LATE UPPER ORDOVICIAN SOLITARY RUGOSE CORALS OF EASTERN NORTH AMERICA

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Robert Jacob Elias

B.Sc.(Hons.), University of Manitoba, 1974
M.S., University of Cincinnati, 1977

UNIVERSITY OF CINCINNATI

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I hereby recommend that the thesis prepared under my supervision by Robert Jacob Elias

entitled

Late Upper Ordovician Solitary Rugose Corals of Eastern North America

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

Kenneth E. Caster

David L. Meyer

Paul Edwin Potter

Late Upper Ordovician Solitary Rugose Corals of Eastern North America

Robert J. Elias

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Late Upper Ordovician Solitary Rugose Corals of Eastern North America

Robert J. Elias[1]

ABSTRACT

Late Upper Ordovician solitary rugose corals of eastern North America are assigned to three provinces distinguished on the bases of assemblages and characteristic species. The distribution of these provinces, as well as taxa within them, was determined by regional environmental parameters related to paleogeography. The Richmond Province occupied a narrow belt extending northward from the Nashville Dome of Tennessee, along the Cincinnati Arch region of Kentucky-Indiana-Ohio, to Manitoulin Island, Ontario, and eastward through southern Ontario and Quebec. It coincided with a carbonate platform at the margin of an epicontinental sea which was receiving clastic sediments from the Queenston delta (Ontario, New York, Pennsylvania, Ohio). Solitary coral diversity was low, but variability within several species was great. This province was isolated by the positive Canadian Shield, Taconic upland, and Nashville Dome, and by deeper water in which the Maquoketa shale was deposited (upper Mississippi valley).

Solitary corals of the Maquoketa Group and continental margin belonged to the Red River-Stony Mountain Province,

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[1] Present address: Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.

which included most of North America during the Late Ordovician. The vast continental interior portion was occupied by shallow, interconnected epicontinental seas, whereas normal open marine environments were present at the continental margins. The Maquoketa Subprovince was characterized by the paucity and very low diversity of solitary corals in carbonate beds within shales of the Maquoketa Group. The diverse assemblage associated with carbonate sequences in the Maritime Subprovince (Anticosti Island and Gaspé Peninsula of Quebec, northern Maine) included typical continental interior species together with genera characteristic of North American continental margins and the Baltoscandian Province.

At the close of the Richmondian Stage, regression of the eastern North American epicontinental sea resulted in extinction of corals in the Richmond Province and Maquoketa Subprovince. The latest Ordovician (? Gamachian Stage) Edgewood Province coincided with a carbonate sequence deposited in normal open marine environments during a transgression into the continental interior (upper Mississippi valley). The solitary corals resembled those previously restricted to continental margins, and foreshadowed the cosmopolitan Silurian fauna.

Key words: Ordovician, North America, corals, taxonomy, paleoecology, biostratigraphy, biogeography, lithofacies, paleogeography.

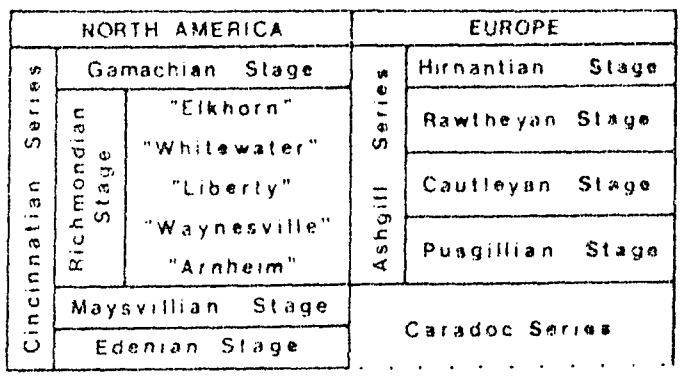
INTRODUCTION

This study comprises a comprehensive taxonomic, paleoecologic, biostratigraphic, and biogeographic analysis of late Upper Ordovician (Richmondian-Gamachian - Ashgillian) solitary rugose corals of eastern North America (Text-figs. 1, 2).

Text-figure 1.--Time-stratigraphic subdivisions of the Upper Ordovician for North America (Twenhofel, et al, 1954) and Europe (Ingham and Wright, 1970), including informal subdivisions of the Richmondian.

Text-figure 2.--Late Upper Ordovician paleogeography, lithofacies, and solitary rugose coral localities in eastern North America (compiled from many sources). Locations: 1. Cincinnati Arch region, OH-IN-KY; 2. Burkesville, KY; 3. Goodlettsville-Gallatin, TN; 4. Little Sturgeon Bay, WI; 5. Little Bay de Noc, MI; 6. Drummond Island, MI; 7. Manitoulin Island, Ont.; 8. Meaford, Ont.; 9. Streetsville, Ont.; 10. Montreal, Que.; 11. Lake St. John, Que.; 12. NE Iowa; 13. SE Iowa-NE Illinois; 14. Thebes, IL; 15. Arbuckle Mountains, OK; 16. Cape Girardeau Co., MO; 17. Pike Co., MO; 18. Will Co., IL; 19. Penobscot Co., ME; 20. Ashland, ME; 21. Percé, Que.; 22. Anticosti Island, Que.

Text-figure 1.--Time-stratigraphic subdivisions of the Upper Ordovician for North America (Twenhofel, et al, 1954) and Europe (Ingham and Wright, 1970), including informal subdivisions of the Richmondian.



Text-fig. 1

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Text-figure 2.--Late Upper Ordovician paleogeography, lithofacies, and solitary rugose coral localities in eastern North America (compiled from many sources). Locations: 1. Cincinnati Arch region, OH-IN-KY; 2. Burkesville, KY; 3. Goodlettsville-Gallatin, TN; 4. Little Sturgeon Bay, WI; 5. Little Bay de Noc, MI; 6. Drummond Island, MI; 7. Manitoulin Island, Ont.; 8. Meaford, Ont.; 9. Streetsville, Ont.; 10. Montreal, Que.; 11. Lake St. John, Que.; 12. NE Iowa; 13. SE Iowa-NE Illinois; 14. Thebes, IL; 15. Arbuckle Mountains, OK; 16. Cape Girardeau Co., MO; 17. Pike Co., MO; 18. Will Co., IL; 19. Penobscot Co., ME; 20. Ashland, ME; 21. Percé, Que.; 22. Anticosti Island, Que.

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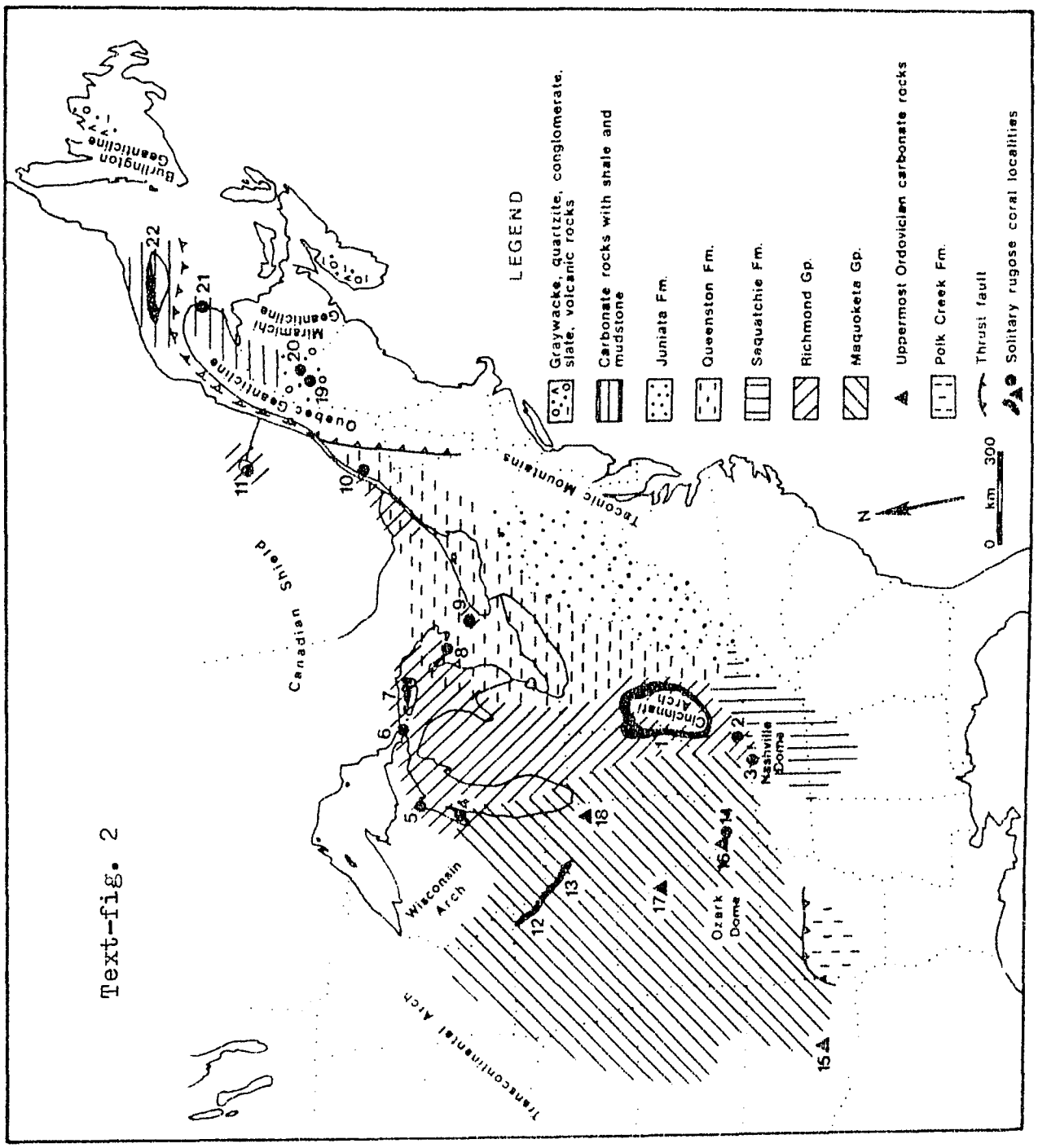

Text-fig. 2

Field work in Missouri, Tennessee, Kentucky, Indiana, Ohio, northern Michigan, and southern Ontario in the summers of 1977 and 1978 provided extensive collections as well as paleoecologic and stratigraphic data. In order to ensure stratigraphic control, all sections examined have been described in the literature, or are near described sections (see Localities and the text). The lithology and biota were observed at each locality, and an extensive search for solitary corals was made. Where present, their exact stratigraphic position was recorded. Relative abundance was estimated qualitatively (rare, sparse, uncommon, common, abundant), with rare meaning one to several corallites were found and abundant meaning they were so prolific it was not feasible to collect all the specimens. When possible, orientation on bedding surfaces was noted. All corallites seen were collected. At the few horizons where they were abundant, the search was terminated when a relatively large number had been found. Almost one thousand specimens were collected for this study.

