



EARLY CAMBRIAN APPALACHIAN ARCHAEOCYATHS: FURTHER AGE CONSTRAINTS FROM THE FAUNA OF NEW JERSEY AND VIRGINIA, U.S.A.

MARK A.S. McMENAMIN, FRANÇOISE DEBRENNE & ANDREY YU. ZHURAVLEV

McMENAMIN M.A.S., DEBRENNE F. & ZHURAVLEV A.Yu 2000. Early Cambrian Appalachian Archaeocyaths: further age constraints from the fauna of New Jersey and Virginia, U.S.A. [Faune d'Archéocyathes du New Jersey et de Virginie, (U.S.A.). Nouvelles contraintes pour l'âge du Cambrien inférieur des Appalaches]. *GEOBIOS*, **33**, 6: 693-708. Villeurbanne le 31.12.2000.

Manuscrit déposé le 22.11.1999; accepté définitivement le 22.03.2000.

ABSTRACT - New data allow us to correlate the Early Cambrian archaeocyathan faunas of the Appalachian (eastern) and Cordilleran (western) faunal provinces of Laurentia. The precise relationships of fossil assemblages between these provinces have hitherto been controversial, with the correlation of the *Elliptocephala asaphoides* Fauna posing particular problems. New and revised data (including the new taxa *Sekwicyathus tillmani* nov. sp. DEBRENNE & A. ZHURAVLEV and *Archaeosycon balsami* nov. sp. DEBRENNE & A. ZHURAVLEV on archaeocyathan assemblages from the Appalachians New Jersey and Virginia allow correlation of these assemblages to the middle *Bonnia-Olenellus* Zone of the Pacific Laurentia (Late Botoman) and the *Elliptocephala asaphoides* Fauna with the middle-upper *Bonnia-Olenellus* Zone (Late Botoman-Early Toyonian). The Appalachian archaeocyathan assemblages are not endemic but originated from archaeocyaths of the Pacific Region in or near the Middle Botoman; then, during the Middle Botoman-Late Botoman, they migrated northward along the Appalachian margin of Laurentia (in term of modern coordinates). We discuss here the development and the extent of influence of the Hawke Bay regressive event, and the pattern of archaeocyathan migration as the Appalachian margin of Laurentia drifted northward into equatorial latitudes.

KEYWORDS: LAURENTIA, LOWER CAMBRIAN, NEW ARCHAEOCYATHS, APPALACHIAN-CORDILLERAN CORRELATIONS.

RÉSUMÉ - De nouvelles données nous permettent de corréliser les faunes du Cambrien inférieur des provinces fauniques de la Laurentia, les Appalaches à l'Est et la Cordillère à l'Ouest. Jusqu'à présent, des relations précises entre les assemblages fauniques des deux provinces ont été sujets à discussion, la corrélation de la Faune à *Elliptocephala asaphoides* posant un problème particulier. Les assemblages d'archéocyathes des Appalaches ont été révisés et complétés par l'étude des nouvelles formes, *Sekwicyathus tillmani* nov. sp. DEBRENNE & A. ZHURAVLEV et *Archaeosycon balsami* nov. sp. DEBRENNE & A. ZHURAVLEV, permettant l'établissement de corrélations entre ces assemblages et la partie inférieure et moyenne de la Zone à *Bonnia-Olenellus* (Botomen supérieur) de la Laurentia (Cordillère Pacifique) et de la Faune à *Elliptocephala asaphoides* avec les parties moyennes et supérieures de la Zone à *Bonnia-Olenellus* (Botomen supérieur - Toyonien inférieur). Les assemblages d'archéocyathes des Appalaches ne sont pas endémiques mais proviennent des archéocyathes de la Région Pacifique, vers le milieu du Botomen; puis, pendant le Botomen moyen et le Toyonien inférieur, ils migrent vers le Nord le long de la marge appalachienne de la Laurentia (en coordonnées récentes). Sont discutés ici l'influence du développement et de l'extension de l'événement régressif de Hawke Bay et le modèle de la migration des archéocyathes lors de la dérive nord de la marge appalachienne de la Laurentia vers des latitudes équatoriales favorables aux archéocyathes.

MOTS-CLÉS: LAURENTIA, CAMBRIEN INFÉRIEUR, NOUVEAUX ARCHÉOCYATHES, CORRÉLATIONS APPALACHES-CORDILLÈRE PACIFIQUE.

INTRODUCTION

The Appalachian archaeocyath fauna has been studied since the end of the nineteenth century (Ford 1873a, 1873b, 1878; Walcott 1886, 1890; Lesley 1889; Resser 1938; Stose & Jonas 1939; Okulitch 1943; Lochman 1956; Palmer 1971; Palmer & Rozanov 1976; Bearce & McKinney 1977; James & Debrenne 1980; McMEnamin et al. 1994). Its importance has long been noted, and even though scarce and incompletely preserved archaeocyaths have been used to support extensive paleogeographic

and paleoecologic inferences and stratigraphic correlations (e.g.: Lochman 1956; Palmer & Rozanov 1976; Peiffer-Rangin 1979; Theokritoff 1979; Mansy et al. 1993; McMEnamin et al. 1994; Naimark & Rozanov 1997). These studies have been limited by the fact that virtually none of the eastern Laurentian archaeocyaths have been subjected to thorough and up-to-date taxonomic study.

Appalachian archaeocyaths promise key information for a variety of paleontological and geological research areas associated with the Cambrian stra-

tigraphy. In addition, the fauna may provide constraints for the controversial correlations of the *Elliptocephala asaphoides* Fauna with the Lower Cambrian subdivisions of Cordilleran Laurentia (Theokritoff 1982, 1985; Landing 1988, 1992; Palmer & Repina 1993; Landing & Bartowski 1996). The *Asaphoides* fauna contains relicts of the earlier Tommotian-Atdabanian biota (such as *Fordilla* and mobergellans) and thus provides upper limits for the stratigraphic ranges of these paleontologically important taxa.

A variety of nomenclatural problems are associated with Appalachian archaeocyath taxonomy. Their original descriptions, based on weathered specimens rather than oriented thin sections, do not mesh easily with modern methods of study. The preservation and weathered nature of most of the type material precludes the preparation of adequate thin sections. Thus, although these classic taxa are valid species and genera, they are in many cases not sufficiently well described for the purposes of modern taxonomic work. One goal of this paper is to partly remedy this situation.

FOSSIL OCCURRENCES

Two main localities have provided archaeocyaths for the present study. The first collection came from the lower few meters of the Leithsville Formation in Franklin, New Jersey, (Palmer & Rozanov 1976), (Fig. 1). They mentioned the presence of four different archaeocyathan species, and illustrated two of them. The locality was recollected by McMenamin and his students in 1989.

The archaeocyathan locality is approximately 112 m east and 41 m south of the northwest corner of the Franklin 7.5 minute quadrangle map, (Fig. 1).

At this locality a short monoclinical section dips westward at an angle of about 57°. Approximately 4 m of the underlying coarse-grained Hardyston Quartzite are poorly exposed here above gneissic basement (Palmer & Rozanov 1976).

The second locality was collected by F. Boyer in 1966 during a Paris-VI University excursion at Austinville, Virginia. A. Yu. Rozanov and C.G. Tillman also collected in the same area in 1975 (Fig. 2). The second collection and a part of the first collection are presently housed in the National Museum of Natural History, Paris, France (MNHN); the remaining specimens are held by the New York State Museum, Albany, U.S.A. (NYSM). A third collection is deposited in the Paleontological Institute, Russian Academy of Sciences, Moscow (PIN).

Virginian archaeocyathan reefs cropping out north-east of Austinville were described by Currier 1935, Resser 1938 and Butts 1940. The validity of this archaeocyath occurrence has been questioned by Balsam 1970, 1974. He supposed that the archaeocyaths cited from Virginia were chiefly bioturbation fabrics.

A specimen from the Mount Holyoke collection (n° 6046, labelled *Archaeocyathus*, Lower Cambrian, Wythe County, Virginia) appears to be from the same locality or at least the same lithology as shown in the middle picture of Resser's plate 1, 1938 (from Bud Branch, a mile northeast of Austinville, Virginia). This specimen has the same curving veins (up to 3.5 cm wide) of concentric layered, banded to sparry recrystallised calcite. This recrystallisation is part of the same event that led to the emplacement of nearby lead-zinc ores (Fig. 2) and to development of zones of alternating layers of white and dark recrystallised dolomite in much of the ore (Foley et al. 1981). The calcite veins merge together to enclose subspherical chunks of

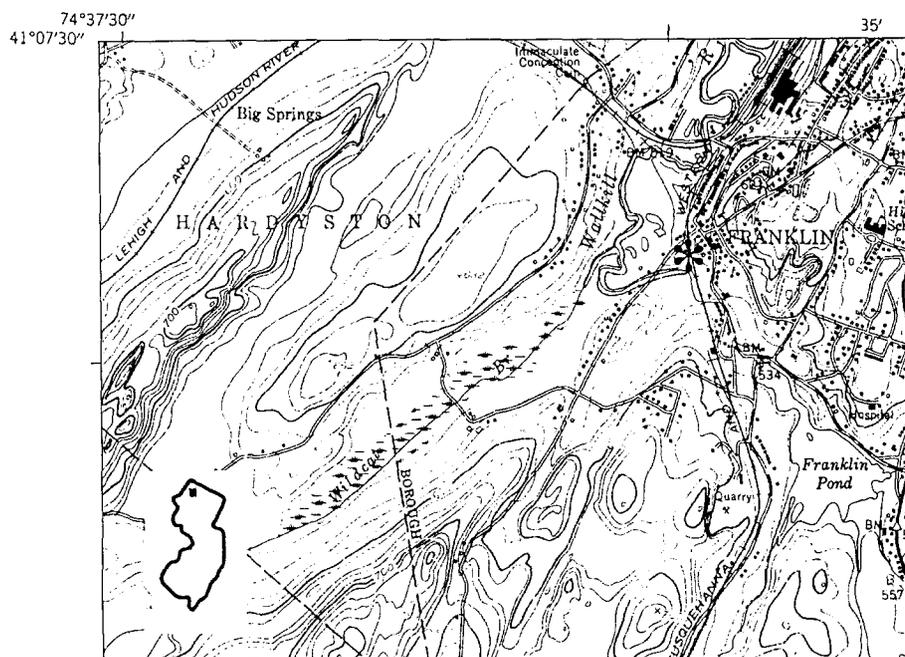
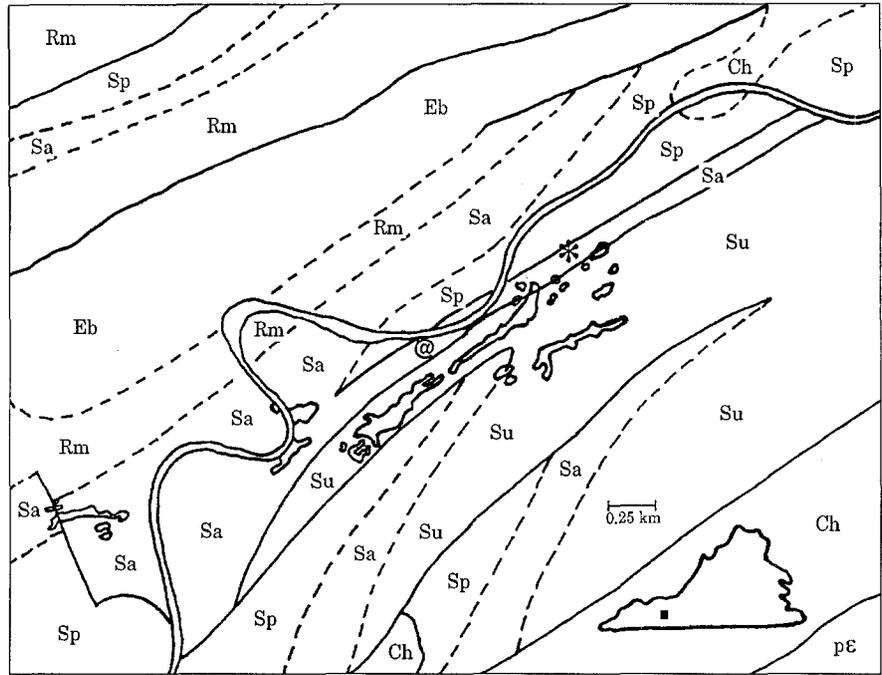


FIGURE 1 - Franklin area, New Jersey. Région de Franklin.

