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EPISTOMINID FORAMINIFERAL ZONATION OF THE MIDDLE-LATE JURASSIC AND EARLIEST CRETACEOUS ON THE CANADIAN ATLANTIC SHELF

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ABSTRACT

The Bathonian to Valanginian sediments of the Canadian Atlantic Shelf contain highly diversified and often abundant epostominid assemblages. Epistominids show the highest biozonation potential among all groups of Foraminifera. They have allowed the establishment of a zonation at the stage level, and at the ½ stage level for the Callovian and the Tithonian intervals. In the Tithonian-Berriasian section, the stratigraphic ranges of the epistominid zone markers have been calibrated with associated calpionellid assemblages at both ends of the study area: the Georges Bank Basin at the Canada-U.S.A. border and the easternmost Grand Banks of Newfoundland. Comparison of highest stratigraphic occurrences of epistominids from the Canadian and adjoining norternmost U.S. Atlantic Shelves with those of their counterparts from Europe and circum-North Atlantic D.S.D.P. Sites, has shown almost identical stratigraphic ranges for nearly all species across the North Atlantic, whenever neritic facies and Tethyan or Tethyan transitional to Boréal regions are compared. The proposed zonation appears therefore well suited to correlate coeval sediments of Bathonian to Valanginian age across the North Atlantic Ocean.

RÉSUMÉ

Les sédiments du Bathonien au Valanginien de la plateforme atlantique canadienne contiennent des associations d'épistominides très diversifiés et souvent abondants. Parmi tous les groupes de foraminifères, les épistominides possèdent le plus grand potentiel de biozonation. Elles ont permis d'établir une zonation au niveau d'étage et au niveau ½ etage pour les intervalles calloviens et tithoniens. Dans la section Tithonien-Berriasien, les distributions stratigraphiques des épistominides marqueurs de zone ont été calibrés avec les associations de calpionelles associés apparaissant aux deux limites de la région étudiée: le Georges Bank Basin à la frontière Canada-U.S.A. et la partie orientale des Brands Bancs de Terre-Neuve. Les plus hautes "last appearance data" des épistominides dans la plateforme atlantique canadienne et dans la partie plus septentrionale de la plateforme atlantique americaine ont été comparées avec celles de leurs

correspondants en Europe et sur le pourtour des Sites D.S.D.P. de l'Atlantique Nord. Toutes les fois que l'on a comparé les faciès néritiques de les régions téthysiennes ou transitoires aux régions boréales, cette comparaison a montré des distributions stratigraphiques presque identiques pour la majorité des espèces de part et d'autre de l'Atlantique Nord. Il semble donc que la zonation proposée convienne pour effectuer des corrélation stratigraphiques entre sédiments contemporains d'age bathonienne-valanginienne à travers l'Atlantique Nord.

INTRODUCTION

Detailed micropaleontologic-biostratigraphic studies of the Canadian Atlantic Shelf were initiated by Geological Survey of Canada micropaleontologists in 1971, at its Atlantic Geoscience Centre Division (AGC) in Dartmouth, Nova Scotia. One of AGC's main objectives was to carry out a thorough biostratigraphic, lithostratigraphic and geophysical study of the Canadian Atlantic Shelf, in order to reconstruct its geological history, identify and evaluate its hydrocarbon potential, and to advise the Government of Canada on how to exploit this potential in the best interest of the country.

Oil exploration on the Canadian Atlantic Shelf began in 1966, and since then over 250 deep exploratory wells have been drilled on the Scotian Shelf, Grand Banks of Newfoundland, Flemish Pass and Labrador Shelf. The most promising oil finds so far are in the Jeanne d'Arc Basin of the eastern Grand Banks, where the giant Hibernia field (Fig. 1) is estimated to contain between 94 and 137 million cubic metres of oil, most of which is reservoired in Upper Jurassic and Lower Cretaceous sandstones. On the Scotian Shelf, considerable amounts of gas have been discovered in the Sable Island area, again in Upper Jurassic and Lower Cretaceous beds. Exploitation of both areas is planned, should an increase of oild and gas prices make production economically viable.

The geology of the Canadian continental margin off Nova Scotia and Newfoundland - and particularly its tectonic framework, lithostratigraphy and basin features - was described in detail by Jansa and Wade (1975) and Grant et al. (1986) amont others. They indicated that the Mesozoic-Cenozoic areas off of the eastern margin of North America are characterized by shallow basement platforms and ridges which flank deep marginal sedimentary basins and, farther seaward a deep water oceanic basin. They developed in a passive margin environment during the breakup of Pangaea. These basins had similar histories in the initial rifting phase during the Late Triassic and Early Jurassic but differ somewhat during the Late Jurassic and Early Cretaceous due to differences in timing of breakup along the margin. Triassic-Early Jurassic synrift sediments consist predominantly of red clastics and locally thick evaporites which pass upward into progressively more marine postrift facies. In the Late Jurassic, carbonate facies were common in the more stable parts of the margin while thick clastic facies were deposited in the

adjacent depocentres. The initial Cretaceous sedimentation was predominantly continental grading upward through shallow marine to deep marine with the latter due to margin subsidence and the Late Cretaceous eustatic rise of sea-level.

The wells studied are from the Baltimore Canyon Trough and Georges Bank Basin on the American margin and the Scotian, Carson, Jeanne d'Arc and Flemish Pass Basins on the Canadian margin (Fig. 1).

