

CALPIONELLID AND FORAMINIFERAL-OSTRACOD
BIOSTRATIGRAPHY
AT THE JURASSIC-CRETACEOUS BOUNDARY,
OFFSHORE EASTERN CANADA

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KEY-WORDS: Calpionellids - Foraminifera - Ostracoda - Jurassic Cretaceous Boundary - Biostratigraphy - Lithostratigraphy - Paleoecology - Paleooceanography - Offshore Eastern Canada.

Abstract. Calpionellid assemblages found in five offshore oil exploratory wells drilled on the Canadian Atlantic Shelf, can be correlated with the European Late Tithonian-earliest Berriasian calpionellid zones « A » and « B », indicating that the Grand Banks and the Iberian Peninsula were already separated by a deep sea in the Tithonian. The established calpionellid zonation permits calibration of the stratigraphic ranges of Foraminifera and Ostracoda at and near the Jurassic-Cretaceous boundary in offshore eastern Canada. The top of the Tithonian has been placed at the highest stratigraphic occurrence of *Anchispirocyclina lusitanica* (Egger), which in Bonniton H-32 corresponds to the lower part of calpionellid zone « B ».

The co-occurrence of Tethyan and Boreal foraminiferal species near the Jurassic-Cretaceous boundary on the Scotian Shelf and Grand Banks is interpreted to reflect paleocirculation pattern with the Tethyan species favouring warmer waters and thus occurring in shallower environments and the Boreal species flourishing in colder, deeper waters. Colder waters from North Europe and Greenland, providing favourable living conditions for Boreal foraminiferal species, probably flowed southward along the North American margin, while warmer waters rich in Tethyan species were outflowing from the Mediterranean into the North Atlantic. The warm water influence on the central North Atlantic is confirmed by the presence of calpionellids in five Deep Sea Drilling Project sites from eastern and western North Atlantic. Calpionellids at these sites are assigned to Late Tithonian zones « A » and « B ».

Résumé. Les associations de Calpionelles trouvées dans cinq sondages offshore forés dans la plateforme atlantique canadienne, peuvent être corrélées avec les zones « A » et « B » de Calpionelles du Tithonien supérieur-Berriasien basal. Elles indiquent qu'au Tithonien les « Grand Banks » de Terre-Neuve et la Péninsule Ibérique étaient déjà séparés par une mer profonde. La zonation établie avec les Calpionelles permet de calibrer les répartitions stratigraphiques des foraminifères et des ostracodes dans

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la plateforme atlantique canadienne à ou près de la limite Jurassique-Crétacé. Le sommet du Tithonien a été placé à la plus haute occurrence stratigraphique de *Anchispirocyclina lusitanica* (Egger), qui, dans Bonnition H-32, correspond à la partie inférieure de la zone « B » à Calpionelles. On interprète que la coexistence des espèces de foraminifères téthyennes et boréales près de la limite Jurassique-Crétacé sur le « Scotian Shelf » et les « Grand Banks » a été causée par des différences de paléocirculation et de température de l'eau. Les espèces téthyennes préféraient les eaux plus chaudes et apparaissaient ainsi dans des environnements moins profonds et les espèces boréales florissaient dans les eaux plus froides et plus profondes. Les eaux froides du Nord de l'Europe et du Groënland, fournissant des conditions de vie favorables aux espèces boréales de foraminifères, coulèrent probablement vers le Sud, le long de la côte nord américaine, tandis que les eaux plus chaudes, riches en espèces téthyennes, coulèrent de la Méditerranée dans l'Atlantique Nord. L'influence de l'eau chaude sur le centre de l'Atlantique Nord est confirmée par la présence de Calpionelles dans cinq sites de « Deep Sea Drilling Project » de l'Est à l'Ouest de l'Atlantique Nord. Les Calpionelles, dans ces sites, sont attribuées aux zones « A » et « B » du Tithonien supérieur.

1. Introduction (1).

The main objective of this paper is to discuss the occurrence of calpionellids on the North American Atlantic margin and their relationship to the foraminiferal-ostracod biostratigraphy in this area. Calpionellids were found during thin section studies of sedimentary rocks from the oil exploratory wells of this area. In Mobil-Gulf Bonnition H-32 (Grand Banks) and Shell Mohican I-100 (Scotian Shelf), calpionellids are relatively common and provide detailed stratigraphic control, as well as correlation with the regional foraminiferal-ostracod zonation (Ascoli, 1976). Three more wells on the Canadian Atlantic Shelf (Shell Moheida P-15, Amoco-Imp Puffin B-90 and Amoco-Imp Kittiwake P-11; see Fig. 1) contain only isolated loricae of calpionellids, too rare to be usable for detailed biostratigraphy. The occurrences of calpionellids from this region was preliminary reported by Jenkins et al. (1974), Gradstein et al. (1975) and Ascoli (1976).

The calpionellid-bearing limestones on the Grand Banks, which represent the most northerly records of these fossils on the American continent, are intercalated with silty shales containing Foraminifera, thus providing a unique opportunity to integrate the Tethyan calpionellid and the foraminiferal biozonations. The calpionellids also permitted calibration of the stratigraphic ranges of Foraminifera and Ostracoda on the Canadian Atlantic Shelf with the standard calpionellid biozonation (Allemann et al., 1972).

(1) General compilation of data and lithostratigraphy are by L. F. Jansa; calpionellid biostratigraphy and paleoecology by J. Remane; foraminiferal-ostracod biostratigraphy and paleoecology by P. Ascoli.

2. Geologic Setting and Stratigraphy.

The area studied encompasses the Canadian Atlantic Shelf, extending from about the southern tip of Nova Scotia northward to the Flemish Cap on the Grand Banks (Fig. 1). The more than one hundred exploratory wells drilled here in the past decade have provided a multitude of geologic and stratigraphic information about the strata underlying the shelf.

The geology and lithostratigraphy of this area have been described

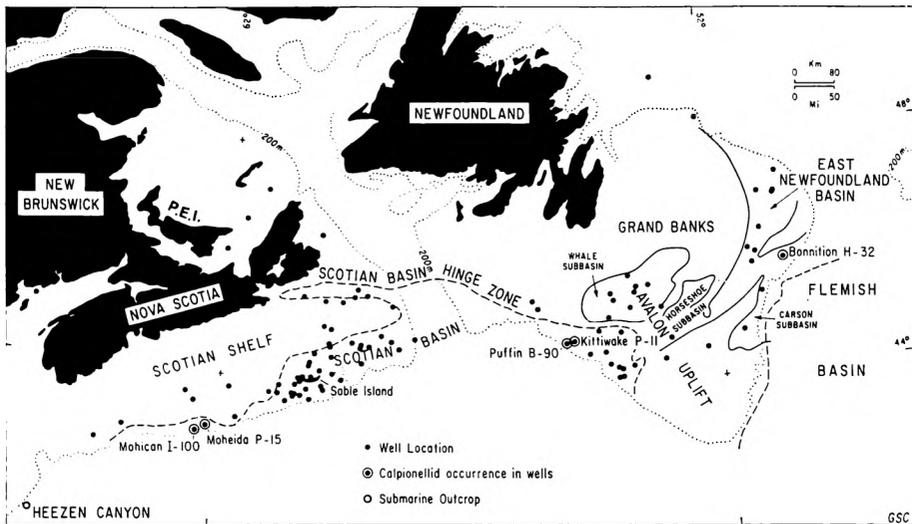


Fig. 1 - Location map.

in detail by McIver (1972), Amoco Canada Petroleum Company Ltd. (1973), Jansa and Wade (1975), Given (1977), and Wade (1978), and the biostratigraphy by Williams (1975), Ascoli (1976), and Gradstein (1976). The Mesozoic strata, other than isolated outcrops of continental Cretaceous beds, are not present on land and thus all the stratigraphic information about the Mesozoic is derived from the offshore wells. Two major depositional basins — the Scotian Basin and the East Newfoundland Basin — dominate this offshore region (Fig. 1). The basement in these basins is Proterozoic-Paleozoic metamorphics which are overlain by 9 to 12 km of Mesozoic-Cenozoic sediments (Wade, 1978). Several smaller subbasins are present on the Grand Banks (Amoco Canada Petroleum Company Ltd., 1973; Fig. 1), in which the sedimentary strata are less thick. The tectonic

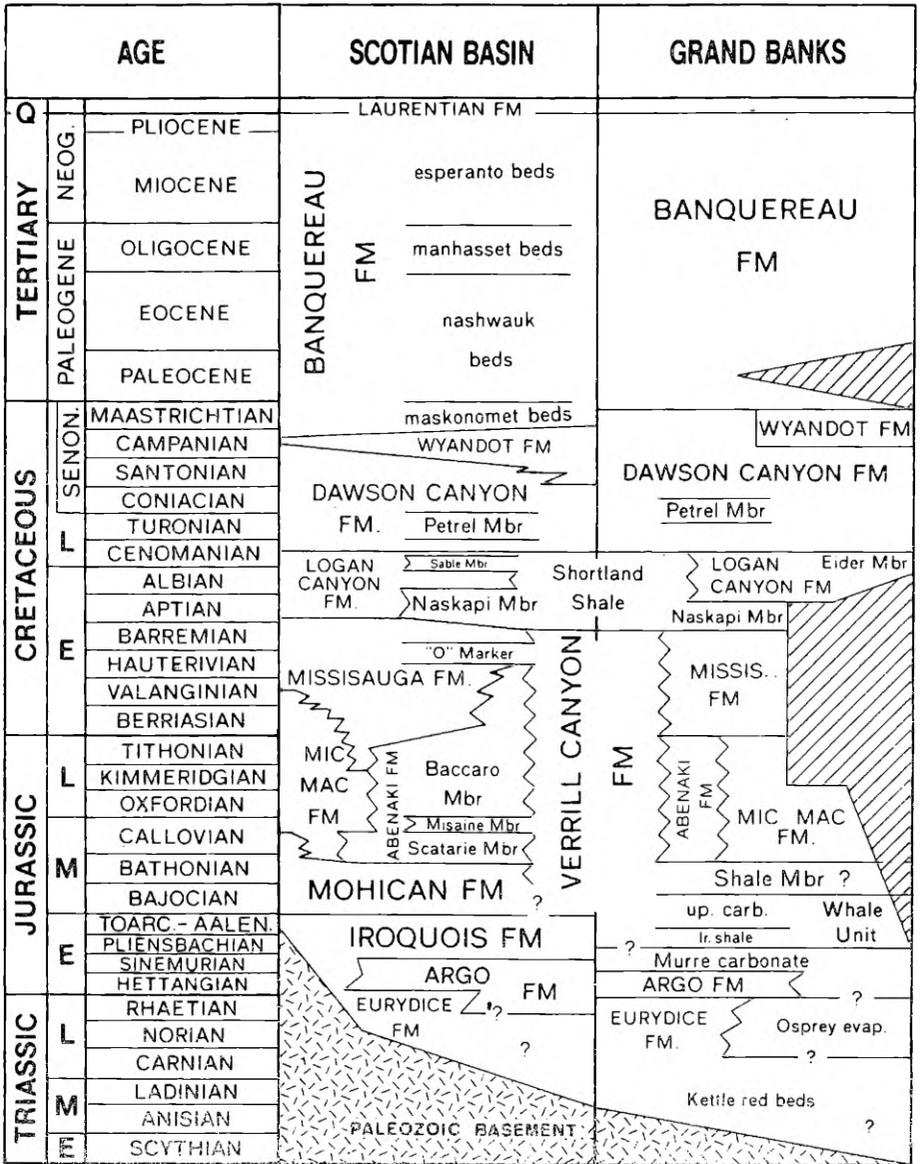


Fig. 2 - Formation chart, Scotian Basin and Grand Banks of Newfoundland.

structure of the eastern margin of the Grand Banks is poorly known, because of the lack of seismic reflection data in this region.

The oldest sedimentary Mesozoic strata penetrated on the Grand Banks are the Triassic Kettle red beds (Fig. 2) and the Upper Triassic Osprey evaporites (Jansa, Gradstein et al., 1977). In the Scotian Basin Paleozoic basement is overlain by Upper Triassic red beds (Eurydice Formation) and Rhaetian evaporites (Argo Formation) (McIver, 1972; Jansa & Wade, 1975; Bujak & Williams, 1977). The Jurassic was a period of primarily carbonate deposition (Iroquois and Abenaki Formations), interrupted during Early and Middle Jurassic time by a short period of regression and clastics deposition (Mohican Formation). In contrast to the Scotian Basin, carbonate deposition ceased during the Pliensbachian on the Grand Banks (Jansa et al., 1976) and the rest of the Jurassic is dominated by fine-grained terrigenous sediments (shales and silts), with only locally occurring thin carbonates.

The Late Kimmerian tectonic phase (Ziegler, 1975) influenced both the Scotian Shelf and Grand Banks regions, but to different degrees. On the Grand Banks, the south-eastern part of the shelf was uplifted in pre-Albian time, and the previously deposited Lower Jurassic-Cretaceous sediments were removed by erosion, which locally cut into the Pliensbachian (Jansa & Wade, 1975; Jansa et al., 1977). However, in the deeper parts of the basins, distant from the Avalon Uplift (Fig. 1), deposition continued without interruption and the sediments across the Jurassic-Cretaceous boundary are preserved. One such example is the Carson Subbasin (Fig. 1). Here the limestones are calpionellid-bearing, as documented by the Mobil-Gulf Bonniton H-32 well. A different situation near the Jurassic-Cretaceous boundary developed in the Scotian Basin. There, as a result of Kimmerian tectonic unrest, the provenance area was rejuvenated and coarse clastics were deposited in the basin during the Early Cretaceous, thus terminating the Abenaki Formation carbonates deposition (Fig. 2). The first clastics reached the present shelf edge region in the Berriasian, but it was not until the Early Hauterivian that clastics became here predominant. Thus, favorable conditions for pelagic deposition existed in the distal parts of the Scotian Basin during the Late Jurassic. This is reflected in the occurrence of calpionellid-bearing limestones in the Shell Mohican I-100 and Moheida P-15 wells (Scotian Shelf), and by the presence of rare calpionellids in shales of the Amoco Puffin B-90 and Amoco-Imp Kittiwake P-11 wells (western Grand Banks) (Fig. 1).

2.1. METHOD AND STUDIED MATERIAL.

The biostratigraphy and lithostratigraphy are based on a study of ditch cuttings and sidewall and conventional cores. Composite samples of ditch cuttings from 10 m intervals every 33 m were examined for biostratigraphy and from each 3 m interval for lithostratigraphy. No conventional core was taken in the Bonniton H-32 well. Here 135 thin sections were prepared from cuttings in the interval found to contain calpionellids. Three conventional cores from the Mohican I-100 well, sampled at 2525-2533, 2533-2542, and 2840-2850 m, were available for our study. From these cores and from cuttings, 94 thin sections were prepared and studied. Most of the cuttings and also some of the sidewall cores are contaminated by younger fossil material caved from upper parts of the wells. Therefore, the stratigraphically highest or last occurrences (« tops ») of the fossils have been used in this paper for biostratigraphic zonation.

In addition to the core and cuttings examination, a suite of mechanical logs (spontaneous potential, resistivity, sonic and gamma ray) was used for establishing lithostratigraphic units boundaries.

3. Grand Banks-Carson Subbasin (Mobil-Gulf Bonniton H-32).

Calpionellid-bearing limestones occur in the Mobil-Gulf Bonniton H-32 well, which is located on the eastern Grand Banks, approximately 390 km to the southeast of St. John's, Newfoundland (lat. 45°51'26.79" N; long. 48°19'31.76" W). The well is situated near the present shelf edge and was drilled in 110 m of water to a total depth of 3048 m and bottomed in Kimmeridgian calcareous shales. Lack of seismic reflection data for the eastern Grand Banks margin does not permit the definite placing of Bonniton H-32 in the Grand Banks tectonic framework. The Bonniton well is probably located in the Carson subbasin, which may be a part of a larger Flemish Basin (Fig. 1).

