratinae [Calycoceras (Proeucalycoceras), Eucalycoceras, Pseudocalycoceras, Neocardioceras], Euomphaloceratinae, Mammitinae and Vascoceratidae. *Cretaceous Research*, **15**: 469-501.

MANCINI, E. A., 1979. Late Albian and early Cenomanian ammonite biostratigraphy in North-Central Texas. *Journal of Paleontology*, **53**: 1013-1022.

MITCHELL, S. F. & PAUL, C. R. C., 1994. Carbon isotopes and sequence stratigraphy. Pp. 20-23 *In:* JOHNSON, S. D., (Ed.). High resolution sequence stratigraphy: Innovations and applications. Abstracts. 411 pp. (Department of Earth Sciences, Liverpool University, Liverpool).

MORTER, A. A. & WOOD, C. J., 1983. The biostratigraphy of Upper Albian - Lower Cenomanian *Aucellina* in Europe. *Zitteliana*, **10:** 515-529.

ORBIGNY, D' A., 1847. Paléontologie française. Terrains Crétacés IV. Brachiopodes. 390 pp. Masson, Paris.

PAUL, C. R. C., MITCHELL, S. F., MARSHALL, J. D., LEARY, P. N., GALE, A. S., DUANE, A. M. & et FITCHFIELD, P. W., 1994. Palaeoceanographic events in the Middle Cenomanian of Northwest Europe. *Cretaceous Research*, **15**: 707 - 738.

PERCH-NIELSEN, K., 1979. Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. *In:* WIEDMANN, J. (Ed.) Aspekte der Kreide Europas IUGS Series A6, 223-272, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

PERCH-NIELSEN, K., 1985. Mesozoic calcareous nannofossils. Pp. 329-346 *In:* BOLLI, H. M. *et al.* (Eds). Plankton Stratigraphy, Cambridge University Press, Cambridge.

ROBASZYNSKI, F., 1984: The Albian, Cenomanian and Turonian Stages in their type-regions. *Bulletin Geological Society of Denmark*, **33**: 191-198.

ROBASZYNSKI, F. & CARON, M., in press. Planktonic foraminifera zones. *In:* THIERRY, J. *et al.*, (Eds). Cretaceous chrono- and sequence stratigraphy of European Basins. Society of Economic Paleontologists and Mineralogists Special Publication.

ROBASZYNSKI, F., CARON, M., AMEDRO, F., DUPUIS, C., HARDENBOL, J., GONZALES-DONOSO, J. M., LINARES, D., GARTNER, S., 1993. Le Cénomanien de la région de Kalaat Senan (Tunisie Centrale). *Bulletin Centres Recherche Exploration-Production Elf-Aquitaine*, **17**: 395-433.

ROBASZYNSKI, F., CARON, M., AMEDRO, F., DUPUIS, C., HARDENBOL, J., GONZALES DONOSO, J. M., LINARES, D., GARTNER, S., 1994. Le Cénomanien de la region de Kalaat Senan (Tunisie Centrale). *Revue de Paléobiologie*, **12**: 351-505.

SCHOLLE, P. A. & ARTHUR, M. A. 1980. Carbon isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool. *American Association of Petroleum Geologists Bulletin*, **64**: 67-87.

SCHOLZ, G., 1973. Sur l'âge de la faune d'Ammonites au Château près de St-Martin-en-Vercors (Drôme) et quelques considérations sur l'évolution des Turrilitidés et des Hoplitidés vracono-cénomaniens. *Géologie Alpine*, **49**: 119-129.

SIGAL, J., 1948. Notes sur les genres de foraminifères *Rotalipora* Brotzen, 1942 et *Thalmmanninella*, famille des Globorotaliidae. *Revue Institut français du Pétrole*, **3**, n°4: 100.

SISSINGH, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. *Geologie en Mijnbouw*, **56**: 37-65.

THIERSTEIN, H. R., 1973. Lower Cretaceous calcareous nannoplankton biostratigraphy. *Abhandlungen der Geologischen Bundesanstalt*, **29**: 52 pp.

THOMEL, G., 1987. La famille des Tetragonitidae (Ammonoidea) dans le Cénomanien du sud-est de la France. *Annales de Paléontologie (Vertébrés-Invertébrés)*, **73**: 241-272.

THOMEL, G., 1992. Ammonites du Cénomanien et du Turonien du Sud-Est de la France. **1**, 422 pp. , 42 pls; **2**, 383 pp. , 130 pls. (Editions Serre, Nice).

WOODS, H., 1912. A monograph of the Cretaceous Lamellibranchia of England. *Palaeontographical Society Monographs*. Volume **2**: 261-284.

WRIGHT, C. W., KENNEDY, W. J. & HANCOCK, J. M., 1984. Introduction: 1-37. *In*: WRIGHT, C.W. & KENNEDY, W. J.. The Ammonoidea of the Lower Chalk. Palaeontographical Society Monographs.

YOUNG, K., 1957. Upper Albian (Cretaceous) Ammonoidea from Texas. *Journal of Paleontology*, **31**: 1-33.

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The Turonian stage and substage boundaries

by Peter BENGTSON (compiler)

with contributions by William A. Cobban, Paul Dodsworth, Andrew S. Gale, William James Kennedy, Marcos A. Lamolda, Tatsuro Matsumoto, Richard A. Reyment, Ekbert Seibertz and Karl-Armin Tröger.

Abstract

Formal definitions of the Cenomanian-Turonian and lower-middle Turonian boundaries are proposed, following discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995. The Global boundary Stratotype Section and Point (GSSP, "golden spike") for the Cenomanian-Turonian boundary should be placed at the base of Bed 86 in a section at Rock Canyon Anticline, west of Pueblo, Colorado, USA, coincident with the first occurrence of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981. A GSSP for the lower-middle Turonian boundary is proposed at the level of first occurrence of the ammonite *Collignoniceras woollgari* (MANTELL, 1822) in the same section (Bed 120). For the middle-upper Turonian boundary no GSSP can be proposed at present.

Key-words: Turonian, Upper Cretaceous, chronostratigraphy, biostratigraphy, cyclostratigraphy, carbon isotopes, ammonites, inoceramids, foraminifers, nannofossils, stratotypes, GSSP.

Résumé

Des définitions formelles sont proposées pour la limite Cénomanien-Turonien et pour la limite Turonien inférieur-moyen, suite aux discussions lors du "Second International Symposium on Cretaceous Stage Boundaries" (Bruxelles 8-16 septembre 1995). Le "Global boundary Stratotype Section and Point" (GSSP, "golden spike") pour la limite Cénomanien-Turonien devrait être placé dans une section à Rock Canyon Anticline, à l'ouest de Pueblo, Colorado, USA, à la base du Banc 86 qui coïncide avec la première apparition de l'ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981. Comme GSSP pour la limite Turonien inférieur-moyen la première apparition de l'ammonite *Collignoniceras woollgari* (MANTELL, 1822) dans la même section (Banc 120) a été proposée. Pour la limite Turonien moyen-supérieur aucun GSSP ne peut être proposé pour le moment.

Mots-clefs: Turonien, Crétacé supérieur, chronostratigraphie, biostratigraphie, cyclostratigraphie, isotopes du carbone, ammonites, inocéramidés, foraminifères, nannofossiles, stratotypes, GSSP.

Туронский ярус и границы подъяруса: предложения Рабочей Группы Туронского яруса Подкомиссии Меловой Стратиграфии.

Резюме.

Формальное определение Сеномано-Туронской и нижне-средней Туронской границ было предложено после обсуждений, прошедших в течение второго Международного Симпозиума (Брюссель, 8-16 сентября 1995), посвящённого Границам Меловых Ярусов. «Global boundary Stratotype Section and Point» (GSSP, «golden spike») для Сеномано-Туронской границы должен быть определён в разрезе Rock Canyon Anticline, на западе Pueblo, Колорадо, США, в основании Слоя 86, совпадающего с первым появлением аммонита *Watinoceras devonense* (WRIGHT & KENNEDY, 1981). В качестве GSSP для нижне-средней Туронской границы было предложено первое появление аммонита *Collignonoceras woollgari* (MANTELL, 1822) того же разреза (Слой 120). Что касается средне–верхнего Турона, то на данный момент предложить какой-либо GSSP не представляется возможным.

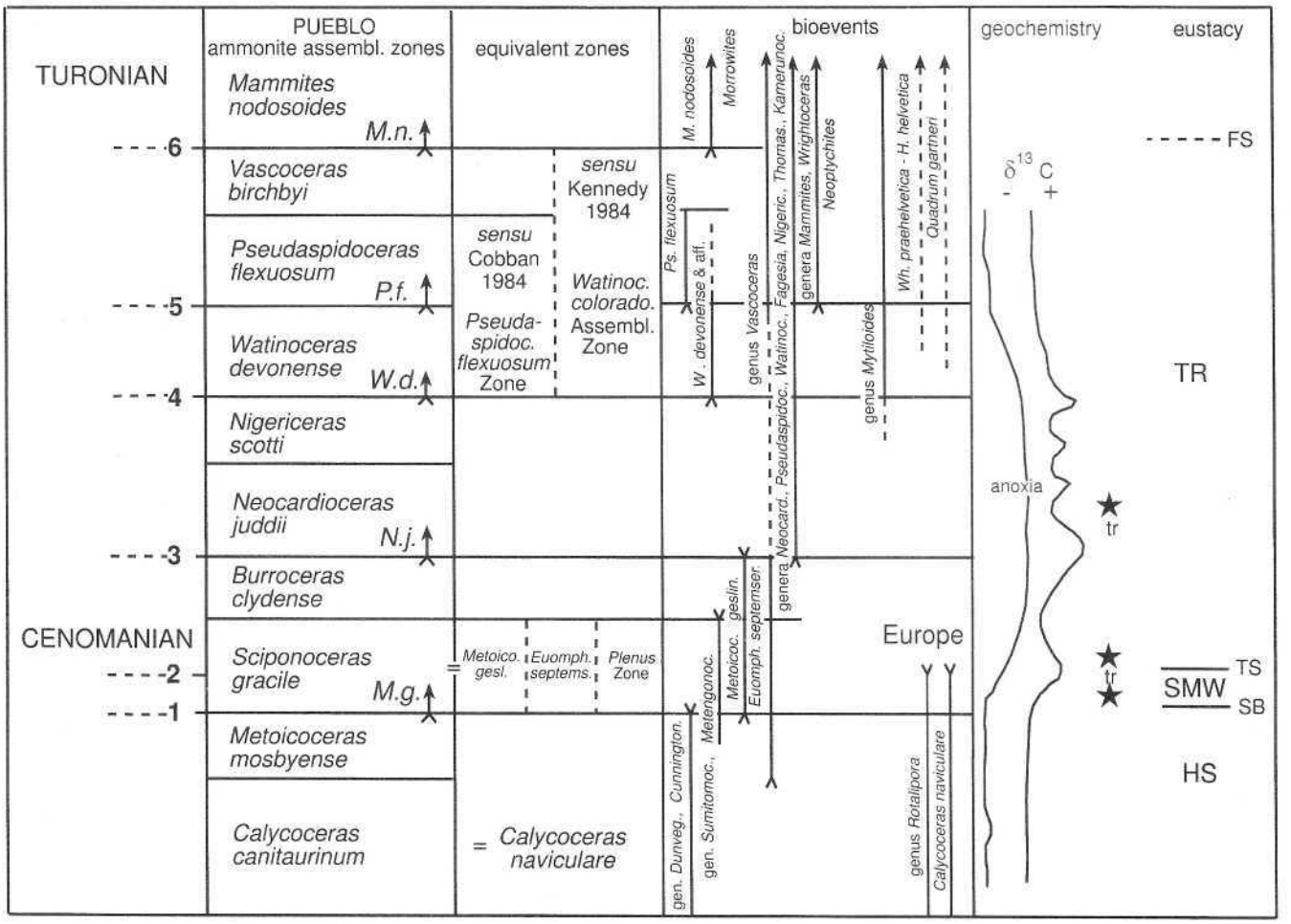
Ключевые слова: Туронский ярус, верхний мел, хроностратиграфия, биостратиграфия, циклостратиграфия, карбонические изотопы, аммониты, иноцерамы, фораминиферы, нанофоссилии, стратотипы, GSSP.

Introduction

The Turonian Working Group of the Subcommission on Cretaceous Stratigraphy has in recent years been primarily concerned with the definition of the bases of the Turonian substages. According to informal but well-established usage the Turonian Stage is best subdivided into three substages. Work has focused on agreeing about suitable chronostratigraphical levels for the bases of the lower, middle and upper Turonian substages, respectively, and on finding suitable boundary stratotypes in which these levels can be appropriately fixed through GSSPs (Global boundary Stratotype Sections and Points or, colloquially, golden spikes). The Cenomanian-Turonian boundary (i.e., the base of the [lower] Turonian) has become one of the least controversial among the Cretaceous stage boundaries. The reason for

[1] Stage (and substage) boundaries are chronostratigraphical datum planes and by definition globally isochronous. As biostratigraphical markers, such as first occurrences (FOs) of taxa or bases of biozones, are bound to be diachronous (no matter how insignificantly, geologically speaking) they cannot be used to define stage boundaries. The International Commission on Stratigraphy (REMANE 1995) recommends that stage boundaries should be defined by Global boundary Stratotype Sections and Points (GSSPs). Biostratigraphical or other markers in the rock record inferred to be nearly isochronous are then important instruments for the worldwide recognition of boundaries defined by GSSPs.

this is partly to be sought in the considerable international attention given to the Cenomanian-Turonian boundary in recent years, as a result of the discovery of a world-wide oceanic anoxic event and a possible mass extinction event near or at the boundary. In 1991, at Grenoble, France, an entire international symposium was devoted to the Cenomanian-Turonian boundary (cf. ROBASZYNSKI & GALE, 1993). The biostratigraphical ''definition'' [1] of the boundary has remained relatively stable during the past decade or so; this is also true of the lower-middle Turonian boundary, whereas the concept of the middle-upper Turonian boundary remains more elusive. The Turonian stage and substage boundaries are discussed here and proposals made for GSSPs for the Cenomanian-Turonian and lower-middle Turonian boundaries, respectively. These proposals are the main outcome of discussions at the Second International Symposium on Cretaceous Stage Boundaries, held in Brussels, 8-16 September 1995, and subsequent postal voting among the members of the Turonian Working Group.



Text-fig. 1 — Cenomanian-Turonian boundary stratigraphy, illustrated by the section at Rock Canyon Anticline, near Pueblo, Colorado, USA, showing six of the alternative levels for defining the boundary.

1. Base of the *Sciponoceras gracile-Metoicoceras geslinianum-Euomphaloceras septemseriatum-Actinocamax plenus* Assemblage Zone, with FO of *M. geslinianum* (D'ORBIGNY, 1850) and LOs of the genera *Dunveganoceras* and *Cunningtoniceras*. Commencement of $\delta^{13}C$ excursion. Sequence boundary.

2. LO of *Calycoceras naviculare* (MANTELL, 1822), approximately coincident with LO of the genus *Rotalipora*, notably *Rotalipora cushmani* (MORROW, 1934), at the transgressive surface, coincident with the first $\delta^{13}C$ maximum.

3. FOs of *Neocardioceras juddii* (BARROIS & DE GUERNE, 1878) and the genera *Pseudaspidoceras, Watinoceras, Fagesia*, etc. LOs of *M. geslinianum* and *E. septemseriatum* (CRAGIN, 1893), approximately coincident with the second $\delta^{13}C$ maximum.

4. FO of *Watinoceras devonense* WRIGHT & KENNEDY, 1981, approximately coincident with the FOs of the genus *Mytiloides* and *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977. $\delta^{13}C$ starts to fall.

5. FOs of *Pseudaspidoceras flexuosum* POWELL, 1963, and the genera *Mammites, Wrightoceras* and then *Neoptychites*.

6. FOs of *Mammites nodosoides* (SCHLÜTER, 1871) and the genus *Morrowites*. Flooding surface.

(Modified after ROBASZYNSKI & GALE, 1993, table 1.)

The Cenomanian-Turonian boundary (= base of the [lower] Turonian)

Historical review

A large number of biostratigraphical datums have been used historically and in more recent times as markers for the Cenomanian-Turonian boundary. In order to preserve continuity it is important that the boundary level to be chosen agree with the historical view as expressed by d'Orbigny (1850, 1852; see review by Wright & Kennedy 1981, p. 126). In terms of the traditional "standard" ammonite zonation this means that the boundary should be chosen so as to fall within the interval between the top of the *Metoicoceras geslinianum* ammonite Zone and the base of the *Mammites nodosoides* ammonite Zone as used by Wright & Kennedy (1981). Most of the boundary markers discussed at the first international meeting on Cretaceous stage boundaries, in Copenhagen 1983 (Birkelund *et al.*, 1984), fall within this interval (with a, g, h and possibly f lying below):

(a) Base of the *Metoicoceras geslinianum* ammonite Zone (or the slightly higher level of the FO of the ammonite *Euomphaloceras septemseriatum* [Cragin, 1893]).
(b) Base of the *Pseudaspidoceras flexuosum* ammonite Zone (or the FO of a vascoceratid such as *Vascoceras proprium* [Reyment, 1954]).
(c) Base of the *Watinoceras coloradoense* ammonite Assemblage Zone.
(d) A definition based on the *Mytiloides* inoceramid lineage.
(e) The appearance of a flood of representatives of the genus *Mytiloides* at the base of the *Mammites nodosoides* ammonite Assemblage Zone.
(f) The FO of the nannofossil *Quadrum gartneri* Prins & Perch-Nielsen, 1977 (in the *Neocardioceras juddii* ammonite Zone).
(g) The LO of the planktonic foraminifer genus *Rotalipora* in the *Metoicoceras geslinianum* ammonite Zone.
(h) The FO of the planktonic foraminifer *Whiteinella archaeocretacea* (Pessagno, 1967) in the middle of the *Metoicoceras geslinianum* ammonite Zone.
(i) The FO of the planktonic foraminifer *Helvetoglobotruncana helvetica* (Bolli, 1945), although this datum is arguably diachronous and the presence of "*praehelvetica*" is ambiguous.

Alternative c, i.e. the base of the *Watinoceras coloradoense* Zone, was cited as the boundary level currently accepted by most European ammonite workers. This level was also said to be close to that of alternative b, the base of the *Pseudaspidoceras flexuosum* Zone (although Kennedy & Cobban [1991, p. 23] have shown that the base of the *W. coloradoense* Zone in sections exposed near Pueblo, Colorado [= base of *W. devonense* Zone], is actually at a much lower level than that of the *P. flexuosum* Zone). Birkelund *et al.* (1984) concluded that alternative b, i.e. the base of the *Pseudaspidoceras flexuosum* Zone, gained some support during the meeting (although the zonal index has a restricted geographical distribution). Important support for that boundary definition is the widespread appearance of early representatives of the inoceramid genus *Mytiloides*.

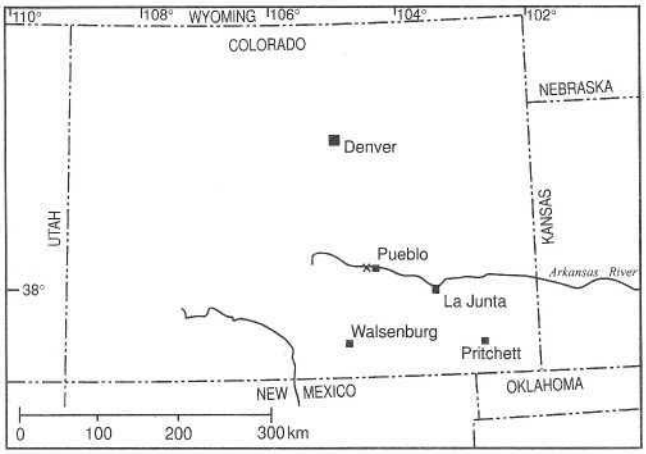
Birkelund *et al.* (1984) argued that a suitable boundary stratotype for alternative b should lie in Texas or Mexico, where both the *Pseudaspidoceras flexuosum* Zone and the underlying *Neocardioceras juddii* Zone are rich in ammonites. The section chosen should also contain *Mytiloides* and other groups such as planktonic foraminifers.

In the plenary session of the 1991 Grenoble meeting the boundary alternatives were discussed further and illustrated graphically by Robaszynski & Gale (1993; Text-fig. 1 herein). A section at Rock Canyon Anticline, near Pueblo, Colorado, USA, which had been studied in detail by Kennedy & Cobban (1991), was given serious thought as a possible boundary stratotype. Other sections mentioned, in the Niger Republic and Tunisia, were still incompletely known.

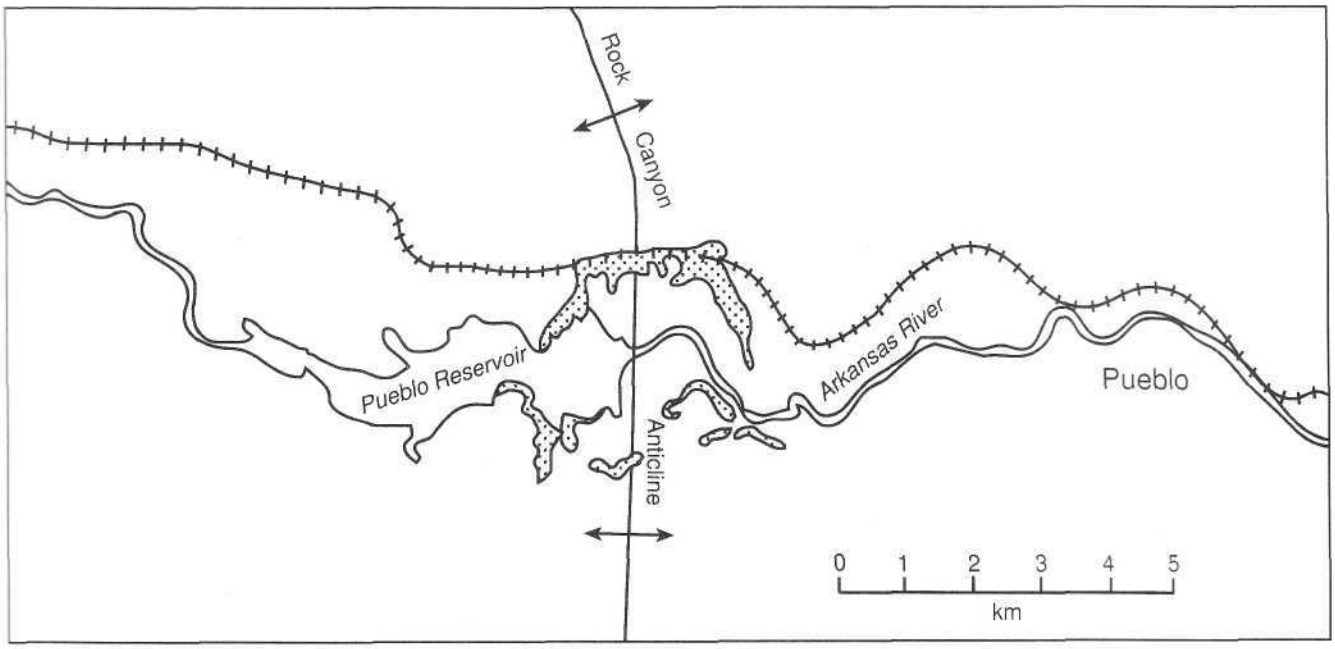
A detailed proposal for the section at Rock Canyon Anticline near Pueblo to be adopted as the Cenomanian-Turonian boundary stratotype and for the boundary point to be placed in this section at the FO of the ammonite species *Watinoceras devonense* Wright & Kennedy, 1981, was submitted by W. A. Cobban (Denver), A. S. Gale (London) and W. J. Kennedy (Oxford) (unpublished report, 1995; cf. Reyment, 1995) and circulated among the members of the Turonian Working Group before the Brussels meeting.

The section at Rock Canyon Anticline, near Pueblo, Colorado

A suitable section for the Cenomanian-Turonian boundary should include as many of the biostratigraphical



Text-fig. 2 — Location of the section at Rock Canyon Anticline, near Pueblo, Colorado, and other important Cenomanian-Turonian boundary sections in Colorado (from Kennedy & Cobban, 1991, fig. 1).



Text-fig. 3 — Sketch map of the area west of Pueblo showing outcrops (stippled) of the Cenomanian-Turonian boundary sequence around the axis of the Rock Canyon Anticline (from KENNEDY & COBBAN, 1991, fig. 7).

marker horizons listed above as possible, comprise a non-condensed succession without obvious gaps, be well-documented with respect to geochemical and isotope data and should furthermore be dated numerically. The section should also be well exposed, permanent and easily accessible. The section at Rock Canyon Anticline near Pueblo, Colorado (Text-figs 2-3), proposed herein, fulfils many of these criteria. The following description is largely adapted from KENNEDY & COBBAN (1991) and from the written proposal by W. A. Cobban *et al.* (unpublished report, 1995) to the Turonian Working Group.

The Rock Canyon Anticline section is known since the last century (e.g., STANTON, 1894). It was mapped by SCOTT (1964, 1970) and the ammonite faunas have been documented by COBBAN & SCOTT (1973), COBBAN (1985), COBBAN *et al.* (in press), ELDER (1985) and KENNEDY & COBBAN (1991). The inoceramid bivalves have been documented by ELDER (1991) and KENNEDY & COBBAN (1991), planktonic foraminifers by EICHER & DINER (1985), calcareous nannofossils by WATKINS (1985) and BRALOWER (1988), stable isotopes by PRATT (1981, 1983, 1984, 1985), PRATT & THRELKELD (1984) and PRATT *et al.* (1993), iridium anomalies by ORTH *et al.* (1988), and isotopic dating of correlative sections has been carried out by OBRADOVICH (1994). ELDER (1985, 1987), HARRIES & KAUFFMAN (1990) and HARRIES (1993) discussed extinctions across the Cenomanian-Turonian boundary. Additional information was given by PRATT *et al.* (1985).

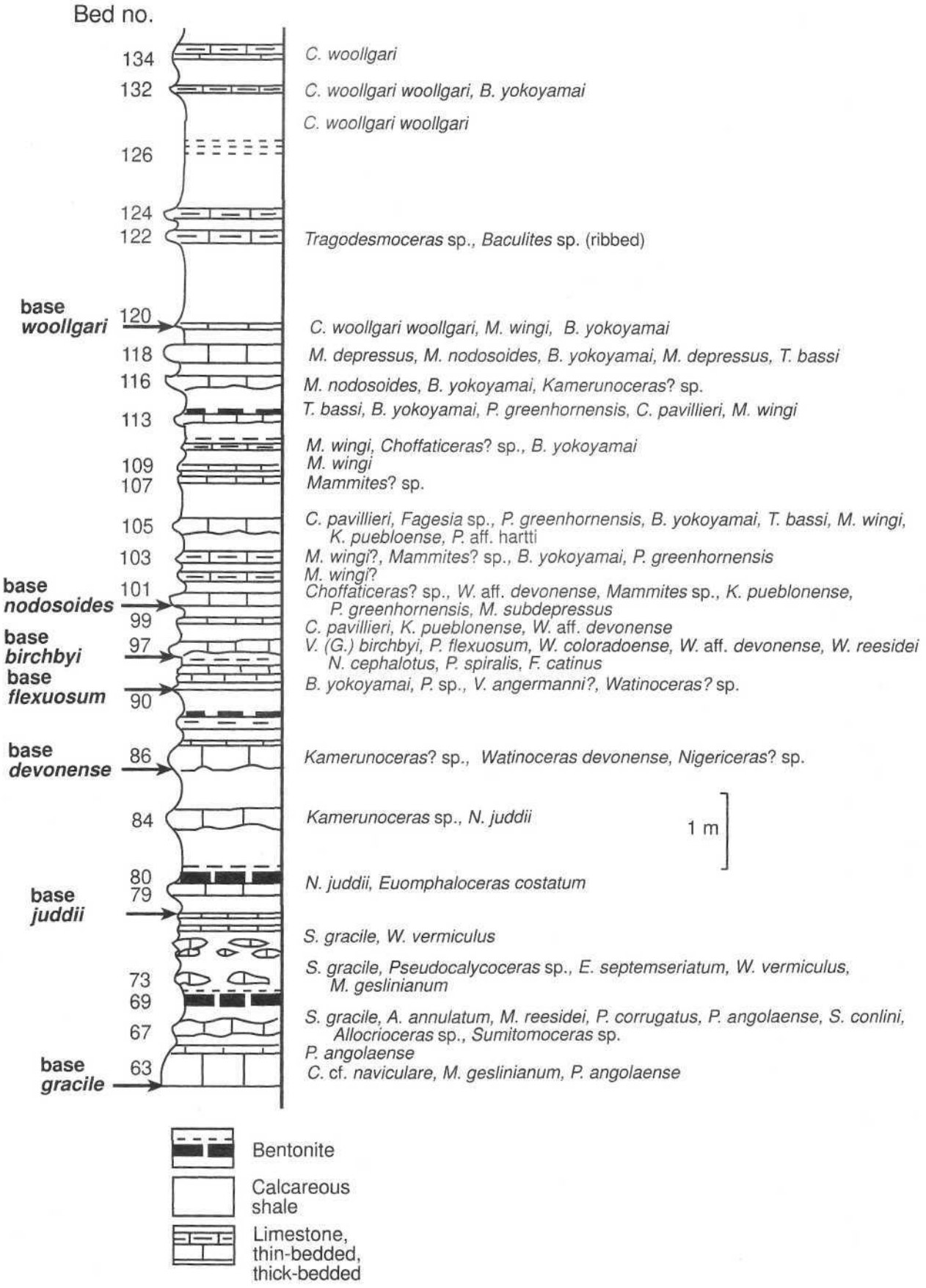
The sequence exposed at Rock Canyon Anticline shows no obvious signs of condensation or non-sequence across the boundary interval. It consists of diagenetically modified limestone-marl cycles and individual limestone and marl beds corresponding to the lower part of the Bridge Creek Member of the Greenhorn Limestone. Individual Milankovich couplets can be traced across a distance of 700 km into Kansas (e.g. HATTIN, 1971).

The proposed stratotype is in the Rock Canyon Anticline, west of Pueblo, where the Arkansas River cuts through the Cretaceous succession (Text-fig. 3). The construction of a dam and the development of a state park (the Pueblo Reservoir State Recreation Area) provide easy access by metalled roads. The section is permanent and lies in an area of natural badlands. Fossil collecting from natural outcrops in the state park is not permitted; however, relocation of the adjacent Denver and Rio Grande Western Railroad (Text-fig. 3) has provided several kilometres of fresh cuts through the boundary succession.