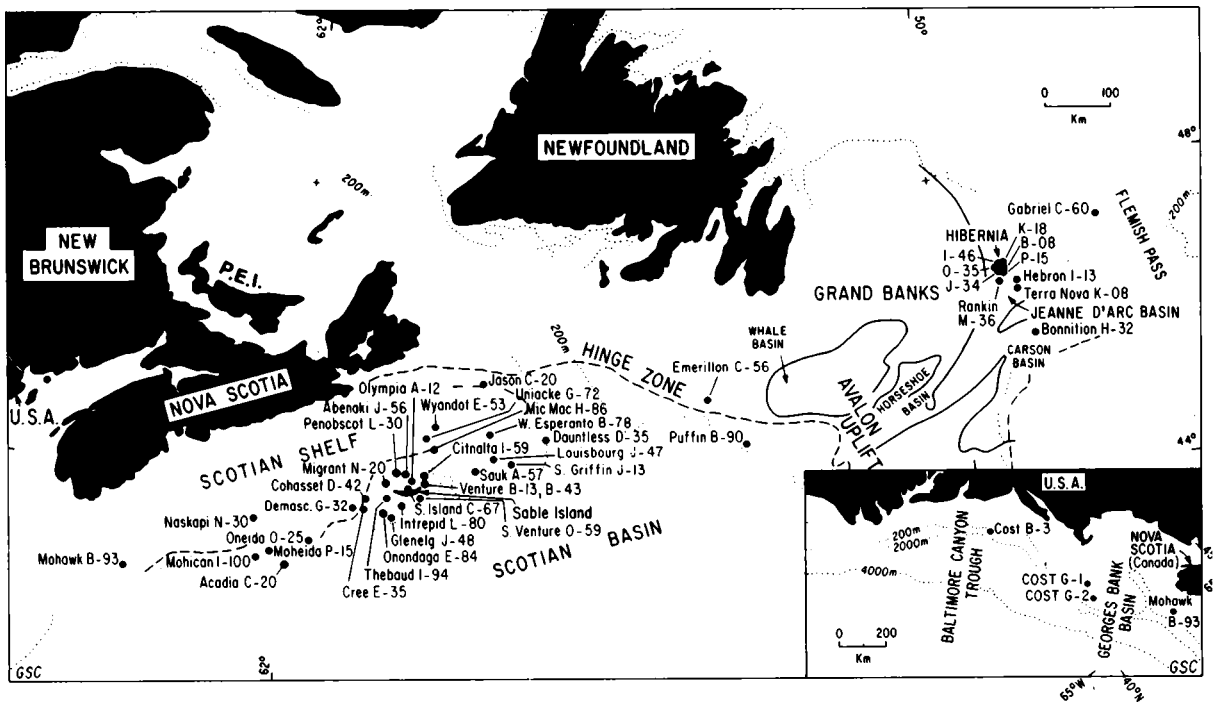

Figure 1

Location map of studied wells, Canadian and northernmost U.S. Atlantic Shelves.

Carte localisant les sondages étudiés dans la plateforme atlantique canadienne et la partie plus septentrionale de la plateforme atlantique americaine.

In the field of micropaleontological biostratigraphy, the following publications are particularly concerned with the Middle Jurassic to Early Cretaceous section of the Canadian Atlantic Shelf (Labrador Shelf excluded), and with the northernmost part of the adjoining U.S. Atlantic Shelf. Ascoli (1976) established a Jurassic to Miocene four-fold foraminiferal-ostracod zonation of the Scotian Basin (= Scotian Shelf + Western Grand Banks), whereas Gradstein (1976) established a Jurassic foraminiferal zonation for the central and eastern Grand Banks. Ascoli's 1976 zonation (updated for the Late Jurassic by Ascoli, 1981) was partially extrapolated and applied to the Carson Basin of the Eastern Grand Banks by Jansa, Remane and Ascoli (1980),

to the northern part of the Baltimore Canyon Trough and Georges Bank Basin (northernmost part of the U.S. Atlantic Shelf) by Poag (1980, 1982) and by Ascoli, Poag and Remane (1984). A calpionellid zonation of the Tithonian-Berriasian interval was firstly established by Remane for the Scotian and Carson Basins (cf. Jansa, Remane and Ascoli, 1980). This zonation was later expanded, applied to the Geoges Bank Basin, re-described on the basis of highest stratigraphic occurrences of characteristic forms, and closely integrated with zones of Foraminifera and Ostracoda by Remane and Ascoli in Ascoli, Poag and Remane (1984). More recently, Stam (1986) established a foraminiferal zonation for the Middle and Late Jurassic of the Grand Banks, updating for the Bajocian-Kimmeridgian interval Gradstein's 1976 zonation and adopting for the Tithonian Ascoli's 1976 zonation. Williamson (1987) published a quantitative foraminiferal zonation, based on a study of 13 wells, for the Late Jurassic and Early Cretaceous of the East Newfoundland Basin, proposing eleven zones for the Kimmeridgian-Cenomanian interval.

A new expanded and updated version of Ascoli's 1976 zonation is outlined in Williams et al. (in press), and described in greater detail in Ascoli (in press-b). This improved zonation for the Canadian and northernmost U.S. Atlantic Shelf is based on the biostratigraphic study of three categories of different microfossils (planktic and benthic Foraminifera, Ostracoda and calpionellids) in 52 wells spanning an area between the Flemish Pass (bordering the Labrador Shelf) and the Baltimore Canyon Trough.

BIOZONATION

Planktic Foraminifera, calcareous benthic Foraminifera, arenaceous benthic Foraminifera, ostracod and calpionellid zones have been used by the author since 1976 (calpionellid zones since 1980) for dating and correlating not only the Bathonian-Valanginian, but also the Hauterivian to Late Miocene subsurface sediments of the studied area. All these zones are informal assemblage zones, whose upper boundaries are defined by the highest stratigraphic occurrences, or "LAD" (= "last appearance datum") of one or two "zone marker species", after which all zones are named (Ascoli, 1976, 1981). The use of highest or last occurrences for naming all zones instead of the most commonly used lowest or first occurrences, has been necessary because most of the examined material is composed of cuttings samples, which are commonly contaminated by younger fossil material caved from overlaying beds.