3.1. LITHOSTRATIGRAPHY.

The sedimentary sequences in the Bonniton H-32 well are subdivided into seven units of which only the unit containing calpionellids (Unit 6) is described here in detail (Fig. 3). The well penetrated a Tertiary sequence lithologically similar to the Banquereau Formation. The Eocene unconformably overlies some thick shallow-water peloid-skeletal limestone beds which are presumably Cretaceous. The limestone is separated by another hiatus from an underlying 755 m thick shale-siltstone sequen-

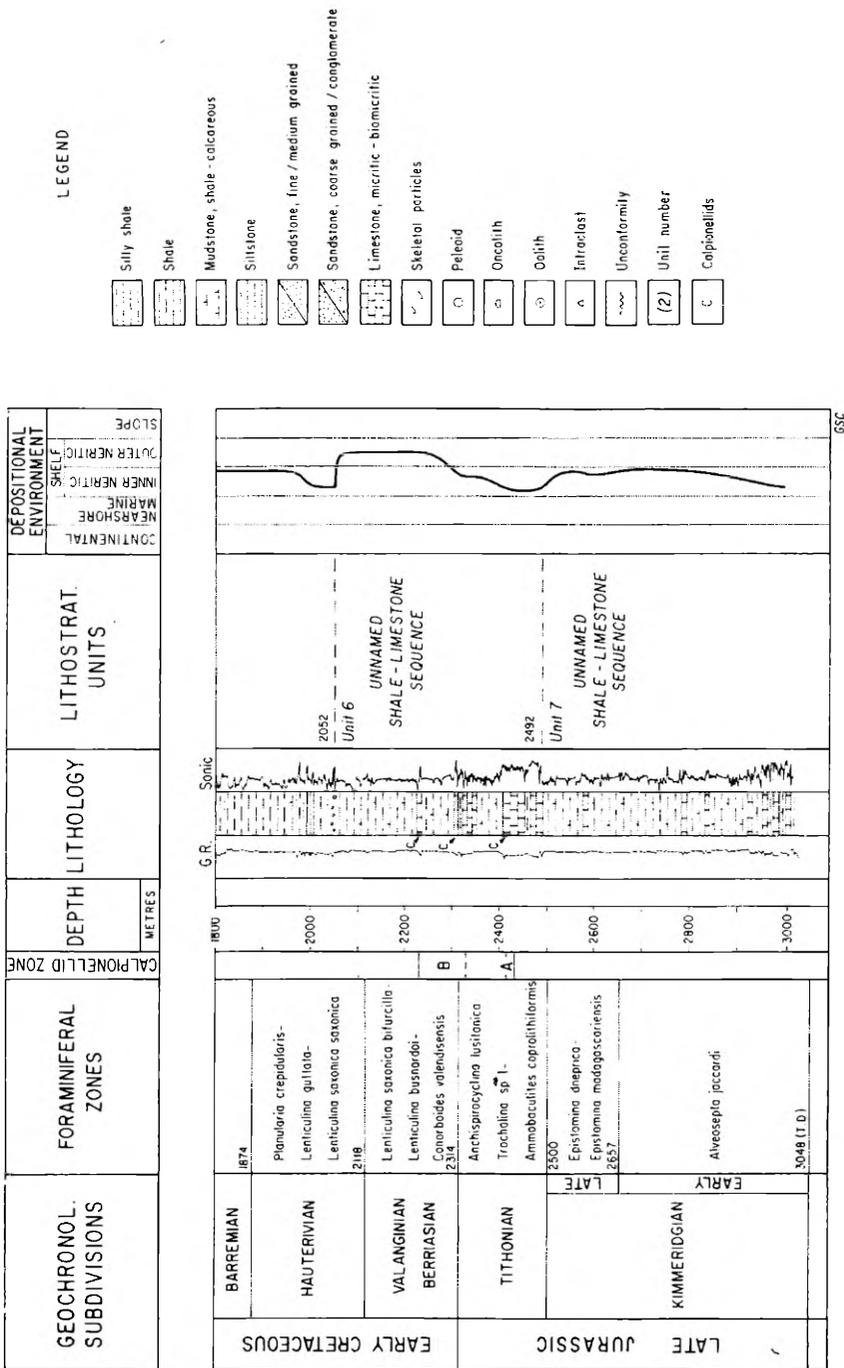


Fig. 3 - Stratigraphy and depositional environment of Mobil-Gulf Bonnitton H-32, Grand Banks (interval 1800 - 3048 m).

ce, containing rare fine-grained sandstone and conglomeratic sandstone beds at the base. This sequence constitutes Unit 5 which is Hauterivian-Barremian and synchronous with the Mississauga Formation of the Scotian Basin (Fig. 2).

Unit 6 (2054-2492 m) straddles the Jurassic-Cretaceous boundary and it is composed of light brownish gray silty calcareous shale with three limestone zones with calpionellid-bearing horizons at 2234-2237 m, 2309-2351 m, and 2411-2492 m (Fig. 3).

The shale which dominates unit 6 is light brownish grey and composed of clay minerals, minor quartz silt grains, and micrite particles. Plagioclase, glauconite, pyrite and plant debris occur in traces. Nannofossils and calcisphaerulids are rare, with *Nannoconus* present below 2137 m. Other fossils include abundant arenaceous and calcareous Foraminifera, Ostracoda, Gastropoda, Pelecypoda, Echinoidea and, below 2347 m, numerous Radiolaria.

The limestone at 2234 m is only 3 m thick and it is composed of light gray biomicrite, containing rare calpionellids, Foraminifera, calcisphaerulids, quartz silt and traces of pyrite. The second limestone at 2309 m is 47 m thick and consists of 0.6-2 m thick skeletal-intraclast grainstone, skeletal wackestone and packstone and argillaceous, pelleted biomicrite beds, intercalated with calcareous shales. The skeletal-intraclast grainstone is composed of subrounded micrite intraclasts (some of which enclose calpionellids), coated grains, oncolites and rare oolites. The fauna consists of Foraminifera, echinoderms, mollusc debris and occasionally blue-green algae and ?sponge debris. Skeletal grains are cemented by ferroan sparry calcite. Faunal debris of highly micritized skeletal fragments of unidentified algae, bryozoans, gastropods, pelecypods, sponge spicules with rare Foraminifera and calpionellids are present in the skeletal wackestone and packstone. At 2326 m, the skeletal wackestones grade into argillaceous, pelleted biomicrites with calpionellids, *Globochaete*, *Eotrix alpina*, calcisphaerulids, calcitized radiolarians and rare sponge spicules. The third limestone zone at 2412 m has a bioturbated biomicrite at the top. This is composed of silt-size skeletal debris, rare calpionellids, *Globochaete*, calcitized Radiolaria, Ostracoda, calcisphaerulids, Foraminifera and traces of Bryozoa. Penecontemporaneous micrite intraclasts are common. The biomicrite grades downward into pelleted biomicrite intercalated with pelleted-intraclast wackestone, intraclast-superficial-oolite grainstone and skeletal-intraclast wackestone and grainstone beds. The intraclasts are composed of biomicrite. Echinoderm, solitary coral, mollusc, and bryozoan debris are present, being

poorly preserved and mostly micritized. Large Foraminifera and red algae fragments are rare. Below 2469 m, a buff oolitic-skeletal grainstone cemented by fibrous and biaded sparry calcite occurs. The oolitic limestone is underlain by skeletal wackestone similar in composition to those in the upper part of this limestone zone. The limestone at the base of the unit has a sharp contact with the underlying shale, which is the topmost bed of unit 7.

Unit 7 (2492-3048 m T.D.) has lithologic characteristics very similar to unit 6 (Fig. 3). It is also composed of medium grey to medium dark grey calcareous shale which in the lower part of the sequence is intercalated with 3 to 6 m thick beds of limestones. The limestones are of variable composition with biomicrites, pelleted-skeletal wackestones and grainstones and oolitic and intraclast grainstones. The composition of the limestones is similar to that occurring in unit 6, apart from the absence of calpionellids. Units 6 and 7 show closest lithologic similarity to the Verrill Canyon Formation of the Scotian Shelf, from which they differ in having intercalated neritic limestone beds.

3.2. DEPOSITIONAL ENVIRONMENT.

The moderate sorting and rounding of quartz grains in the sandstone beds, presence of glauconite, plant debris, occurrence of epistominids and Ostracoda in unit 5 indicate that deposition was in a marine, probably inner neritic, upward shallowing environment (Fig. 3). The absence of coarser clastics in units 6 and 7 and predominance of silty shales containing glauconite, plant debris, nannofossils, Foraminifera and Ostracoda and intercalated pelagic limestones indicate deposition was probably in an outer, deeper shelf environment. The limestone at 2234 m, in which calpionellids, calcified radiolarians, calcisphaerulids, rare Foraminifera and Ostracoda are present and benthic microfossils are missing, was deposited in a similar, deeper, outer, shelf environment. The other two limestone zones were deposited under shallower neritic conditions. The presence of intraclasts, pellets and reworked skeletal fragments in the limestones at 2309-2351 m indicate a shallower, periodically subjected to erosion and bottom scouring environment. Common algal encrustations, algae, sponge, mollusc and coral debris, benthic Foraminifera and Ostracoda suggest perhaps development of small biohermes in the interval 2316 to 2332 m. The intercalations of neritic and pelagic limestones may indicate that the well penetrated the upper slope of the outer shelf carbonate bank.

In the third limestone zone (2411-2492 m), the presence of calpionellids near the top of the zone suggests a pelagic influence on deposition. The skeletal wackestone and oolitic grainstone in the lower part of this zone suggests shallowing, with brief periods of a very shallow, not more than 3 m deep, high energy environment, when oolites were formed. Skeletal wackestone with algal encrustations, peloids, echinoderms, mollusc fragments, Foraminifera and rare intraclasts near the base of the zone may suggest slight deepening of the depositional environment.

The sharp boundary between the limestones and the underlying shales suggests that the limestone development was influenced by a periodic drop of sea level resulting from either eustatic sea level change or tectonic unrest related to the Late Kimmerian tectonic phase.

3.3. CALPIONELLID BIOSTRATIGRAPHY.

The small size of individual rock fragments in the Bonniton H-32 well made a thorough statistical evaluation of calpionellid faunas impossible. However, faunules of some approximately 10 longitudinal sections allow recognition of the calpionellid zones, if one takes into account the general aspect of the assemblage. Somewhat more tentatively, subzones can also be determined. The resultant ages show close agreement with data obtained from other microfossils.

3.3.1. Calpionellid faunas of the interval 2234 to 2247 m. Observed Species and their Stratigraphic Significance.

This interval consists of a calpionellid limestone grading downward into calcareous shale (Fig. 3). Calpionellids are rare in rock fragments from the upper part but become more abundant downwards. Nevertheless, the fauna appears to be very homogeneous. The following three species have been identified:

Calpionella alpina Lorenz: always small forms as occurring in the upper part of calpionellid zone B, from 2237-2240 m to 2243-2247 m;

Crassicollaria parvula Remane at 2237-2240 m and 2243-2247 m;

Tintinnopsella carpathica (Murg. & Fil.): small forms, from 2240-2243 m to 2243-2247 m.

No other species have been observed.

The faunal assemblage and the aspect of *C. alpina* and *T. carpathica* (small forms only) permit its definite assignment to calpionellid zone B

(latest Tithonian-earliest Berriasian) as defined in the Western Alps (Remane, 1963, 1964). The predominance of very small specimens of *C. alpina* (Pl. 5, fig. 1) indicates that this interval can be assigned to the upper part of zone B, i.e. basal Berriasian. One rock fragment at 2243-2247 m yielded five specimens of *C. alpina*, one of *Crassicollaria parvula*, and one of *T. carpathica*. Such a small sample is of course statistically not reliable, but significantly the relative frequencies of species are the same as observed in Europe (Remane, 1963, 1964).

3.3.2. Calpionellid faunas of the interval 2314 m to 2332 m and the Jurassic-Cretaceous boundary.

Limestones containing calpionellids are rare in this interval. There is, however, no doubt that the same species observed from 2235 to 2247 m are also present, permitting assignment to zone B. At 2326-2329 m, a faunule of nine specimens of *C. alpina* (Pl. 5, fig. 3), one of *Cr. parvula*, and one small *T. carpathica* has been encountered; *C. alpina* (Pl. 5, fig. 2) occurs throughout, while *Cr. parvula* (2314-2316 m, 2319-2323 m, 2326-2329 m) and *T. carpathica* (always small forms, at 2319-2323 m, 2326-2329 m) are more sporadic.

C. alpina is represented by a larger, spherical form, as characteristic of the lower part of zone B (see fig. 8/15 in Remane, 1971). The interval 2326-2332 m can therefore be attributed to the latest Tithonian. There is no evidence for the presence of older microfossils, so the boundary between zones A and B must be placed between 2332 and 2418 m.

The higher part of the interval studied (from 2314 to 2316 m) cannot be precisely dated. Calpionellid limestones are so rare that their presence may be due to caving. Therefore, it seems reasonable to place the Jurassic-Cretaceous boundary (i.e. the Tithonian-Berriasian boundary as actually defined in the Mediterranean realm) between 2255 and 2286 m.

3.3.3. Calpionellid faunas of, the interval 2418 to 2438 m and below 2438 m.

The faunal assemblages between 2418 and 2438 m are not as uniform as in the two higher intervals, with a notable change occurring at 2427 m.

The interval 2418-2420 m to 2423-2427 m seems to contain a uniform assemblage. Numerous *Crassicollaria*, with *Cr. parvula*, *Cr. intermedia*, *Cr. brevis* (Pl. 5, fig. 7) and also specimens questionably assigned to *Cr. massutiniana* (Pl. 5, fig. 9) occur with large *Calpionella alpina*. This is characteristic of calpionellid zone A (Pl. 5, fig. 4). As far as quantitative

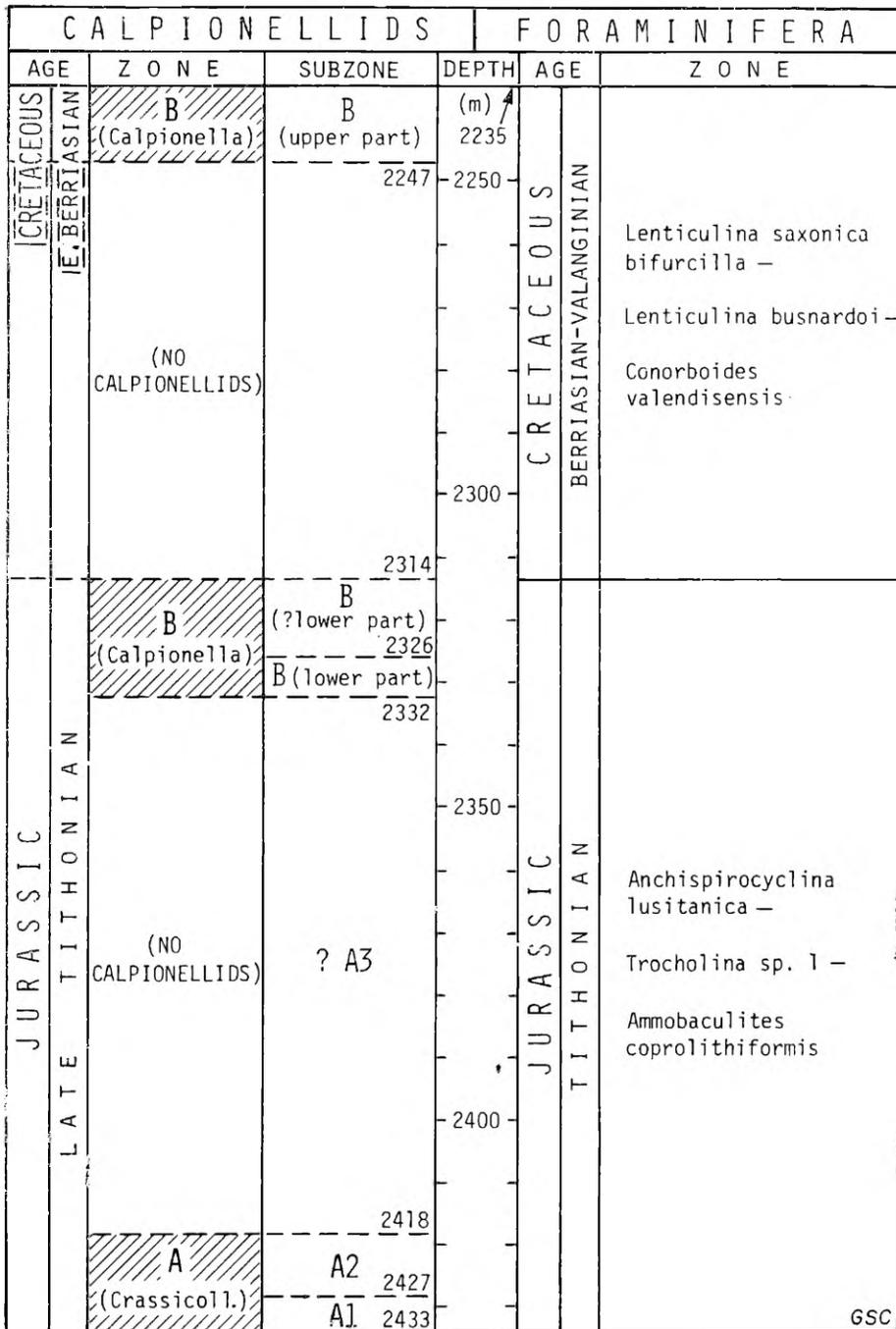
estimates can be made, the genus *Crassicollaria* is mostly predominant, with *Cr. intermedia* sometimes being the most abundant species. One faunule at 2420-2423 m consists of three specimens of *Calpionella alpina*, one of *Crassicollaria brevis*, two of *Cr. intermedia*, and nine of *Crassicollaria* sp. (Pl. 5, fig. 6). The last are mostly oblique sections which are too long to belong to *Cr. brevis*. This indicates that the interval 2418 to 2247 m is assignable to subzone A2. Some of the cuttings may be from higher levels such as A3 or even from the A-B transition. However, the absence of cuttings without *C. alpina* suggests that we are still above subzone A1.

The interval 2427-2435 m contains calpionellid limestones, all of which are devoid of *C. alpina*. Calpionellids are scarce and the assemblage is similar to those found in subzone A1 of Western Europe, with mainly small specimens of *Crassicollaria* (Pl. 5, fig. 4) and forms approaching very small *Tintinnopsella carpathica*. Such an assemblage would be expected to occur below the interval 2418 to 2427 m. However, micritic limestones without calpionellids appear at 2427-2429 m. The proportion of cuttings containing calpionellid limestones from 2429 to 2438 m decreases downwards, being zero at 2435-2438 m. Some of the micritic limestones without calpionellids contain radiolarians indicating pelagic deposition. The absence of calpionellids in this facies must therefore be stratigraphically significant, indicating that the interval is older than Late Tithonian. Unfortunately, there are no positive arguments for such an age assignment, since *Chitinoidea* (which normally precedes calpionellids in the fossil record) and *Saccocoma* microfacies were not observed.

In conclusion, either A1 is very thin and therefore mixed up secondarily with older materials in the cuttings (pelagic limestones with Radiolaria and without calpionellids), or pebbles of different ages are occurring together in a breccia or some similar deposits.

The samples below 2438 m contain only caved material and there are no calpionellids below 2499 m. The appearance of the first calpionellids is consequently placed at 2433-2435 m or even higher.

The following stratigraphical interpretation of the early Late Tithonian seems the most probable from the above evidence: the interval 2418 to 2427 m is, at least in part, assignable to subzone A2 (middle A). The presence of subzone A3 (upper A) in this interval is conjectural, but this subzone may very well occur higher up in the unexamined interval 2332-2418 m. There is no positive argument for a stratigraphical gap between calpionellid zones A and B.



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Fig. 4 - Calpionellid and foraminiferal biozonations of the calpionellid-bearing interval (2235 - 2433 m) at the Jurassic-Cretaceous boundary in Mobil-Gulf Bonnitton H-32, Grand Banks.