FIGURE 2 - Austinville area, Virginia. Geologic Map of the Austinville area, Virginia. New River (lower left to upper right). Areas with solid borders: zones of Pb-Zn mineralization. Sedimentary rock units in ascending stratigraphic order: Ch. Chilhowee Group (Erwin Formation); Sp. Shady Dolomite, Patterson Member; Sa. Shady Dolomite, Austinville Member; Su. Shady Dolomite, Upper Shady Dolomite Member; Rm. Rome Formation; Eb. Elbrook Formation. Other symbols: @. Austinville; *. Archaeocyathan locality. Inlet: position of site within the State of Virginia. *Région d'Austinville, Virginie. New River (bas gauche à haut droit); limites en lignes continues: zones de minéralisations. Pb-Zn. En ordre stratigraphique ascendant, unités sédimentologiques: Ch...etc. Insert: position du site dans l'état de Virginie.*



relatively unaltered limestone. Mount Holyoke 6046 has been recently thin sectioned: the rock contains sponge spicules, echinoderm ossicles and trilobite fragments but lacks archaeocyaths: the possible specimen of *Archaeocyathus* which seems to appear on a saw-cut surface is, in fact, part of concentric layers as described above. Balsam's (1970, 1974) concerns about the authenticity of the Wythe County Archaeocyaths are thus reinforced.

Willoughby (1976) concluded that archaeocyaths in the Austinville area of Virginia are restricted to the upper Austinville Member of the Shady Dolomite, which is quarried by the New Jersey Zinc Company Mine. He further concluded that archaeocyaths do not occur in Resser's 1938, p. 24 so-called 'archaeocyathid reef' in the 'fossil point limestone fauna' whose faunal list includes *Archaeocyathus* sp.

Numerous finds of unequivocal archaeocyaths confirm their presence in the Shady Dolomite (James & Debrenne 1980; Pfeil & Read 1980; Kobluk 1982, 1985; Read & Pfeil 1983; Naimark & Rozanov 1997). Detailed studies have been published concerning the Shady Dolomite Reefs of Virginia (Pfeil & Read 1980; Kobluk 1982, 1985; Read & Pfeil 1983; Barnaby & Read 1990; Pratt 1995) but none of these studies focused on the archaeocyaths. With the exceptions of Resser 1938 and Okulitch 1943, who figured a few weathered-out specimens, Austinville archaeocyaths have neither been illustrated nor described subsequently. The archaeocyaths described here are from subsurface strata of the Austinville Member excavated by the mine in section 1 of Pfeil & Read (1980).

The whole Lower Cambrian succession in this part of Virginia begins with the Chilhowee Group which includes, in ascending order, alluvial quartz-pebble conglomerates and feldspathic arenites of the Unicoi Formation, outer shelf to coastal siltstones and arenites of the Hampton Formation, and coas-

tal quartzitic arenites with subordinate mudstones of the Erwin Formation. The Unicoi Formation contains trace fossils, hyoliths occur in the Hampton Formation, and the Erwin Formation has yielded the trilobite *Olenellus* and the brachiopod '*Obolella*' (Simpson & Sundberg 1987). The Chilhowee Group is interpreted as synrift-early postrift deposits formed during the opening of the Iapetus Ocean in the Early Cambrian as part of the break-up of Rodinia (Bond et al. 1984; Fichter & Diecchio 1986).

The Shady Dolomite (640-1300 m thick) marks a shift to carbonate deposition. Barnaby & Read (1990) and Pratt (1995) described the depositional succession of the Shady Dolomite. Carbonate sediment accumulation was initiated on an earlier siliclastic reef and led to the deposition of a thick sequence of deep-ramp, nodular limestones (Patterson Member). This facies shallowed upward into a carbonate ramp fringed by low-relief, stromatolite-archaeocyath mud-mounds (Austinville Member). These mud-mounds consist of irregularly laminoid crusts of locally peloidal micrite with scattered echinoderm ossicles, sporadic lenses with *Salterella* and trilobite bioclasts (Pratt 1995). These build-ups pass downslope into conglomerates and deep-ramp carbonate facies; cyclic peritidal sequences developed landward of the build-ups. As the ramp increased in relief into the latest Early Cambrian, dendrolites (calcimicrobial bioherms) and grainstones were established on the high-energy margin to form a high-relief rimmed shelf with thick off platform deposits immediately seaward of the shelf edge (upper Shady Dolomite). In the shelf interior, a major regression during the Early to Middle Cambrian transition resulted in a significant but obscure unconformity and deposition of red beds of the overlying Rome Formation (Barnaby & Read 1990).

MICROFACIES

New Jersey

- Description: Archaeocyathan bioherms occur about 3 m above the top of the Harliston quartzite in the lower part of the Leithsville Formation. These reefs are dark grey dolomitic bafflestones composed of intergrowths of branching specimens of *Archaeocyathus* sp. which were strengthened by secondary skeletal structures of the same species (Fig. 3.1-4). Rare reworked archaeocyaths belonging to *Cordilleracyathus* ? sp. (Figs 3.2,6), hyoliths, calciate brachiopods and trilobites are confined to interreefal floatstone. The calcareous micrite in the floatstone is clotted and penetrated by burrows with pellets fills.

- Interpretation: the clotted texture of the mud may result from bacterial activity (Wood et al. 1993) and may reflect bacterial colonisation and binding of sediment particles suspended by metazoan bioturbation (McMenamin & McMenamin 1990: 155) or other types of sediment disturbance. The development of intense bacterial scum, together with the accumulation of pure mudstone in the absence of winnowing, and the in situ occurrence of archaeocyathan thickets, is suggestive of calm subtidal conditions during bioherm formation.

Virginia

- Description: In Virginia, the carbonate part of the Lower Cambrian is subdivided now into: Patterson Member, Austinville Member, Ivanhoe Member, and Upper Shady Dolomite Member (all are Members of the Shady Dolomite), and the overlying Rome Formation (Pfeil & Read 1980). Archaeocyaths are restricted to the Austinville Member where they are confined to a 30 m thick and 3.5 km wide stromatolite mud-mound complex (Barnaby & Read 1990). Individual mounds are between 1 and 30 m thick and many are laterally extensive biostromes. The Austinville Member mud-mounds comprise two principal microfacies: a bafflestone-floatstone that interfingers with a stromatolite-rich mudstone. The bafflestone is primarily formed by branching *Archaeocyathus resseri* individuals (Fig. 4.1-5). Other archaeocyaths (*Ethmophyllum whitnei*, Fig. 4.6-7; *Archaeosycon balsami*, Fig. 4.8) and associated organisms (echinoderms, spicular sponges, cancelloriids, radiocyaths) are present as soft-bottom dwellers rather than as frame-builders. They form interreefal floatstone along with the trilobite remains. Rare colonies of calcimicrobes and the coralomorph *Labyrinthus* encrust the *Archaeocyathus* cups. The matrix of bafflestone consists of pure calcareous micrite with an admixture of quartz grains and monaxon spicules. Dolomitisation affect

ed largely the archaeocyathan skeletons, calcimicrobes and coralomorphs. The stromatolite-rich mudstone contains abundant stromatolite cavities, which are rimmed with fibrous to bladed marine cement, often of two generations and floored with internal sediment. The remaining space is filled with sparry calcite.

- The Ivanhoe Member mudstone was originally illustrated by Resser (1938, Plate 1) as bearing archaeocyathan reefs (Brown & Weinberg 1968). These facies were subsequently reinterpreted by Balsam (1974) as a burrowed mudstone. Archaeocyaths are now known not to occur in these rocks showing burrowed fabrics. The bioturbated microfacies has burrows up to 20 mm in cross sections, these burrows have very distinct walls, up to 2 mm thick, that consist of pellets, 0.1-1.3 mm in diameter; a microspar fills the space between the pellets (Fig. 3.7); occasional echinoderm ossicles are present in the pellets. The remaining cavities of the burrows are filled with bladed cement and sometimes with mud, which, in turn, is penetrated by smaller burrows of approximately 2 mm diameter.

- Interpretation: the general structure of the Austinville reefs is very similar to the Franklin reefs described above, and consists of *Archaeocyathus*-bafflestone with interreefal floatstone. The difference lies in the absence of clotted fabrics and in the intensive development of stromatolite cavities in the Austinville Member reefs. The fibrous-bladed cement infilling the cavities is a marine cement, commonly found in Early Cambrian reefs. The cement development and the presence of calcimicrobes (renalcids) probably indicate a slightly more agitated environment than in the Leithsville Formation, but is subtidal (James & Klappa 1983; Kruse et al. 1995). In addition, a subtidal setting below fair-weather wave base is indicated by the abundant lime mud, paucity of current-induced structures, occurrence of whole and abraded fossils and interbedded deep-ramp nodular limestone and shale (Barnaby & Read 1990).

- The larger burrowing animal of the Ivanhoe Member strengthened the walls of its burrows with organically bound pellets, which preserved the burrows for subsequent cementation. The organic binding matter is apparently replaced by microspar. Although echinoderm ossicles are observed in the pellets, this fact does not necessarily indicate that the burrower was carnivorous, because such ossicles are widely dispersed in the mud. Deposit-feeders will occasionally ingest such debris when they encounter it (Thayer 1983). Astashkin (1983, 1985) has assigned trace fossils such as these to the genus *Aulophycus* which was originally described as an alga by Fenton & Fenton 1939, from the Upper

FIGURE 3 - Archaeocyaths of the Leithsville Formation, Franklin, New Jersey (Figs 1-6) and biogenic fabrics from the Austinville Member, Shady Dolomite, Virginia (Figs 7-9). 1. *Archaeocyathus* sp., MNHN M83334, oblique-longitudinal section, x 5. 2. (bottom), *Archaeocyathus* sp. MNHN M83333, transverse section, x 5. (superior), *Cordilleracyathus* ? sp. MNHN M83331, oblique transversal section, x 5. 3. *Archaeocyathus* sp. MNHN M83335, longitudinal section, x 5. 4. *Archaeocyathus* sp. MNHN M83336, transverse section, x 4. 5. *Archaeocyathus* sp. MNHN M83337, part of a longitudinal section; note a foreign body on the left, which cause the development of vesicles in the archaeocyath intervallum, x 5. 6. *Cordilleracyathus* ? sp. MNHN M83332, transverse section, x 10. 7. MNHN M83349, oblique-transverse section of a burrow with pellets cemented in the wall, x 4. 8. MNHN M83348, radiocyath longitudinal section, x 2.5. 9. *Ajacyathina* gen. et sp. indet., PIN 48131, oblique transverse section, x 4.