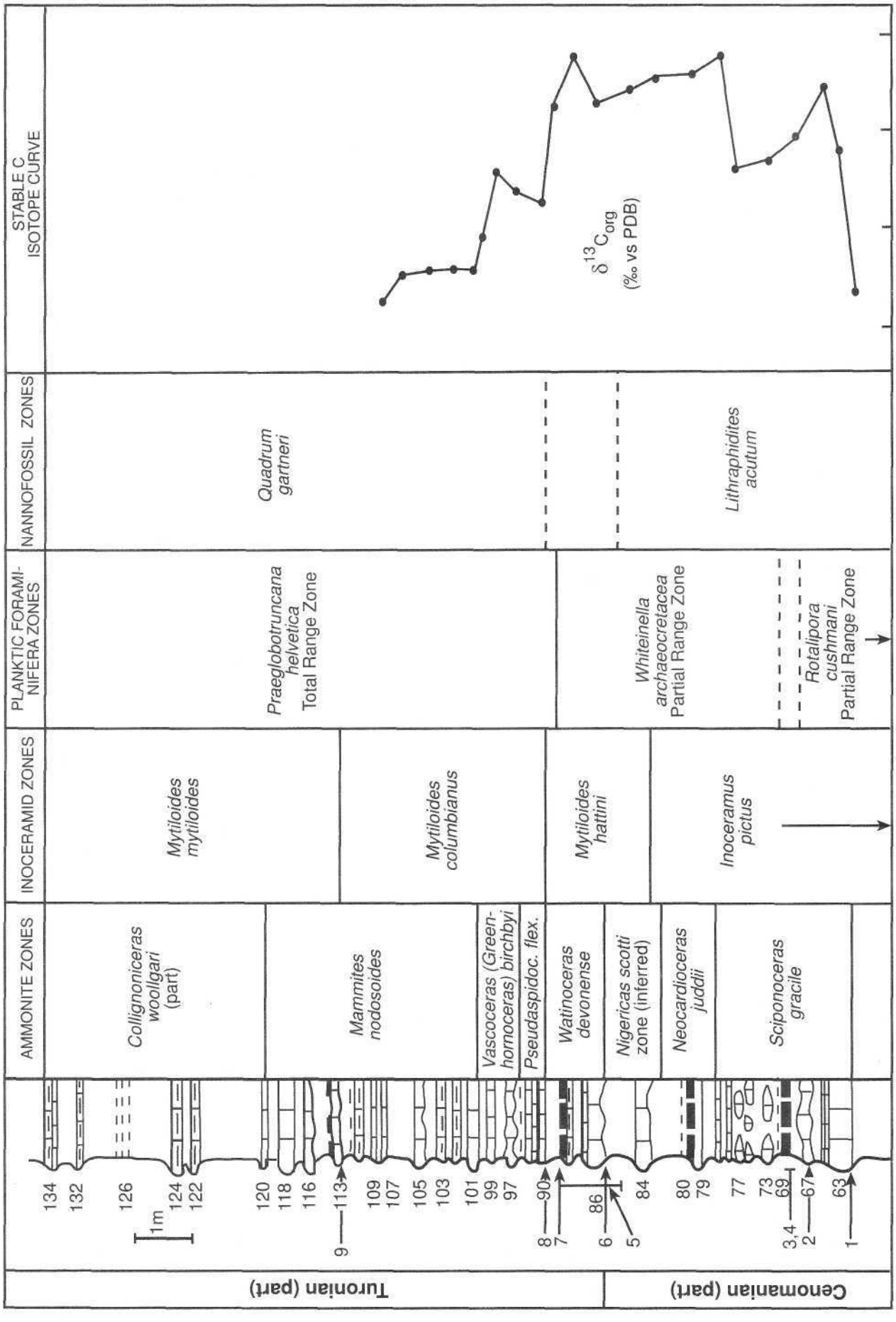
The ammonite zonation and succession at Rock Can-

ZONE	SUBSTAGE
Mammites nodosoides	LOWER TURONIAN
Vascoceras (Greenhornoceras) birchbyi	
Pseudaspidoceras flexuosum	
Watinoceras devonense	
Nigericeras scotti	UPPER CENOMANIAN (part)
Neocardioceras juddii	
Burroceras clydense	
Sciponoceras gracile	

Text-fig. 4 — The succession of ammonite zones across the Cenomanian-Turonian boundary in the southern U.S. Western Interior (from KENNEDY & COBBAN, 1991, fig. 2).



Text-fig. 5 — Stratigraphical chart of the part of the Rock Canyon Anticline sequence referred to the Cenomanian-Turonian boundary interval (beds 63-134), showing ammonite zonal boundaries and levels of species occurrences (after KENNEDY & COBBAN, 1991, fig. 8).


Cenomanian (part)
Turonian (part)
AMMONITE ZONES
INOCERAMID ZONES
PLANKTIC FORAMINIFERA ZONES
NANNOFOSSIL ZONES
STABLE C ISOTOPE CURVE
Collignoniceras woollgari (part)
Mammites nodosoides
Vascoceras (Greenhormoceras) birchbyi
Pseudaspidoc. flex.
Watinoceras devonense
Nigericas scotti zone (inferred)
Neocardioceras juddii
Sciponoceras gracile
Mytiloides mytiloides
Mytiloides columbianus
Mytiloides hattini
Inoceramus pictus
Praeglobotruncana helvetica Total Range Zone
Whiteinella archaeocretacea Partial Range Zone
Rotalipora cushmani Partial Range Zone
Quadrum gartneri
Lithraphidites acutum
δ13Corg (‰ vs PDB)
-24
-25
-26
-27
1m
134
132
126
124
122
120
118
116
113
109
107
105
103
101
99
97
90
86
84
80
79
77
73
69
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63
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8
7
6
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3,4
2
1

yon Anticline are shown in Text-figs 4 and 5, respectively.

Few well-documented alternatives to the section at Rock Canyon Anticline for a Cenomanian-Turonian boundary stratotype have been suggested, none of which formally. Candidates were mainly the Tunisian sections and the Oyubari section in Hokkaido (HASEGAWA *in* REYMENT, 1995); however, these were considered less satisfactory in comparison with the Rock Canyon Anticline section. An alternative boundary point was also considered by the Working Group at the Brussels meeting (see below).

PROPOSAL FOR A CENOMANIAN-TURONIAN GSSP

Arguments in favour of the section at Rock Canyon Anticline near Pueblo, Colorado, to be chosen as the Cenomanian-Turonian boundary stratotype section have been outlined above. W. A. Cobban *et al.* (unpublished report, 1995) suggested that the boundary point should be placed at the FO of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981, in the Rock Canyon Anticline section. This level (the base of the *Watinoceras devonense* Zone) coincides with the base of Bed 86 (nomenclature and numbering system of COBBAN & SCOTT, 1973), according to current state of knowledge. It is close to the FOs of the planktonic foraminifer *Helvetoglobotruncana helvetica* (BOLLI, 1945) (cf. EICHER & DINER, 1985, p. 64) and the nannofossil *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977, and to the LO of the last *Rotalipora* morphotypes. *Watinoceras devonense* is an easily recognisable species and both this species and the potential boundary proxies *H. helvetica* and *Rotalipora* are geographically widespread taxa, which should facilitate correlation of the boundary. Alternative boundary levels were suggested by E. G. Kauffman (Boulder, Colorado) and E. Seibertz (Braunschweig, Germany), viz. the FOs of the inoceramid species *Mytiloides hattini* ELDER, 1991 (= *M.* aff. *sackensis* of authors) and *M. wiedmanni* LOPEZ, 1992 (SEIBERTZ, 1995), respectively, both appearing first in shale Bed 85 in the Rock Canyon Anticline section (but see below).

The original proposal by W. A. Cobban *et al.* (unpublished report, 1995) gained the most support, although as primary boundary marker the base of Bed 86 was preferred rather than the coincident FO of *Watinoceras devonense*. The Cenomanian-Turonian boundary point proposed here was thus selected primarily on cyclostratigraphical grounds. (With present-day biostratigraphical knowledge of the Rock Canyon Anticline section the result is, however, the same as if the biostratigraphical marker *W. devonense* had determined the choice.)

ARGUMENTS IN FAVOUR OF THE PROPOSED BOUNDARY POINT

The following main circumstances and arguments support the proposal of the base of Bed 86 in the section at Rock Canyon Anticline, near Pueblo, Colorado, as the Cenomanian-Turonian boundary point.

— The base of Bed 86 can be correlated cyclostratigraphically over tens of thousands of square kilometres of the U.S. Western Interior (across up to 700 km into Kansas).
— The ammonite *Watinoceras devonense* and other species of *Watinoceras* appear (FOs) at the base of Bed 86; *W. devonense* is easily recognisable, widely spread, and the type material is fully accessible in the collections of the Natural History Museum (London), which makes the FO of this and other *Watinoceras* species outstanding secondary markers and prime biostratigraphical markers and correlation tools.
— The planktonic foraminifer *Helvetoglobotruncana helvetica* appears (FO) less than 1 m above the base of Bed 86.
— The inoceramid bivalves *Mytiloides hattini* and *M. wiedmanni* appear (FOs) in the shales less than 1 m below the base of Bed 86 (ELDER, 1991, fig. 1; E. Seibertz, personal communication, 1996).
— The last *Rotalipora* morphotypes disappear (LO) near but below the base of Bed 86.

←

Text-fig. 6 — Integrated ammonite, inoceramid, planktonic foraminifer and nannofossil zonation of the Bridge Creek Limestone Member in the Rock Canyon Anticline section with bases of zones indicated and the plot of the $\delta^{13}C$ organic carbon excursion (stable carbon isotope curve) from a nearby core (PRATT & THRELKELD, 1984).
1. FO of *Metoicoceras geslinianum* (d'ORBIGNY, 1850);
2. FO of *Euomphaloceras septemseriatum* (CRAGIN, 1893);
3. LO of *Rotalipora cushmani* (MORROW, 1934) as well as of other *Rotalipora* morphotypes;
4. FO of *Whiteinella archaeocretacea* (PESSAGNO, 1967);
5. Interval containing FO of *Quadrum gartneri* PRINS & PERCH-NIELSEN, 1977, *fide* WATKINS (1985), although there is conflicting evidence (KENNEDY & COBBAN, 1991, p. 18);
6. Base of *Watinoceras devonense* Zone at the base of Bed 86, corresponding to the FOs of *Watinoceras devonense* WRIGHT & KENNEDY, 1981, and *Watinoceras* spp.; the proposed Cenomanian-Turonian boundary level;
7. FO of *Praeglobotruncana helvetica* (BOLLI, 1945) (= *Helvetoglobotruncana helvetica* herein);
8. Base of *Pseudaspidoceras flexuosum* Zone;
9. Flood of *Mytiloides mytiloides* (MANTELL, 1822). (After KENNEDY & COBBAN, 1991, Fig. 9, and Cobban *et al.*, unpublished report, 1995.)

HEBERT 1864–1866
BARROIS 1878
DE GROSSOUVRE 1901
KENNEDY & HANCOCK 1976
AMEDRO in ROBASZYNSKI et al. 1980
KENNEDY, HANCOCK & WRIGHT 1983
AMEDRO et al. 1983
recommendations of the Colloque sur le Turonien (1981) 1983
CONIACIAN pars
TURONIAN
U. CENOMANIAN
L. TURONIAN
MIDDLE TURONIAN
U. TURONIAN
U. CENOMANIAN
lower
middle
upper
Micraster cortestudinarium
Micraster breviporus
Rhynchonella cuvieri
Terebratulina gracilis
Echiniconus subrotundus
Inoceramus labiatus
Belemnites plenus
Barroisiceras haberfellneri
Romaniceras deverianum
Romaniceras ornatissimum
Romaniceras bizeti
Mammites nodosoides
Acanthoceras rhotomagense
Peroniceras tricarinatum
Subprionocyclus neptuni
Collignoniceras woollgari
(Watinoceras coloradoense)
Sciponoceras gracile
Eucalycoceras pentagonum
Peroniceras tridorsatum A.Z.
Subprionocyclus neptuni A.Z.
Romaniceras deverianum A.Z.
Romaniceras ornatissimum A.Z.
Romaniceras kallesi A.Z.
Kamerunoceras turoniense A.Z.
Mammites nodosoides A.Z.
Watinoceras coloradoense
Metoicoceras geslinianum A.Z.
Reesideoceras petrocoriense
Peroniceras tricarinatum I.Z.
Reeside. petrocoriense I.Z.
Collignoniceras woollgari I.Z.
Subprionocyclus neptuni I.Z.
Romaniceras deverianum I.Z.
Romaniceras ornatissimum I.Z.
Romaniceras kallesi I.Z.
Kamerunoceras turoniense P.R.Z.
Mammites nodosoides T.R.Z.
Watinoceras coloradoense I.Z.
Neocardioceras juddii
Neocardioceras juddii I.Z.
Metoicoceras geslinianum I.Z.

— There is a carbon isotope peak ca. 0.5 m above the base of Bed 86.
— The faunal association of the Rock Canyon Anticline section is neither typically Boreal nor Tethyan but rather a mixed assemblage, which enhances its correlation potential.
— The ammonite fauna of Bed 86 at Rock Canyon Anticline has recently been described and illustrated (COBBAN *et al.*, in press).

An integrated biozonation for the Cenomanian-Turonian boundary beds of the Rock Canyon Anticline section was presented by KENNEDY & COBBAN (1991, fig. 9) with minor amendments by COBBAN *et al.* (unpublished report, 1995); it is reproduced herein as Text-fig. 6. It should be noted that, as a result of different taxonomic opinions the base of their *Mytiloides hattini* Zone (originally *M.* aff. *sackensis* Zone) lies at a lower level than the FO of the species, *sensu* ELDER (1991), KAUFFMAN *et al.* (1994) and HARRIES *et al.* (1996). A more detailed inoceramid zonation for the entire Western Interior Basin was presented by KAUFFMAN *et al.* (1994, figs 7-8); a revised inoceramid zonation is also in preparation by E. Seibertz (personal communication, 1996); cf. also HARRIES *et al.* (1996).
The presence of bentonites in the Rock Canyon Anticline section which can be dated radiometrically adds to the value of the section. The time interval spanning the "proxies" listed above is estimated at approximately 25,000 years, which lies near the limits of biostratigraphical resolution.

The lower-middle Turonian boundary (base of the middle Turonian)

Widespread usage has been to place the lower-middle Turonian boundary at the FO of the widely distributed ammonite *Collignoniceras woollgari* (MANTELL, 1822). This was also the recommendation of the 1981 colloquium on the Turonian (ROBASZYNSKI, 1983a, p. 210, fig. 1, reproduced as Text-fig. 7 herein; ROBASZYNSKI, 1983b), although it was noted that the phylogenetic origin of *C. woollgari* was uncertain. In a written report to the Turonian Working Group before the Brussels meeting, W. J. Kennedy (unpublished report, 1995) proposed that usage should be formalised and that the section at Rock Canyon Anticline near Pueblo should be chosen as the boundary stratotype. The phylogenetic origins of *C. woollgari* can now be seen to lie in the lower Turonian genus *Cibolaites* COBBAN & HOOK, 1983.

In the Rock Canyon Anticline section *C. woollgari* appears first in Bed 120 (Text-figs 5 and 6). This level is coincident with the FOs of the widely spread inoceramid species *Mytiloides hercynicus* (PETRASCHECK, 1903) and *Inoceramus cuvierii* J. Sowerby, 1814 (KAUFFMAN *et al.*, 1994, p. 430, fig. 6; but see HARRIES *et al.*, 1996). The proposed boundary point lies within the *Helvetoglobotruncana helvetica* planktonic foraminifer Total Range Zone and the *Quadrum gartneri* nannofossil Zone.

The Rock Canyon Anticline section near Pueblo and the FO of *Collignoniceras woollgari* in this section are here proposed as a GSSP for the lower-middle Turonian boundary. Additional microfossil data will be required for the subsequent formal submission to the ICS.

The middle-upper Turonian boundary (base of the upper Turonian)

To define the base of the upper Turonian is a less straightforward matter than for the other two Turonian substages (cf. Text-fig. 7). In ammonite terms two views prevail: (1) the FO of *Romaniceras deverianum* (d'ORBIGNY, 1841) and (2) the FO of *Subprionocyclus neptuni* (GEINITZ, 1849). Neither of these species has a worldwide occurrence, although *S. neptuni* is widely distributed. The main problem lies, however, in the fact that the relative positions of the FOs of the two species are uncertain, as they rarely co-occur. The 1981 colloquium on the Turonian suggested that for western Europe *R. deverianum* might be used as a provisional boundary marker (ROBASZYNSKI, 1983a, p. 212).

Further taxonomic and biostratigraphical work is required before a GSSP for the middle-upper Turonian boundary can be formally proposed. It may be that ammonites are less suitable as a basis for a boundary point. An alternative might be the FO of *Inoceramus costellatus* WOODS, 1912 (SEIBERTZ, 1995), which lies near the FO of *S. neptuni*.

No suitable potential stratotype is known at present, which underscores the need for further investigations. An informal working group of inoceramid specialists led by K.-A. Tröger (Freiberg, Germany) was set up at the Brussels symposium, with the purpose of finding a suitable inoceramid datum close to the FOs of *R. deverianum* and *S. neptuni* and to recommend on a GSSP.

Conclusions

The proposals of the Turonian Working Group of the Subcommission on Cretaceous Stratigraphy for Global boundary Stratotype Sections and Points are as follows:

Cenomanian-Turonian boundary: The base of Bed 86 in the section at Rock Canyon Anticline west of Pueblo, Colorado, USA, exposing the Bridge Creek Member of the Greenhorn Limestone. According to current state of knowledge this level coincides with the first occurrence

←

Text-fig. 7 — Recommendations of the 1981 colloquium on the Turonian, with historical zonations for France for comparison (from ROBASZYNSKI, 1983a, fig. 1).

of the ammonite *Watinoceras devonense* WRIGHT & KENNEDY, 1981, in the section.

Lower-middle Turonian boundary: The first occurrence of the ammonite *Collignoniceras woollgari* (MANTELL, 1822) in the section at Rock Canyon Anticline west of Pueblo, Colorado, exposing the Bridge Creek Member of the Greenhorn Limestone. According to current state of knowledge this level lies within Bed 120 and coincides with the first occurrence of the inoceramid bivalves *Mytiloides hercynicus* (PETRASCHECK, 1903) and *Inoceramus cuvierii* J. SOWERBY, 1814, in the section.

Middle-upper Turonian boundary: No proposal for a GSSP is possible at present. Work should be concentrated on finding a suitable boundary section and on increasing the biostratigraphical knowledge of the inoceramid bivalves and ammonites, in particular.

Acknowledgements

The proposals and conclusions presented herein are the results of a joint effort by several members of the Turonian Working Group. The preparatory work leading up to the discussions at the Second International Symposium on Cretaceous Stage Boundaries in Brussels, in September 1995, was coordinated by Richard A. Reyment (Uppsala). A written proposal for the definition of the Cenomanian-Turonian boundary was submitted for this meeting by W.A. Cobban (Denver, Colorado), A. S. Gale (London) and W.J. Kennedy (Oxford); in addition, W.J. Kennedy and E. Seibertz (Braunschweig) circulated reviews of the middle and upper Turonian substages.

At the Brussels meeting 28 out of 39 Working Group members were present. The result of the subsequent postal voting on the proposal for a Cenomanian-Turonian GSSP as presented herein was 34 votes in favour (including the ballots not returned), 3 votes against the proposal and 2 abstentions. Two of the negative voters argued that the boundary stratotypes should be selected in Europe where the historical stage stratotypes are and that the proposed Rock Canyon Anticline section in Colorado belongs to another palaeobiogeographical region, which may lead to diachronism in correlation of boundary stratotypes and stage stratotypes. The third negative voter considered the proposed Rock Canyon Anticline section to be still too poorly known, in particular with respect to the microfossil stratigraphy. The proposal for a GSSP for the lower-middle Turonian boundary received 33 votes in favour (including the ballots not returned), 4 votes against the proposal and 2 abstentions. The reasons given for the negative votes were the same as for the stage boundary proposal.

Working Group members who have contributed to the elaboration of this proposal (other than through mere voting) are listed as contributors below the title of the article. In particular the assistance by W.J. Kennedy in providing data for this report is gratefully acknowledged. Additional data on the inoceramids were contributed by E. Seibertz (Braunschweig) and on the planktonic foraminifers by M. A. Lamolda (Bilbao, Spain).

The graphical work was done by Rolf Koch (Geologisch-Paläontologisches Institut, Heidelberg).

References

BIRKELUND, T., HANCOCK, J.M., HART, M.B., RAWSON, P.F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F., 1984. Cretaceous stage boundaries - proposals. *Bulletin of the Geological Society of Denmark*, **33** (1-2): 3-20.

BRALOWER, T.J., 1988. Calcareous nannofossil biostratigraphy and assemblages of the Cenomanian-Turonian boundary interval: implications for the origin and timing of oceanic anoxia. *Palaeoceanography*, **3** (3): 275-316.

COBBAN, W.A., 1985. Ammonite record from Bridge Creek member of Greenhorn Limestone at Pueblo Reservoir State Recreation area, Colorado. *In:* PRATT, L.M., KAUFFMAN, E.G. & ZELT, F. (Editors), Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of cyclic sedimentary processes. *Society of Economic Paleontologists and Mineralogists, Midyear Field Trip Guidebook*, **4**: 135-138.

COBBAN, W.A. & SCOTT, G.R., 1973. Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado. *United States Geological Survey Professional Paper*, **645** [for 1972]: 1-108, pls. 1-39.

COBBAN, W.A., ELDER, W.F., KENNEDY, W.J. & KIRKLAND, J.I., in press. Lower Turonian (Upper Cretaceous) Watinoceras devonense Zone ammonite fauna in Colorado. *United States Geological Survey Bulletin*, **2134**: B1-B8, Pls. 1-2.

EICHER, D.L. & DINER, R., 1985. Foraminifera as indicators of water mass in the Cretaceous Greenhorn sea, Western Interior. *In:* PRATT, L.M., KAUFFMAN, E.G. & ZELT, F. (Editors), Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of cyclic sedimentary processes. *Society of Economic Paleontologists and Mineralogists, Midyear Field Trip Guidebook*, **4**: 60-71.

ELDER, W.P., 1985. Biotic patterns across the Cenomanian-Turonian extinction boundary near Pueblo, Colorado. *In:* PRATT, L.M., KAUFFMAN, E.G. & ZELT, F. (Editors), Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of cyclic sedimentary processes. *Society of Economic Paleontologists and Mineralogists, Midyear Field Trip Guidebook*,**4**: 157-169.

ELDER, W.P., 1987. The paleoecology of the Cenomanian-Turonian (Cretaceous) stage boundary extinctions at Black Mesa, Arizona. *Palaios*, **2** (1): 24-40.

ELDER, W.P., 1991. *Mytiloides hattini* n. sp., a guide fossil for the base of the Turonian in the Western Interior of North America. *Journal of Paleontology*, **65** (2): 234-241.

HARRIES, P.J. 1993. Dynamics of survival following the Cenomanian-Turonian (Upper Cretaceous) mass extinction event. *Cretaceous Research*, **14** (4/5): 563-583.

HARRIES, P.J. & KAUFFMAN, E.G., 1990. Patterns of survival and recovery following the Cenomanian-Turonian (Late Cretaceous) mass extinction in the Western Interior Basin, United States. *In:* KAUFFMAN, E.G. & WALLISER, O.H. (Editors), Extinction events in earth history. Lecture Notes in Earth History, 30. Springer-Verlag, Berlin, pp. 277-298.

HARRIES, P.J. *et al.*, 1996. Lower Turonian Euramerican Inoceramidae: a morphologic, taxonomic, and biostratigraphic overview. *In:* SPAETH C. (Editor). Proceedings of the 4th International Cretaceous Symposium, Hamburg 1992 (Jost Wiedmann Memorial Volume). *Mitteilungen aus dem Geologisch-paläontologischen Institut der Universität Hamburg*, **77:** 641-671.

HATTIN, D.E., 1971. Widespread, synchronously deposited,

burrow-mottled limestone beds in Greenhorn Limestone (Upper Cretaceous) of Kansas and southeastern Colorado. *American Association of Petroleum Geologists Bulletin*, **55** (3): 412-431.

KAUFFMAN, E.G., SAGEMAN, B.B., KIRKLAND, J.I., ELDER, W.P., HARRIES, P.J. & VILLAMIL, T., 1994. Molluscan biostratigraphy of the Cretaceous Western Interior Basin, North America. *In:* CALDWELL, W.G.E. & KAUFFMAN, E.G. (Editors), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39** [for 1993]: 397-434.

KENNEDY, W.J. & COBBAN, W.A., 1991. Stratigraphy and interregional correlation of the Cenomanian-Turonian transition in the Western Interior of the United States near Pueblo, Colorado, a potential boundary stratotype for the base of the Turonian Stage. *Newsletters on Stratigraphy*, **24** (1/2): 1-33.

OBRADOVICH, J., 1994. A Cretaceous time scale. *In:* CALDWELL, W.G.E. & KAUFFMAN, E.G. (Editors), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39**: 379-396.

ORBIGNY, A. d', 1850. Prodrome de paléontologie stratigraphique universelle des animaux mollusques et rayonnés faisant suite au cours élémentaire de paléontologie et de géologie stratigraphiques, 2. Masson, Paris, 427 pp.

ORBIGNY, A. d', 1852. Cours élémentaire de paléontologie et de géologie stratigraphique, 2. Masson, Paris, pp. 383-847.

ORTH, C.J., ATTREP, M., MAO, X., KAUFFMAN, E.G., DINER, R. & ELDER, W.P., 1988. Iridium abundance maxima in the upper Cenomanian extinction interval. *Geophysical Research Letters*, **15**: 346-349.

PRATT, L.M., 1981. A paleo-oceanographic interpretation of the sedimentary structures, clay minerals and organic matter in a core of the Middle Cretaceous Greenhorn Formation near Pueblo, Colorado. Ph.D. thesis, Princeton University, Princeton, N.J., 176 pp.

PRATT, L.M., 1983. Isotopic studies on organic matter and carbonates in mid-Cretaceous strata near Pueblo, Colorado. *In:* Penrose Conference on Paleoclimates, Florissant, Colorado, Excursion Guidebook, pp. 77-98.

PRATT, L.M., 1984. Influence of paleoenvironmental factors on preservation of organic matter in Middle Cretaceous Greenhorn Formation, Pueblo, Colorado. *American Association of Petroleum Geologists Bulletin*, **68** (9): 1146-1159.

PRATT, L.M., 1985. Isotopic studies of organic matter and carbonate rocks in the Greenhorn marine cycle. *In:* PRATT, L.M., KAUFFMAN, E.G. & ZELT, F. (Editors), Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of cyclic sedimentary processes. *Society of Economic Paleontologists and Mineralogists, Midyear Field Trip Guidebook*, **4**: 38-48.

PRATT, L.M., ARTHUR, M.A., DEAN, W.E. & SCHOLLE, P.A., 1994. Paleo-oceanographic cycles and events during the Late Cretaceous in the Western Interior seaway of North America. *In:* CALDWELL, W.G.E. & KAUFFMAN, E.G. (Editors), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39** [for 1993]: 333-353.

PRATT, L.M., KAUFFMAN, E.G. & ZELT, F.B., (Editors) 1985. Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of cyclic sedimentary processes. *Society of Economic Paleontologists and Mineralogists, Midyear Field Trip Guidebook*, **4**: 249 + 26 pp.

PRATT, L.M. & THRELKELD, C.N., 1984. Stratigraphic significance of $\delta^{13}C/\delta^{12}C$ ratios in mid-Cretaceous rocks of the Western Interior. *Memoir of the Canadian Society of Petroleum Geologists*, **9**: 305-312.

REMANE, J., 1995. Draft of the revised "Guidelines for the establishment of global chronostratigraphic standards by ICS". *In*: Second International Symposium on Cretaceous Stage Boundaries [Brussels, 8-16 September 1995], Abstract volume: p. 100. Subcommission on Cretaceous Stratigraphy (SCS).

REYMENT, R.A., (compiler) 1995. The Turonian Working Group. *In:* Second International Symposium on Cretaceous Stage Boundaries [Brussels, 8-16 September 1995], Abstract volume: 150-152. Subcommission on Cretaceous Stratigraphy (SCS).

ROBASZYNSKI, F., (compiler) 1983a. Conclusions au Colloque sur le Turonien: Échelles biostratigraphiques intégrées et cartes de faciès et contrées limitrophes. *Mémoires du Muséum National d'Histoire Naturelle, Nouvelle série, Série C, Sciences de la Terre*, **49** [for 1981]: 209-241.

ROBASZYNSKI, F., (compiler) 1983b. Conclusions to the Colloquium on the Turonian stage: Integrated biostratigraphic charts and facies maps (France and adjacent areas). *Zitteliana*, **10**: 585-594.

ROBASZYNSKI, F. & GALE, A.S., 1993. The Cenomanian-Turonian boundary: a discussion held at the final session of the colloquium on Cenomanian-Turonian events, Grenoble, 26th May 1991 (France). *Cretaceous Research*, **14** (4/5): 607-611.

SCOTT, G.R., 1964. Geology of the Northwest and Northeast Pueblo Quadrangles, Colorado. *United States Geological Survey Miscellaneous Geological Investigations*, Map 1-408.

SCOTT, G.R., 1970. Geologic Map of the Southwest and Southeast Pueblo Quadrangles, Colorado. *United States Geological Survey Miscellaneous Geological Investigations*, Map 1-597.

SEIBERTZ, E., 1995. Turonian inoceramid evolution and its use for stage and zonal boundary definition. *In:* Second International Symposium on Cretaceous Stage Boundaries [Brussels, 8-16 September 1995], Abstract volume: p. 113. Subcommission on Cretaceous Stratigraphy (SCS).

STANTON, T.W., 1894. The Colorado formation and its invertebrate fauna. *United States Geological Survey Bulletin*, **106** [for 1893]: 1-288, pls. 1-45.

WATKINS, D.K., 1985. Biostratigraphy and paleoecology of calcareous nannofossils in the Greenhorn marine cycle. *In:* PRATT, L.M., KAUFFMAN, E.G. & ZELT, F. (Editors), Fine-grained deposits and biofacies of the Cretaceous Western Interior Seaway: evidence of cyclic sedimentary processes. *Society of Economic Paleontologists and Mineralogists, Midyear Field Trip Guidebook*, **4**: 151-156.

WRIGHT, C.W. & KENNEDY, W.J., 1981. The Ammonoidea of the Plenus Marls and the Middle Chalk. *(Monograph of the) Palaeontographical Society, Publication*, **560** [part of Vol. 134 for 1980]: 1-148, Pls. 1-32.

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The Coniacian stage and substage boundaries

by Erle G. KAUFFMAN (compiler), W. Jim KENNEDY & Christopher J. WOOD,

with contributions by Annie V. Dhondt, Jake M. Hancock, Ludmila F. Kopaevich, Ireneusz Walaszczyk

Abstract

The Coniacian Working Group of the Cretaceous Subcommission on Stratigraphy has recommended the First Occurrence (FO) of the inoceramid bivalve *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege) as criterion for recognising the Turonian-Coniacian boundary. This boundary lies between the LO of the ammonite *Prionocyclus germari* (uppermost Turonian of Eurasia and North America), and the FOs of the ammonites *Forresteria (Harleites) petrocoriensis* (Europe) and *F. peruana* and *F. brancoi* (North America), thus preserving the sense of the original ammonite definition of the boundary.

The working group further recommends that:
– the Lower-Middle Coniacian substage boundary be drawn at the FO of the inoceramid *Volviceramus koeneni* and, where ammonites are preserved, at or near the FO of *Peroniceras* (*Peroniceras*) *tridorsatum*,
– the Middle-Upper Coniacian boundary be drawn at the FO of the cosmopolitan inoceramid, *Magadiceramus subquadratus*.

The Coniacian Working Group unanimously recommended the Salzgitter-Salder Quarry section, near Salzgitter-Salder, Lower Saxony, Germany, as the Turonian-Coniacian boundary stratotype. The T-C boundary at this quarry is placed in bed MK-47 of the Wood *et al.* (1984) section, above the *Didymotis* ecoevent II and the flood occurrence of *Cremnoceramus? waltersdorfensis waltersdorfensis*.

