

# A NEW AREOLIGERACEAN DINOFLAGELLATE FROM THE MIOCENE OF OFFSHORE EASTERN CANADA AND ITS EVOLUTIONARY IMPLICATIONS

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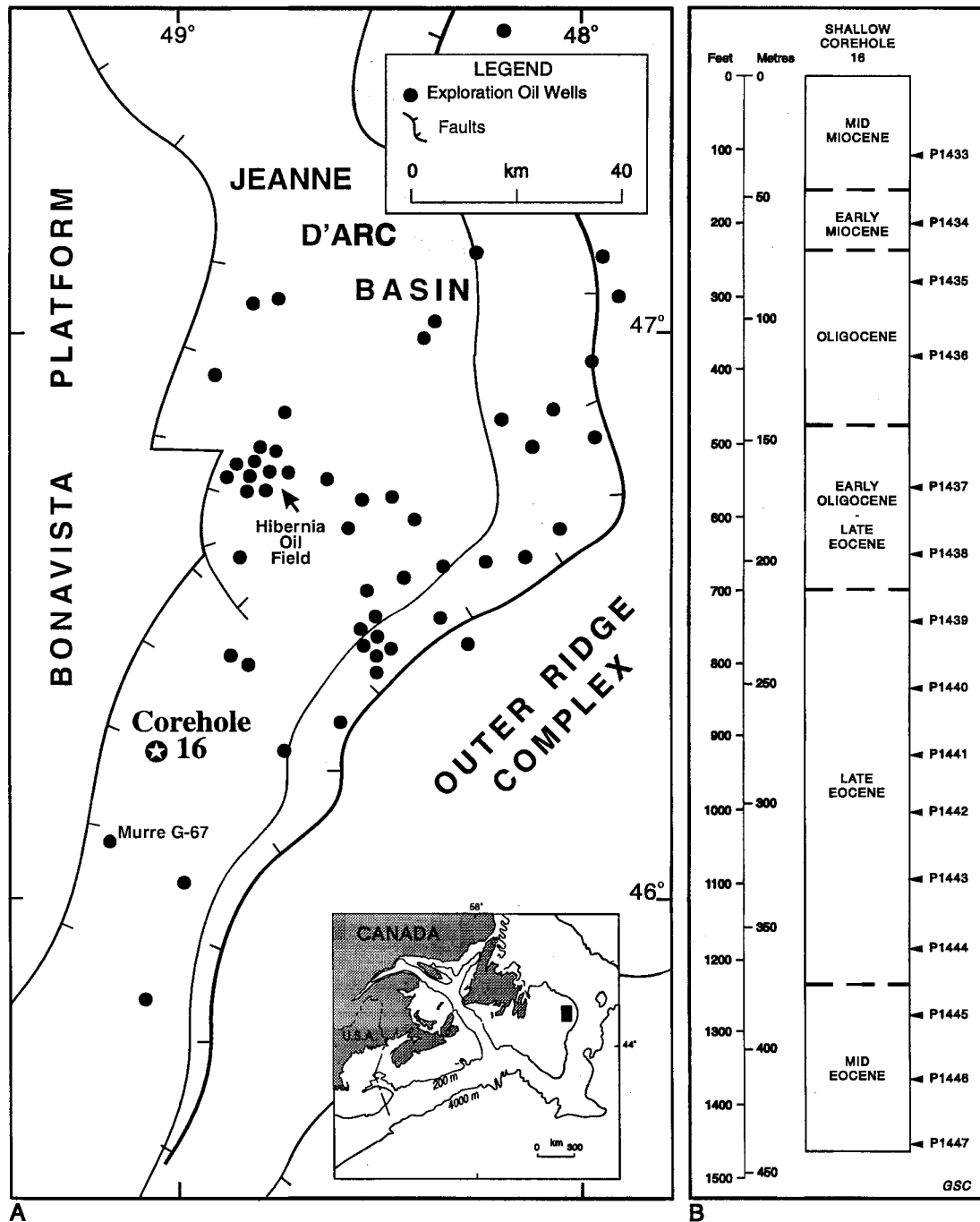
**ABSTRACT.** The dinoflagellate family Areoligeraceae, now extinct, was prominent from the Late Jurassic through to the Paleogene. Some areoligeracean species extend into the Neogene but, until now, no genus was known to originate in that interval. Thus, *Ramidinium* gen. nov., represented by *Ramidinium tridens* sp. nov. from the Lower to Middle Miocene of the Jeanne d'Arc Basin, offshore eastern Canada, becomes the last known areoligeracean genus to have appeared.

IN 1965, during an evaluation of the geology of the Grand Banks, offshore eastern Canada, Pan American Petroleum Corporation (now Amoco Production Company) and Imperial Oil Enterprises carried out a shallow corehole drilling programme (Amoco and Imperial 1973). Several of these coreholes penetrated Mesozoic and Cenozoic strata, including Corehole 16, which provided the material for the present study. Corehole 16 (46° 15' N; 49° 03' W; Text-fig. 1A) was drilled in 66.8 m of water to a depth of 448 m. Subsequently, numerous hydrocarbon exploration wells were drilled, but the shallow coreholes remain a valuable source of information and stratigraphical control.

