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FORAMINIFERAL-OSTRACOD LATE JURASSIC BIOZONATION OF THE SCOTIAN SHELF

by

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ABSTRACT

The writer's 1977 foraminiferal and ostracod biozonation of the Scotian Shelf has been updated and refined for the Late Jurassic interval and extended to the East Newfoundland Basin of the Grand Banks. The use of four categories of microfossils (planktonic Foraminifera, calcareous benthonic Foraminifera, arenaceous benthonic Foraminifera and Ostracoda) makes possible the correlation of coeval deposits of widely different facies (littoral-inner neritic, outer neritic and bathyal).

Planktonic Foraminifera provide one assemblage zone, of Callovian-Oxfordian age; calcareous benthonic Foraminifera three zones, of Oxfordian, Kimmeridgian and Tithonian age; arenaceous benthonic Foraminifera two zones, of Oxfordian-Early Kimmeridgian and Late Kimmeridgian-Tithonian age, and Ostracoda three zones, of Oxfordian, Kimmeridgian and Tithonian age. The combined use of these different zones has effected good stratigraphic correlation between 19 wells of the Scotian Shelf and one well of the East Newfoundland Basin (Mobil-Gul Bonnition H-32), even when dealing with poor foraminiferal and ostracod assemblages.

Calpionellid assemblages have been studied in detail in Shell Mohican I-100 (Scotian Shelf) and in Bonnition H-32 and have allowed spearation of the Late Tithonian from the Early Berriasian and a precise definition of the Jurassic-Cretaceous boundary in the latter well. The established calpionellid biozonation - identical to the "standard biozonation" of the Mediterranean area - permitted calibration of the stratigraphic ranges of foraminiferal and ostracod marker species at and near the Jurassic-Cretaceous boundary. The top of the Tithonian has been placed at the highest stratigraphic occurrence of Anchispirocyclina lusitanica (Egger),

which in Bonnition H-32 corresponds to the lower part of calpionellid Zone "B".

The combined use of foraminiferal, ostracod and calpionellid biozonations has been found to provice excellent stratigraphic definition across the Jurassic-Cretaceous boundary, from the East Newfoundland Basin to the Georges Bank area. This definition is undoubtedly better than that attainable by using one category of microfossils alone.

INTRODUCTION

The first foraminiferal-ostracod biozonation of the Scotian Shelf (Ascoli, 1977) comprised ten deep exploratory wells studied in detail: Shell Mohawk B-93, Shell Naskapi N-30, Shell Mohican I-100, Shell Oneida O-25, Shell Onondaga E-84, Mobil Sable Island C-67, Shell MicMac H-86, Shell Wyandot E-53, Mobil Dauntless D-35 and Amoco IOE Puffin B-90 (western Grand Banks). Since then, twelve additional wells from the Scotian Shelf and two from the Grand Banks (East Newfoundland Basin) were micropaleontologically studied in detail by the writer. These wells are Shell Cree E-35, Mobil-Tetco-Pex Thebaud I-94, Mobil-Tetco-Pex Migrant N-20 and Texaco-Shell Intrepid L-80 (Scotian Shelf) and Mobil-Gulf Bonnition H-32 (East Newfoundland Basin), which were examined in their entirety. Furthermore, of eight selected wells from the Scotian Shelf only the interval between approximately 500' above the top of the Abenaki Formation and total depth was examined in detail. This was done to establish as precisely as possible foraminiferal-ostracod zones, ages and paleoenvironments of this formation in these wells. Listed in geographic order from SW to NE, these wells are:

Shell Moheida P-15, Chevron Acadia K-62, Shell Demascota G-32, Mobil-Tetco Cohasset D-42, Shell Penobscot L-30, Shell Abenaki J-56, Mobil-Tetco-Texaco Citnalta I-59 and Union _et al._ Jason C-20. Finally, of the Chevron _et al._ Hibernia P-15 well (still confidential), the interval between 2400 m and T.D. was examined. A location map of all wells studied is shown on Fig. I.

The amount of new biostratigraphic data acquired in the present study is considerable and particularly is this true for the Late Jurassic. This made it therefore convenient to release the present report.

After the study of over one thousand additional samples of cuttings, sidewall cores and conventional cores, the stratigraphic ranges of several foraminiferal and ostracod species used as marker fossils turned out to be greater than previously known: the range of some marker species remained unchanged, while numerous others, new or previously not considered stratigraphically useful, were delineated as reliable stratigraphic markers.

At the same time, the biostratigraphic study of calpionellids from the Bonnition H-32 well established with great precision the Jurassic-Cretaceous boundary in the East Newfoundland Basin and allowed calibration of Scotian Shelf-Grand Banks foraminiferal-ostracod stratigraphic markers with the "Calpionellid Standard Biozonation" in the Tithonian-Berriasian interval (see Alleman _et al._, 1972 and Jansa, Remane and Ascoli, 1980). Furthermore, detailed examination of conventional core no. 3 (dated Kimmeridgian) in Mohican I-100 and conventional core no. 2 (dated Oxfordian) in Penobscot L-30, provided good calibration with in place, uncontaminated material, for the stratigraphic ranges of the writer's foraminiferal-ostracod marker species in the Oxfordian-Kimmeridgian.

Finally, the writer's entire ostracod collection from the Scotian

Shelf has been compared with the type material of the Oxfordian, Kimmeridgian and Purbeckian stratotypes, enabling him to check correct species identification and to calibrate their stratigraphic ranges according to their occurrence in the European stratotypes. This comparison was possible through the courtesy of Dr. R. H. Bate (British Museum of Natural History, London), Dr. T. I. Kilenyi (Sir John Cass School of Science and Technology, London) and Dr. J. W. Neale (Geology Department, Hull University).

The main benefits of the above study has been a considerable inprovement in the resolution of the foraminiferal-ostracod biozonation of the Late Jurassic for the Scotian Shelf as proposed in Ascoli (1977). The latter biozonation has been updated and revised and the results are outlined in the following pages, where the revised Late Jurassic zones are described and compared with the 1977 zones and extended to the Grand Banks area as far northeast as the East Newfoundland Basin (Bonnition H-32 well).

DESCRIPTION OF ZONES

All zones described here are "assemblage zones" as defined and described in Ascoli (1977, p. 658-672) and, as in that paper, are subdivided into four main groups: "planktonic Foraminifera zones", "calcareous benthonic Foraminifera zones", "arenaceous benthonic Foraminifera zones" and "ostracod zones". This permits recognition of the zones in all three prevailing marine environments on the Scotian Shelf (littoral-inner neritic, with prevailing coarse sedimentation; outer neritic, with prevailing fine sedimentation, and bathyal, and thereby simplifying correlation. The areanaceous benthonic Foraminifera and ostracod zones are most applicable in littoral and inner neritic environments; the calcareous benthonic Foraminifera and to a lesser degree the ostracod zones in outer neritic environment, and the planktonic Foraminifera and calcareous benthonic Foraminifera zones in bathyal environment. For relationships between the biostratigraphic zones and lithologic formations on the Scotian Shelf-Grand Banks, see Ascoli, 1977 (pp. 655 and 707-713).

All Late Jurassic revised zones and "zone marker species" are listed in Fig. 4. In this figure, as well as in the following pages, the number 2 (in parenthesis (2) in the test) following the name of a "zone marker" means "having highest stratigraphic occurrence at the top of its zone", whereas the number 1 (in parenthesis (1) in the text) means "having the highest stratigraphic occurrence in the lower part of its zone". Whenever zones markers are not followed by the numbers (1) and (2), they always range to the top of the zone. Furthermore, Figs. 2 and 3 give the ranges of all foraminiferal and ostracod "zone markers" and "zone diagnostic species" (i.e. species other than zone markers but having their highest stratigraphic occurrence in a particular zone) which are mentioned in the desciption of the zones, but were not reported in Ascoli (1977) and in Jansa, Remane and Ascoli (1980). Finally, condensed synonymies and bibliographic references of all zone marker species are reported in alphabetic order in Appendix on page 21.

1. Planktonic Foraminifera Zones

The "Globigerina" ex gr. oxfordiana Zone" of Callovian-Oxfordian age erected by Ascoli (1977) remains unchanged and is not described here nor referenced in Fig. 4, since the upper part only of this zone is of Late

Jurassic age. The "zone diagnostic species" of the Oxfordian part of this zone are listed and discussed under the "Epistomina soldanii - Conorboides paraspis Zone" which is described on this page.