In the Cincinnati Arch region, 34 localities were examined in order to prepare 14 composite sections (Text-fig. 3). Data for horizons not seen in this study were obtained from the literature. Four localities near Burkesville, Kentucky, and three in the Goodlettsville-Gallatin area of Tennessee provided data for composite sections 15 and 16 (Text-fig. 3). Composite section 17 at

Little Bay de Noc, Michigan, is based on three localities and the literature (Text-fig. 18). Stratigraphy at Drummond and Manitoulin Islands is shown in composite section 18-19 (Text-fig. 18). Three sections were studied on Drummond Island. Of 25 exposures seen on Manitoulin Island, six have important solitary coral-bearing horizons. In eastern Missouri, sections 20a, b in Cape Girardeau Co. and sections 21a, b in Pike Co. were examined (Text-fig. 21).

Approximately one thousand corallites from many of the above areas and from collections made elsewhere in eastern North America were obtained on loan. Most specimens from the Cincinnati Arch region, Michigan, Ontario, and Quebec were collected by A.F. Foerste. W.H. Twenhofel's extensive collection was the major source of material from Anticosti Island, Quebec. Solitary corals from Maine were collected by R.B. Neuman (U.S. Geological Survey). Composite stratigraphic sections for areas not seen in this study are based on literature cited in the text (Text-figs. 18, 21, 22).

Morphological and descriptive terminology used herein follows Elias (1976, p. 11-13). In order to determine internal morphology, most corallites were sectioned transversely in several places and a relatively small number were sectioned longitudinally. Thin sections of more than 300 corallites have been prepared.

Repositories of specimens are abbreviated as follows:

GSC (Geological Survey of Canada, Ottawa), LU (Laurentian University, Sudbury, Ontario), ROM (Royal Ontario Museum, Toronto), SIU (Southern Illinois University, Carbondale), SUI (State University of Iowa), UCGM (University of Cincinnati Geological Museum), UI (University of Illinois at Urbana-Champaign), UMMP (University of Michigan Museum of Paleontology), USGS (U.S. Geological Survey, Smithsonian Institution, Washington, D.C.), USNM (U.S. National Museum, Smithsonian Institution, Washington, D.C.), YPM (Peabody Museum, Yale University).

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LATE UPPER ORDOVICIAN PALEOGEOGRAPHY, LITHOFACIES, AND SOLITARY RUGOSE CORALS OF EASTERN NORTH AMERICA

OVERVIEW

The Late Ordovician Taconic Mountains along the continental margin of North America were the source of the Richmondian clastic wedge deposited on the craton (R.B. Neuman, 1976; Dennison, 1976) (Text-fig. 2). Nearest the uplift, the Juniata Formation comprises continental channel and overbank sandstones with some siltstones and shales. Distally, it consists of lower delta plain redbeds which grade into the grayish red deltaic shales and siltstones of the Queenston Formation. The Sequatchie Formation and Richmond Group carbonate rocks and shales, and the Maquoketa Group shales were deposited in an epicontinental sea. The Richmond Group thins and its dolomite and arenaceous content increases along the Cincinnati Arch, which was probably a subtle platform, to the positive Nashville Dome. The carbonate and arenaceous content of the Maquoketa Group increases and its thickness decreases toward the Transcontinental and Wisconsin Arches and the Ozark Dome, which were slightly positive. In general, Richmondian sedimentation in eastern North America was affected by positive structures rather than well defined subsiding basins. The typically regressive stratigraphic sequences may reflect a eustatic sea-level drop accompanying Late Ordovician glaciation centered in Africa (Berry and Boucot,

1973; Dennison, 1976).

Following a period of post-Maquoketa erosion, a thin unit of uppermost Ordovician carbonate rocks formed in the Arbuckle Mountain area of Oklahoma, in eastern Missouri-western Illinois, and northern Illinois. These deposits represent the initial stage of a transgression possibly related to deglaciation.

On the continental margin, a thick carbonate-shale sequence was deposited at Anticosti Island, and a carbonate-mudstone unit formed at Gaspé Peninsula. These carbonate rocks grade into a very thick sequence of polymict conglomerates, graywackes, and siltstones in northern Maine. Late Upper Ordovician conglomerates, graywackes, quartzites, slates, and volcanic rocks are present in Nova Scotia and Newfoundland. Black graptolitic shale of the Polk Creek Formation occurs in the Ouachita Mountains of Arkansas and Oklahoma.

Late Upper Ordovician solitary rugose corals are found almost exclusively in carbonate rocks. They are most common in the Richmond Group, in carbonates of the continental margin, and in the uppermost Ordovician carbonate unit overlying the Maquoketa Group (Text-fig. 2). Solitary corals are sparse in carbonate beds within the Maquoketa. They are associated with calcareous debris in the clastic sequence of northern Maine.

I. RICHMOND GROUP

INTRODUCTION

The Richmond Group forms a narrow carbonate belt extending from the Nashville Dome in Tennessee along the Cincinnati Arch region of Kentucky-Indiana-Ohio to northern Michigan and Manitoulin Island, Ontario (Text-fig. 2). It was deposited at the margin of an epicontinental sea between the Queenston deltaic shales and Maquoketa marine shales. In general, the group comprises a regressive sequence including characteristic interbedded carbonates and shales, carbonate units, and horizons of abundant colonial corals and stromatoporoids. An incursion of the Richmond Group occurs at the top of the Maquoketa in the Green Bay, Wisconsin, area. In the vicinity of Meaford, Streetsville, and Montreal in southern Ontario and Quebec, the Richmond Group is overlain by sediments of the prograding Queenston delta. An outlier including Richmond strata is present at Lake St. John, Quebec. Although the Richmond Group is seldom lithologically distinct from the underlying Edenian-Maysvillian sequence, the term is retained herein for reference to this belt of Richmondian strata having a similar depositional history and fauna.

1. CINCINNATI ARCH REGION

Stratigraphy

Prior to 1960, stratigraphic subdivision of the Richmond Group in the Cincinnati Arch region (Text-fig. 2, no. 1) was based on faunal zonation, and resulted in recognition of the Arnheim, Waynesville, Liberty, Whitewater, and Elkhorn formations. The history of development of this classification was reviewed by Weiss and Norman (1960). These divisions are now viewed as invalid rock-stratigraphic units, but have commonly been used in the sense of time-stratigraphic subdivisions of the Richmondian Stage. They are used informally as such herein (Text-fig. 1).

Since 1961, when the Code of Stratigraphic Nomenclature was published by the American Commission of Stratigraphic Nomenclature, attempts have been made to subdivide the Cincinnatian sequence lithostratigraphically. In Indiana, this has been done by Fox (1962), Brown and Lineback (1966), and Gray (1972). Subdivision by Gray (1972, table 1) into the Dillsboro Formation and Whitewater Formation with Saluda Member is followed. Richmondian strata on the northeastern side of the Cincinnati Arch region are lithologically similar to those in Indiana, and Gray's classification is herein extended into Ohio. In Kentucky, the Richmond Group has been lithostratigraphically subdivided through the mapping program of the U. S. Geological Survey in cooperation with the Kentucky Geological Survey. These units have been

described on U.S. Geological Survey Quadrangle Maps, and discussed by Weir, Greene, and Simmons (1965), Peck (1966), Simmons and Oliver (1967), and Peterson (1970).

The Richmond Group of the Cincinnati Arch region is overlain by the Middle Llandoverian (Lower Silurian) Brassfield Formation. The contact is generally disconformable, but a paraconformity exists in the eastern part of the region (Gray and Boucot, 1972, p. 1301).

Southeast. On the southeastern side of the Cincinnati Arch region (Text-fig. 3, sections 6-9), the Ashlock Formation,

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Text-figure 3.--Ohio, Indiana, Kentucky, and Tennessee: Richmond Group stratigraphic sections to scale and distribution of solitary rugose corals (Streptelasma and Grewingkia) (see Localities).