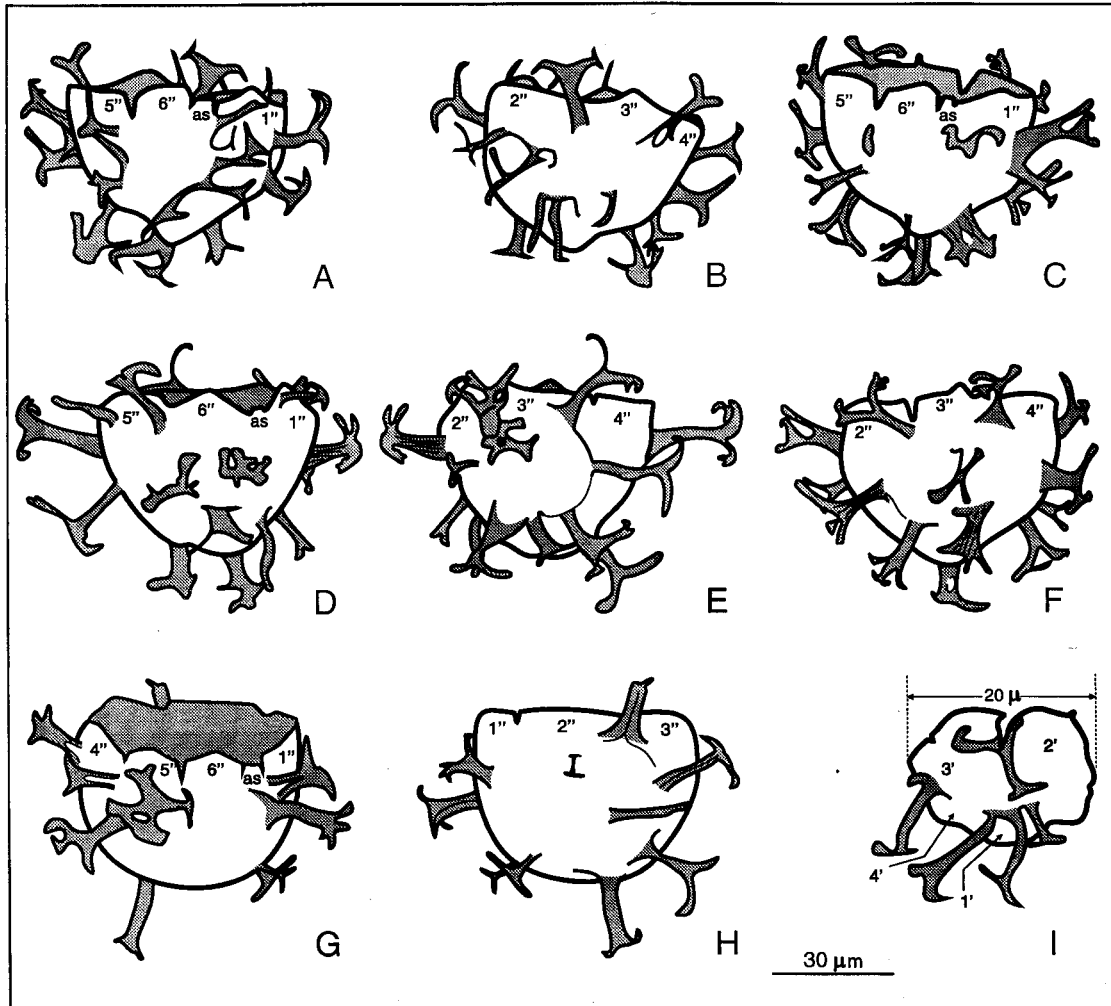
Williams and Brideaux (1975) studied 15 samples from Corehole 16 (Text-fig. 1B), which they considered to be Mid Eocene to Mid? Miocene. In the present re-examination of this material, a new genus and species was found in the uppermost sample (33–36 m), which Williams and Brideaux dated as Mid? Miocene. The new taxon is clearly a gonyaulacalean dinoflagellate of the family Areoligeraceae: like other areoligeraceans it has an offset sulcal notch, a lenticular shape and an apical archaeopyle. However it bears commonly trifurcate sutural processes and thus superficially resembles the common gonyaulacacean species, *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854. The main purpose of this paper is to describe the new taxon, assess its phylogenetic relationships, and reassess the age of the uppermost sample of Corehole 16.

## MATERIALS AND METHODS

The samples used for this study were originally processed in 1972, and the records from this work indicate that a two minute oxidation procedure (otherwise unspecified) was carried out. However, when the residues were re-examined in 1994, there appeared to be no evidence of this earlier oxidation. In order to make the original residues amenable to study, it was necessary to carry out a very mild oxidation treatment (10 per cent. nitric acid for 1.5 minutes) and base treatment (ammonia for 1 minute). These procedures were in addition to the standard hydrochloric and hydrofluoric acid treatments (carried out in 1972), heavy liquid separation of the organic component, differential centrifugation to remove fine particles, screening to divide the residue into fine (10–20  $\mu\text{m}$ ) and coarse (20–180  $\mu\text{m}$ ) fractions, and staining with Bismarck Brown (all in 1994). The reprocessed material was mounted in Elvacite and a cellosize substitute.