No stratotype sections were recommended for the Coniacian substages because the data in support of any one of the two candidates have not yet been fully developed. Under study are the lower Austin Chalk of the Dallas-Fort Worth area of Texas, and the Seaford Head exposures of the Upper Chalk in southern England.

Key-words: Coniacian, Upper Cretaceous, biostratigraphy, ammonites, inoceramids, stratotypes.

Résumé

Le Groupe de Travail Coniacien de la Sous-Commission de Stratigraphie du Crétacé recommande que la première apparition du bivalve inocéramidé *Cremnoceramus rotundatus (sensu* Tröger *non* Fiege) soit reconnue comme critère pour la limite Turonien-Coniacien. Cette limite se situe entre l'extinction de l'ammonite *Prionocyclus germari* (Turonien tout à fait supérieur de l'Eurasie et d'Amérique du Nord) et l'apparition des ammonites *Forresteria (Harleites) petrocoriensis* (en Europe) et *F. peruana* et *F. brancoi* (en Amérique du Nord); ainsi la limite reste définie à un endroit proche de celui désigné à l'origine sur base des ammonites.

Le Groupe de Travail recommande aussi que:
– la limite entre les sous-étages Coniacien Inférieur et Moyen soit placée à l'apparition de l'inocéramidé *Volviceramus koeneni* et, quand il y a des ammonites, à ou près de l'apparition de *Peroniceras (Peroniceras) tridorsatum*,
– la limite entre les sous-étages Coniacien Moyen et Supérieur corresponde à l'apparition de l'inocéramidé cosmopolite *Magadiceramus subquadratus*.

Unanimement le Groupe de Travail recommande la carrière Salzgitter-Salder, près de Salzgitter-Salder, Basse Saxe, Allemagne, comme stratotype de la limite Turonien-Coniacien. Dans cette carrière, la limite T-C est placée dans le niveau MK 47 de la coupe décrite par Wood *et al.*, 1984; ce niveau se situe au-dessus du *Didymotis* "ecoevent II" et de l'apparition en masse de *Cremnoceramus waltersdorfensis waltersdorfensis*.

Pour les limites des sous-étages du Coniacien, aucun stratotype n'a été désigné parce que les données des deux coupes-candidates ne sont pas assez bien connues. L'Austin Chalk inférieur des environs de Dallas-Fort Worth au Texas et des affleurements de l'Upper Chalk de Seaford Head dans le sud de l'Angleterre sont à l'étude.

Mots-clefs: Coniacien, Crétacé supérieur, biostratigraphie, ammonites, inocéramidés, stratotypes

Определение Туроно-Коньякской границы.

Резюме.
Рабочая Группа Коньякского Яруса Стратиграфической Меловой Подкомиссии рекомендует признать первое появление иноцерамного двустворчатого моллюска *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege) в качестве критерия для определения Туроно-Коньякской границы. Последняя располагается между границей исчезновения аммонита *Prionocyclus germari* (самый верхний Турон Евразии и Северной Америки) и появлением аммонитов *Forresteria (Harleites) petrocoriensis* (в Европе) и *F. peruana* и *F. brancoi* (в Северной Америке), предохраняя таким образом подлинное значение аммонитового определения границы.
Рабочая Группа также рекомендует:
- определять границу между подъярусами Нижнего и Среднего Коньяка при первом появлении иноцерама *Volviceramus koeneni* или, в том случае если аммониты сохранены, при первом появлении *Peroniceras tridorsatum*,
- определять границу между подъярусами Верхнего и Среднего Коньяка при первом появлении распространённого иноцерама, *Magadiceramus subquadratus*.

Рабочая Группа Коньякского Яруса единогласно рекомендует разрез в карьере Salzgitter-Salder, недалеко от Salzgitter-Salder, (Нижняя Саксония, Германия), в качестве стратотипа для Туроно-Коньякской границы. В этом карьере Туроно-Коньякская граница определена в слое МК-47 разреза WOOD et al., (1984; рис.4), над *Didymotis ecoevent* II и появлением множества *Cremnoceramus? waltersdorfensis waltersdorfensis*.
Что касается подъярусов Коньяка, то учёные не рекомендовали ни один разрез в качестве стратотипа, так как данные в поддержку каждого из двух вариантов не были ещё достаточно рассмотрены. В настоящий момент специалисты изучают Lower Austin Chalk в районе

Dallas-Fort Worth (Техас), а также отложения Seaford Head на юге Англии (Upper Chalk).

Ключевые слова: Коньякский ярус, верхний мел, биостратиграфия, аммониты, иноцерамы, стратотипы.

Introduction

The Coniacian is the shortest Cretaceous stage, enhancing the dynamic aspect of major changes in ocean-climate systems and their marine biotas. Based on ^{40}Ar-^{39}Ar radiometric dating of bentonites in the Western Interior Basin of North America, OBRADOVICH (1994) estimated a 2.4 Ma duration for the Coniacian, and presented new ages of 86.92 $\pm$ 0.39 Ma for a bentonite in the Late Coniacian ammonite biozone of *Protexanites bourgeoisianus*, and 88.34 $\pm$ 0.6 Ma for a bentonite in the *Scaphites preventricosus* Zone, Early Coniacian in age as a result of the recommendations of the Coniacian Working Group in Brussels.

Defining stage and substage boundaries: historical perspectives and recommendations

The Turonian-Coniacian (T-C) boundary

The Coniacian stage was introduced by COQUAND (1857 b). The type locality of the Coniacian is at the Richemont Seminary, near Cognac, Charente, France [COQUAND, 1857 a (p. 84), 1857 b (p. 748); SÉRONIE-VIVIEN, 1972, 1980; BIRKELUND *et al.*, 1984; KENNEDY, 1984 a, b], where a prominent regional disconformity separates Turonian rudistid-bearing limestones, capped by a hardground, from basal Coniacian glauconitic sands (which are unfossiliferous, apart from oysters); biostratigraphically important groups like the Inoceramidae and ammonites are absent (KENNEDY, 1984 a, b).

Therefore, BIRKELUND *et al.* (1984) proposed other possible candidates for the Turonian-Coniacian (T-C) boundary stratotype, including:

(a) The ''Priesener Schichten'' in the Czech Republic, which have a diverse ammonite and inoceramid fauna, as well as facies suitable for microbiotic analyses (= Brezno Fm., *sensu* CECH *et al.*, 1980); and

(b) the El Kef section in Tunisia with its high potential for micro- and nannofossil recovery.

Neither of these sections has been subsequently proposed or specifically favoured by members of this committee as the best stratotype, however, although both remain valid candidates.

WOOD *et al.* (1984) described the Salzgitter-Salder Quarry, in Lower Saxony (Germany), as a regional reference section for the Turonian and Lower Coniacian, and formally proposed that it should be regarded as an international standard section.

During the course of preliminary communications of the working group and at the Brussels meeting (KAUFFMAN, 1995; subsequently discussed, unpublished) a fourth stratotype candidate, in the Fort Hays Limestone Member, Niobrara Formation, near Wagon Mound, New Mexico, USA, was formally proposed by E. G. Kauffman.

Five additional Turonian-Coniacian sequences were informally proposed for consideration by the Working Group in correspondence leading up to the Brussels meeting (subsequently discussed), but none of these was formally presented at or before the meeting.

Criteria for the definition of the Turonian-Coniacian boundary presented at the Copenhagen meeting are as follows (BAILEY *et al.* 1984; BIRKELUND *et al.*, 1984):

(a) The first occurrence (FO) of the ammonite Forresteria (Harleites) petrocoriensis (*Coquand*) (= *Barroisiceras haberfellneri,* of authors, recorded from the Charente by de GROSSOUVRE, 1894 to SÉRONIE-VIVIEN, 1972; KENNEDY, 1984 a, b). Other ammonites are rare, so that this boundary definition relies heavily on the occurrence of a single species, *Forresteria (H.) petrocoriensis* (see: KENNEDY, 1984 a, b).

This definition received the greatest support in the Copenhagen meeting (BIRKELUND *et al.*, 1984).

(b) The FO of Cremnoceramus deformis (Meek) and/or Cr. schloenbachi (Boehm), as discussed by BAILEY *et al.* (1984), TRÖGER (1981), and especially as shown at the cement quarry near Erwitte, eastern Westphalia.

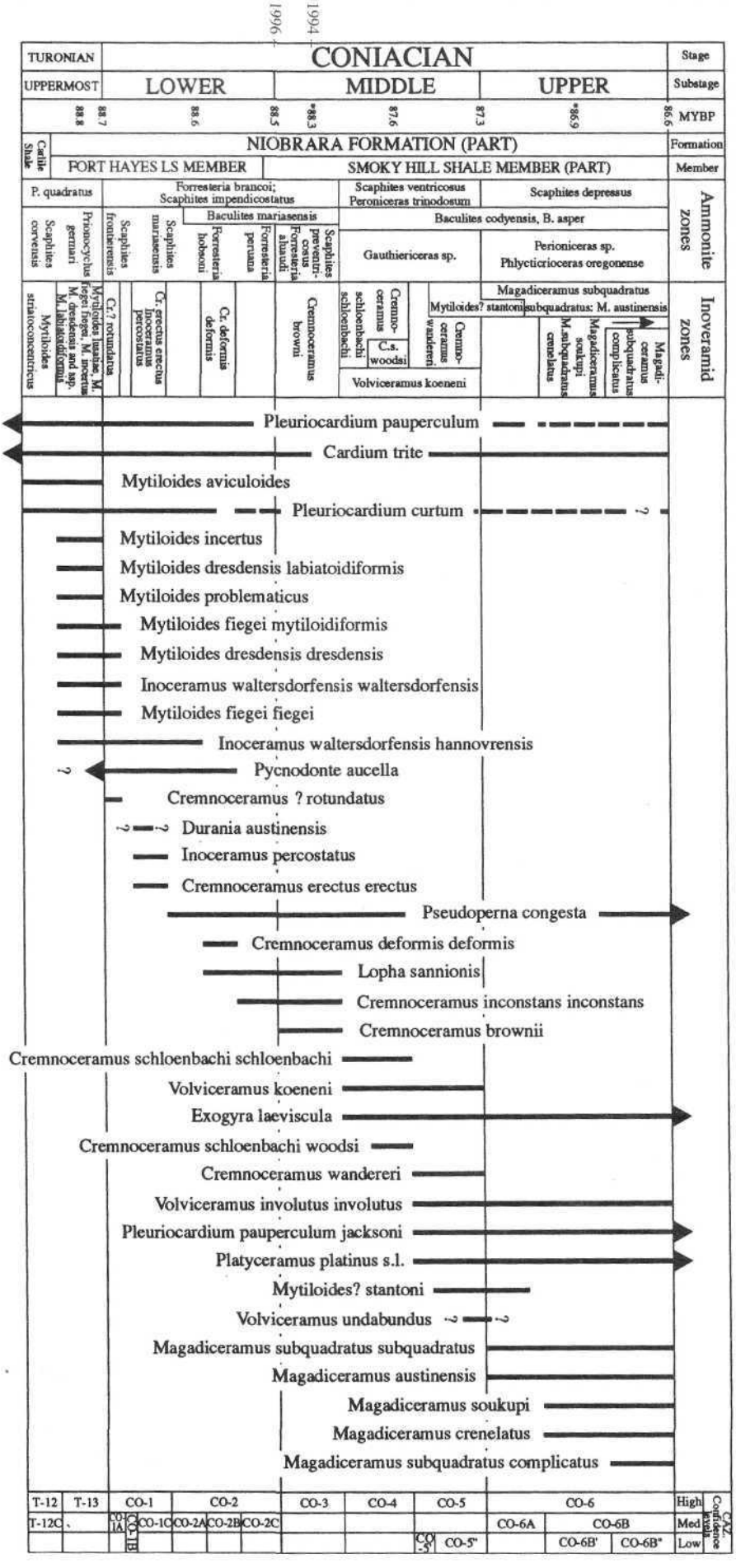
(c) The FO of Cremnoceramus rotundatus (sensu Tröger non Fiege).

The FO of *Cremnoceramus rotundatus* as described in TRÖGER, 1967, p. 110-114.

This FO is found in bed MK 47 at the Salzgitter-Salder Quarry, Lower Saxony, Germany (WOOD *et al.*, 1984; BAILEY *et al.*, 1984).

→

Fig. 1 — Standard Coniacian ammonite-inoceramid bivalve, biostratigraphic zones for the Western Interior of North America (modified after KAUFFMAN *et al.*, 1994) matched to radiometric and calculated ages (left columns) and composite range zones for biostratigraphically useful bivalve species. Radiometric ages (*) from OBRADOVICH (1994); calculated ages from KAUFFMAN *et al.*. (1994). Composite assemblage zones (CAZ: right) divided into high-, medium-, and low-confidence- level zones based on number of coeval FOs and LOs at zone boundaries. Key: 1994 - defines the boundary between the Early and Middle Coniacian selected by KAUFFMAN *et al.* (1994) for North America; 1996 - Early-Middle Coniacian substage boundary as recommended by members of the Coniacian Working Group of the Cretaceous Subcommission on Stratigraphy at Brussels. (For *Peroniceras trinodosum* read *Pe. tridorsatum*)


1996
1994
TURONIAN
CONIACIAN
Stage
UPPERMOST
LOWER
MIDDLE
UPPER
Substage
88.8
88.7
88.6
88.5
*88.3
87.6
87.3
*86.9
86.6
MYBP
Carlile Shale
NIOBRARA FORMATION (PART)
Formation
FORT HAYES LS MEMBER
SMOKY HILL SHALE MEMBER (PART)
Member
P. quadratus
Forresteria brancoi; Scaphites impendicostatus
Scaphites ventricosus Peroniceras tridonosum
Scaphites depressus
Ammonite zones
Scaphites corvensis
Prionocyclus germari
Scaphites frontierensis
Scaphites mariaeteistis
Baculites mariasensis
Forresteria hobsoni
Forresteria peruana
Forresteria alluaudi
Scaphites preventricosus
Baculites codyensis, B. asper
Gauthiericeras sp.
Perioniceras sp. Phlyctirioceras oregonense
Mytiloides striatoconcentricus
Mytiloides lusatiae, M. fiegei fiegei, M. incertus, M. dresdensis and ssp. M. labiatoidiformis
Cr.? rotundatus
Cr. erectus erectus Inoceramus percostatus
Cr. deformis deformis
Cremnoceramus browni
Cremnoceramus schloenbachi
C.s. woodsi
Cremnoceramus wandereri
Volviceramus koeneni
Mytiloides? stantoni
Magadiceramus subquadratus: M. austinensis
M. subquadratus crenelatus
Magadiceramus soukupi
Magadiceramus subquadratus complicatus
Magadiceramus
Inoveramid zones
Pleuriocardium pauperculum
Cardium trite
Mytiloides aviculoides
Pleuriocardium curtum
Mytiloides incertus
Mytiloides dresdensis labiatoidiformis
Mytiloides problematicus
Mytiloides fiegei mytiloidiformis
Mytiloides dresdensis dresdensis
Inoceramus waltersdorfensis waltersdorfensis
Mytiloides fiegei fiegei
Inoceramus waltersdorfensis hannovrensis
Pycnodonte aucella
Cremnoceramus ? rotundatus
Durania austinensis
Inoceramus percostatus
Cremnoceramus erectus erectus
Pseudoperna congesta
Cremnoceramus deformis deformis
Lopha sannionis
Cremnoceramus inconstans inconstans
Cremnoceramus brownii
Cremnoceramus schloenbachi schloenbachi
Volviceramus koeneni
Exogyra laeviscula
Cremnoceramus schloenbachi woodsi
Cremnoceramus wandereri
Volviceramus involutus involutus
Pleuriocardium pauperculum jacksoni
Platyceramus platinus s.l.
Mytiloides? stantoni
Volviceramus undabundus
Magadiceramus subquadratus subquadratus
Magadiceramus austinensis
Magadiceramus soukupi
Magadiceramus crenelatus
Magadiceramus subquadratus complicatus
T-12
T-13
CO-1
CO-2
CO-3
CO-4
CO-5
CO-6
High
T-12C
CO-1A
CO-1B
CO-1C
CO-2A
CO-2B
CO-2C
CO-6A
CO-6B
Med
CO-5'
CO-6B'
CO-6B"
Low
CAZ Confidence levels

(d) The FOs of the echinoids Micraster decipiens (Bayle) and/or M. normanniae Bucaille at the base of the Western European *M. cortestudinarium* zone were suggested by POMEROL (1983) and POMEROL *et al.* (1983) as a means of defining the base of the Coniacian. The boundary, so defined, is especially well preserved at Saint-Julien-du-Sault, near Sens (Yonne, France). The localised occurrences of these echinoids, problems in taxonomic definition of the species, their possible occurrences with both Upper Turonian and Lower Coniacian ammonites, and the probability of strong ecological and preservational control on their occurrence, led BIRKELUND *et al.* (1984) and BAILEY *et al.* (1984) to reject the use of these biostratigraphic criteria in defining the T-C boundary.

(e) The FO of Marthasterites furcatus (Deflandre) has commonly been used by nannofossil specialists as the base of the Coniacian. But this FO lies well within the range of typical Upper Turonian ammonites such as *Subprionocyclus neptuni* (Geinitz), and below the acme-zone of this species (BAILEY *et al.*, 1984). This boundary definition thus does not honour the original concept of the Turonian-Coniacian boundary near Cognac.

(f) The FO of the foraminifera Marginotruncana of the M. sinuosa group, together with the evolution of the Dicarinella primitiva-concavata group can be used (BIRKELUND *et al.*, 1984; MARKS, 1984) to distinguish the Coniacian from the Turonian.

(g) The FO of the foraminifers Lingulogavelinella sp. cf. L. vombensis (Brotzen) (i.e. Gavelinella arnagerensis Soliakus), Reussella kelleri (Vassilenko), and Stensioina spp. (e.g. *S. granulata levis* Koch). BAILEY *et al.* (1984) present arguments against these criteria for the Turonian-Coniacian boundary; the FOs of these taxa are highly discrepant between localities, suggesting that the species may be subject to strong ecological controls on occurrence; the first two foraminiferid taxa are also known to co-occur with *Subprionocyclus neptuni*, *Didymoceras saxonicum* (Schlüter) and *Scaphites geinitzii* (d'Orbigny), implying Upper Turonian FOs as well as a Lower Coniacian range for these species of foraminifera.

Criteria suggested for the definition of the Turonian-Coniacian boundary at the Brussels meeting are as follows:

(1) The first occurrence (FO) of the ammonite Forresteria (Harleites) petrocoriensis (Coquand) had strong support in Brussels and in correspondence leading up to that meeting. In particular, E. Seibertz expressed preference for a single ammonite entry level, that of *F. (H.) petrocoriensis*, as a basis for defining the Turonian-Coniacian boundary. W. J. Kennedy emphasised at the meeting that the final definition of the Turonian-Coniacian boundary should honour the placement of *F. (H.) petrocoriensis* in the Lower Coniacian [as was also proposed by MATSUMOTO (1984) for Japan and by ROBASZYNSKI (1984) for France], and below it the occurrence of *Prionocyclus germari* (Reuss) in the Upper Turonian .

[The approximately equivalent FO in North America maybe that of *F. (E.) peruana* (Brüggen, 1901) and/or *F. (F.) brancoi* (Solger, 1904) (KAUFFMAN *et al.*, 1994; Fig. 1 herein)].

In the Münster Basin of Germany (KAPLAN & KENNEDY, 1994; KAPLAN & KENNEDY, in press; KENNEDY, unpublished report to the Coniacian Working Group, 1995), it has been noted that the earliest appearance of the typical Coniacian inoceramid lineage of *Cremnoceramus* [e.g. *Cr. rotundatus* (*sensu* Tröger *non* Fiege)], lies below the FOs of *Forresteria (H.) petrocoriensis*, and above the LO of *Prionocyclus germari*.

The choice of the FO of *Cr. rotundatus* (*sensu* Tröger *non* Fiege) as the Turonian-Coniacian boundary marker by the Coniacian Working Group in Brussels honours KENNEDY's request, but places the T-C boundary significantly below the FO of *F. (H.) petrocoriensis* in Europe.

In the Western Interior of North America (KAUFFMAN *et al.*,1994 and herein) the FO of *Cr. rotundatus* lies below the FOs of *F. (E.) peruana* and/or *F. (E.) brancoi*, respectively (Fig. 1) and at the boundary level utilised in the Western Interior of North America (KAUFFMAN *et al.*, 1994: Fig. 1 herein) and previously tentatively throughout Europe and the Caribbean Province, where ammonites are relatively rare (KAUFFMAN, 1978 a, b).

(2) The FO of Cremnoceramus deformis (Meek) and/or Cr. schloenbachi (Boehm). KAPLAN & KENNEDY (1994) and KENNEDY (unpublished report to the Coniacian Working Group, 1995) both noted that the FO of *Forresteria (Harleites) petrocoriensis* is at, or slightly below, or slightly above, the first appearance of *Cremnoceramus erectus* (Meek), the second oldest Lower Coniacian biozone, and thus well below the occurrence of either *Cr. deformis* or *Cr. schloenbachi*.

In the Western Interior of North America (KENNEDY & COBBAN, 1991; KAUFFMAN *et al.*, 1994: Fig. 1 herein), the first appearance of *Cremnoceramus deformis sensu* Meek, lies several metres above the FOs of *Forresteria peruana*, *F. brancoi*, *Cr. erectus*, and *Cr. rotundatus*, all regarded as Lower Coniacian taxa. *Cr. schloenbachi* first appears above the *Cr. deformis* zone in this area, in the lower Middle Coniacian as defined by KAUFFMAN *et al.* (1994).

Criterion 2 is thus considered invalid.

[Editor's note: in Europe, following WALASZCZYK (1992), Cremnoceramus schloenbachi (Boehm, 1912) has been replaced by its earlier synonym Cr. crassus (Petrascheck, 1903)].

(3) The FO of Cremnoceramus rotundatus (sensu Tröger non Fiege).

I. Walaszczyk and C. J. Wood, written comm., May 1996 and Figures 4 and 5 herein, confirm the position of the FO of *Cr. rotundatus*; it approaches the criterion for definition of the T-C boundary established at Brussels.

Below the *Cr. rotundatus* bed at Salzgitter-Salder (WOOD *et al.*, 1984), in levels MK 45 and KM 46, is the flood occurrence of small forms of *Cr. waltersdorfensis hannovrensis* (Heinz) [now considered to be conspecific with the type concept of *Cr. waltersdorfensis waltersdorfensis* (I. Walaszczyk and C. J. Wood, written comm., May 1996)] together with abundant *Didymotis* in the upper *Didymotis* event and the unique specimen of *Cremnoceramus* sp. aff. *Cr. rotundatus (sensu* Tröger *non* Fiege) [this inoceramid is now considered a transitional form between *Cr. waltersdorfensis waltersdorfensis* (Andert) and *Cr. rotundatus* (Tröger non Fiege), I. Walaszczyk and C. J. Wood, written comm., May 1996]. These two levels (MK 45 -KM 46) are correspondingly reassigned to the uppermost Turonian (I. Walaszczyk and C. J. Wood, written comm., May 1996).

Further, despite the successful regional tracing of these flood occurrences in Germany, Bohemia, (Czech Republic) (CECH, 1989) northern Spain (KÜCHLER & ERNST, 1989) and even to England (WOOD *et al.*, 1984), on a more global scale their epiboles could be environmentally regulated at different times in different places, and thus not be inter-regional bioevents s.s.

In the Münster Basin of Germany (KAPLAN & KENNEDY, 1994; KENNEDY, unpublished report to the Coniacian Working Group, 1995), it has been noted that the earliest appearance of the typical Coniacian inoceramid lineage of *Cremnoceramus* [e.g. *Cr. rotundatus* (*sensu* Tröger *non* Fiege)], lies below the FOs of *Forresteria (H.) petrocoriensis*, and above the LO of *Prionocyclus germari.*

The choice of the FO of *Cr. rotundatus* (*sensu* Tröger *non* Fiege) as the Turonian-Coniacian boundary marker by the Coniacian Working Group in Brussels honours KENNEDY's request, but places the T-C boundary significantly below the FO of *F. (H.) petrocoriensis* in Europe.

In the Western Interior of North America (KAUFFMAN *et al.*,1994 and herein) the FO of *Cr. rotundatus* lies below the FOs of *F. (E.) peruana* and/or *F. (E.) brancoi,* respectively (Fig. 1, herein), at the base of the *Forresteria brancoi-Scaphites impendicostatus* assemblage biozone, the boundary level utilised in the Western Interior of North America (KAUFFMAN *et al.*, 1994). This assemblage is associated with rare *Didymotis*, and *Cremnoceramus? waltersdorfensis* (Andert) in the upper part of its range zone. The regional LOs of several species of uppermost Turonian *Mytiloides* [*M? lusatiae* (Andert), *M. incertus* (Jimbo), *M. dresdensis labiatoidiformis* (Tröger), *M. problematicus* (Schlotheim)] also occur at this boundary in North America. These are predominantly cosmopolitan inoceramid species with high correlation potential.

An alternative ammonite/inoceramid zonation was presented for the Western Interior of North America by KENNEDY & COBBAN (1991), using scaphitids and fewer inoceramid zones than in the KAUFFMAN *et al.*, 1978 scheme. KENNEDY & COBBAN (1991) clearly state that *Scaphites (Sc.) impendicostatus* Cobban, 1952 is restricted to the *Inoceramus deformis* Zone and thus occurs above *Forresteria brancoi.* They tied their zonation in with the French Coniacian.

The FOs of *Cr. rotundatus* and *Didymotis* spp. were recently proposed as criteria for defining the base of the Coniacian Stage in Germany and Spain (KÜCHLER & ERNST, 1989), and in the Brandenberg Basin, Austria (HERM *et al.*, 1979).

L. F. Kopaevich (Moscow State University) noted (personal communication, 1995) that the base of the Coniacian in Russia, Daghestan, Kazakhstan, and central Europe, which had traditionally been drawn at the FO of *Cremnoceramus deformis* (now known to be later Early Coniacian in age: KAUFFMAN *et al.*, 1994; Fig. 1 herein), has now been redefined to coincide with the FOs of *Cr. rotundatus, Forresteria petrocoriensis*, the foraminifera *Ataxophragmium nautiloides* (Brotzen, 1936), and *Gavelinella praeinfrasantonica* (Mjatluik, 1947), and the LOs of *Globorotalites hangensis* Vassilenko, 1956 and *Gavelinella moniliformis* (Reuss, 1845). Collectively, this boundary definition seems to fit the favoured European boundary criteria well (e.g. BAILEY *et al.*, 1984; KENNEDY, 1984 b and unpublished report to the Coniacian Working Group, 1995).

Selected Turonian-Coniacian boundary marker

By a vote of 24 to 0, with 3 abstentions, the Coniacian Working Group in Brussels approved criterion 3 (discussed above) for definition of the Turonian-Coniacian boundary.

Thus, the boundary will lie between the LO of *Prionocyclus germari* and the FO of *Forresteria* (*Harleites*) *petrocoriensis*, and at the FO of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege).

The use of other biostratigraphic data, chronostratigraphic event surfaces, and climate cycle deposits in helping to bracket and define the Turonian-Coniacian boundary was encouraged.

These criteria are well represented at the chosen boundary stratotype, the Salzgitter-Salder Quarry in Lower Saxony (WOOD *et al.*, 1984; subsequently discussed): the FO of *Cremnoceramus rotundatus* occurs at the base of the Coniacian, in a regionally correlatable shale-limestone bedding sequence, just above two regional bioevents - the second *Didymotis* ecoevent and a flood occurrence of *Cr.? waltersdorfensis waltersdorfensis*, as described by WOOD *et al.* (1984), shown in Figures 4 and 5, and adjusted by I. Walaszczyk & C. J. Wood, written comm., 1996. Ammonites (scaphitids and baculitids) oc-

cur at several levels below and above this boundary, but are not found at the boundary; *Scaphites kieslingswaldensis doylei* ranges across the boundary, while the first unequivocal Coniacian ammonites, i.e. *Sc. kieslingswaldensis kieslingswaldensis* and *Scalarites turoniensis* first appear significantly above the boundary. There is a regional planktonic foraminiferal change at or near the boundary, which is marked particularly by a significant increase in *Globotruncana paraventricosa* (Hofker) (BRÄUTIGAM, 1962). The boundary is also bracketed by numerous regionally correlated cyclostratigraphic and event beds or faunas (Figures 4 and 5).

Defining Coniacian substages.

Substage division of the Coniacian has been attempted by a number of past authors. DE GROSSOUVRE (1901) proposed a two-fold division of the Coniacian in parts of France based on ammonite zones; a lower *Barroisiceras haberfellneri* Zone, and an upper *Mortoniceras emscheris* Zone.

But as KENNEDY (1984 b) pointed out, neither of these species actually occurs in France. KENNEDY (1984 b) proposed a three-fold substage division of the Coniacian for large areas of France, as follows:

(1) a Lower Coniacian *Forresteria* (*Harleites*) *petrocoriensis* Zone;
(2) a Middle Coniacian *Peroniceras* (*Peroniceras*) *tridorsatum* Zone;
(3) a sequence of two ammonite zones (*Gauthiericeras margae* Zone below, *Paratexanites serratomarginatus* Zone above) referred to the Upper Coniacian.

KENNEDY (1984 b) discussed these divisions and listed additional ammonite taxa in each; his proposed substage boundaries are marked by the FOs of the ammonite taxa characterizing the overlying zone. As KENNEDY (KENNEDY & COBBAN, 1991) subsequently pointed out, however, it is not possible at present to define Coniacian substages internationally using ammonites because cosmopolitan taxa are not common, and ammonites, in general, are too rare, or absent, in most sections (also KENNEDY, unpublished proposal to the Coniacian Working Group, 1995).

KAUFFMAN *et al.* (1978) formally proposed substage divisions for the Late Albian through the Coniacian in the Western Interior of North America based on assemblage biozones composed of largely endemic ammonites and cosmopolitan inoceramid bivalves.

In this work, the base of the Lower Coniacian was defined by the FOs of *Cremnoceramus rotundatus* (Fiege), *Pycnodonte aucella* (Roemer), and *Forresteria* spp., the base of the Middle Coniacian was defined by the FO of *Inoceramus (= Cremnoceramus) browni* (Cragin), and the base of the Upper by the FO of *Magadiceramus subquadratus* (Schlüter). This has subsequently been applied more widely in the Western Hemisphere (KAUFFMAN, 1978 b).

At the Brussels meeting, it was agreed that no internationally consistent definition of Coniacian substages and substage boundaries has yet been developed. Further, the most comprehensive published substage divisions, those of KENNEDY (1984 b) based on European ammonites, and of KAUFFMAN *et al.* (1994) for the Western Interior of North America, based on assemblage biozones consisting of largely endemic ammonites and mainly cosmopolitan inoceramid bivalves (Fig. 1) are not completely similar and cannot be compared in detail on the basis of ammonite zonation. Ammonites are poorly preserved in many Coniacian sequences, especially in fine-grained carbonates, and the American ammonite indices are largely endemic, insofar as they are currently known. Thus ammonites do not provide the best biostratigraphic basis for definition of the Turonian-Coniacian boundary.