In some zones, one of the two "zone marker species" (or, exceptionally, a third one) has "LAD" in the lower part of the zone, thereby effecting a subdivision of the latter in lower and upper part. In addition to "zone marker species", also "zone diagnostic species" have been used to help identify zone boundaries. "Zone diagnostic species" are species other than "zone marker species" which also have their "LAD" at the top or in the lower part of their zone.

From the paleoenvironmental standpoint, the arenaceous benthic foraminiferal and ostracod zones are best recognized in littoral and inner neritic, mostly coarse-grained deposits; the calpionellid, calcareous benthic and planktic foraminiferal zones are best recognized particularly in finer-grained middle and outer neritic and bathyal deposits. Of course, there is, in many cases, a certain "environmental overlap" between coeval zones, in the sense that arenaceous foraminiferal and/or ostracod assemblages are present in calcareous Foraminifera zones, and vice-versa. Likewise, not all arenaceous benthic Foraminifera "zone marker species" and "zone diagnostic species" are 100% arenaceous, but they also include a few associated calcareous benthic species (belonging to the genera Trocholina and Neotrocholina) which typically characterize shallow water environments as well. Relationships between microfossil zones and lithostratigraphic units on the Scotian Shelf and Grand Banks have been described by Ascoli (1976).

Within the framework of this comprehensive zonation, the objective of this paper is to describe the most effective foraminiferal zonation so far available for the Bathonian-Valanginian interval of the studied area, having two main purposes in mind: 1) to provide a detailed zonation of the hydrocarbon-bearing formations of the Canadian Atlantic Shelf, most of which have been assigned to Late Jurassic and earliest Cretaceous age; and 2) to establish with precision, after calibration with calpionellid zonation, the position of the Jurassic-Cretaceous boundary, which for several years has been quite a contentious point among several micropaleontologists involved in the biostratigraphic study of the Canadian Atlantic Shelf.

THE ROLE OF EPISTOMINIDS

Calcareous benthic Foraminifera - as well as Ostracoda - were found most useful in providing a detailed biostratigraphic breakdown (seven zones) of the Bathonian-Valanginian interval. Arenaceous benthic Foraminifera - plus the calcareous benthic genera Trocholina and Neotrocholina normally associated with them - provide six zones, whereas planktic Foraminifera could be successfully utilized for establishing only three zones so far, respectively of Bathonian, Callovian-Oxfordian and (?Berriasian) Valanginian-Barremian age. This leaves a gap in the planktic Foraminifera zonation corresponding to the Kimmeridgian, Tithonian and Berriasian stages, where no planktic Foraminifera in situ have been recognized with confidence thus far.

The reasons why a detailed calcareous benthic Foraminifera zonation could be established in the Bathonian-Valanginian interval of the studied area, are two-fold. First, most wells examined provide a nearly continuous sequence of Middle-Late Jurassic and earliest Cretaceous marine sediments. Major unconformities and consequent stratigraphic hiatuses are in fact remarkably rare and generally limited in time in the studied wells, in most cases corresponding to a time interval of approximately a stage, or even less. Second, most sediments

of Bathonian to Valanginian age are often constituted by medium to fine-grained clastics (silty sandstones, siltstones, calcareous shales, claystones), which were generally deposited in a prevailing neritic environment, where calcareous benthic Foraminifera assemblages are typically abundant and well diversified. Within this group of Foraminifera, a high diversification at the species level has been noticed among lenticulinids (genera Lenticulina,, Planularia, Saracenaria) and particularly epistominids (genera Epistomina, Garantella and Reinholdella). Furthermore, the genus Conorboides is well diversified within the Oxfordian-Kimmeridgian interval. Consequently, the calcareous benthic Foraminifera zonation established by Ascoli (1976) for the Scotian Basin and here updated and expanded northward as far as the Flemish Pass and southward as far as the Baltimore Canyon Trough, utilizes mostly epistominids for defining all zones from Bathonian to Valanginian. The only exception is the Lenticulina saxonica bifurcilla - Lenticulina busnardoi Zone, of Valanginian age. The main reason why this zone is defined by lenticulinid instead of epistominid "zone marker species" is not because epistominid having "LAD" at the top of this zone (such as Epistomina praeornata) are lacking, but because both L. saxonica bifurcilla and L. busnardoi occur more frquently than E. praeornata in the examined wells. The latter species, however, is a good "diagnostic species" for this zone and in several cases it has been used for assigning foraminiferal assemblages deprived of both L. saxonica bifurcilla and L. busnardoi to this zone.

In conclusion, the examined area can be considered one of the most favourable of the world for studying the evolutionary sequence of the epistominid genera Epistomina, Garantella and Reinholdella during Middle-Late Jurassic and earliest Cretaceous times. This is because the latest Jurassic-earliest Cretaceous section in the examined wells is represented by mainly marine sediments, whereas in Europe the coeval deposits are composed of the dominantly marginal marine and continental Portlandian-Purbekian-Wealdian facies, which are devoid of epistominids.

In the studied area the genera Epistomina, Garantella and Reinholdella are often represented by abundant specimens and by a very high number of species (several dozen). The stratigraphically most significant species, among which there are probably several new taxa, are represented on Figure 2. The probable new species are: ?Epistomina sp. 1, Epistomina sp. 2, Epistomina sp. 3, Epistomina sp. 4, Epistomina sp. 5, Epistomina aff. E. uhligi Mjatliuk, Epistomina ?mosquensis Uhlig and Epistomina aff. E. mosquensis Uhlig (all preliminarly described in Ascoli, 1984). Epistomina aff. E. minutereticulata Espitalié and Sigal and Epistomina aff. E. praereticulata Mjatliuk have been described in Ascoli (in press-a).