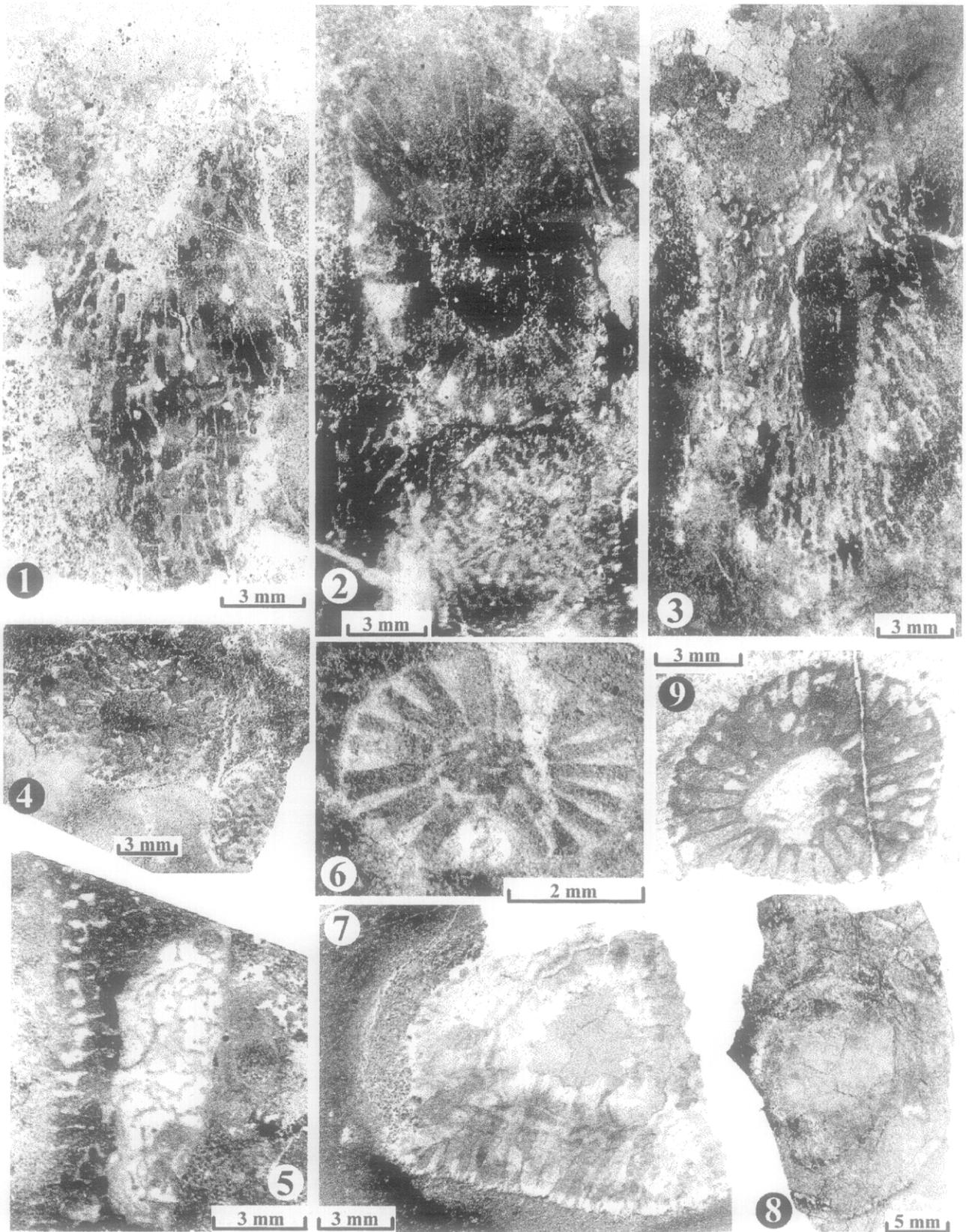


FIGURE 3 (suite) - Archéocyathes de la Formation de Leithsville, Franklin, New Jersey (Fig. 1-6) et structures biogéniques du Membre d'Austinville, Shady Dolomite, Virginie (Fig. 7-9), en lames minces. 1. *Archaeocyathus* sp., MNHN M83334, section longitudinale oblique, x 5. 2. (bas), *Archaeocyathus* sp., MNHN M83333, section transversale, x 5; (haut), *Cordilleracyathus* ? sp., MNHN M83331, section transversale oblique, x 5. 3. *Archaeocyathus* sp., MNHN M83335, section longitudinale, x 5. 4. *Archaeocyathus* sp., MNHN M8336, section transversale, x 4. 5. *Archaeocyathus* sp., MNHN M83337, section partielle; réaction du calice par le développement de vésicules dans l'intervalum, au contact d'un corps étranger (à gauche), section oblique transversale, x 5. 6. *Cordilleracyathus* ? sp., MNHN M83332, section transversale, x 10. 7. MNHN M83349, section transversale oblique d'un terrier avec pellets cimentés dans la muraille, x 4. 8. *Radiocyathe*, MNHN M83348, section longitudinale, x 2.5. 9. *Ajacicyathina* gen. sp., PIN 48131, section transversale oblique, x 4.

Cambrian of the United States. A nearly identical ichnofossil from the Upper Cambrian siliciclastic 'Gallatin' Formation of Wyoming has been attributed to the hexactinellid sponge *Multivasculatus* because of the presence of abundant spicules (Howell & Van Houten 1940). Similar burrow systems in Early Cambrian carbonates of the Keteme Formation from the Siberian Platform were subsequently considered to be calcified cyanobacteria and were given the name *Ketemella* (PYANOVSKAYA, 1974). Other similar burrows from the Upper Cambrian Peerless Formation and Lower Ordovician Manitou Formation of Colorado are assigned to the well-known, primarily mesozoic ichnogenus *Thalassinoides* (MYROW, 1995). These trace fossils may represent nearly identical forms, but the problem of the *Aulophycus* FENTON & FENTON / *Multivasculatus* HOWELL & VAN HOUTEN / *Thalassinoides* EHRENBERG / *Ketemella* PYANOVSKAYA synonymy is beyond the scope of this paper. Some of these trace fossils may be distinguished by the presence or absence of mucus-impregnated walls, pellets, swellings, vertical shafts, and other features. If the analogies with the *Callianassa* burrows suggested by Balsam 1974 and based on observations by Weimer & Hoyt 1964 are valid, shallow intertidal conditions would be indicated for the perireefal facies of the Austinville Member. This suggestion is in accord with recent observations on similar burrow systems by Bromley 1990. In the Early Cambrian of the Siberian Platform, similar bioturbation fabrics are indeed restricted to leeward areas (Astashkin 1985). A general shallowing in the Austinville Member-Ivanhoe Member sequence, as inferred by Barnaby & Read 1990, is thus supported by ichnological considerations. The disappearance of archaeocyaths from reefs of Virginia, in spite of the fact that reef growth continued through the rest of the Early Cambrian, may be related to this shallowing.

- The Toyonian reefs of the upper Shady Dolomite are built by a dense mass of renalcids including *Renalcis*, *Girvanella*, *Gordonophyton* (*Epiphyton* in Pfeil & Read 1980, figs 8b, 9a-d; Read & Pfeil 1983, figs 5a, 6a-f, 8d; Kobluk 1985, figs 3, 4.1-2, 7.1, 11.1-2), *Tarthinia* (globular foraminifers in Kobluk 1985, fig. 5), and *Kordephyton* (tufted *Girvanella* in Read & Pfeil 1983, fig. 7c). However archaeocyaths are completely absent (Read & Pfeil 1983; Kobluk 1985; Barraby & Read 1990).

SYSTEMATIC PALAEOLOGY

PHYLUM PORIFERA: Class ARCHAEOCYATHA
Order AJACICYATHIDA R. & J. Bedford, 1939 -
Suborder AJACICYATHINA R. & J. Bedford, 1939
Superfamily ETHMOPHYLLOIDEA Okulitch, 1937
Family FALLOCYATHIDAE Rozanov, 1969

Genus *Sekwicyathus* HANDFIELD, 1971

Sekwicyathus tillmani nov. sp. DEBRENNE & A.
ZHURAVLEV

Holotype - GSC 64019 (James & Debrenne 1980; Fig. 4.4) not refigured herein.

Type-locality - Canada, Western Newfoundland, Forteau Formation, Early Cambrian, Botoman Stage.

Synonymy

1980 Kijacyathidae genus B - James & Debrenne, p. 1612, pl. 1, fig. 4 (see errata below).

Derivatio nominis - Named in memory of American Geologist C.G. Tillman.

Diagnosis - A species of *Sekwicyathus* with cups possessing thick walls and non-porous septa; the outer wall bears projecting bulbous canals and the inner wall possesses bracts on central cavity side.

Description - Small solitary cups of 7 mm in diameter. The outer wall is pierced by 2-3 rows of spherical hollow chambers (bulbous canals) per intersept. Each chamber bears a vertical spine in the plane of the wall and is connected with the intervallum and outer milieu by openings oriented downward, imparting a V-shaped structure in longitudinal section. Canal diameter is 0.25-0.32 mm; distance between adjacent canals 0.15 mm; wall thickness 0.1 mm. The inner wall consists of bracts which cover a single row of simple pores per intersept; stirrup-like pores may occur occasionally in front of a new septum; wall thickness 0.5 mm, pore size 0.35 mm; non porous septa 0.1 mm thick.

Comparison - The new species differs from *S. nahanniensis* HANDFIELD by thicker outer and inner walls (0.1 mm versus 0.01-0.05 mm and 0.5 mm versus 0.1 mm, respectively) and by better developed bracts on the inner wall.

Discussion - Pores at the junction of septa and inner wall (stirrup pores) are considered as generic characters when there are no other communications between the intervallum and the central cavity. In the case of *Sekwicyathus*, the inner wall has one row of simple pores and in some specimens additional pores in front of septa, morphologically but not functionally equivalent to stirrup pore sensu stricto.

Material - Cross sections of a cup from the Forteau Formation, western Newfoundland.

Errata - Genus A, in James & Debrenne 1980 (GSC 64020) was correctly labelled in plate 1 caption as fig. 5 but misquoted in text as fig. 4: it is now assigned to *Sekwicyathus nahanniensis* (GSC 64019). The same mistake for Genus B (GSC 64019), misquoted in text as fig. 5 and correctly labelled in plate caption as fig. 4. Genus B is now assigned to *Sekwicyathus tillmani*.

Family ETHMOPHYLLIDAE OKULITCH, 1937

Genus *Ethmophyllum* MEEK, 1868

Ethmophyllum whitneyi MEEK, 1868
Fig. 4.6-7

Synonymy

1868 *Ethmophyllum whitneyi* - Meek, p. 62.

1993 *Ethmophyllum whitneyi* MEEK - Mansy et al., p. 670, pl. 4, figs 5-6 (includes species synonymy).

Description - Solitary archaeocyaths with conical-cylindrical cups up to 5 mm in diameter. The outer wall is penetrated by hollow spherical cham-