3.4. FORAMINIFERAL AND OSTRACOD BIOSTRATIGRAPHY.

The Foraminifera and Ostracoda have been studied throughout Bonition H-32, but only those from the top of the Hauterivian (1874 m) to T.D. at 3048 m (Kimmeridgian) are discussed in this paper. The interval containing calpionellids (2234 to 2433 m) has been analyzed in detail, to determine the relationships between foraminiferal-ostracod and calpionellid distribution, and to calibrate the stratigraphic ranges of Foraminifera and Ostracoda near the Jurassic-Cretaceous boundary in this well with the standard calpionellid biozonation.

The ranges of the foraminiferal and ostracod stratigraphic markers for the five zone established for the Kimmeridgian-Hauterivian interval are summarized in Fig. 5. Full details of the microfaunal assemblages are given in Appendix 1 (p. 107). A « stratigraphic marker » for a stage is a species which has its highest stratigraphic occurrence (« or « extinction point ») in that stage but whose stratigraphic range is not necessarily limited to that stage only. All foraminiferal and ostracod species with open nomenclature are those reported and illustrated in Ascoli (1976). The foraminiferal and ostracod assemblage zones established by this author for the Scotian Shelf in 1976 were found to be applicable also on the Grand Banks and are thus used in the present paper.

3.4.1. Foraminiferal Assemblage Zones of the interval 1874 to 3048 m (T.D.).

Lenticulina saxonica saxonica - *Lenticulina guttata* - *Planularia crepidularis* Zone - 1874 to 2097-2118 m (Hauterivian).

Foraminifera are abundant in the upper part (1874-1966 m) and rather scarce in the lower part (1966-2118 m) of this interval. The ostracod fauna is very scarce throughout. The Foraminifera are predominantly lenticulinids and epistominids, among which *Epistomina* aff. *reticulata* (Reuss) and *E. gr. reticulata* (Reuss) are probably new species. Species reported here for the first time from the Canadian Atlantic Shelf are *Epistomina* aff. *reticulata*, *E. gr. reticulata*, and *E. suturalis* Ten Dam and the ostracod species *Mandocythere villierensis* (Stchepinsky). *Conorboides valendisensis* (Bartenstein & Brand), a Scotian Shelf Valanginian marker after Ascoli (1976) and world-wide Valanginian marker after Bartenstein (1977), is here reported for the first time in the Hauterivian of the Canadian Atlantic Shelf.

A Hauterivian age is assigned to the interval 1874 to 2097 - 2118 m on

the basis of the highest stratigraphic occurrence of the foraminiferal species *Planularia crepidularis* (Roemer) and *Epistomina tenuicostata* (Bartenstein & Brand) and of the ostracod specie *Schuleridea* gr. *thoerensis* Triebel (Ascoli, 1976) (Fig. 5). The ostracod species *Cytherelloidea ovata* Weber is a well known Hauterivian marker in Europe (Bartenstein & Bettenstaedt, 1962) as well as on the Scotian Shelf (Ascoli, 1976).

Conorboides valendisensis - *Lenticulina busnardoii* - *Lenticulina saxonica*
bijurcilla Zone - 2118 to 2311-2314 m (Berriasian-Valanginian).

Below 2118 m, the foraminiferal assemblages are less abundant and the Ostracoda are represented by two species only. As in the Hauterivian, epistominids and lenticulinids are represented by numerous species, and the genus *Trocholina* includes at least three specie. *Trocholina valdensis* (Reichel), *Epistomina* aff. *praereticulata* Mjatluk, *E.* gr. *tenuicostata* Bartenstein & Brand, *Epistomina* sp. 2 and *Epistomina* sp. 1 (open nomenclature of this paper, not of Ascoli, 1976) are reported for the first time from the Canadian Atlantic Shelf. All these species except *T. valdensis* are probably new.

The presence of the two Early Cretaceous Valanginian markers *Saracenaria valanginiana* Bartenstein & Brand and *Lenticulina busnardoii* Moullade (Pl. 8) (Bartenstein & Brand, 1951; Moullade, 1974; Ascoli, 1976) indicates that this interval is Berriasian-Valanginian. This is supported by the highest stratigraphic occurrence of *Buccicrenata italica* Dieni & Massari (Pl. 8) and of the ostracod species *Cardiobairdia* sp. 1 (Ascoli, 1976; Fig. 5). According to L. Brun, W. Maync and R. Schroeder (personal communications), *B. italica* Dieni & Massari, 1966 is a junior synonym of *Everticyclammina virguliana* (Koechlin, 1943).

Ammobaculites coprolithiformis - *Trocholina* sp. 1 - *Anchispirocyclina lusitanica* Zone - 2314 to 2485-2515 m (Tithonian).

The foraminiferal assemblages of this interval are abundant in most samples and the average dimension of the arenaceous foraminiferal specimens are larger than those from the Berriasian-Valanginian. Epistominids are still relatively abundant, but lenticulinids become rare. Arenaceous Foraminifera, rare in the overlying Cretaceous section, are common and represented by several species of *Haplophragmoides*, *Pseudocyclammina* and particularly *Trocholina* (at least 8 species). Ostracoda are very rare, but Radiolaria, absent in the Cretaceous section, are common. The foraminiferal species *Astacolus primus* (d'Orbigny), *Conor-*

boides irregularis Groiss, *Eoguttulina exserta* (Berthelin), *Epistomina* aff. *uhligi* Mjatluk, *Neobulimina varsoviensis* Bielecka & Pozaryski, *Planularia dofleini* (Kasanzev), *Trocholina burgeri* Emberger, and *T. solecensis* Bielecka & Pozaryski are reported for the first time from the Canadian Atlantic Shelf.

A Tithonian age has been assigned to this interval on the basis of the occurrence of the Tithonian marker *Conorboides irregularis* and of the highest stratigraphic occurrence of *Anchispirocyclina lusitanica* (Egger) (Pl. 8), *Epistomina uhligi* Mjatluk (Pl. 8) and *E. stellcostata* Bielecka & Pozaryski (Pl. 8) (Ascoli, 1976; Groiss, 1967; Hottinger, 1967; Gradstein, 1976; Fig. 5). According to Maync (1959) and Van Hinte (1976) — but not Hottinger (1967) — *A. lusitanica* ranges from Early Kimmeridgian to Early Valanginian. However, no reliable evidence of Berriasian-Valanginian age is provided by these authors for justifying the presence of *A. lusitanica* in the earliest Cretaceous. Reported for the first time in Canada by Gradstein et al. (1975), *A. lusitanica* is considered by Gradstein (1976) and by Ascoli (1976) to be a very good Tithonian zone marker for both the Grand Banks (Gradstein) and the Scotian Shelf (Ascoli). The highest occurrence of *A. lusitanica* in the Bonniton H-32 well at 2314 m, approximately 33 m below the Jurassic-Cretaceous boundary as established by calpionellids (Fig. 5), supports the stratigraphic range of this species for the Canadian Atlantic Shelf as given by the above authors. This species seems to be restricted to the Tithonian, since no evidence for a Cretaceous age has been found so far in the *Anchispirocyclina lusitanica* beds of the Canadian Atlantic Shelf.

Epistomina madagascariensis - *Epistomina dneprica* Zone - 2485-2515 m to 2646-2668 m (Late Kimmeridgian).

Abundant specimens of *Epistomina*, *Trocholina* and *Neobulimina* characterize the Late Kimmeridgian of Bonniton H-32. This interval also contains several ostracod species, among which *Galliaecytheridea* aff. *pfanenstieli* (Steghaus), *Pontocyprilla suprajurassica* Oertli, *Protocythere* cf. *nealei* Kilenyi and *Protocytheropteron brodiei* (Jones) are reported for the first time from the Canadian Atlantic Shelf, together with the foraminiferal species *Lenticulina vistulae* Bielecka & Pozaryski, *Conorboides marginata* Llyod, *Planularia cordiformis* Terquem and *Epistomina* aff. *omninoreticulata* Espitalié & Sigal (Fig. 5).

A Late Kimmeridgian age is suggested by the presence of the Kimmeridgian markers *Conorboides marginata* Lloyd and *Cytherelloidea pa-*

raweberi Oertli (Ascoli, 1976) in association with *Lenticulina quenstedti* (Guembel), *Epistomina madagascariensis* Espitalié & Sigal and *E. mosquensis* Uhlig (Pl. 9). The last three species have their highest stratigraphical occurrences in the Late Kimmeridgian (Espitalié & Sigal, 1963; Gradstein, 1976; Ascoli, 1976).

In Bonniton H-32 between 2668 and 3048 m (Fig. 5) *Epistomina mosquensis* has been found associated with *Alveosepta jaccardi* (Schrodt) for the first time on the Grand Banks. According to Maync (1960), *A. jaccardi* in Europe, Africa and Asia ranges from the Late Oxfordian to the Early Kimmeridgian. This has been substantiated for the Grand Banks by Gradstein (1976) and for the Scotian Shelf by Ascoli (1976). Since the highest stratigraphic occurrence of *A. jaccardi* is at 2668 m and the highest occurrence of *E. mosquensis* is at 2515 m, the extinction of the latter species in Bonniton H-32 and on the Scotian Shelf appears to occur in the Late Kimmeridgian.

Alveosepta jaccardi Zone - 2668 to 3048 m (T.D.) (Early Kimmeridgian).

Although represented by numerous species, the foraminiferal assemblage of this interval has fewer specimens than that of the Late Kimmeridgian. An abundant foraminiferal fauna has been found only at 2819 m, where *Epistomina mosquensis* is most abundant. The genera *Epistomina* and *Trocholina* represent most of the fauna and lenticulinids are more abundant than in the Late Kimmeridgian. Ostracoda are rare although eight species have been identified, all of them for the first time on the Canadian Atlantic Shelf. They occur with the foraminiferal species *Eoguttulina inovroclaviensis* Bielecka & Pozaryski, *Planularia beierana* (Guembel) and *P. cordiformis* Terquem (Fig. 5).

The age of the interval 2668-3048 m is Early Kimmeridgian, as indicated by the Early Kimmeridgian ostracod markers *Schuleridea strzalkowiensis* Bielecka et al., *Galliaecytheridea raripunctata* Bielecka et al., *Protocythere rodewaldensis* (Klinger) (Bielecka et al., 1976; Klinger, 1955) and by the highest stratigraphic occurrence of *Alveosepta jaccardi*.

4. Scotian Basin (Shell Mohican I-100).

Calpionellids were found to be present in four exploratory wells in the Scotian Basin (Fig. 1). They are sufficiently numerous to warrant detailed biostratigraphic study in the Mohican I-100 well, but too rare to be useful in the other three wells, Shell Moheida P-15, Amoco Puffin

B-90, and Amoco-Imp. Kittiwake P-11 (Fig. 1). In the Moheida P-15 well, which is located 27 km northeast of Mohican I-100, calpionellids were found to be present at least at one stratigraphic level (2562.85 to 2564 m). Four species could be identified: small *Calpionella alpina* Lorenz and large *Tintinnopsella carpathica* (Murg. & Fil.) which are rather frequent and *Calpionella elliptica* Cadisch and *Remaniella cadischiana* (Colom), both very rare. This assemblage can be equated with zone C of the Mediterranean realm (Remane, 1963, 1964) which is Early Berriasian. Unfortunately, these faunas occur at an unconformity and seem to be reworked, although they prove the existence of Berriasian calpionellid facies which has not been documented in other wells. The two other wells (Puffin B-90 and Kittiwake P-11) are located at the northern portion of the Scotian Basin, where the scarcity of calpionellids precludes their use for detailed biostratigraphic studies. Hence only the stratigraphy of the Mohican I-100 well is described in detail here.

Shell Mohican I-100 is located approximately 214 km south of the Nova Scotia coast, near the outer Scotian Shelf (lat. 42°59'39.04"N and long. 62°28'51.32"W) (Fig. 1). The well was drilled in 170 m water to a total depth of 4.367 m. It penetrated Pleistocene and Tertiary sediments with the Miocene unconformity overlying the Cenomanian which in turn is underlain by Lower Cretaceous and Jurassic sediments. The well bottomed in the Lower Jurassic evaporites of the Argo Formation. Structurally the Mohican well is located in the distal (seaward) portion of the Scotian Basin (Jansa & Wade, 1975).

4.1. LITHOSTRATIGRAPHY.

The sedimentary strata penetrated by the Mohican well were included in 8 formations, but only the Verrill Canyon and Abenaki Formations, pertinent to the discussion of calpionellid occurrences, are described here (Fig. 6). The Verrill Canyon Formation shale (2402-2515 m) is composed of kaolinite, irregular mixed clay mineral. Illite, chlorite, quartz silt grains, glauconite, plant and coaly debris are minor constituents. Rare nannofossils, *Nannoconus*, sponge spicules and Foraminifera (*Epistomina*, *Lenticulina*) are present. The Verrill Canyon shale overlies the Abenaki carbonate with a sharp contact.

The Abenaki Formation (2515-3621 m) is a carbonate sequence which was subdivided by McIver (1972) into 3 formal members: the Baccaro (upper limestone), the Misaine (middle shale) and the Scatarie (lower limestone). Calpionellids were found in the Baccaro Member limestones

of subunit A (2515-2711 m). In this subunit, skeletal wackestones, oolitic and pelleted-intraclast limestones are interbedded with silty shales and sandstones. The lithologic variability has been documented in two conventional cores (core 1 - 2525-2533 m; core 2 - 2533-2542 m), which show intercalations of strongly bioturbated beds of calcareous shale, siltstone, silty shale, argillaceous biomicrite and skeletal wackestone.

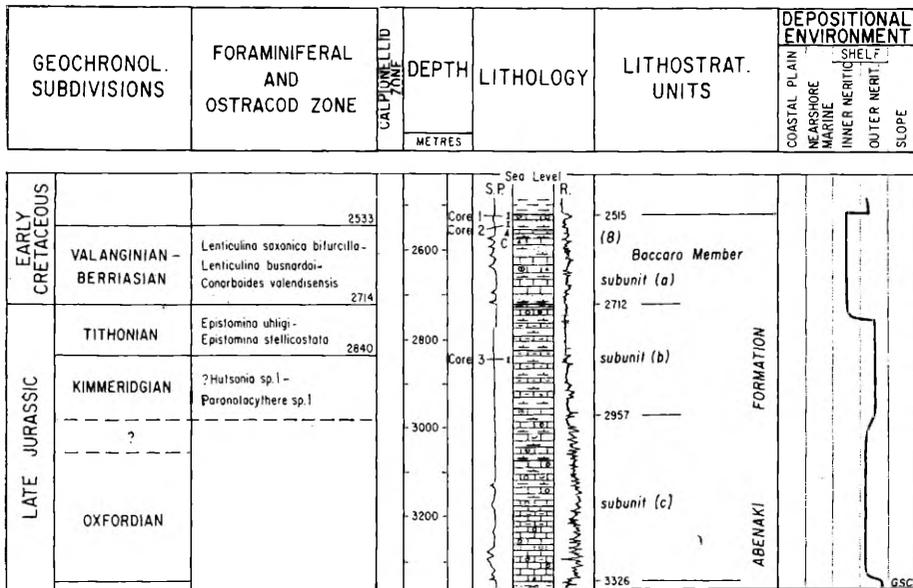


Fig. 6 - Stratigraphy and depositional environment of Shell Mohican I-100, Scotian Shelf (interval 2500 - 3350 m) (symbol explanation on Fig. 3).

Minor scouring and slumping is visible in some of the shales. Oncolites, coated grains, and debris of pelecypods are widely dispersed in some of the shaly beds (Pl. 6). In core 2 (2533-2542 m) a 3 m thick siltstone of varying argillaceous content is underlain by 4.3 m of bioturbated calcareous shale, enclosing pelecypods fragments. The shale in turn has sharp contact at 2540 m with a 0.6 m thick peloid biomicrite, which grades into calcareous shale enclosing oncolites, bioclast and rare limestone intraclasts of light grey microsparite. This 0.5 m thick shale is underlain by a 0.3 m thick skeletal wackestone with scattered oncolites. Calpionellids were found in the lower part of this core (below 2540 m).

In subunit B (2711-2957 m), the light grey, argillaceous, silty mi-

critic limestone and calcareous shale are interbedded. The limestones are bioturbated. The fauna in the limestone consists of mostly silt-size debris of mollusc, echinoderm, ostracod, gastropod, bryozoan, annelid and foraminiferal tests, with rare *Aptychi*, *Globochaete* and calcisphaerulids. Conventional core No. 3 (2840-2850 m) is located in this subunit.

4.2. DEPOSITIONAL ENVIRONMENT.

The presence of abundant epistominids and lenticulinids and the absence of coarser clastics suggest a middle neritic environment for the Verrill Canyon shale, which overlies the Abenaki carbonate with a sharp contact. The pinkish coloration of the uppermost limestone beds and high alteration (leaching and ferroan sparry calcite replacement of the fossils) may indicate a short lacuna at the top of the Abenaki Formation.

The oolites, oncolites and intraclast-skeletal limestones and shallow neritic fauna (Mollusca, Annelida, Bryozoa, Gastropoda, Ostracoda) in the limestones of subunit A, indicate a shallow water depositional environment, with variable water dynamics. The area was periodically supplied by coarser terrigenous clastics from the prograding delta distributaries. The paleogeographic reconstruction of the Late Jurassic in the Scotian Basin (Jansa & Wade, 1975) indicates that the limestone was located in the middle to outer shelf area and was part of the Late Jurassic carbonate bank complex developed in this region. Subunit B is characteristic by the disappearance of coarser clastics, the dominance of biomicrites with varying proportions of fine-quartz silt and clay and by the presence of Gastropoda, bivalves, serpulids, benthic Foraminifera and Ostracoda, all of which indicate a strong neritic influence. The subunit B is thus interpreted to have been deposited in a low energy, semiprotected, moderately deep shelf environment.