TEXT-FIG. 1. A, location map, offshore eastern Canada (modified from McAlpine 1990). B, stratigraphical distribution of the palynological samples in Corehole 16 (after Williams and Brideaux 1975).



TEXT-FIG. 2. *Ramidinium tridens* gen. et sp. nov.; line sketches. A–B, GSC Atlantic slide no. P1433–10, coordinates 86.2 × 10 (EF K15/0), GSC specimen no. 116293. A, ventral surface, ventral view. B, dorsal surface, dorsal view (based on an inverted image). C, F, GSC Atlantic slide no. P1433–10, coordinates 93.3 × 8.3 (EF H23/3), GSC specimen no. 116304; C, ventral surface, ventral view; F, dorsal surface, dorsal view (based on an inverted image). D–E (holotype), GSC Atlantic slide no. P1433–10, coordinates 84.7 × 2 (EF B14/1), GSC specimen no. 116295; D, ventral surface, ventral view (based on an inverted image); E, dorsal surface, dorsal view. G–H, GSC Atlantic slide no. P1433–10, coordinates 97.5 × 5 (EF E27/0), GSC specimen no. 116297; G, ventral surface, ventral view (based on an inverted image); H, dorsal surface, dorsal view. I, GSC Atlantic slide no. P1433–10, coordinates 110.8 × 21 (EF V41/3), GSC specimen no. 116298; operculum, apical view. (For line drawings of dinoflagellates, it is conventional to show an ‘external’ view; thus for those illustrations indicated to be based on an inverted view, the drawing here is a mirror image of the appearance of the specimen in the microscope.) Scale bar represents 30 μm.

Light microscopy was undertaken using Zeiss photomicroscopes at the Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, Dartmouth, Nova Scotia. Coordinates quoted are from the Vernier Scale of Zeiss photomicroscope serial no. 4660390. The corresponding England Finder (EF) coordinates are given in the Plate and Text-figure explanations. Type and

figured specimens are lodged in the National Collection of Type Invertebrate and Plant Fossils, Geological Survey of Canada, Ottawa, Ontario, Canada.

Some specimens were picked, mounted and coated with gold for scanning electron microscopy. An ElectroScan E3 environmental SEM at the Geological Survey of Canada (Atlantic) was used under a partial pressure of water vapour.

#### STRATIGRAPHY

Corehole 16 is located on the south-western margin of the Jeanne d'Arc Basin, which extends roughly north-south for about 220 km on the eastern periphery of the Grand Banks of Newfoundland. In areal extent the basin is about 15000 km<sup>2</sup>, with a maximum sedimentary thickness in excess of 22 km. It is a Mesozoic failed rift basin with some Tertiary fill (McAlpine 1990) and will be the most petroleum-productive basin in offshore eastern North America when the Hibernia field starts to produce oil in 1997. Shallow Corehole 16 is 18.2 km north-north-east of Amoco-Imperial Murre G-67 well, the first exploratory well drilled in the basin, and which attained a depth of 3337.3 m in 64.6 m of water. The youngest dated sediments in Murre G-67 are early Oligocene and are underlain sequentially by Eocene and Campanian strata (Barss *et al.* 1979). The total thickness of the Tertiary section is about 1000 m.

All preparations studied from Corehole 16 are from clastic sediments; more detailed lithological information was not available to the present authors.