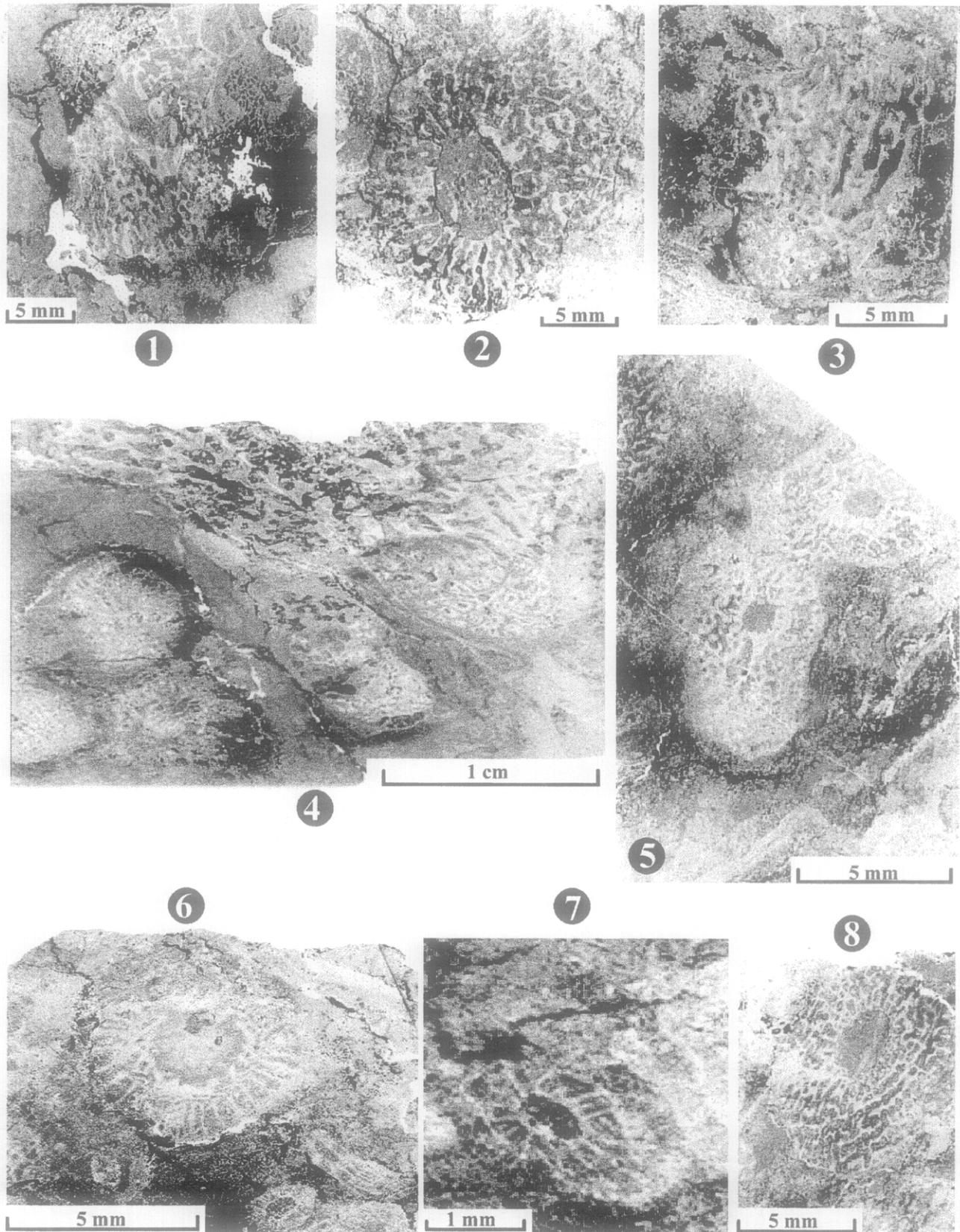


FIGURE 4 - Archaeocyaths of the Austinville Member, Shady Dolomite, Virginia (in thin sections). 1. *Archaeocyathus resseri* (OKULITCH, 1943), MNHN M83342, longitudinal section, x 2.5. 2. *Archaeocyathus resseri* MNHN M83343, transverse section, x 2.5. 3. *Archaeocyathus resseri* MNHN M83344, longitudinal section of a branching form, x 5. 4. *Archaeocyathus resseri* MNHN M83345, oblique-longitudinal section, x 4. 5. *Archaeocyathus resseri* MNHN M83346, transverse section of a branching form, x 4. 6. *Ethmophyllum whitneyi* MEEK, 1868, MNHN M83338 (top), transverse section, M83339 (bottom), transverse section of a juvenile cup, M83340 (right), longitudinal section of a juvenile cup, x 7. 7. *Archaeocyathus resseri* M83341, transverse section of a juvenile cup, x 18. 8. *Archaeosycon balsami* nov. sp. DEBRENNE & A. ZHURAVLEV, holotype MNHN M83347, transverse section, x 4. *Archéocyathes* du Membre d'Austinville, Shady Dolomite, Virginie (en lames minces). 1. Section longitudinale, x 2.5. 2. Section transversale, x 2.5. 3. Section longitudinale d'une forme branchue, x 5. 4. Section longitudinale oblique, x 4. 5. Section transversale d'une forme branchue, x 4. 6. Section transversale; M83339 (bas), section transversale d'une forme juvénile; M83340 (droite), section longitudinale d'une forme juvénile, x 7. 7. Section transversale d'une forme juvénile, x 18. 8. Section transversale, x 4.

bers (bulbous canals), each of which bears a vertical spine growing in the wall plane and is connected with the intervallum and outer milieu by openings oriented downward. The spine protrudes from the lower side of chambers which are hexagonal in cross section and arranged in 4-5 vertical rows per intersept. The thickness of wall is 1 mm in the largest cup observed. The inner wall consists of V-shaped structures in longitudinal section. It is penetrated by one row of pores per intersept that are formed by fluting of inner edges of septa and continuing into a branching and confluent canal system of upward and sideward direction. The inner wall is 0.8 mm thick and the canal diameter is 0.3 mm. There are aporose septa in the intervallum.

Ontogeny - The inner wall is simple and 0.05 mm thick at a cup diameter of 1 mm (Fig. 4.7). It becomes thicker (0.08 mm) at a cup diameter of 1.3 mm and the annular structures start to develop (Fig. 4.6, bottom). The diameter of inner wall pores is 0.1 mm at this level; the distal zone of the inner wall is formed later.

Material - Seven cups sectioned in a variety of orientations from the Austinville Member, Shady Dolomite, Austinville, Virginia (MNHN M83338-M83341).

Genus *Cordilleracyathus* ? HANDFIELD, 1971

Cordilleracyathus ? sp.
Fig. 3.2,6

Synonymy

1976 ajacicyathid - Palmer & Rozanov, p. 774.
1994 ajacicyathid - McMenamin et al., p. 225, pl. 1, fig. 2.

Description - Solitary archaeocyaths which have relatively small cups with even surfaces. The largest diameter is 10 mm and the intervallum in the biggest cup is 2.7 mm in width. The outer wall is 0.15 mm thick and bears 4 pore rows per intersept. Pores are of 0.15 mm in diameter and are separated by 0.025 mm thick lintels. The inner wall is thicker (0.2 mm) with larger pores (0.2 mm) forming short irregular intercommunicating canals terminated by small bracts. The canals are arranged in one, rarely two vertical rows per intersept. Aporous septa of 0.025 mm thick; intersept of 0.35 mm at the inner wall and of 0.5 mm at the outer wall. The septal coefficient is about 5 in the larger cups.

Material - Four transverse thin sections of different cups from the Leithsville Formation, locality 754 in Franklin, New Jersey (NYSM 16133 is figured in McMenamin et al. (1994) and MNHN M83331-M83332 are figured herein).

Discussion - The skeletal carbonate has been dissolved and replaced by sparry calcite, thus the actual sizes of skeletal elements are altered. This incompleteness of the material does not allow precise species or even generic determination. Nonetheless, the general features of skeletal elements and available numeric data (number of pore rows per intersept, septal coefficient) are very similar to those of specimens of *Cordilleracyathus blussoni* HANDFIELD described by James & Debrenne (1980) from the Lower Forteau Formation of Newfoundland.

Order ARCHAEOCYATHIDA Okulitch, 1935
Suborder ARCHAEOCYATHINA Okulitch, 1935
Superfamily ARCHAEOCYATHOIDEA Hinde, 1889
Family ARCHAEOCYATHIDAE Hinde, 1889

Genus *Archaeocyathus* BILLINGS, 1861

Archaeocyathus resseri (OKULITCH, 1943)
Fig. 4.1-5

Synonymy

1938 *Archaeocyathus* sp. - Resser, p. 36, pl. 2, fig. 28.
1943 *Metethmophyllum resseri* - Okulitch, p. 80, pl. 14, fig. 1.

Diagnosis - Large, branching archaeocyath with a prominent bulging of the outer surface and dense intervallar structure.

Description - A low modular branching form. The largest individuals measured in thin section are 20 mm in diameter. Okulitch (1943) noted 45 mm in diameter cup in the weathered material. Prominent bulging of the outer surface is present (Fig. 4.1). The intervallum width is one third of the cup diameter in all specimens studied, with diameters ranging from 3.3 mm to 45 mm. Thin outer wall has centripetally arranged pores. The inner wall is 0.2 mm thick and is pierced by pore-tubes of 0.8-0.9 mm diameter. The thickness of intervallar elements, pseudotaeniae and synapticalae is 0.2-0.3 mm. The size of pores in pseudotaeniae and the distance between adjacent synapticalae vary from 0.2 to 0.3 mm. Pseudotaenial pores are equidimensional and rounded-angular pseudotaeniae are spaced from 0.3 mm to 0.5 mm. The secondary skeletal lamination is well expressed, especially in the smaller cups.

Comparison - *A. resseri* differs from other Laurentian species of *Archaeocyathus*. *A. atlanticus* BILLINGS has a wider intervallum (4 mm rather than 3 mm in cups with 10 mm diameter) and by looser intervallar structures. *Archaeocyathus arborensis* OKULITCH has a smaller diameter of inner wall pore-tubes (0.3 mm versus 0.8-0.9 mm) and by smaller cup size (8 mm versus 20-45 mm).

Ontogeny - At a cup diameter of 3.5 mm, the intervallar elements and inner wall are 0.08 mm thick; the inner wall bears small bracts only. At a cup diameter of 5.0 mm, the intervallar elements become thicker, up to 0.15 mm thick, and pore-tubes appear on the inner wall.

Material - The specimen collected by C.E. Resser from the Shady Dolomite, locality 13w, near Quebec, 5 miles south-east of Marion, Virginia, has been selected by Okulitch (1943) as the holotype. It resides in the United States National Museum (USNM 94736) and consists of a naturally weathered oblique section. More than 40 cups are present in our material from the Austinville Member, Shady Dolomite, Austinville, Virginia, 14 of which have been measured (MNHN M83342 to M83346 are figured).

Discussion - Although the material of '*Metethmophyllum resseri*' OKULITCH is incomplete, the species described here is the only species from this region that fits Okulitch's description and figure (1943, pl. 14, fig 1). In spite of Okulitch's assignment to the genus *Metethmophyllum*, the original figure cited above has features (regular pseudotaenial structure of the intervallum) more typical of *Archaeocyathus*

than of *Metaldetes* and of its junior synonym *Methmophyllum* (Debrenne & James 1981; Debrenne & A. Zhuravlev 1992).

Archaeocyathus sp.
Fig. 3.1-5

Synonymy

- 1976 *Protopharetra* sp. - Palmer & Rozanov, p. 774, fig. 1a.
1976 *Archaeocyathus* (= *Pycnoidocyathus*) sp. - Palmer & Rozanov, p. 774, fig. 1b.
1976 *Dictyocyathus* - Palmer & Rozanov, p. 774.
1994 *Archaeocyathus* (= *Pycnoidocyathus*) sp. - McMenamin et al., p. 225.
1994 dictyocyathid - McMenamin et al., p. 225, pl. 1, fig. 4.
1994 *Protopharetra* sp. - McMenamin et al., p. 225.

Description - Low modular, branching archaeocyaths. The diameter of the largest individual cup is slightly more than 20 mm. The intervallum width is almost constant for individuals from 6 to 10 mm in diameter and spans one third of the diameter. The outer wall is centripetal, thin, 0.05 mm thick in the best preserved cup. A slight bulging of the outer wall is observed on some individuals. The inner wall is up to 0.8 mm thick and bears well developed pore-tubes which form an almost complete annular structure on some horizontal levels (Fig. 3.1). The inner wall pores are 0.23-0.3 mm in diameter and are arranged in one vertical row per intersept. The intervallar space is filled with coarsely porous pseudotaeniae and regularly spaced synapticalae. The thickness of intervallar elements is 0.1 mm. Pseudotaeniae are 0.4-0.8 mm apart. The distances between vertical elements of pseudotaeniae and synapticalae are 0.15-0.17 mm in smaller cups and up to 0.25 mm in the larger ones; distances between horizontal elements are 0.4-0.5 mm in the larger cups. The younger parts of cups tend to be covered by extensive layers of secondary calcareous skeletal material. Vesicles are not common and are developed only as defensive elements, isolating the affected parts of individual archaeocyaths from adjacent (and presumably competing) organisms (Fig. 3.5).

Material - The seven best preserved individuals, sectioned in various orientations, have been measured from the Leithsville Formation, locality 754 in Franklin, New Jersey (NYSM 16134 is figured in McMenamin et al. (1994) and MNHN M83333 - M83337 are figured here).