4.3. CALPIONELLID BIOSTRATIGRAPHY OF THE INTERVAL 2540 TO 2850 M.

The study of the calpionellids in the cuttings from Mohican I-100 did not lead to conclusive results since calpionellids-containing limestones are extremely rare and are probably caved as are the cuttings with planktonic Foraminifera (*Hedbergella* or similar forms). Results from the cores also proved to be problematic. In conventional core No. 2 (2533-2542 m), the rich late Tithonian calpionellid faunas described below are at variance with the Foraminifera, Ostracoda and palynomorphs, which date this core as Valanginian (pp. 90, 91). It seems inevitable that the calpionellids are reworked, although the faunas seem to be homo-

geneous in themselves. Therefore they are discussed here in some detail, especially since the conventional cores offer the only opportunity of a quantitative analysis based on good quality thin sections. Only the lowest portion of core 2, from 2540.20 to 2541.37 m, contains micritic limestones, which have a texture favorable for the preservation of calpionellids. Rich faunas have been observed at 2540.31, 2540.66, 2541.12, and 2541.37 m. The macrofauna consists of Gastropoda, fragments of bivalves and terebratulids, debris of echinoderms, and Bryozoa, which often also form the nuclei of onkoids. The microfauna also strongly indicates a neritic environment. There is a rich and varied fauna of benthonic Foraminifera, with Ostracoda also being common. Radiolaria are absent. The micrites, although belonging to a calm environment, are undoubtedly shallower than most calpionellid-bearing sediments (see microfacies in Pl. 6 and Pl. 7, fig. 1). This might be the reason for certain faunal anomalies described below.

The micritic limestones at the base of core 2 have yielded the following calpionellid species: *Calpionella alpina* Lorenz (Pl. 7, figs. 9, 10), *Crassicollaria brevis* Remane (very rare), *Crassicollaria intermedia* (Durand Delga) (Pl. 7, figs. 2-4), *Crassicollaria massutiniana* (Colom) (Pl. 7, figs. 5, 6), *Crassicollaria parvula* Remane (Pl. 7, figs. 7, 8), and ? *Tintinnopsella carpathica* (Murg. & Fil.). The last species is a questionable identification, being represented by very rare, small forms only.

Crassicollaria intermedia, *Cr. brevis*, and *Cr. massutiniana* are exclusively Late Tithonian (they do not even reach the top of this stage), whereas *Cr. parvula* may also occur in the Early Berriasian. *Calpionella alpina* ranges from Late Tithonian to basal Valanginian, but relatively large spherical forms like the ones observed here do not range higher than the Early Berriasian. *T. carpathica* extends into the Valanginian, but the Cretaceous assemblages (except in the basal Berriasian) are always dominated by large forms which are absent here.

All the forms observed in core 2 belong to a very limited stratigraphic interval, wholly Late Tithonian or perhaps in part Early Berriasian, while typical Berriasian genera such as *Remaniella*, *Calpionellopsis* and *Lorenziella* are missing.

The four calpionellid faunas of sufficient abundance to analyse statistically (see Table 1) fall roughly into two assemblages: an upper uniform fauna from at least 2540.31 to 2540.66 m, and a lower less homogeneous fauna at 2541.12 and 2541.37 m.

The upper assemblage (2540.31-2540.66 m) contains only two calpionellid species (*C. alpina* and *Crassicollaria parvula*), both having ap-

| Depth of sample | 2540.31 m | 2540.66 m | 2541.12 m | 2541.37 m |
|------------------------------------|-----------|-----------|-----------|------------|
| Metres and (feet) | (8334'4") | (8335'6") | (8337') | (8337'10") |
| Number of specimens per fauna | 206 | 117 | 197 | 258 |
| <i>Calpionella alpina</i> | 45 | ca. 52 | 3? | 2? |
| <i>Crassicollaria</i> sp. | 4 | 2 | 28 | 51 |
| <i>Crassicollaria brevis</i> | 1 | — | 2 | 1 |
| <i>Crassicollaria intermedia</i> | — | — | 13 | 30 |
| <i>Crassicollaria massutiniana</i> | — | — | 7 | 10 |
| <i>Crassicollaria parvula</i> | 50 | ca. 45 | 46 | 3 |
| <i>Tintinnopsella carpathica</i> | — | — | 2(?) | 3(?) |

Table 1 - Stratigraphic distribution and relative frequencies in % of calpionellid species in the lower part of core 2 of Mohican I-100. Depths are in metres and in feet. At 2540.66 m (8335'6") the thickness of thin sections makes that the values for *Cr. parvula* (and hence also for *C. alpina*) are somewhat dubious. «*Crassicollaria* sp.» includes also all sections of the four species of this genus which are too oblique to be determined on specific level.

proximately the same abundance. The rare «*Crassicollaria* sp.» may be badly preserved *Cr. parvula*. The absence of *Crassicollaria* species except *Cr. parvula* indicates an age corresponding to calpionellid zone B or, possibly, lower C. (Remane, 1963, 1964). But it cannot be included in the latter because of the presence of rather large, spherical specimens of *C. alpina* (Pl. 7, figs. 9, 10) and the absence of *T. carpathica*. In the Mediterranean successions there is, however, only one level near the base of zone B where *Crassicollaria parvula* is as abundant as *C. alpina*.

In the two faunas forming the lower assemblage (2541.12 - 2541.37 m) *Calpionella alpina* and *Tintinnopsella carpathica* are very rare; 95% of the fauna consists of different species of the genus *Crassicollaria*. When compared with Mediterranean faunas, this assemblage equates with the upper part of subzone A1, above the extinction of the small variety of *Tintinnopsella carpathica* and below the first occurrence of *Calpionella alpina*. The upper fauna is even more problematic because of its great abundance of *Crassicollaria parvula*.

The forms identified as calpionellids by Gradstein et al. (1975) in conventional core No. 3 (2840 - 2850 m), proved to be oblique sections of ostracods of the «*Patelloides*» type. Both studied intervals (2840 - 2841

m and 2844.4-2847.4 m) show the same type of microfacies, that is micrites with varying proportions of fine quartz grains and biogenes. After comparison with core 2, it is evident that the absence of calpionellids is not facies dependent in core 3, which must therefore be older than Late Tithonian.

A quantitative comparison of calpionellid faunas from Mohican I-100 with Mediterranean assemblages is difficult. Either the Scotian Shelf assemblages can only be assigned to a very limited interval or they have no precise counterpart in Europe. The presence of an Early Berriasian assemblage in the nearby Shell Moheida P-15 well indicates that the former is the case. There can however be no doubt about the zonal attribution of the observed assemblages in the Mohican I-100 well, since all the discrepancies are limited to the subzonal level.

It is difficult to prove on the basis of paleontological evidence only that the Late Tithonian calpionellids from core 2 are reworked, since the individual assemblages are homogeneous in themselves, with no stratigraphic mixing of species, which are all typically Late Tithonian. The only calpionellid evidence lending support to the hypothesis of reworking is the stratigraphical gap (circa A2 + A3 in terms of Mediterranean subzones) between the two main assemblages. This is not a very strong argument.

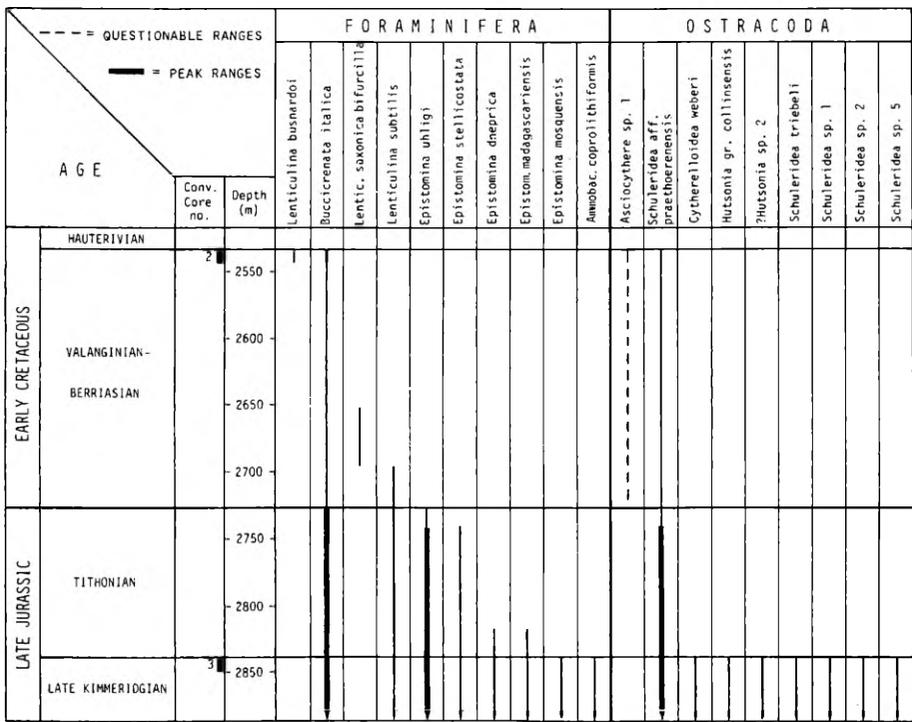
The Valanginian age indicated by all the other microfossils, however, (pp. 91, 92) does not permit any other plausible explanation, especially since Late Jurassic reworked Ostracoda and palynomorphs are also present in this core (p. 92). Core 2 below 2540 m most probably drilled into a large block of displaced Upper Tithonian limestone. Unfortunately the core did not penetrate the slumped block. Recent drilling in this region demonstrated that the Abenaki limestones were briefly exposed and eroded during the Early Cretaceous, which would support our interpretation.

4.4. FORAMINIFERAL AND OSTRACODS BIOSTRATIGRAPHY.

The foraminiferal and ostracod biostratigraphy of the Mohican I-100 well was published by Ascoli (1976). This is presented in part in Fig. 6. The Kimmeridgian-Tithonian boundary, originally placed at 2816 m (Ascoli, 1976, p. 682), is now placed at 2840 m following the examination of new material. The discussion of the foraminiferal and ostracod faunas in the Mohican I-100 well is limited here to the interval spanning the Jurassic-Cretaceous boundary, that is between conventional cores No. 2

(2533 - 2542 m) and 3 (2840 - 2850 m). From these cores, ten washed samples plus 14 cuttings samples from the interval between 2542 and 2840 were examined. As in Bonniton H-32, each cutting sample is a composite one representing a 10 m thick interval.

The biostratigraphy of the interval 2533 to 2850 m is described



GSC

Fig. 7 - Range-chart of the foraminiferal and ostracod stratigraphic markers in the Late Kimmeridgian-Valanginian interval (2533-2849 m) of Shell Mohican I-100, Scotian Shelf.

below and the microfaunal assemblages are listed in Appendix 2 (p. 109). Ranges of foraminiferal and ostracod stratigraphic markers are reported at Fig. 7.

4.4.1. Foraminiferal-Ostracod Assemblage Zones of the Interval 2533 to 2850 m.

Conorboides valendisensis - *Lenticulina busnardoii* - *Lenticulina saxonica bifurcilla* Zone - 2533 to 2704-2725 m (Berriasian-Valanginian).

Both foraminiferal and ostracod faunas are abundant in conventional core No. 2 (2533-2542) and rather scarce below. The dominant Foraminifera are abundant specimens of *Buccicrenata italica* Dieni & Massari (Pl. 8) and *Spirillina* spp. The genus *Lenticulina* is represented by several species. *Schuleridea* aff. *praethoerenensis* Bartenstein is the most abundant ostracod species (Fig. 7).

The presence of the Valanginian markers *Lenticulina busnardoii* Moullade (Pl. 8) and *L. saxonica bifurcilla* Bartenstein & Brand, indicates a Valanginian age for this interval (Bartenstein & Brand, 1951; Moullade, 1974). This is supported by the highest stratigraphic occurrence of the foraminiferal species *Buccicrenata italica* and *Lenticulina subtilis* Wisniowski and of the ostracod species *Asciocythere* sp. 1 and *Schuleridea* aff. *praethoerenensis* (Ascoli, 1976).

The Late Jurassic ostracod species *Cytherella index* Oertli (of Callovian-Oxfordian age) found in cuttings at 2694 m and *Hutsonia* gr. *collinsensis* Swain & Brown of Kimmeridgian-Early Tithonian age, found in the conventional core No. 2 at 2533 to 2542 m, are interpreted as reworking. In the same core, Late Jurassic reworked palynomorphs occur (G.L. Williams, personal communication). The presence of Late Jurassic reworked microfossil in core No. 2 therefore supports the interpretation that the Late Tithonian calpionellids identified in this core are enclosed in a « large block » of Upper Tithonian limestone displaced into Valanginian sediments.

Epistomina stellicostata - *Epistomina uhligi* Zone - 2725 to 2840 m (Tithonian).

The interval 2725-2840 m is characterized by foraminiferal and ostracod assemblages which are not as rich in number of species or specimens as those from the interval 2533-2725 m. The epistominids and abundant specimens of *Buccicrenata italica* are the dominant Foraminifera while the Ostracoda are primarily *Schuleridea* aff. *praethoerenensis*. This interval has been dated Tithonian on the basis of the highest stratigraphic occurrence of *Epistomina stellicostata* Bielecka & Pozaryski (Pl. 8) and *E. uhligi* Mjatluk (Ascoli, 1976) (Fig. 7; Pl. 8).

Paranotacythere sp. 1 - ? *Hutsonia* sp. 1 ostracod Zone - 2840 to 2850 m (Late Kimmeridgian).

Conventional core No. 3 (2840-2850 m) contains abundant Foraminifera, with *Buccicrenata italica*, epistominids and lenticulinids being

common. The rich ostracod assemblage includes 15 species, with *Schuleridea* aff. *praethoerenensis* and the genera *Asciocythere* and *Cytherella* being dominant.

A Late Kimmeridgian age has been assigned to the core on the basis of the presence of *Epistomina mosquensis* Uhlig (Pl. 9), which in this well has its highest stratigraphic occurrence within the core. This is 139 m higher than that of the Early Kimmeridgian marker *Alveosepta jaccardi* (Schrodt) (p. 34). Core 3 also contains the well known Kimmeridgian ostracod markers *Cytherelloidea weberi* Steghaus and *Schuleridea triebeli* (Steghaus) (Kilenyi, 1969). Two other ostracod species in this core, ? *Hutsonia* sp. 2 and *Schuleridea* sp. 5, were thought by one of the authors (Ascoli, 1976) to occur in his ? *Hutsonia* gr. *collinsensis*-*Galliaecytheridea postrotunda*-*Schuleridea* sp. 1 Zone of Tithonian age. However, the latest information on the stratigraphic ranges of ? *Hutsonia* sp. 2 and *Schuleridea* sp. 5 on the Scotian Shelf (p. 111), indicates that these two species do not occur higher than the Kimmeridgian « *Paranocythere* sp. 1 - ? *Hutsonia* sp. 1 » Zone.

5. Foraminiferal and Ostracod Biostratigraphy of the Jurassic-Cretaceous Boundary on the Canadian Atlantic Shelf.

The stratigraphic ranges of the Scotian Shelf and Grand Banks foraminiferal and ostracod markers at the Jurassic-Cretaceous boundary (= Tithonian-Berriasian boundary) are given in Fig. 8, which also depicts the ranges of these markers in the stratigraphic interval extending from Early Kimmeridgian to Late Valanginian.

The 30 foraminiferal and ostracod stratigraphic markers shown in this figure have been selected from those reported by Ascoli (1976), to whom reference should be made for species with open nomenclature, Gradstein (1976), and those described here.

An analysis of the ranges of marker species reported in Fig. 8 in descending stratigraphic order, shows that the top of the Valanginian is defined (as in Ascoli, 1976) by the highest stratigraphic occurrence of a Tethyan foraminiferal marker: *Lenticulina busnardoii* Moullade (Pl. 8). Four other foraminiferal and three ostracod marker species have their highest stratigraphic occurrences coinciding with that of *L. busnardoii* (Fig. 8). Two of the Foraminifera, *Buccicrenata italica* Dieni & Massari (Pl. 8) and *Lenticulina busnardoii*, have been found in the majority of Scotian Shelf and Grand Banks wells where both, and particularly the first one, are generally abundant. They can thus be considered the most

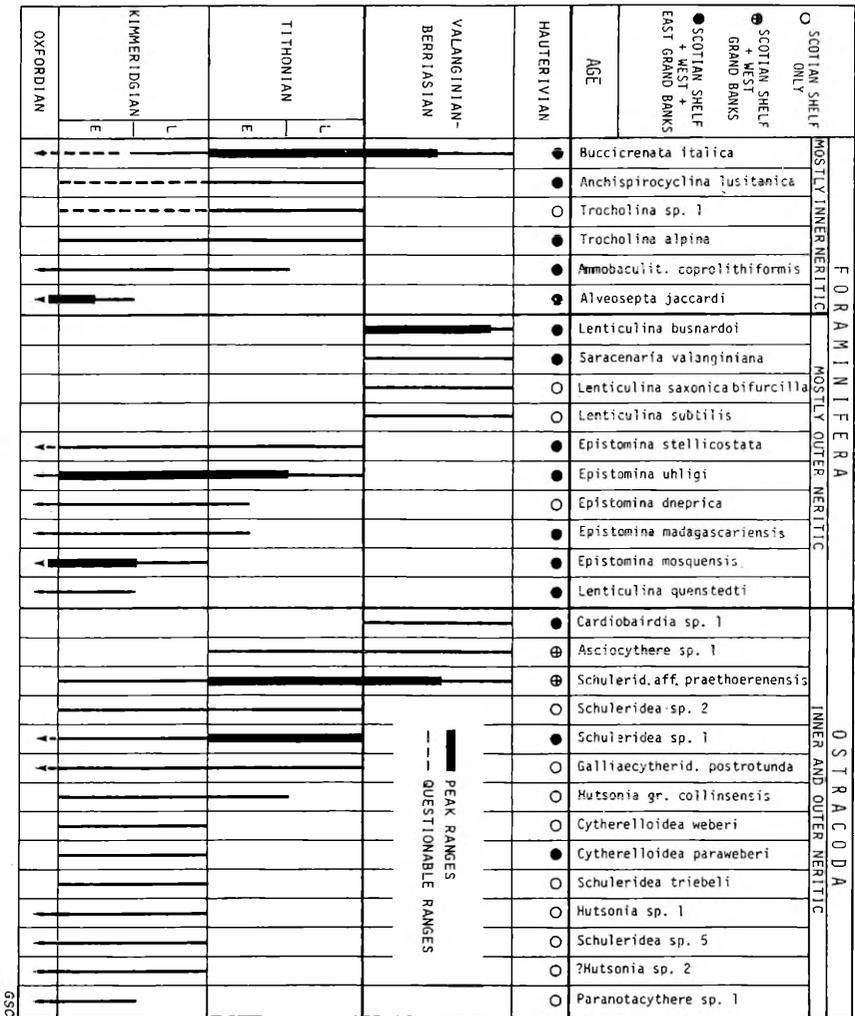


Fig. 8 - Range-chart of the foraminiferal and ostracod stratigraphic markers near the Jurassic-Cretaceous boundary on the Canadian Atlantic Shelf.

reliable Berriasian-Valanginian foraminiferal markers for the Canadian Atlantic Shelf, together with the ostracod marker *Schuleridea* aff. *praethoerenensis* Bartenstein.