On the whole, the "epistominid stock" of the Canadian Atlantic Shelf provides well delineated evolutionary sequences which can be recognized from basin to basin, and which are therefore most suitable for establishing a detailed biozonation not only for the Middle-Late

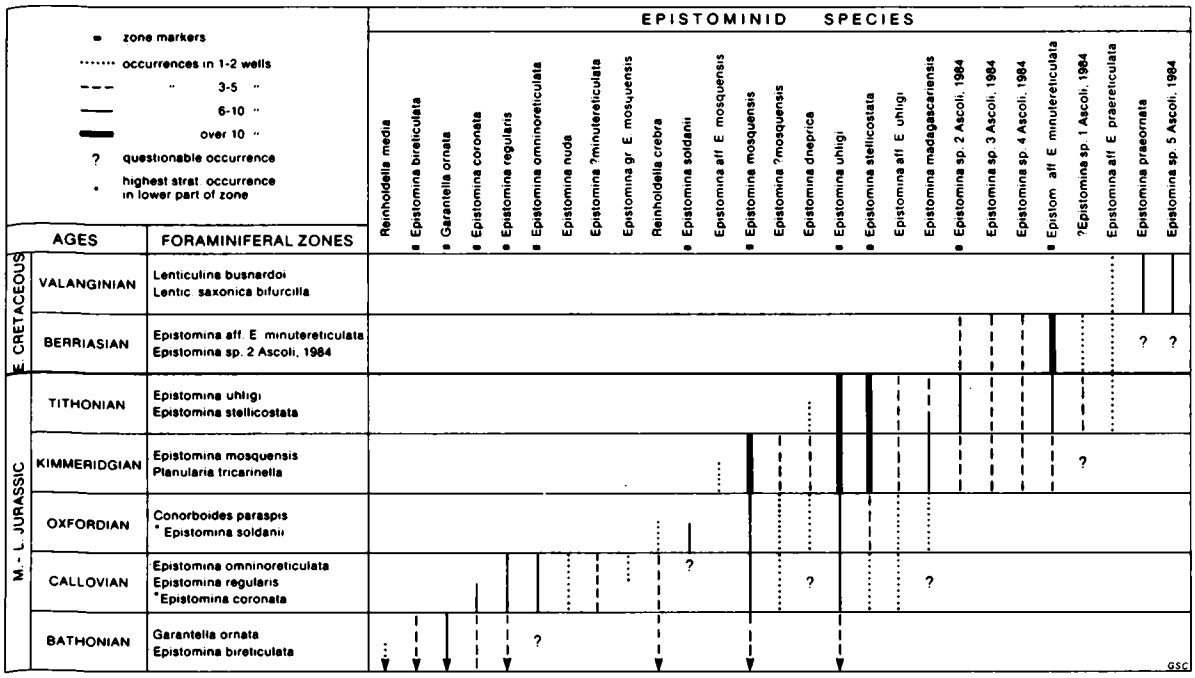

Figure 2

Foraminiferal zonation and stratigraphic ranges of selected epistominid species in the Middle-Late Jurassic and earliest Cretaceous of the Canadian and northernmost U.S. Atlantic Shelves.

Zonation des foraminifères et distributions stratigraphiques de quelques espèces d'épistominides dans le Jurassique Moyen-Supérieur et le Crétacé basal de la plateforme atlantique canadienne et de la partie plus septentrionale de la plateforme atlantique americaine.

Jurassic and earliest Cretaceous (where the Tithonian-Berriasian interval has been calibrated with the "Standard Calpionellid Biozonation"), but for most of the Early, Middle and Late Cretaceous as well (Williams et al., in press; Ascoli, in press-b).

The calcareous benthic Foraminifera (mostly epistominid) zones recently established for the Bathonian-Valanginian interval of the Canadian Atlantic Shelf (Labrador Shelf excluded), and for the adjoining northernmost part of the U.S. Atlantic Shelf, are reported on Figure 2 and listed and described in stratigraphic order, from oldest to youngest in the following chapter. For each zone, the stratigraphically most significant arenaceous benthic foraminiferal species are listed as well.

DESCRIPTION OF ZONES

1) Epistomina bireticulata - Garantella ornata Zone

The top of this zone is defined by the highest stratigraphic occurrence, or "LAD" (= last appearance datum) of Epistomina bireticulata Pazdro and Garantella ornata (Hofker). The base

of the zone corresponds to the "LAD" of the Bajocian indicators Epistomina praecursor Ohm, Garantella semiornata (Schwager) and Garantella ampasindavaensis Espitalié and Sigal (Ohm, 1967; Espitalié and Sigal, 1963/b). "Zone diagnostic species" having "LAD" at the top of this zone include Reinholdella aff. R. crebra Pazdro, Reinholdella media (Kaptarenko) and Lenticulina daphne Bielecka and Styk. "Zone diagnostic species" of associated arenaceous Foraminifera include Ammopalmula infrajurensis (Terquem).

Occurrence in wells: This zone has been recognized in ten wells of the Scotian Basin and two wells of the Jeanne d'Arc Basin. Its microfossil assemblages are particularly abundant and well diversified in the West Esperanto B-78 and South Griffin J-13 wells (Scotian Basin) and in the Terra Nova K-08 well (Jeanne d'Arc Basin). For details on occurrence of this and following zones in studied wells see Ascoli (in press-b).

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Bathonian according to Ohm (1967), Malinowska (1980) and Stam (1986). This zone is therefore assigned a Bathonian age.

2)* Epistomina coronata - Epistomina regularis - Epistomina omninoreticulata Zone

The top of this zone is defined by the "LAD" of Epistomina regularis Terquem and E. omninoreticulata Espitalié and Sigal, whereas *E. coronata Terquem has "LAD" in the lower part of the zone. The base of the zone corresponds to the top of the previously described Epistomina bireticulata - Garantella ornata Zone. "Zone diagnostic species" having "LAD" at the top of this zone include Epistomina minutereticulata Espitalié and Sigal, E. nuda Terquem, E. gr. E. mosquensis Uhlig, Epistomina sp. 6, Epistomina sp. 7, Reinholdella crebra Pazdro, Lenticulina fracta Espitalié and Sigal, Vaginulinopsis eritheles Loeblich and Tappan and Ophthalmidium carinatum Kübler and Zwingli.