Discussion - Incomplete preservation again prevents precise comparison with other American *Archaeocyathus* species. Nevertheless it is clear that the new material represents the same taxon figured by Palmer & Rozanov (1976). Palmer & Rozanov (1976, fig. 1b) also recognised *Archaeocyathus* in their material. It is not surprising that they put *Pycnoidocyathus* in parentheses as a possible alternative name, because *Archaeocyathus* species with prominent pore-tubes on the inner wall have been commonly confused with *Pycnoidocyathus* species. The later differ by less porous and but well expressed taeniae (Debrenne & A. Yu. Zhuravlev 1992). *Protopharetra* sp. figured by Palmer & Rozanov (1976, fig. 1a) is a cross section of a young branching individual with pore-tubes not yet developed on the inner wall (Fig. 3.4). *Dictyocyathus* (in Palmer & Rozanov 1976, p. 774) is obviously an

ontogenetically intermediate part of the cup between the '*Protopharetra*' and '*Archaeocyathus*' stages. Some individuals with abundant, incompletely preserved vesicles may also be confused with *Metaldetes* (Fig. 3.5), but the apparent restriction of vesicles in *Archaeocyathus* to the areas of deterioration permits recognition of these two genera even when other features are not clear.

Family ARCHAEOSYCONIIDAE ZHURAVLEVA, 1960

Genus *Archaeosycon* TAYLOR, 1910

Archaeosycon balsami nov. sp. DEBRENNE & A.
ZHURAVLEV
Fig. 4.8

Synonymy

- 1943 *Coscinocyathus* sp. - Okulitch, p. 67, pl. 4, fig. 7.
1943 *Archaeosycon vesiculosum* - Okulitch, pl. 15, fig. 2.

Derivatio nominis - Named for American Geologist William Balsam, specialist of the Cambrian of Virginia and of archaeocyath functional morphology.

Holotype - Thin section MNHN M83347 (oblique cross section, Fig. 4.8).

Type-locality - U.S.A., Virginia, Austinville; lower Shady Dolomite. Early Cambrian, Botoman stage.

Diagnosis - *Archaeosycon* species with cups possessing tabulate centripetal outer wall and compound inner wall; the inner wall bears bracts, S-shaped in longitudinal section; the intervallum contains coarsely porous taeniae and segmented tabulae.

Description - Small solitary cups of 10 mm in diameter. The intervallum width is one third of the diameter. The tabular outer wall and the segmented tabulae forming the wall are centripetal with angular pores of 0.05 mm in size and lintels of 0.01 mm thick; the wall thickness is 0.05 mm. The inner wall is compound and consists of bracts (S-shaped in longitudinal section) and of a cover of tabular microporous plates. Its width is 0.08 mm without bracts and 0.25 mm with bracts. The inner wall pore size varies from 0.25 to 0.3 mm; lintel thickness varies from 0.08 to 0.2 mm. Taeniae are pierced by frequent pores of 0.08-0.1 mm in diameter. The average distance between tabulae is 0.5 mm.

Comparison - The new species differs from *A. billingsi* (WALCOTT) by more densely spaced tabulae (0.5 mm against 1-1.5 mm) and by smaller inner wall pores (0.25-0.3 mm against 0.5 mm); from *A. copulatus* (DEBRENNE & GANGLOFF) by the presence of bracts on the inner wall.

Material - Oblique cross sections of two cups from the Shady Dolomite, Austinville, Virginia (MNHN M83347 is figured).

Discussion - '*Coscinocyathus*' sp. (Okulitch 1943, pl. 4, fig. 7) is probably conspecific to *Archaeosycon vesiculosum* from the same locality (Okulitch 1943, pl. 15, fig. 2) but not to the Labrador specimens, which are junior synonyms of *A. billingsi* (WALCOTT) (Debrenne & James 1981). Both Virginia specimens possess taeniae rather than septa. Moreover, the axis of symmetry of their tabulae is in the middle of the central cavity, a characteristic

feature of the Archaeocyathida but absent in Coscinocyathina (suborder of Capsulocyathida); thus, the Virginia specimens described herein represent remains of *Archaeosycon*.

APPALACHIAN ARCHAEOCYATHAN ASSEMBLAGES

In a previous paper (Mansy et al. 1993), Zhuravlev & Debrenne proposed an archaeocyathan zonation for Laurentia. The entire ranges of the stratigraphic distribution of archaeocyathan species are given by Mansy et al. (1993: Table 2). It should be kept in mind that this zonation is based on the Oppel zone conception and thus, the index species cross the zonal boundaries. From bottom to top this zonation includes: (1) unnamed beds coeval with the lower 'Nevadella' trilobite zone in the Great Basin, U.S.A.; (2) *Ethmophyllum whitneyi*-*Sekwicyathus nahanniensis* Zone coeval with the upper 'Nevadella' Zone in the Great Basin, U.S.A. and in western Canada; (3) *Claruscoscinus fritzi*-*Metacyathellus caribouensis*; (4) *Pycnoidocoscinus ? serratus* - *Tabulaconus kordeae* zones; (5) *Archaeocyathus atlanticus* beds and (6) *Tegerocyathus greenlandensis* - *Pycnoidocyathus pearylandicus* beds. The subdivisions 3 to 6 fall within *Bonnia-Olenellus* trilobite Zone and all but the upper most one are in the limits of the lower to middle *Bonnia-Olenellus* trilobite Zone in Western Canada. Some of the better known Appalachian archaeocyathan assemblages were tentatively placed in this scheme. Recently, Palmer (1988a) has proposed a nomenclature for stages and series for the Cambrian of Laurentia. Palmer (1998a, p. 324) provides 'Bounding Zones or Subzones' as proposed delineations of his new series and stage units, but he does not develop his biostratigraphic scheme to the extend of correlation of the new series and stages with previous trilobite zones, nor does he provide faunal ranges within the new stages. Thus, for the time being, we prefer to follow here the well-known western Laurentian trilobite zones.

New data will complete and amend the previous work. The upper subdivisions, the *A. atlanticus* and *Tegerocyathus greenlandensis* - *Pycnoidocyathus pearylandicus* beds, have been established in remote regions of Eastern Canada and Northern Greenland. These areas lack a continuous record of archaeocyaths. Intermediate archaeocyathan assemblages may exist. The study of the Appalachian section helps to fill out possible gaps and improves Western-Eastern Laurentian correlation.

Western Newfoundland is the northernmost part of the Appalachian region. The clear stratigraphic position of the Newfoundland archaeocyathan fauna determines the upper limit for the assemblages discussed below. In the lower red-coloured limestones of the Forteau Formation, recognised on the East flank of the Long Ranges as the Devil's Cove Member (North 1971), an assemblage of ajacyathids has been found (James & Debrenne 1980). It includes (earlier identifications are given in brackets):

Cordilleracyathus blussoni (*C. aff blussoni*), *Sekwicyathus nahanniensis* (Genus A), *S. tillmani* nov. sp.

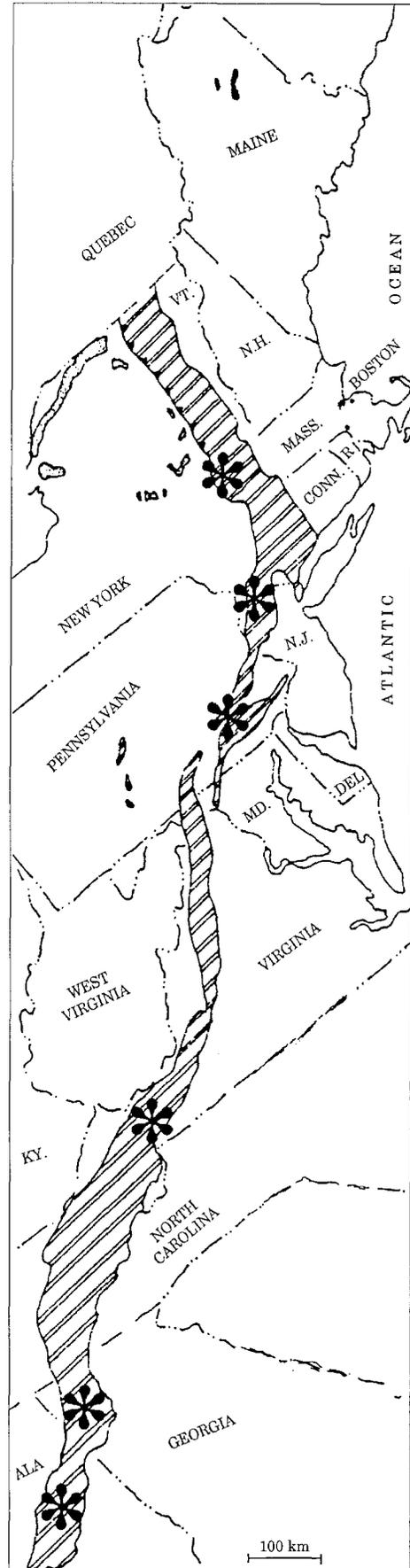


FIGURE 5 - The principal regions of Cambrian outcrops in eastern United States with the location of archaeocyathan assemblages (modified from Palmer 1971), explanations in the text. *Principaux gisements cambriens dans l'est des Etats-Unis.*

FIGURE 6 - Correlation chart of the Appalachian sections containing archaeocyaths. *Schéma de corrélation des sections des Appalaches contenant des archéocyathes.*

Stages	Laurentian archaeocyathan zones	Labrador-Newfoundland	Eastern New York	New Jersey	Pennsylvania	Central Virginia	Georgia-Alabama
Toyonian	<i>Tegerocyathus greenlandensis</i> - <i>Pycnoidocyathus pearylandicus</i>	Hawke Bay	Hatch Hill			Rome	Rome
	<i>Archaeocyathus atlanticus</i>	*					
Botoman	<i>Pycnoidocoscinus ? serratus-Tabulaconus kordeae</i>	Forteau *	Middle Granville *	Lower Leithsville	Kinzers ? *		
		*	Brown's Pond *	*	Vintage		Shady
	<i>Claruscoscinus fritzi</i> - <i>Metacyathellus caribouensis</i>	Bradore	Nassau	Hardyston	Antietam	Shady	*
	<i>Ethmophyllum whitneyi</i> - <i>Sekwicyathus nahanniensis</i>					*	*
Atdabanian	unnamed				Harpers	Erwin	Weisner
							Hampton

(Kijacyathidae Genus B) and is informally called *Sekwicyathus tillmani* assemblage. These taxonomic revisions were made by Zhuravlev (in Voronova et al. 1987) and Debrenne & Zhuravlev (in Mansy et al. 1993), as well as herein.

Cordilleracyathus and *Sekwicyathus* are genera typical of the *whitneyi-nahanniensis* and *serratus-kordeae* zones. Associated fossils include *Wanneria logani* (WALCOTT), *Labradoria miseri* (BILLINGS), *Calodiscus lobatus* (HALL), *Fordilla troyensis* BARRANDE, *Insolitheca communis* (BILLINGS), *Discinella micans* (BILLINGS), and *Salterella*. SPENCER, 1981, Landing & Bartowski 1996 support a correlation of the *Sekwicyathus tillmani* assemblage with the *serratus-kordeae* Zone because *Salterella* appears within the *serratus-kordeae* Zone in western Laurentia and *Wanneria* occurs above it (Voronova et al. 1987; Fritz & Yochelson 1988). The presence of these fossils also implies a correlation with the middle *Bonnia-Olenellus* Zone (Fritz 1972). The *serratus-kordeae* Zone is followed immediately by the *A. atlanticus* beds (Fig. 6).

Further South, a single archaeocyath, described as *Ajacyathus rimouski* OKULITCH, 1943 is known from the Tremadoc-Arenig limestone conglomerate of Cap Enrangé Formation, in a boulder collected in the vicinity of Bic Harbour, Quebec (Ed Landing personal communication, 1999). '*Ajacyathus rimouski*, according to its original description (Okulitch 1943) possesses large outer wall pores arranged in one pore row per intersept, a simple inner wall with large pores (one row per intersept) and aporous to sparsely porous septa. On original figures which unfortunately lack sufficient

contrasts, the presence of interpore vertical spines and bracts on the outer wall may be perceived on the bottom part of Okulitch (1943) Fig. 4.5. Inner wall (Fig. 4.4) has one row of pores per intersept, possibly with an occasional pore in front of a new septum and aporous to sparsely porous septa. These features may correspond to *Sekwicyathus*, although the material is insufficient to provide the comparison at the species level with *S. nahanniensis*. Thus, a *serratus-kordeae* age for at least a part of the Lower Cambrian Cap Enrangé Formation appears quite likely.