After much debate, the Coniacian Working Group, by an 18 to O vote, 6 abstentions, approved the FO of the inoceramid genus *Volviceramus*, and specifically *Vo. koeneni, as the criterion for defining the Lower-Middle Coniacian Stage boundary.*

Although KENNEDY (1984 b) proposed for the Middle-Upper Coniacian an ammonite boundary (FO of *Gauthiericeras margae*) for parts of Europe, he acknowledged that ammonites are too rare in this interval to be useful, as currently known, in regional to global correlation of the Middle-Upper Coniacian substage boundary (unpublished report to the Coniacian Working Group, 1995). He also favoured the FO of *Magadiceramus subquadratus* to define the substage boundary.

This was the only boundary criterion discussed for the Middle-Upper Coniacian boundary by the working group at Brussels, and was approved by a 16 to 0 vote, 4 abstentions.

Boundary stratotype proposals

All aspects of the Coniacian and its stage and substage boundaries were discussed at the Brussels meeting, resulting in a number of recommendations to the Subcommission on Cretaceous Stratigraphy.

Turonian-Coniacian Boundary Stratotype. – Because neither of the Turonian-Coniacian boundary sections suggested as possible stratotype candidates [the Priesener Schichten (= Brezno Formation of present day stratigraphy) in the Czech Republic, and the El Kef section in Tunisia] at the Copenhagen meeting by BIRKELUND *et al.* (1984) has subsequently been studied in detail, published, and supported by a formal proposal to the Coniacian Working Group they could not be considered as viable candidates at the Brussels meeting.

Despite a rich and varied fossil record, the T-C boundary is below outcrop level at the proposed Czech stratotype (and, moreover it lies within the Teplice Formation rather than within the Brezno Formation – see CECH, 1989); the El Kef section lacks a significant macrofauna,

and access may be limited in the future.

Three new proposals for the Turonian-Coniacian boundary stratotype were presented at the Brussels meeting, and in correspondence leading up to that meeting, and an additional five informal proposals were made in correspondence, but were not pursued further at the meeting. The three Brussels proposals were as follows:

(1) The Vistula River section in central Poland, which contains an excellent Upper Turonian through upper Lower Coniacian (*Cremnoceramus deformis* Zone) macrofossil record, including ammonites and inoceramid and *Didymotis* bivalves (WALASZCZYK, 1992) and which shows little diagenesis, suggesting the potential for good microfossil recovery;

(2) The Wagon Mound, New Mexico (USA) section (COLLOM, 1991; KAUFFMAN, 1995) an easily accessible, well exposed, road-cut section of cyclically bedded calcareous shale and hemipelagic limestone (Milankovitch climate cycle deposits) with excellent preservation of foraminifers and inoceramid bivalves, detailed geochemical data (stable isotope and organic carbon profiles), and scattered ammonites;

(3) The Salzgitter-Salder Quarry section in Lower Saxony, Germany, originally studied in detail by WOOD *et al.* (1984) and proposed as a regional reference section and possible boundary stratotype for the T-C boundary. This section is well exposed, accessible, documented at very high levels of resolution, and contains a rich foraminifer, nannofossil, inoceramid and didymotid bivalve record, scattered ammonites, and numerous regionally persistent event marker beds (WOOD *et al.*, 1984; Figs. 2, 3, 4 herein). BURNETT (pers. comm.) placed the base in nannofossil zone CC 138 (defined by the FO of *Lithastrinus septenarius*. A preliminary $\delta^{13}C$ curve was published by ERNST & WOOD (1995); more detailed stable isotope data will be published by VOIGT & HILBRECHT (in prep.).

During the two-year deliberations of the working group, a number of regional stratotype sections for the Turonian-Coniacian boundary were informally proposed, but not formally presented at the Brussels meeting; these included:

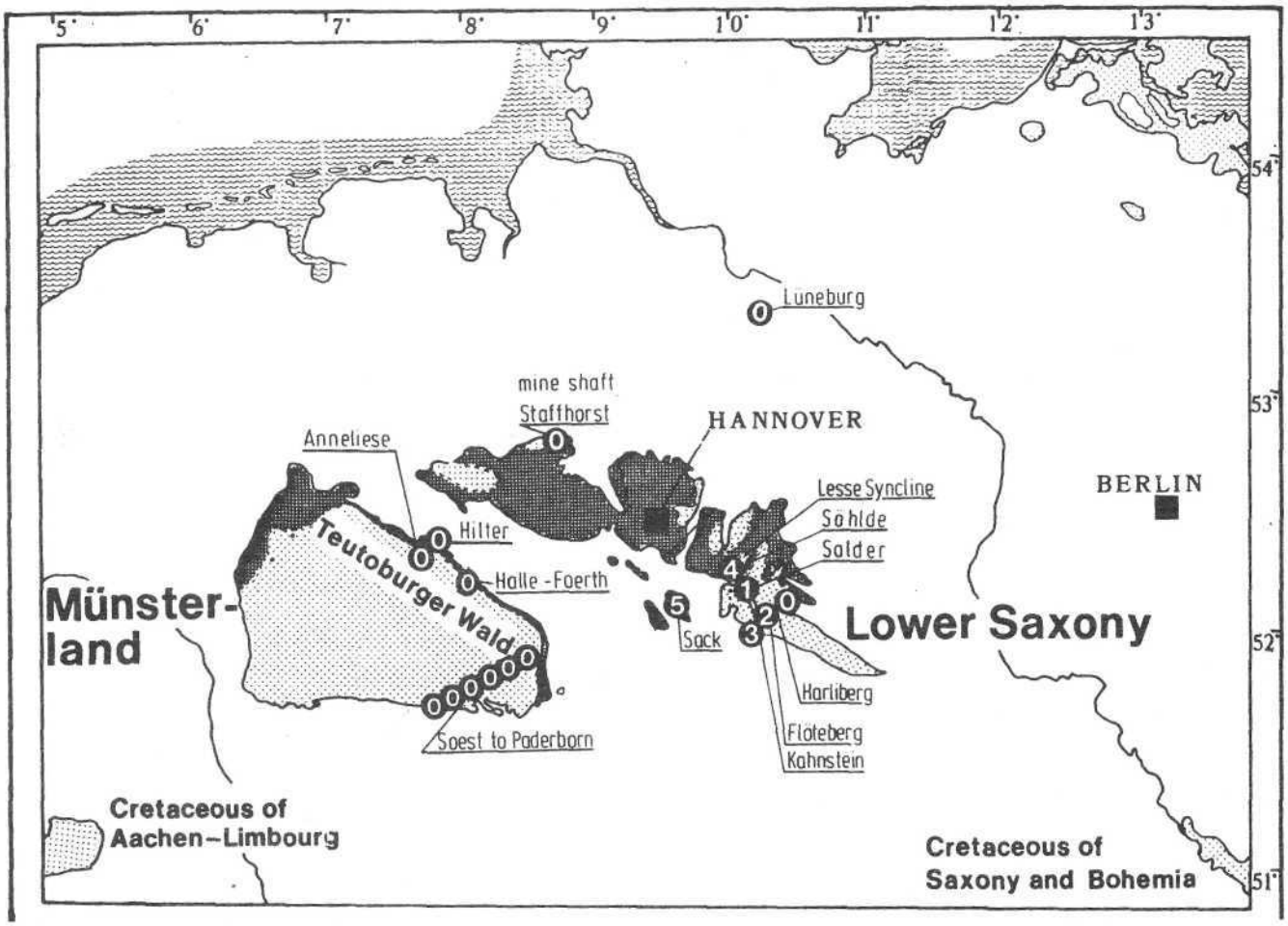


Fig. 2 — Locality map of Lower Saxony, Germany, showing the position of the Salzgitter-Salder Quarry (see Salder), the site of the stratotype section for the Turonian-Coniacian boundary recommended by the Coniacian Working Group at Brussels (After WOOD *et al.*, 1984).

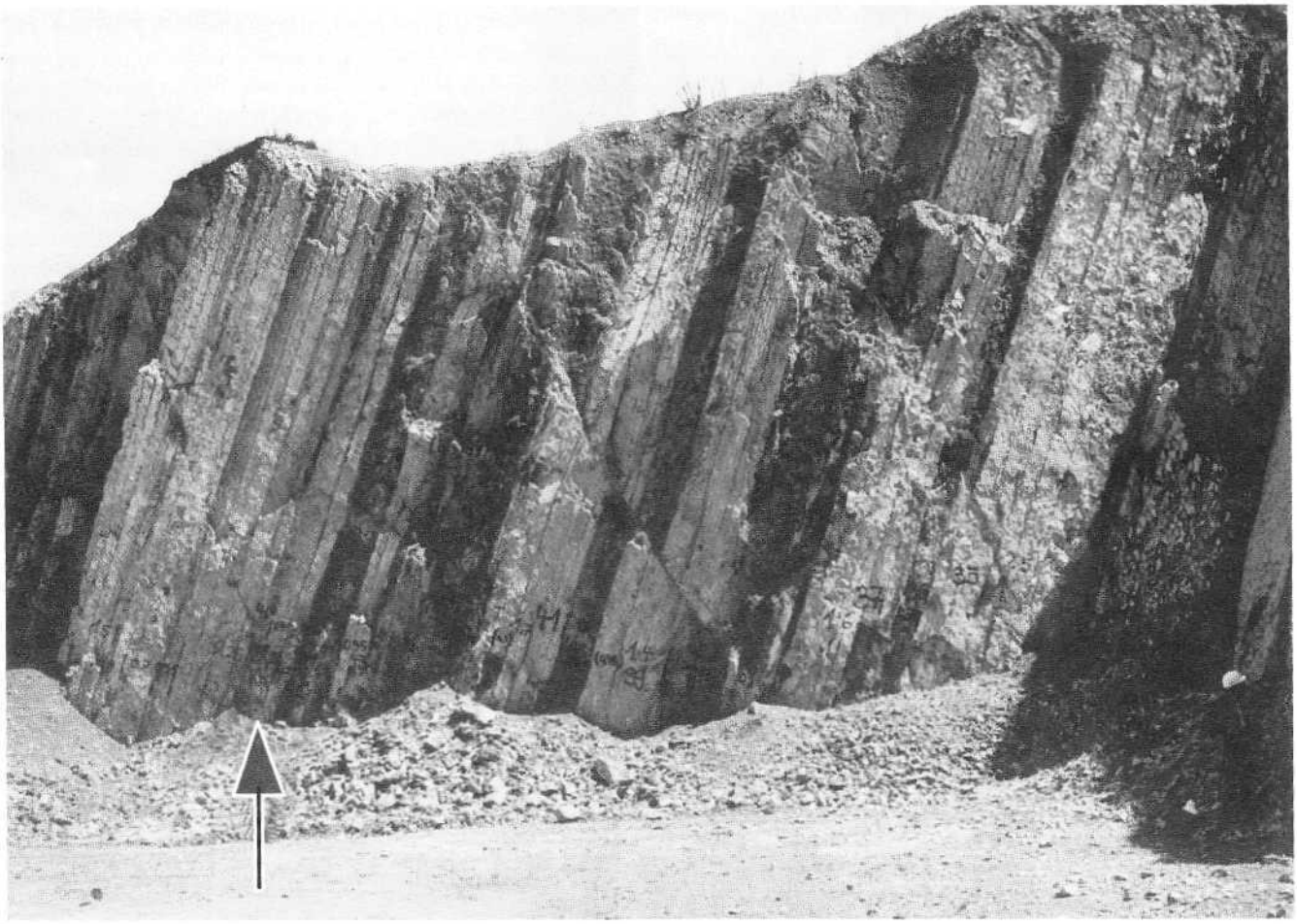


Fig. 3 — Photograph of the Turonian-Coniacian boundary stratotype section at the Salzgitter-Salder Quarry, Lower Saxony, Germany. The arrow designates the T-C boundary (see Figure 4) at the base of bed MK-47. (Photograph courtesy of C. J. Wood).

(1) T. Matsumoto (Fukuoka, Japan) proposed that the best reference sections for the Turonian-Coniacian boundary in Japan may be the Pombets (Ponbetsu)-Gono-sawa section in the Ikushambets (or "Mikasa") area of central Hokkaido (MATSUMOTO, 1984). The integrated micro- and macropalaeontology, and event stratigraphy of this boundary sequence is described in detail in TOSHIMITSU *et al.* (1995). The systematics and biostratigraphy of the Early Coniacian *Inoceramus (Cremnoceramus) deformis* group from the Obira area, northwestern Hokkaido, critical to the definition of the T-C boundary, has been completed recently by NODA (in press).

(2) W. A. Cobban (U. S. Geological Survey, Denver, USA), suggested that the Fort Hays Limestone section at Pueblo, Colorado, might be a good Turonian-Coniacian stratotype because *Forresteria* spp. are more abundant in the Lower Coniacian limestones there than at Wagon Mound, New Mexico (North American reference section proposed by E. G. Kauffman), and they may occur closer to the T-C boundary. A rich and diverse inoceramid bivalve fauna also spans the boundary here, but is not as well preserved as to the south. The interval is widely exposed, well preserved, and fully accessible within a Colorado State Recreation Area.

However, this boundary sequence is more condensed than in New Mexico or at the Salzgitter-Salder Quarry, and thus may contain some omission surfaces. Further, the Pueblo section has much thinner and more weathered marl and shale intervals between the limestones, which yield a depleted and somewhat poorly preserved microbiota. For these reasons, this T-C boundary section was withdrawn from consideration before the Brussels meeting.

(3) Ludmila F. Kopaevich (Moscow State University, Moscow, Russia) recommended three possible T-C stratotype sections, as follows:

(a) the Shakh-Bogota section, northern Mangyshlak, Kazakhstan; this is a complete and well exposed, fossiliferous section where the base of the Coniacian is marked by the FO of *Cremnoceramus? waltersdorfensis*, the benthic foraminifers *Gavelinella* sp. cf. *G. vombensis* (Brotzen)

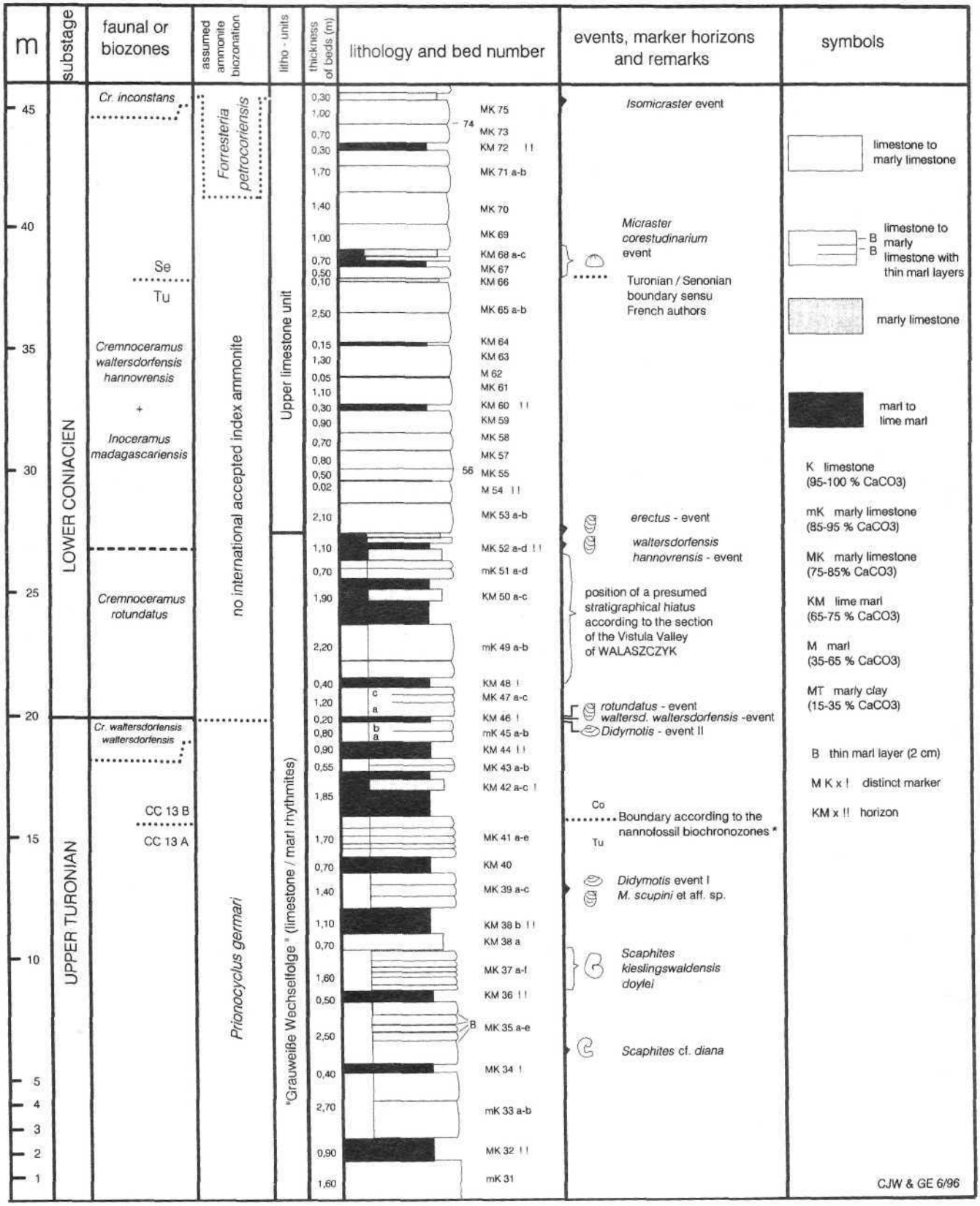


Fig. 4 — Detailed litho- and event stratigraphy of the Turonian-Coniacian stratotype boundary sequence, of the proposed international standard section Salzgitter-Salder Quarry (Lower Saxony, Germany) modified after Wood *et al.*, 1984.

and *Stensioina* sp. ex. gr. *S. granulata* (Olbertz), as well as a flood occurrence of planospiral marginotruncanid foraminifers (NAIDIN *et al.*, 1984);

(b) a bentonite between Turonian and Coniacian strata marks the boundary on the Voronezh High (Russia), Central part of Russian platform (KOPAEVICH *et al.*, 1995)

(c) abundant inoceramids, brachiopods, foraminifers, coccoliths, and numerous regional bioevents across the T-C boundary at the Aksu-dere section in southwest Crimea, The Ukraine (KOPAEVICH & WALASZCZYK, 1990).

The Mangyshlak section was proposed as the T-C boundary stratotype in preliminary communications.

Because formal proposals for the Vistula River Section, the Hokkaido section, the Pueblo section, the Kazakh, the Russian and the Ukrainian sections were not presented at the Brussels meeting (e.g. proposals including high-resolution stratigraphic, geochemical, and biostratigraphic data as well as justifications for choosing this stratotype section), and the mandate of the Coniacian Working Group was to decide at this meeting on criteria for defining the Turonian-Coniacian boundary, Coniacian substage boundaries, and boundary stratotypes, these proposals were subsequently withdrawn from consideration.

The Coniacian Working Group did endorse the concept of further documenting these sequences as regional reference sections for the T-C boundary.

Arguments were presented in favour of the Wagon Mound, New Mexico, USA, and of the Salzgitter-Salder, Lower Saxony, Germany sections; the latter was chosen as the new boundary stratotype of the Turonian-Coniacian boundary.

The Wagon Mound section (New Mexico, USA) section. – KAUFFMAN (1995) proposed the Wagon Mound, New Mexico (USA) locality of the Fort Hays Limestone Member, Niobrara Formation, as a candidate for the Turonian-Coniacian stratotype boundary. Data from this locality were obtained from the graduate thesis work of LAFERRIERE (1987 a) and COLLOM (1991), publications of LAFERRIERE (1987 b), LAFERRIERE *et al.* (1987), LAFERRIERE & HATTIN (1989), and subsequent field work by E. G. Kauffman in 1995. According to E.G. Kauffman this section meets all the requirements of an acceptable boundary stratotype. Detailed biostratigraphic continues on this section by E.G. Kauffman and students.

The Salzgitter-Salder Quarry Section, Lower Saxony, Germany. – WOOD *et al.* (1984) proposed the Salzgitter-Salder Quarry exposure as the best Turonian-Coniacian boundary reference section for northern Europe, and a possible candidate for the T-C boundary stratotype. Figure 3 shows the exposure of the boundary interval (arrow marks the position of the T-C boundary, as defined by criteria approved by the Coniacian Working Group at Brussels), and a detailed stratigraphic section, with regional marker beds noted, is shown in Figure 4.

The quarry is situated near the village of Salzgitter-Salder in Lower Saxony, Germany. It lies on the southeastern margin of the asymmetrical Lesse Syncline, just to the north of the Lichtenberg inversion structure. The quarry section comprises over 230 m of continuously exposed Middle Turonian through Lower Coniacian strata, dipping N at 70°, which have been documented in very high-resolution stratigraphic detail by WOOD *et al.* (1984, and references therein) (Figures 4 and 5). The sequence is richly fossiliferous, and especially through the Upper Turonian - Lower Coniacian interval: inoceramid bivalves dominate the macrofaunas, and calcareous plankton are well preserved.

The proposed Turonian-Coniacian boundary in the Salzgitter-Salder Quarry (Figs. 3, 4) is situated near the top of the "Grauweisse Wechselfolge" lithostratigraphic unit, at an horizon 207 m above the base of the WOOD *et al.* (1984) measured section and 61 m above the interregionally persistent tuff TF. The boundary (revised from the position taken in WOOD *et al.*, 1984) is drawn at the base of bed MK 47 (Figure 4), coincident with the FO of *Cremnoceramus rotundatus* (*sensu* TRÖGER *non* FIEGE), above the second flood occurrence of the bivalve *Didymotis* cf. *costatus* (FRIC) [*Didymotis* II] and above an acmezone of *Cremnoceramus waltersdorfensis waltersdorfensis*; these bioevents collectively constitute an interregional event-bundle (I. Walaszczyk & C.J. Wood, written communication, May 1966). This revised interpretation places both the two main *Didymotis* events into the terminal Turonian and agrees with the recorded LO of the upper Turonian zonal index ammonite *Prionocyclus germari* in and immediately above *Didymotis* II in the Bohemian Cretaceous Basin (cf. CECH, 1989).

The T-C boundary approximates to a minor negative $\delta^{13}C$ peak at the culmination of an overall broadly negative excursion (see ERNST & WOOD, 1995, fig. 4.5, and VOIGT & HILBRECHT, in prep.) beginning with the *Hyphantoceras* event. The boundary between nannofossil zones CC 13A and CC 13B based on the FO of *Lithastrinus septenarius* lies between middle Bed MK 41c and middle Bed KM 42a, i.e. ca 5-7 m below the T-C boundary (Burnett, unpublished data).

A distinctive set of discretely bundled, thickening upwards shale-limestone bedding couplets (Fischer bundles?) is present in the 50 m sequence underlying the T-C boundary (WOOD *et al.*, 1984, figs 2, 3); current work (KRÖGER, in prep.) seeks to demonstrate whether or not these couplets are orbitally controlled (Milankovitch rhythms) and the extent to which they can be used for high resolution regional correlation. In addition, several event beds and/or event-bundles bound the Turonian/Coniacian boundary (Figures 4 and 5). These are, in ascending order:

– (1) an interregionally persistent event-bundle (see WRAY & WOOD, 1995) comprising tuff TF, marl MF and the *Micraster* bioevent marl MG (acme-occurrence of advanced *Micraster* of the *bucailli* lineage), 58 m below the T-C boundary;

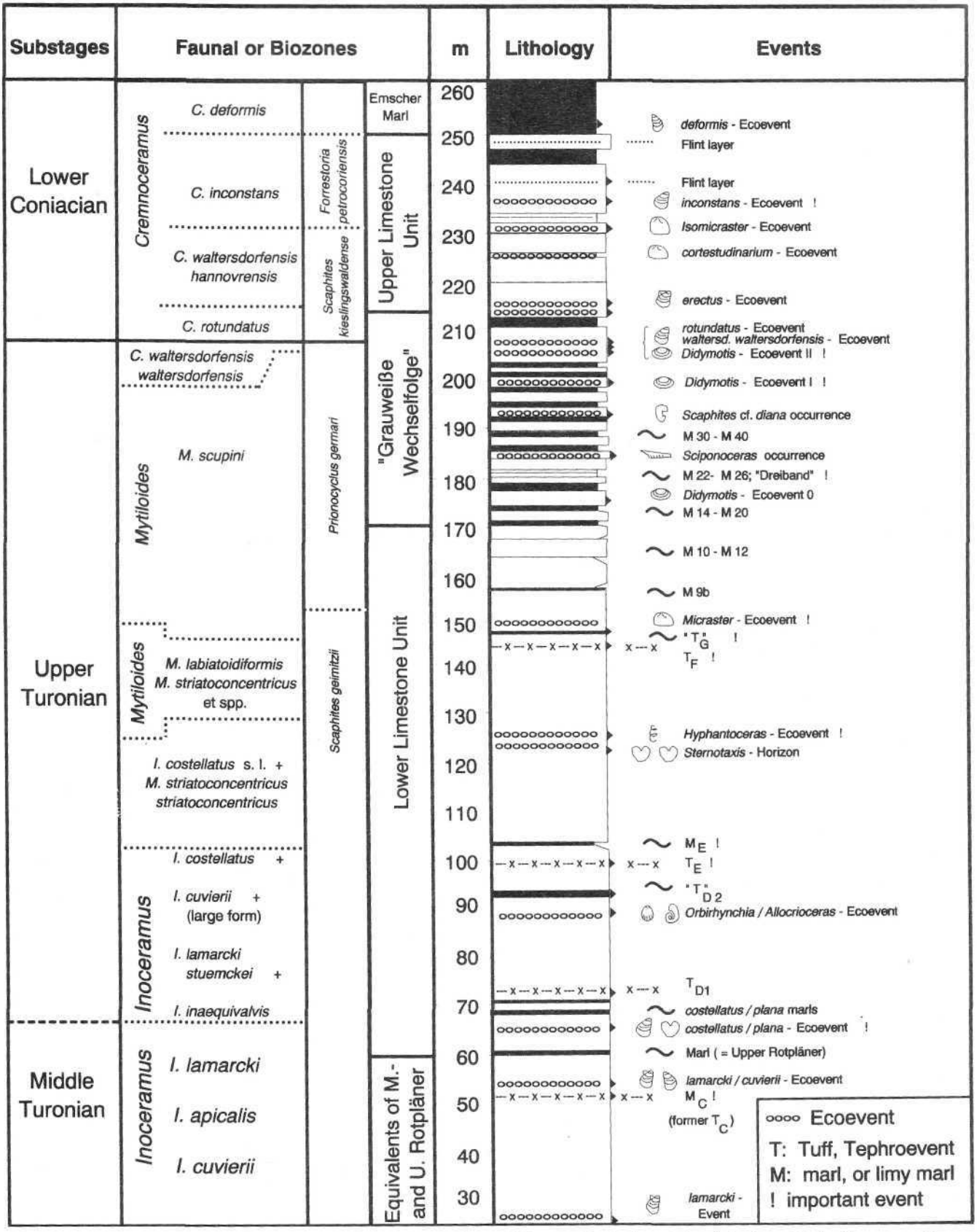


Fig. 5 — Bio- and event stratigraphy of the Upper Turonian and Lower Coniacian of the Salzgitter-Salder limestone Quarry (Lower Saxony, Germany).

– (2) a (recently) discovered *Didymotis* event in Bed mK 19 (KRÖGER, in prep.);
– (3) a *Sciponoceras* occurrence bed (mK 29), 23 m below the T-C boundary;
– (4) a *Scaphites* aff. *diana* occurrence bed (mK 35a), 14 m below the T-C boundary;
– (5) a *Sc. kieslingswaldensis doylei* [formerly *Sc. lamberti*] occurrence bed (37), 10-11 m below the T-C boundary;
– (6) the *Didymotis* ecoevent I (Bed MK 39b), 7.5 m below the T-C boundary, comprising a flood occurrence of *Didymotis* cf. *costatus* associated with a *Mytiloides scupini* zone assemblage comprising *M. scupini* (Heinz), *M. herbichi* (Atabekian) and *Inoceramus lusatiae* (Andert);
– (7) an event bed (Bed MK 41c), 5.3 m below the T-C boundary, with the same inoceramid assemblage as *Didymotis* I, but without *Didymotis* records;
– (8) the *Didymotis* ecoevent II in the limestone bed (MK 45b), 0.5 m below the T-C boundary, with a flood occurrence of *Didymotis* cf. *costatus* associated with a near-monospecific inoceramid assemblage conspecific with ANDERT's (1911) type material of *Cremnoceramus waltersdorfensis waltersdorfensis* [previously recorded by WOOD *et al.*, 1984 as small forms of *C. waltersdorfensis hannovrensis* (Heinz)];
– (9) a flood occurrence of crushed, bivalved *C. waltersdorfensis waltersdorfensis* associated with rare large *Didymotis* sp. in the marl bed (KM 46), 0-0.2 m below the T-C boundary;
– (10) the FO of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege) and its bioevent (acmezone), associated with forms transitional to *C. erectus* (Meek) and rare *Didymotis* sp. in the limestone bed (MK 47a): the base of this event bed is taken as the base of the Coniacian Stage;
– (11) the FO and bioevent (acmezone) of *Cremnoceramus waltersdorfensis hannovrensis* in Bed KM 52b, 7 m above the T-C boundary; and a *Cremnoceramus erectus* bioevent (acmezone) in Bed MK 53a, 8.5 m above the T-C boundary.

There are many advantages to this section as the Turonian-Coniacian boundary stratotype, as reviewed by WOOD *et al.* (1984) and as presented in the Brussels Symposium:

- it is a thick, continuously exposed, depositional sequence across the boundary without obvious hiatuses;
- it has numerous event and cycle marker beds at and bracketing the T-C boundary with proven regional correlation potential (e.g. WOOD *et al.*, 1984, Figures 4 and 5);
- it is richly fossiliferous, especially in inoceramid bivalves, which form the basis for biostratigraphic determination of Coniacian Stage and Substage boundaries; sufficient ammonites and echinoids are known from the section to provide independent biostratigraphic tie-points to other zonal schemes;
- diverse planktic microfossils are preserved in the sequence;
- utilizing bivalve (especially inoceramid) shell material, a detailed chemostratigraphic profile can be constructed for the section $\delta^{13}C$ (ERNST & WOOD, 1995; VOIGT & HILBRECHT, in press): whole rock analysis may be more difficult considering the tectonic deformation and resulting carbonate diagenesis of the strata;
- the section is accessible, continuously exposed, with fresh rock surfaces, and is still partially quarried with steep cliff faces that will remain relatively unweathered for the foreseeable future.

The only significant disadvantages relate to the diagenetic alteration of the carbonate, which makes fossils (especially microfossils) difficult to extract, and the paucity of ammonites.

By a 16 to 3 vote (no abstentions) the Coniacian Working Group proposed the Salzgitter-Salder Quarry section in Lower Saxony as the stratotype for the Turonian-Coniacian boundary, with the position of the T-C boundary there placed at the FO of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege), above the first flood occurrence of *Cremnoceramus? waltersdorfensis waltersdorfensis*, and above the second flood occurrence of *Didymotis* sp. cf. *D. costatus* associated with a significant regional turnover in planktonic foraminifers (Figures 4 and 5).