2. Calcareous Benthonic Foraminifera Zones

Environment of deposition

As already pointed out in Ascoli (1977), the "calcareous benthonic Foraminifera zone markers" and "zone diagnostic species" reported in the following pages may be present in shallow water environments close to shore. However, they generally characterize deeper-water environments distant from shore (outer neritic) and characterized by mostly fine-grained sediment which represent slow accumulation.

a) Epistomina soldanii (1) - Conorboides paraspis (2) Zone

The top of this zone is defined by the highest stratigraphic occurrence of Conorboides paraspis (Schwager). The base of the zone corresponds to the top of the underlying Epistomina coronata - Epistomina omninoreticulata Zone (Ascoli, 1977). Diagnostic species having highest stratigraphic occurrence at the top of the zone include Lenticulina dilecta Loeblich and Tappan, Astacolus aff. ectypus Loeblich and Tappan, Saracenaria cornucopiae (Schwager, S. triquetra (Guembel), Conorboides scutuliformis (Seibold and Seibold), Ophthalmidium ex gr. strumosum (Guembel) and Patellinella sp. 2.

Beside the zone marker Epistomina soldanii, diagnostic species having their highest stratigraphic occurrence in the lower part of the zone include Reinholdella crebra Pazdro, Lenticulina audax Loeblich and Tappan and Marginulinopsis phragmites Loeblich and Tappan.

Occurrence in wells (listed from SW to NE): Mohican I-100, Acadia K-62, Oneida O-25, Migrant N-20, Penobscot L-30, Wyandot E-53 and Dauntless D-35 (Figs. 5 and 6).

Age: The above listed zone markers and "zone diagnostic species" according to Loeblich and Tappan (1950a, 1950b), Seibold and Seibold (1960), Wall (1960) and Ascoli (1977), have their highest stratigraphic occurrence in the Oxfordian. The zone has therefore been dated Oxfordian.

Remarks: This zone replaces the "*Lenticulina varians* - *L. quenstedti* Zone" of Ascoli (1977), which was originally assigned an Oxfordian age. However, both the zonal markers *L. varians* and *L. quenstedti* have been recently found in sediments of Kimmeridgian age. Consequently the zone is herein named after the two species *Epistomina soldanii* and *Conorboides paraspis* which are known only from the Oxfordian (Ohm, 1967; Seibold and Seibold, 1960).

b) *Lenticulina quenstedti - Epistomina mosquensis* Zone

The top of this zone is defined by the highest stratigraphic occurrence of *Lenticulina quenstedti* (Guembel) and *Epistomina mosquensis* Uhlig. The latter species has its highest occurrence respectively 456' and 500' higher than that of the world wide Early Kimmeridgian indicator *Alveosepta jaccardi* (Schrodt) (see p. 13) in Mohican I-100 and Bonnition H-32. The base of the zone corresponds to the top of the underlying *Epistomina soldanii* - *Conorboides paraspis* Zone. Diagnostic species having their highest stratigraphic occurrence at the top of this zone include *Epistomina* ex gr. *mosquensis* Uhlig, *E.* aff. *uhligi* Mjatliuk, *E. praereticulata*

Mjatliuk, Lenticulina varians Bornemann, L. vistulae Bielecka and Pozaryski, L. brueckmanni Mjatliuk, Planularia tricarinella (Reuss), Conicospirillina basiliensis Mohler, Conorboides marginata Lloyd and Trocholina solecensis Bielecka and Pozaryski. Diagnostic species having their highest stratigraphic occurrence in the lower part of this zone include Lenticulina polonica Wisniowski and Eoguttulina inovroclaviensis (Bielecka and Pozaryski).

Occurrence in wells: Mohican I-100, Oneida O-25, Demaskota G-32, Cohasset D-42, Migrant N-20, Abenaki J-56, Citnalta I-59, Dauntless D-35 and Bonnitnon H-32 (East Newfoundland Basin) (Figs. 5 and 6).

Age: The above listed zone markers and "zone diagnostic species", according to Bielecka and Pozaryski (1954), Ascoli (1977) and Jansa, Remane and Ascoli (1980), have their highest stratigraphic occurrence in the Kimmeridgian. This zone, therefore, has been assigned a Kimmeridgian age.

Remarks: This zone replaces in part the "Epistomina madagascariensis - Epistomina dneprica Zone" (of Kimmeridgian-Early Tithonian age) erected by Ascoli (1977) and is equated with the "Kimmeridgian" of the French and German authors, which is defined by the top of the "pseudomutabilis" ammonite zone (zonation of Arkell, 1956), or by the top of the "autissiodorensis" ammonite zone (revised zonation reported by Kilenyi, 1978). The top of both zones corresponds to the top of the Early Kimmeridgian in the type-locality in England (Jansa, Remane and Ascoli, 1980, pp. 96, 111). The French-German definition of the Kimeridgian is preferred to the British since this allows corelation of the top of the Kimmeridgian with the base of the Tithonian and also places the top of the Jurassic at the top of the

Tithonian (Jansa, Remane and Ascoli, 1980, pp. 96, 97, 111). Close similarity of the Scotian Shelf Kimmeridgian with the Early Kimmeridgian of the "Kimmeridge Clay" has been checked through a direct comparison of the Scotian Shelf Kimmeridgian Ostracoda with those of the "Kimmeridge Clay".

c) Epistomina stellicostata - Epistomina uhligi Zone

The top of this zone is defined by the highest stratigraphic occurrence of Epistomina stellicostata Bielecka and Pozaryski and Epistomina uhligi Mjatliuk. The base of the zone corresponds to the top of the underlying Lenticulina quenstedti - Epistomina mosquensis Zone. Diagnostic species having highest stratigraphic occurrence at the top of this zone include Conorboides aff. marginata Lloyd, Eoguttulina exserta (Berthelin), Neobulimina varsoviensis Bielecka and Pozaryski, Trocholina alpina (Leupold) and Trocholina sp. 1. Diagnostic species which have their highest stratigraphic occurrence in the lower part of this zone include Epistomina dneprica Kaptarenko, Epistomina madagascariensis (Espitalié and Sigal) and Patellinella sp. 1.

Occurrence in wells: Mohican I-100, Naskapi N-30, Moheida P-15, Oneida O-25, Demaskota G-32, Cree E-35, Thebaud I-94, Migrant N-20, Sable Island C-67, Penobscot L-30, Citnalta I-59, MicMac H-86, Dauntless D-35 and Bonnition H-32 (East Newfoundland Basin) (Figs. 5 and 6).

Age: The above listed zone markers and "zone diagnostic species", according to Bielecka and Pozaryski (1954), Groiss (1967) and Ascoli (1977) have their highest stratigraphic occurrence in the Tithonian. This zone therefore has been assigned a Tithonian age. The stratigraphic ranges of some foraminiferal marker species of this zone found in Bonnition H-32 (East Newfoundland Basin) have been calibrated with ranges of calpionellid marker species identified in the same well. According to evidence from the latter fossils, the Tithonian-Berriasian boundary (corresponding to the middle part of calpionellid zone "B") is at about 7500' (Jansa, Remane and Ascoli 1980, p. 77). This compares favourably with the highest stratigraphic occurrences of Epistomina uhligi, Neobulimina varsoviensis and Trocholina alpina, which have been observed between 7650 and 7700' in the same well (Ascoli, 1978). Calibration with the calpionellid biozonation therefore confirms that all these foraminiferal marker species range as high as Late Tithonian either on the East Newfoundland Basin or on the Scotian Shelf, where their highest stratigraphic occurrence has been observed in the same part of the section.

Remarks: The top of this zone corresponds exactly to the top of the homonym zone by Ascoli (1977). The base of the zone corresponds to the top of the Lenticulina quenstedti - Epistomina mosquensis Zone (top of Kimmeridgian) whereas in Ascoli (1977), by contrast, the base of the same zone corresponded to the top (of age uncertain between late Kimmerdigian and Early Tithonian) of the Epistomina madagascariensis - E. dneprica Zone.

3. (+)Arenaceous Benthonic Foraminifera Zones

Environment of deposition

The "arenaceous benthonic Foraminifera" zone markers and "zone diagnostic species" reported in the following pages may be present in deep

(+) Not all the "zone diagnostic species" listed in the "arenaceous Benthonic Foraminifera Zones" are necessarily arenaceous. The most characteristic and abundant associated calcareous species (all belonging to the genus Trocholina) have also been listed.

waters far from shore (particularly the genus Ammobaculites and other "small, simple arenaceous taxa"). More frequently, however, (and this is particularly true for the "large, complex arenaceous taxa, such as the genera Alveosepta, Anchispirocyclina and Everticyclammina) they indicate medium depth (around 100m) to shallow water environments found near coastal areas (inner neritic) affected by a generally fast accumulation rate of mostly coarse-grained sediments.

a) Alveosepta jaccardi Zone

The top of this zone is defined by the highest stratigraphic occurrence of Alveosepta jaccardi (Schrodt). The base of the zone corresponds to the top of the Trocholina conica - Haplophragmoides canui Zone of Ascoli (1977). Diagnostic species having their highest stratigraphic occurrence at the top of this zone, include Gaudryina ex gr. heersumensis Lutze and Everticyclammina sp. 2. Diagnostic species having their highest stratigraphic occurrence in the lower part of this zone include Gaudryina heersumensis Lutze, Haplophragmoides rotunda Barnard and Verneuilinoides tryphera Loeblich and Tappan.