No foraminiferal or ostracod species indicate the top of the Berriasian (Fig. 8). This stage is well defined and zoned on calpionellids in Europe (Le Hegarat & Remane, 1968) with the upper B and C zones and

the two lowermost and part of the top subzone of D being present. However, according to Magné (1965) it seems impossible to define this stage on the basis of highest occurrences of foraminiferal species only.

On the Scotian Shelf, three foraminiferal species have been reported by Ascoli (1976) as having their highest stratigraphic occurrence in the lower part of the Berriasian-Valanginian interval. These are *Ammobaculites alaskensis* Tappan, *A. irregulariformis* Bartenstein & Brand, and *Conorboides valendisensis* Bartenstein & Brand. However, none of these species could be used to determine the lower part of the Berriasian-Valanginian interval on the Grand Bank, since *Ammobaculites alaskensis* and *A. irregulariformis* have not been found to date on the Grand Banks, while *Conorboides valendisensis* ranges as high as Hauterivian in Bonnition H-32 (Fig. 5). None of the 64 ostracod species reported by Neale (1967) as ranging into the Berriasian in Europe have as yet been recognized on the Canadian Atlantic Shelf.

The top of the Tithonian has been placed here at the highest stratigraphic occurrence of the foraminifer *Anchispirocyclina lusitanica* (Egger) (Pl. 8), which in Bonnition H-32 has its highest occurrence at 2314 m. This depth corresponds to the lower part of the standard calpionellid zone « B » (= latest Tithonian) and is 67 m below the upper part of the same calpionellid zone (= Early Berriasian) (Fig. 4). *A. lusitanica* has its highest occurrence in sediments of the same age in Amoco IOE Egret K-36 on the northeastern Grand Banks (Gradstein, 1976) and in Shell Oneida 0-25 and Shell Mohawk B-93 on the Scotian Shelf (Ascoli, 1976).

In Bonnition H-32, the same cuttings sample in which *A. lusitanica* has its highest stratigraphic occurrence (2314 to 2317 m), also contains calpionellids in place. This is probably the first time that *A. lusitanica* and calpionellids are reported within a 3 m thick stratigraphic interval, with *A. lusitanica* being in inner neritic shales and the calpionellids in middle neritic limestones.

Other foraminiferal markers associated with *A. lusitanica* and having almost identical highest stratigraphic occurrences on the Canadian Atlantic Shelf are *Trocholina* sp. 1 (p. 110, Pl. 8, absent in Bonnition H-32), *Trocholina alpina* (Leupold), *Epistomina stelicostata* Bielecka & Pozaryski (Pl. 8) and *E. uhligi* Mjatluk (Pl. 8). Among the four species mentioned above, numerous specimens of *Epistomina stelicostata* and particularly *E. uhligi* have been found in the majority of the studied wells. Three ostracod species which have their highest stratigraphic occurrence coinciding with that of *A. lusitanica* are *Schuleridea* sp. 2 (p. 111, Pl. 9)

and *Galliaecytheridea postrotunda* Oertli (Pl. 9) reported from the Scotian Shelf by Ascoli (1976) and *Schuleridea* sp. 1 (Pl. 9) reported from the Scotian Shelf by Ascoli (1976) and from Amoco-Imp - Skelly Egret K-36, easternmost Grand Banks, by Gradstein (1976).

Delineation of the base of the Tithonian is very important on the Canadian Atlantic Shelf, since this stage is the oldest one in which calpionellids are found. In the literature, definition of the base of this stage (and consequently of the top of the Kimmeridgian) is still very controversial. The original definition of the Kimmeridgian and Portlandian stages by d'Orbigny (1842-51) is ambiguous. The ammonite genus *Gravesia*, considered as typically Portlandian by d'Orbigny, was later discovered in the Kimmeridge Clay. This has resulted in divergent opinions concerning the Kimmeridgian-Portlandian boundary (for a resumé, see Enay, 1963).

The top of the type-Kimmeridgian in England is defined by the top of the *Pavlovia pallasoides* ammonite zone (Arkell, 1956; Lloyd, 1959, 1962; Kilenyi, 1969; Christensen & Kilenyi, 1970), whereas in France, Switzerland and Germany, most biostratigraphers (Heim, 1919, in Oertli, 1959; Maync, 1960; Klingler et al., 1962; Oertli, 1963; Barthel et al., 1973) prefer to place the top of the Kimmeridgian at the top of the *Aulacostephanus pseudomutabilis* ammonite zone. In England this zone marks the top of the Early Kimmeridgian in its type-section (Fig. 9). The top of the Kimmeridgian defined by the top of the « *pseudomutabilis* » zone corresponds to the base of the Tithonian (Maync, 1960; Oertli, 1963). By contrast, the top of the Kimmeridgian as defined by the top of the « *pallasoides* » zone falls within the upper part of the Tithonian, making the correlation top Kimmeridgian = base Tithonian impossible (Fig. 9). Since this correlation is needed for the present study, we prefer to equate the Kimmeridgian-Tithonian boundary on the Canadian Atlantic Shelf with that adopted by the above mentioned French, Swiss and German Authors, i.e. with the top of the « *pseudomutabilis* » ammonite zone. On the Scotian Shelf, the top of the Late Kimmeridgian can be determined by three ostracod species (*Cytherelloidea weberi* Steghaus, *C. paraweberi* Oertli, and *Schuleridea triebeli* (Steghaus), which according to Oertli (1959), Klingler et al. (1962) and Christensen and Kilenyi (1970) range into the Late Kimmeridgian in Germany, France and Switzerland and into the Early Kimmeridgian in England. One of these species (*C. paraweberi*) is also present in Bonniton H-32, the only well on the Grand Banks where Jurassic Ostracoda have been studied in detail. Three other ostracod species (? *Hutsonia* sp. 1, *Schuleridea* sp. 5, and ? *Hutsonia* sp. 2) become

extinct on the Scotian Shelf at the same time as the three previously mentioned Late Kimmeridgian ostracod markers.

The good resolution of ostracod biostratigraphy for the delineation of the Kimmeridgian-Tithonian boundary on the Canadian Atlantic Shelf, is not reflected in the foraminiferal biostratigraphy. On the Scotian Shelf, Ascoli (1976) reported that five species — *Epistomina dneprica* Kaptaren-

| AMMONITE ZONES | *CORRELATION OF STRATIGRAPHIC TERMS | | | | |
|---------------------------------|-------------------------------------|--------------|-----------------|-------------------------------|-------|
| | ENGLAND | S. E. FRANCE | N. W. GERMANY | | |
| Titanites giganteus | PORTLANDIAN | TITHONIEN | "Münder Mergel" | | |
| Glaucolithes gorei | | | | | |
| Zaraiskites albani | | | | | |
| Pavlovia pallasioides | KIMMERIDGIAN | | LATE | "Eimbeckhäuser Schichten" | |
| Pavlovia rotunda | | | | | |
| Pectinatites pectinatus | | | | | |
| Subplanites wheatleyensis | | | MIDDLE | "Gigas Schichten" | |
| Subplanites sp. sp. | | | | | |
| Gravesia gigas | | | | | |
| Gravesia gravesiana | EARLY | | KIMMERIDGIEN | KIMMERIDGE ("Mittlerer Malm") | L |
| Aulacostephanus pseudomutabilis | | | | | M |
| Rasenia mutabilis | | | | | EARLY |
| Rasenia cymodoce | | | | | |
| Pictonia baylei | | | | | |

Fig. 9 - Correlation of the Kimmeridgian, Tithonian and Portlandian stages according to ammonite zones (* after Oertli, 1963,*modified).

ko-Chernoussova, *E. aff. dneprica* Kaptarenko-Chernoussova, *E. madagascariensis* Espitalié & Sigal, *E. aff. regularis* Terquem, and *Ammobaculites coprolithiformis* (Schwager) — range as high as Kimmeridgian-earliest Tithonian (« *Epistomina madagascariensis*-*Epistomina dneprica* Zone »). Gradstein (1976) recorded five other species (*Epistomina mosquensis* Uhlig, *E. uhligi* Mjatluk, *Lenticulina quenstedti* (Guembel), *L.*

tricarinnella (Reuss) and *Valvulina meentzeni* (Klingler), which range as high as Early-Middle and possibly Late Kimmeridgian («*Epistomina mosquensis* Zone») on the Grand Banks. However, examination of additional material from conventional core 3 (2840 to 2850 m) in Mohican I-100 (pp. 109-111), has shown that four ostracod species (? *Hutsonia* sp. 2, *Schuleridea* sp. 5, *Cytherelloidea weberi* and *Schuleridea triebeli*), which range as high as Late Kimmeridgian in Europe and on the Scotian Shelf (Ascoli, 1976), have their highest stratigraphic occurrence in this core, together with that of the foraminiferal species *Epistomina mosquensis*. The highest occurrence of the latter species in Mohican I-100 and in Bonition H-32 is respectively 139 and 153 m higher than that of the Early Kimmeridgian foraminiferal marker *Alveosepta jaccardi* (Schrodt) in the same wells (pp. 84, 92). *Epistomina mosquensis* can therefore be considered a Late Kimmeridgian foraminiferal marker for the Grand Banks and the Scotian Shelf.

Finally, the top of the Early Kimmeridgian is defined here (as in Ascoli, 1976, and Gradstein, 1976) by the highest stratigraphic occurrence of the Tethyan foraminiferal marker *Alveosepta jaccardi* (p. 84), which corresponds to the highest occurrences on the Canadian Atlantic Shelf of *Lenticulina quenstedti* and of the ostracod marker *Paranotacythere* sp. 1.

6. Tethyan-Boreal Foraminiferal Assemblages and North Atlantic Paleo-Circulation Near the Jurassic-Cretaceous Boundary.

The Kimmeridgian-Hauterivian of the Scotian Shelf and Grand Banks is represented by shallow water clastic sediments and middle to outer shelf limestones which contain abundant specimens of several foraminiferal species. These include *Alveosepta jaccardi* (Schrodt), *Buccicrenata italica* Dieni & Massari, and *Anchispirocyclus lusitanica* (Egger), which have been defined as «complex arenaceous species» by Gordon (1970) and are considered in the literature* (Maync, 1960; Dieni & Massari, 1966; Hottinger, 1967; Gordon, 1970; Brun & Rey, 1975) to be typical of the Tethyan (1) realm. However, the associated and locally interbedded shales contain foraminiferal faunas characterized by abundant epistominids, len-

(1) The term «Tethyan realm» or «zone» mentioned in the following pages is as defined by Gordon (1970), whereas the term «Boreal realm» or «zone» corresponds to the «Shelf zone» of Gordon, i.e. the zone immediately north of the Tethys, which is taken to be «Boreal» by the majority of paleontologists (cf. Casey & Rawson, 1973).

ticulinids and « simple arenaceous species » such as *Epistomina dneprica*, *Lenticulina vistulae* and *Trocholina solecensis*, which appear to be more typical of the boreal domain (Gordon, 1970). Several « cosmopolitan » species common to both the Tethyan and Boreal realms (as *Planularia crepidularis* (Roemer), *Epistomina uhligi* Mjatliuk and *Ammobaculites coprolithiformis* (Schwager) are also present. Thus the Canadian Atlantic Shelf shows mixing of Boreal, Tethyan, and cosmopolitan foraminiferal faunas. The Tethyan fauna is mostly found in « shallower » neritic deposits (both clastics and carbonates), whereas the Boreal forms seem to be more frequent in deeper neritic shales. The relative abundance of cosmopolitan species appears to be approximately the same both in the shallow and deep neritic deposits.

According to Jansa and Wade's (1975) paleogeographic reconstruction of the Scotian Shelf and Grand Banks in the Late Jurassic (Fig. 10), the former lay approximately westward to and opposite the opening of Tethys into the central North Atlantic. The deep-water central North Atlantic sediments and the enclosed fauna indicate that an open, deep as well as surface water circulation existed between the Atlantic and Tethys during the Late Jurassic and Early Cretaceous (Bernoulli et al., 1972; Jansa, Gardner et al., 1977). Thus the outflowing surface water from the Mediterranean would provide favorable conditions for the dispersal of the Tethyan microfauna into the central North Atlantic. The presence of Tethyan microfauna on the Scotian Shelf and Grand Banks documents the influence of the Tethys (warm) surface waters on this region (Fig. 10). However, during the Late Jurassic the epicontinental North European sea was also a part of the paleo-circulation system. The interconnection was at the northern periphery of the central North Atlantic Basin, northeast of the Grand Banks. Thus, an additional temperature driven flow is suggested as existing between the central North Atlantic and the North European sea. The presence of Boreal microfauna on the Grand Banks and the Scotian Shelf can be attributed to these south flowing « colder » North European-Greenland waters, which were dispersing Boreal forms (Fig. 10). The faunal distribution seems to further indicate that the colder waters flowed southward along the western Atlantic margin, similarly to the situation today. Bowen (1966, p. 144) had suggested a 15° - 20°C equatorial-polar spread in mean annual temperature during the Jurassic. If this is the case, the influence of temperature on ocean circulation would have been much less than at present and the circulation more sluggish, with the main driving force being the wind and salinity differences.

We therefore attribute the mixing of Boreal and Tethyan microfaunas

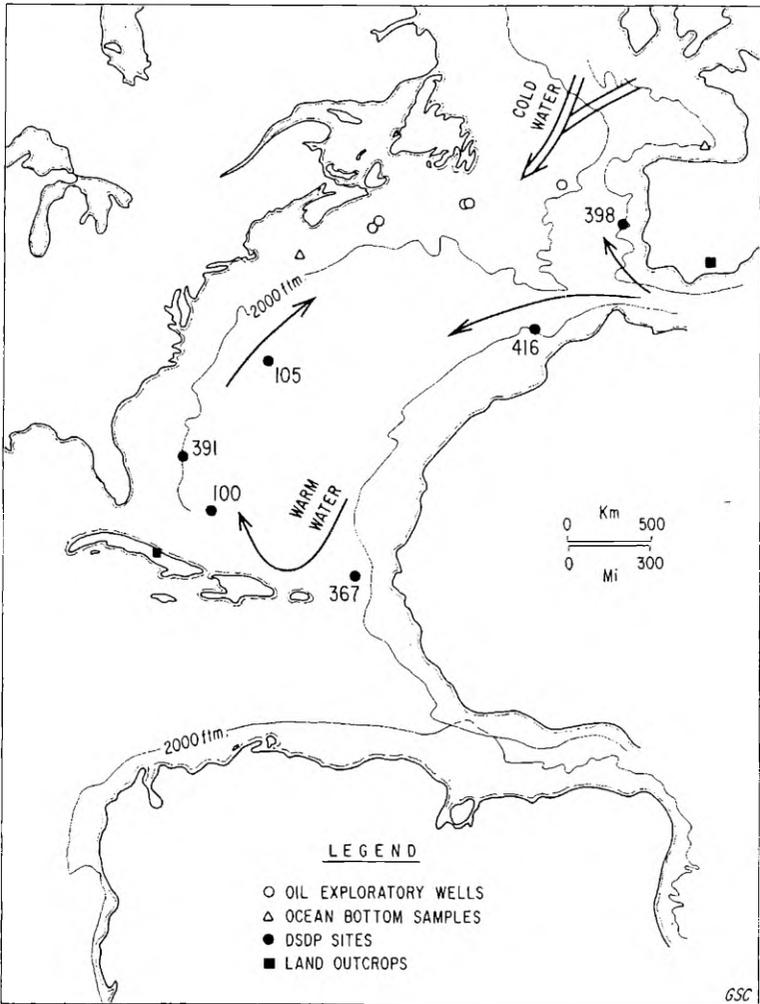


Fig. 10 - Calpionellid occurrences and paleocirculation, central North Atlantic.

on the Scotian Shelf and Grand Banks to the Late Jurassic paleocirculation pattern, with the warmer littoral-upper neritic waters being populated mostly by Tethyan species and the colder, deeper neritic waters mostly by Boreal species. Numerous cosmopolitan species were adapted to live in both environments.