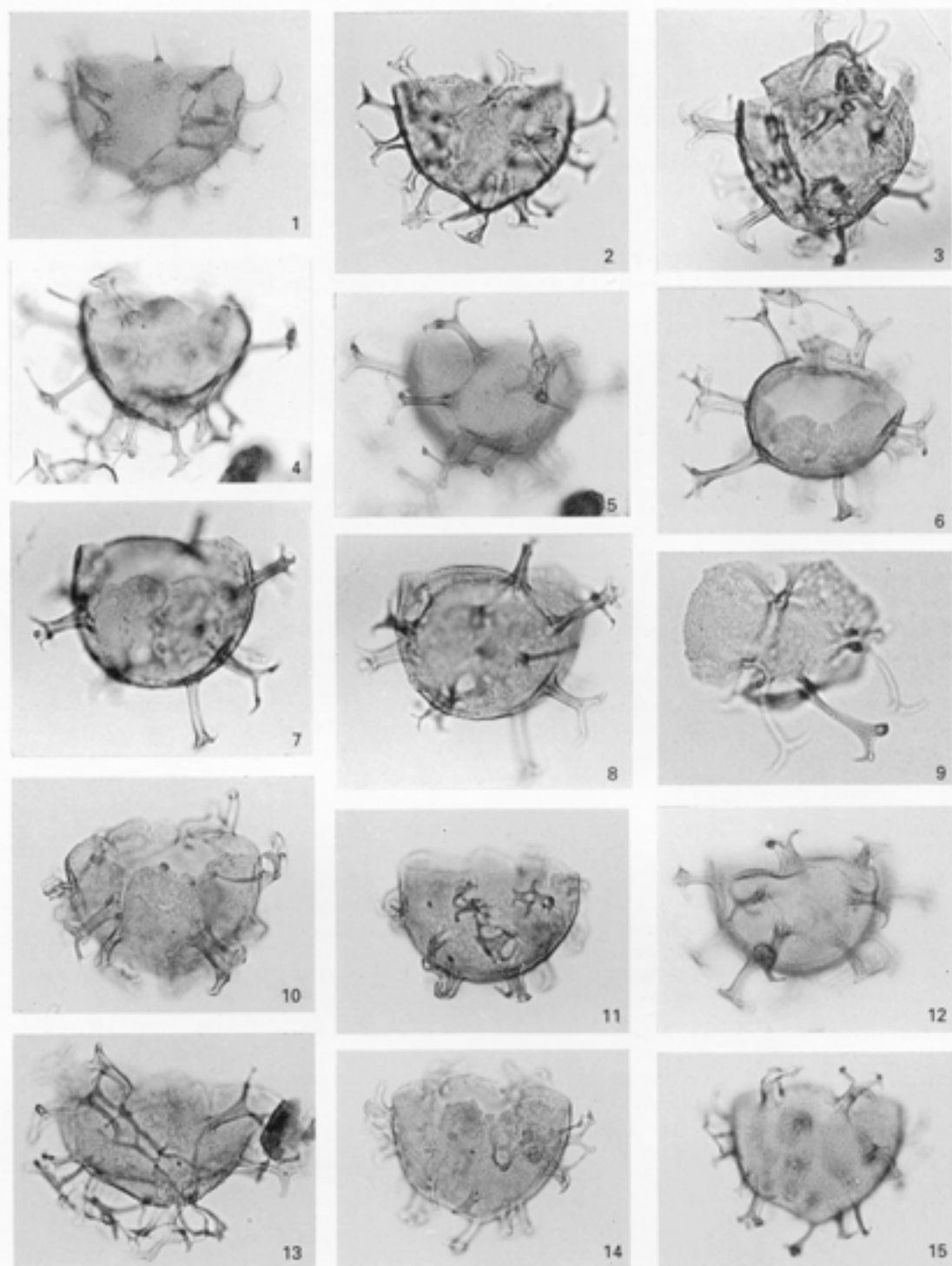
Biostratigraphical control in Corehole 16, as in Murre G-67, is based on palynomorphs, primarily dinoflagellates. Williams and Brideaux (1975) considered the sample at 32.9–36.0 m (108–118'), from which the new taxon was recovered, to be no younger than mid Miocene. This was based on their recognition of the following species: *Tanyosphaeridium* sp. A (now *Distatodinium paradoxum* (Brosius, 1963) Eaton, 1976), *Thalassiphora delicata* Williams and Downie, 1966 (now identified as *Invertocysta tabulata* Edwards, 1984), *Tuberculodinium rossignoliae* Drugg, 1970 and *Lingulodinium* sp. B (now *Sumatradinium druggii* Lentin, Fensome and Williams, 1994).

Williams (1975) outlined a palynostratigraphical zonation for the Mesozoic–Cenozoic rocks of offshore eastern Canada. The *Apteodinium spiridoide*s Benedek, 1972 (as *Apteodinium* sp. B) Zone, of Early Miocene age, was defined on the Last Appearance Datum (LAD) of *A. spiridoide*s. In the sample, *A. spiridoide*s occurs together with *Sumatradinium soucouyantiae* and *Thalassiphora* sp. 1 of

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#### EXPLANATION OF PLATE 1

Figs 1–15. *Ramidinium tridens* gen. et sp. nov. 1–2, GSC Atlantic slide no. P1433–10, coordinates 86.2 × 10 (EF K15/0), GSC specimen no. 116293. 1, ventral surface, ventral view. 2, dorsal surface, ventral view. 3, GSC Atlantic slide no. P1433–10, coordinates 117.3 × 2 (EF B84/1), GSC specimen no. 116294; ventral surface, dorsal view of specimen with operculum. 4–5, holotype, GSC Atlantic slide no. P1433–10, coordinates 84.7 × 2 (EF B14/1), GSC specimen no. 116295. 4, ventral surface, ventral view. 5, dorsal surface, ventral view. 6, GSC Atlantic slide no. P1433–10, coordinates 84.4 × 10 (EF K13/0), GSC specimen no. 116296; ventral surface, ventral view. 7–8, GSC Atlantic slide no. P1433–10, coordinates 97.5 × 5 (EF E27/0), GSC specimen no. 116297. 7, ventral surface, dorsal view. 8, dorsal surface, dorsal view. 9, GSC Atlantic slide no. P1433–10, coordinates 110.8 × 21 (EF V41/3), GSC specimen no. 116298; operculum, antapical view; × 1470. 10, GSC Atlantic slide no. P1433–10, coordinates 91.4 × 18.8 (EF T20/2), GSC specimen no. 116299; ventral surface, ventral view. 11, GSC Atlantic slide no. P1433–10, coordinates 98.7 × 15.5 (EF P28/4), GSC specimen no. 116300; dorsal surface, dorsal view. 12, GSC Atlantic slide no. P1433–10, coordinates 108.4 × 3.8 (EF C39/4), GSC specimen no. 116301; dorsal surface, dorsal view. 13, GSC Atlantic slide no. P1433–10, coordinates 99 × 18.9 (EF T28/0), GSC specimen no. 116302; ventral surface, ventral view. 14–15, GSC Atlantic slide no. P1433–10, coordinates 113.7 × 10.7 (EF L44/1), GSC specimen no. 116303. 14, ventral surface, ventral view. 15, dorsal surface, ventral view.  
All × 490, except where indicated.