Occurrence in wells: Mohawk B-93, Mohican I-100, Naskapi N-30, Moheida P-15, Oneida O-25, Penobscot L-30, MicMac H-86, Wyandot E-53 and Bonnition H-32 (East Newfoundland Basin) (Figs. 5 and 6).

Age: The zone markers and "zone diagnostic species" listed above, according to Loeblich and Tappan (1950a), Maync (1960), Lutze (1960) and Ascoli (1977) have their highest stratigraphic occurrence in the Oxfordian-Early Kimmeridgian. This zone, therefore, has been dated Oxfordian-Early

Kimmeridgian.

Remarks: This zone corresponds to the Alveosepta jaccardi Zone of Ascoli (1977); in that paper a zonal marker was not established for the lower part of the zone, where there are sparse occurrences of some widely known Oxfordian indicators, such as Gaudryina heersumensis and Haplophragmoides rotunda. Alveosepta jaccardi is abundant in several wells, both from the "inner Scotian Shelf" (such as Mohawk B-93 and Naskapi N-30) and from the "outer Scotian Shelf" (such as Oneida O-25). The maximum number of specimens ("peak") of this species has been observed mostly in the middle-upper part of the zone, approximately corresponding to the top of the Oxfordian. The highest stratigraphic occurrence of this species in Mohican I-100 and Bonnition H-32 is respectively 456' and 500' lower than that of Epistomina mosquensis identified in the same wells.

b) Ammobaculites coprolithiformis (1) - Anchispirocyclina lusitanica (2) Zone.

The top of this zone is defined by the highest stratigraphic occurrence of Anchispirocyclina lusitanica (Egger). The base of the zone corresponds to the top of the underlying Alveosepta jaccardi Zone. Diagnostic species having highest stratigraphic occurrence at the top of this zone, include Trocholina alpina (Leupold), Trocholina sp. 1, Everticyclammina sp. 3 and Haplophragmoides ex gr. canui Cushman.

The zone marker A. coprolithiformis has its highest stratigraphic occurrence in the lower part of the zone, whereas Alveosepta aff. jaccardi (Schrodt), Alveosepta gr. jaccardi (Schrodt) and Everticyclammina sp. 1 never occur higher than the lowermost part of zone.

Occurrence in wells: Mohawk B-93, Acadia K-62, Oneida O-25, Migrant N-20, Penobscot L-30, Citnalta I-59, Wyandot E-53 and Bonnition H-32 (East Newfoundland Basin) (Figs. 5 and 6).

Age: The above listed zone markers and "zone diagnostic species", according to Ascoli (1977) and Gradstein (1978) have their highest stratigraphic occurrence in the Tithonian on the Scotian Shelf and Grand Banks. This zone, therefore, has been dated Tithonian. In Bonnition H-32, Anchispirocyclina lusitanica ranges as high as 7590' (Ascoli, 1978) and is associated with calpionellids indicative of the lower part of zone "B" (= latest Tithonian) within a 10' thick stratigraphic interval (Jansa, Remane and Ascoli, 1980, p. 95). This therefore supports the Late Tithonian age previously assigned by Ascoli (1977) and Gradstein (1978) to the highest stratigraphic occurrence of A. lusitanica on the Scotian Shelf and on the Grand Banks respectively.

Remarks: The top and base of this zone exactly correspond to those of the "Ammobaculites coprolithiformis - Trocholina sp. 1 - Anchispirocyclina lusitanica Zone" of Ascoli (1977), and only those diagnostic species not listed by Ascoli (1977) are mentioned here.

4. Ostracod Zones

Environment of deposition

The ostracod zone markers and "zone diagnostic species" reported in the following pages are found in inner and outer neritic environments, where there may be coarse-grained or fine-grained sedimentation. Generally their optimum habitat is in medium depth waters (middle neritic) not far from shore.

a) Eocytheropteron aff. decoratum Zone

The top of this zone is defined by the highest stratigraphic occurrence of Eocytheropteron aff. decoratum (Schmidt), which corresponds to Eocytheropteron decoratum (Schmidt) of Kilenyi 1969 and 1978. The base of the zone corresponds to the top of the underlying Lophocythere s. l. Zone of Ascoli (1977). Diagnostic species having their highest stratigraphic occurrence at the top of this zone, include Eocytheropteron gr. purum (Schmidt) and Vesticytherura gr. costaeirregularis Whatley. Diagnostic species having their highest stratigraphic occurrences in the lower part of the zone, include ?Fastigatocythere sp. 1, ?Hutsonia sp. 4, Eucytherura reticulata Peterson, Vesticytherura horrida Whatley, V. scottia Whatley and Vesticytherura sp. 1.

Occurrence in wells: Mohawk B-93, Mohican I-100, Naskapi N-30, Oneida O-25, Penobscot L-30, MicMac H-86, Wyandot E-53 and Jason C-20 (Figs. 5 and 6).

Age: The zone markers and "zone diagnostic species" listed above have their highest stratigraphic occurrences in the Oxfordian according to Whatley (1970), Ascoli (1977) and Kilenyi (1978). This zone therefore has been assigned an Oxfordian age.

Remarks: This zone replaces the Cytherella index Zone of Ascoli (1977), which was originally dated Oxfordian. However, its zone marker Cytherella index has recently recognized in sediments belong to the Paranotacythere sp. 1 - ?Hutsonia sp. 1 Zone of Ascoli (1977), which was dated Kimmeridgian. Consequently, in this report, Cytherella index has been replaced, as the zone marker of the homonym zone of Ascoli (1977), by Cytheropteron aff. decoratum.

b) Eocytheropteron decoratum (1) - Cytherelloidea weberi (2) - Schuleridea triebeli (2) Zone.

The top of this zone is defined by the highest stratigraphic occurrence of Cytherelloidea weberi Steghaus and Schuleridea triebeli (Steghaus). The base of the zone corresponds to the top of the underlying Cytheropteron aff. decoratum Zone. Diagnostic species having their highest occurrence at the top of this zone include ?Hutsonia sp. 1, Hutsonia sp. 2, Schuleridea sp. 5, Schuleridea sp. 6, Cytherelloidea paraweberi Oertli, Cytherella index Oertli, Eocytheropteron purum (Schmidt), Eocytheropteron sp. 6, Eucytherura heteromorpha Peterson, Eucytherura sp. 1 and ?Nodophthalmocythere sp. 1.

Besides the zone marker Eocytheropteron decoratum (Schmidt), diagnostic species having their highest stratigraphic occurrences in the lower part of the zone include Schuleridea strzalkowiensis Bielecka et al., Procytheropteron sp. of Kilenyi 1969, Haplocytheridea sp. 1 and Galliaecytheridea sp. 2. For differences between Eocytheropteron decoratum (Schmidt) and Eocytheropteron aff. decoratum (Schmidt), see p. 24.

Occurrence in wells: Mohawk B-93, Mohican I-100, Naskapi N-30, Moheida P-15, Acadia K-61, Oneida O-25, Demaskota G-32, Cohasset D-42, Abenaki J-56, Jason C-20, Dauntless D-35 and Bonnition H-32 (East Newfoundland Basin) (Figs. 5. and 6).

Age: The above listed zone markers and "zone diagnostic species", according to Christensen and Kilenyi (1970), Ascoli (1977) and Kilenyi (1978) have their highest stratigraphic occurrences in the Kimmeridgian. This zone, therefore, has been assigned a Kimmeridgian age. The meaning of the term "Kimmeridgian" in this paper has been discussed on p. 10.

Remarks: This zone corresponds to the coeval Paranotachythere sp. 1 - ?Hutsonia sp. 1 Zone of Ascoli (1977), in which both zone markers reported under open nomenclature have been replaced by the three widely known European Kimmeridgian markers Eocytheropteron decoratum, Cytherelloidea weberi and Schuleridea triebeli. This allows ready correlation of the zone with European section of Kimmeridgian age.

c) Hutsonia gr. collinsensis (1) - Galliaecytheridea postrotunda (2) - Schuleridea sp. 1 (2) Zone.