Occurrence in wells: This zone has been recognized in one well of the Baltimore Canyon Trough, one well of the Georges Bank Basin, seventeen wells of the Scotian Basin and one well of the Jeanne d'Arc Basin. Its microfossil assemblages are particularly abundant and well diversified in the Acadia C-20, Penobscot L-30, MicMac H-86 and Oneida O-25 wells (Scotian Basin) and in the Rankin M-36 well (Jeanne d'Arc Basin).

*All species preceeded from now on by the asterisk *have "LAD" in the lower part of their respective zone.

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Callovian according to Pazdro (1969), Ascoli (1976) and Malinowska (1980). This zone is therefore assigned a Callovian age.

3) *Epistomina soldanii - Conorboides paraspis Zone

The top of this zone is defined by the "LAD" of Conorboides paraspis (Schwager), whereas *Epistomina soldanii Ohm has "LAD" in the lower part of the zone. The base of the zone corresponds to the top of the previously described *Epistomina coronata - Epistomina regularis - Epistomina omninoreticulata Zone. "Zone diagnostic species" having "LAD" at the top of this zone include Conorboides scutuliformis (Seibold and Seibold), Lenticulina dilecta Loeblich and Tappan, L. audax Loeblich and Tappan, Saracenaria cornucopiae (Schwager), Ophthalmidium strumosum (Gümbel) and Patellinella sp. 2. By contrast, *?Reinholdella crebra Pazdro, *Astacolus ectypus Loeblich and Tappan, *Saracenaria triquetra Gümbel, *Marginulinopsis phragmites Loeblich and Tappan and *Planularia enodis Loeblich and Tappan have "LAD" in the lower part of the zone. "Zone diagnostic species" of associated arenaceous Foraminifera and trocholinids include Trocholina transversarii Paalzow, Textularia foeda Reuss, Verneuilinoides aff. V. tryphera Loeblich and Tappan, Ammobaculites spongiphilus Seibold and Seibold, A. venustus Loeblich and Tappan, *Haplophragmoides aff. canui Cushman, *Gaudryina heersumensis Lütze and *Trocholina conica (Schlumberger).

Occurrence in wells: This zone has been recognized in one well of the Baltimore Canyon Trough, one well of the Georges Bank Basin, fourteen wells of the Scotian Basin and one well of the Jeanne d'Arc Basin. Its microfossil assemblages are particularly abundant and well diversified in the Penobscot L-30, Emerillon C-56 and Dauntless D-35 wells (Scotian Basin).

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Oxfordian according to Ohm (1967), Seibold (1960) and Moullade (1984). This zone is therefore assigned an Oxfordian age.

4) Planularia tricarinella - Epistomina mosquensis Zone

The top of this zone is defined by the "LAD" of Planularia tricarinella (Reuss) and Epistomina mosquensis (Uhlig). The base of the zone corresponds to the top of the previously described *Epistomina soldanii - Conorboides paraspis Zone. "Zone diagnostic species" having "LAD" at the top of this zone include Epistomina ?mosquensis by Ascoli 1984, Lenticulina brueckmanni Mjatliuk, L. vistulae Bielecka and Pozaryski, Conorboides marginata Lloyd, C. aff. C.

paraspis (Schwager), Conorboides sp. 1 and Eoguttulina liassica (Strickland). By contrast, *Epistomina aff. E. mosquensis by Ascoli 1984 and *Eoguttulina inovroclaviensis (Bielecka and Pozaryski) have "LAD" in the lower part of the zone. "Zone diagnostic species" of associated arenaceous Foraminifera and trocholinids include Neotrocholina solecensis (Bielecka and Pozaryski), Alveosepta aff. A. jaccardi (Schrodt), A. gr. A. jaccardi (Schrodt), Everticyclammina sp. 1, *Alveosepta jaccardi (Schrodt), *Valvulina cf. V. meentzeni Klingler, *Gaudryina gr. G. heersumensis Lütze and *Everticyclammina sp. 2.

Occurrence in wells: This zone has been recognized in one well of the Baltimore Canyon Trough, two wells of the Georges Bank Basin, fifteen wells of the Scotian Basin, six wells of the Jeanne d'Arc Basin and one well of the Carson Basin. Its microfossil assemblages are particularly abundant and well diversified in the COST G-2 well (Georges Bank); Mohican I-100, Moheida P-15 and Oneida O-25 (Scotian Basin); Hibernia P-15 and Hibernia B-08 (Jeanne d'Arc Basin) and Bonnition H-32 (Carson Basin).

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Kimmeridgian ("sensu gallico") according to Ascoli (1976), Jansa et al. (1980), Lloyd (1962), Mjatliuk (1939) and Bielecka and Pozaryski (1954). In so assigning to this zone a Kimmeridgian age, we should, however, take into account the fact that the top of the Kimmeridgian "sensu gallico" corresponds to the top of the Early Kimmeridgian "sensu anglico" (cf. Jansa et al., 1980, p. 97).