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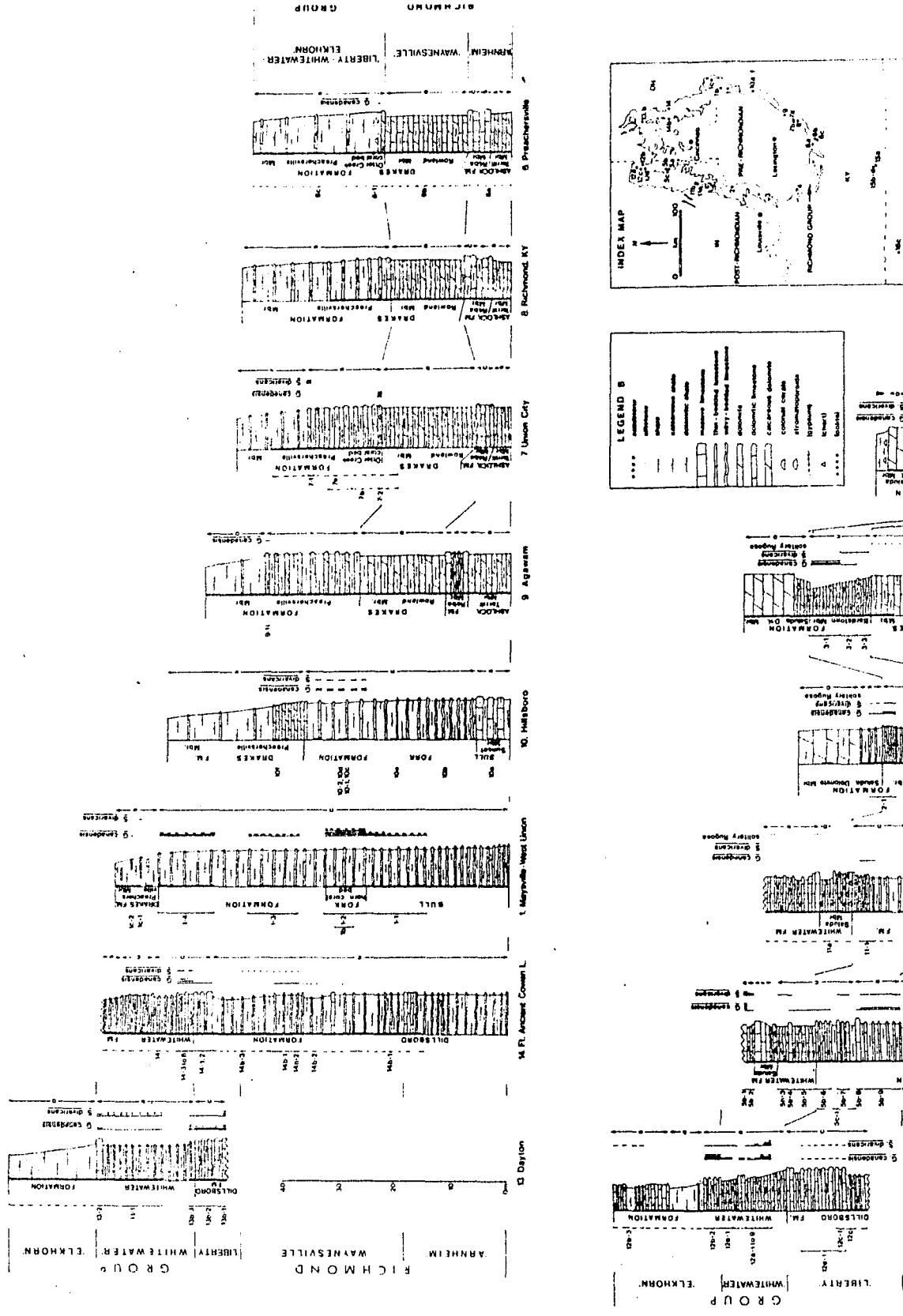
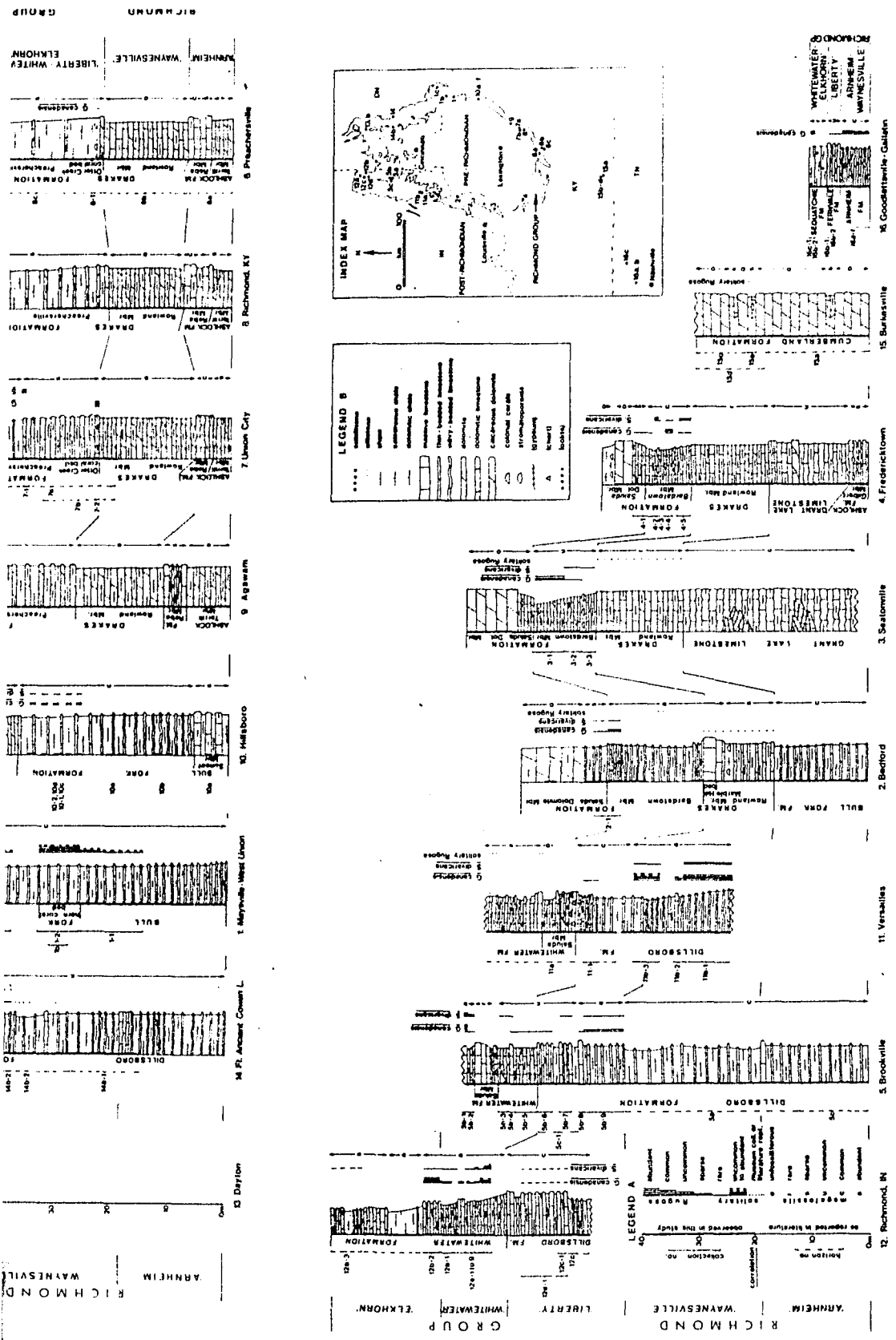
which is partly Maysvillian in age, is overlain by the Drakes Formation. The Terrill Member of the Ashlock Formation consists primarily of evenly laminated, greenish gray, dolomitic mudstone. Ripple marks and mud cracks are locally common. Bryozoans and brachiopods are occasionally sparse at the base, and small stromatolites are sometimes found near the top of the member (Weir, Greene, and Simmons, 1965, p. 13). The unit is silty in the vicinity of sections 7 and 8, and becomes more shaly to the north at section 9. The

Text-figure 3.--Ohio, Indiana, Kentucky, and Tennessee: Richmond Group stratigraphic sections to scale and distribution of solitary rugose corals (Streptelasma and Grewingkia) (see Localities).





Text-fig. 3

basal portion of the overlying Reba Member, Ashlock Formation, consists of gray, micritic limestone with sparse ostracods and abundant cylindrical burrows perpendicular to bedding planes in southern localities. The upper portion is wavy-bedded, silty, medium grained limestone that generally becomes argillaceous toward the top and contains abundant bryozoans and brachiopods (Weir, Greene, and Simmons, 1965, p. 13).

The Rowland Member forms the lower part of the overlying Drakes Formation. It consists of laminated, greenish gray, dolomitic or limy, silty mudstone. The unit becomes less silty but increasingly dolomitic and argillaceous to the north. Bedding surfaces sometimes have ripple marks or mud cracks. Megafossils are absent to rare (Weir, Greene, and Simmons, 1965, p. 17). The uppermost Richmondian unit is the Preachersville Member of the Drakes Formation. It is similar to the Rowland Member, but contains argillaceous dolomite and dolomitic limestone in resistant beds that are commonly thicker near the base of the member and increase in abundance northward. Poorly preserved bryozoans and sparse brachiopods occur in some beds (Weir, Greene, and Simmons, 1965, p. 18). The Otter Creek coral bed is locally present at the base of the Preachersville Member in the vicinity of sections 6 and 7 (Simmons and Oliver, 1967). It is usually less than a meter thick, and consists of gray, generally medium grained, argillaceous limestone with abundant colonial corals of the genera Calapoecia, Foerstephyllum, and

Tetradium. Also common are solitary corals, cylindrical stromatoporoids, and brachiopods.

Southwest. On the southwestern side of the Cincinnati Arch region (Text-fig. 3, sections 3, 4), the Grant Lake Limestone is overlain by the Drakes Formation. The type Grant Lake Limestone on the eastern side of the Cincinnati Arch is Maysvillian in age (Peck, 1966, p. 14, 16), but on the southwestern side it extends into the Richmondian. The unit consists of irregularly bedded, silty and argillaceous, gray, fossiliferous limestone, and shale in discontinuous beds and partings. Thick cross-bedded zones of limestone occur locally. Brachiopods and bryozoans are abundant, especially in the limestone. To the south, the portion of Grant Lake Limestone at the base of the Richmondian grades into the Gilbert Member of the Ashlock Formation (Weir, Greene, and Simmons, 1965, p. 12). This member, in the vicinity of section 4, consists of evenly to wavy-bedded, gray, fossiliferous limestone with gray shale partings and interbeds. It contains brachiopods and gastropods, with stromatoporoids near the top.