In making this decision, the working group cited three major advantages of the Salzgitter-Salder Quarry section over other candidates, as follows:

- this is the best studied of the proposed boundary stratotypes, with exceptionally high-resolution stratigraphic data already published (e.g. WOOD *et al.*, 1984), and a detailed chronology based on integrated event marker beds and mollusc-foraminifer biozones. Collectively, these event horizons and biozone boundaries allow precise correlation, and location of the boundary interval, over much of Europe;
- the quarry contains one of the richest and most persistent records of inoceramid bivalves in Europe, including *Cremnoceramus rotundatus*, the FO of which coincides with other widely distributed bioevent horizons (see above), and which has been chosen as the main criterion for internationally defining the T-C boundary. (Inoceramids are the principal basis for refined biostratigraphic zonation and regional to global correlation in the Coniacian because they are well preserved in hemipelagic and pelagic carbonate facies, which otherwise show a preservational bias against ammonites). There is a major turnover in the species composition of the calcareous foraminifer assemblage coincident with the FO of *Cr. rotundatus* and the T-C boundary at Salzgitter-Salder; and
- the Salzgitter-Salder Quarry is still somewhat active, with steep clean walls, and is not likely to be filled or deeply weathered in the near future.

Substage stratotypes: Whereas two possible stratotype sections were discussed for the Lower-Middle Coniacian boundary, none were considered well enough known at present to make a final selection. The membership did approve, however, by a vote of 16-0, with 4 abstentions, to encourage research teams from the Coniacian Working Group to document in detail possible boundary stratotypes in the following areas, with a report due back to the committee in 1996:
(1) the Dallas-Fort Worth area of Texas, in the Lower Austin Chalk (A. S. Gale, E. G. Kauffman, P. Larson, and colleagues);
(2) the Seaford Head exposures of the Upper Chalk in southern England (R. Mortimore, C. J. Wood, A. S. Gale and colleagues);

Each of these sections has excellent exposures, a rich inoceramid fauna and microbiota, some ammonites, and rock/fossils amenable to geochemical analysis. Volcanic ash layers (bentonites) for possible radiometric dating and refined chronostratigraphic correlation occur in the Texas sections. At the time this manuscript was completed, none of these groups had completed their regional studies.

No stratotype sections were proposed by the working group for the Middle-Upper Coniacian boundary, but the three general areas listed above for the Lower-Middle Coniacian boundary are all being investigated as potential candidates.

References

BAILEY, H. W., GALE, A. S., MORTIMORE, R. N., SWIECICKI, A., & WOOD, C. J., 1984. Biostratigraphical criteria for the recognition of the Coniacian to Maastrichtian stage boundaries in the Chalk of north-west Europe, with particular reference to southern England. *Bulletin of the Geological Society of Denmark*, **33**: 31-39.

BIRKELUND, T., HANCOCK, J. M., HART, M. B., RAWSON, P. F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F., 1984. Cretaceous stage boundaries - Proposals. *Bulletin of the Geological Society of Denmark*, **33**: 3-20.

BRÄUTIGAM, F., 1962. Zur Stratigraphie und Paläontologie des Cenomans und Turons im nordwestlichen Harzland. Thesis TH Braunschweig. 261 pp.

CECH, S., 1989. Upper Cretaceous *Didymotis* Events from Bohemia. *In:* WIEDMANN, J., Ed.: Cretaceous of the Western Tethys, Schweizerbart'sche Verlagsbuchhandlung, pp. 657-676.

CECH, S., KLEIN, V., KRIZ, J. & VALECKA, J., 1980. Revision of the Upper Cretaceous stratigraphy of the Bohemian Cretaceous Basin. *Vestnik ustredniho ustavu geologickeho* **55:** 227-296.

COLLOM, C. J., 1991. High-resolution stratigraphic and paleoenvironmental analysis of the Turonian-Coniacian stage boundary interval (Late Cretaceous) in the lower Fort Hays Limestone Member, Niobrara Formation, Colorado and New Mexico. Unpublished M. Sc. Thesis, Brigham Young University, USA, 371 pp.

COQUAND, H., 1857a. Notice sur la formation crétacée du département de la Charente. *Bulletin de la Société géologique de France* (2), **14**: 55-98.

COQUAND, H., 1857b. Position des *Ostrea columba* et *biauriculata* dans le groupe de la craie inférieure. *Bulletin de la Société géologique de France* (2), **14**: 745-766.

ERNST, G. & WOOD, C.J., 1995. Exkursion B. Die tiefere Oberkreide des subherzynen Niedersachsens (Raum Hildesheim-Salzgitter-Vienenburg). Faziesgeschichte, Beckendynamik, Events und Sequenzen. *In:* BOETZKES, M. & VESPERMANN, J. Exkursionsführer der 65. Jahrestagung der Paläontologischen Gesellschaft Hildesheim, 25-30 September 1995. pp. 41-84.

GROSSOUVRE, A. DE, 1894. Recherches sur la craie supérieure, 2. Paléontologie. Les ammonites de la craie supérieure. *Mémoires du Service de la Carte géologique detaillée de la France*. 264 pp.

GROSSOUVRE, A. DE, 1901. Recherches sur la craie supérieure, 1. Stratigraphie générale. *Mémoires du Service de la Carte géologique detaillée de la France*. vii + 1013 pp.

HERM, D., KAUFFMAN, E. G. & WIEDMANN, J., 1979, The age and depositional environment of the 'Gosau'-Group (Coniacian-Santonian), Brandenberg/Tirol, Austria. *Mitteilungen Bayerische Staatssammlung für Paläontologie und historische Geologie*, **19**: 23-92.

KAPLAN, U. & KENNEDY, W. J., 1994. Ammoniten des westfälischen Coniac. *Geologie und Paläontologie in Westfalen* **31**: 155 pp.

KAPLAN, U. & KENNEDY, W. J., in press. Upper Turonian and Coniacian Ammonite Stratigraphy of Westphalia, NW-Germany.

KAUFFMAN, E. G., 1978 a. British middle Cretaceous inoceramid biostratigraphy. *In*: REYMENT, R. A. & THOMEL, G. (eds.), Mid-Cretaceous Events: Reports on the Biostratigraphy of Key Areas. *Annales du Muséum d'Histoire Naturelle de Nice*, **4**: IV-1 - IV-12 (imprint 1976).

KAUFFMAN, E. G., 1978 b. Middle Cretaceous bivalve zones and stage implications in the Antillean Subprovince, Caribbean Province. *In:* REYMENT, R. A., & THOMEL, G. (eds.), Mid-Cretaceous Events: Reports on the Biostratigraphy of Key Areas. *Annales du Muséum d'Histoire Naturelle de Nice*, **4:** XXX-1 - XXX-10 (imprint 1976).

KAUFFMAN, E. G., 1995. Proposed Turonian-Coniacian boundary stratotype, Wagon Mound, northern New Mexico, USA. Abstracts, Second International Symposium on Cretaceous Stage Boundaries, Sept. 8-16, 1995, Brussels, Belgium: p. 174.

KAUFFMAN, E. G., COBBAN, W. A., & EICHER, D. L., 1978. Albian through Lower Coniacian strata, biostratigraphy, and principal events in the Western Interior, United States. *In:* REYMENT, R. A. & THOMEL, G. (eds.), Mid-Cretaceous Events: Reports on the Biostratigraphy of Key Areas. *Annales du Muséum d'Histoire Naturelle de Nice*, **4**: XXIII-1 - XXIII-49 (imprint 1976).

KAUFFMAN, E. G., SAGEMAN, B. B., KIRKLAND, J. I., ELDER, W. P., HARRIES, P. J., & VILLAMIL, T., 1994, Molluscan Biostratigraphy of the Cretaceous Western Interior Basin, North Amer-

ica. *In:* CALDWELL, W. G. E., & KAUFFMAN, E. G. (eds.), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39:** 397-434.

KENNEDY, W. J., 1984a. Systematic palaeontology and stratigraphic distribution of the ammonite faunas of the French Coniacian. *Special Papers in Palaeontology*, **31**: 160 pp.

KENNEDY, W. J., 1984b. Ammonite faunas and the 'standard zones' of the Cenomanian to Maastrichtian Stages in their type areas, with some proposals for the definition of the stage boundaries by ammonites. *Bulletin of the Geological Society of Denmark*, **33**: 147-161.

KENNEDY, W.J. & COBBAN, W. A., 1991. Coniacian ammonite faunas from the United States Western Interior. *Special Papers in Palaeontology* **45:** 96 pp.

KOPAEVICH, L. F., OLFERIEV, A. G., OSIPOVA, L.M., 1995. Turonian/Coniacian boundary on the Russian Platform. Abstracts, Second International Symposium on Cretaceous Stage Boundaries, Sept. 8-16, 1995, Brussels, Belgium: p. 69

KOPAEVICH, L. F. & WALASZCZYK, I., 1990. An integrated inoceramid-foraminiferal biostratigraphy of the Turonian and Coniacian strata in south-western Crimea, Soviet Union. *Acta geologica polonica*, **40** (1-2): 83-96.

KÜCHLER, T. & ERNST, G., 1989. Integrated biostratigraphy of the Turonian-Coniacian transition interval in Northern Spain with comparison to NW Germany. *In:* WIEDMANN, J., Ed.: Cretaceous of the Western Tethys, Schweizerbart'sche Verlagsbuchhandlung, pp. 161-190

LAFERRIERE, A. P.,1987a. Regional analysis of rhythmic bedding in the Fort Hays Limestone Member, Niobrara Formation (Upper Cretaceous), U. S. Western Interior. Unpublished Ph. D. Thesis, Indiana University, 278 pp.

LAFERRIERE, A. P., 1987 b. Cyclic sedimentation in the Fort Hays Limestone Member, Niobrara Formation (Upper Cretaceous) in northeastern New Mexico and southeastern Colorado. *New Mexico Geological Society Guidebook, 38th Field Conference, NE New Mexico,* p. 249-254

LAFERRIERE, A. P., HATTIN, D. E., & ARCHER, A. W., 1987, Effects of climate, tectonics, and sea-level changes on rhythmic bedding patterns in the Niobrara Formation (Upper Cretaceous), U. S. Western Interior. *Geology*, **15**: 233-236.

LAFERRIERE, A. P., & HATTIN, D. E., 1989. Use of rhythmic bedding patterns for locating structural features, Niobrara Formation, United States Western Interior. *American Association of Petroleum Geologists Bulletin*, **73, 5**: 630-640.

MARKS, P., 1984. Proposal for the recognition of boundaries between Cretaceous stages by means of planktonic foraminiferal biostratigraphy. *Bulletin of the Geological Society of Denmark*, **33**: 163-169.

MATSUMOTO, T., 1984, The so-called Turonian-Coniacian boundary in Japan. *Bulletin of the Geological Society of Denmark*, **33**: 171-181.

NAIDIN, D.P., BENYAMOVSKY, V. N. & KOPAEVICH, L. F., 1984. Methods of transgression and regression study exemplified by Late Cretaceous Basins of west Kazakhstan. 162 pp. Moscow University Press, Moscow (in Russian)

OBRADOVICH, J., 1994. A Cretaceous time scale. *In:* CALDWELL, W. G. E., & KAUFFMAN, E. G. (eds.), Evolution of the Western Interior Basin. *Geological Association of Canada, Special Paper*, **39**: 379-396.

POMEROL, B., 1983. The correlation of the Turonian-Senonian boundary in the Senonian stratotype area and southern England. *In:* BIRKELUND, T., BROMLEY, R., CHRISTENSEN, W. K., HAAKANSSON, E., & SURLYK, F. (eds.), Symposium on Cretaceous Stage Boundaries, Copenhagen, Denmark, p. 161-165.

POMEROL, B., DAMOTTE, R., FOURAY, M., & MONCIARDINI, C., 1983, Précisions biostratigraphiques sur la limite Turonien-Sénonien dans la région stratotypique de Sens (Yonne). *Comptes Rendus Académie Sciences, Paris*, **297**, II: 421-424.

ROBASZYNSKI, F., 1984, The Albian, Cenomanian and Turonian Stages in their type-regions. *Bulletin of the Geological Society of Denmark*, **33**: 191-198.

SÉRONIE-VIVIEN, M., 1972, Contribution à l'étude du Sénonien en Aquitaine septentrionale. Les stratotypes: Coniacien, Santonien, Campanien. *Les stratotypes français*, **2**, 195 pp. , éditions C.N.R.S.

SÉRONIE-VIVIEN, M. 1980, Coniacien, Santonien. *In:* Les étages français et leurs stratotypes. *Mémoires Bureau Recherches Géologiques et Minières*, **109:** 150-160.

TOSHIMITSU, S., MATSUMOTO, T, NODA, M., & NISHIDA, T., 1995. Toward an integrated mega-, micro- and magneto-stratigraphy of the Upper Cretaceous in Japan, *Journal of the Geological Society of Japan*, **101**, 1: 19-29.

TRÖGER, K.-A., 1967. Zur Paläontologie, Biostratigraphie und faziellen Ausbildung der unteren Oberkreide (Cenoman bis Turon). Teil I. Paläontologie und Biostratigraphie der Inoceramen des Cenomans bis Turons Mitteleuropas. *Abhandlungen des Staatlichen Museums für Mineralogie und Geologie zu Dresden*, **12**: 13-207.

TRÖGER, K.-A., 1981, Zur Problemen der Biostratigraphie der Inoceramen und der Untergliederung des Cenomans und Turons in Mittel- und Osteuropa. *Newsletters of Stratigraphy*, **9**: 139-156.

VOIGT, S. & HILBRECHT, H. (in press). Stable carbon isotope stratigraphy of the European Boreal and Tethyan Upper Cretaceous. *Palaeogeography, Palaeoclimatology, Palaeoecology.*

WALASZCZYK, I., 1992. Turonian through Santonian deposits of the Central Polish Uplands; their facies development, inoceramid palaeontology and stratigraphy. *Acta geologica polonica,* **42:** 1-122.

WOOD, C. J., ERNST, G., & RASEMANN, G., 1984, The Turonian-Coniacian stage boundary in Lower Saxony (Germany) and adjacent areas: the Salzgitter-Salder Quarry as a proposed international standard section. *Bulletin of the Geological Society of Denmark*, **33**: 225-238.

WRAY, D. S. & WOOD, C. J., 1995. Geochemical identification and correlation of tuff layers in Lower Saxony, Germany. *Berliner geowissenschaftliche Abhandlungen*, **E 16** (Gundolf Ernst Festschrift): 215-225.

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The Santonian Stage and substages

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Abstract

The recognition of the Coniacian-Santonian boundary is easy with good correlation of macro- and microfossil evidence. The Santonian Working Group (SWG) recommends the lowest occurrence of *Cladoceramus undulatoplicatus* (Roemer) as the marker for the Coniacian-Santonian boundary. As yet, the SWG cannot make a formal proposal for a Boundary Stratotype Section, because the biostratigraphy must be better known and integrated first. Three candidates for Boundary Stratotype Section, Olazagutia Quarry (Navarra, Spain), Seaford Head (Sussex, England) and Ten Mile Creek (Dallas, Texas, USA) were selected for further decision. To achieve a useful subdivision of the Santonian into substages a better understanding of taxa ranges and correlation through different biogeographic realms is needed. Formal proposals for subdivision would be premature at present, but a three-fold division is favoured.

Key-words: Santonian, Upper Cretaceous, stratotypes, chronostratigraphy, biostratigraphy, ammonites, belemnites, crinoids, foraminifera, inoceramids, nannofossils.

Résumé

La reconnaissance de la limite Coniacien-Santonien se fait aisément grâce à une bonne correlation sur base des marqueurs macro- et microfossiles.

Le Groupe de Travail du Santonien (SWG) a recommandé la première apparition de *Cladoceramus undulatoplicatus* (Roemer) comme marqueur de la limite Coniacien-Santonien. Le SWG considère qu'une proposition formelle pour un stratotype de la limite ne peut pas encore être faite car la biostratigraphie est encore insuffisamment connue et doit être mieux intégrée. Trois propositions de stratotypes de la limite ont été sélectionnées, la carrière Olazagutia (Navarre, Espagne), Seaford Head (Sussex, Angleterre) et Ten Mile Creek (Dallas, Texas, USA), pour des recherches plus approfondies.

La subdivision du Santonien en sous-étages nécessite une meilleur compréhension des extensions des taxa et une corrélation dans différentes régions biogéographiques. Des propositions formelles pour la subdivision de l'étage seraient encore prématurées, mais une division en trois sous-étages paraît préférable.

Mots-clefs: Santonien, Crétacé supérieur, stratotypes, chronostratigraphie, biostratigraphie, ammonites, bélemnites, crinoides, foraminifères, inocéramidés, nannofossiles.

Сантонский ярус и подъярусы: рекомендации Рабочей группы Сантонского яруса.

Резюме.
Граница Коньяка и Сантона легко опознаётся благодаря существующей корреляции индекс-видов макро- и микрофоссилий.

Рабочая группа Сантонского яруса рекомендует считать первое появление *Cladoceramus undulatoplicatus* (Roemer) как индекс-вид для Коньяко-Сантона. Рабочая группа Сантонского Яруса считает, что, на данный момент, формальное предложение для стратотипа границы не может быть сформулировано, так как биостратиграфия ещё не достаточно известна и должна быть лучше интегрирована. Для проведения более подробных опытов были отобраны 3 предложения стратотипа: карьер Olazagutia (Navarra, Испания), Seaford Head (Sussex, Англия) и Ten Mile Creek (Dallas, Техас, США).
Разделение Сантона на подъярусы требует лучшего понимания распространения таксонов и корреляции разных биогеографических районов. Формальные предложения по разделению яруса являются преждевременными; тем не менее, разделение на три подъяруса кажется предпочтительным.

Ключевые слова: Сантонский ярус, верхний мел, стратотипы, хроностратиграфия, биостратиграфия, аммониты, белемниты, *Crinoida*, фораминиферы, иноцерамы, нанофоссилии.

Historical

The Santonian Stage was proposed by COQUAND (1857), presumably named after the town of Saintes in south-west France. One of the localities which Coquand mentioned was Javrezac, a village on the north-west side of Cognac. The boundary there was drawn on a hardground of glauconitic, nodular limestone, with many "*Exogyra*", of the Coniacian below, and soft micaceous chalk of the Santonian above.

At the First Symposium on Cretaceous Stage Boundaries (BIRKELUND *et al.*, 1984) the consensus was that the first appearance of *Texanites (Texanites)* and of *Cladoceramus undulatoplicatus* (Roemer) are the two best boundary criteria. *Texanites (Texanites)* has been used over a wide area, although in classic regions of north-west Europe this subgenus is far too rare to be a practical marker (HANCOCK, 1991). *Cladoceramus undulatoplicatus* is widespread, and owing to its characteristic form and sculpture is easy to identify. The appearance of *Platyceramus siccensis* (Pervinquière) is well known in north Africa

associated with *Texanites*, and it could be another possible marker for the base of the Santonian.

In the Santonian Working Group report to the Second Symposium on Cretaceous Stage Boundaries (Brussels, September 1995), other macro- and microfossils were mentioned as possible indices for the Coniacian-Santonian Boundary.

Thus, the lowest occurrence of the ammonite *Placenticeras polyopsis* (Dujardin) is relatively close to lower *Texanites (Texanites)*. Similarly, the entry of the *Sphenoceramus pachti-cardissoides* group is a possible marker for this boundary, associated with *Texanites* and *Cladoceramus undulatoplicatus*. Further discussion on macrofossil criteria were reported by KENNEDY (1995).

Published calcareous nannofossil events do not precisely define the Coniacian-Santonian boundary, which SISSINGH (1977) placed in CC 14 [above the first occurrence (F.O.) of *Micula staurophora* (Gardet) Stradner]: e.g., the lowest occurrence of *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen is unreliable (WAGREICH, 1992), and recent studies (e.g., at Ten Mile Creek in Dallas, Texas; J. A. Burnett, written comm.) show that the Coniacian-Santonian boundary actually lies above the F.O. of *Reinhardtites anthophorus* (i.e. in CC 15 of SISSINGH, 1977). Nannofossil events which approximate the boundary are (from stratigraphically old to young): F.O. of *Lithastrinus grillii* Stradner, last occurrence (L.O.) of *Quadrum gartneri* Prins & Perch-Nielsen, L.O. of *Flabellites oblongus* (Bukry) Crux (all below the boundary) and the L.O. of *Lithastrinus septenarius* Forchheimer above the boundary. All these events fall within CC 15. Other nannofossil events, such as the L.O. of *Eprolithus floralis* (Stradner) Strover, and F.O. of *Micula concava* (Stradner) Verbeek occur later or earlier than entries of *Texanites* and *Cladoceramus undulatoplicatus*. Nevertheless, FLORES *et al.* (1987) commented that *Micula concava* and *Lithastrinus grillii* are present in greater abundances in the Santonian than in the Coniacian, and this may serve as a general guide, although nannofossil abundance is related to ecological and taphonomical factors which are generally not cosmopolitan in their extent.

First occurrences of the planktonic foraminiferan *Sigalia deflaensis* (Sigal) and *S. carpathica* Salaj have been used as markers of the latest Coniacian and the Coniacian-Santonian Boundary (SALAJ, 1975; SIGAL, 1977, respectively). Also, the first occurrence of *Dicarinella asymetrica* (Sigal), belonging to the *D. concavata* group, dates early Santonian, since it post-dated lower *Texanites* and *Cladoceramus undulatoplicatus*. Successive occurrences of these three taxa are very promising for correlation with macrofaunal ranges, and a definition of the Coniacian-Santonian Boundary.

Boundary criteria proposed at Copenhagen, and other ones commented in the Working Group reports, were discussed at Brussels during the Second Symposium in 1995.

Discussion

AMMONITES

Once it had been concluded that the species *Texanites texanus* (Roemer) does not occur in the Aquitaine Basin, nor in other European localities, (BIRKELUND *et al.*, 1984) pointed out the first appearance of the subgenus *Texanites (Texanites)* could still be a good marker of the Coniacian-Santonian boundary. Nevertheless, *Texanites (Texanites)* is rare in many areas where other indices occur, only in Zululand (South Africa), Madagascar and Texas is the subgenus common (reported by KENNEDY, 1995).

In the Anglo-Paris Basin, Texanitidae are rare, although in a hard-ground level in the Craie de Villedieu, France, *Texanites gallicus* Collignon occurs with *Placenticeras polyopsis* (Dujardin) and *Inoceramus (Cladoceramus)* (JARVIS & GALE, 1984). In Sussex in S. England, *Texanites* has not been found, but *Spinaptychus*, an aptychus associated with *Texanites*, is recorded below and close to the *Cladoceramus undulatoplicatus* event (BAILEY *et al.*, 1983, p. 34; see below in the inoceramid chapter).

KENNEDY (1995) cited Germany as a region where there are well documented co-occurrences of *Texanites* and *Cladoceramus undulatoplicatus* (Roemer), particularly the species *Texanites (T.) pseudotexanus* de Grossouvre (= *Texanites texanus* auct.). SEITZ (1961) cited in the shaft Ewald Section the coexistence of *T. texanum* (= *T. (T.) pseudotexanus*) and *Inoceramus pachti* (Arkhanguelsky) (*fide* Tröger, written comm.; see below inoceramid chapter).

In the Gosau Group, in Austria, TRÖGER & SUMMESBERGER (1994), have reported that *Texanites quinquenodosus* (Redtenbacher) co-occurs with *Sphenoceramus cardissoides* (Goldfuss) and *Parapuzosia daubreei* (de Groussouvre). This assemblage is several metres below the first occurrence of *Cladoceramus undulatoplicatus*, and above the Coniacian inoceramid *Volviceramus involutus* (J. de C. Sowerby). Such a sequence is well correlated with TRÖGER's (1989) inoceramid biostratigraphy. WAGREICH (1992) correlated lower Santonian localities in Austria (Gosau Valley and Bad Ischl-Nussensee) with *Texanites quinquenodosus*, associated with the first occurrences of the planktonic foraminifera *Sigalia deflaensis* and *Dicarinella asymetrica*. Also, those assemblages were directly correlated with the *Cladoceramus undulatoplicatus*-bed in the Brandenberg area.

In the Pyrenees *Texanites (T.)* occurs at several levels in the Santonian. In north Spain (MARTINEZ *et al.*, 1996) *Texanites (T. hispanicus* Collignon, *T.* cf. *quinquenodosus*, *T. gallicus*) occurs in several sections. These species have an irregular distribution, but *T. gallicus* and *Texanites* sp. are sometimes found below *Cladoceramus undulatoplicatus*: more than 40 m in the Oteo section (Lopez, written comm.). In Tunisia, also a Tethyan area, at Djebl Fguira Salah, *Texanites (T.) olivetti* (= *T. quinquenodosus*) occurs in the lowermost Santonian levels, with *Platyceramus siccensis* (Pervinquière) (*fide* BIRKELUND *et*

al., 1984; SALAJ, 1980, p. 91). In the Corbières, S.E. France, *Texanites soutoni* (Baily), *T. quinquenodosus* and *T. gallicus* occur in "Middle" Santonian but not in the Lower Santonian *Nowakites carezi* Subzone (KENNEDY *et al.*, 1996); as in the Craie de Villedieu, *T. gallicus* co-occurs with *Placenticeras polyopsis*. Although no texanitids have been found immediately above a distinctive Upper Coniacian *Paratexanites serratomarginatus* Zone, with *Protexanites* spp. , there is otherwise a macrofaunal turnover, whose species belong to the genera *Muniericeras, Texasia, Pseudoschloenbachia, Nowakites*, etc., which mark the base of the Santonian (KENNEDY *et al.*, 1996).

Near Austin in Texas the *Texanites stangeri densicostatus* Zone, as understood by K. Young, begins some distance (but probably 2 m) below the lowest *Cladoceramus undulatoplicatus* (YOUNG, 1963, particularly fig. 4); moreover, its main abundance is near the top of the *T. stangeri densicostatus* Zone. In the Dallas area of north central Texas there is a record of *Texanites* (LARSON *et al.*, 1991, fig. 10.6) in a bed which A. S. Gale and J. M. Hancock found to be at least 12 m below the lowest *Cl. undulatoplicatus* (Hancock, written comm.). This figure agrees with data from northern Spain. Therefore the lowest *Texanites* cannot be used as an accurate and absolute standard for the base of the Santonian stage.

At Amakusa, in S.W. Japan, the Coniacian-Santonian boundary is marked by the occurrence of *T. collignoni* Klinger and Kennedy (= *T. olivetti* auct.) which is associated with *Inoceramus amakusensis* Nagao and Matsumoto (UEDA, 1962; T. Matsumoto, written comm.), whereas in the Haboro area, N.W. Hokkaido, *I. amakusensis* occurs below *T. collignoni* (TOSHIMITSU *et al.*, 1995, fig. 2, p. 24), but just above the Coniacian species *I. mihoensis* Matsumoto.

The first appearance of *Texanites*, particularly *T. (Plesiotexanites) kawasakii* (Kawada) and *Inoceramus amakusensis* are the two best criteria for the Coniacian-Santonian boundary in Sakhalin. Both species lie above *Peroniceras* sp. and *Inoceramus mihoensis* (E.A. Yazykova, written comm., YAZYKOVA, 1996) (Figure 1).

INOCERAMIDS

Three species have been used to define the Coniacian-Santonian boundary: the widespread species *Cladoceramus undulatoplicatus*, the north Temperate *Sphenoceramus pachti-cardissoides* group and the north African *Platyceramus siccensis*.

The last species, possibly related to the *Pl. cycloides* group, was cited in Algeria (SIGAL, 1952) and Tunisia associated with *Sigalia carpathica* Salaj; both occurrences are above the late Coniacian species *S. deflaensis* (Sigal) (SALAJ, 1980). No occurrence is known outside north Africa.

Cladoceramus undulatoplicatus is an almost worldwide species, whose appearance has been used to define the Coniacian-Santonian boundary. It is associated with *Sphenoceramus* in North Temperate areas, and lies above *Magadiceramus subquadratus* (Schlüter) in the Northern Hemisphere (DHONDT, 1992; LOPEZ *et al.*, 1992).

In the Western Interior of N. America, KAUFFMAN *et al.* (1994) reported the co-occurrence of *Cladoceramus undulatoplicatus* s.s., *Sphenoceramus pachti*? and *Platyceramus cycloides* (Wegner) at the base of the Santonian, which are associated with *Cordiceramus cordiformis* (J. de C. Sowerby) in overlying beds. Near Austin, Texas, the lowest *Cladoceramus undulatoplicatus* occurs at an uncertain distance above the base of the Zone of *Texanites stangeri densicostatus* (for details, see above in "Ammonites").

In the north German-Polish Basin it is common to find the succession of uppermost Coniacian *Magadiceramus subquadratus* [TRÖGER, 1989's Zone 24] and lowermost Santonian *Sphenoceramus pachti* and *Sph. cardissoides* (TRÖGER (1989)'s Zone 25). They are followed (TRÖGER, 1989) by occurrences of *Cladoceramus undulatoplicatus*. SEITZ (1961, fig. 2, p. 19) cited, in the Ewald shaft section, the coexistence of *Sphenoceramus pachti* and *Texanites texanum* (Roemer) [= *Texanites (T.) pseudotexanus*], and SEITZ (1965) mentioned occurrences of *Cl. undulatoplicatus* cf. *michaeli* (Heinz) with *Texanites* sp. ;

	CONIACIAN			SANTONIAN		
Magadiceramus subquadratus	*	*	*			north-central Texas
Cladoceramus undulatoplicatus				*	*	
Texanites stangeri densicostatus			*	*	*	
Texanites		*	*	*	*	
Volviceramus involutus	*					Gosau Group Austria
Spenoceramus cardissoides		*				
Cladoceramus undulatoplicatus				*	*	
Texanites quinquenodosus		*	*	*		
Sigalia deflaensis			*	*	*	
Dicarinella asymetrica			*	*	*	
Lucianorhabdus cayeuxii				*	*	
Magadiceramus subquadratus	*	*				Germany
Cladoceramus undulatoplicatus				*	*	
Sphenoceramus pachti			*			
Sphenoceramus cardissoides			*			
Texanites pseudotexanus			*	*	*	
Magadiceramus subquadratus	*	*	*			north Spain
Cladoceramus undulatoplicatus				*	*	
Texanites gallicus		*	*	*	*	
Texanites	*	*	*	*	*	
Sigalia carpathica				*		
Inceramus mihoensis	*					Japan
Inceramus amakusensis		*	*			
Platyceramus mantelli	*	*	*	*	*	
Texanites collignoni			*	*	*	

Fig. 1 — Distribution of possible markers for the Coniacian-Santonian boundary in different palaeobiogeographic provinces.

he also cited the sequence of *Sph. cardissoides* subsp. ind. and *Sph. pachti* followed by *Texanites pseudotexanus* at Recklinghausen (*fide* K. A. Tröger, written comm.).

In England there is a double *Cladoceramus* event, which can also be traced throughout the Anglo-Paris Basin, N.W. Germany (BAILEY *et al.*, 1984) and north Spain. Below these levels, in S. England there are no occurrences of sphenoceramids: the lower occurrence of *Sphenoceramus cardissoides* was collected above the double *Cladoceramus* event (BAILEY *et al.*, 1983; C. J. Wood, written comm.). Recent field work by A. S. Gale in the Isle of Thanet (S.E. England) has demonstrated that in addition to the two main *Cladoceramus* events, there are three additional minor *Cladoceramus* occurrences in the overlying succession. This total known range of *Cladoceramus* matches occurrences of *Spinaptychus*. There is no evidence in S. England for the existence of a *Sphenoceramus pachti-cardissoides* group Zone below the *Cl. undulatoplicatus* Zone (C. J. Wood, written comm.).