5) Epistomina stellicostata - Epistomina uhligi Zone

The top of this zone is defined by the "LAD" of Epistomina stellicostata Bielecka and Pozaryski and Epistomina uhligi Mjatliuk. The base of the zone corresponds to the top of the previously described Planularia tricarinella - Epistomina mosquensis Zone. "Zone diagnostic species" having "LAD" at the top of this zone include Epistomina aff. E. uhligi by Ascoli 1984, E. madagascariensis (Espitalié and Sigal) (pro Epistomina alveolata Mjatliuk var. madagascariensis Espitalié and Sigal, 1963), Neobulimina varsoviensis Bielecka and Pozaryski, Eoguttulina exserta (Berthelin), Eoguttulina sp. 1 and Patellinella sp. 1. "Zone diagnostic species" having "LAD" in the lower part of the zone include *Epistomina dneprica Kaptarenko, *Lenticulina quenstedti (Gümbel), *L. varians (Bornemann), *L. polonica Wisniowski and *Planularia beierana (Gümbel). "Zone diagnostic species" of associated arenaceous Foraminifera and trocholinids include Anchispirocyclina lusitanica (Egger), Haplophragmoides canui Cushman, Neotrocholina gr. N. alpina (Leupold), N. elongata (Leupold), Trocholina sp. 1 by Ascoli 1976 and *Ammobaculites coprolithiformis (Schwager).

Occurrence in wells: This zone has been recognized in one well of the Baltimore Canyon Trough, two wells of the Georges Bank Basin, twenty-three wells of the Scotian Basin, five wells of the Jeanne d'Arc Basin and one well of the Carson Basin. Its microfossil assemblages are particularly abundant and well diversified in the COST G-2 well (Georges Bank Basin), Mohican I-100 (Scotian Basin), Hibernia P-15 (Jeanne d'Arc Basin) and Bonnition H-32 (Carson Basin).

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Tithonian according to Bielecka and Pozaryski (1954), Jansa et al. (1980) and Ascoli et al. (1984). This zone has therefore been assigned a Tithonian age. The stratigraphic ranges of foraminiferal markers in this zone have been calibrated with coexisting calpionellid marker species in the Bonnition H-32 well (Carson Basin) (Jansa et al., 1980) and in the COST G-2 well (Georges Bank Basin) (Ascoli et al., 1984). The Tithonian-Berriasian boundary, which is present in the middle part of calpionellid Zone "B", is at about 7500 ft (2285 m) in the Bonnition well; the "LAD" of Epistomina uhligi, Neobulimina varsoviensis and Neotrocholina alpina have been observed between 7650 and 7700 ft (2332 and 2347 m) in the same well, where A. lusitanica has been found as high as 7592 ft (24314 m). In the COST G-2 well, calpionellid zonation establishes the Tithonian-Berriasian boundary at about 5700 ft (1737 m). The "LAD" of Epistomina uhligi and E. stellicostata has been observed at 5856 ft (1785 m) in this well. Therefore, the Jurassic-Cretaceous boundary established by calcareous benthic Foraminifera nearly coincides (within 150 ft = 46 m) with that established by calpionellids.

6) Epistomina sp. 2 Ascoli 1984 - Epistomina aff. E. minutereticulata Zone

The top of this zone is defined by the "LAD" of Epistomina sp. 2 by Ascoli 1984 and Epistomina aff. E. minutereticulata Espitalié and Sigal by Ascoli (in press-a). The base of the zone corresponds to the top of the previously described Epistomina stellicostata - Epistomina uhligi Zone. "Zone diagnostic species" having "LAD" at the top of this zone include Epistomina aff. E. praereticulata Mjatliuk by Ascoli (in press-a), ?Epistomina sp. 1 by Ascoli 1984, Epistomina sp. 3 by Ascoli (1984), Epistomina sp. 4 by Ascoli (1984), Astacolus calliopsis (Reuss), A. vacillantes Espitalié and Sigal and Lenticulina haesitans Espitalié and Sigal. "Zone diagnostic species" of associated arenaceous Foraminifera include Ammobaculites alaskensis Tappan.

Occurrence in wells: This zone has been recognized in one well of the Georges Bank Basin, eight wells of the Scotian Basin, seven wells of the Jeanne d'Arc Basin and one well of the Flemish Pass. Its microfossil assemblages are particularly abundant and well diversified in the COST G-2 and Oneida O-25 wells (Georges Bank and Scotian Basins), in the Hibernia B-08 and Hibernia P-15 wells (Jeanne d'Arc Basin) and in the Gabriel C-60 well (Flemish Pass).

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Berriasian according to Jansa et al. (1980), Ascoli (1984), Ascoli et al. (1984) and Ascoli (in press-a). This zone has therefore been assigned a Berriasian age. In the COST G-2 well (Georges Bank Basin), the "LAD" of Epistomina aff. E. minutereticulata, Epistomina sp. 3 and Epistomina sp. 4 corresponds to that of associated calpionellids of Zone "D" of Late Berriasian-earliest Valanginian age (Ascoli et al., 1984). In the Bonnition H-32 well (Carson Basin), the "LAD" of ?Epistomina sp. 1, Epistomina sp. 2, Epistomina sp. 3 and Epistomina aff. E. minutereticulata occurs 25 m above calpionellid assemblages of upper part of Zone "B" (Early Berriasian), i.e. in sediments of probable Middle Berriasian age (Ascoli, in press-a). Calpionellid zonation therefore confirms the approximate Late Berriasian age given to the "LAD" of the above mentioned foraminiferal zone markers and "zone diagnostic species".

7) Lenticulina saxonica bifurcilla - Lenticulina busnardoi Zone

The top of this zone is defined by the "LAD" of Lenticulina saxonica bifurcilla Bartenstein and Brand and Lenticulina busnardoi Moullade. The base of the zone corresponds to the top of the previously described Epistomina sp. 2 - Epistomina aff. E. minutereticulata Zone. "Zone diagnostic species" having "LAD" at the top of this zone include Epistomina praeornata Bartenstein and Brand, E. aff. E. praeornata Bartenstein and Brand, E. aff. E. tenuicostata Bartenstein and Brand, E. aff. E. praereticulata Mjatliuk, Epistomina sp. 5 by Ascoli 1984, Conorboides aff. C. hofkeri (Bartenstein and Brand), Saracenaria valanginiana Bartenstein and Brand, Marginulina bettenstaedti Bartenstein and Brand, Paalzowella feifeli (Paalzow) and Marginulinopsis sp. 1.