In the northern Appalachians, the Taconic allochthon fauna of New York is diverse and puzzling (Figs 5,6, locality 2). Archaeocyaths have been known here since the end of the XIXth century and have served as a basis for the establishment of two new genera, namely *Archaeocyathellus* and *Procyathus* (Ford 1873a,b, 1878; Walcott 1886, 1890). Unfortunately, parts of the initial collections have been lost (Okulitch 1943). Subsequent finds were fragmental (Okulitch 1943; Lochman 1956; Landing & Bartowski 1996) but may shed some light on the systematics of these remains. All these archaeocyaths apparently belong to Ajacyathina.

Two groups may be recognised among these fossils. The first is the '*Archaeocyathellus rensselaericus*-Group'. In addition to the 'type species' described by Ford (1873a,b) it includes '*Ethmophyllum rensselaericum*' in Walcott (1886, Pl. V, fig. 1f) and '*A. walcotti*' OKULITCH in Lochman (1956, Pl. 1, fig. 4). The specimens are characterised by a smooth finely porous but thick outer wall with 3-6 pore rows per intersept, large stirrup-like openings in the inner wall,

aporse septa and possible pectinate tabulae (Ford 1873a; Walcott 1886; Lochman 1956, Pl. 1, fig. 4). These morphological traits remind some outer and inner wall features of *Ethmophyllum* but an assignment to this genus cannot be made with confidence. A re-examination of the type species of *Archaeocyathellus* by Debrenne & Zhuravlev has confirmed its affinity with *Ethmophylloidea* but details of the inner wall are obscure. The second group is the '*Protocyathus rarus* Group' (after the name given by Ford 1878). Revision of the type specimen (NYSM 52) in the scope of the preparation of the new Treatise of Paleontology (*Archaeocyatha* by F. Debrenne, A. Yu. Zhuravlev & P.D. Kruse) completely modifies the previous interpretations. Affinities with *Sekwicyathus*, as proposed by James & Debrenne (1980), Voronova et al. (1987), Mansy et al. (1993), have to be dismissed. *Protocyathus rarus* itself (holotype: NYSM 52) shows straight stirrup canals in the outer wall, stirrup pores and annuli on the inner wall, and non-porous septa (Debrenne & Zhuravlev, pers. observation). By these features it is close to 'gen. et sp. indet.' in Voronova et al. (1987 pl. III, fig. 3) and belongs to the family Kijacyathidae. However, the interpretation is limited by the indifferent preservation of the material as has been noted elsewhere (Handfeld 1971; James & Debrenne 1981). Only the type species is known.

Thus, the presence of *Ethmophylloidea* gen. and sp. indet. is confirmed for the Taconic region. Although archaeocyath remains as well as other fossils have been transported downslope to their present position in the *Elliptocephala asaphoides* Fauna (Lochman 1956; Landing & Bartowski 1996), they give some constraints on the lower age limit of this fauna. Lochman (1956, Table 2) estimates that the entire stratigraphic range of the Taconic archaeocyaths corresponds to the whole range-zone of the *Elliptocephala asaphoides* Fauna. Her own samples collected from Cambridge and Hoosick quadrangles, New York, however, indicate the co-occurrence of archaeocyaths only with the lower elements of this fauna. In terms of the present lithostratigraphic nomenclature (Landing & Bartowski 1996), her finds are restricted to the Upper Browns Pond formation (Fig. 6). However, the later authors noted archaeocyathan fragments in the overlying Middle Granville Formation, which is Ford's 1878 locality as well.

The *Elliptocephala asaphoides* Fauna has been correlated with the upper *Bonnia-Olenellus* Zone (Lochman 1956) or the middle *Bonnia-Olenellus* Zone (Theokritoff 1985; Palmer & Repina 1993). Based on archaeocyaths, the lower *Elliptocephala asaphoides* Fauna, which also contains trilobites *Wanneria* sp., (Middle Granville Formation only) and *Calodiscus lobatus* (HALL), molluscs *Fordilla troyensis* BARRANDE, tomotiids *Lapworthella scho-dackensis* (LOCHMAN), hyoliths *Insolitheca communis* (BILLINGS), and mobergellans *Discinella micans* (BILLINGS) (Lochman 1956; Bird & Rasetti 1968; Theokritoff 1985; Landing & Bartowski 1996,) may be attributed to the *S. tillmani* beds, i.e., the middle *Bonnia-Olenellus* Zone. The entire suit of fossil indicates a correlation with the lower Forteau Formation (Landing & Bartowski 1996).

Another northern Appalachian archaeocyathan locality occurs in the Leithsville Formation in New Jersey (Figs 1, 5, 6). Palmer & Rozanov (1976) correlated this assemblage with the Botoman or Lower Elankian (now Toyonian) based on faunas from Labrador and Newfoundland. According to correlations with the Labrador-western Newfoundland sections, Palmer & Rozanov (1976) inferred the existence of a previously unrecognised major unconformity (called the Hawke Bay event; Palmer & James 1979; Landing 1998) within the Leithsville and equivalent carbonates of the thin Early Cambrian sequence from eastern Pennsylvania to northern Massachusetts. As *Archaeocyathus* sp. and *Cordilleracyathus* ? sp. are present in this fauna, its age is reinterpreted as coeval with other *serratocyathus-kordee* age Appalachian faunas, since it includes ethmophyllids but not any elements of the younger *A. atlanticus* beds.

Central Appalachian archaeocyathan assemblages are known from southeastern Pennsylvania and Virginia. Unfortunately, nothing is known about archaeocyaths in Pennsylvania, except for their possible restriction to the middle member of the Kinzers Formation, represented by 25 m of pure to argillaceous limestones (Stose & Jonas 1939; Palmer 1971; herein Fig. 5, 6). This position above the lower member with the famous Kinzers soft-bodied fauna (Resser & Howell 1938; Garcia-Bellido Capdevila & Conway Monis 1999), *Salterella* and *Wanneria* (FRITZ & YOCHELSON, 1988) allows us to date this assemblage as coeval with those discussed above. The occurrence of *Salterella*, an index fossil for the middle *Bonnia-Olenellus* Zone (Voronova et al. 1987; Fritz & Yochelson 1988) supports the assignment of these ghost archaeocyaths to the *serratocyathus-kordee* Zone.

Okulitch (1943) compiled a long list of archaeocyathan species from Virginia including *Metethmophyllum resseri* OKULITCH, *Archaeosycon vesiculosum* OKULITCH, *Ajacyathus* cf. *profundomimus* OKULITCH, *Coscincyathus* sp., *Cambrocyathus* sp., and *Protopharetra* sp. In addition, James & Debrenne (1980) noted the presence of *Cordilleracyathus* ? and '*Ethmophyllum*' *ceratodyctioides* RAYMOND. The revised list of Virginia species includes now: *Ethmophyllum whitneyi* MEEK, *Archaeocyathus resseri* (OKULITCH), and *Archaeosycon balsami* nov. sp.

The coralomorph *Labyrinthus soraufi* KOBLUK occurs with the archaeocyaths but above the level with *Ethmophyllum* (KOBLUK, 1982). This coralomorph is known from the Forteau Formation of Labrador where it is associated with the fauna of the *Archaeocyathus atlanticus* beds (Kobluk 1979; James et al. 1989; Mansy et al. 1993). *Labyrinthus soraufi* thus defines the upper limit for the age of the archaeocyathan assemblage. The trilobites *Bonnia crassa*, *Kootenia browni* and *Prozacanthoides virginicus* occur in the Ivanhoe Member 60 to 180 m above the top of the Austinville Member (Willoughby 1976), and are of middle-upper *Bonnia-Olenellus* Zone. *Salterella* is found below and at the same level as archaeocyaths, in the Patterson and Austinville members (Byrd et al.

1973), and the first *Olenellus* is known from the underlying Erwin Formation (Simpson & Sundberg 1987). Thus, the archaeocyathan assemblage belongs to the *S. tillmani* beds and to the middle *Bonnia-Olenellus* Zone. The presence of *Ethmophyllum whitneyi*, as well as radiocyathan remains (Fig. 3.8) known within the *fritzi-caribouensis* Zone in western Canada (Zhuravlev & Sayutina 1985; Mansy et al. 1993) suggests the Austinville Member archaeocyathan assemblage has to be correlated with the *fritzi-caribouensis* Zone rather than with the *serratocyathus-kordee* Zone.

Southern Appalachian archaeocyaths are known from the Shady Dolomite of Georgia (Okulitch 1943) and Alabama (Bearce & McKinney 1977) (Figs 5, 6). In Georgia, Okulitch (1943) has identified *Archaeocyathus atlanticus* BILLINGS, *Cambrocyathellus* sp., *C. cf. profundus* (BILLINGS), two or three species of *Ajacicyathus* and three species of *Coscinocyathus*. Only a single specimen (*Coscinocyathus* sp., Okulitch 1943, Pl. 4, fig. 5) was figured, showing obvious features of Archaeocyathina rather than Coscinocyathina. The age of this fauna is problematical.

Abundant Alabaman archaeocyaths occurring in the Shady Dolomite were assigned by Bearce & McKinney (1977, Figs 3, 4) to *Coscinocyathellus*, the Robustocyathidae and Irregulares; presently Archaeocyathida. '*Coscinocyathellus*' is characterised by finely porous to aporous septa and tabulae which are typical of *Claruscoscinus*. The 'Robustocyathidae', in our opinion, correspond probably to specimens possessing a single row of pores in a thick inner wall, too general a character to be used. This assemblage permits correlation of the fauna with the *serratus-kordeae* or *fritzi-caribouensis* Zones, as discussed elsewhere (Mansy et al. 1993). *Salterella* occurs above the archaeocyaths (Palmer 1971).

INTERREGIONAL CORRELATION

An improved correlation between the Appalachian and Cordilleran regions thus seems possible now on a better basis. First, the *Sekwicyathus tillmani* assemblage, which occurs in the Lower Forteau Formation of western Newfoundland, the upper Brown's Pond and Middle Granville formations of eastern New York and the Leithsville Formation of New Jersey, are correlated with the *Pycnoidocoscinus ? serratus-Tabulaconus kordeae* Zone in western Laurentia. Thus, the *Archaeocyathus atlanticus* beds follow the *serratus-kordeae* Zone without a recognisable gap and correspond to the upper middle *Bonnia-Olenellus* trilobite Zone or to an informal level within Cambrian strata of Laurentia that bear *Wanneria* and *Salterella* (= middle Dyeran of Palmer 1998).

The lower *Bonnia-Olenellus* Zone containing archaeocyaths of the *fritzi-caribouensis* and *serratus-kordeae* zones, including the middle-upper Botoman *Polythalamia*, *Tegerocyathus*, *Krasnopeevaecyathus*, *Molybdocyathus*, *Claruscoscinus*, *Keriocyathus* and

Pseudosyringocnema, some of which are restricted to the middle Botoman in Siberia. Thus, the *Archaeocyathus atlanticus* beds are a time equivalent of the late Botoman rather than of early Toyonian in Siberia as has been widely accepted (e.g. Mansy et al. 1993). On the other hand, the age of the Hawke Bay Formation in western Newfoundland is defined now as the uppermost *Bonnia-Olenellus* Zone-*Glossopleura* Zone, and the age of its lower Siliciclastic Member overlying the Forteau Formation is restricted to the uppermost *Bonnia-Olenellus* Zone (Knight & Boyce 1987).