The top of this zone is defined by the highest stratigraphic occurrence of Galliaecytherdea postrotunda Oertli and Schuleridea sp. 1 Ascoli (1977). The base of the zone corresponds to the top of the underlying Eocytheropteron decoratum - Cytherelloidea weberi - Schuleridea triebeli Zone. Diagnostic species having their highest stratigraphic occurrence at the top of this zone include Asciocythere sp. 4, Schuleridea sp. 2 and Eocytheropteron aff. brodiei (Jones). Besides the zone marker Hutsonia gr. collinsensis Swain and Brown, diagnostic species having their highest stratigraphic occurrences in the lower part of this zone include Asciocythere gr. amygdaloides (Cornuel), Klieana aff. alata Martin and Macrodentina aff. lineata Martin.

Occurrence in wells: Mohawk B-93, Mohican I-100, Naskapi N-30, Moheida

P-15, Oneida O-25, Demaskota G-32, Cree E-35, Abenaki J-56, MicMac H-86, Wyandot E-53 and Dauntless D-35 (Figs. 5 and 6).

Age: The zone markers and "zone diagnostic species" listed above, according to Klingler, Malz and Martin (1962), Oertli (personal communication), Swain (personal communication) and Ascoli (1977), have their highest stratigraphic occurrences in the Tithonian. This zone, therefore, has been assigned a Tithonian age.

Remarks: This zone corresponds to the homonym zone of Ascoli (1977) and only those diagnostic species not mentioned by Ascoli (1977) are listed here.

CONCLUSIONS

The stratigraphic resolution of the above described revised Late Jurassic biozonation of the Scotian Shelf is considerably refined when compared to that of Ascoli (1977).
The following main improvements are noted:

a) Calcareous benthonic Foraminifera Zones:

1) Top of "*Epistomina stellicostata*-*Epistomina uhligi* Zone" found to correspond exactly to the top of the Tithonian, as based upon calibration with the calpionellid biozonation.

2) Top of new "*Lenticulina quenstedti*-*Epistomina mosquensis* Zone" equated with the top of the Kimmeridgian (the top of the corresponding "*Epistomina madagascariensis*-*Epistomina dneprica* Zone" of Ascoli (1977) was originally dated Kimmeridgian to Early Tithonian.

3) New "*Epistomina soldanii* (1) - *Conorboides paraspis* (2) Zone", of

Oxfordian age, subdivided into lower and upper part (the corresponding "Lenticulina varians - Lenticulina quenstedti Zone" of Ascoli (1977) was not subdivided).

b) Arenaceous benthonic Foraminifera Zones:

No major change introduced, but the number of "diagnostic species" considerably increased. The top of the "Ammobaculites coprolithiformis (1) - Anchispirocyclina lusitanica (2) Zone" is equated with the top of the Tithonian as based upon calibration with the calpionellid biozonation.

c) Ostracod Zones:

1) Top of "Hutsonia gr. collinsensis (1) - Galliaecytheridea postrotunda (2) - Schuleridea sp. 1 (2) Zone" is equated with the top of the Tithonian, based upon calibration with the calpionellid biozonation. From the rich Kimmeridgian assemblages recently studied in detail, numerous additional "zone diagnostic species" have been added to those reported by Ascoli (1977) and compared with specimens of the same species present in the type Kimmeridgian section.

2) Zone marker species of the lower and upper part of the "Eocytheropteron decoratum - Cytherelloidea weberi - Schuleridea triebeli Zone" of Kimmeridgian age are now three widely known European Kimmeridgian indicators, whereas the corresponding "Paranotacythere sp. 1 - ?Hutsonia sp.1 Zone" of Ascoli (1977) was identified by marker species reported under open nomenclature. It is now much easier to correlate with European coeval sections.

The use of the above revised Late Jurassic zones permits good correlation between the wells studied to date, notwithstanding their scarce foraminiferal and ostracod fossil assemblages. Figs. 5 and 6 show that the combined use of calcareous benthonic Foraminifera, arenaceous benthonic Foraminifera and ostracod zones provides more effective correlation between wells, with the exception of the non-marine parts of the section which can be correlated only by using palynomorphs (Bujak and Williams, 1977). The most important practical application so far of this revised and improved Late Jurassic biozonation of the Scotian Shelf, is its extrapolation as far northeast as the East Newfoundland Basin, as demonstrated in the study of the Bonnition H-32 well (see Ascoli, 1978 and Jansa, Remane and Ascoli, 1980).

The newly discovered Hibernia oil field is located in the East Newfoundland Basin and it seems likely that the biozonation presented in this paper will be helpful in resolving the main biostratigraphic problems of dating and correlating the Mesozoic section between wells of this field and other wells on the Grand Banks and Scotian Shelf.

The northernmost occurrence of calpionellids on the American Continent and Continental Shelf has also been reported from the East Newfoundland Basin (Bonnition H-32 well) by Jansa, Remane and Ascoli (1980). This new finding has important paleogeographic and paleoecologic implications, because it indicates that the Grand Banks and the Ibernia Peninsula were already separated by deep water during the Tithonian and that the influence of the Tethyan warm water paleocurrents was felt as far northwest as the East Newfoundland Basin.

The biostratigraphic implications of the discovery of calpionellids in this area are even more important. Calpionellid assemblages from Bonnition H-32 have permitted the establishment of the Jurassic-Cretaceous boundary in this well with great precision, identifying and separating the latest Tithonian from the earliest Berriasian for the first time on the Canadian Atlantic Shelf. The detailed calpionellid biozonation established in Bonnition H-32 has thus permitted calibration of the stratigraphic ranges of the foraminiferal, ostracod and palynomorph marker species at and near the Jurassic-Cretaceous boundary in this and other wells of the Grand Banks and Scotian Shelf.

This has been possible from the East Newfoundland Basin (Bonnition H-32) to the southern Scotian Shelf, where abundant calpionellids have also been reported by Jansa, Remane and Ascoli (1980) in the Mohican I-100 well. Furthermore, rich calpionellid assemblages have now been found in the Georges Bank area, immediately south of the Scotian Shelf.

In conclusion, all these recent findings increasingly emphasize the role of calpionellids on the Canadian Atlantic Shelf as a most valuable stratigraphic tool for establishing a refined biozonation across the Jurassic-Cretaceous boundary. This refinement is immediately reflected in the foraminiferal-ostracod biostratigraphy, because more numerous calpionellid findings mean more precise calibration of Scotian Shelf-Grand Banks foraminiferal-ostracod biozonations (Ascoli, 1977; Gradstein, 1978; Ascoli this paper). This also allows more precise correlation of Scotian Shelf-Grand Banks Tethyan foraminiferal-ostracod marker species with the coeval European ones, since some of the latter have been also calibrated with the calpionellid biozonation of the Mediterranean Area.

The practical use of an integrated system of different biozonations

(Foraminifera, Ostracoda, calpionellids, palynomorphs, nannofossils, etc.) is strongly recommended for the biostratigraphic study of the Upper Jurassic-Lower Cretaceous sediments of the Scotian Shelf-Grand Banks. From our experience of integrating foraminiferal, ostracod and calpionellid biozonations in the East Newfoundland Basin and Scotian Shelf, we have learned that such a system can take maximum advantage of the complementary nature of these different biozonations, and will provide the most precise stratigraphic results, not possible when relying on one biozonation alone.

APPENDIX

Condensed synomies and bibliographic references for all zone marker species mentioned in the previous pages are given here in alphabetic order according to genus and species. Foraminiferal species are listed first, followed by ostracod species.

1) Foraminiferal species

Alveosepta jaccardi (Schrodt) emend. Maync 1958

Cyclammina jaccardi Schrodt, 1894, p. 734, fig. tfs [SIC!].
Pseudocyclammina jaccardi (Schrodt). Maync 1958, pp. 9-16, pl.1, figs.1-4; pl.2, fig.1.
Pseudocyclammina jaccardi (Schrodt). Maync 1960, pp. 103-118, pl.1, figs.1-11; pl.2, figs. 1-23.
Alveosepta jaccardi (Schrodt). Hottinger 1967, pp. 79-80, pl.15, figs.9-13; pl.16, figs. 1-9; text-fig.40
Alveosepta jaccardi (Schrodt). Ascoli 1977, p.693, pl.11, fig.a.
Pseudocyclammina jaccardi (Schrodt). Gradstein 1978, pp.99-100,104,pl.1, figs.1, 5.

Remarks. The "Alveosepta jaccardi group" of species is represented on the Scotian Shelf by the "typical" A. jaccardi (in the sense of Maync 1958 and 1960) and by two other species of the genus which are very closely related to A. jaccardi, but are larger in size, thicker and less depressed in the central part of the test. These species range as high as the top of the Kimmeridgian and have conventionally been named "Alveosepta gr. jaccardi" and "Alveosepta aff. jaccardi" (see page 14 and fig. 2).