Analyzing the ratio of Tethyan versus Boreal foraminiferal species in the Bonniton H-32 and Mohican I-100 wells from the Kimmeridgian to

the Hauterivian, we have observed a general increase of Boreal species in the younger strata. Most Kimmeridgian species are « temperate-Boreal » (i.e. present in the southern part of the Boreal realm) or cosmopolitan, except *Buccirenata italica* Dieni & Massari, *Alveosepta jaccardi* (Schrodt), *Pseudocyclamina lituus* (Yokoyama), *Trocholina alpina* (Leupold), *T. elongata* (Leupold) and *Epistomina madagascariensis* Espitalié & Sigal, which are wholly Tethyan, apart from *P. lituus*, which is generally Tethyan. Of these species, all except *Alveosepta jaccardi* are also present in the Tithonian, where another Tethyan representative, *Anchispirocyclina lusitanica* (Egger), occurs. The rest of the assemblage is composed of « temperate-Boreal » and « cosmopolitan » species. In the Berriasian-Valanginian, the proportion of « temperate-Boreal » and « cosmopolitan » species is even higher, the only « Tethyan » species being *Buccirenata italica*, *Pseudocyclamina lituus* and *Lenticulina busnardoii* Moullade. Finally, in the Hauterivian the foraminiferal assemblage is composed solely of « temperate-Boreal » and « cosmopolitan » species. This gradual decrease of Tethyan species in foraminiferal assemblages from Kimmeridgian to Hauterivian could be interpreted as either indicating a decrease of the Tethys influence on the Scotian Shelf and eastern Grand Banks due to changes in the paleocirculation pattern or reflect a change of lithofacies. A major facies change occurred during Late Jurassic-Early Cretaceous time on the Scotian Shelf, where the Upper Jurassic shales and limestones were replaced by marginal marine clastic sediments during the Early Cretaceous. Thus, it is uncertain whether the observed faunal change is here related to the change in paleocirculation or to the change of lithofacies. On the eastern Grand Banks (Bonniton H-32), the shale-limestone deposition continued from the Late Jurassic into the Valanginian with no major facies change. In this area, the observed decrease of Tethyan Foraminifera in the younger sequences is similar to that noted on the Scotian Basin. This supports our interpretation that the change in paleocirculation was the dominant factor causing the change in the foraminiferal assemblages. Until more data from shelf edge and upper slope wells are available, this interpretation has to be considered as tentative.

7. Calpionellid Paleobiogeography.

The presence of calpionellids on the Scotian Basin and the Grand Banks is of great paleobiogeographic importance. On the western side of the Atlantic this is by far the northernmost occurrence, the nearest one

being at DSDP site 105 (Lehmann, 1972), 600 km east of Cape Hatteras and more than 1000 km to the southwest (Figs. 10, 11).

The examination of calpionellids from the Jurassic-Cretaceous boundary of the Canadian continental margin has shown that all of the Mediterranean Late Tithonian/early Berriasian species are represented, with no endemic forms being observed. Qualitatively, the assemblages from the two regions are identical, the only differences concerning relative frequencies of species, at least on the Scotian Shelf. The quantitative data for the Grand Banks is insufficient to draw precise conclusions, but assemblages seem to be almost identical to the Mediterranean ones.

In addition to the Scotian Shelf and Grand Banks, calpionellids were also found in several DSDP sites on both sides of the central North Atlantic Basin (Figs. 10, 11). Lehmann (1972) reported *Calpionella alpina* (predominating) and *Tintinnopsella carpathica* (small variety) from DSDP site 105 (Fig. 10) and suggested an age close to the Jurassic-Cretaceous boundary or earliest Berriasian. A typical *Saccocoma* microfacies has been reported by the same author, in beds underlying the calpionellid-bearing limestones.

Luterbacher (1972) identified calpionellids in washed residues from DSDP site 100 on the Blake-Bahama Abyssal Plain (Fig. 10). Species are, however, difficult to recognize in SEM photographs and so far only *Remaniella cadischiana*, a Berriasian/Valanginian species, has been positively identified.

In order to obtain some quantitative data about calpionellids of the deep North Atlantic Basin, a total of seven thin sections from the following DSDP sites were studied: site 105 (core 33-1, 81-85 cm), site 367 (core 32-5, 62-63 cm), site 391-C (core 45-1, 48-50 cm and core 46-1, 70-72 cm), and site 398 (core 128-4, 86 cm); for locations and correlation, see Figs. 10 and 11. For site 105, the observations of Lehmann (1972) are confirmed by a fauna of *Calpionella alpina* Lorenz (78 specimens) and *Crassicollaria parvula* Remane (7 specimens). This assemblage is typical of the latest Tithonian (lower part of zone « B ») and identical in all aspects to samples from the Western Alps. The same assemblage occurs in core 45-1 at site 391-C (127 *C. alpina*, 10 *Cr. parvula* and 3 small *Tintinnopsella carpathica*). Core 46-1 can be assigned to zone « B », probably representing the very base of this zone. The two assemblages from the Eastern side of the Atlantic show close agreement to contemporaneous European assemblages. At site 398, west of Portugal, limestone pebbles within a debris flow contain a calpionellid fauna typical of subzone A2 (*C. alpina* = 27%, *Crassicollaria* sp. = 47%, *Cr. intermedia* = 12%, *Cr. parvula* =

9%, *Cr. massutiniana* = 3%, *Cr. brevis* = 1%, and *Tintinnopsella carpathica* = 1%). Latest Tithonian calpionellids, referable to lower part of Zone «B», are also found at Site 367, where rather small, spherical *C. alpina* largely predominate over some small specimens of *T. carpathica*.

The paleogeographic position of calpionellid faunas from the continental margin of Canada is not as extreme as it appears from the recent

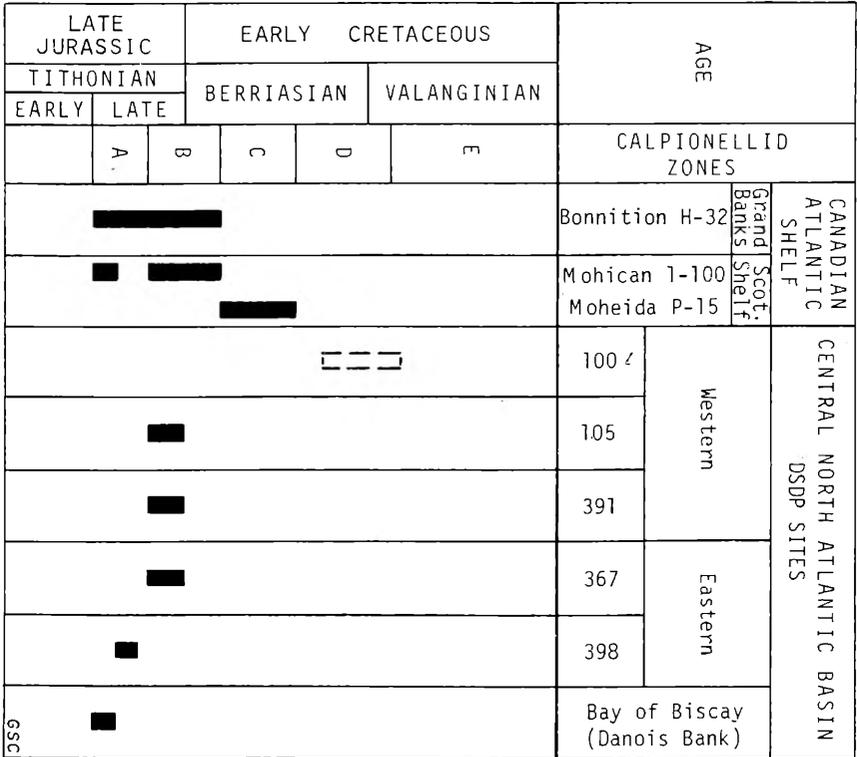


Fig. 11 - Stratigraphic chart of calpionellid occurrences in the North Atlantic Basin

geographic setting. During the Late Jurassic-Early Cretaceous the North Atlantic Basin was approximately half its present width. The calpionellids lived in the surface water of the Atlantic from the Cape Verde and Bahama basins northward to the northeastern Grand Banks and Bay of Biscay (Fig. 10). In the latter region, calpionellid occurrences are known from the Danois Bank and the Shell-ERAP Cormorant I well and were described by Durand Delga (1973). This author found on the Danois Bank

an assemblage from basal calpionellid zone A1, with forms transitional between *Chitinoidea* and *Tintinnopsella* (*Praetintinnopsella*). Biogeographic control alone of the absence of *Chitinoidea* on the Grand Banks thus appears less probable.

Occurrence of calpionellids as far north as the Bay of Biscay and northeastern Grand Banks is very significant to the plate tectonic interpretation of this segment of the North Atlantic. Occurrence of calpionellid-bearing pelagic limestones indicate that the Grand Banks and the Iberian Peninsula were already separated by the deep sea in the Tithonian. The sea was probably similar in depth or slightly shallower than the central North Atlantic Ocean, which at the Jurassic-Cretaceous boundary was about 3500-4000 m deep (Jansa, Enos et al., 1979). The presence of this Late Jurassic deep sea between the Grand Banks and the Iberian Peninsula implies either separation of continental plates in this region earlier than is generally believed (Williams & McKenzie, 1971; Dewey et al., 1973; Wilson, 1975), or that continental separation can develop in a deep epicontinental basin without prior thermal doming (Jansa & Wade, 1975; Montadert et al., 1976). If the second hypothesis is correct, the current theories of plates separation, based primarily on the East African Rift and young oceans such as Gulf of Aden analogues, have to be significantly modified. There thus appears to be two very different tectonic processes involved in the separation of continental plates.

Calpionellids as paleoceanographic indicators further suggest that open free circulation existed during the latest Jurassic between Tethys and the central North Atlantic as well as across the North Atlantic, with warm surface waters extending at least from about 10°N to 46°N of present latitude.

8. Conclusions.

1) Calpionellids have been recovered from 5 exploratory wells drilled to date on the Canadian Atlantic Shelf. The northernmost occurrence is in the Mobil-Gulf Bonniton H-32 well, located at latitude 45°51'N, on the eastern Grand Banks. All wells where calpionellids have been recorded are located near the present shelf edge. The calpionellid-bearing sequence consists of intercalated shallow to deep neritic limestones and shales. The postulated depositional environment for this sequence indicates fluctuating sea level, with general decrease of water depth in the younger stratigraphic units, within the Lower Cretaceous.

2) Detailed study of the calpionellids has provided evidence that the faunal successions are the same on the Canadian Atlantic Shelf and the Western Mediterranean realm; consequently, Western Mediterranean zones « A », « B » and « C » and probably also subzones of zone « A » can be recognized on the Canadian Atlantic Shelf.

3) The fact that Western Mediterranean Calpionellid zones could be applied to the Canadian Atlantic Shelf permitted calibration of the stratigraphic ranges of foraminiferal and ostracod marker species at and near the Jurassic-Cretaceous boundary. Sixteen selected foraminiferal and 14 ostracod marker species are proposed for dating and correlating the Kimmeridgian to Valanginian sediments of the Scotian Shelf and Grand Banks, whether in shallow water or in deep water facies.

The top of the Kimmeridgian on the Canadian Atlantic Shelf has been placed at the highest stratigraphic occurrence of the foraminiferal marker *Epistomina mosquensis* Uhlig and of six ostracod marker species. The top of the Tithonian and of the Jurassic has been placed at the highest occurrence of *Anchispirocyclus lusitanica* (Egger), which in Bon-nition H-32 is in the lower part of the calpionellid zone « B » (= latest Tithonian according to the Standard Calpionellid Biozonation). Four other foraminiferal and three ostracod species have their highest stratigraphic occurrences at the same horizon as *A. lusitanica*. The top of the Berriasian-Valanginian has been placed at the highest occurrence of *Lenticulina busnardoï* Moullade, plus four other foraminiferal and three ostracod marker species.

4) « Tethyan », « Boreal » and « cosmopolitan » foraminiferal species (i.e. present in both Tethyan and Boreal realms) have been identified. Tethyan species include *Alveosepta jaccardi* (Schrodt), *Pseudocyclammia lituus* (Yokoyama), *Trocholina alpina* (Leupold), *T. elongata* (Leupold), *Buccicrenata italica* Dieni & Massari, *Epistomina madagascariensis* Espitalié & Sigal, *Anchispirocyclus lusitanica* (Egger) and *Lenticulina busnardoï* Moullade. Boreal species include *Conorboides marginata* Lloyd, *Epistomina dneprica* Kaptarenko-Chernousova, *Lenticulina vistulae* Bielecka & Pozaryski, *L. saxonica* Bartenstein & Brand and *Conorboides valendisensis* (Bartenstein & Brand).

The co-occurrence of Tethyan, Boreal and « cosmopolitan » species is thought to be related to the differences in water temperature, with the Tethyan species favouring warmer surface waters and thus occurring in shallower environments and the Boreal species flourishing in colder, deeper waters. This conclusion supports the findings of Scheibnerova

(1971) that temperature was the primary controlling factor in the distribution of Mesozoic Foraminifera. Since the calpionellid microfauna is typically Tethyan, its distribution provides additional insight into the paleocirculation pattern existing in the central North Atlantic in the Late Jurassic. The occurrence of calpionellids from the Bay of Biscay region southward to the Cape Verde Basin along the eastern Atlantic and from south of Flemish Cap to Cuba on the western side of the Atlantic, suggests the existence of a deep ocean basin in the Late Jurassic, extending from 46°N southward to about 10°N of present latitude. The faunal distribution indicates a paleocirculation regime with « colder » North European-Greenland waters flowing southward along the North American margin and surface Mediterranean waters outflowing into the central North Atlantic. The surface water circulation in the central North Atlantic could have been wind driven, possibly giving way to a central Atlantic clockwise gyre.

The presence of a latest Jurassic deep sea between the Grand Banks and the Iberian peninsula requires modification of either the time of plate separation between Europe and North America, which would have to be pre-Tithonian, or the present ideas concerning the mechanism of plate separation. The process of lithospheric plate separation may have evolved in a deep epicontinental basin setting, without preceding domal uplift.

5) Accurate dating of the Tithonian calpionellid-bearing limestones within the Valanginian sequence in Mohican I-100 provides new evidence for vertical tectonic movements on the Scotian Shelf, resulting in the erosion of Upper Tithonian limestones. These movements can now be bracketed to have occurred between Late Tithonian and Valanginian time. A tectonic movement of approximately similar age influenced the southeastern Grand Banks (Amoco, 1973; Jansa & Wade, 1975) and is also reflected in the geologic development of the Bonniton H-32 well, as demonstrated in this paper. The tectonic unrest is interpreted as part of the Kimmerian tectonic phase, which also influenced the geologic development of western Europe (Ziegler, 1975).

9. Appendix.

Foraminiferal-ostracod faunal lists of selected intervals from Mobil-Gulf Bonniton H-32 (Grand Banks; interval 1874 to 3048 m T.D.) and Mohican I-100 (Scotian Shelf; interval 2533 to 2850 m).

Since highest instead of lowest stratigraphic occurrences had to be used for biozonation purposes (see p. 72), microfaunal assemblages are described in descending stratigraphic order in both wells. The depths of extinction points or «tops» of foraminiferal and ostracod stratigraphic markers are reported in parentheses after the name of each marker. All fossils are rare, except when marked with (C) (= common) or (F) (= frequent). Fossils marked with an asterisk (*) have their stratigraphic range reported in Fig. 5 (Bonnition H-32) and Fig. 7 (Mohican I-100). Microfossil zones and species reported with open nomenclature in both wells are those by Ascoli (1976).

9.1.1. Mobil-Gulf Bonnition H-32: list of microfaunal assemblages from the top of the Hauterivian (1874 m) to T.D. (3048 m).

Lenticulina saxonica saxonica - *Lenticulina guttata* - *Planularia crepidularis* Zone - 1874 to 2097 - 2118 m (Hauterivian).

Foraminifera:

- * *Conorboides valendisensis*
(Bartenstein & Brand) (C) (1874)
- Conorboides* sp.
- * *Epistomina caracolla* (Roemer)
- * *Epistomina* gr. *caracolla* (Roemer) (1874)
- * *Epistomina* gr. *reticulata* (Reuss) (C)
- * *Epistomina* aff. *reticulata* (Reuss)
- * *Epistomina suturalis* Ten Dam
- * *Epistomina tenuicostata*
Bartenstein & Brand (C) (1874)
- * *Lenticulina nodosa* (Reuss)
- Lenticulina saxonica bifurcilla*
Bartenstein & Brand (2057)
- Lenticulina wissellmanni* (Bettenstaedt)
- Lenticulina* spp.
- * *Marssonella kummi* Zedler

- * *Planularia crepidularis* (Roemer) (1874)
- Saracenaria frankei* Ten Dam
- Saracenaria forticosta* (Bettenstaedt)
- * *Trocholina* gr. *infragranulata* Noth
- Trocholina* spp.

Ostracoda:

- * *Asciocythere brevis* (Cornuel)
- * *Cytherelloidea ovata* Weber (2057)
- Dolocytheridea amygdaloides* (Cornuel)
- * *Mandocythere villierensis* (Stchepinsky)
- * *Schuleridea* gr. *thoerenensis* Triebel (1874)

Other fossils:

- Gastropoda
- Lamellibranchiata
- Echinoid spines

Conorboides valendisensis - *Lenticulina busnardoii* - *Lenticulina saxonica bifurcilla* Zone - 2118 to 2311 - 2314 m (Berriasian-Valanginian).

Foraminifera:

- Brizalina* sp. 1
- Brizalina* sp.
- * *Buccirenata italica* Dieni & Massari
- * *Conorboides valendisensis*
(C) (Bartenstein & Brand)
- Conorboides* spp.
- Eoguttulina erserta* (Berthelin)
- * *Epistomina* aff. *praereticulata*
Mjatliuk (2149)

- * *Epistomina* gr. *reticulata* Reuss
- * *Epistomina tenuicostata*
Bartenstein & Brand (F)
- Epistomina* gr. *tenuicostata*
Bartenstein & Brand (2149)
- * *Epistomina* sp. 1
- * *Epistomina* sp. 2
- * *Lenticulina busnardoii* Moullade (2118)
- Lenticulina eichenbergi*
Bartenstein & Brand

- * *Lenticulina nodosa* (Reuss)
Lenticulina saxonica saxonica
 Bartenstein & Brand (2123)
Lenticulina gr. *subtilis* Wisniowski (2123)
Marginulinopsis reticulosa
 (Ten Dam) (2240)
- * *Marssonella kummi* Zedler
Saracenaria forticosta (Bettenstaedt)
Saracenaria valanginiana
 Bartenstein & Brand (2118)
Trocholina gr. *alpina* (Leupold)
- * *Trocholina* gr. *infragranulata* Noth
 * *Trocholina valdensis* (Reichel) (2210)
- Ostracoda:
- * *Cardiobairdia* sp. 1 (2118)
Paracypris acuta (Cornuel)
- Other fossils:
- Gastropoda
 Lamellibranchiata

Ammobaculites coprolithiformis - *Trocholina* sp. 1 - *Anchispirocyclina lusitanica* Zone - 2314 to 2485 - 2515 m (Tithonian).