Occurrence in wells: This zone has been recognized in one well of the Baltimore Canyon Trough, two wells of the Georges Bank Basin, seventeen wells of the Scotian Basin, nine wells of the Jeanne d'Arc Basin, one well of the Carson Basin and one well of the Flemish Pass. Its microfossil assemblages are particularly abundant and well diversified in the Mohican I-100, Oneida O-25 and Intrepid L-80 wells (Scotian basin) and in the Bonnition H-32 well (Carson Basin).

Age: The zone markers and "zone diagnostic species" of this zone have "LAD" in the Valanginian according to Bartenstein and Brand (1951), Ascoli (1976), Ascoli et al. (1984), Moullade (1984) and Ascoli (in press-a). This zone has therefore been assigned a Valanginian age.

The relationships between the stratigraphic ranges (and particularly the "LADS") of the Middle-Late Jurassic and Early Cretaceous species of the genus Epistomina on the Canadian Atlantic Shelf and those of their European counterparts have been outlined by Ascoli (1976) in his biostratigraphic study of ten wells from the Scotian Basin. In his paper (p. 723) Ascoli pointed out that "All European Jurassic species of Epistomina (except E. regularis and E. soldanii) show their highest stratigraphic occurrence later on the Scotian Shelf than in western Europe (Germany) and much later than in eastern Europe (Poland and U.S.S.R.).... By contrast, all the Early Cretaceous and Late Cretaceous western European Epistomina species, have their highest stratigraphic occurrences on the Scotian Shelf at the same time as in western Europe."

"LADS" of epistominids across the North Atlantic appear now much closer to one another when the stratigraphic ranges of eastern Canadian and European species of the genus Epistomina are re-examined and expanded to the whole epistominid stock (i.e. including the genera Garantella and Reinholdella) and updated for the Bathonian-Valanginian interval of the 46 wells examined in the study area (Fig. 1).

On Figure 2 there are 15 espistominid species identified with confidence (i.e. excluding all species reported under open nomenclature and those preceded by question marks and connotations of "affinity" or "ex group"). Two of these were originally described from Madagascar (Epistomina omninoreticulata and E. madagascariensis) and the remaining 13 from Europe. Of these 13 species, nine (Reinholdella media, Epistomina bireticulata, Garantella ornata, E. coronata, E. regularis, E. nuda, E. soldanii, E. stellicostata and E. praeornata) have on the Canadian Atlantic Shelf the same "LAD" - with a half stage approximation - as in Europe. The European stratigraphic ranges considered for this comparison are those reported by Ohm (1967), Pazdro (1969), Bartenstein (1979), Malinowska (1980), Jenkins and Murray (1981) and Grigelis (1985a and 1985b). The remaining four European species have, by contrast, "LAD" consistently lower in Europe than on the eastern Canadian offshore: Reinholdella crebra in the Early Callovian vs. Early Oxfordian, Epistomina mosquensis in the Late Oxfordian vs. Late Kimmeridgian, E. dneprica in the Late Callovian vs. Early Tithonian, and E. uhligi in the Late Kimmeridgian vs. Late Tithonian. This would appear to confirm in part what was observed previously by Ascoli (1976). For these four species, differences in stratigraphic range between Europe and eastern Canada appear, however, almost negligeable if examined in a wider context, i.e. also taking into consideration geographic occurrences outside Europe and between Europe and Canada (circum-Atlantic D.S.D.P. Sites), and not restricting comparisons to only the typical specimens of each species, but extending them to specimens belonging to species varieties and/or subspecies as well. For instance, our Callovian-Early Oxfordian specimens of Reinholdella crebra are identical to those reported as "Reinholdella crebra var." (i.e. specimens of R. crebra slightly different from the typical ones, but still within the species variability range) by Gradstein (1976), and that range

as high as the top of the Callovian on the central and eastern Grand Banks. Kimmeridgian and possibly even Tithonian occurrences of Epistomina mosquensis have been reported from Madagascar by Espitalié and Sigal since 1963, and from northwestern Atlantic D.S.D.P. Sites 99, 100 and 105 by Luterbacher (1972). Epistomina uhligi has been reported, again by Espitalié and Sigal (1963), under the synonym of Epistomina ventriosa n. sp. (fide Ohm, 1967) from the Tithonian of Madagascar. Moreover, Kimmeridgian-Tithonian occurrences of E. uhligi - Epistomina aff. E. uhligi are also known from both the northwestern Atlantic (Luterbacher, 1972; Gradstein, 1978: D.S.D.P. Site 534) and from the northeastern Atlantic (Sliter, 1980: D.S.D.P. Site 416A).

Considering now the two Epistomina species originally described from Madagascar which also have different "LAD" in eastern Canada (Kimmeridgian in Madagascar vs. Callovian in Canada for E. omninoreticulata and Kimmeridgian vs. Tithonian for E. madagascariensis), it should be pointed out that our specimens of E. omninoreticulata are not exactly identical to the most typical ones from Madagascar. but rather intermediate between the Madagascar specimens and those belonging to a very closely related species, E. minutereticulata. In Madagascar E. minutereticulata has not been reported higher than Callovian, i.e. as our specimens referred to E. omninoreticulata. As to E. madagascariensis (originally described in 1963 by Espitalié and Sigal as "Epistomina alveolata Mjatliuk var. madagascariensis n. v."), this species ranges in Madagascar as high as top of the Kimmeridgian "sensu anglico", which corresponds to the base of the Middle Tithonian (cf. Jansa et al., 1980, p. 97).