Such data allow us to infer that the Hawke Bay Event occurred during the early Toyonian time. our reference is generally in accord with the conclusions of Alvaro & Vennin 1998 and Geyer 1998 regarding the timing of the Hawke Bay Event beginning (with question) in the late Botoman in Baltica. The Hawke Bay interval is represented by regressive sequences on the Baltic and Siberian platforms, in South Australia, and in Spain (Brangulis et al. 1986; Gravestock & Hibbert 1991; Liñan & Gamez-Vintaned 1993; Zhuravlev 1998). Thus, the Hawke Bay regression appears to have been an eustatic event of global extent (McMenamin et al. 1994; Zhuravlev & Wood 1994; Zhuravlev 1996).

The Hawke Bay event coincides with a Toyonian decline of Laurentian archaeocyaths. It is possible that the Hawke Bay regression has a relationship to the terminal Early Cambrian extinction of the *Olenellina* (Palmer 1998b). Deterioration of carbonate platforms (as a result of falling sea level) has been implicated in Cambrian extinctions (Thomas 1991).

CONCLUSIONS

1. The Appalachian archaeocyathan fauna apparently migrated from the western (Cordilleran) Laurentia during the *Claruscoscinus fritzi - Metacyathellus caribouensis* and *Pycnoidocoscinus ? serratus - Tabulaconus kordeae* time (Middle Botoman). The faunas of both regions feature such endemic Laurentian genera as *Sekwicyathus*, *Ethmophyllum*, *Cordilleracyathus*, *Archaeosycon*: *Retilamina* and *Arrhythmocricus*.
2. The Appalachian archaeocyathan fauna is essentially uniform from Newfoundland to Virginia at the same stratigraphic level i.e., the *Pycnoidocoscinus ? serratus - Tabulaconus kordeae* Zone. The beds may be slightly older in Central Virginia and Alabama (Fig. 6).
3. Archaeocyaths now constrain the age of the *Elliptocephala asaphoides* Fauna to the middle-upper *Bonnia-Olenellus* Zone, or middle Dyerian of Palmer 1998 (i.e. Late Botoman-Early Toyonian).
4. The oldest (Middle Botoman) archaeocyathan fauna of the Appalachians occurs in the south, and the youngest occurs in the north (Fig. 6). Only in Labrador did the fauna persist until Late Botoman *Archaeocyathus atlanticus* time. Thus, the age of

the Appalachian archaeocyathan assemblage records the expansion of their geographic range from south to north (in recent co-ordinates). A south Cordilleran (Mexican) origin of the Appalachian fauna is probable as has been pointed out by McMenamin et al. (1994).

5. The apparent polar wander path (APW) for Laurentia suggests that the craton moved rapidly from high to low latitudes during Early and Middle Cambrian, with the Cordilleran margin leading and the Appalachian margin trailing obliquely (Kirschvink et al. 1997). The migration of archaeocyaths from Mexico to New Jersey tracks the northward motion of Appalachian margin (Fig. 5) into equatorial latitudes increasingly favourable for carbonate accumulation and development of archaeocyaths.

6. This study confirms that detailed taxonomy aids the precise correlation of Lower Cambrian strata between regions. The revision of even a few existing Appalachian archaeocyathan taxa clearly indicates that there are no significant discrepancies between a correlation based on archaeocyathan species and that judged by trilobites or other fossils.

Acknowledgements - We thank François Boyer who gave the MNHN material from Austinville, Virginia. A. Zhuravlev thanks the Museum National d'Histoire Naturelle, Paris which supported his visiting professorship. Max Debrenne is greatly thanked for excellent photographic work on poorly preserved material; we also thank the UMR 8569 (CNRS) technicians, Françoise Pilard for the drawings and Michel Lemoine for the thin sections. The paper is significantly benefited by the constructive critiques of Pete Palmer and Ed Landing. Many thanks to Ed Landing for his corrections to archaeocyath distribution in eastern New York.

REFERENCES

- ÁLVARO J.J. & VENNIN L. 1998 - Stratigraphic signature of terminal Early Cambrian regressive event in the Iberian Peninsula. *Canadian Journal of Earth Sciences*, 35: 402-411.
- ASTASHKIN V.A. 1983 - *Aulofikus* [*Aulophycus*]. In SOKOLOV B.S. & ZHURAVLEVA I.T. (eds), *Yarusnoe raschlenenie nishnego kembriya Sibiri. Atlas okamenelostey* [Lower Cambrian stage subdivision of Siberia. Atlas of fossils]. *Akademiya nauk SSSR, Sibirskoe otdelenie, Institut geologii i geofiziki*. Trudy, 558: 176-177. Novosibirsk.
- 1985 - Problematicnye organizmy porodoobrazovately v nizhnokembriyskikh otlozheniyakh Sibirskoy platformy [Problematic rock-forming organisms in the Lower Cambrian of the Siberian Platform]. *Akademiya nauk SSSR, Sibirskoe otdelenie, Institut geologii i geofiziki*, Trudy, 632: 144-149. Novosibirsk.
- BALSAM W.L. 1970 - Reinterpretation of a Lower Cambrian archaeocyathid reef. *Geological Society of America, Abstracts with Programs*, 2: 11.
- 1974 - Reinterpretation of an archaeocyathid reef Shady Formation, South Western Virginia. *Southeastern Geology*, 16: 121-129.
- BARNABY R.J. & READ J.F. 1990 - Carbonate ramp to rimmed shelf evolution: Lower to Middle Cambrian continental margin, Virginian Appalachians. *Geological Society of America Bulletin*, 102: 391-404.
- BEARCE D.N. & MCKINNEY F.K. 1977 - Archaeocyathids in eastern Alabama: Significance to geologic interpretation of Coosa deformed belt. *Geology*, 5: 467-470.
- BIRD J.M. & RASETTI F. 1968 - Lower, Middle and Upper Cambrian faunas in the Taconic Sequence of eastern New York: Stratigraphic and biostratigraphic significance. *Geological Society of America Special Paper*, 11: 1-66.
- BOND G.C., NICKESON P.A. & KAMINZ M.A. 1984 - Breakup of a supercontinent between 625 Ma and 555 Ma: New evidence and implication for continental histories. *Earth and Planetary Science Letters*, 70: 325-345.
- BRANGULIS A., MURNIEKS A., NATLE A. & FRIDRIHSONE A. 1986 - Srednebaltskiy fatsial'nyy profil' venda i kembriya [Middle Baltic facies profile of the Vendian and Cambrian]. In PIRRUS E.A. (ed.), *Fatsii i stratigrafiya venda i kembriya zapada Vostochno-Evropeyskoy platformy* [Vendian and Cambrian facies and stratigraphy in the west of the East European Platform]. *Akademiya nauk Estonskov SSR*, Tallin: 24-33.
- BROMLEY R.G. 1990 - *Trace Fossils. Biology and Taphonomy*, 280 p., Unwin Hyman, London.
- BROWN W.H. & WEINBERG E.L. 1971 - Geology of the Austinville-Ivanhoe District, Virginia. In RIDGE J.D. (ed.), *Ore Deposits of the United States, 1933-1967*, 1: 169-186. *American Institute of Mining, Metallurgy and Petroleum Engineers*, New York.
- BUTTS C. 1940 - Geology of the Appalachian Valley in Virginia. Part I, geologic text and illustrations. *Virginian Geological Survey Bulletin*, 52: 1-568.
- BYRD W.J., WEINBERG E.L. & YOCHELSON E.L. 1973 - Salterella in the Lower Cambrian Shady Dolomite of southwestern Virginia. *American Journal of Science*, 273-A: 252-260.
- CURRIER L.W. 1935 - Zinc and lead regions of southwestern Virginia. *Virginia Geological Survey Bulletin*, 43: 1-122.
- DEBRENNE F. 1987 - Archaeocyatha from Mexico in the Smithsonian Institution. New data from recent collections. *Geobios*, 20: 267-273.
- , GANDIN A. & ROWLAND S.M. 1989 - Lower Cambrian bioconstructions in northwestern Mexico (Sonora). Depositional setting, paleoecology and systematics of the archaeocyaths. *Geobios*, 22: 137-195.
- & JAMES N.P. 1981 - Reef associated archaeocyathans from the Lower Cambrian of Labrador and Newfoundland. *Palaeontology*, 24: 343-378.
- & ZHURAVLEV A. 1992 - Irregular Archaeocyaths: Morphology. Ontogeny. Systematics. Biostratigraphy. Palaeoecology. *Cahiers de Paléontologie*, 212 p. C.N.R.S. éditions, Paris.
- , ZHURAVLEV A. YU. & ROZANOV A. YU. 1989 - Pravil'nye arkheotsiaty [Regular Archaeocyaths]. *Akademiya nauk SSSR, Paleontologicheskii institut Trudy*, 233: 1-198.
- FENTON C. & FENTON M. 1939 - Pre-Cambrian and Palaeozoic algae. *Geological Society of America Bulletin*, 50: 89-126.
- FICHTER L.C. & DIECCHIO R.J. 1986 - Stratigraphic model for timing the opening of the Proto-Atlantic Ocean in northern Virginia. *Geology*, 14: 307-309.
- FOLEY N.K., KRISHNA SINHA A. & CRAIG J.R. 1981 - Isotopic composition of lead in the Austinville-Ivanhoe Pb-Zn district, Virginia. *Economic Geology*, 76: 2012-2017.
- FORD S.W. 1873a - On some new species of fossils from the Primordial or Potsdam group of Rensselaer county, N.Y. (Lower Potsdam). *American Journal of Science and Arts*, 3, 5: 211-215.
- 1873b - Remarks on the distribution of fossils in the Lower Potsdam rocks at Troy, N.Y., with a description of four new species. *American Journal of Science and Arts*, 3, 6: 134-140.
- 1878 - Description of two new species of Primordial fossils. *American Journal of Science and Arts*, Series 3, 15: 124-127.
- FRITZ W.H. 1972 - Lower Cambrian trilobites from the Sekwi Formation type section, Mackenzie Mountains, northwestern Canada. *Geological Survey of Canada Bulletin*, 212: 1-90.
- & YOCHELSON E.L. 1988 - The status of *Salterella* as a Lower Cambrian index fossil. *Canadian Journal of Earth Sciences*, 25: 403-416.
- GARCIA-BELLIDO CAPDEVILA D. & CONWAY MORRIS S. 1999 - New fossil worms from the Lower Cambrian of the Kinzers Formation, Pennsylvania, with some comments on Burgess Shale-type preservation. *Journal of Paleontology*, 73: 394-402.
- GEYER G. 1998 - Intercontinental, trilobite-based correlation of the Moroccan early Middle Cambrian. *Canadian Journal of Earth Sciences*, 35: 374-401.
- GRAVESTOCK D.I. & HIBBERT J.E. 1991 - Sequence stratigraphy of the eastern Off ce and Arrowie basins: a framework for Cambrian oil search. *The APEA Journal*, 1991: 177-190.
- HANDFIELD R.C. 1971 - Archaeocyatha from the Mackenzie and Cassiar Mountains, Northwest Territories, Yukon Territory and British Columbia. *Geological Survey of Canada Bulletin*, 201: 1-119.