Foraminifera:

- * *Ammobaculites coprolithiformis*
 (Schwager) (2314)
- * *Anchispirocyclina lusitanica* (Egger (2314)
Asiacolus primus (d'Orbigny) (2362)
Brizalina sp. 1
Brizalina spp.
- * *Conorboides irregularis* Groiss (2332)
Conorboides spp.
Eoguttulina exserta (Berthelin)
- * *Epistomina* aff. *praereticulata*
 Mjatliuk (C)
- * *Epistomina* cf. *stellicostata*
 Bielecka & Pozaryski (2423)
- * *Epistomina uhligi* Mjatliuk (2347)
- * *Epistomina* sp. 1
 * *Epistomina* sp. 2
- ? *Haplophragmoides* sp. 1
 ? *Haplophragmoides* sp. 2
Haplophragmoides spp.
- * *Neobulimina varsoviensis*
 Bielecka & Pozaryski (C) (2347)
Planularia dofeini (Kasanzev) (2347)
- * *Pseudocyclamina lituus*
 (Yokoyama) (2332)
Pseudocyclamina sp. 1
Pseudocyclamina sp. 2
- * *Trocholina alpina* (Leupold) (C) (2332)
Trocholina burgeri Emberger
 * *Trocholina elongata* (Leupold) (2332)
 * *Trocholina* gr. *infragranulata* Noth (C)
 * *Trocholina solecensis*
 Bielecka & Pozaryski (2347)
- * *Trocholina valdensis* (Reichel)
Trocholina spp. (C)
- Ostracoda:
- ? *Darwinula* sp.
Procytheropteron aff. *brodiei* (Jones)
Procytheropteron sp.
- Other fossils:
- Gastropoda
 Lamellibranchiata
 Radiolaria (F)
 Echinoid spines

Epistomina madagascariensis - *Epistomina dneprica* Zone - 2485 - 2515 to 2646 - 2668 m (Late Kimmeridgian).

Foraminifera:

- Alveosepta* gr. *jaccardi* (Schrodt) (2545)
Alveosepta aff. *jaccardi* (Schrodt)
Astacolus matutinus (d'Orbigny) (2515)
- * *Conicospirillina* gr. *basilensis*
 Mohler (C) (2515)
- * *Conorboides marginata* Lloyd (2515)
Conorboides spp.
Cyclamina sp. 1
- * *Epistomina madagascariensis*
 Espitalié & Sigal (2545)
- * *Epistomina mosquensis* Uhlig (C) (2515)
- * *Epistomina* aff. *omnino-reticulata*
 Espitalié & Sigal (2576)
- * *Epistomina* aff. *praereticulata* Mjatliuk
 * *Epistomina uhligi* Mjatliuk
 * *Epistomina* aff. *uhligi* Mjatliuk
 * *Epistomina* sp. 1
 * *Epistomina* sp. 2
Everticyclamina sp. 1
- * *Lenticulina quenstedti* (Guembel) (2636)
Lenticulina varians (Bornemann) (2576)
 * *Lenticulina vistulae*
 Bielecka & Pozaryski (2515)
- * *Neobulimina varsoviensis*
 Bielecka & Pozaryski (C)
Paalzowella spp.
Planularia cordiformis Terquem

- * *Pseudocyclammina lituus* (Yokoyama)
- * *Trocholina alpina* (Leupold)
- * *Trocholina conica* (Schlumberger) (2515)
- * *Trocholina elongata* (Leupold)
- Trocholina* spp.

Ostracoda:

- * *Cytherelloidea* cf. *paraweberi*
Oertli (2485)
- Galliaecytheridea* aff. *pfnannenstieli*
(Steghaus)

Alveosepta jaccardi Zone - 2668 to 3048 m (T.D.) (Early Kimmeridgian).

Foraminifera:

- * *Alveosepta jaccardi* (Schrodt) (2668)
- * *Ammobaculites coprolithiformis*
(Schwager)
- Ammobaculites suprajurassicus*
(Schwager)
- * *Comicospirillina* gr. *basilienensis* Mohler
- Conorboides marginata* Lloyd
- * *Conorboides* spp.
- Cyclammina* sp. 1
- Eoguttulina inovroclaviensis*
Bielecka & Pozaryski
- Eoguttulina liassica* (Strickland)
- * *Epistomina madagascariensis*
Espitalié & Sigal
- * *Epistomina mosquensis* Uhlig (C)
- * *Epistomina* gr. *mosquensis*
Uhlig (F) (2743)
- * *Epistomina* cf. *stellicostata*
Bielecka & Pozaryski
- * *Epistomina uhligi* Mjatluk
- * *Epistomina* sp. 1
- * *Epistomina* sp. 2
- Everticyclammina* sp. 1
- Everticyclammina* sp. 2 (C) (2728)
- Gaudryina* aff. *heersumensis* Lutze
- * *Lenticulina quenstedti* (Guembel)
- Lenticulina varians* (Bornemann)
- * *Neobulimina varsoviensis*
Bielecka & Pozaryski

- Pontocyprella suprajurassica*
Oertli (2515)
- Protocythere* cf. *nealei* Kilenyi (2576)
- Protocytheropteron brodiei* (Jones)

Other fossils:

- Gastropoda (C)
- Lamellibranchiata (C)
- Radiolaria (C)
- Brachiopoda
- Echinoid spines



- Patellina feifeli* (Paalzow)
- Planularia beierana* (Guembel)
- Planularia cordiformis* Terquem
- Planularia tricarinnella* (Reuss) (2926)
- * *Pseudocyclammina lituus* (Yokoyama)
- * *Trocholina conica* (Schlumberger)
- * *Trocholina elongata* (Leupold)
- Trocholina* spp. (C)

Ostracoda:

- Galliaecytheridea* gr. *cuneiformis*
Bielecka et al. (2972)
- * *Galliaecytheridea raripunctata*
Bielecka et al. (2697)
- * *Galliaecytheridea wolburgi*
(Steghaus) (2668)
- Macrodentina annulata* Malz
- Macrodentina sculpta* Klingler
- Eccytheropteron purum* (Schmidt)
- * *Protocythere rodewaldensis*
(Klingler) (2697)
- * *Schuleridea strzalkowiensis*
Bielecka et al. (2668)

Other fossils:

- Gastropoda (C)
- Lamellibranchiata (C)
- Brachiopoda
- Radiolaria
- Echinoid spines

9.2.2. Shell Mohican I-100: list of microfaunal assemblages between conventional cores no. 2 (2533-2542 m) (top of Valanginian) and no. 3 (2840-2850 m) (top of Kimmeridgian).

Conorboides valendisensis - *Lenticulina busnardoii* - *Lenticulina saxonica bifurcilla* Zone - 2533 to 2704-2725 m (Berriasian-Valanginian).

Foraminifera:

- Ammobaculites* sp. 4274
Espitalié & Sigal (2533-2542)

- * *Buccicrenata italica*
Dieni & Massari (F) (2533-2542)
- Epistomina caracolla* (Roemer)

- * *Lenticulina busnardoii* Moullade (2533-2542)
Lenticulina nimbifera
(Espitalié & Sigal) (2533-2542)
Lenticulina nodosa (Reuss)
* *Lenticulina saxonica bifurcilla* (2652)
Bartenstein & Brand
* *Lenticulina subtilis* Wisniewski (2694)
Marginulinopsis reticulosa
(Ten Dam) (2591)
Marssonella kummi Zedler (2533-2542)
Marssoneila oxycona (Reuss)
Marssonella praeoxycona (Moullade)
Patellina gr. *fejeli* (Paalzow)
Planularia crepidularis (Roemer)
Pseudocyclammina lituus (Yokoyama)
(2533-2542)
Spirillina spp.
Trocholina sp. 1 (reworked) (2533-2542)
- Ostracoda:
Asciocythere gr. *brevis* (Cornuel)
(2533-2542)
* *Asciocythere* sp. 1 (2533-2542)
Cytherella index Oertli (reworked) (2694)
Cytherelloidea ovata Weber
Dolocytheridea sp.
Hutsonia gr. *collinsensis* (reworked)
Swain & Brown (2533-2542)
* *Schuleridea* aff. *praethoerenensis*
Bartenstein (F) (2533-2542)
- Other fossils:
Gastropoda
Pelagic Lamellibranchiata
Bryozoa
Echinoid spines

Epistomina stelicostata - *Epistomina uhligi* Zone - 2725 to 2840 m (Tithonian).

- Foraminifera:
* *Buccicrenata italica* Dieni & Massari
* *Epistomina dneprica* Kaptarenko-
Chernoussova (2816)
* *Epistomina madagascariensis*
Espitalié & Sigal (2816)
* *Epistomina stelicostata*
Bielecka & Pozaryski (2740)
* *Epistomina uhligi* Mjatliuk (F) (2725)
Epistomina spp.
Lenticulina spp.
Marginulinopsis sp.
Patellina fejeli (Paalzow)
- Spirillina* spp.
Trocholina spp.
- Ostracoda:
Asciocythere spp.
Cytherella index Oertli (reworked)
* *Schuleridea* aff. *praethoerenensis*
Bartenstein
- Other fossils:
Pentacrinus sp. (2816)
Bryozoa
Echinoid spines

Paranotacythere sp. 1 - ? *Hutsonia* sp. 1 ostracod Zone - 2840 to 2850 m (conventional core No. 3) (Late Kimmeridgian).

- Foraminifera:
* *Ammobaculites coprolithiformis*
(Schwager) (2840-2850)
* *Buccicrenata italica* Dieni & Massari (F)
* *Epistomina dneprica* Kaptarenko-
Chernoussova
Epistomina aff. *dneprica* Kaptarenko-
Chernoussova (2840-2850):
Espitalié & Sigal
* *Epistomina mosquensis* Uhlig (2840-2850)
* *Epistomina stelicostata*
Bielecka & Pozaryski
* *Epistomina uhligi* Mjatliuk
* *Epistomina* spp. (C)
Lenticulina spp. (F)
Marginulinopsis spp.
- Trocholina* sp. 1 (2840-2850)
Trocholina spp.
- Ostracoda:
* *Acrocythere* sp. (2840-2850)
Asciocythere gr. *amygdaloides* (Cornuel)
(2840-2850)
Asciocythere spp. (F)
Cytherella index Oertli (reworked)
Cytherella spp. (F)
* *Cytherelloidea weberi* Steghaus (2840-2850)
Galliaecytheridea postrotunda Oertli
(2840-2850)
Galliaecytheridea cf. *wolburgi* (Steghaus)
(2840-2850)
* *Hutsonia* gr. *collinsensis* Swain & Brown
(2840-2850)

* ? *Hutsonia* sp. 2 (2840-2850)

Schuleridea aff. *praethoerenensis*
Bartenstein

* *Schuleridea triebeli* (Steghaus) (2840-2850)

Schuleridea sp. 1 (2840-2850)

* *Schuleridea* sp. 2 (2840-2850)

* *Schuleridea* sp. 5 (2840-2850)

Other fossils:

Gastropoda

Brachiopoda

Bryozoa

Echinoid spines

Sponge spines

Pentacrinus sp.

REMARKS.

Trocholima sp. 1 (Pl. 8), illustrated but not described by Ascoli (1976), is characterized by its very small dimensions (diameter 0.21-0.37 mm). The test is lenticular-low conical, with dorsal side slightly raised and very finely pitted, and has six to eight equally broad whorls of chambers visible. The umbilical side is flat, with the central part filled with approximately 15-20 coarse calcite granules, merging radial ridges toward the outer margin.

Schuleridea sp. 2 (Pl. 9, figs. 6-10), neither described nor illustrated by Ascoli (1976), is very similar to *Schuleridea* sp. 1 (Pl. 9, figs. 4, 5), of which has the same dimensions (length 0.34-0.44 mm). It differs, however, from the latter species in having the anterior margin of the right valve more strongly depressed, and in the dorsal margin being evenly rounded in both valves, with no antero-dorsal corner. The carapace, slightly more coarsely pitted, is thicker at the anterior third.

Addendum

The ammonite zonation of the type Kimmeridgian by Arkell (1956), reported by Oertli (1963) and by us in Fig. 9 (p. 97), has been later revised by several authors, as Christensen and Kilenyi (1970) and Callomon and Cope (1971).

In the recent publication « A stratigraphical index of British Ostracoda », (R. H. Bate and E. Robinson, Editors) published in 1978 by Seel House Press, Liverpool (*Geol. Jour. Spec. Issue* n. 8, pp. 1-538), a revised ammonite zonation of the type Kimmeridgian is reported and compared with that by Arkell (1956) (see page 112).

If we accept the ammonite zonation of the type Kimmeridgian reported by Bate and Robinson, the top of the type Kimmeridgian should then be defined by the top of the *Pavlovia rotunda* (instead of *Pavlovia pallasioides*, as in p. 96) ammonite zone, whereas the top of the Early Kimmeridgian should be defined by the top of the *Aulacostephanus autisiodorensis* (instead of *Aulacostephanus pseudomutabilis*, as in p. 96) ammonite zone.

| Bate & Robinson 1978 | Arkell 1956 |
|---|--|
| <i>Pavlovia rotunda</i> | <i>Pavlovia pallasoides</i> |
| <i>Pavlovia pallasoides</i> | <i>Pavlovia rotunda</i> |
| <i>Pectinatites pectinatus</i> | <i>Pectinatites pectinatus</i> |
| <i>Pectinatites huddlestoni</i> | <i>Subplanites wheatleyensis</i> |
| <i>Subplanites wheatleyensis</i> | <i>Subplanites grandis</i> |
| <i>Pectinatites scitulus</i> | <i>Subplanites</i> spp. |
| <i>Pectinatites elegans</i> | } <i>Gravesia gigas</i> |
| | } <i>Gravesia gravesiana</i> |
| <i>Aulacostephanus autissiodorensis</i> | } <i>Aulacostephanus pseudomutabilis</i> |
| <i>Aulacostephanus eudoxus</i> | |
| <i>Rasenia mutabilis</i> | <i>Rasenia mutabilis</i> |
| <i>Rasenia cymodoce</i> | <i>Rasenia cymodoce</i> |
| <i>Pictonia baylei</i> | <i>Pictonia baylei</i> |

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PLATE 5

Calpionellids observed in cuttings from the Mobil-Gulf Bonniton H-32 well, Grand Banks. All figs. $\times 360$. Depths are in metres and in feet.

Fig. 1-4 - *Calpionella alpina* Lorenz.

1-3 - smaller forms as characteristic of Zone B (especially 2, 3) or higher levels; GSC No. 61297 - 61299.

4 - large form (slightly oblique section) typical of Zone A; GSC No. 61300.

Fig. 5, 6 - *Crassicollaria* sp.; GSC No. 61301 - 61302.

Fig. 7, 8 - *Crassicollaria brevis* Remane; GSC No. 61303 - 61304.

Fig. 9 - *Crassicollaria massutiniana* (Colom); GSC No. 61305.

Depths: 1: 2240.3 - 2243.3 m (7.350 - 7.360'); 2: 2319.5 - 2322.6 m (7610 - 7620'); 3: 2325.6 - 2328.7 m (7630 - 7640'); 6, 7, 9: 2420.1 - 2423.2 m (7940 - 7950'); 4, 5, 8: 2435.4 - 2438.4 m (7990 - 8000').

Abbreviations used in Plates 1-5:

cutt. = cuttings

swc = sidewall core

conv. = conventional core

car. = carapace

LV = left valve

RV = right valve

F. = female

M. = male

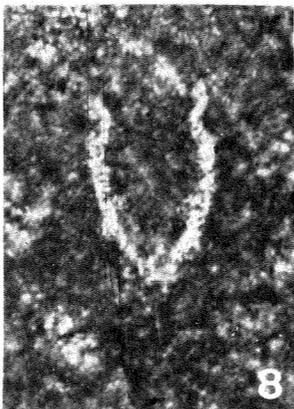
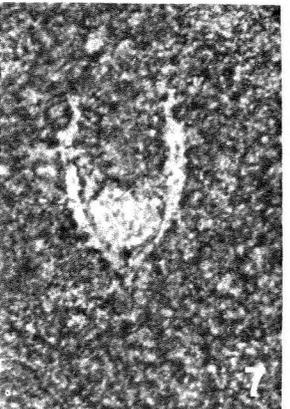
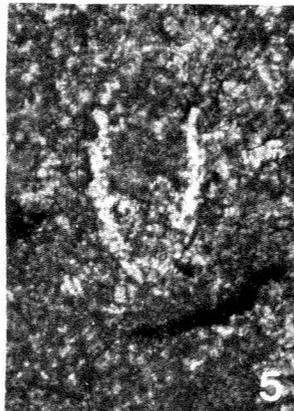
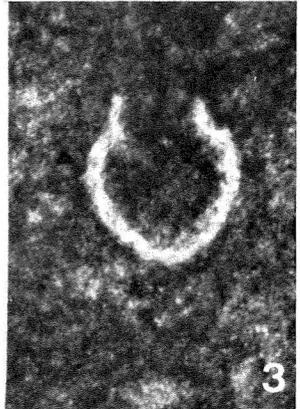
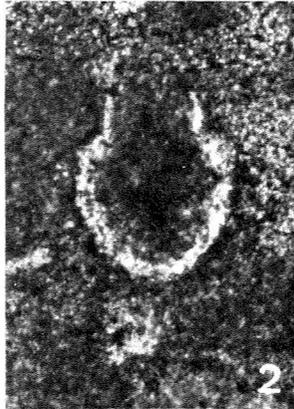
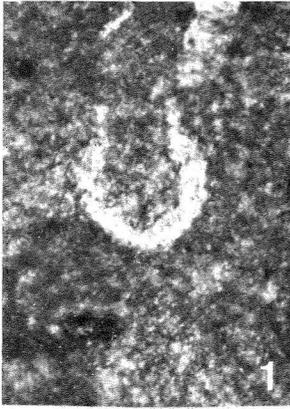


PLATE 6

Microfacies from core 2, Shell Mohican I-100 (Scotian Shelf), $\times 35$.