The Rowland Member at the base of the Drakes Formation is similar to the member on the southeastern side of the arch, but is more calcareous and fossiliferous. The overlying Bardstown Member consists of gray, silty and argillaceous limestone in discontinuous and lenticular beds, with sparse to abundant fossils and fossil fragments

(Peterson, 1970). Common fossils include brachiopods, bryozoans, solitary corals, and molluscs. The colonial corals Tetradium, Foersterophyllum, Favistina, and Calapoecia form prominent zones. The Saluda Dolomite Member occurs at the top of the Drakes Formation. At its base, the dolomite is thinly bedded, calcitic, silty, and argillaceous. Above this, it appears massive in outcrop and is generally unfossiliferous. In the upper part, it is locally finely laminated and burrowed. At the top of the member, limestone or dolomite and shale are sometimes preserved, and locally contain the colonial coral Tetradium, or ostracods and gastropods.

East. On the eastern side of the Cincinnati Arch region (Text-fig. 3, sections 1, 10), the Richmond Group comprises the Bull Fork and overlying Drakes formations. The Bull Fork Formation consists of alternating shale and limestone. The gray shale content increases from about 20 percent at the base to about 80 percent near the top of the unit. The generally fossiliferous limestone forms even to wavy and irregular beds that are occasionally ripple marked. Beds of sparsely fossiliferous micritic limestone with locally common ostracods increase in abundance southward, whereas evenly bedded to cross-bedded grainstone is more common northward. Brachiopods and bryozoans are the most abundant fossils, but corals, trilobites, molluscs, crinoids, and ostracods are locally abundant. In the vicinity of section 1, a zone of abundant solitary corals is present near the

middle of the formation (Peck, 1966, p. 16-22). The Sunset Member occurs at the base of the Bull Fork Formation in the vicinity of section 10. The member is predominantly argillaceous to silty limestone, with the remainder being clay shale. Brachiopods are sometimes found near the base, and stromatoporoids are locally present, especially near the top.

Overlying the Bull Fork, the Drakes Formation comprises a northern extension of the upper part of the Preachersville Member. It consists of calcareous to dolomitic mudstone with minor sparsely fossiliferous dolomite and limestone interbeds and lenses. The mudstone is generally grayish green, but is locally reddish purple near the top, as at locality 1c.

West. On the western side of the Cincinnati Arch (Text-fig. 3, section 2), the Bull Fork Formation intertongues with the upper Grant Lake Limestone of the southwest. In the vicinity of section 2, the Richmond Group comprises the upper part of the Bull Fork Formation and the overlying Drakes Formation. The Bull Fork Formation is lithologically similar to the type area on the eastern side of the arch. The Rowland Member at the base of the Drakes Formation consists of argillaceous, micritic limestone in even to nodular beds up to a meter thick, with mudstone interbeds. The member is not dolomitic, as it is to the south. Colonial corals are abundant in local zones, and brachiopods and bryozoans are scattered in the unit. The

Marble Hill bed of this area is included in the Rowland Member and consists of gastropodal limestone and bioclastic grainstones (Swadley, 1977). The overlying Landstown Member consists of fossiliferous limestone in thin, even to irregular beds, with gray shale interbeds. Brachiopods and bryozoans are abundant, together with solitary corals, molluscs, crinoids, and trilobites. The shale content is greater than to the south. The Landstown thickens immediately north of section 2 where the Rowland Member pinches out, and is indistinguishable from the underlying Bull Fork Formation. The overlying Saluda Dolomite Member of the Drakes Formation is the uppermost Richmondian unit in this area. In the basal portion, thin beds of argillaceous limestone containing brachiopods and bryozoans occur in argillaceous dolomite. The upper part of the member is generally unfossiliferous, thickly bedded dolomite. A thin bed of fossiliferous limestone is rarely present at the top.

Northwest. On the northwestern side of the Cincinnati Arch region in Indiana (Text-fig. 3, sections 11, 5, 12), the Maysvillian to Richmondian Dillsboro Formation is overlain by the upper Richmondian Whitewater Formation, which includes the Saluda Member. These formations correspond to the Bull Fork Formation and Saluda Dolomite Member, Drakes Formation, of Kentucky. The Dillsboro Formation (equivalent to the Tanners Creek Formation of Fox, 1962, p. 626-628), consists of thinly interbedded argillaceous limestone and calcareous

shale. Fossils are generally common to abundant, and include bryozoans, brachiopods, and trilobites. Solitary corals are sometimes common in the upper Dillsboro in southern localities such as section 11 and the Clifty Power Plant section of Mattin, et al (1961, p. 328-331). Limestone beds are much more fossiliferous than the shales. The biostratigraphy was discussed by Fox (1962). Faunal distribution and abundance has been shown for horizon 5a (Hay, 1977, fig. I-10) and horizons 5b-6 to 9 (Hay, 1977, fig. I-8, Liberty Formation).

The overlying Whitewater Formation is composed predominantly of a variety of thin and often rubbly bedded argillaceous limestones, with some shale and dolomite (Fox, 1962, p. 628; Brown and Lineback, 1966, p. 1022). Shale intervals occur toward the top of the formation at northern localities. Fossils, especially bryozoans, brachiopods, solitary corals, and molluscs, are abundant in the lower Whitewater Formation in the north. Faunal distribution and abundance has been shown for horizons 12a-1 to 9 (Hay, 1977, fig. I-6) and horizons 5b-1 to 5 (Hay, 1977, fig. I-8). The upper Whitewater is unfossiliferous to sparsely fossiliferous. Biostratigraphy of the formation was discussed by Fox (1962). The Saluda Member in Indiana is a northward-thinning wedge of dolomite, dolomitic limestone, and dolomitic mudstone with a colonial coral zone near its base (Brown and Lineback, 1966, p. 1021, 1022). The Saluda occurs at the base of the Whitewater

Formation in the south (Clifty Power Plant section of Hattin, et al, 1961, p. 328-331; section 11), and within the Whitewater to the north. The dolomitic content decreases northward, and at section 5 near the northern limit of the member, the colonial coral zone is overlain by generally thickly bedded limestone. Except for the colonial coral zone, the Saluda Member contains very few fossils other than ostracods.

Northeast. The Richmond Group on the northeastern side of the Cincinnati Arch region in Ohio (Text-fig. 3, sections 13, 14) is lithologically similar to the group in Indiana, but shale is more abundant in the Whitewater Formation, and the Saluda Member is not present.

Depositional Environments

Previous work. Fox (1968) studied the composition, texture, and structure of sedimentary rocks as well as the biota of the Richmond Group in Indiana. He concluded that the Dillsboro Formation was deposited in a stable marine environment below effective wave base. He found evidence of shoaling with some subaerial exposure in the Whitewater Formation immediately below and above the Saluda Member, which formed in a lagoon that was periodically subaerially exposed. Another episode of shoaling occurred during later "Whitewater" time. Fox (1968), on the basis of the sparite-micrite ratio in limestones, interpreted the Dillsboro as a regressive sequence interrupted by a transgressive phase near the end.

Scotford (1965) studied the shale petrology of the "Waynesville" in the Cincinnati Arch region and found sand and silt dominant in the south, and clay more abundant to the north. Kohut and Sweet (1968) noted that the Richmond Group is more argillaceous toward the south and grades into shales and limestones northward, where they believed deposition occurred in deeper water. They recognized southern and northern conodont faunas probably related to depth.

Hatfield (1968) studied the lithostratigraphy and paleoecology of the lenticular Saluda Member on the western side of the Cincinnati Arch region in Indiana and Kentucky. The unit was deposited in a quiet, saline, very shallow to

periodically subaerially exposed lagoon that was isolated by encompassing colonial coral-stromatoporoid banks. On the basis of lithology, Anstey and Fowler (1969) stated that water depth was at a maximum during "Arnheim-Waynesville" time, at a minimum during Saluda Member deposition, and of intermediate depth in the "Liberty" and "Whitewater". Martin (1975, 1977) studied the composition, texture, structure, and biota of Richmond Group limestones in Indiana and Ohio. He concluded that the Dillsboro Formation was deposited in a shallow, generally low energy, offshore environment. Following Saluda deposition, the Whitewater Formation was deposited in more normal marine conditions. After slight deepening, a slow regression proceeded from offshore through nearshore to finally periodically subaerially exposed environments.

Hay (1977) discussed the Richmondian lithofacies sequence in Indiana, and suggested a regressive peak with possible unconformity at the end of "Arnheim" deposition. The transgression that followed culminated in the "upper Waynesville-lower Liberty", and the final regression with some oscillation occurred during the "upper Liberty-Whitewater-Elkhorn" interval. The "Arnheim" horizon marks the upper limit of a small number of conodonts characteristic of the European fauna that are more conspicuously represented in pre-Maysvillian Ordovician strata of the Cincinnati Arch region (Kohut and Sweet, 1968). During late "Waynesville"

time, an upper Richmond conodont fauna migrated into the region and reached its climax in the "Whitewater".

Present Study. Most stratigraphic, sedimentologic, and paleontologic work on the Richmond Group in the Cincinnati Arch region has been done in Indiana, with very few studies considering the entire region. Exceptions are the work on shale petrology by Scotford (1964, 1965) and Butler and Scotford (1973), and the conodont study of Kohut and Sweet (1968). The nature of the Richmond Group is seen in the 14 stratigraphic sections around the Cincinnati Arch region examined in the present study (Text-fig. 3). The following characteristics are demonstrated:

1. The Richmond Group thickens from about 45 m in the south to about 90 m in the north on both eastern and western sides of the arch.
2. The argillaceous, silty, and dolomitic sediments of the south grade northward into interbedded shales and limestones.
3. Sections on the eastern side of the arch contain more shale and dolomite than those on the west, where limestone is more common.
4. Fossils generally increase in abundance northward, and are more common on the western side than on the eastern side of the arch.
5. On the eastern side of the arch, dolomitic shale of the Preachersville Member occurs at the top of the Richmond

Group, whereas the lenticular Saluda Dolomite Member is present at or near the top on the west side from section 5 southward.