In both France and north Spain, inoceramid assemblages are good markers for the Coniacian-Santonian boundary. *Magadiceramus subquadratus* (Schlüter) followed by *Cl. undulatoplicatus* characterise the uppermost Coniacian and lowermost Santonian, respectively (LOPEZ *et al.*, 1992). Lower Santonian assemblages, in north Spain, are rich and diverse. In addition to *Cl. undulatoplicatus* other divergent rib species are found: *Platyceramus cycloides wegneri* (Boehm) and *Cordiceramus cordiinitialis ickernensis* (Seitz) (MARTINEZ *et al.*, 1996). Sphenoceramids have not been found in Spain, and therefore Zone 25 of TRÖGER (1989) is not recognisable (see below).

In Austria, in the Gosau basin, assemblage sequences are similar to other Tethyan localities, but with north temperate affinities, e.g., *Actaeonella laevis* (J. de C. Sowerby) and *Volviceramus involutus* in the Upper Coniacian, and *Texanites quinquenodosus*, *Parapuzosia daubreei*, *Sphenoceramus cardissoides*, *Platyceramus cycloides cycloides* (Wegner) and *Cladoceramus undulatoplicatus* in the Lower Santonian are recorded (TRÖGER & SUMMESBERGER, 1994). According to these authors there is no clear evidence of TRÖGER's inoceramid zones 24 (uppermost Coniacian) and 25 (lowermost Santonian). *Sphenoceramus pachti* has also been found in Austria by K.A. Tröger & H. Summesberger (K. A. Tröger, written comm.). The occurrences of the genus *Magadiceramus* in Tyrol (SEITZ, 1970; KAUFFMAN, *in* HERM *et al.*, 1979) are doubtful according to TRÖGER & SUMMESBERGER (1994, p. 179). However, it seems that *Cl. undulatoplicatus* and *Texanites quinquenodosus* co-occur in the Mühlbach Section (TRÖGER & SUMMESBERGER, 1994: p. 184).

In the Caucasus Region and central Asia (Turkmenia; MOSKVIN, 1986) the Coniacian-Santonian transition shows an upper Coniacian with *Volviceramus involutus* overlain by *Cl. undulatoplicatus*, and sometimes *Sphenoceramus cardissoides*.

In far-east Asia (Japan, Sakhalin) *Inoceramus amakusensis* Nagao and Matsumoto is a well known marker for the base of the Santonian, associated with *Texanites* (*T.*) *collignoni* or *T. (Plesiotexanites) kawasakii* (Kawada). The succession of *Inoceramus mihoensis* overlain by *I. amakusensis* characterises the Coniacian-Santonian Boundary in the Haboro area (Hokkaido; TOSHIMITSU *et al.*, 1995), and Sakhalin (E. A. Yazykova, written comm.). Some Coniacian inoceramid species, in Europe, may have higher occurrences in far-east Asia, since *Platyceramus mantelli* (de Mercey) is known in the Upper Coniacian and also "Santonian" together with *I. amakusensis* (T. Matsumoto, written comm.). The species *Cladoceramus undulatoplicatus* is unknown in far-east Russia.

Sphenoceramids are widespread, but occur only rarely in the Tethyan Realm. The species *Sphenoceramus pachti* and *Sph. cardissoides* characterise the lowermost Santonian (TRÖGER's Zone 25, 1989), but this zone is only well recognised in the north German-Polish Basin, where both species are associated with *Sph. bornholmensis?* (Tröger & Christensen), and *Platyceramus cycloides ahsenensis* (Seitz) (TRÖGER, 1989). Nonetheless, either *Sph. pachti* and *Sph. cardissoides*, mainly the latter, are recorded at many localities from the Northern Temperate Realm (DHONDT, 1992; LOPEZ *et al.*, 1992), overlying Coniacian volvoceramids or *Magadiceramus* assemblages, and underlying *Cladoceramus undulatoplicatus* and *Platyceramus cycloides wegneri* (Boehm) assemblages.

Even in the Gosau Basin, a Tethyan locality, *Sph. cardissoides* is recorded close to *Cl. undulatoplicatus* (see: TRÖGER & SUMMESBERGER, 1994), but probably underlying it. Sphenoceramids have also been recorded in the Charente, S.W. France (DHONDT, 1992), on a northern border of the Tethyan Realm. In contrast, in other Tethyan localities, e.g., Crimea and Caucasus (DOBROV & PAVLOVA, 1959), *Sph. cardissoides* is associated with *Cl. undulatoplicatus*.

Up till now, no sphenoceramids have been found in north Spain, but the species *Pl. cycloides ahsenensis* is common and is associated with *Cl. undulatoplicatus*, as in the north German-Polish Basin. In consequence, it is possible to make a good correlation between Lower Santonian rocks belonging to the Northern Temperate and Tethyan Realms (see LOPEZ *et al.*, 1992, for additional common species between north Germany and north Spain) (Figure 1).

FORAMINIFERA AND NANNOFOSSILS

This group shows different assemblages controlled by biogeography. In general, low and middle latitudes have good occurrences of planktonic foraminifera, whereas in

the Temperate Realm benthic foraminiferal assemblages characterise the Coniacian-Santonian boundary.

In the Mediterranean area of the Tethys, the succession of species *Sigalia deflaensis* (Sigal), *S. carpathica* Salaj and *Dicarinella asymetrica* (Sigal) characterise the Coniacian-Santonian transition. *S. deflaensis* has a widespread occurrence in the Tethyan Realm (see MASTER, 1977), but *S. carpathica* is only known from the Mediterranean Region and, like *D. asymetrica*, was also rare in shallow water facies. Nevertheless, as the lower occurrence of *S. carpathica* is associated with *Cl. undulatoplicatus* and *Texanites (T.)* spp. in north Spain MARTINEZ *et al.*, 1996), or with *Platyceramus siccensis* in north Africa (SALAJ, 1980), it is a good regional index (SIGAL, 1977) which should be checked throughout the Tethyan Realm, where both *S. deflaensis* and *D. asymetrica* associated with inoceramids and texanitids occur. Both species *S. deflaensis* (= *S. carpathica*; M. Wagreich, written comm.) and *D. asymetrica*, with *D. concavata* (Brotzen), were cited by WAGREICH (1992) in Austria, as markers of the Coniacian- Santonian Boundary. Especially, in the Bad Ischl-Nussensee section successive occurrences of *S. deflaensis, D. asymetrica* and *S. decoratissima* (de Klasz) are similar to Tunisian localities.

Nannofossil occurrences in these levels are similar to other boundary sections, e.g., rare upper *Eprolithus floralis* (Stradner) Strover, *Lithastrinus septenarius* Forchheimer and *Quadrum gartneri* Prins & Perch-Nielsen, associated with lower occurrences of *L. grillii* Stradner and *Micula decussata* Vekshina [= *M. staurophora* (Gardet) Stradner], in upper Coniacian beds. All these entries lie below *Lucianorhabdus cayeuxii* Deflandre (WAGREICH, 1992), an early Santonian species.

The species *Stensioina polonica* Witwicka used to be a good marker of the Coniacian-Santonian boundary in the North Temperate Region, from England to eastern Europe. In S.E. England *St. polonica* occurs with lower *Cladoceramus undulatoplicatus*, which marks a significant macrofaunal and microfaunal turnover (C. J. Wood, written comm.). In eastern Temperate Europe the F.O. of *Stensioina exsculpta exsculpta* (Reuss) is a very convenient marker for the Coniacian-Santonian boundary (L. F. Kopaevich, written comm.). Other benthic species, such as *Neoflabellina gibbera* (Wedekind), occur in north Africa and western Carpathia, and its stratigraphical range is similar to *Sigalia carpathica* (SALAJ, 1980). Furthermore, this author correlated the *S. carpathica* Zone from western Carpathia with the lower part of the *Anomalina (A.) infrasantonica* Zone (VASILENKO, 1961), allowing a correlation of western Tethys with its eastern European areas.

Criteria proposed for the Coniacian-Santonian boundary

1) FO of *Texanites (Texanites)*
2) FO of *Sigalia carpathica*
3) FO of *Dicarinella asymetrica*
4) FO of *Platyceramus siccensis*
5) FO of *Cladoceramus undulatoplicatus*
6) FO of *Sphenoceramus pachti*

No nannofossil event is suitable for the Coniacian-Santonian boundary

Selected marker for the Coniacian-Santonian boundary

Primary marker: The lowest occurrence of *Cladoceramus undulatoplicatus.* It is a taxon easily recognisable and widespread. It is known from N. America, Europe, Africa, Madagascar, and central Asia.

This proposal was supported by a majority at Brussels. (Yes = 23; No = 1; Abstentions= 2)

Postal vote: 20 votes (out of 39 WG members) were returned (Yes = 17; No = 1; Abstentions = 2).

Secondary marker: *Sigalia carpathica*. This planktonic foraminiferan is widespread in the Mediterranean Region of the Tethys. It is associated with *Inoceramus siccensis* and *Texanites* in Tunisia. In north Spain (Navarra) it is very close to the lowest occurrence of *Cladoceramus undulatoplicatus*.

This secondary marker has been supported by a postal ballot (Yes = 10; No = 3; Abstentions = 7).

Some voting members have emphasised the usefulness of other planktonic foraminifera (D. Herm) and the convenience of benthic forms as secondary markers in the Temperate Realm (L. Kopaevich).

Rejected

Texanites (Texanites). Its first occurrence is below the lowest *Cladoceramus undulatoplicatus*. It has been cited in assemblages with inoceramids normally regarded as Coniacian.

Dicarinella asymetrica. Its first appearance is above the lowest *Sigalia carpathica*, and therefore is not suitable to characterise the Coniacian-Santonian boundary. Moreover it is restricted to basinal facies.

Platyceramus siccensis. Only known from north Africa, although it may be correlated with other areas through the lowest *Sigalia carpathica*.

Sphenoceramus pachti. It is a temperate species, rare at middle latitudes and unknown in palaeotropics (Tethys).

Boundary Stratotype Section

As yet, we cannot make a formal proposal, because we need to know and integrate the biostratigraphy better.

We have selected three candidates:

1) Olazagutia Quarry (Navarra, Spain). M. Lamolda would collate data and report to the Chairman.
2) Seaford Head (Sussex, England). R. Mortimore and C.J. Wood would collate data and report to the Chairman.
3) Ten Mile Creek (Dallas, Texas). E. G. Kauffman and A. S. Gale would collate data and report to the Chairman.

This proposal was approved UNANIMOUSLY
(Yes = 34; No = 0; Abstentions = 0)
The postal ballot also supported this proposal (Yes = 18; No = 1; Abstention = 1).
J. Salaj (Bratislava) has sent a new proposal to the chairman for the C/S boundary stratotype in the El Kef Area, Tunisia, whose fossil content is cited above. C. J. Collom (Calgary) has sent a proposal for this boundary in the Cold Temperate Province; several sections are located at the Smoky River, Bad Heart River and Tipper's Coulee, all of them in west-central Alberta (Canada), having a very rich fossil content. L. F. Kopaevich (Moscow) has proposed a section at Emdy-Kurgan, Mangyshlak (Kazakhstan), which is being studied by D. P. Naidin, L.F. Kopaevich and A. S. Gale.

Substages of the Santonian Stage

Criteria for the subdivision of the Santonian Stage have been changeable since de GROUSSOUVRE (1901) proposed two zones in the Corbières, a lower Santonian *Mortoniceras texanum* Zone and an upper Santonian *Placenticeras syrtale* Zone. Both indices are American species and unknown in France (HANCOCK, 1991). In Europe, both *Texanites gallicus* and *T. quinquenodosus* are common in the Lower Santonian, but they are not recorded in the Corbières (KENNEDY & WRIGHT, 1983; see above Ammonite chapter). For the upper Santonian several indices have been used, thus *Placenticeras paraplanum* Wiedmann seems to characterise the top Santonian (HANCOCK, 1991; KENNEDY, 1995), whereas in north Spain the index could be *Eupachydiscus isculensis* (Redtenbacher) (MARTINEZ *et al.*,1996).

Results outside Europe are also confusing and show endemic zonations, whose correlations up till now are not suitable. It is possible to distinguish two to five subdivisions, according to the literature.

Inoceramids show a similar picture. A detailed zonation in the north German-Polish Basin (TRÖGER, 1989) is not recognised everywhere (see Inoceramid chapter for the lowermost Santonian Tröger's Zone 25).

Thus, in north Spain (MARTINEZ *et al.*, 1996) 4 or 5 subdivisions are recognisable, but most of them are quite different from TRÖGER's zones, because cold temperate taxa - mainly the genus *Sphenoceramus* - have not been found in Spain; except for the lower Santonian *Cladoceramus undulatoplicatus* Zone, which is very common worldwide. KENNEDY (1995) suggested the first occurrence of the cosmopolitan species *Inoceramus (Cordiceramus) cordiformis* (J. de C. Sowerby) as the base of the Middle Santonian.

KENNEDY (1995) favoured the first appearance of the cosmopolitan *Uintacrinus socialis* Grinnell as the base of the Upper Santonian (see also GALE *et al.*, 1995). Nevertheless LEAHY & LERBEKMO (1995) have shown that the appearance of the crinoid *Uintacrinus socialis* (and *Marsupites*) in the Western Interior of N. America should be time transgressive relative to its appearance in Europe, according to its correlation with the base of Chron 33r.

The Santonian of N.W. Europe is subdivided into five *Gonioteuthis* zones, whereas the Santonian of the Russian Platform is subdivided into only two zones (CHRISTENSEN, 1990). Nevertheless, the base of the Santonian cannot be defined on the basis of belemnites, because *Gonioteuthis* is extremely rare in the lower Lower Santonian. The L.O. of *Cladoceramus undulatoplicatus* may be identical with/or very close to the base of the *coranguinum/ westfalica* Zone, and *Gonioteuthis granulata* (Blainville) appears slightly later than *Uintacrinus socialis* (W. K. Christensen, written comm.). Russian workers favoured a two fold division of the Santonian in cold temperate regions (L. F. Kopaevich and E. A. Yazykova, written communication).

Recent research on planktonic foraminifera has changed known occurrences (ROBASZYNSKI *et al.*, 1984) for both *Globotruncanita elevata* (Brotzen) and *Gl. stuartiformis* (Dalbiez). The first occurrence of *Gl. elevata* is younger (see PREMOLI SILVA & SLITER, 1994, fig. 2) and probably suitable to correlate the basal 'upper' Santonian. Both J. Salaj and L. F. Kopaevich disagreed with Santonian occurrences of *Gl. arca* (Cushman), because those stratigraphically younger specimens actually belong to ancestral species in the phylogeny of *G. arca*. Lamolda supports that opinion: he used to find (unpublished data) *Gl. convexa* Sandidge in north Spain in 'upper' Santonian rocks, but not *Gl. arca* s.s. First occurrences of *Gl. convexa* and *Gl. manaurensis* Gandolfi had been cited by SIGAL (1977) as upper Santonian markers in the Mediterranean Region (also, see SALAJ, 1980). The status and ranges of all these species should be cleared but they are interesting for Santonian subdivision.

Nannofossils present several problems related to preservation of the genera *Calculites* and *Lucianorhabdus*. Nevertheless, *Calculites obscurus* (Deflandre) Prins & Sissingh used to be a marker of the 'upper' Santonian and *Lucianorhabdus cayeuxii* Deflandre for 'middle' Santonian (WAGREICH, 1992). The first occurrence of *Amphizygus minimus* Bukry was reported by BURNETT (1996) close to the lowest *Uintacrinus socialis* Grinnell. In the Bottaccione Section, GARDIN *et al.* (in press) have found a similar sequence of nannofossil events - successive occurrences of *L. cayeuxii* followed by *A. minimus* - to those in England (S. Gardin, written comm.). Therefore, it will be necessary to check other sections to contrast correlations of these indices, especially the relative horizons of *L. cayeuxii, A. minimus*, *Uintacrinus socialis*, and *C. obscurus*.

After discussion this motion was put:
1) A threefold division should be used for the Santonian;
2) Formal proposals are premature at present;
3) A possible datum for the base of the Middle Santonian is the extinction point of *Cladoceramus undulatoplicatus*.

4) A possible datum for the base of the Upper Santonian is the first occurrence of *Uintacrinus socialis*.
The WG voted: Yes = 15; No = 0; Abstentions = 6.
The postal ballot supported the motion by a majority: Yes = 12; No = 5; Abstentions = 3.

Substage boundary stratotypes

At present, the WG has no proposals for the substage boundary stratotypes. Possible boundary sections in Texas, along the Channel Coast, in Germany and Mangyshlak were discussed. Integration of macro-, micro-, nannofossil datum-levels, stable isotope-ratios and palaeomagnetism, is necessary before further progress is possible.

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References

BAILEY, H. W., GALE, A. S., MORTIMORE, R. N., SWIECICKI, A. & WOOD, C. J., 1983. The Coniacian-Maastrichtian Stages of the United Kingdom, with particular reference to southern England. *Newsletters on Stratigraphy*, **12**: 29-42.

BAILEY, H. W., GALE, A. S., MORTIMORE, R. N., SWIECICKI, A. & WOOD, C. J., 1984. Biostratigraphical criteria for the recognition of the Coniacian to Maastrichtian stage boundaries in the Chalk of north-west Europe, with particular reference to southern England. *Bulletin geological Society of Denmark*, **33**: 31-39.

BIRKELUND, T., HANCOCK, J. M., HART, M. B., RAWSON, P. F., REMANE, J., ROBASZYNSKI, F., SCHMID, F. & SURLYK, F., 1984. Cretaceous stage boundaries-Proposals. *Bulletin geological Society of Denmark*, **33**: 3-20.

BURNETT, J. A., 1996. Nannofossils and Upper Cretaceous (sub-)stage boundaries - state of the art. *Journal of Nannoplancton Research*, **18**.

CHRISTENSEN, W. K. 1990. Upper Cretaceous belemnite stratigraphy of Europe. *Cretaceous Research*, **11**: 371-386.

COQUAND, H., 1857. Position des Ostrea columba et biauriculata dans le groupe de la craie inférieure. *Bulletin Societé géologique de France*, (2) **14**: 745-766.

DHONDT, A. V., 1992. Cretaceous inoceramid biogeography: a review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **92**: 217-232.

DOBROV, S. A. & PAVLOVA, M. M., 1959. Inoceramus. *In*: MOSKVIN, M. M. (Editor), Atlas verkhnemelovoi fauny severnogo Kavkaza i Kryma. Gosudartsvennoe Nauchnotekhnicheskoe Izdatel'stvo Neftyanoj I Gorno-toplivnoj literarury. Moskva, pp. 130-163.

FLORES, J. A., GOROSTIDI, A. & LAMOLDA, M. A., 1987. Nanoflora y bioestratigrafia del paso Coniaciense - Santoniense en Alava noroccidental. *Paleontologia i Evolucio*, **20** (1986): 151-163.

GALE, A. S., MONTGOMERY, P., KENNEDY, W. J., HANCOCK, J. M., BURNETT, J. A. & MCARTHUR, J. M., 1995. Definition and global correlation of the Santonian-Campanian boundary. *Terra Nova*, **7**: 611-622.

GARDIN, S., DEL PANTA, F., MONECHI, S. & POZZI, M. (in press), Toward a better definition of the Santonian/Campanian and Campanian/Maastrichtian boundaries. New calcareous nannofossil results from the Bottaccione section (Gubbio, Italy). *Marine Micropalaeontology*

GROSSOUVRE, A. de, 1901. Recherches sur la craie supérieure. I. Stratigraphie générale. *Mémoires pour servir à l'explication de la Carte Géologique détaillée*, pp. 1-1013.

HANCOCK, J. M., 1991. Ammonite scales for the Cretaceous System. *Cretaceous Research*, **12**: 259-291.

HERM, D., KAUFFMAN, E.G. & WIEDMANN, J., 1979. The age and depositional environment of the 'Gosau' Group (Coniacian-Santonian), Brandenberg/Tirol, Austria. *Mitteilungen der Bayerischen Staatssamlung für Paläontologie und historische Geologie*, **19**: 27-92.

JARVIS, I. & GALE, A. S., 1984. The Late Cretaceous transgression in the S.W. Anglo-Paris Basin: stratigraphy of the Craie de Villedieu Formation. *Cretaceous Research*, **5**: 195-224.

KAUFFMAN, E. G., SAGEMAN, B. B., KIRKLAND, J. I., ELDER, W. P., HARRIES, P. J., & VILLAMIL, T., 1994. Molluscan biostratigraphy of the Cretaceous Western Interior Basin, north America. *In*: CALDWELL, W. G. E. & KAUFFMAN, E.G. (Editors), Evolution of the Western Interior Foreland Basin. *Geological Association of Canada, Special Publication*, **39**: 397-434 (misdated 1993).

KENNEDY, W. J., 1995. Defining the base of the Santonian and its substages using macrofossils. Report to the Santonian Working Group, Brussels, September 1995.

KENNEDY, W. J., BILOTTE, M. & MELCHIOR, P., 1996. Ammonite faunas, biostratigraphy and sequence stratigraphy of the Coniacian- Santonian of the Corbières (N.E. Pyrenees). *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, **19**: 377-499.

KENNEDY, W. J. & WRIGHT, C. W., 1983. *Ammonites polyopsis* Dujardin, 1837 and the Cretaceous ammonite family Placenticeratidae Hyatt, 1900. *Palaeontology*, **26**: 855-873.

LARSON, P. A., MORIN, R. W., KAUFFMAN, E. G. & LARSON, A., 1991. Sequence stratigraphy and cyclicity of Lower Austin/Upper Eagle Ford outcrops (Turonian-Coniacian), Dallas County, Texas. Guidebook, DGS Field Trip 9. Dallas Geological Society, 61 pp.

LEAHY, G. D. & LERBEKMO, J. F., 1995. Macrofossil magneto-bio-stratigraphy for the upper Santonian-lower Campanian interval in the Western Interior of North America: comparisons with European stage boundaries and planktonic foraminiferal zonal boundaries. *Canadian Journal of Earth Sciences*, **32**: 247-260.

LOPEZ, G., MARTINEZ, R. & LAMOLDA, M. A. 1992., Biogeographic relationships of the Coniacian and Santonian inocera-

mid bivalves of northern Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **92**: 249-261.

MARTINEZ, R., LAMOLDA, M. A., GOROSTIDI, A., LOPEZ, G. & SANTAMARIA, R., 1996. Bioestratigrafia integrada del Cretacico Superior de la Region Vascocantabrica. *Revista española de Paleontologia*, **nº extraordinario**: 157-168.

MASTER, B. A., 1977. Mesozoic planktonic foraminifera, a world-wide review and analysis. *In*: RAMSAY, A. T. S. (Editor), Oceanic Micropaleontology, 1. London. Academic Press, pp. 301-731.

MOSKVIN, M. M., (Editor), 1986. Stratigraphiya SSSR. Melovaya sistema. Akademia Nauk SSSR, Moscow, 1, 338 pp.

PREMOLI SILVA, I. & SLITER, W. V., 1994. Cretaceous planktonic foraminiferal biostratigraphy and evolutionary trends from the Bottaccione section, Gubbio, Italy. *Palaeontographica Italica*, **82**: 1-89.

ROBASZYNSKI, F., CARON, M., GONZALEZ DONOSO, J. M. & WONDERS, A. H. (Eds.) & European Working Group on planktonic foraminifera, 1984. Atlas of Late Cretaceous Globotruncanids. *Revue de Micropaléontologie*, **26**: 145-305.

SALAJ, J., 1975. Contribution à la microbiostratigraphie du Mésozoïque et du Tertiaire de la Tunisie septentrionale. Cinquième Colloque Africain de Micropaléontologie, Addis Ababba. *Revista espanola de Micropaleontologia*. Monografias: 703-783.

SALAJ, J., 1980. Microbiostratigraphie du Crétacé et du Paléogène de la Tunisie septentrionale et orientale (Hypostratotypes tunisiens). Geologicky Ustav Dionyza Stura, Bratislava, 238 pp.

SEITZ, 0., 1961. Die Inoceramen des Santon von Nordwestdeutschland. I. Teil (Die Untergattungen *Platyceramus*, *Cladoceramus* und *Cordiceramus*). *Beihefte zum Geologischen Jahrbuch*, **46**: 1-186.

SEITZ, 0., 1965. Die Inoceramen des Santon und Unter-Campan von Nordwestdeutschland. II. Teil (Biometrie, Dimorphismus und Stratigraphie der Untergattung *Sphenoceramus* J. Böhm). *Beihefte zum Geologischen Jahrbuch*, **69**: 1-194.

SEITZ, 0., 1970. Über einige Inoceramen aus der Oberen Kreide. 1. Die Gruppe des *Inoceramus subquadratus* Schlüter. 2. Die Muntigler Inoceramenfauna und ihre Verbreitung im Ober-Campan und Maastricht. *Beihefte zum Geologischen Jahrbuch*, **86**: 1-171.

SIGAL, J., 1952. Aperçu stratigraphique sur la micropaléontologie du Crétacé. XXe Congrès Géologique International, Alger. *Monographies régionales* **(1), 26**. 45 pp.

SIGAL, J., 1977. Essai de zonation du Crétacé méditerranéen à l'aide des foraminifères planctoniques. *Géologie Méditerranéenne*, **4**: 99-108.

SISSINGH, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. *Geologie en Mijnbouw*, **56**: 37-65.

TOSHIMITSU, S., MATSUMOTO, T., NODA, M., NISHIDA, T. & MAIYA, S., 1995. Towards an integrated mega-, micro- and magneto-stratigraphy of the Upper Cretaceous in Japan. *Journal Geological Society of Japan*, **101**: 19-29 (in Japanese)

TRÖGER, K.-A., 1989. Problems of Upper Cretaceous Inoceramid Biostratigraphy and Palaeobiogeography in Europe and Western Asia. *In*: WIEDMANN, J. (Editor). Cretaceous of the Western Tethys. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, pp. 911-930.

TRÖGER, K.-A. & SUMMESBERGER, H., 1994. Coniacian and Santonian inoceramid bivalves from the Gosau-Group (Cretaceous, Austria) and their biostratigraphic and palaeobiogeographic significance. *Annalen Naturhistorisches Museum Wien*, **69A**: 161-197.

UEDA, Y., 1962. The Type Himenoura Group, with Paleontological Notes by T. MATSUMOTO & Y. UEDA. *Memoirs Faculty of Science, Kyushu University*, (D), **12** (2): 129-178.

VASILENKO, V.P., 1961. Upper Cretaceous Foraminifera from the Mangyshlak peninsula. *Trudy VNIGRI* **171**.

WAGREICH, M., 1992. Correlation of Late Cretaceous calcareous nannofossil zones with ammonite zones and planktonic Foraminifera: the Austrian Gosau sections. *Cretaceous Research*, **13**: 505-516.

YAZYKOVA, E.A., 1996. Post-crisis recovery of Campanian desmoceratacean ammonites from Sakhalin, Far East Russia. *In*: HART, M. B. (Editor), Biotic Recovery from Mass Extinction Events. *Geological Society (London), Special Publication*, **102**: 299-307.

YOUNG, K.,1963. Upper Cretaceous ammonites from the Gulf Coast of the United States. *University of Texas Publication*, **6304**: 1-373.

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The Campanian Stage

by Jake M. HANCOCK & Andrew S. GALE

with contributions from Silvia Gardin, W. Jim Kennedy, Marcos A. Lamolda, Tatsuro Matsumoto & Dmitri P. Naidin

Abstract

The Campanian working party in Brussels did not wish to make a conclusive recommendation but there was a strong feeling that the base of the stage should be fixed at the extinction-level of the crinoid *Marsupites*. Other criteria discussed included ammonites, belemnites, foraminifera, calcareous nannofossils and magnetostratigraphy. Candidates for a boundary-stratotype occur in central Texas and south-east England. Until these sections have been described in detail, it will not be possible to choose a boundary-stratotype, and hence make a firm recommendation to the International Subcommission for the base of the stage.

It was felt that three substages should be used for the Campanian, but international correlations within the stage are still too uncertain to make recommendations for the definitions of these substages.

Key-words: Campanian, Upper Cretaceous, *Placenticeras*, *Submortoniceras*, *Gonioteuthis*, inoceramids, *Marsupites*, *Broinsonia*, *Dicarinella*, magnetostratigraphy.

Résumé

Le Groupe de Travail du Campanien n'a pas souhaité décider définitivement la position de la limite Santonien-Campanien mais un consensus s'est dégagé en faveur du tracé de la base de l'étage Campanien au niveau de l'extinction du crinoide *Marsupites*. D'autres critères discutés concernent, entre autres, les ammonites, les bélemnites, les foraminifères, les nannofossiles calcaires et la magnétostratigraphie. Des coupes retenues comme candidates pour le stratotype de la limite se trouvent au Texas central et dans le SE de l'Angleterre. Aussi longtemps que ces sections n'auront sont pas été décrites en détail, il sera impossible de choisir un stratotype de la limite, et donc de faire une recommendation formelle à la Sous-commision Internationale pour la base de l'étage.

Il a été considéré qu'une division en trois sous-étages serait utile pour le Campanien, mais les correlations internationales sont encore trop incertaines pour faire des recommendations concernant la définition de ces sous-étages.

Mots-clefs: Campanien, Crétacé supérieur, *Placenticeras, Submortoniceras, Gonioteuthis*, inoceramids, *Marsupites, Broinsonia, Dicarinella*, magnetostratigraphie.

Кампанский ярус.

Резюме.
Рабочая Группа Кампанского Яруса предпочла не определять окончательную позицию Сантоно-Кампанской границы; тем не менее, согласие было достигнуто о проведении основания Кампанского яруса на уровне протяжения морской лилии *Marsupites*. Другие затронутые критерии касаются, между прочим, аммонитов, белемнитов, фораминифер, известковых нанофоссилий и магнитостратиграфии. Отобранные в качестве возможных вариантов для стратотипа границы разрезы располагаются в центральном Тексасе и на юго-востоке Англии. Выбор стратотипа границы, а следовательно и формальные рекомендации для Международной Подкомиссии касательно основания яруса будут невозможны до тех пор пока эти разрезы не будут детально описаны.
Было принято во внимание, что разделение Кампанского яруса на 3 подъяруса может оказаться полезным, но глобальные корреляции являются на данный момент достаточно неопределёнными для того, чтобы давать какие-либо рекомендации, касающиеся определения подъярусов.

Ключевые слова: Кампанский ярус, верхний мел, *Placenticeras, Submortoniceras, Gonioteuthis*, иноцерамы, *Marsupites, Broinsonia, Dicarinella*, магнитостратиграфия.

Original concept

The Campanian stage was introduced by COQUAND (1857). It is generally agreed that it is the rock-succession in the hillsides of Grande Champagne near Aubeterre-sur-Dronne, some 45 km west-north-west of Périgueux in northern Aquitaine, France, which best represents what COQUAND had in mind out of all the sections which he mentioned. The sediments there are much burrowed shallow water limestones, rich in benthic foraminifera and bivalves (including scattered rudists); some beds contain cyclolitid corals and many polyzoa. Studies by SÉRONIE-VIVIEN (1972) and VAN HINTE (1979) have shown that there is no obvious base to the stage near Aubeterre. Earlier studies suggested that the top of the stage was reached, but even this is now known to be wrong (KENNEDY, 1986). With the near-absence of ammonites, rarity of planktic foraminifera, and presumably an incomplete representation of nannoplankton, the original stratotype no longer has even a potential value as an international standard.