Ammobaculites coprolithiformis (Schwager)

Haplophragmium coprolithiforme Schwager, 1867, p. 661, pl.1, fig.3.
Ammobaculites coprolithiformis (Schwager). Bielecka and Pozaryski 1954, pl.3, fig. 6 a-b.
Ammobaculites coprolithiformis (Schwager). Ascoli 1977, p. 692, pl.6, fig. 10.

Anchispirocyclina lusitanica (Egger) emend. Maync 1959.

Dicyclina lusitanica Egger, 1902, pp. 585-586, pl.6, figs. 3-5.
Spirocyclina infravalenginiensis [sic] Egger 1902 (part), p.586, pls.3-6.
Meandropsina vidali Schlumberger. Egger 1902, p.586, pls.3-6.
Anchispirocyclina lusitanica (Egger). Hottinger 1967, pp. 74-76, pl.13, figs. 6-8, text-fig. 37a-b.
Anchispirocyclina lusitanica (Egger). Ascoli 1977, p. 692, pl. 6, fig. 12a-b.
Anchispirocyclina lusitanica (Egger). Jansa, Remane & Ascoli 1980, pp. 81-83, 95, pl.8, figs. 7-8.

Conorboides paraspis (Schwager)

Rosalina paraspis Schwager, 1866, p. 310, fig. 16.

Conorboides ? paraspis (Schwager). Seibold & Seibold 1960, pp. 382-383, fig. 7s-t.

Discorbis ? paraspis (Schwager). Oesterle 1968, p. 774, fig. 49.

Epistomina mosquensis Uhlig

Epistomina mosquensis Uhlig, 1883, p. 766, pl. 7, figs. 1-3.

Epistomina mosquensis Uhlig. Espitalié & Sigal 1963, p. 66, pl. 31, fig. 2.

Epistomina mosquensis Uhlig. Ohm 1967, pp. 125-127, pl. 16, figs. 7-10; pl. 17, figs. 1-12.

Epistomina mosquensis Uhlig. Gradstein 1978, pp. 100, 104, pl. 1, figs. 4a-b, 6a-b.

Epistomina mosquensis Uhlig. Jansa, Remane & Ascoli 1980, pp. 84, 93, 98, pl. 9, figs. 1-3.

Remarks. The "Epistomina mosquensis group" of species is represented on the Scotian Shelf and East Newfoundland Basin by the "typical", E. mosquensis (in the sense of Ohm, 1967) and by at least two other, probably new, species of Epistomina, both of which are very closely related to E. mosquensis. One of them, conventionally called "Epistomina ex gr. mosquensis", is characterized by a plano-convex profile, with the umbilical side almost completely flat. Its stratigraphic range appears to be Kimmeridgian on the Scotian Shelf (see page 9 and fig. 2)

Epistomina soldanii Ohm

Epistomina soldanii Ohm, 1967, pp. 130-131, fig. 25a-d.

?Epistomina soldanii Ohm. Gradstein 1978, p. 104.

Epistomina stellicostata Bielecka and Pozaryski

Epistomina stellicostata Bielecka and Pazaryski, 1954, p. 71, pl. 12, fig. 60a-c.

Epistomina stellicostata Biel. & Poz. Ascoli 1977, pp. 683-684, pl. 2, fig. 6a-f.

Epistomina stellicostata Biel. & Poz. Jansa, Remane & Ascoli 1980, pp. 83, 92, 95, pl. 8, figs. 9-11.

Remarks. Specimens of Epistomina stellicostata from the Scotian Shelf have been compared and found to be conspecific with paratypes of the same species kindly loaned by Mrs. W. Bielecka (Warsaw).

Epistomina uhligi Mjatliuk

Epistomina uhligi Mjatliuk, 1953, p. 219, pl. 2, fig. 5a-b.

Epistomina parastelligera (Hofker). Lutze 1962, p. 491, pl. 33, figs. 3-6.

Epistomina uhligi Mjatliuk. Kaptarenko-Chernoussova et. al. 1963, pl. 10, fig. 12.

Epistomina uhligi Mjatliuk. Ohm 1967, pp. 128-130, pl. 18, fig. 4, test figs. 22a-c, 23a-c.

Epistomina uhligi Mjatliuk. Ascoli 1977, pp. 683-684, pl. 3, fig. 1a-d.
Epistomina uhligi Mjatliuk. Gradstein 1978, pp. 100, 104, pl. 1, fig. 2a-b.
Epistomina uhligi Mjatliuk. Jansa, Remane & Ascoli 1980, pp. 82-83, 92-98, pl. 8, figs. 4-6.

Remarks. The "Epistomina uhligi group", comprising all Jurassic species of Epistomina having a smooth or very finely pitted test, is represented on the Scotian Shelf and East Newfoundland Basin by the "typical" E. uhligi (in the sense of Ohm, 1967) and by at least another species of Epistomina, probably new, which is very closely related to E. uhligi. This species, conventionally called Epistomina aff. uhligi, is smooth and characterized by its plano-convex profile, with flat umbilical side (cf. page 9 and fig. 5). Its stratigraphic range seems to be Kimmeridgian on the Scotian Shelf and East Newfoundland Basin.

Lenticulina quenstedti (Guembel)

Cristellaria quenstedti Guembel, 1862, p. 226, pl. 4, fig. 2a-b.
?Lenticulina dilecta Loeblich and Tappan, 1950b, pp. 7-8, pl. 1, figs. 5-8.
Lenticulina (L.) quenstedti (Guembel). Seibold & Seibold 1955, p. 105, pl. 13, fig. 3, test-fig. 3f-g.
Lenticulina (L.) quenstedti (Guembel). Seibold & Seibold 1960, p. 349.
?Lenticulina dilecta Loeblich and Tappan. Wall 1960, pp. 68-69, pl. 9, fig. 5; pl. 16, figs. 13-16.
Lenticulina quenstedti (Guembel). Espitalié & Sigal 1963, p. 24, pl. 4, figs. 8-14.
Lenticulina quenstedti (Guembel). Brooke & Braun 1972, pp. 12-14, pl. 13, figs. 21-31.
Lenticulina quenstedti (Guembel). Ascoli 1977, p. 683, pl. 2, fig. 3.
Lenticulina quenstedti (Guembel). Gradstein 1978, pp. 100, 104, pl. 1, fig. 3

Remarks. Lenticulina dilecta Loeblich and Tappan, 1950 is possibly a junior synonym of Lenticulina quenstedti (Guembel), 1862.

2) Ostracod species

Cytherelloidea weberi Steghaus

Cytherelloidea weberi Steghaus, 1951, p. 207, pl. 14, figs. 4, 6.
Cytherelloidea weberi Steghaus. Oertli 1957, pp. 650-651, pl. 1, fig. 11.
Cytherelloidea weberi Steghaus. Oertli 1959, pp. 17-18, pl. 2, figs. 28-29.
Cytherelloidea weberi Steghaus. Kilenyi 1969, pp. 115-116, pl. 23, figs. 6-7.
Cytherelloidea weberi Steghaus. Kilenyi 1978, pp. 264, 290, pl. 1, fig. 3.

Eocytheropteron decoratum (Schmidt)

Cytheropteron (C.) decoratum Schmidt, 1954, p. 82, pl. 5, figs. 1-2; pl. 6, figs. 16-18.
Eocytheropteron decoratum (Schmidt). Oertli 1963, pl. 44-I, fig. s; pl. 45-I, fig. s.

Eocytheropteron aff. decoratum (Schmidt)

?Eocytheropteron ? decoratum (Schmidt). Oertli 1957, p. 663, pl. 4, figs. 109-112.
Eocytheropteron decoratum (Schmidt). Kilenyi 1969, p. 142, pl. 28, figs. 14-17.
Eocytheropteron decoratum (Schmidt). Kilenyi 1978, pp. 280, 293, pl. 9, figs. 5-6.

Remarks. "Eocytheropteron aff. decoratum" corresponds to Eocytheropteron decoratum (Schmidt) of Kilenyi 1969 and 1978. The specimens illustrated by Kilenyi differ from the typical Eocytheropteron decoratum (Schmidt) in having a more elongate shape, no sexual dimorphism (which is very strong in the typical E. decoratum) and ornamentation characterized by "semicircular faint ribs" instead of a more or less regular pattern. Moreover, this form shows a thinner and less curved ventral rib, which does not overhang the ventral margin (as in the typical C. decoratum).