6. Colonial coral horizons occur on the southeastern side of the arch in the Otter Creek coral bed, and are prominent on the western side particularly in association with the Saluda Member.

It is apparent from lithologies and thicknesses that the Richmondian epicontinental sea became progressively deeper to the north, with depositional strike oriented east-west. On the eastern side of the Cincinnati Arch region nearest the Queenston delta, marine environments were more restricted and terrigenous input was greater than to the west. Less restricted environments prevailed on the western side which faced the main body of the epicontinental sea, although in later Richmondian time the development of colonial coral banks resulted in Saluda deposition within a restricted lagoon.

At some sections, a regressive peak may have been followed by transgression near the base of the Richmond Group. Such a peak may be represented by the top of the "Arnheim" in Indiana and the top of the Terrill Member, Ashlock Formation, in the southeastern part of the Cincinnati Arch region. Generally speaking, the Richmond Group represents a regressive sequence.

Cincinnati Arch

The Cincinnati Arch, which extends northward from the Nashville Dome, was definitely a positive structure in the Middle Silurian related to subsidence of the Illinois Basin on the west and Ohio Basin on the east. The Cincinnati Arch bifurcated into the Kankakee and Findlay arches marking the southern margin of the subsiding Michigan Basin (Shaver, 1974, fig. 6). These positive areas controlled the location and development of carbonate banks and reefs.

The history of studies dealing with the time of initial relative uplift of the Cincinnati Arch was summarized by Scotford (1964). Few authors have considered the structure to be earlier than Silurian in age. Scotford (1964) examined the problem on the basis of Ordovician shale petrology in the Cincinnati Arch region. Shale parameters in the "Waynesville" vary in a north-south rather than east-west direction, indicating that the axis of the arch was not a barrier to sedimentation. This variation would be expected with an east-west depositional strike and northward dip. At the top of the Richmond Group, six of eight significant shale parameters differ on the east and west sides of the arch. Scotford (1964, p. 436) stated that these data "suggest the possibility that a weak barrier may have been developing along the axis of the arch, but its influence on the character of the shales on opposite sides of the axis was minor". He felt that the Cincinnati Arch should not be

assigned an age earlier than Silurian.

If the Cincinnati Arch represents a broad, nearly level platform without a definite axis (Green, 1961), lithologies of the arch region as a whole should be compared with those to the east and west in order to determine effects of the structure on sedimentation. During Richmondian time, the Richmond Group was deposited in a narrow zone extending from the positive Nashville Dome northward along the Cincinnati Arch region (Text-fig. 2). It formed a carbonate belt separating the Queenston shales on the east and Maquoketa shales on the west. Extensive colonial coral banks developed along the southwestern margin of the Richmond Group facing the main body of the epicontinental sea. Coincidence of the Richmond Group and Cincinnati Arch suggest that the structure was a subtle, broad platform sloping slightly to the north and influencing carbonate sedimentation and organic buildups during the Richmondian Stage (Text-fig. 4).

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Text-figure 4.--Middle Richmondian ("Liberty") paleogeography and lithofacies of a 90,000 km^2 area centered on the Cincinnati Arch region (shaded), seen from the present northwest. Vertical scale greatly exaggerated. Colonial coral buildups shown in the southwestern Cincinnati Arch region. Arrows indicate current directions. Based on data in Text-figs. 2, 3, 5, and Gray (1972).

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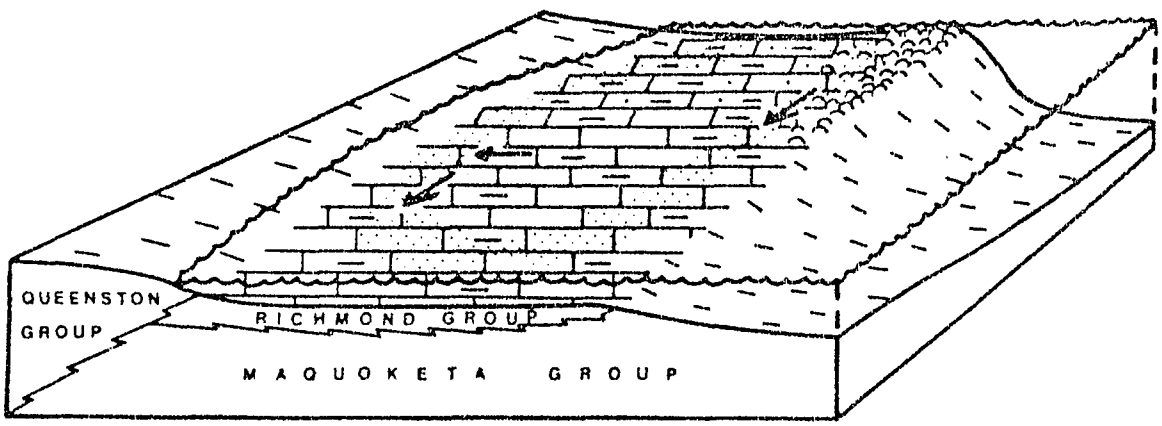
Text-figure 4.--Middle Richmondian ("Liberty") paleogeography and lithofacies of a 90,000 km^2 area centered on the Cincinnati Arch region (shaded), seen from the present northwest. Vertical scale greatly exaggerated. Colonial coral buildups shown in the southwestern Cincinnati Arch region. Arrows indicate current directions. Based on data in Text-figs. 2, 3, 5, and Gray (1972).



Text-fig. 4

Solitary Rugose Corals

Two species of solitary corals, Grewingkia canadensis (Billings, 1862) and Streptelasma divaricans (Nicholson, 1875), are present in the Richmond Group of the Cincinnati Arch region. Their distribution and relative abundance are shown in Text-fig. 3.

A. Grewingkia canadensis (Billings, 1862)

Stratigraphic Distribution. Grewingkia canadensis generally occurs within and on limestone beds containing common to abundant brachiopods and branching bryozoans. The earliest occurrence of the species at the base of the "Waynesville" in the vicinity of sections 11 and 2 on the western side of the Cincinnati Arch region and section 1 on the east suggests introduction during an early Richmondian transgression. The initial distribution along depositional strike about half way between the deeper north and shallower, periodically subaerially exposed southern ends of the region indicates preference for "normal" marine water in the "intermediate" depth range where calcium carbonate sediments accumulated and brachiopods and bryozoans thrived. The species migrated to the north and south as favorable environmental conditions appeared elsewhere, and is most widely distributed in the "Liberty-lower Whitewater". G. canadensis does not occur in the restricted Saluda lagoon, or in very shallow environments of the final regression at the top of the Richmond Group.

Orientation of Corallites. Growth lines, septal grooves, and interseptal ridges are rarely preserved on corallites of Grewingkia canadensis, and the outer portion of the stereozone is generally absent. Tips of the corallites are almost always rounded, and the rim of the calyx was sometimes broken prior to deposition (Plate 5, figs. 17, 32). Corallites oriented with the calyx approximately horizontal and facing up, presumably in growth position (Wells, 1957), are extremely rare. Of more than 500 corallites collected, two at horizon 5c-1 (UCGM 45288) and one at horizon 14b-1 (UCGM 45465) were preserved in this way. All others were lying on their sides when buried (Plate 2, fig. 16). Of 143 corallites, 76 percent are oriented in the most stable position with an alar side facing up (ie. plane of curvature horizontal), and only 15 percent and 9 percent were deposited with the counter and cardinal sides up, respectively (App. 1). These features indicate that the corallites were abraded and transported prior to final deposition and burial.

The directional orientation of G. canadensis corallites lying on bedding surfaces was measured at seven sections in the Cincinnati Arch region (Text-fig. 5). The distributions

Text-figure 5.--Grewingkia canadensis (Billings, 1862): directional orientations, Richmond Group (see App. 2).

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Text-figure 5.--*Grewingkia canadensis* (Billings, 1862): directional orientations, Richmond Group (*see* App. 2).