Powell (1988). Powell (1992) placed the LAD of *A. spiridoides* in the early Burdigalian (Early Miocene); however, de Verteuil and Norris (1992) extended the LAD into the basal Serravallian. *S. soucouyantiae* de Verteuil and Norris 1992, originally described from the lower Middle Miocene of Maryland (de Verteuil and Norris 1992), is restricted to the Miocene. *Thalassiphora* sp. 1 of Powell (1988) has a stratigraphical range of Burdigalian–Langhian in surface sections from the eastern USA.

The above association indicates a Burdigalian–Langhian (20·0–15·2 Ma; Early to early Mid Miocene) age for the sample. If Williams (1975) and Powell (1992) are correct in believing that *Apteodinium spiridoides* has its LAD in the Burdigalian, this would support a Burdigalian (late Early Miocene) age.

#### SYSTEMATIC PALAEOLOGY

Division DINOFLAGELLATA (Bütschli, 1885) Fensome, Taylor, Norris, Sarjeant, Wharton and Williams, 1993

Class DINOPHYCEAE Pascher, 1914

Order GONYAULACALES Taylor, 1980

Family AREOLIGERACEAE Evitt, 1963

Genus RAMIDINIUM gen. nov.

*Derivation of name.* From the Latin *ramus* = branch, in reference to the branched processes, and the usual dinoflagellate suffix ‘-dinium’.

*Type.* Plate 1, figures 4–5; Text-figure 2D–E. *Ramidinium tridens*, gen. et sp. nov.

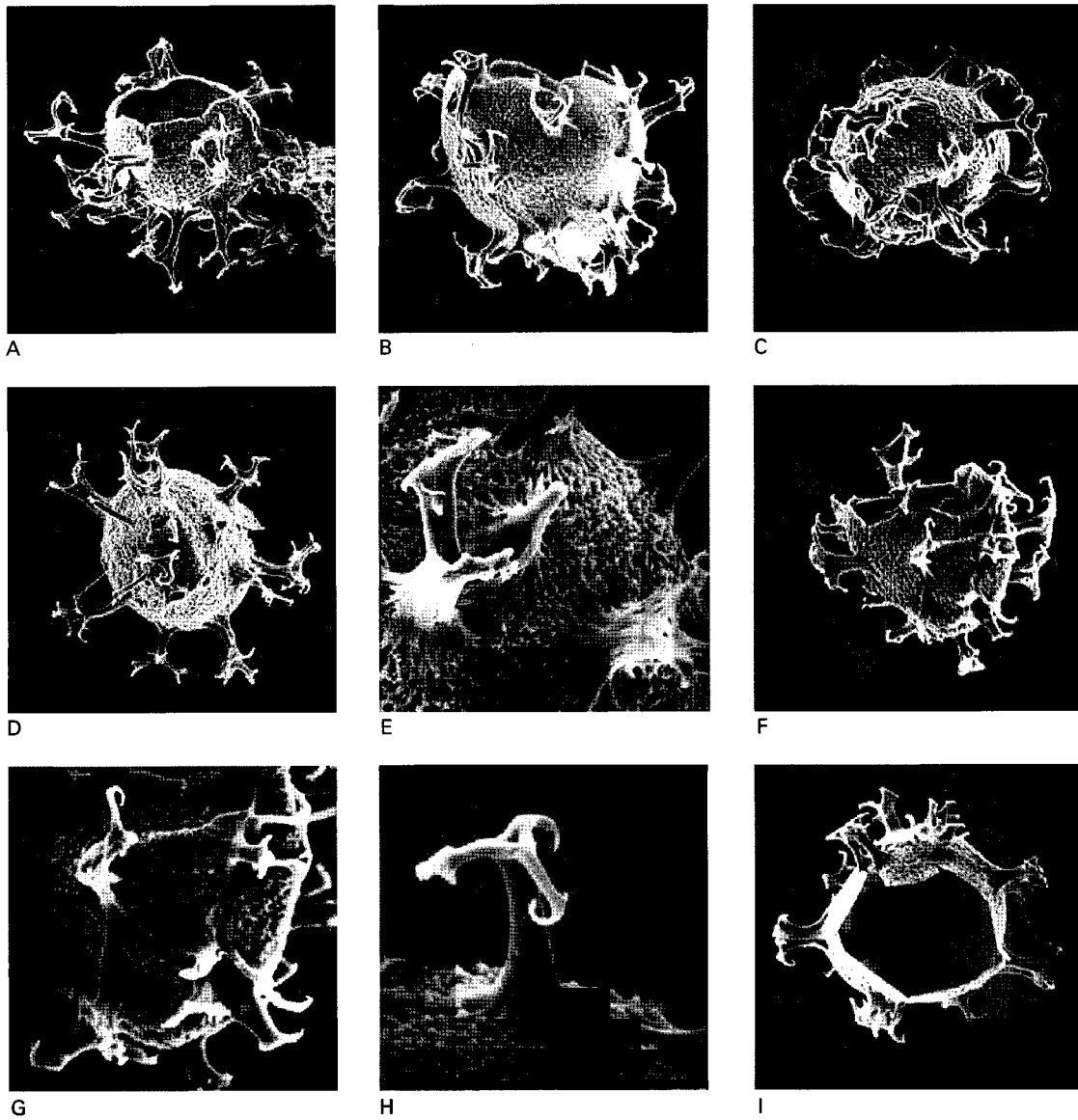
*Diagnosis.* Areoligeracean proximochorate to usually chorate, acavate cysts, with processes that are primarily parasutural and typically irregularly branched.