Galliaecytheridea postrotunda Oertli

Galliaecytheridea postrotunda Oertli, 1957, pp. 656-657, pl. 2, figs. 44-55.
Galliaecytheridea postrotunda Oertli. Oertli 1959, p. 25, pl. 3, figs. 89-90.
Galliaecytheridea postrotunda Oertli. Kilenyi 1969, p. 129, pl. 27, figs. 5-14.
Galliaecytheridea postrotunda Oertli. Ascoli 1977, p. 700, pl. 8, fig. 7a-c.
Galliaecytheridea postrotunda Oertli. Kilenyi 1978, pp. 270, 291, pl. 4, figs. 10-12.
Galliaecytheridea postrotunda Oertli. Jansa, Remane & Ascoli 1980, pp. 94, 96, pl. 9, figs. 11-12.

Remarks. Specimens of Galliaecytheridea postrotunda from the Scotian Shelf have been compared with topotypes of this species kindly provided by Dr. H. J. Oertli (Pau) and found to be conspecific.

Hutsonia ex gr. collinsensis Swain and Brown

? Hutsonia collinsensis collinsensis Swain and Brown, 1972, pp. 41-42, pl. 8, figs. 8-14, 22-23; text-fig. 25.
? Hutsonia collinsensis attenuata Swain and Brown, 1972, p. 42, pl. 8, fig. 15; text-fig. 26.

Hutsonia gr. collinsensis Swain and Brown. Ascoli 1977, p. 700, pl. 8, fig. 6a-d.
Hutsonia gr. collinsensis Swain and Brown. Jansa, Remane & Ascoli 1980, pp. 91, 93-94.

Remarks. Specimens of Hutsonia ex. gr. collinsensis from the Scotian Shelf have been compared with topotypes of Hutsonia collinsensis collinsensis Swain and Brown kindly provided by Dr. F. M. Swain (Minneapolis) and found to be probably conspecific. As a result of the somewhat poor state of preservation of these topotypes, it was not possible to ascertain whether the Scotian Shelf specimens fall within the variability range of Hutsonia collinsensis collinsensis, H. collinsensis attenuata or perhaps of both subspecies. The more general name "Hutsonia ex gr. collinsensis" has therefore been preferred for the Scotian Shelf specimens for the time being.

Schuleridea triebeli (Steghaus)

Haplocytheridea triebeli Steghaus, 1951, p. 214, pl. 15, figs. 27-29.
Schuleridea triebeli (Steghaus). Oertli 1957, p. 654, pl. 1, figs. 25-29.
Schuleridea triebeli (Steghaus). Oertli 1959, p. 25, pl. 3, figs. 87-88.
Schuleridea triebeli (Steghaus). Klingler, Malz & Martin 1962, p. 177, pl. 25, fig. 25; pl. 26, fig. 22.
Schuleridea triebeli (Steghaus). Kilenyi 1969, pp. 118-119, pl. 23, figs. 21-33.
Schuleridea gr. triebeli (Steghaus). Ascoli 1977, p. 700.
Schuleridea triebeli (Steghaus). Kilenyi 1978, pp. 268, 291, pl. 3, figs. 9-12.
Schuleridea triebeli (Steghaus). Jansa, Remane & Ascoli 1980, pp. 91, 93, 94, 96.

Remarks. Specimens of Schuleridea triebeli from the Scotian Shelf have been found to be conspecific with topotypes of this species kindly provided by Dr. T.I. Kilenyi (London) and Dr. J.W. Neale (Hull). S. triebeli is the most abundant Late Jurassic species of Schuleridea of the Scotian Shelf and can therefore be considered the best ostracod marker species for the Kimmeridgian of this area.

Schuleridea sp. 1 Ascoli

Schuleridea sp. 1, Ascoli 1977, p. 700, pl. 8, fig. 8a-d.
Schuleridea ap. 1 Ascoli. Jansa, Remane & Ascoli 1980, pp. 94, 111, pl. 9, figs. 4-5.

Remarks. Schuleridea sp. 1 Ascoli is probably a new species and is characterized by its small dimensions (length 0.34 - 0.44 mm). It has a finely pitted surface, a rather broad posterior end and an anterior margin which is strongly depressed in the right valve (Ascoli, 1977, p. 700).

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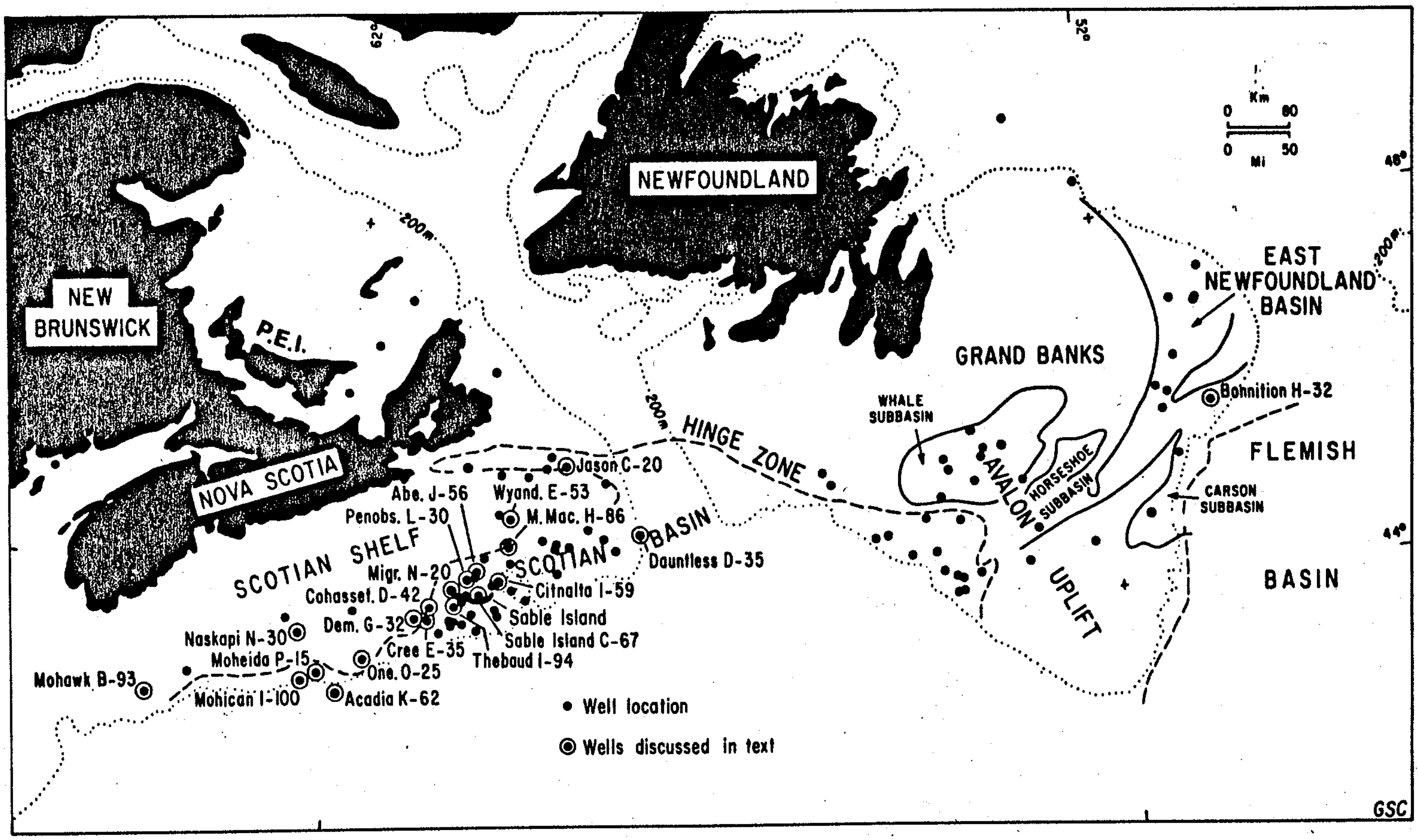

Figure 1: Location Map.