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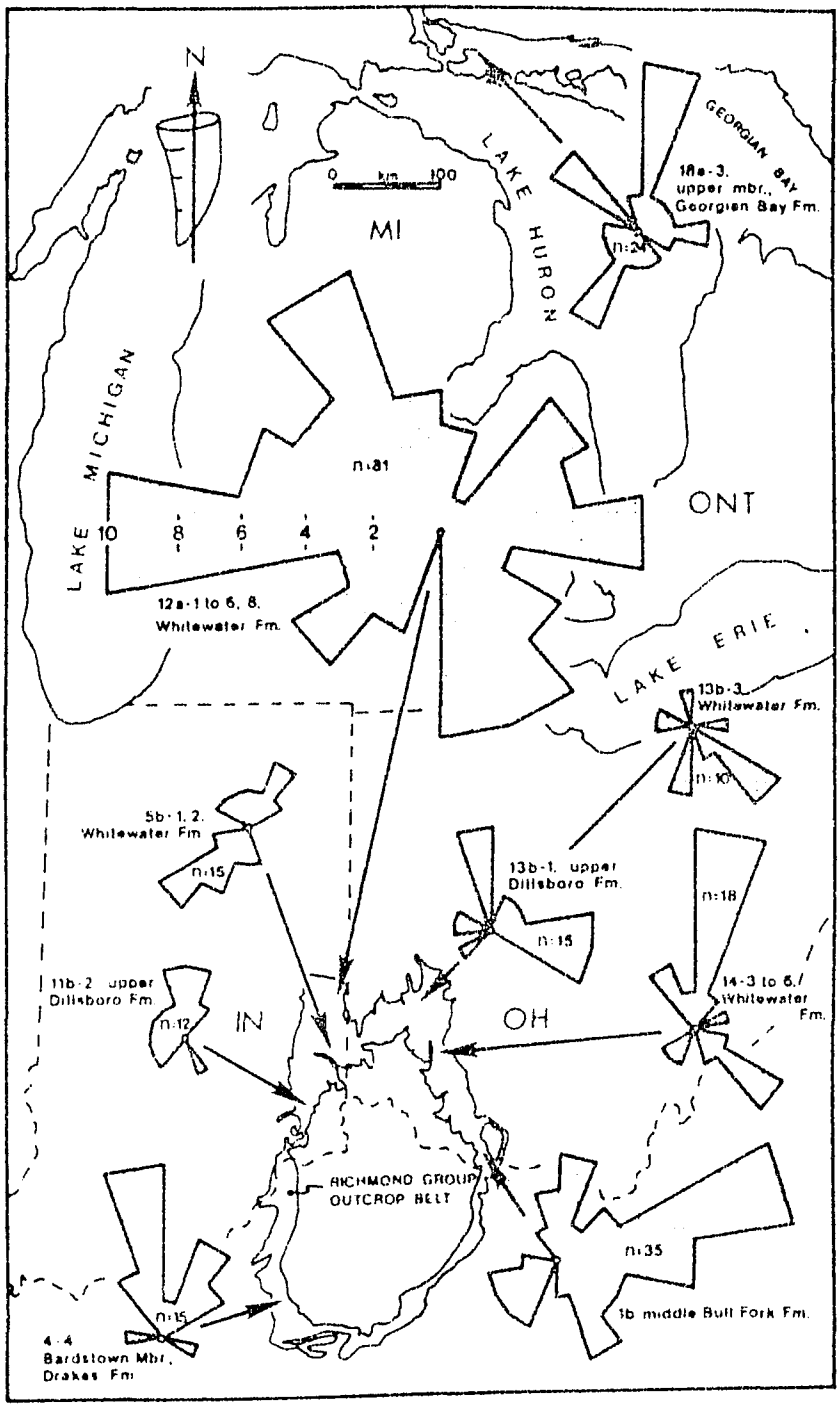


Text-fig. 5

suggest preferential orientation due to predominant current directions. A unidirectional distribution would be expected if corallites were oriented with the tip facing the current. A symmetrical distribution with peaks 180 degrees apart could be produced in an oscillating current, or if the cylindrical corallites were rolled perpendicular to the current or parallel to waves, with tips facing either way (Nagle, 1967). A current from the south is suggested at sections 4 and possibly 11 on the western side of the Cincinnati Arch region. The distributions at sections 5 and 12 on the northwestern side of the region are somewhat bilaterally symmetrical. This could reflect oscillating southwest-northeast and southeast-northwest currents at sections 5 and 12, respectively. If the corallites were rolled perpendicular to the current, it may have been from the southeast or northwest at section 5, and southwest or northeast at section 12. On the northeastern side of the region at sections 13, 14, and 1, corallite orientations suggest currents from the south and west. Unfortunately, few paleocurrent data for the Upper Ordovician and particularly the Richmond Group of the Cincinnati Arch region are available for comparison[1]. Potter and Pettijohn (1963, fig. 4-15) found that megaripples in limestones of the Cincinnatian Series, including a small proportion from the Richmondian Stage in the vicinity of section 1, generally strike approximately north-south. The average cross-bedding

[1]Bucher (1919*, fig. 14h-k) presented a small number of para-ripple strike directions in the Richmond Group. The predominant direction in Indiana is east-northeast, but the significance of this is uncertain because localities from which data were combined are widely separated. Strike directions in Oldham Co., Kentucky, are predominantly east-west. This is consistent with solitary corals facing to the north at section 4. Strike directions in Adams Co., Ohio, and Fleming Co., Kentucky, are predominantly north-northwest and north-south, respectively. These trends are consistent with solitary corals facing east at section 1.

*Bucher, W. H.

1919. On ripples and related sedimentary surface forms and their paleogeographic interpretation. Am. J. Sci., vol. 47, pp. 149-210, 241-269, 6 tbls., 14 figs.

direction is to the west, although directions in quadrants containing Richmondian strata are to the north, south, and east. Immediately east of Cincinnati, Hofmann (1966) found that paleocurrent indicators in the Edenian and Maysvillian [illegible] from the east and north, respectively. Immediately [illegible] Cincinnati, [illegible] (1968) concluded that [illegible] during Edenian-Maysvillian time. [illegible] Cincinnati, [illegible] (1971) found [illegible] south-southeast during the same time [illegible].

I. canadensis corallites do not possess a base of attachment, and clusters growing in lateral contact are very rare (Plate 6, fig. 3). Corallites are ceratoid (Plate 5, figs. 23, 24) to trochoid (Plate 5, fig. 17) and are generally very weakly curved in early to intermediate stages, becoming cylindrical in late stages (Plate 5, figs. 16, 24). They can be longer than 13 cm. This growth form suggests that the corals lived in low energy, stable environmental conditions in which the corallite slowly sank vertically into the sediment due to added weight during growth (Wells, 1957). The corallites were overturned, abraded, and transported in higher energy conditions before final deposition.

Corallite Size: Length. The length-frequency distribution of Grewingkia canadensis corallites in the Richmond Group, Cincinnati Arch region, is bimodal with peaks at 22.5 and 57.5 mm (Text-fig. 6). This general distribution is independent of stratigraphic horizon or geographic location (Text-figs. 6, 7). A similar distribution occurs at

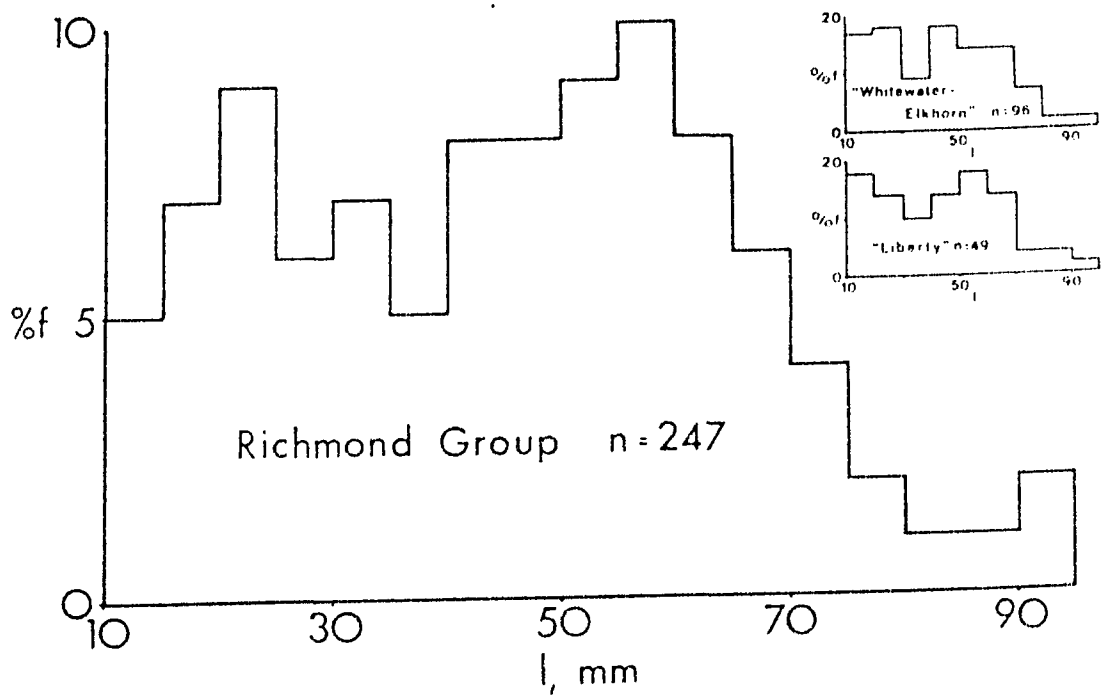
Text-figure 6.--Grewingkia canadensis (Billings, 1862): length of corallites (l) in the Richmond Group and two horizons within it, Cincinnati Arch region (see App. 3; Table 4).

Text-figure 7.--Grewingkia canadensis (Billings, 1862): length of corallites (l, mm), Richmond Group sections (see Text-figs. 3, 18; App. 3).

Drummond Island, Michigan. Collecting bias is thought to contribute, at least in part, to low frequency values only for lengths less than 10 or 20 mm.