Boundary Criteria

As usual, workers in different fields have got used to

SANTONIAN
CAMPANIAN
83.9 Ma
United States
Western Interior
central Texas
England
Mangy-
shlak
radiometric
dates
ammonite
zones
crinoid
ranges
U.S. states
with crinoids
crinoid
ranges
formations
ammonite
ranges
crinoid
ranges
standard
zones
palaeomagnetism
nannoplankton
crinoid
ranges
Clioscaphites choteauensis
Desmoscaphites erdmanni
Desmoscaphites bassleri
Scaphites leei III
Uintacrinus socialis
Marsupites
Colorado
Montana
Wyoming
Kansas
Montana
Wyoming
U. angl.
BURDITT CHALK
vanuxemi
Submortoniceras
tequesquitense
Texanites lonsdalei
JONAH
- C H A L K -
- D E S S A U -
Micraster coranguinum
34N
33R
Offaster pilula
Broinsonia parca
U. anglicus

different criteria for the Santonian-Campanian boundary. This has seldom been regarded as a problem because there has been little reason to believe that they differed significantly from one another. It is only the more recent requirements of sequence-stratigraphy and the possibilities of Milankovitch-rhythm stratigraphy that have raised the need to achieve correlations at resolutions better than 0.25 Ma. At this level of accuracy it is necessary to know how the various boundary standards stack up in relation to one another. There is now a valuable discussion of the boundary-criteria by GALE *et al.* (1996).

The possible boundary levels discussed at Copenhagen in 1983 (BIRKELUND *et al.*, 1984) and at Brussels in 1995 included the following.

AMMONITES

1) Since the survey by de GROSSOUVRE (1901) of Upper Cretaceous ammonite zonation, the most widely quoted base of the Campanian stage has been the Zone of *Placenticeras bidorsatum* (sometimes listed as *Diplacmoceras bidorsatum* or *Diplacomoceras bidorsatum*), e.g. HAUG (1911), WRIGHT in ARKELL *et al.* (1957). *P. bidorsatum* (Roemer) was originally described from north Germany (KENNEDY & KAPLAN, 1995) but it was Aquitaine which de GROSSOUVRE had in mind when introducing the zonal name. He listed the species from just three localities; no specimens have been found in modern times. The species is equally rare in north Germany (SCHMID, 1960). It probably evolved from *P. paraplanum* Wiedmann (ULBRICH, 1971; KENNEDY, 1984), but it is too rare to be able to know its true total range. At the Brussels meeting W. Jim Kennedy said that it was even difficult to find specimens in museum collections.

2) *Placenticeras bidorsatum* has not been recorded outside north-west Europe. Tethyan regions yield far richer assemblages of Campanian ammonites. Of the possible markers in places like Madagascar, South Africa and Texas, attention has been focussed on the genus *Submortoniceras*. Although it was stated to be Campanian when the name was introduced by SPATH (1926), he was being frankly speculative.

COLLIGNON (1948, p. 51) bracketed *Bevahites quadratus* and *Submortoniceras renniei* in a table as joint zonal indices for the bottom of the Campanian in Menabe on the western side of Madagascar, but in his text he indicated that *Bevahites* was the earlier Campanian genus. By 1960 he had abandoned *Submortoniceras* as a zonal index.

YOUNG (1963) found the genus to be a reliable index in Texas, taking *S. tequesquitense* Young as the zonal index, accompanied by two other species of *Submortoniceras*.

In South Africa also the genus *Submortoniceras* has been found to be a practical indicator for the base of the Campanian (KLINGER & KENNEDY, 1980; KENNEDY, 1984).

Should an ammonite standard be adopted as the boundary-criterion, the lowest *Submortoniceras* has much in its

←

Fig. 1 — This table shows the correlation of four regions around the Santonian-Campanian boundary based on stratigraphical ranges of the crinoids *Uintacrinus* and *Marsupites*. The only tie-lines between the regions (printed in bold lines) are based on: the appearance of *Uintacrinus* (*U. socialis* GRINNELL, 1876); the highest *Uintacrinus socialis* and the lowest *Marsupites* [*M. testudinarius* (SCHLOTHEIM, 1820)], which are usually separated by less than one metre of sediment, and locally overlap; and the highest *Marsupites* (ornamented *M. testudinarius*), which is usually separated by less than one metre of sediment from the lowest *Uintacrinus anglicus* RASMUSSEN, 1961, where that species occurs. The occurrences of *Uintacrinus* and *Marsupites* in the Western Interior of the USA are based on COBBAN (1995) and HATTIN (1982). The ranges of these crinoids in the other three regions are based on collecting by ASG.

In the Western Interior of the USA the occurrence of these crinoids, particularly *Marsupites*, is sporadic, though it is known that both genera are to be found in the *bassleri* Zone in Wyoming and Montana. But the lower limit of *Uintacrinus* and the upper limit of *Marsupites* are still uncertain in the Western Interior. There is one reliable radiometric date of 83.91 0.43 Ma for the *Desmoscaphites bassleri* Zone by OBRADOVICH (1994); on the assumption that the Zone of *Scaphites leei* III is the lowest zone of the Campanian, he dates the base of the stage at 83.5 Ma.

In central Texas the ranges of the ammonites are based mainly on work by YOUNG (1963 and personal communication). There is no simple correlation with the ammonite zonation of the western interior seaway from Colorado to Montana. The crinoid ranges in central Texas are derived from sections at Brushy Creek, Hutto; Little Walnut Creek, Austin; and the Waxahachie Dam Spillway.

The crinoid ranges in England have long been known and form the basis of the standard zonation there for the higher Santonian; sections occur in the cliffs and on the shore between Foreness Point and White Ness in north-east Kent; and west of Seaford Head in Sussex. The boundary between Chron 34N and 33R is from MONTGOMERY in GALE *et al.* (1996). The appearance of *Broinsonia parca parca* STRADNER is based on work by J. BURNETT in the Isle of Wight.

Ranges of *Uintacrinus* and *Marsupites* in Mangyshlak are based on collecting at Emdy-Kurgan, about 100 km north of Aktau. Other macro-fossils are scarce in this section but are known from Shakh-Bogota, west of Tauchik (NAIDIN *et al.*, 1984, figs. 4 and 5).

The vertical ranges are not to scale, neither in years, nor in sediment thickness. The vertical range of *Uintacrinus socialis* occupies more space in the table than that of *Marsupites testudinarius* because *Uintacrinus* is known from more ammonite zones in the U.S. Western Interior. In the Chalk of Kent in England, the *Marsupites* Zone is nearly 15 m thick and the *Uintacrinus* Zone is only 10 m thick.

favour. As recognised by COLLIGNON, YOUNG, KLINGER and KENNEDY, it evolved from *Texanites*, a typically Santonian genus. In addition to being common in Madagascar, South Africa and Texas, it is known from Mexico and the Pacific coast of the United States, British Columbia and Spain.

3) There is a third ammonite candidate for the base of the stage. This is the lowest *Scaphites hippocrepis* III, the highest of three subspecies of *S. hippocrepis* (De Kay) (COBBAN, 1969). According to Cobban this is probably the same form as *Scaphites aquisgranensis* Schlüter of European writers. This is said to occur with *Placenticeras bidorsatum* in Germany. Although this scaphitid index has the advantage of occurring and being accurately placed in the ammonite rich succession of the Western Interior of the USA, as well as being known from the Atlantic and Gulf Coasts, and occurring in northern Aquitaine, north-west Germany, Belgium and the Netherlands, this possible boundary-criterion was not discussed at the Brussels meeting. The problem is that older scaphitids have now been found above the base of the *P. bidorsatum* Zone in Aquitaine (KENNEDY, 1986). COBBAN (1994) now places the base of the Campanian in the Western Interior at the base of the Zone of *Scaphites leei* III.

BELEMNITES

In north-west Germany the base of the Zone of *Gonioteuthis granulataquadrata* has been used for the base of the Campanian stage (SCHMID, 1956). However, at any one level there is variation in the morphology of guards in the *G. granulata* - *G. quadrata* lineage and one needs an assemblage of about ten specimens to fix the exact horizon (ERNST, 1964, 1968). Outside Germany there are rarely sufficient numbers of *Gonioteuthis* from around this level to make the necessary statistical analysis. Nevertheless, at both Copenhagen and Brussels the hope was expressed that whatever criterion were adopted, it would be desirable if it agreed with the German standard.

INOCERAMIDS

Inoceramids were not considered as possible boundary-criteria at either Copenhagen or Brussels. It has long been a popular idea that inoceramids of the group of *Inoceramus* (*Endocostea*) *balticus* Boehm characterise the Campanian e.g. ERNST *et al.* (1979), and that the appearance of this species should be close to the stage boundary, e.g. SCHULZ *et al.* (1984). In fact both SEITZ (1967) in Germany and KAUFFMAN *et al.* (1994) in the USA regard *I.* (*E.*) *balticus* s.s. as a species with a considerable range, easily straddling the Santonian-Campanian boundary, however it be defined.

There is undoubtedly a need for more figures of accurately recorded inoceramids from around these levels. SEITZ does record some actual ranges but it is not easy to work out the exact horizons of his figured specimens. Similarly, KAUFFMAN *et al.* subdivide their Lower Campanian into six (ammonite) zones, but the only modern figures are in the general survey by KAUFFMAN (1977) and a few accurately located specimens in general stratigraphy papers by COBBAN. In particular, there is a need for an accurate record of the inoceramids from the Austin Chalk group in Texas.

CRINOIDS

Once de GROSSOUVRE's concept of 1901 for the Santonian/Campanian boundary had become popular, his indication for its recognition in northern Europe, where ammonites are rare, namely the top of the Zone of *Marsupites testudinarius*, came to be used (de GROSSOUVRE, 1901). This criterion has been particularly favoured by British geologists because in the British Isles there are no ammonites around these levels, inoceramids for the most part are poorly preserved, and *Gonioteuthis* is uncommon except in Northern Ireland. In contrast, *Marsupites* is relatively common. *Marsupites* is geographically more widespread than any other recorded macrofossil boundary-marker, being known from British Columbia, Montana, Wyoming, Texas, Mississippi, Northern Ireland, England, northern France, Aquitaine, northern Germany, the Volga Basin, the Ukraine, Crimea, the Caucasus, the eastern slopes of the central Urals, Mangyshlak in north-west Kazakhstan, the Kopet Dagh in southern Turkmenistan, Algeria, Madagascar, southern India, and the Perth and Carnarvon Basins in Western Australia (COBBAN, 1995; GALE *et al.*, 1995).

Doubts were expressed in Brussels on the reliability of an extinction event as a boundary-criterion. There is some justification for this viewpoint for fine-scale correlation, that is at a resolution of less than one ammonite zone. At the Plymouth Bluff section in Mississippi the vertical range of *Marsupites* is only 0.1 m, with ammonites below this range which are known to occur with *Marsupites* in Texas, e.g. *Submortoniceras tequesquitense* and *Texanites lonsdalei* Young. However, there are two criteria which can be used to check when one has a *Marsupites* at or near its actual extinction level. First, there is a stratigraphical succession of distinct forms of the plates: this has been observed in Mangyshlak (D. P. Naidin, personal communication); southern England (ASG); and Texas (ASG). The strongly ornamented plates characterise the upper third of the Zone. Secondly, where the succession is complete the Zone of *Marsupites testudinarius* is overlain by a Zone of *Uintacrinus anglicus*. This was originally recognised in southern England by BRYDONE (1914), and is now also known in Yorkshire (MITCHELL, 1994), Mangyshlak (ASG), Texas (ASG) and Western Australia (ASG). Should the highest *Marsupites* be taken as the boundary-level for the base of the Campanian, the boundary-stratotype should be taken in one of these regions.

Foraminifera

There was discussion and disagreement at Brussels on ranges of foraminifera.

The lowest *Globotruncana arca* Cushman has been used as a criterion. Many workers, e.g. Sliter, 1989, believe this species appeared within the Santonian, but at the meeting both L.F. Kopaevich (Moscow) and J. Salaj (Bratislava) emphasised that true *G. arca* does not occur in the Santonian; the Santonian forms are phylogenetic ancestors.

The lowest *Globotruncana elevata* (Brotzen) which has been used as a marker, is now considered to appear in the Santonian. M. Apthorpe (Perth) reports it as going down into the Coniacian in Australia and DSDP cores.

The highest *Dicarinella asymetrica* (Sigal) (see Marks, 1984) and *D. concavata* are probably the most widely used foraminiferal criteria for the stage boundary. Although mainly a tethyan species, *D. concavata* is known as far north as southern England (Bailey & Hart, 1979). Nobody raised strong objections in Brussels to the use of these species as secondary criteria.

M. B. Hart (Plymouth) pointed out that the lowest occurrence of the benthic foraminifera of the *Bolivinoides* group and *Stensioina* can be used as a link with the succession of both planktic foraminifera and the crinoid zones.

Calcareous Nannofossils

Discussion at Brussels was concentrated on the appearance of the coccolith *Broinsonia parca parca* (Stradner).

J. A. Burnett (London) pointed out that where one places this horizon depends on how the species is studied. This view was supported by S. Gardin (Firenze) who gave an elegant presentation which showed that it was essential to use specimens of all sizes because there are stratigraphical changes in size; there is a precise series of 'subspecies' with which one can distinguish fine subdivisions. The true *B. parca parca* comes in well above the base of the Campanian defined on the extinction level of *Marsupites*. In Culver Cliff, Isle of Wight in southern England this nannofossil level is 10 m up in the Campanian.

Magnetostratigraphy

The long Cretaceous Quiet Zone extends from the Aptian to the Santonian. It is often assumed that the reversed Magnetochron 33R above this starts at the Santonian/Campanian boundary or within the Lower Campanian. This has usually been based on the succession at Gubbio in Umbria (Italy) where the base of 33R is 1 m below the lowest *Globotruncana elevata* (Premoli Silva, 1977). Montgomery (in Gale *et al.*, 1996) has now shown that in southern England the start of Chron 33R lies in the middle of the Zone of *Uintacrinus socialis*, i.e. well below the top of the Santonian on the crinoid scale.

Carbon isotope Stratigraphy

This criterion was not discussed at Brussels but a small $\delta^{13}C$ positive excursion has been found at the top of the range of *Marsupites* in the counties of Kent and Sussex in England (Jenkins, *et al.*, 1994), and at Lägerdorf in north Germany (Schönfeld, *et al.*, 1991).

Recommendations

Boundary-Criterion

D. P. Naidin (Papulov & Naidin, 1979) and G. Ernst (Ernst, 1963) both pressed for the use of the extinction level of *Marsupites* as the boundary-criterion. Whilst this was the general sympathy at the meeting of the working group in Brussels, it was felt that a fuller investigation of relative stratigraphical levels of the various distinctive features should be made before making a definite decision. Accordingly, the following motion was put to the meeting -

1. The definition of the base of the Campanian stage should be compatible with the classic definition by de Grossouvre, that is the lowest level with *Placenticeras bidorsatum*.
2. This corresponds to the extinction-level of *Marsupites testudinarius* (Schlotheim), which we recommend provisionally as the boundary-marker for the base of the Campanian stage.
3. This datum-level should be linked to:
(a) extinctions in the planktonic foraminiferal group of *Dicarinella concavata*;
(b) nannofossil data, including the lineage of *Broinsonia parca*;
(c) and directly or indirectly to the 33R/34N palaeomagnetic boundary.
4. We invite reports on correlation of these events from members of the working group.

The vote for this motion was: 23 for, none against and no abstentions.

Boundary-Stratotype

It was further agreed, without a formal vote being taken, that should the crinoid standard eventually be adopted, there were candidate boundary-stratotypes in Texas and southern England. Accordingly, reports should be prepared on the sections in England at Seaford Head, Sussex (and possibly Foreness Point, Kent) by R. Mortimore, C. J. Wood and A. S. Gale, and in north-central Texas at the

Waxahachie dam-spillway by A. S. Gale, J. M. Hancock and K. Young.

Substages of the Campanian stage

By a vote of 17 to 2 (with 4 abstentions) it was agreed that the working group should endeavour to subdivide the Campanian into three sub-stages, Lower, Middle and Upper (though a small number of people felt that the stage was so long that an attempt should be made to divide it into four sub-stages). If possible, each sub-stage should be of approximately equal duration. It was not possible at this time to make any formal proposals on definitions of the bases of the Middle and Upper Campanian.

Postscript

Several correspondents have emphasised that even *Marsupites* is not found everywhere in the world. For this reason it is going to be exceptionally important to develop the use of secondary criteria for the boundary, which must be accurately related stratigraphically to the primary criterion, i.e. the extinction level of *Marsupites*.

References

Arkell, W.J., Kummel, B & Wright, C.W., 1957. Mesozoic Ammonoidea. *In* Moore, R.C.(Ed.) Treatise on Invertebrate Paleontology, Part L, Mollusca 4, Cephalopoda Ammonoidea. pp. L80-L465. Geological Society of America and University of Kansas Press.

Bailey, H.W. & Hart, M.B., 1979. The correlation of the early Senonian in Western Europe using Foraminiferida. Pp. 159-169 *In* Wiedmann, J. (Ed.) Aspekte der Kreide Europas. *International Union of Geological Sciences* **(A), 6**.

Birkelund, T., Hancock, J.M., Hart, M.B., Rawson, P.F., Remane, J. Robaszynski, F., Schmid, F. & Surlyk, F., 1984. Cretaceous stage boundaries - proposals. *Bulletin of the Geological Society of Denmark* **33:** 3-20.

Brydone, R.M., 1914. The Zone of *Offaster pilula* in the south English Chalk. Parts 1-4. *Geological Magazine* **51**: 359-369, 405-411, 449-457, 509-513.

Cobban, W.A., 1969. The late Cretaceous ammonites *Scaphites leei* Reeside and *Scaphites hippocrepis* (De Kay) in the Western Interior of the United States. *Professional Papers of the United States Geological Survey* **619**: 1-27.

Cobban, W.A., 1994. Diversity and distribution of Late Cretaceous ammonites, Western Interior, United States. Pp. 435-451. *In* Caldwell, W.G.E. & Kauffman, E.G. (Eds) Evolution of the Western Interior Basin. *Geological Association of Canada Special Paper* **39** (mis-dated 1993).

Cobban, W.A., 1995. Occurrences of the free-swimming Upper Cretaceous crinoids *Uintacrinus* and *Marsupites* in the Western Interior of the United States. *Bulletin of the United States Geological Survey* **2113**: C1-C6.

Collignon, M., 1948. Ammonites neocrétacées du Menabe (Madagascar) I. Les Texanitidae (suite). *Annales Géologiques du Service des Mines de Madagascar* **14**: 7-101.

Collignon, M., 1960 (mis-dated 1959). Corrélations sommaires entre les dépôts du Crétacé supérieur de Madagascar et ceux de l'Europe occidentale, en particulier de la France. *Comptes rendus du Congrès des Sociétés Savantes de Paris et des départements* tenu à Dijon en 1959. Section des Sciences, sous-section de Géologie. Colloque sur le Crétacé supérieur français 41-52 + table.

Coquand, H., 1857. Position des *Ostrea columba* et *biauriculata* dans le groupe de la craie inférieur. *Bulletin de la Société Géologique de France* **(2), 14**: 745-766.

Ernst, G., 1963. Zur Feinstratigraphie und Biostratonomie des Obersanton und Campan von Misburg und Höver bei Hannover. *Mitteilungen aus dem Geologischen Staatsinstitut in Hamburg* **32**: 128-147.

Ernst, G., 1964. Ontogenie, Phylogenie und Stratigraphie der Belemnitengattung *Gonioteuthis* Bayle aus dem nordwestdeutschen Santon/Campan. *Fortschrifte Geologie Rheinland und Westfalen* **7**: 113-174.

Ernst, G., 1968. Die Oberkreide-Aufschlüsse im Raume Braunschweig-Hannover und ihre stratigraphische Gliederung mit Echinodermen und Belemniten. I Teil: Die jüngere Oberkreide (Santon-Maastricht). *Beihefte zu den Berichten der Naturhistorische Gesellschaft zu Hannover* **5**: 235-284.

Ernst, G., Schmid, F. & Klischies, G., 1979. Multistratigraphische Untersuchungen in der Oberkreide des Raumes Braunschweig-Hannover. Pp. 11-46. *In* Wiedmann, J. (Ed.) Aspekte der Kreide Europas. *International Union of Geological Sciences* **(A) 6**.

Gale, A.S., Montgomery, P., Kennedy, W.J., Hancock, J.M., Burnett, J.A. & McArthur, J.M., 1996. Definition and global correlation of the Santonian-Campanian boundary. *Terra Nova* **7** (for 1995): 611-622.

Grossouvre, A., de, 1901. Recherches sur la craie supérieure 1: stratigraphie générale. *Mémoires pour servir à l'explication de la carte géologique détaillée de la France* 1013 + vii pp.

Hattin, D. E., 1982. Stratigraphy and depositional environment of Smoky Hill Chalk Member, Niobrara Chalk (Upper Cretaceous) of the type area, western Kansas. *Bulletin of the Kansas Geological Survey* **225**, 108 pp.

Haug, E., 1908-1911. Traité de Géologie. Masson, Paris.

Hinte, J. E. Van, 1979. The Coniacian, Santonian and Campanian stratotypes. *Lethaia* **12**: 183-187.

Jenkins, H.C., Gale, A.S. & Corfield, R.M., 1994. Carbon and oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its palaeoclimatic significance. *Geological Magazine* **131**: 1-34.

Kauffman, E. G., 1977. Illustrated guide to biostratigraphically important Cretaceous macrofossils, western interior basin, U.S.A. *The Mountain Geologist* **14**: 225-274.

Kauffman, E. G, Sageman, B. B., Kirkland, J. I., Elder, W. P., Harries, P. J. & Villamil, T. 1994. Molluscan biostratigraphy of the Cretaceous Western Interior Basin, North

America. Pp. 397-434 *In* CALDWELL, W.G.E. & KAUFFMAN, E.G. (Eds). Evolution of the Western Interior Basin. *Geological Association of Canada Special Paper* **39** (mis-dated 1993).

KENNEDY, W.J., 1984. Ammonite faunas and the "standard zones" of the Cenomanian to Maastrichtian Stages in their type areas, with some proposals for the definition of the stage boundaries by ammonites. *Bulletin of the Geological Society of Denmark* **33**: 147-161.

KENNEDY, W. J., 1986. Campanian and Maastrichtian ammonites from northern Aquitaine, France. *Special Papers in Palaeontology* **36**, 145 pp.

KENNEDY, W. J. & KAPLAN, U., 1995. *Parapuzosia (Parapuzosia) seppenradensis* (LANDOIS) und die Ammonitenfauna der Dülmener Schichten, unteres Unter-Campan, Westfalen. *Geologie und Paläontologie in Westfalen* **33**: 1-127.

KLINGER, H. C. & KENNEDY, W. J., 1980. Cretaceous faunas from Zululand and Natal, South Africa. The ammonite subfamily Texanitinae Collignon, 1948. *Annals of the South African Museum* **80**: 1-357.

MARKS, P., 1984. Proposals for the recognition of boundaries between Cretaceous stages by means of planktonic foraminiferal biostratigraphy. *Bulletin of the Geological Society of Denmark* **33**: 163-169.

MITCHELL, S. F., 1994. New data on the biostratigraphy of the Flamborough Chalk Formation (Santonian, Upper Cretaceous) between South Landing and Danes Dyke, North Yorkshire. *Proceedings of the Yorkshire Geological Society* **50**: 113-118.

NAIDIN, D. P., BENJAMOVSKY, V.N. KOPAEVICH, L.F., 1984. Methods of studying transgressions and regressions (exemplified by the Late Cretaceous basins of western Kazakhstan). 164 pp. Moscow University [in Russian].

OBRADOVICH, J. G., 1994. A Cretaceous Time Scale. Pp. 379-396 *In* CALDWELL, W.G.E. & KAUFFMAN, E.G. (Eds). Evolution of the Western Interior Basin. *Geological Association of Canada Special Paper* **39** (mis-dated 1993).

PAPULOV, G. N. & NAIDIN, D. P., 1979. The Santonian-Campanian boundary on the Eastern European platform. *Akademya Nauk SSSR; Uralski Nauchni Centr. Trudy Izvestiya Geologii i Geokhimii* **148**, 118 pp. Sverdlovsk. (in Russian).

PREMOLI-SILVA, I., 1977. Upper Cretaceous - Palaeocene magnetic stratigraphy at Gubbio, Italy. II Biostratigraphy. *Bulletin of the Geological Society of America* **88**: 371-374.

SCHMID, F., 1956. Jetziger Stand der Oberkreide-Biostratigraphie in Nord-westdeutschland: Cephalopoden. *Paläontologische Zeitschrift* **30**: 7-10 + table.

SCHÖNFELD, J., SIROCKO, F. & JØRGENSEN, N.O., 1991. Oxygen isotope composition of Upper Cretaceous chalk at Lägerdorf (NW Germany): its original environmental signal and palaeotemperature interpretation. *Cretaceous Research* **12**: 27-46.

SCHULZ, M.-G., ERNST, G., ERNST, H. & SCHMID, F., 1984. Coniacian to Maastrichtian stage boundaries in the standard section for the Upper Cretaceous white chalk of NW Germany (Lägerdorf-Kronsmoor-Hemmoor): definitions and proposals. *Bulletin of the Geological Society of Denmark* **33**: 203-215.

SEITZ, O., 1967. Die Inoceramen des Santon und Unter-Campan von Nordwestdeutschland. III. Teil. Taxonomie und Stratigraphie der Untergattungen *Endocostea, Haenleinia, Platyceramus, Cladoceramus, Selenoceramus* und *Cordiceramus* mit besonderer Berücksichtigung des Parasitismus bei diesen Untergattungen. *Beihefte zum Geologischen Jahrbuch* **75**, 171 pp.

SÉRONIE-VIVIEN, M., 1972. Contribution à l'étude du Sénonien en Aquitaine septentrionale. Ses stratotypes: Coniacien, Santonien, Campanien. *Les Stratotypes Français* **2**, 195 pp. Centre National de la Recherche Scientifique, Paris.

SLITER, W.V., 1989. Biostratigraphic zonation for Cretaceous planktonic foraminifers examined in thin section. *Journal of Foraminiferal Research* **19**: 1-19.

SPATH, L.F., 1926. On new ammonites from the English Chalk. *Geological Magazine* 63: 77-83 + table.

ULBRICH, H., 1971. Mitteilungen zur Biostratigraphie des Santon und Campan des mittleren Teils der Subherzynen Kreidemulde. *Freiberger Forschungshefte* **(C) 267**: 47-60.

YOUNG, K., 1963. Upper Cretaceous ammonites from the Gulf Coast of the United States. *University of Texas Publications* **6304**, 373 pp.

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Definition of a Global Boundary Stratotype Section and Point for the Campanian/ Maastrichtian boundary

by Gilles S. ODIN (compiler)

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Abstract

The Maastrichtian Working Group of the Subcommission of Cretaceous Stratigraphy looked for a section which could contain the Global Boundary Stratotype Section and Point in the Campanian/ Maastrichtian transition. Over the last three years new data have been collected from a section situated in the Tethyan Realm, but connected with the Temperate Realm.

During the meeting in Brussels, the working group considered the markers which could be used for the localisation of this boundary. Various sections in which this boundary is well exposed, were compared. The characteristics of these sections were discussed in respect of the requirements recommended by the Commission on Stratigraphy for the Boundary stratotype point.

As a result, the Campanian/ Maastrichtian boundary will be proposed at a precise point in the disused quarry at Tercis (Landes, France) at the immediate proximity of the level where the oldest *Pachydiscus neubergicus* (von HAUER, 1858) has been found. At this site, that level has been directly related with the appearance or disappearance of taxa of different groups, including a very diverse and rich echinoid fauna, various inoceramids, ammonites of which the replacement allows a zonation. Furthermore, the sediments contain sufficient material which permits the fundamental characterisation by benthic and planktonic foraminifera, dinocysts and pollens and calcareous nannofossils. Other faunal groups are also present, such as the brachiopods, crinoids, asteroids, ophiuroids which can be used as biostratigraphical tools amongst others for the necessary connection between the historical stratotypes and the succession at Tercis. Also for the characterisation and correlation, lithostratigraphical, chemostratigraphical and magnetostratigraphical tools are also being studied in detail.

The strata of the Tercis quarry are already well studied, but their richness means that one can envisage other important developments in the future.

Key-words:
Maastrichtian, Upper Cretaceous, stratotypes, GSSP proposal, biostratigraphy, ammonites, belemnites, foraminifera, coccoliths.

Résumé

Le Groupe de Travail Maastrichtien de la Sous-commission de Stratigraphie du Crétacé a cherché une section qui pourrait contenir le "Global Boundary Stratotype Section and Point" pour la transition Campanien/ Maastrichtien. Ces trois dernières années, des données nouvelles ont été récoltées dans une section appartenant au domaine téthysien, tout en étant reliée au domaine tempéré.

Pendant la réunion de Bruxelles, le groupe de travail a considéré les marqueurs qui pourraient permettre la localisation de cette limite. Plusieurs sections où cette limite est bien exposée, ont été comparées. Les caractéristiques de ces sections ont été discutées en considérant les règlements présentés pour la désignation du "Boundary stratotype point" par la Commission de Stratigraphie.

A la suite de ces discussions, la limite Campanien/ Maastrichtien proposée se trouve à un point précis dans la carrière abandonnée de Tercis (Landes, France) à proximité immédiate de l'endroit où a été trouvé le plus ancien *Pachydiscus neubergicus* (von HAUER, 1858). Dans cette carrière, ce niveau a été mis en relation directe avec l'apparition et la disparition de taxa appartenant à différents groupes, dont une faune diverse et riche d'échinoides, de nombreux inocérames, des ammonites dont le renouvellement permet une zonation. En outre, les sédiments ont livré des témoins suffisants pour la fondamentale caractérisation à l'aide des foraminifères benthiques et planctoniques, des dinocystes, des pollens et des nannofossiles calcaires. Plusieurs groupes fauniques présents entre autres les brachiopodes, les crinoïdes, les astérides ou les ophiurides, peuvent servir d'outils de corrélation biostratigraphiques notamment vis à vis de la nécessaire connexion entre les stratotypes historiques et la succession de Tercis.

Pour la caractérisation et la corrélation détaillées, les outils lithostratigraphiques, chimiostratigraphiques et magnétostratigraphiques sont aussi étudiés.
Les strates de la carrière de Tercis ont déjà été beaucoup étudiés, mais leur richesse laisse envisager d'autres développements importants dans l'avenir.

Mots-clefs: Maastrichtien, Crétacé supérieur, stratotypes, proposition du GSSP, biostratigraphie, ammonites, bélemnites, foraminifères, coccolites.

Определение «Global Boundary Stratotype Section and Point» для Кампанско-Маастрихтской границы.