Fig. 1 - Part of a large onkoid with a recrystallized bivalve fragment as nucleus and algal envelop also containing serpulids and encrusting bryozoans (2541.37 m; 8337'10"); GSC No. 61306.

Fig. 2 - Typical microfacies at 2541.12 m (8337'), showing a biomicrite rich in echinoderm debris, small gastropods, and benthonic Foraminifera, one of which has an agglutinated calpionellid; GSC No. 61307.

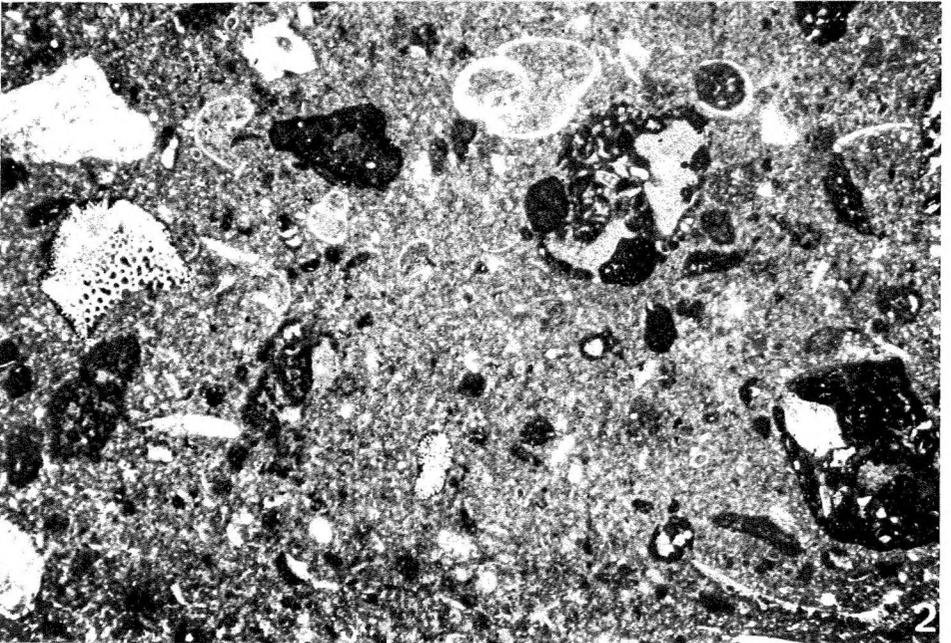
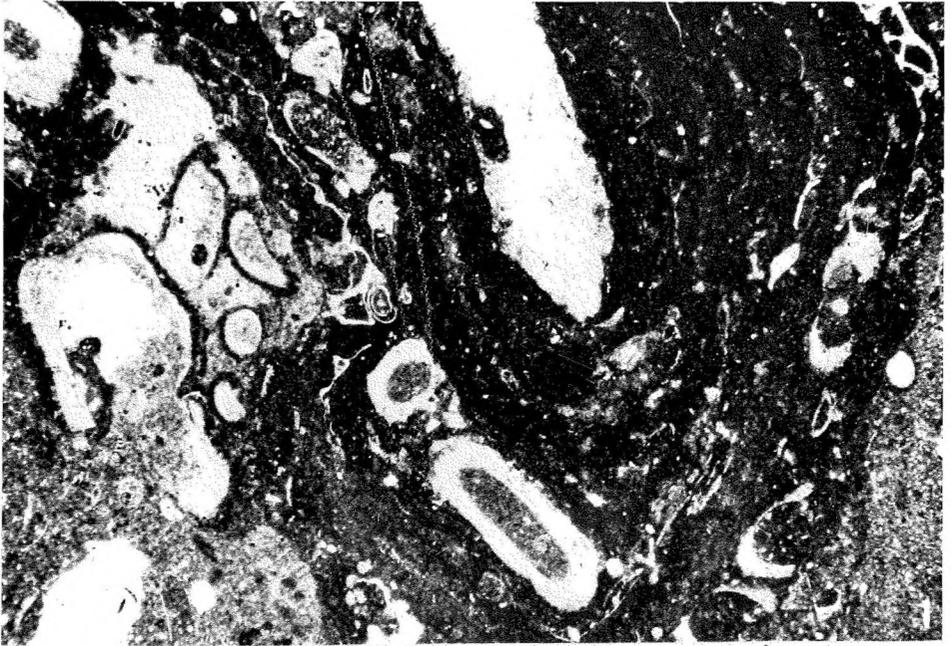


PLATE 7

Calpionellids from core 2, Mohican I-100, Scotian Shelf.

- Fig. 1 - Small gastropod and oblique section of a *Crassicollaria* (very probably *Cr. intermedia*) in a halo of finely dispersed pyrite at 2541.37 m (8337'10") in core 2 of Shell Mohican I-100 (Scotian Shelf), \times 90; GSC No. 61308.
- Fig. 2-10 - Individual calpionellids from core 2, Mohican I-100, all \times 360.
- Fig. 2, 3, 4 - *Crassicollaria intermedia* (Durand Delga), all from 2541.37 m (8337'10"); GSC No. 61309-61311.
- Fig. 5, 6 - *Crassicollaria massutiniana* (Colom), both from 2541.37 m (8337'10"); GSC No. 61312-61313.
- Fig. 7, 8 - *Crassicollaria parvula* Remane, both from 2541.12 m (8337'); GSC No. 61314-61315.
- Fig. 9, 10 - *Calpionella alpina* Lorenz, both from 2540.66 m (8335'6"); GSC No. 61316-61317.

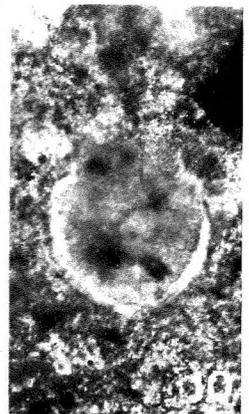
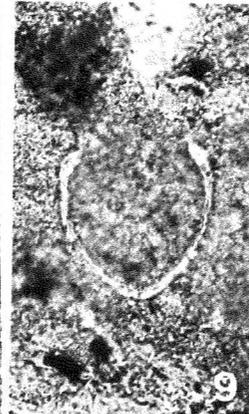
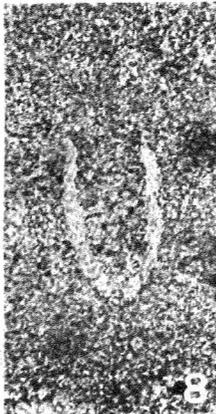
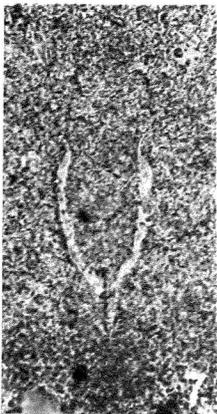
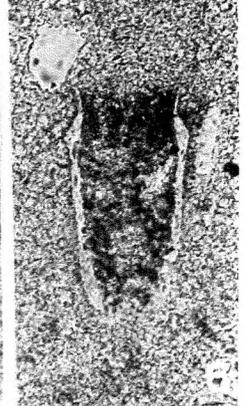
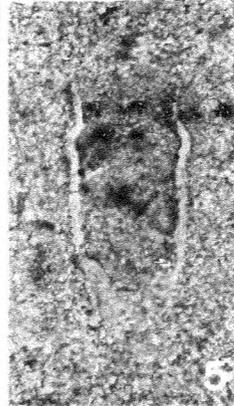
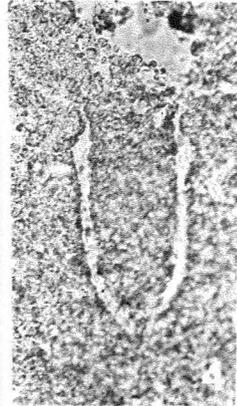
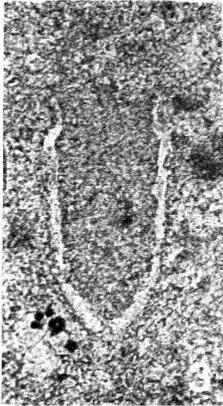
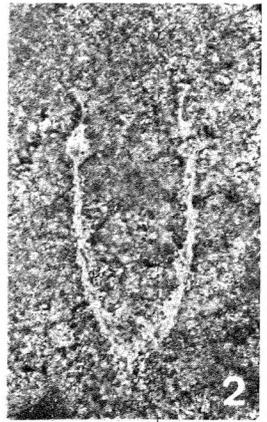
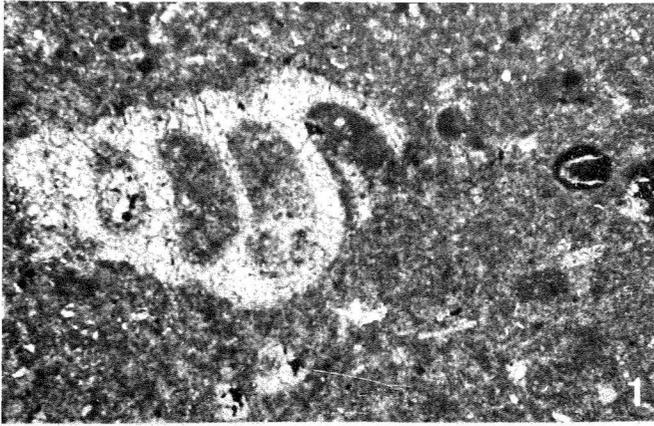


PLATE 8

Foraminiferal marker species near the Jurassic-Cretaceous boundary, Canadian Atlantic Shelf.

- Fig. 1, 2 - *Buccicrenata italica* Dieni & Massari.
Shell Naskapi N-30: cutt. 1726 m (5660'), *Alveosepta jaccardi* Zone (Early Kimmeridgian).
1 - Edge view \times 49; GSC No. 53885.
2 - Side view \times 40; GSC No. 53886.
- Fig. 3 - *Lenticulina busnardoii* Moulade.
Mobil-Gulf Bonniton H-32: cutt. 2118 m (6950'), *Conorboides valendisensis* - *Lenticulina busnardoii* - *Lenticulina saxonica bifurcilla* Zone (Berriasian-Valanginian).
Side view \times 109; GSC No. 60884.
- Fig. 4 - 6 - *Epistomina uhligi* Mjatluk.
4,5: Sheli Mohican I-100: cutt. 2725 m (8940'), *Epistomina stelicostata* - *E. uhligi* Zone (Tithonian); 6: Shell Naskapi N-30: swc 1713 m (5620'), *E. stelicostata* - *E. uhligi* Zone (Tithonian).
4 - Spiral view \times 62; GSC No. 53804.
5 - Umbilical view \times 68; GSC No. 53802.
6 - Edge view \times 60; GSC No. 53803.
- Fig. 7, 8 - *Anchispirocyclina lusitanica* (Egger).
Mobil-Gulf Bonniton H-32: cutt. 2423 m (7950'), *Ammobaculites coprolithiformis* - *Trocholina* sp. 1 - *Anchispirocyclina lusitanica* Zone (Tithonian).
7 - Side view (leached specimen) \times 29; GSC No. 60885.
8 - Side view \times 31; GSC No. 60886.
- Fig. 9 - 11 - *Epistomina stelicostata* Bielecka & Pozaryski.
Shell Mohican I-100: conv. core no. 3, 2840-2850 m (9314-9344'), *Paranotacythere* sp. 1-? *Hutsonia* sp. 1 Zone (Kimmeridgian).
9 - Spiral view \times 98; GSC No. 53798.
10 - Edge view \times 94; GSC No. 53799.
11 - Umbilical view \times 95; (same specimen as 9).
- Fig. 12 - 14 - *Trocholina* sp. 1 Ascoli, 1976.
Shell Mohican I-100: conv. core no. 3, 2840-2850 m (9314-9344'), *Paranotacythere* sp. 1-? *Hutsonia* sp. 1 Zone (Kimmeridgian).
12 - Spiral view \times 116; GSC No. 53881.
13 - Edge view \times 124; GSC No. 53882.
14 - Umbilical view \times 95; GSC No. 53880.

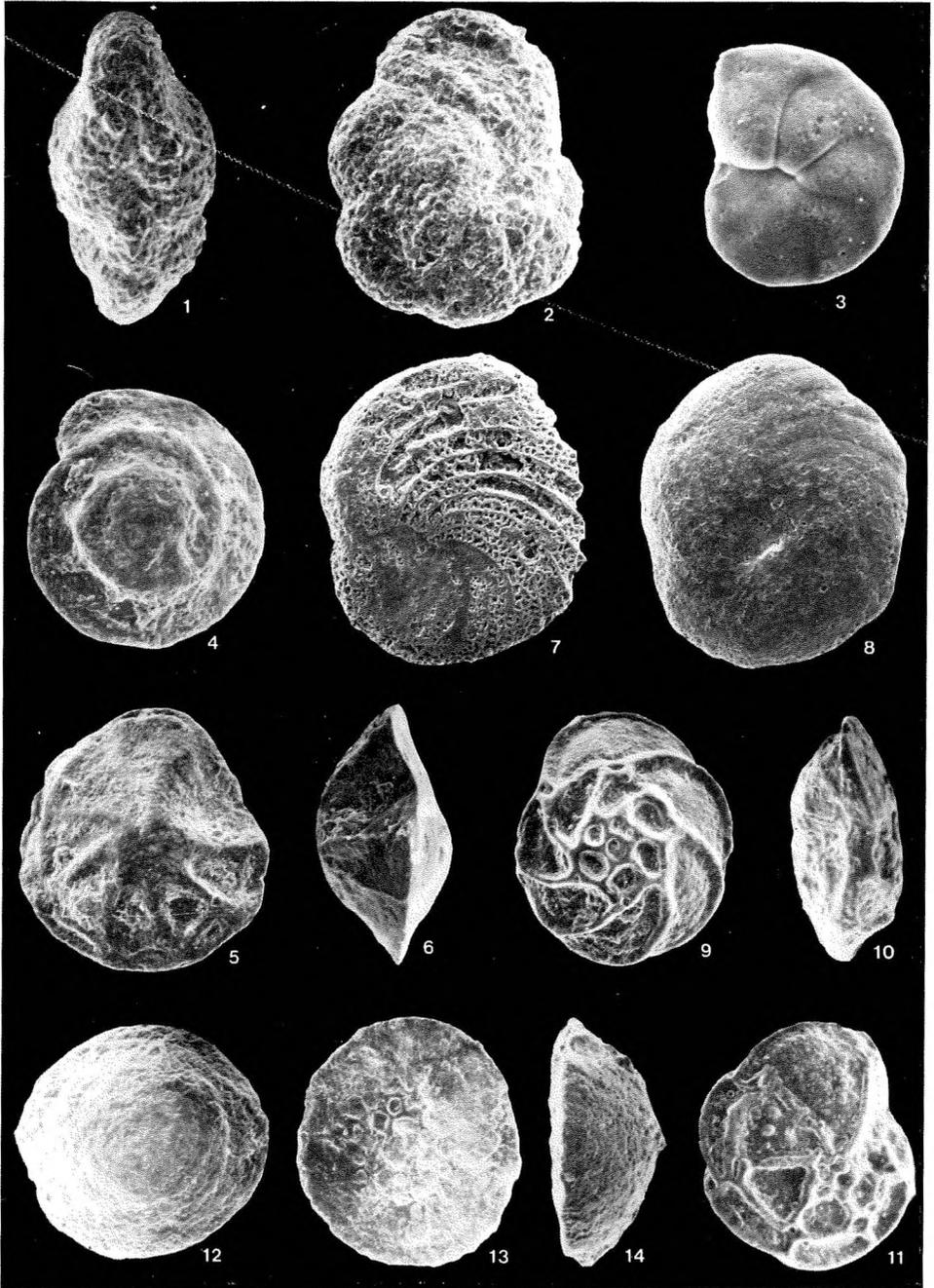


PLATE 9

Foraminiferal and ostracod marker species near the Jurassic-Cretaceous boundary, Canadian Atlantic Shelf.

- Fig. 1 - 3 - *Epistomina mosquensis* Uhlig.
Mobil-Gulf Bonniton H-32: cutt. 2546 m (8350'), *Epistomina madagascariensis* - *E. dneprica* Zone (Kimmeridgian).
1 - Spiral view \times 119; GSC No. 60887.
2 - Edge view \times 129; GSC No. 60888.
3 - Umbilical view \times 124; GSC No. 60889.
- Fig. 4, 5 - *Schuleridea* sp. 1 Ascoli, 1976.
Shell Mohican I-100: conv. core no. 3, 2840-2850 m (9314-9344'). *Paranotacythere* sp. 1-? *Hutsonia* sp. 1 Zone (Kimmeridgian).
4 - Car. dors. view \times 116; GSC No. 53932.
5 - M. RV lat. view \times 126; GSC No. 53934.
- Fig. 6-10 - *Schuleridea* sp. 2 Ascoli, 1976.
6, 8-10: Shell Mohican I-100: conv. core no. 3, 2840-2850 m (9314-9344'), *Paranotacythere* sp. 1-? *Hutsonia* sp. 1 Zone (Kimmeridgian).
7: Mobil Dauntless D-35: cutt. 3741 m (12,270'), *Hutsonia* gr. *collinsensis* - *Galliaecytheridea postrotunda* - *Schuleridea* sp. 1 Zone (Tithonian).
6 - F. LV lat. view \times 116; GSC No. 60890.
7 - Car. lat. view RV \times 119; GSC No. 60891.
8 - M. RV lat. view \times 124; GSC No. 60892.
9 - Car. dors. view \times 113; GSC No. 60893.
10 - M. LV lat. view \times 102; GSC No. 60894.
- Fig. 11, 12 - *Galliaecytheridea postrotunda* Oertli.
11: Shell Mohican I-100: cutt. 2869 m (9410'), *Paranotacythere* sp. 1-? *Hutsonia* sp. 1 Zone (Kimmeridgian).
12: Shell Mohawk B-93: cutt. 1805 m (5920'), *Paranotacythere* sp. 1-? *Hutsonia* sp. 1 Zone (Kimmeridgian).
11 - Car. lat. view RV \times 69; GSC No. 53929.
12 - Car. dors. view \times 62; GSC No. 53928.