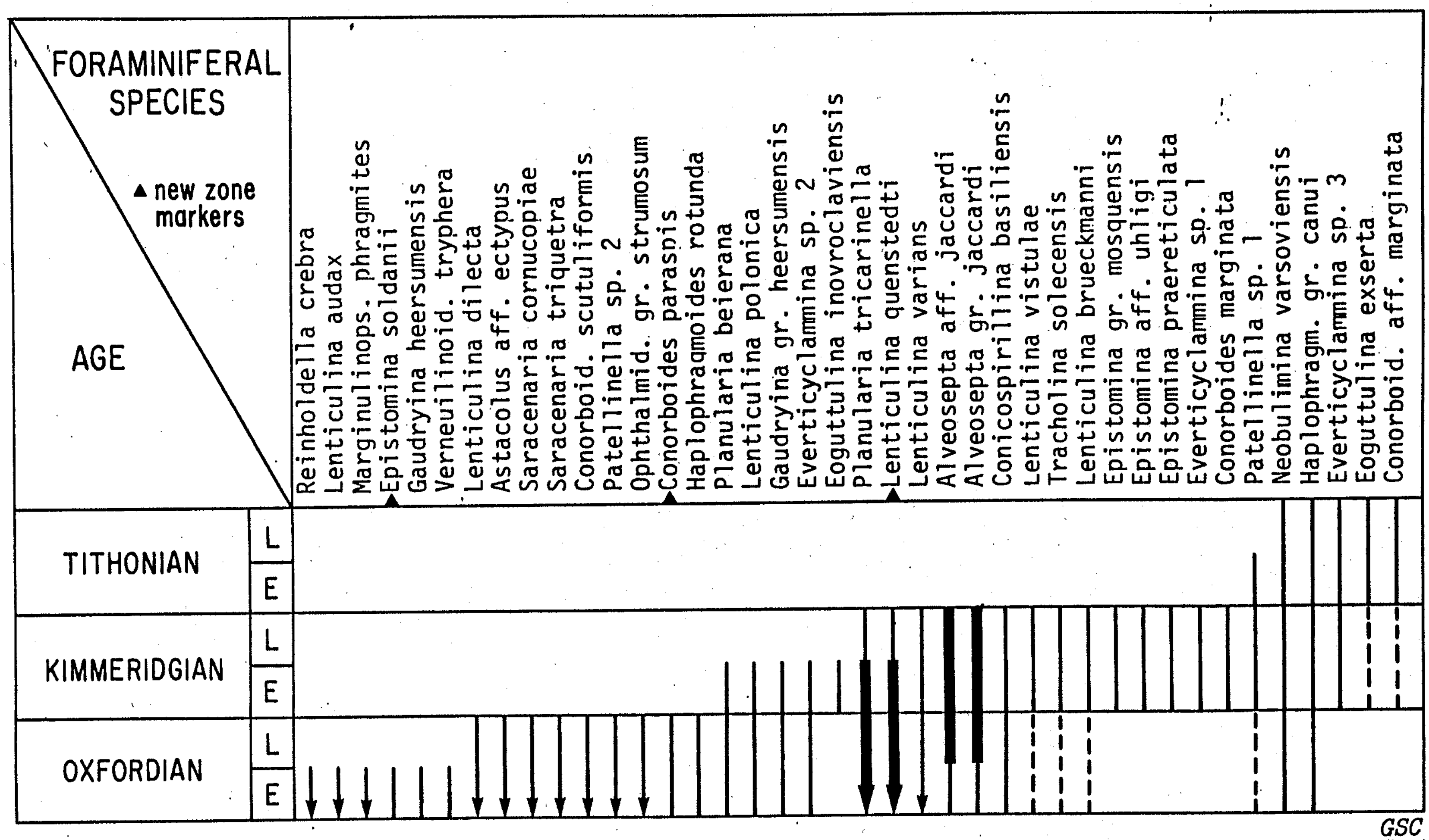

Figure 2: Stratigraphic ranges of Scotian Shelf Late Jurassic foraminiferal zone marker and "zone diagnostic" species not reported in or revised from Ascoli (1977) and Jansa, Remane and Ascoli (1980).

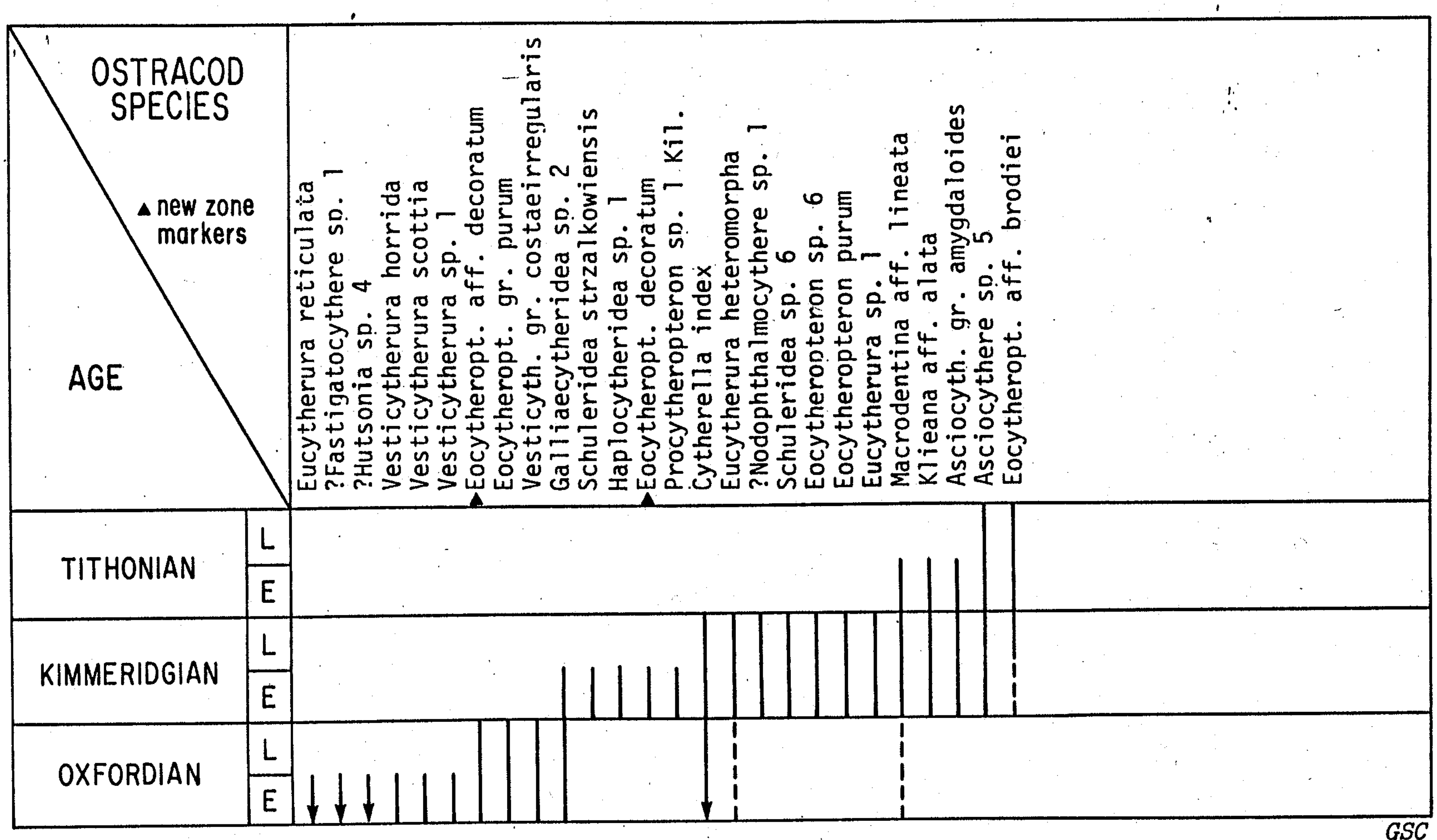

Figure 3: Stratigraphic ranges of Scotian Shelf Late Jurassic ostracod zone marker and "zone diagnostic" species not reported in or revised from Ascoli (1977) and Jansa, Remane and Ascoli (1980).

AGE		CALCAREOUS BENTHONIC FORAMINIFERA ZONES	
		Ascoli (1977)	Ascoli (this paper)
TITHONIAN	L E	Epistomina uhligi Epistomina stellicostata	Epistomina uhligi Epistomina stellicostata
KIMMERIDGIAN	L E	Epistomina dneprica Epistomina madagascariensis	Epistomina mosquensis Lenticulina quenstedti
OXFORDIAN	L E	Lenticulina quenstedti Lenticulina varians	2 Conorboides paraspis 1 Epistomina soldanii

AGE		ARENACEOUS BENTHONIC FORAMINIFERA ZONES	
TITHONIAN	L E	2 Anchispirocyclina lusitanica 2 Trocholina sp. 1	2 Anchispirocyclina lusitanica
KIMMERIDGIAN	L	1 Ammobaculites coprolithiformis	1 Ammobaculites coprolithiformis
	E	Alveosepta jaccardi	Alveosepta jaccardi
OXFORDIAN	L E		

AGE		OSTRACOD ZONES	
TITHONIAN	L E	2 Schuleridea sp. 1 2 Galliaecytheridea postrotunda 1 Hutsonia gr. collinsensis	2 Schuleridea sp. 1 2 Galliaecytheridea postrotunda 1 Hutsonia gr. collinsensis
KIMMERIDGIAN	L E	2 ?Hutsonia sp. 1 1 Paranotacythere sp. 1	2 Schuleridea triebeli 2 Cytherelloidea weberi 1 Eocytheropteron decoratum
OXFORDIAN	L E	Cytherella index	Eocytheropteron aff. decoratum

GSC

2 = highest stratigraphic occurrence at top of zone
1 = highest stratigraphic occurrence in lower part of zone

Figure 4: Foraminiferal and ostracod assemblage zones in the Late Jurassic of the Scotian Shelf.