*Comparisons.* Among areoligeraceans, *Ramidinium* is distinct in having parasutural, branched processes. *Chiropteridium* Gocht, 1960 is also an areoligeracean with some isolated processes but differs from *Ramidinium* in having proximally membranous, confluent septa that occur principally in the marginal areas. Schindler (1992) described five *Chiropteridium* morphotypes, each exhibiting four lateral, crest-like structures on the dorsal and ventral surfaces, extending meridionally from the apical to the antapical region. These structures in *Chiropteridium* may be parasutural in part, although this is not clear from published descriptions. *Ramidinium* has a more uniform distribution of processes, and the crest-like structures of *Chiropteridium* are absent or may be represented by the low ridges joining adjacent processes (Pl. 1, figs 1–2; Text-figs 2A, 3G). These low ridges may be relicts of the membranes observed in *Chiropteridium*. *Areoligera* Lejeune-Carpentier, 1938 is characterized by the presence of arcuate complexes and *Glaphyrocysta* Stover and Evitt, 1978 has processes that are predominantly marginate in position and typically nontabulate or intratabulate. *Enneadocysta* Stover and Williams, 1995 also has an apical archaeopyle and some dorsoventral compression, but differs from *Ramidinium* in having intratabular processes that, around the antapex, are apparently arranged in the partiform pattern. *Cooksonidium* Stover and Williams, 1995 differs from *Ramidinium* in having intratabular processes, which sometimes occur in penitabular complexes. *Spiniferites* Mantell, 1850 and *Achomosphaera* Evitt, 1963, which also have parasutural processes with furcate endings, are distinguished from *Ramidinium* by having a precingular archaeopyle.

*Ramidinium tridens* sp. nov.