To sum up, six species of Epistomina and Reinholdella from the "Old World" appear at first to differ in "LAD" by at least one stage with respect to their counterparts from the Canadian Atlantic Shelf. However, after taking into consideratioin their entire array of varieties and subspecies, and their D.S.D.P. circum-Atlantic occurrences as well, only one species - Epistomina dneprica - still shows such a difference in stratigraphic range. In the particular case of E. dneprica, the absence of this typically middle-outer neritic species in the Oxfordian to Early Tithonian neritic sediments of eastern Europe and U.S.S.R. is probably due to Boreal environmental conditions which must have existed in this region not only from Oxfordian to Early Tithonian times, but also later, thereby excluding the existence of Tethyan calpionellids from Late Tithonian to Valanginian. In contrast, environmental conditions of the Tethyan type, which were well established on the Canadian Atlantic Shelf by Oxfordian time, allowed the existence of E. dneprica, and of calpionellids during Late Tithonian-Berriasian times in this region. The existence of Boreal conditions in eastern Europe and U.S.S.R. probably accounts for the absence of Epistomina mosquensis in the Kimmeridgian and of E. uhligi in the Kimmeridgian and Tithonian neritic sediments of these regions as well.. By contrast, the absence of practically the entire "Epistomina stock" in the Kimmeridgian ("sensu gallico")-Tithonian of West Germany and in the

Middle-Late Kimmeridgian ("sensu anglico")-Portlandian of England, where a transition between Boreal and Tethyan conditions existed at that itme, appears to have been caused by adverse environmental conditions of a different kind. These were the onset of mainly coarse clastic shallow water sedimentation which caused the deposition of a thick, wide-spread section of inner neritic-littoral and marginal marine-continental sediments during most of the Middle-Late Kimmeridgian and Portlandian. This sedimentation mode persisted across the Jurassic-Cretaceous boundary and into the earliest Cretaceous with the deposition of the Purbeckian and Wealdian facies, thereby preventing the existence of the typically neritic genus Epistomina in the whole area between West Germany and the British Isles.

The above mentioned results suggest that major differences in stratigraphic range between Middle-Late Jurassic-earliest Cretaceous epistominid species within Europe, between Europe and eastern Canada through D.S.D.P. circum-Atlantic sites, and even between Europe or Canada and Madagascar, are very rare, and, whenever present, are due to major differences in paleoenvironmental conditions existing at that time in some specific areas.

CONCLUSIONS

1. Comparison of highest stratigraphic occurrences of epistominids from the Canadian and adjoining northernmost U.S. Atlantic Shelf with those of their counterparts from Europe, Madagascar and circum-North Atlantic D.S.D.P. Sites, has shown almost identical ranges for nearly all species across the Atlantic, whenever neritic facies and Tethyan or Tethyan transitional to Boreal regions are compared. Among these regions, the Canadian Atlantic Shelf provides the most abundant and diversified evolutionary record of epistominid species for the Bathonian to Valanginian section, and within it, even more so for the Tithonian-Berriasian interval. Since this record is far more diversified and recognizable on the Canadian Atlantic Shelf than that of the associated lagenids and ceratobuliminids, the genera Garantella, Reinholdella and particularly Epistomina have the stratigraphic potential to effect a zonation approximately at the half-stage level not only for the Bathonian-Valanginian interval (Fig. 2), but probaly also for the whole Bajocian-Albian section in this region (Ascoli, in press-b).
2. The epistominid zonation presented here, mostly at the stage level, is only an additional step towards the establishment of a zonation at the half-stage level. Moreover, comparison with literature and European epistominid type-material, indicates that this zonation appears well suited to zone the coeval neritic sediments on the opposite side of the Atlantic as well, both in Europe (for the Bathonian to Oxfordian, Tithonian and Valanginian stages), and in the easternmost North Atlantic - Site 416A - (for the Kimmeridgian-Tithonian stages). As to the Berriasian, of the five species of Berriasian

epistominids observed on the eastern Canadian offshore (Fig. 2), only two, Epistomina sp. 2 and Epistomina sp. 3 by Ascoli (1984), have so far been recognized in the Kimmeridgian sediments of Portugal (Stam, pers. comm.). Epistominids-bearing sediments of Berriasian age seem to be missing in Portugal, as is the case everywhere else in western Europe.

3. The practical applicability in Europe of the mostly epistominid zonation presented here has been confirmed by Moullade (1984). In his European-North Atlantic smaller benthic Foraminifera zonation for the Late Jurassic-Early Cretaceous sediments of Tethyan facies, he used several of the author's "zone marker species", which have been utilized previously for zonation purposes on the Canadian Atlantic Shelf since 1976. These species are Conorboides paraspis (used for Moullade's "paraspis" Zone of Oxfordian age), Epistomina uhligi (for his "uhligi" Zone of Tithonian age) and Lenticulina busnardoi (for his "busnardoi" Zone of Early Valanginian age, this zone being the only one based on the zonal marker's first instead of last occurrence datum).

4. However successful the zonation presented here may be in terms of applicability in Europe, within the North Atlantic area and for effecting trans-Atlantic stratigraphic correlations, a lot of work still lies ahead to reach the desired half-stage zonal resolution and to extend the zonation downward to include at least the Bajocian (for which biostratigraphic occurrences of suitable foraminiferal marker species are presently sparse) and upward to include the whole Early Cretaceous, for which fossil occurrences and microfaunal diversity are, fortunately, much higher. Such a task is made even more difficult by the inherent nature of the samples available for study, which are almost entirely contaminated well cuttings, hardly well suited to provide a reliable biostratigraphic picture of any subsurface section represented by them. In order to overcome this problem, work is now in progress to establish a proper identification of our preliminarily identified species and to correlate our well cuttings fossil occurrences with more reliable ones from in situ outcropping sections from Europe. Samples from Bajocian to Callovian type-localities from Poland, as well as U.S.S.R. samples from the Oxfordian-Berriasian interval, are being compared with our coeval material from the eastern Canadian offshore. The first results of these comparisons are encouraging, and suggest that a further refinement of our present zonation may be achieved in the near future.

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