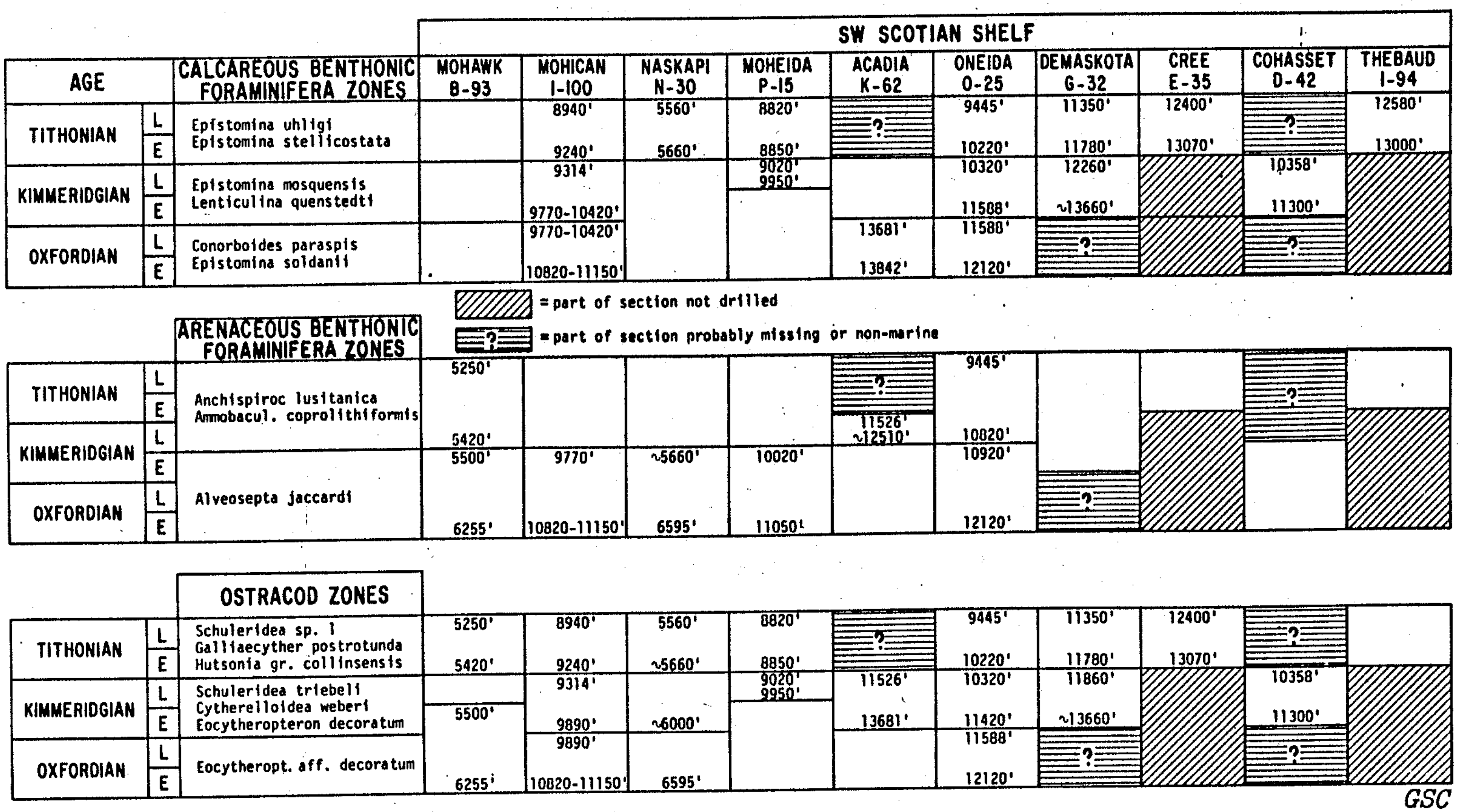

Figure 5: Stratigraphic correlation of Late Jurassic foraminiferal and ostracod assemblage zones in 10 wells (listed in geographic order from SW to NE) of the southwest Scotian Shelf. All depths are in feet.

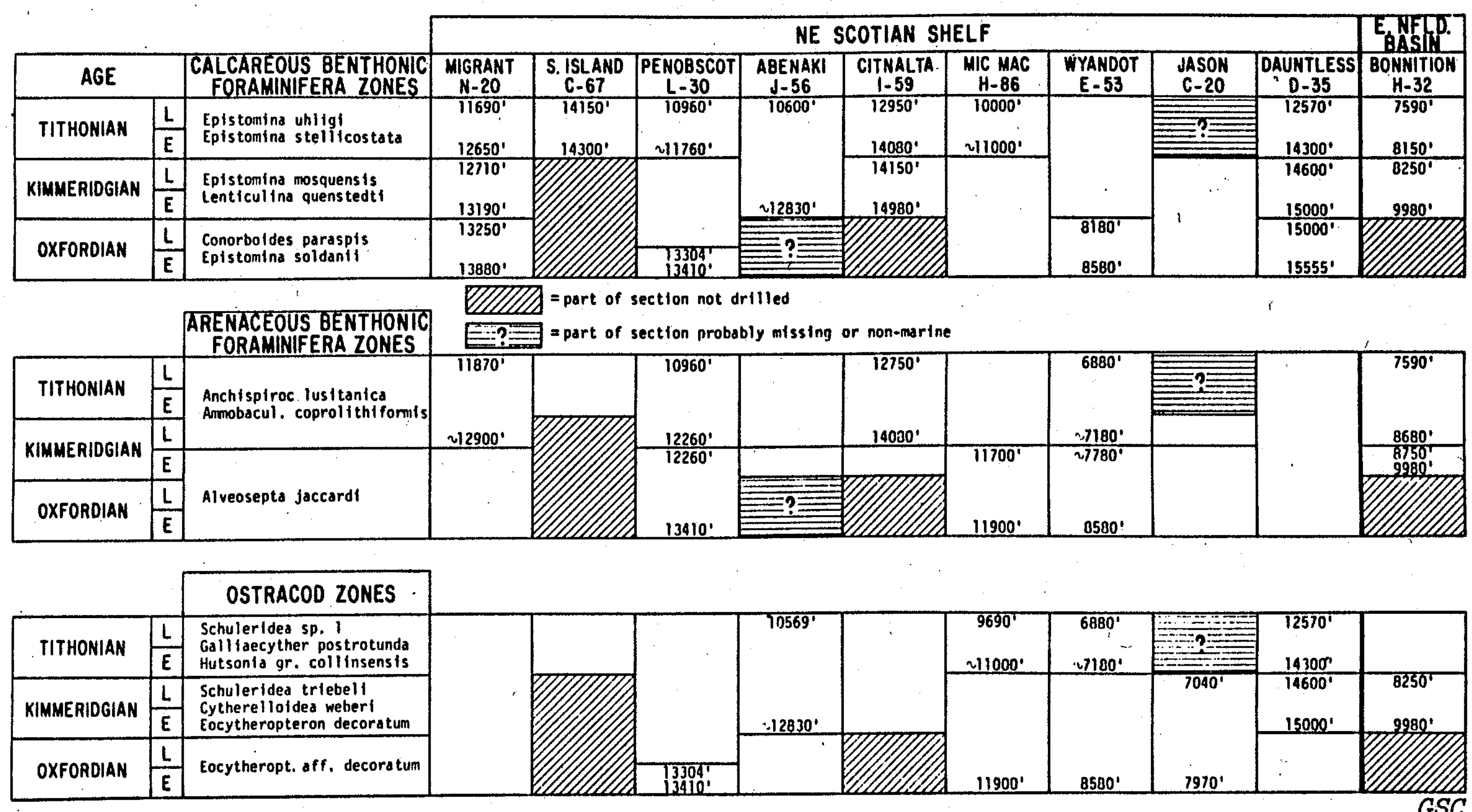

Figure 6: Stratigraphic correlation of Late Jurassic foraminiferal and ostracod assemblage zones in 9 wells (listed in geographical order from SW to NE) of the northeast Scotian Shelf and in Mobil-Gulf H-32 (East Newfoundland Basin). All depths are in feet.