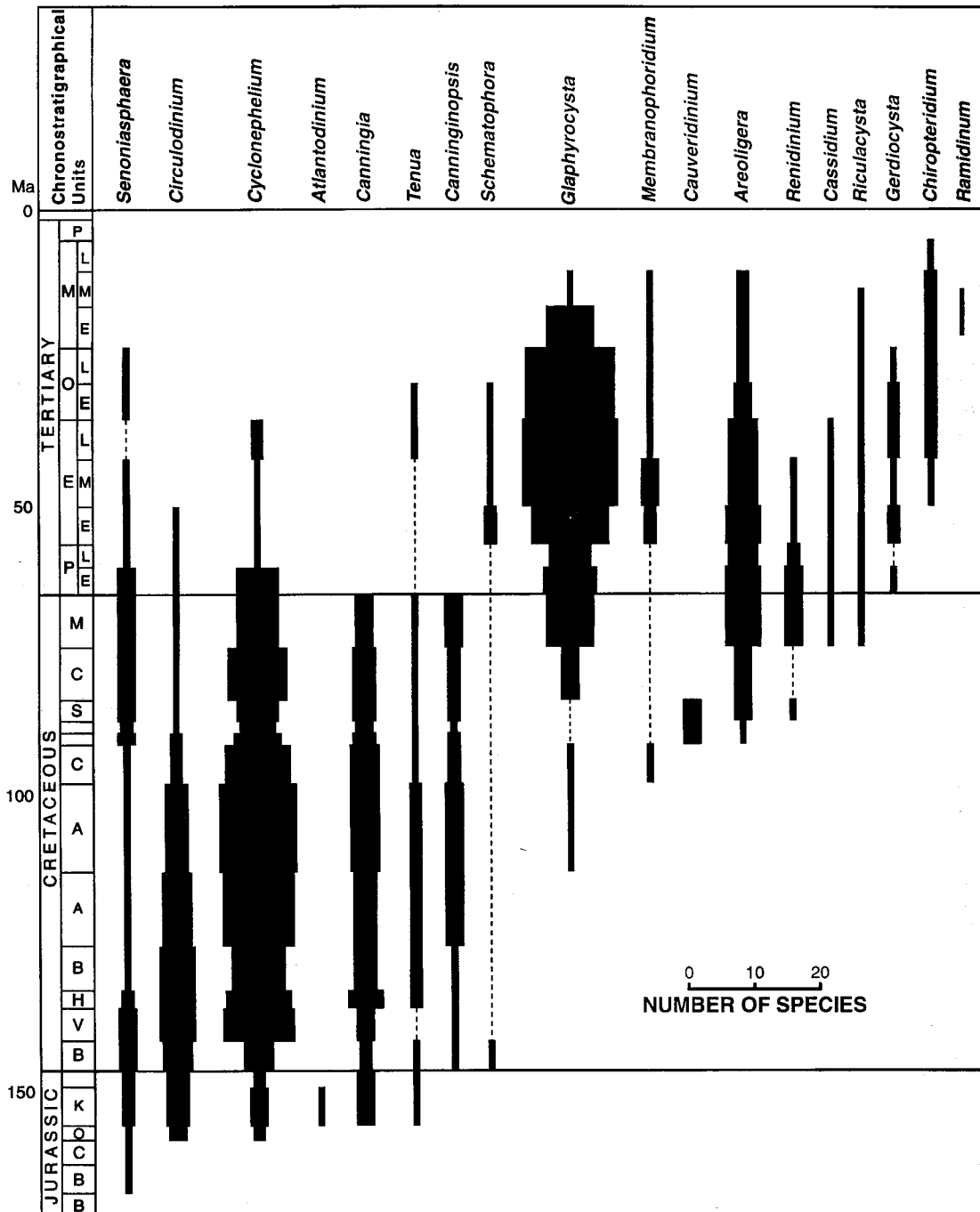
Plate 1; Text-figures 2–3

*Derivation of name.* From the Latin *tridens* = trident, fork with three tines, in reference to the distal nature of the processes. The specific epithet is a noun in apposition.



TEXT-FIG. 3. *Ramidinium tridens* gen. et sp. nov., scanning electron photomicrographs; GSC Atlantic preparation P1433. A, stub no. 1433a, GSC specimen no. 116305, specimen lost; ventral view; x 526. B, stub no. 1433a, GSC specimen no. 116306 (specimen lost); ventral view?; x 847. C, stub no. 1433a, GSC specimen no. 116307 (specimen lost); x 581. D, stub no. 1433a, GSC specimen no. 116308 (specimen lost); x 555. E, stub no. 1433r, GSC specimen no. 116309; detail showing the wall structure and processes; x 1786. F-G, stub no. 1433r, GSC specimen no. 116310. F, ventral view; x 658. G, detail showing processes joined basally by low ridges; x 1538. H, stub no. 1433r, GSC specimen no. 116311; detail of trifurcate process; x 1389. I, stub no. 1433r, GSC specimen no. 116312; apical view; x 741.

*Holotype.* Plate 1, figures 4-5; Text-figure 2D-E. GSC specimen no. 116295, National Collection of Type Invertebrate and Plant Fossils, Geological Survey of Canada, Ottawa, Ontario, Canada; GSC Atlantic slide No P1433-10, coordinates: 84.7° x 2 (EF B14/1). Type locality: 108-118 feet, Corehole 16, 46° 15' N, 49° 03' W, Grand Banks, offshore eastern Canada.



TEXT-FIG. 4. Spindle plots showing the species diversity of individual genera of the family Areoligeraceae per unit time. The width of each bar represents number of species. See text for further details. Stages (Mesozoic) and epochs and subepochs (Tertiary) are indicated as follows, in ascending order: Jurassic stages: B = Bajocian, B = Bathonian, C = Callovian, O = Oxfordian, K = Kimmeridgian, unlabelled = Portlandian. Cretaceous stages: B = Berriasian, V = Valanginian, H = Hauterivian, B = Barremian, A = Aptian, A =



*Diagnosis.* A species of *Ramidinium* with c. 20–26 primarily parasutural processes that have mostly irregular trifurcate endings.

### Description

*Shape.* Cysts proximochorate to chorate, dorsoventrally compressed, central body lenticular. Antapical outline symmetrical or asymmetrical.

*Wall relationships.* Autophragm only.

*Wall features.* Autophragm finely ornamented, typically irregularly reticulate to rugulate (Text-fig. 3E). There are 20–26 processes, 11 or 12 on the epicyst, five to nine on the hypocyst, and four or five on the paracingulum. Processes usually gonal and intergonal (Pl. 1, figs 7–8; Text-fig. 2D–H), possibly sometimes intratabular; they are usually cylindrical or rounded triangular in cross section, solid and generally ending in irregular trifurcations (Text-fig. 3D, H), but they may be distally bifurcate or asymmetrically expanded (Text-fig. 2B, H–I). Some processes may be hollow (Text-fig. 3E) and, occasionally, taeniate processes occur that give the impression of two stems joined by a membrane (Pl. 1, figs 6, 10–12, 15; Text-fig. 3B, E–F, I). Adjacent processes are sometimes joined basally by low, possibly parasutural ridges (Pl. 1, figs 1–2, 5, 10; Text-fig. 3G). Delicate trabeculae occasionally connect postcingular processes (Pl. 1, fig. 13).

*Paratabulation.* Areoligeracean paratabulation indicated on epicyst by archaeopyle sutures and location of parasutural processes. Elsewhere on central body, paratabulation indicated solely by primarily parasutural processes. Generally there is no process between paraplate 6'' and the anterior sulcal paraplate (Text-figs 2A, D, G, 3A).

*Paracingulum.* Indicated by four or five processes in gonal or intergonal positions.

*Parasulcus.* Position indicated anteriorly by offset parasulcal notch (Text-fig. 2D, G). Rarely parasulcal notch medial or only slightly offset (Pl. 1, fig. 14).

*Archaeopyle.* Apical, type (tA); operculum tetratabular, simple, free and longer transversally than dorsoventrally (Pl. 1, figs 3, 9; Text-fig. 2I).