Резюме.
Рабочая Группа Маастрихтского яруса Подкомиссии Меловой Стратиграфии занимается поиском разреза, способного стать Global Boundary Stratotype Section and Point для Кампанско-Маастрихтской границы. В течение трёх последних лет, были собраны новые данные по разрезу, принадлежащему к области Тетис, но связанному тем не менее с бореальской палеобиогеографической областью.
В течение брюссельского заседания, Рабочая Группа установила указатели, которые смогли бы локализовать вышеупомянутую границу. Учёные сравнили несколько разрезов, в которых эта граница была ярко выраженной и обсудили харатеристики этих разрезов, учитывая представленные Стратиграфической Комиссией положения для определения «Global Stratotype Point».
В результате этих дискуссий, предложенная Кампанско-Маастрихтская граница находится в конкретном пункте нерабочего карьера Tercis (Landes, Франция), в непосредственной близости того уровня, где был найден древнейший Pachydiscus neubergicus (von HAUER, 1858). Этот уровень карьера был прямо связан с появлением и исчезновением таксонов, принадлежащих различным группам, включающим разнообразную и

обильную фауну: морских ежов, многочисленных иноцерамов и аммонитов. Благодаря обновлению последних осуществляется распределение по зонам. К тому же, отложения содержат достаточное количество остатков, благодаря чему становится возможной, при помощи бентических и планктонических фораминифер, диноцист, пыльцы и известковых нанофоссилий, фундаментальная характеризация. Несколько присутствующих, относящихся к фауне групп, между прочим брахиноподов, морских лилий и морских звёзд (*Asteroida* и *Ophiuroida*), могут играть роль биостратиграфических орудий корреляции, в частности, по отношению к необходимой связи между историческими стратотипами и наследием Tercis.
Для детальных корреляции и характеризации также изучаются литостратиграфические, хемостратиграфические и магнитостратиграфические технологии.
Страты карьера Tercis уже были изучены в деталях; тем не менее, их богатство предполагает другие важные открытия в будущем.

Ключевые слова: Маастрихтский ярус, верхний мел, стратотипы, предложение GSSP, биостратиграфия, аммониты, фораминиферы, кокколиты.

The Campanian/ Maastrichtian boundary

At the meeting in Brussels, presentations and discussions connected with the definition of a Global Boundary Stratotype Section and Point (later on GSSP) for a precise definition of the position of the Campanian/ Maastrichtian boundary, considered two points:
1. the level at which this boundary must be placed;
2. the choice of the most appropriate section for the concrete localisation of this level.

After the presentations and discussions in Brussels, the working group members reviewed the situation and gave an indicative vote on the various possibilities presented. The results of this vote are presented herein (Table 1). Since an obvious majority resulted from this consultation, a formal vote was attempted in October 1995 among the 40 members of the working group, entrusted with the consensus on this boundary. The working group largely expressed the same opinion as that previously expressed by the indicative vote in Brussels.

We summarise here,
1) the discussion elements considered for establishing the GSSP of the Campanian/ Maastrichtian boundary, and
2) the characteristics already known from the Tercis site.

For this site, it should be noted that whereas some results are already available, complementary studies are still being undertaken. Thus the chosen site will be a good reference point which can be presented to the Subcommission as GSSP for the Campanian/Maastrichtian boundary.

Table 1.
Markers quoted for location of the Campanian/ Maastrichtian boundary and votes for them.

1st vote: all present were invited to vote for several primary markers amongst all those quoted in the discussion. No vote was given for: LO *Nostoceras hyatti*, LO *Globotruncanita elevata*, FO *G. aegyptiaca*, FO *Lithraphidites praequadratus*.

2nd vote: the four most quoted markers (underlined) were selected and each person present had to vote for one marker only.

3rd vote: in the last vote those present could vote for or against the most favoured marker.

FO = First Occurrence; LO = Last Occurrence.

boundary marker	1st vote	2nd vote (4 abstained)	3rd vote (5 abstained)
Ammonites			
FO *Pachydiscus neubergicus*	25	20	28 for; 8 against.
FO *Hoploscaphites constrictus*	5	–	
FO *Nostoceras hyatti*	2	–	
FO *Pseudokossmaticeras brandti*	1	–	
Belemnites			
FO *Belemnella lanceolata*	12	5	
FO *Belemn. licharevi*	2	–	
Planktonic foraminifera			
FO *Gansserina gansseri*	4	–	
LO *Globotruncanita calcarata*	3	–	
FO *Archaeoglobigerina kefiana*	1	–	
Benthic foraminifera			
Bolivina decurrens	3	–	
Neoflabellina reticulata	3	–	
Orbitoides mammillata	1	–	
Coccoliths			
LO *Aspidolithus parcus constrictus*	11	10	
LO *Reinhardtites anthophorus*	5	–	
Physico-chemical			
Magnetic reversal marker	17	2	
Chemical marker (87Sr/86Sr)	1	–	

Discussion on the Campanian/ Maastrichtian boundary

The potential markers for placing the boundary
In 1984, the conclusions on the proposals for the position of the Campanian/ Maastrichtian boundary (BIRKELUND *et al.*, 1984) mentioned six taxa which had ranges useful for defining this boundary.
appearance:
– of the ammonites
1. *Hoploscaphites constrictus* (J. SOWERBY) type specimen at the Natural History Museum, London
2. *Pachydiscus neubergicus* (von HAUER) type specimen at the Geologische Bundesanstalt, Vienna, Austria - it has been re-figured by KENNEDY & SUMMESBERGER, 1986, pl. 3, figs. 1-3; WARD & KENNEDY, 1993, fig. 28.
– of the belemnite
3. *Belemnella lanceolata* (SCHLOTHEIM)
– of the foraminifer
4. *Globotruncana falsostuarti* (SIGAL)

extinction:
– of the foraminifer
5. *Globotruncanita calcarata* (CUSHMAN)
– of the calcareous nannofossil
6. *Quadrum trifidum*. (STRADNER) sensu PRINS & PERCH-NIELSEN

Since the 1984 restatement, other biomarkers have been cited, recommended, discussed or used: appearance or extinction of *Nostoceras hyatti* (STEPHENSON), extinction of the calcareous nannofossil *Broinsonia parca constricta* (STRADNER) BUKRY HATTNER. Geochemical and geomagnetic markers have also been considered.

Some specialists consider the first criterion of a marker should be its practical use: it should be recognisable at the precise level in the reference section and if possible, throughout the globe. From this point of view, candidates for locating the boundary are limited to macrofossils (if they are sufficiently frequent and easy to identify) or eventually to lithological criteria (but these can rarely be recognised beyond a single basin).

Other specialists argue that macrofossils are generally too rare (or even too long lived) to allow the easy and precise location of a boundary: they prefer to recommend a microfaunal, geochemical or magnetic marker. Table 1 lists all the markers proposed in Brussels.

Sections useful for the definition of the boundary.
The two regions used for the definition of the historical stage stratotypes (around Maastricht in Limburg, The Netherlands, for the Maastrichtian; and the Charentes, SW France, for the Campanian) do not contain sufficiently continuous sections at the Campanian/ Maastrichtian boundary.

Five regions contain possible type section candidates. One is in the cold temperate realm (N. Germany) and four are in the tethyan realm [Basque region (France-Spain), Tunisia, Apennines (Italy), Landes (France)].

The Kronsmoor section (N. Germany) is well known through many publications as indicated by KENNEDY *et al.*, 1995. Furthermore, it is the only section which can be considered if the belemnites have to be the marker of the boundary. In principle, regions further eastwards, in the ex-USSR, could also be considered, but our information on these regions is less complete. Less favourable is that the Kronsmoor quarry is still being worked, and that the loose nature of the sediment makes it difficult to indicate a constant reference point.

In the Basque Region (Pais Vasco) the Zumaya section (Spain) is well studied. The section at Bidart (France) has been fairly well studied. Those sections are easily accessible and especially well exposed. They would be favourable if microfossils were considered as markers. Macrofauna is however rare near the Campanian/ Maastrichtian boundary.

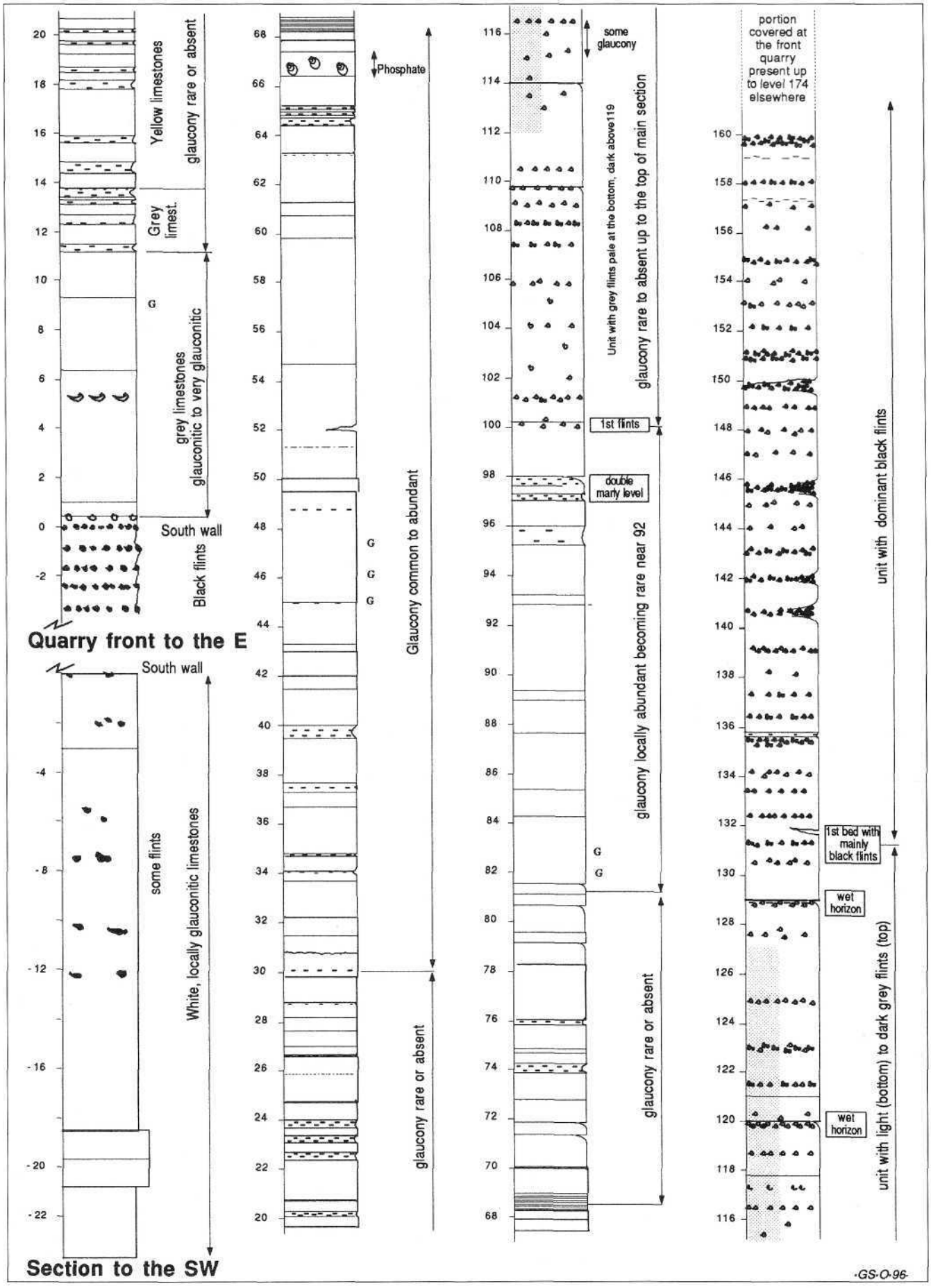
In Tunisia the sediments contain a good microfauna; macrofauna is present but relatively rare. The studies on this region are not sufficiently diversified so far, but, as with the Basque region, Tunisia could be used for comparison when combining different correlative tools to obtain better precision on their relative stratigraphic positions.

The section at Botaccione (Apennines, Italy) has been very thoroughly studied. Microfauna is present but can only be studied in thin sections.

Remarkable is that the Botaccione section offers the possibility to combine biostratigraphic and magnetostratigraphic data. However, it contains no macrofauna. Another problem which might arise with this road side section is that it could become inaccessible. The data accumulated on this section allow worldwide correlations, especially in the deep (bathyal) marine strata.

The Tercis section (Landes, France) is remarkable in the diversity of the macrofauna, except for the absence of belemnites. This section allows to correlate cool temperate macrofauna and tethyan microfauna. The microfauna and the nannofossils are partially less favourably preserved than in deeper-water deposits. Their study is more time consuming than in other basins, but a characterisation is possible. The data concerning this section are being studied in detail. The section's accessibility and permanency are as favourable as possible.

Among the possible sites for defining the Campanian/ Maastrichtian boundary stratotype, none completely covers the criteria summarised elsewhere (ODIN, 1992):
1) quality of the section with accessibility for study and for the preservation of a given point;
2) quality of the sedimentary record with fully marine facies, continuous deposition, good preservation of the "signals" without change of facies;
3) quality of the biostratigraphic record permitting especially a correlation between the cold temperate and tethyan biomarkers;


Yellow limestones
glaucony rare or absent
Grey limest.
grey limestones
glauconitic to very glauconitic
South wall
Black flints
Quarry front to the E
South wall
some flints
White, locally glauconitic limestones
Section to the SW
Phosphate
Glaucony common to abundant
glaucony rare or absent
some glaucony
Unit with grey flints pale at the bottom, dark above119
glaucony rare to absent up to the top of main section
1st flints
double marly level
glaucony locally abundant becoming rare near 92
glaucony rare or absent
portion covered at the front quarry present up to level 174 elsewhere
unit with dominant black flints
1st bed with mainly black flints
wet horizon
wet horizon
unit with light (bottom) to dark grey flints (top)
-GS-O-96-

4) applicability of physico-chemical tools with magnetostratigraphy, chemostratigraphy and radioisotopic dating.

Using sections situated in different palaeogeographic and sedimentary environments, the boundary can be defined more completely by adding to the chosen site for the GSSP, auxiliary reference sections.

The proposals which were preferred during the votes
Table 1 (p. 112) summarises the opinion of the participants at the Brussels meeting.

Where the biomarkers are concerned, the macroscopic and the "hidden" criteria had the same number of supporters. When only one criterion had to be selected the macrofossil supporters were more numerous. The appearance of the ammonite *Pachydiscus neubergicus* seems to be the only criterion which obtained a consensus. This is due largely to the fact that this ammonite has a wide distribution outside the cold temperate realm. HANCOCK & KENNEDY (1993) and KENNEDY *et al.* (1995) cite the taxon from the Basque region to Denmark, from N. Germany, the Ukraine, Russia to Armenia and from Africa: Tunisia, Nigeria, South-Africa, Madagascar, and also from S. India.

After the Brussels meeting, a formal vote was taken on October 15, 1995 by all members of the working group: 40 persons including all those having actively cooperated with the studies of the group and those which had expressed an interest in its activities to the chairman of the subcommission and having actively participated in the discussions. This vote confirmed the conclusions reached in Brussels in which the members expressed the wish to obtain a concrete result and to emphasize Tercis as a reference section.

Substages of the Maastrichtian stage
Where needed the formal Maastrichtian Stage may be subdivided into substages. At the meeting in Brussels, the majority of those attending agreed by vote of 26 to 0, with 6 abstentions, that a subdivision into two substages should be recommended.

←

Fig. 1 — Present section in the quarry at Tercis (simplified from ODIN & ODIN, 1994). The whole succession is limestone with occasional argillaceous beds (10-15% clay: dashed beds). Major bedding planes are shown. Eight units are distinguished with sharp boundaries at levels 0, 11, 30, 68.5, 81, 100 and 131. The relative abundance of poorly evolved glaucony (maximum: 30‰, usually in very small grains - 30 to 100 µm) is one of the few criteria for subdividing the homogeneous lithology. The Campanian/ Maastrichtian boundary is within the 0.3 to 0.6 Ma long dotted interval; it will be constrained to 0.03 Ma when current research has been completed.

There was no agreement on the boundary-criterion for the base of the Upper Maastrichtian. Possible criteria mentioned included:
- the extinction of rudistid reefs,
- the extinction of the majority of the inoceramids,
- the lowest occurrence of a calcareous nannofossils species;
- the lowest occurrence of *Pachydiscus fresvillensis* Seunes.

It was agreed, without a vote being taken, that the section at Zumaya, northern Spain, should be better documented before any final decision is made on the base of the Upper Maastrichtian.

The site of Tercis

Geographically, the village of Tercis is situated in the Landes (S.W. France), in between the Basque Region (well known by numerous, recently undertaken studies) to the south, and the Charentes (with the historical stratotype of the Campanian) to the north. The palaeogeographic position of Tercis, in a small basin north of the Pyrenees, but belonging to the tethyan realm, is favourable for comparison between the cold temperate realm (Charentes, Limburg, N. Germany) and the tethyan realm of which the faunas are found in this Aturian basin.

The site is situated 8 km SE of the railway station at Dax, on the left bank of the Adour River. The outcrop is part of the east-west ridge of Tercis-Angoumé. In the northern flank of this anticline, which is partially of diapiric origin, Mesozoic strata outcrop subvertically; at their centre is Triassic of Germanic facies.

The outcrop is situated in a quarry with five formerly worked "platforms", each 5 to 6 m high, opening westwards between the south and north walls, about 100 m apart. These "levels" allow repeated observation of the series.

The major section of about 165 m thickness, is the old quarry face. A disused quarry just to the south shows 25 m of older strata. Another section, about 60 m thick, is visible around the north entrance of the quarry, which contains part of the uppermost strata of the main section. Younger strata are visible to the north of the quarry in small exposures as far as the "Mur de Bédat", at the Cretaceous/Palaeogene boundary. The whole 40 m just below the K/T boundary can be studied.

Access to the site and "permanence" of the section
Working of the quarry has stopped. In 1993, for security reasons, a considerable re-planning of the site was undertaken. It was aimed at preservation and improvement of the accessibility to its geology. The main section was measured and described (ODIN & ODIN, 1994). Markers have been placed every metre between - 4 and + 161 on at least one level.

About 15 years ago, the first advanced studies on the site were started and directed by J. M. Hancock (HAN-

COCK *et al.*, 1993) who demonstrated the importance of the site. In 1988 P. Ward also studied the site. Since the spring of 1992 a systematic study including the marking of the section and bed by bed collecting has been undertaken. Since 1994, all the results have been accumulated in the framework of the Maastrichtian Working group of the Cretaceous Subcommission and they will be monographed in 1996.

The city of Dax is served by a good railway service from Paris and Spain and easily accessible by road. The road to the quarry is good.

At present the owner of the site is the "Ciments Français". This company readily gives access permits. Soon, as a result of the acceptance of the security planning of the site (18 October 1995) the city of Dax will take charge, in cooperation with the "Conservatoire des Sites d'Aquitaine". This latter institution is empowered by the national French environmental authorities to protect sites. These organisations have shown they are interested in recognising the Tercis site as a public site, accessible yet protected against destruction in the near as well as for the distant future.

Sediments

Depositional environment

The sediments have been deposited in an open marine environment represented by limestones with pithonellids and calcispheres. A depth of 50 to 200 m is probable – thus representing the top of the continental slope or the lower shelf.

Depositional history

The strata were placed in a vertical position by the Pyrenean orogeny. They are cut locally by small faults, mainly visible outside the main section. Their throw ranges from 20 to 30 cm to several m. Foraminifera and nannofossils are locally strongly recrystallised. There is some minor shearing.

Characteristic stratigraphic tools and their correlation potential

Lithostratigraphy

The major section contains generally 95% carbonates. More than 10 % clay is only found in some thin beds, a few cm to 30-40 cm thick.

The main lithological variations are related to the amount of glauconite (not very evolved and fine), and the development of chert (grey or black flints). These criteria have allowed a subdivision into 8 units (ODIN & ODIN, 1994). Specific marker beds provide precise correlations between the sections on different levels within the quarry at Tercis: two beds with *Pycnodonte vesicularis* (oysters), a double marly level, a bed with numerous inoceramids. The most important lithostratigraphic characteristic is the obvious rhythmicity of the concretions of chert. Similar rhythms have been interpreted as being of climatic origin in the Maastrichtian of Limburg (ZIJLSTRA, 1994). This should allow the evaluation of the depositional speed and its regularity. The regular rhythms, especially clear at the Campanian/ Maastrichtian transition, are also a very useful tool for demonstrating the continuity of the deposition.

Biostratigraphy of the macrofauna

The section contains an abundant echinoid fauna, allowing a double zonation: one with *Echinocorys* species, another with *Micraster* species and closely allied taxa (being studied by D. Néraudeau). Inoceramids are present from the base to the top of the section (DHONDT, 1993, and further studies). Ammonites are sufficiently varied and numerous to allow far reaching correlations with the tethyan and cold temperate realms. Further progress has been made since the work by HANCOCK & KENNEDY, 1993: 250 specimens collected *in situ* by the WG chairman are available for study at the Université P. & M. Curie in Paris (contributions by W.A. Cobban, W.J. Kennedy, and P.D. Ward). Macrobrachiopods and microbrachiopods are quite common, but macrobrachiopods are limited to certain beds (under study by D. Gaspard). Asteroid, crinoid and ophiuroid remains have been collected by the WG chairman, and should allow interesting correlations with the Campanian and Maastrichtian historical stratotypes (studies by L. Villier and J. W.J. Jagt).

Biostratigraphy of the microfauna

Benthic (studied by J. Magné and J. Ion) and planktonic Foraminifera (studied by M. Caron and J. Ion); see also SIMMONS *et al.*, in press) are present in most levels. The preservation varies from very good to poor for planktonic foraminifera, and the marker taxa are sometimes only sporadically present. A zonation can be established and correlations can be proposed. The benthic forms are fairly well preserved and also allow a zonation and correlations. Noteworthy is that the beds with the most diverse and well preserved microfauna with the oceanic characteristics are situated very near to the appearance of fossil markers used for the boundary.

Ostracodes (studied by R. Damotte) are present and locally ornate forms permit correlations.

Coccoliths (BURNETT in HANCOCK *et al.*, 1993, and further work by M. Bonnemaison, K. von Salis-Perch-Nielsen, M. Melinte, and more recently by S. Gardin, S. Monechi, J. A. Bergen) are present in most samples. Preservation is average to poor, but zonations have been proposed by several specialists.

Dinocysts and pollens (studied by E. Antonescu, new studies foreseen by J. A. Bergen and G. J. Wilson) are present in many samples, and are well preserved. They should help considerably in correlations, even over long distances.

To summarise: even if the preservation is not perfect for all fossil groups, the sediments of the Tercis section are unique in that they allow a direct correlation potential for many fossil groups (except belemnites and radiolarians) and for a direct interregional correlation.

Physico-chemical stratigraphic tools

Geochemical analysis has been undertaken: trace ele-

ments, Sr isotopes. Trace elements present a potential for regional and global correlation. Sr isotopes have not yet given satisfactory results.

The magnetostratigraphic analysis has been undertaken in the laboratory of B. Galbrun. Only the lower half of the section gave a useful result.

Practical localisation of the GSSP

The actual status of the Tercis quarry allows to consider a GSSP which would be concretely developed and protected. Following an investment of 1000 kF (200.000 US $) for the development of the site and for the safety of visitors to the quarry, negotiations are advancing towards its protection in the near and distant future. The precise location of the GSSP depends on different factors.

Theoretically the choice of the biological marker *Pachydiscus neubergicus* is fundamental. Already at least three scientists have found one or several specimens near the Campanian/ Maastrichtian boundary. These specimens have been identified by at least three specialists (W. A. Cobban, W. J. Kennedy, P. Ward). More recent collections are still being identified.

At the time of the meeting in Brussels, it was believed that the lowest occurrence of *Pachydiscus neubergicus* was somewhere in the range of the levels 112-127, in the limestones with pale grey flints, probably within a thickness of no more than 10 m (representing less than 0.4 Ma). Part of the problem of uncertainty is that the section-measurements in HANCOCK *et al.* (1993), made whilst the quarry was still being worked, are not as accurate as the later measurements in ODIN & ODIN (1994). Nevertheless, it is expected that the placing of the boundary-criterion, i.e. the lowest *P. neubergicus* will shortly be possible to a definite bed, that is to a precision of about 0.03 Ma.

Practically there are three sections in which the GSSP can be fixed. This would allow the complete preservation of a section containing the GSSP, whereas samples and research could be undertaken in the two other stages of the quarry at the critical horizon of the boundary. Furthermore, if the GSSP were destroyed by mistake or otherwise, there still is a discrete sedimentological criterion, found in all three stages of the quarry and distinct within the whole exposure.

Acknowledgements

The results of the working group are largely due to the specialists who have collaborated before and at the meeting in Brussels, and to the results brought together on the sections. The work has been only possible with the access permission and the important development of the Tercis site, authorised and undertaken by the "Ciments Français", Calcia division.

Abbreviations:

GSSP: Global boundary stratotype and section point.

References

BIRKELUND, T., HANCOCK, J. M., HART, M. B. *et al.*, 1984. Cretaceous stage boundaries-proposals. *Bulletin of the Geological Society of Denmark*, **33**: 3 - 20.

DHONDT, A. V., 1993. Upper Cretaceous bivalves from Tercis, Landes, SW France *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, **63**: 211 - 259.

HANCOCK, J. M. & KENNEDY, W. J., 1993. The high Cretaceous ammonite fauna from Tercis, Landes, France. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, **63**: 149 - 209.

HANCOCK, J. M., PEAKE, N. B., BURNETT, J., DHONDT, A. V., KENNEDY, W. J. & STOKES, R. B., 1993. High Cretaceous biostratigraphy at Tercis, south-west France. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, **63**: 133 - 148.

KENNEDY, W. J., CHRISTENSEN, W. K. & HANCOCK, J. M., 1995. Defining the base of the Maastrichtian and its substages, written internal report for the Maastrichtian Working Group, Meeting at Brussels, September 1995.

KENNEDY, W. J. & SUMMESBERGER, H., 1986. Lower Maastrichtian ammonites from Neuberg, Steiermark, Austria. *Beiträge zur Paläontologie von Österreich*, **12**: 181-209.

ODIN, G. S., 1992. New stratotypes for the Paleogene: the Cretaceous/Paleogene, Eocene/Oligocene and Paleogene/ Neogene boundaries. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **186**: 7 - 20.

ODIN, G. S. & ODIN, P., 1994. Première description d'une coupe dans la localité aturienne de Tercis (Landes): contribution à l'étude de la limite Campanien-Maastrichtien. *Géologie de la France*, **2**: 31 - 37.

SIMMONS, M. D., WILLIAMS, C.L. & HANCOCK, J. M. in press. Planktonic foraminifera across the Campanian/ Maastrichtian boundary at Tercis, south-west France. *Newsletters on Stratigraphy*.

WARD, P. D. & KENNEDY, W. J., 1993. Maastrichtian ammonites from the Biscay Region (France, Spain). *Paleontological Society Memoir*, **34**: 58 pp.

ZIJLSTRA, J. J. P., 1994. Sedimentology of the late Cretaceous and early Tertiary (tuffaceous) chalk of NW Europe. *Geologica Ultraiectina*, **119**: 192 pp.

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Seuls seront acceptés les articles originaux. Les manuscrits doivent être rédigés en anglais, français, allemand ou néerlandais. Les articles seront soumis à un comité de lecture dont la décision est souveraine. Celle-ci sera communiquée à l'auteur dans les meilleurs délais. Les manuscrits non conformes aux présentes recommandations seront refusés.
En principe, aucune limite n'est imposée pour la longueur des manuscrits. Cependant, pour des articles particulièrement longs, une contribution financière pourra être demandée à l'auteur.
Les manuscrits sont à envoyer à M. le Directeur de l'I.R.Sc.N.B.
Cinquante tirés-à-part seront gratuits.

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Le texte doit être dactylographié dans sa forme définitive en trois exemplaires sur format DIN A4, avec des marges suffisantes (4 cm côté gauche), double interligne, recto seulement. Il doit mentionner le(s) nom(s), le(s) prénom(s) du (des) auteur(s) et leur adresse professionnelle à placer après les références bibliographiques.
Il doit indiquer, outre le titre, un titre abrégé (35 caractères maximum). Il doit être accompagné d'un résumé en deux langues, dont un en anglais. Chaque résumé sera suivi de trois à six mots-clefs. Le renvoi aux références bibliographiques se fera en mentionnant dans le texte le nom de l'auteur (en petites capitales), suivi de l'année et éventuellement de la page, placées entre parenthèses.
Le manuscrit doit être accompagné des illustrations et de deux photocopies de chacune d'elles. L'auteur mentionnera dans la marge du texte les endroits où il souhaite voir insérer les tableaux et les figures. Dans les manuscrits taxonomiques les listes synonymiques éventuelles doivent être aussi précises que possible.
Short contributions: rubrique pour articles ne dépassant pas 4 pages imprimées (traitant de résultats nouveaux ou d'actualité) qui peuvent être soumis jusqu'à deux mois avant la mise à l'impression du volume.

Liste de références

Les références seront classées par ordre alphabétique des auteurs et par ordre chronologique pour chaque auteur. Les titres des périodiques ne seront pas abrégés, mais écrits en toutes lettres. Les références seront présentés de la manière suivante:

Brown, S., Cassuto, S. & Loos, R.W., 1985. Biomechanics of chelipeds in some decapod crustaceans. *Journal of Zoology*, 188 (2): 143-159.

Gery, J., 1977. Characoids of the World. Tropical Fish Hobbyist Publications Inc. Ltd., Neptune City, U.S.A., 672 pp.

Haq, B.U., 1984. A synoptic review of 200 million years of ocean history. *In*: Haq, B.U. & Milliman, J.D. (Editors), Marine Geology and Oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, London, pp. 201-232.

Mille, G.S., 1913. Revision of the Bats of the genus Glossophaga. *Proceedings of the United States National Museum*, 46: 413-429.

Tableaux

Les tableaux seront présentés séparéments. Ils seront numérotés en chiffres arabes accompagnés d'une légende et porteront le nom de l'auteur.

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Les dessins, photograhies et planches de bonne qualité doivent être réalisés en tenant compte de la justification du Bulletin ($17,6 \times 24,5$ cm pour une page entière et $8,5 \times 24,5$ cm pour une colonne) et de la réduction éventuelle que l'auteur précisera. Chaque illustration portera le nom de l'auteur et le numéro de la figure. Les légendes des illustrations seront dactylographiées sur des feuilles séparées. Il est souhaitable que chaque illustration comporte une échelle.

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Les noms de genres et d'espèces et les mots latins seront soulignés.
On utilisera les unités du système SI et les symboles internationaux.
L'emploi de notes infrapaginales doit être évité si possible.
Les remerciements figureront à la fin du texte avant les références.

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L'auteur recevra une première et éventuellement une seconde épreuve. Les épreuves devront être renvoyées dans les délais fixés. Tout retard entraînera la remise de la publication à une date ultérieure. Les corrections sont apportées en rouge, dans la marge au moyen des signes conventionnels. Toute modification appportée au texte original sera facturée à l'auteur.

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GERY, J., 1977. Characoids of the World. Tropical Fish Hobbyist Publications Inc. Ltd., Neptune City, U.S.A., 672 pp.

HAQ, B.U., 1984. A synoptic review of 200 million years of ocean history. *In*: HAQ, B.U. & MILLIMAN, J.D. (Editors), Marine Geology and Oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, London, pp. 201-232.

MILLE, G.S., 1913. Revision of the Bats of the genus Glossophaga. *Proceedings of the United States National Museum*, 46: 413-429.

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