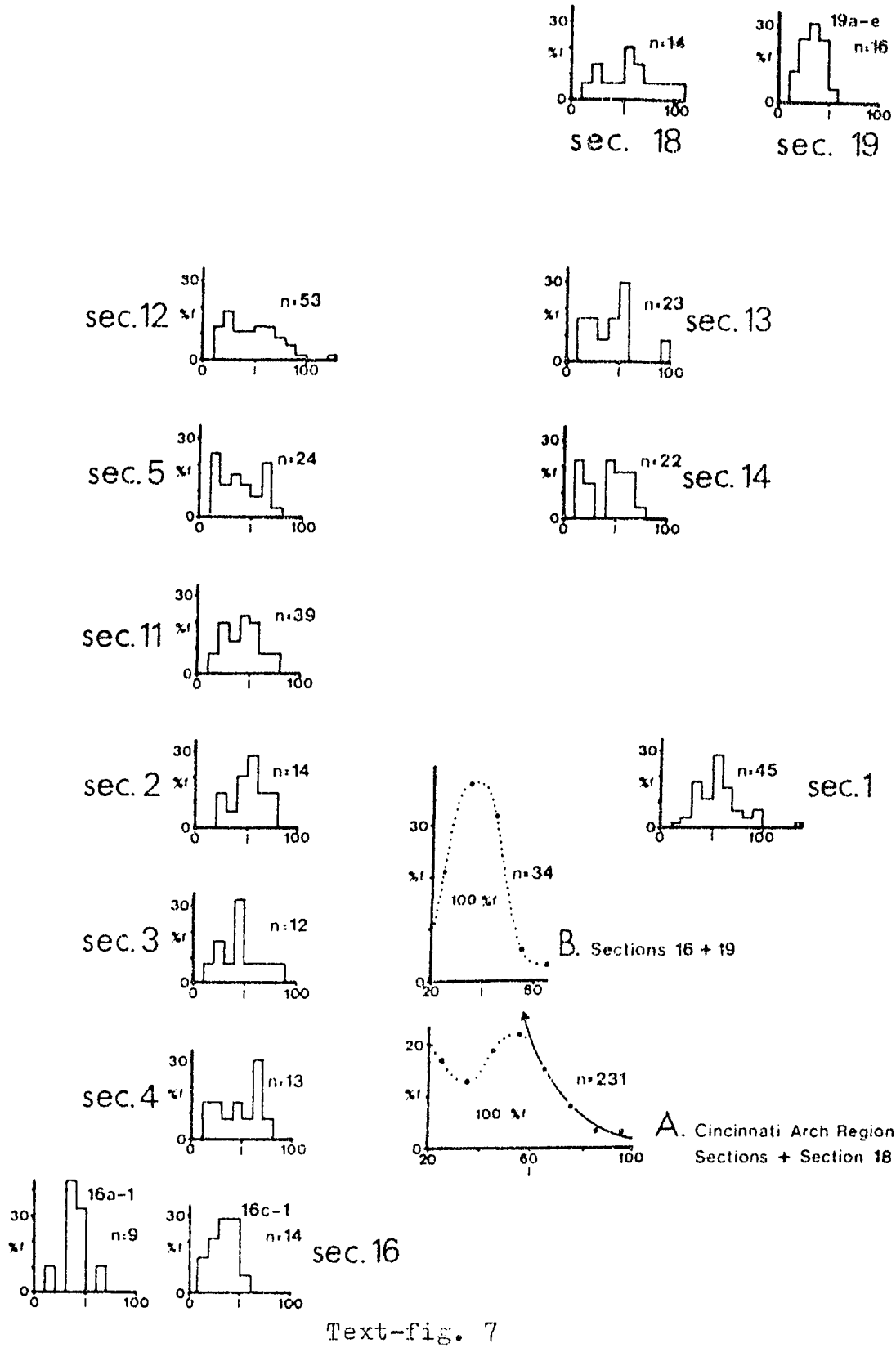
The length-frequency distribution of G. canadensis cannot be understood completely because biologic factors such as birth rate, growth rate, and death rate are unknown. The bimodal distribution of these corallites, which were transported before burial, could be due to current sorting involving partial removal of those less than about 57.5 mm and especially about 37.5 mm long (Text-fig. 7a). Changes

Text-figure 6.--Grewingkia canadensis (Billings, 1862): length of corallites (l) in the Richmond Group and two horizons within it, Cincinnati Arch region (see App. 3; Table 4).



Text-fig. 6

Text-figure 7.--Crewingkia canadensis (Billings, 1862): length of corallites (l, mm), Richmond Group sections (see Text-figs. 3, 18; App. 3).



Text-fig. 7

in external form and degree of septal dilation during ontogeny determined surface area and weight, which would have affected the behavior of different sized corallites in a particular current.

If the bimodal distribution is due to removal of corallites from an initial population by currents, they must have been deposited elsewhere. The length-frequency distributions for G. canadensis corallites in horizons 16a-1 and 16c-1 at Goodlettsville-Gallatin, Tennessee, and horizons 19a to e at Manitoulin Island, Ontario, are unimodal with peaks at 35 mm (Text-fig. 7). This corresponds to the low frequency area of the bimodal distribution (Text-fig. 7a, b). The very low frequency at 60 mm corresponds to the maximum length of corallites thought to have been removed from the initial population. These features suggest that corallites deposited in these horizons at Goodlettsville-Gallatin and Manitoulin Island were removed by currents from an initial population. Further evidence of extensive transportation will be presented in the sections on Goodlettsville-Gallatin, Tennessee, and Manitoulin Island, Ontario. It is noteworthy that the unimodal distributions occur in near-shore areas at extremities of the geographic range of G. canadensis. The rapidly decreasing frequencies below about 35 mm in the unimodal distribution may indicate that all corallites removed from the initial population were not deposited

together. The smallest size fractions could have been transported elsewhere, perhaps even closer to shore. A possible example will be discussed in the section on Streetsville, Ontario.

It is concluded that the bimodal length-frequency distributions for G. canadensis in the Cincinnati Arch region were produced by current sorting. The similarity of these distributions geographically and stratigraphically indicates uniform conditions during periods of high energy. Predominant paleocurrent directions to the north and east suggest that corallites removed from the Cincinnati Arch region may have been deposited north of the present outcrop area and shoreward near the extremity of the Richmond Group to the east.

If the corallites removed by currents could be added to those left behind, it would be possible to reconstruct the length-frequency distribution of the initial G. canadensis population. A combination of the distributions in Text-fig. 7a and b suggests that the initial distribution may have been unimodal, following the solid curve in 7a. Such a distribution would resemble those for Streptelasma divaricans and Grewingkia pulchella, which were buried in growth position or following very little transportation (Text-figs. 14, 23).

Diameter. The rate of corallite expansion is compared using the diameter at a height of 45 to 55 mm (Text-fig. 8).

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Text-figure 8.--Grewingkia canadensis (Billings, 1862): corallite diameters (d, mm) at heights (h) between 45 and 55 mm, Richmond Group sections (see Text-figs. 3, 18; App. 4).

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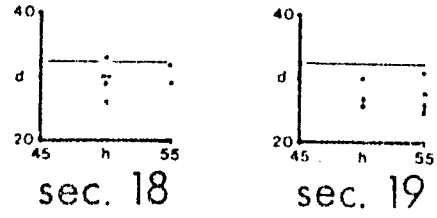
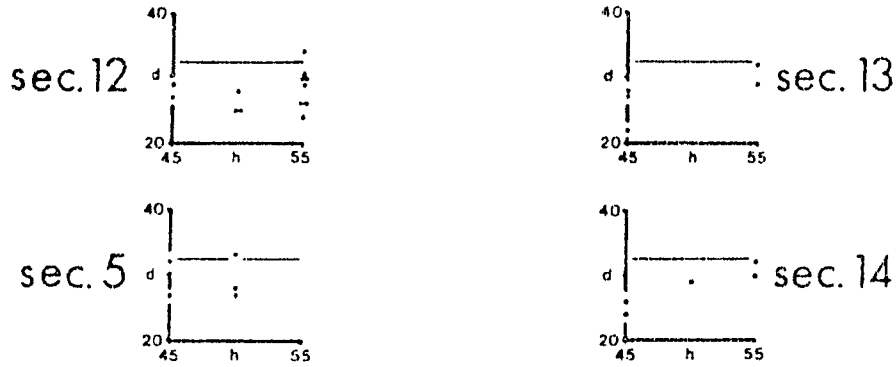
At sections 2, 3, and 4 in the southwestern Cincinnati Arch region, almost all corallites measured are between 33 and 40 mm in diameter. Elsewhere in the region, virtually all have a diameter between 22 and 32 mm. The significance of this distribution will be discussed in the Summary of the Cincinnati Arch region.

Text-figure 8.--Grewingkia canadensis (Billings, 1862): corallite diameters (d, mm) at heights (h) between 49 and 59 mm, Richmond Group sections (see Text-figs. 3, 18; App. 4).





Text-fig. 8

Epifauna. Epifaunal organisms on Grewingkia canadensis corallites comprise bryozoans, solitary corals of Streptelasma divaricans, and colonial corals (App. 5). Epifaunal bryozoans were noted on 285 of 529 corallites (54 percent) in the Richmond Group of the Cincinnati Arch region (Plate 6, fig. 4). This percentage is approximately the same at all sections. Of 36 corallites for which the side facing up on the bedding surface at the time of final deposition is known, 39 percent have epifaunal bryozoans on or mostly on the upper side, 36 percent on or mostly on the lower side, 11 percent on lateral sides, and 14 percent have bryozoans evenly distributed around the exterior. This uniform distribution on the upper exposed and lower buried sides suggests that bryozoans became associated with the host corallites before they were deposited and probably while they were alive in growth position. Burial after deposition was apparently rapid, not allowing time for epifauna to colonize the exposed corallite surface. Five hundred thirteen colonies or groups of colonies of epifaunal bryozoans on 279 corallites are oriented as follows: 37 percent on the counter side, 38 percent on an alar side, and 25 percent on the cardinal side. Bryozoans do not show a strong preference for a particular side of the host. This is also true of epifaunal bryozoans on solitary corallites of the Selkirk Member, Red River Formation (late Middle or Upper Ordovician), southern Manitoba (Elias, 1976, p. 26-28).

Epifaunal S. divaricans corallites are present on seven of 529 G. canadensis corallites. These occur at horizons 5b-1, 12a-1, and 13b-1 where G. canadensis and S. divaricans are more abundant than usual (Text-fig. 3). Four epifaunal corallites occur on the counter side of the host, two are on an alar side, and one is on the cardinal side. S. divaricans may have preferred the counter side. Epifaunal corallites occur at any height above the host's tip. Two were worn down to the base of attachment before burial, suggesting that they lived on the host before it was abraded during transportation. One coral that grew upright from the inner and outer rim of the host's calyx probably became epifaunal after death of the G. canadensis polyp but while the corallite was still in growth orientation. USNM 42517 shows S. divaricans corallites that became epifaunal on G. canadensis after deposition of the host on a bedding surface (Plate 2, fig. 16).

Only one of 529 G. canadensis corallites has an epifaunal colonial coral on its counter side. It was found at horizon 12a-2.