*Size.* Holotype: length of the central body (without operculum): 42  $\mu\text{m}$ ; width of the central body: 53  $\mu\text{m}$ ; process length: 13–19  $\mu\text{m}$ . Range of 20 specimens: length of the central body (including operculum): 47(55)63  $\mu\text{m}$ ; length of the central body (without operculum): 36(41)47  $\mu\text{m}$ ; width of the central body: 47(55)63  $\mu\text{m}$ ; process length: 9–23  $\mu\text{m}$ .

### Comparisons

*Ramidinium tridens* resembles the type material of *Galea twistringiensis* Maier, 1959, which has a smooth wall and distally widened and regularly divided processes. Sarjeant (1983) included *G. twistringiensis* in synonymy with *Spiniferites ramosus* var. *multibrevis*, implying that it has a precingular rather than an apical archaeopyle. *Chiropteridium galea* (Maier, 1959) Sarjeant, 1983 is the species of *Chiropteridium* most similar to *R. tridens*, having processes that may be furcate or

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Albian, C = Cenomanian, unlabelled = Turonian, unlabelled = Coniacian, S = Santonian, C = Campanian, M = Maastrichtian. Tertiary epochs: P = Paleocene, E = Eocene, O = Oligocene, M = Miocene, P = Pliocene. Tertiary epochs are divided into Early (E) and Late (L) or Early (E), Mid (M) and Late (L) subepochs, except for the Pliocene, which is undivided in this study. The unlabelled interval at the top of the plot represents the Quaternary. The timescale used herein is based on that of Harland *et al.* (1990), except for our usage of Portlandian rather than Tithonian for the latest Jurassic stage.

branched. However, *R. tridens* differs from *C. galea* in having processes on the epicyst that are consistently parasutural in position, isolated or united by low ridges only. Processes on *C. galea* may be isolated, but tend to arise from four marginal meridional crests which usually are not obviously parasutural. Nevertheless, in some specimens of *C. galea* from the Grand Banks, meridional membranes are clearly in part parasutural, since they align with the accessory archaeopyle suture between precingular paraplates. *Chiropteridium* Morphotype E of Schindler (1992) also has four meridional membranes almost fully divided into hollow, distally closed and proximally interconnected processes; towards the poles these processes are more slender and distally furcated. However, Morphotype E differs from *R. tridens* in lacking the processes on mid-ventral and mid-dorsal surfaces and in having a distinctly granulate wall. *R. tridens* has an irregularly reticulate to rugulate wall and, occasionally, low proximal ridges joining adjacent processes. *Enneadocysta harrisii* Stover and Williams, 1995 has similar process stems, but the processes are intratabular rather than parasutural and have lirate endings.

*Occurrence.* Lower–lower Middle Miocene (Burdigalian–Langhian, as determined from palynology), Corehole 16, Grand Banks, offshore Eastern Canada.

#### DISCUSSION AND CONCLUSIONS

The family Areoligeraceae is an extinct dinoflagellate family that first occurred in the Late Jurassic and was common throughout the Cretaceous and Paleogene. The stratigraphical distribution and species richness of all areoligeracean genera are shown in Text-figure 4. In the Mesozoic, the family was represented by forms with no, or only low, spines (proximate and proximochorate cysts), whereas during the Paleogene, representatives tended to be spinose (chorate, e.g. *Areoligera* and *Glaphyrocysta*). In the later Paleogene, forms with marginal membranes or wall cavities (e.g. *Membranophoridium* Gerlach, 1961 and *Chiropteridium*) became common. Previously, no new genera were known to have evolved in the Neogene; *Ramidinium*, a possible derivative of *Chiropteridium*, is thus the only known areoligeracean genus to appear in the Neogene.

Information for Text-figure 4 (except for the *Ramidinium* bar, which is based on the present work) was derived from PALYNODATA, a database compiled over the past quarter century by a consortium of several major oil companies and the Geological Survey of Canada. PALYNODATA stores biostratigraphical information from pre-Quaternary palynology publications: at present, PALYNODATA contains information from about 18000 such publications. In Text-figure 4, the number of species per genus per unit time are plotted. It was impractical to check the many hundreds of records that contributed to this plot, although a detailed search of anomalous records eliminated some that clearly represented reworking or contamination (for further elaboration of the techniques involved, see Fensome *et al.* 1996 and MacRae *et al.* 1996). Text-figure 4 emphasizes that *Ramidinium* is indeed the last evolving genus of a prominent and biostratigraphically important family of dinoflagellates.

The later evolutionary pattern of the Areoligeraceae is reflected in our observations of the dinoflagellate assemblages from Corehole 16. The Early Oligocene assemblage (88–91 m) contains the areoligeraceans *Membranophoridium aspinatum* Gerlach, 1961 and *Chiropteridium galea*, with transitional forms between the two species. In the assemblage from the Upper Oligocene (116.5–119.5 m), *C. galea* was the only areoligeracean present and is a dominant element. Thus, there is an apparent trend from the membranous areoligeraceans to forms with divided membranes and isolated processes. This trend appears to culminate with *Ramidinium tridens*.

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Arco Oil and Gas Co., and the Geological Survey of Canada. This is Geological Survey of Canada Contribution no. 1997017.

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