- HOWELL B.F. & VAN HOUTEN F.B. 1940 - A new sponge from the Cambrian of Wyoming. *Wagner Free Institute of Science Bulletin*, 15: 1-8.
- JAMES N.P. & DEBRENNE F. 1980 - First regular archaeocyaths from the northern Appalachians, Forteau Formation, western Newfoundland. *Canadian Journal of Earth Sciences*, 17: 1609-1615.
- & KLAPPA C.F. 1983 - Petrogenesis of early Cambrian reef limestones, Labrador, Canada. *Journal of Sedimentary Petrology*, 53: 1051-1096.
- , KOBLUK D.R. & KLAPPA C.F. 1989 - Early Cambrian patch reefs, southern Labrador. *Canadian Society of Petroleum Geologists Memoir*, 13: 141-150.
- KIRSCHVINK J.L., RIPPERDAN R.L. & EVANS D.A. 1997 - Evidence for a large-scale reorganization of Early Cambrian continental masses by inertial interchange true polar wander. *Science*, 277: 541-545.
- KOBLUK D.R. 1979 - A new and unusual organism from the Lower Cambrian of Labrador. *Canadian Journal of Earth Sciences*, 16: 2040-2045.
- 1982 - First record of *Labyrinthus soraufi* KOBLUK from the southern Appalachians: Lower Cambrian Shady Dolomite, Virginia. *Canadian Journal of Earth Sciences*, 19: 1094-1098.
- 1985 - Biota preserved within cavities in Cambrian Epiphyton mounds, Upper Shady Dolomite, southwestern Virginia. *Journal of Paleontology*, 59: 1158-1172.
- KRUSE P.D., ZHURAVLEV A.YU. & JAMES N.P. 1995 - Primordial metazoan-calcimicrobial reefs: Tommotian (Early Cambrian) of the Siberian Platform. *Palaïos*, 10: 291-321.
- LANDING E. 1988 - Depositional tectonics and biostratigraphy of the western portion of Taconic allochthon, eastern New York State. *New York State Museum Bulletin*, 462: 96-110.
- 1992 - Lower Cambrian of southeastern Newfoundland: Epeirogeny and Lazarus faunas, lithofacies-biofacies linkages, and the myth of a global chronostratigraphy. In LIPPS J.H. & SIGNOR P.W. (eds), *Origin and Early Evolution of the Metazoa*: 283-309. Plenum Press, New York.
- 1998 - Cambrian subdivisions and correlations: Introduction. *Canadian Journal of Earth Sciences*, 35: 321-322.
- & BARTOWSKI K.E. 1996 - Oldest shelly fossils from the Taconic allochthon and late Early Cambrian sea-levels in eastern Laurentia. *Journal of Paleontology*, 70: 741-761.
- LESLEY J.P. 1889 - A dictionary of the fossils of Pennsylvania and neighboring states named in the reports and catalogues of the Survey. *Second Pennsylvania Geological Survey Report*, P4,1, A-M, 437 p.
- LINAN E. & GAMEZ-VINTANED A. 1993 - Lower Cambrian palaeogeography of the Iberian Peninsula and its relation with some neighbouring European areas. *Bulletin de la Société géologique de France*, 130: 831-842.
- LOCHMAN C. 1956 - Stratigraphy, paleontology, and paleogeography of the *Elliptocephala asaphoides* strata in Cambridge and Hoosick quadrangles, New York. *Geological Society of America Bulletin*, 67: 1331-1396.
- MANSY J.L., DEBRENNE F. & ZHURAVLEV A.YU. 1993 - Calcaires archéocyathes du Cambrien inférieur du Nord de la Colombie britannique (Canada). Implications paléogéographiques et précisions sur l'extension du continent américano-koryakien. *Geobios*, 26: 643-683.
- McMENAMIN M.A.S. & McMENAMIN D.L.S. 1990 - The Emergence of Animals: The Cambrian Breakthrough, 217 p. *Columbia University Press*, New York.
- McMENAMIN M.A.S., PITTENGER S.L., CARSON M.R. & LARRABEE E.M. 1994 - Upper Precambrian-Cambrian faunal sequence, Sonora, Mexico, and Lower Cambrian fossils from New Jersey, United States. *New York State Museum Bulletin*, 481: 213-227.
- MEEK F.B. 1868 - Preliminary notice of a remarkable new genus of corals, probably typical of a new family, forwarded for study by Prof. J.D. Whitney, from the Silurian rocks of Nevada Territory. *American Journal of Science and Arts*, 2, 45: 62-64.
- MYROW P.M. 1995 - *Thalassinoides* and the enigma of Early Paleozoic open-framework burrow systems. *Palaïos*, 10: 58-74.
- NAIMARK E.B. & ROZANOV A. Yu. 1997 - Zakonomernosti razvitiya regional'nykh faun pravil'nykh arkheotsiat [Patterns in the development of regional faunas of regular archaeocyaths]. *Stratigrafiya, Geologicheskay korrelyatsiya*, 5: 67-78.
- NORTH F.K. 1971 - The Cambrian of Canada and Alaska. In HOLLAND C.H. (ed.), *Lower Palaeozoic Rocks of the World, Volume 1, Cambrian of the New World*: 219-324. *Wiley-Interscience*, New York.
- OKULITCH V.J. 1943 - North American Pleospongia. *Geological Society of America Special Papers*, 48: 1-112.
- PALMER A.R. 1971 - The Cambrian of the Appalachians and eastern New England regions, eastern United States. In HOLLAND C.H. (ed.), *Lower Palaeozoic Rocks of the World, Volume 1, Cambrian of the New World*: 169-217. *Wiley-Interscience*, New York.
- & ROZANOV A.YU. 1976 - Archaeocyatha from New Jersey: Evidence for an intra-Cambrian unconformity in the north-central Appalachians. *Geology*, 4: 773-774.
- & JAMES N.P. 1979 - The Hawke Bay event: A circum-Iapetus regression near the lower Middle Cambrian boundary. In WONES D.R. (ed.), *The Caledonides in the U.S.A. I.G.C.P. Project 27: Caledonide Orogen*: 15-18. Virginia Polytechnic Institute and State University Blacksburg Virginia.
- & REPINA L.N. 1993 - Through a glass darkly: Taxonomy, phylogeny and biostratigraphy of the Olenellina. *University of Kansas Paleontological Contributions, New Series*, 3: 1-35.
- 1998 - Why is intercontinental correlation within the Lower Cambrian so difficult? *Revista Española de Paleontología*, no extr. Homenaje al Prof. Gonzalo Vidal: 17-21.
- PEIFFER-RANGIN F. 1979 - Les zones isotopiques du Paléozoïque inférieur du nord-ouest mexicain, témoins du relais entre les Appalaches et la cordillère ouest-américaine. *Comptes Rendus de l'Académie des Sciences, Paris*, 228: 1517-1519.
- PFEIL R.W. & READ J.F. 1980 - Cambrian carbonate platform margin facies, Shady Dolomite, Southwestern Virginia, U.S.A. *Journal of Sedimentary Petrology*, 50: 91-116.
- PRATT B.R. 1995 - The origin, biota and evolution of deep-water mud-mounds. *Special Publications, International Association of Sedimentologists*, 23: 49-123.
- PYANOVSKAYA I.A. 1974 - Sravnitel'naya kharakteristika nekotorikh ranne- i srednekembriyskikh form vodoroslevogo proiskhozhdeniya. [Comparative characteristics of some Early and Middle Cambrian forms of algal origin]. In ZHURAVLEVA I.T. & ROZANOV A.YU. (eds), *Biostratigrafiya u paleontologiya nizhnego kembriya Evropy i Severnoy Azii. [Lower Cambrian biostratigraphy and palaeontology of Europe and northern Asia]*: 229-241. Nauka, Moscow.
- READ J.F. & PFEIL R.W. 1983 - Fabrics of allochthonous reefal blocks, Shady Dolomite (Lower to Middle Cambrian), Virginia Appalachians. *Journal of Sedimentary Petrology*, 53: 761-778.
- RESSER C.E. 1938 - Cambrian system (restricted) of the southern Appalachians. *Geological Society of America Special Papers*, 15: 1-140.
- & HOWELL B.F. 1938 - Lower Cambrian *Olenellus* zone of the Appalachians. *Geological Society of America Bulletin*, 49: 195-248.
- ROZANOV A.YU. & ZHURAVLEV A.YU. 1992 - The lower Cambrian fossil record of the Soviet Union. In LIPPS J.H. & SIGNOR P.W. (eds), *Origin and Early Evolution of the Metazoa*: 205-282. Plenum Press, New York.
- SIMPSON E.L. & SUNDBERG F.A. 1987 - Early Cambrian age for synerift deposits of the Chilhowee Group of southwestern Virginia. *Geology*, 15: 123-126.
- SPENCER L.M. 1981 - Paleocology of a Lower Cambrian archaeocyathid interreef fauna from southern Labrador. In TAYLOR M.E. (ed.), *Short Papers for the Second International Symposium on the Cambrian System. U. S. Geological Survey Open-File Report*: 81-743: 215-218.
- STEWART J.H., McMENAMIN M.A.S. & MORALES-RAMIREZ J.M. 1984 - Upper Proterozoic and Cambrian rocks in the Caborca Region, Sonora, Mexico - Physical stratigraphy, biostratigraphy, paleocurrent studies, and regional relations. *U. S. Geological Survey Professional Paper*, 1309, 36 p.
- STOSE G.W. & JONAS A.I. 1938 - A southeastern limestone facies of lower Cambrian dolomite in Wythe and Carroll counties, Virginia. *Virginia Geological Survey Bulletin*, 51: [page numbers pending from Berkeley].
- THAYER C. W. 1983 - Sediment-mediated biological disturbance and the evolution of marine benthos. In TEVEZ M.J.S. & MCCALL P.L. (eds), *Biotic Interactions in Recent and Fossil Benthic Communities*: 480-625, Plenum Press, New York.

- THEOKRITOFF G. 1979 - Early Cambrian provincialism and biogeographic boundaries in the North Atlantic Region. *Lethaia*, 12: 281-295.
- 1982 - Correlation of the *Elliptocephala asaphoides* fauna of eastern New-York State. *Northeastern Geology*, 4: 131-133.
- 1985 - Early Cambrian biogeography in North Atlantic region. *Lethaia*, 28: 283-293.
- THOMAS R.C. 1991 - The role of carbonate platform destruction in the formation of Cambrian extinction (biomere) boundaries. *Geological Society of America Abstracts with Programs*, 8: A403-404.
- VORONOVA L.G., DROZDOVA N.A., ESAKOVA N.V., ZHEGALLO E.A., ZHURAVLEV A.YU., ROZANOV A.YU., SAYUTINA T.A. & USHATINSKAYA G.T. 1987 - Iskopaemye nizhnego kernbriya gor Makkenzi (Kanada). [Lower Cambrian fossils of the Mackenzie Mountains (Canada)]. *Akademiya nauk SSSR, Paleontologicheskii institut, Trudy*, 224: 1-88.
- WALCOTT C.D. 1886 - Second contribution to the studies on the Cambrian faunas of North America. *U.S. Geological Survey Bulletin*, 30: 1-369.
- 1890 - Fauna of the Lower Cambrian or *Olenellus* Zone. *U. S. Geological Survey Annual Report*, 10: 509-774.
- WEIMER R.J. & HOYT J.H. 1964 - Burrows of *Callianassa major* SAY, geologic indicators of littoral and shallow neritic environments. *Journal of Paleontology*, 38: 761-767.
- WILLOUGHBY R. 1976 - Lower and Middle Cambrian fossils from the Shady Formation, Austinville, Virginia. *Geological Society of America Abstracts with Programs*, 8: 301-302.
- WOOD R., ZHURAVLEV A. YU. & CHIMED TSEREN A. 1993 - The ecology of Lower Cambrian buildups from Zuune Arts, Mongolia: implications for early metazoan reef evolution. *Sedimentology*, 40: 829-858.
- ZHURAVLEV A.YU. & SAYUTINA T.A. 1985 - Radiotsiaty Mongolii. K revizii klassa 'Radiocyatha'. [Radiocyaths of Mongolia. Toward the revision of the 'Class' Radiocyatha]. *Akademiya nauk SSSR, Sibirskoe otделение. Institut geologii i geofiziki, Trudy*, 632: 52-62.

M.A.S. McMENAMIN

Mount Holyoke College

Department of Earth and Environment, Clapp Laboratory
South Hadley, Massachusetts, 01075-1484 U.S.A.

F. DEBRENNE

Muséum National d'Histoire Naturelle
Laboratoire de Paléontologie, UMR 8569 du CNRS
8 rue Buffon
F-75005 Paris

A. Yu. ZHURAVLEV

Paleontological Institute, Russian Academy of Sciences
Profsoyuznaya Ul. 123
117868 GSP-7, Moscow B-321, Russie