Endobiota. Organisms that bored into Grewingkia canadensis corallites comprise annelids, bryozoans, and algae. Spionid polychaete annelids probably bored for protection (Cameron, 1969b, p. 690, 698). The borings, assigned to Vermiforichnus cf. V. clarkei Cameron, 1969a, are straight to slightly curved with a circular cross-section (Plate 5, figs. 17, 32). Their diameter-frequency distribution in corallites of the Richmond Group, Cincinnati Arch region, is similar to that in brachiopods, bryozoans, and solitary corals of the "Waynesville" near section 14, as determined by Cameron (1969b) (Text-fig. 9a, b). These borings have an average

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Text-figure 9.--Vermiforichnus cf. V. clarkei Cameron, 1969a: diameter of borings (d, mm). a, Borings in 178 Grewingkia canadensis corallites and 2 Streptelasma divaricans corallites, Richmond Group, Cincinnati Arch region (see App. 6); b, borings in 45 Hebertella insculpta shells, 6 solitary corals, and 21 bryozoans, "Waynesville" strata, Richmond Group, near Waynesville, Ohio (from Cameron, 1969b, fig. 5c); c, borings in 2 Helicelasma, 1 Grewingkia, and 1 Lobocorallium corallite, White Head Fm., near Percé, Quebec (see App. 6); d, borings in 108 Grewingkia, Helicelasma, and Deiracorallium corallites, Selkirk Mbr., Red River Fm., southern Manitoba (from Elias, 1976, fig. 17).

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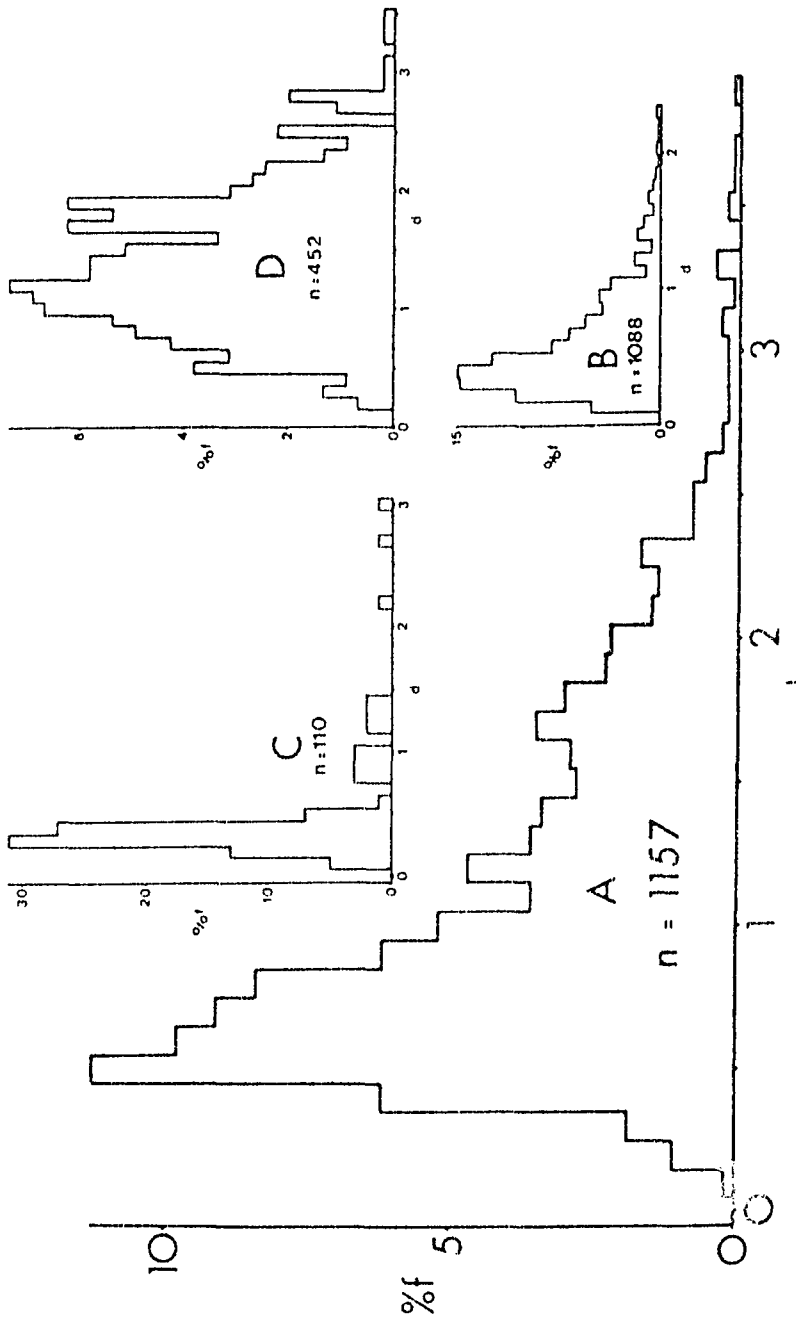
Text-figure 9.--Vermiforichnus cf. V. clarkei Cameron, 1969a: diameter of borings (d, mm). a, Borings in 178 Grewingkia canadensis corallites and 2 Streptelasma divaricans corallites, Richmond Group, Cincinnati Arch region (see App. 6); b, borings in 45 Hebertella insculpta shells, 6 solitary corals, and 21 bryozoans, "Waynesville" strata, Richmond Group near Waynesville, Ohio (from Cameron, 1969b, fig. 5c); c, borings in 2 Helicelasma, 1 Grewingkia, and 1 Lobocorallium corallite, White Head Fm. near Percé, Quebec (see App. 6); d, borings in 108 Grewingkia, Helicelasma, and Deiracorallium corallites, Selkirk Mbr., Red River Fm., southern Manitoba (from Elias, 1976, fig. 17).



Text-fig. 9

diameter larger than those of the White Head Formation (Ashgillian) near Percé, Quebec, but smaller than those of the Selkirk Member, Red River Formation (late Middle or Upper Ordovician), southern Manitoba (Elias, 1976, fig. 17) (Text-fig. 9c, d). Vermiforichnus borings were seen in 38 percent of 466 C. canadensis corallites from the Cincinnati Arch region. This percentage is approximately the same at all sections. The location of 1124 borings in 174 corallites is as follows: 48 percent in the counter side, 36 percent in an alar side, and 16 percent in the cardinal side (App. 6). If all borings were produced after deposition of the corallites, most would be expected in an alar side, which usually faced up. Predominance in the counter side must be due to preference of the boring organism when the corallite was in growth orientation, as in the Selkirk Member, Red River Formation, southern Manitoba (Elias, 1976, p. 23-25). In 26 corallites for which the side facing up on the bedding surface at the time of final deposition is known, 61 percent have borings in or mostly in the upper side, 31 percent have borings uniformly distributed around the corallite, and in 8 percent the borings are in or mostly in the lower side. This indicates that some boring occurred after deposition of the corallites. Richards and Shabica (1969) found that Vermiforichnus borings in brachiopods of the "Arnheim-Waynesville" in the vicinity of section 5 were produced subsequent to deposition of the shells.

Borings produced by ctenostomate bryozoans occur in only three corallites from the "Waynesville" at section 14 (Plate 6, fig. 4). In UCGM 45468 (horizon 14b-1) they are present in the cardinal side, and in UCGM 45469 (horizon 14b-1) and 45470 (horizon 14b-2) they bored into all sides.

Ordovician algal borings were discussed by Elias (1976, p. 134-136). Borings assigned to Dendroichnus Elias, 1976 form a fine dendritic network along the surface and penetrating very shallowly into the corallite wall. They are present in the cardinal-alar side of a single corallite from horizon 11b-1 (UCGM 45304).

Microscopic algal borings are very common in G. canadensis corallites. They are generally filled with black material and penetrate perpendicularly a short distance into the host (Plate 6, fig. 5). That they were produced by algae is beautifully demonstrated by the presence of modern algal borings in UCGM 45302 (Plate 6, fig. 6). The specimen was collected in a stream bed and the exposed surface of the corallite was covered with a green algal film. Thin sections reveal very fine borings filled with green material penetrating a short distance perpendicular to the corallite exterior. Unlike the Ordovician borings, they penetrate micrite and secondary calcite crystals filling Vermiforichnus borings. They are similar in morphology but are finer than the Ordovician borings. Almost all Ordovician algal borings are in the

outer corallite wall, but in two specimens they penetrate septa from the interseptal chambers and in one of these they also enter the corallite from a Vermiforichnus boring. These borings were probably produced after death and decay of the polyp. The position of microscopic algal borings in 38 corallites is as follows: 55 percent have borings in all sides, 13 percent in the counter side, 3 percent in a counter-alar side, 10.5 percent in an alar side, 8 percent in a cardinal-alar side, and 10.5 percent in the cardinal side (App. 7). The algae show no preference for a particular location in the corallites, and are generally present in all ontogenetic stages of the host. This, together with their common occurrence beneath epifaunal bryozoans, suggests that boring occurred very soon after secretion of the corallite wall while the coral was in growth position. Microscopic algal borings are present in 53 of 57 corallites from sections 1 to 5 and 10 to 14 for which thin sections were examined. The only sections at which all corallites do not have borings are 5, 12, and 13 in the northern part of the Cincinnati Arch region. Algal borings are best developed (ie. maximum diameter and length) at section 4 in the southwest, and are most weakly developed (ie. finer and very short) at sections 12, 13, and 14 in the north. Modern boring algae flourish in intertidal environments and may be abundant to a depth of about 20 to 25 m (Bromley, 1970, p. 54). Their development and distribution in the Cincinnati Arch region may reflect an increase in water depth northward.

Algal borings of the same type as those in solitary corals were described in brachiopod shells from the Richmond Group in Ohio (Kobluk and Risk, 1977[1]). The borings are empty, or partially to entirely filled with pyrite.

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[1]Kobluk, D. R., and Risk, M. J.

1977. Algal borings and framboidal pyrite in Upper Ordovician brachiopods. Lethaia, vol. 10, pp. 135-143, 6 figs.

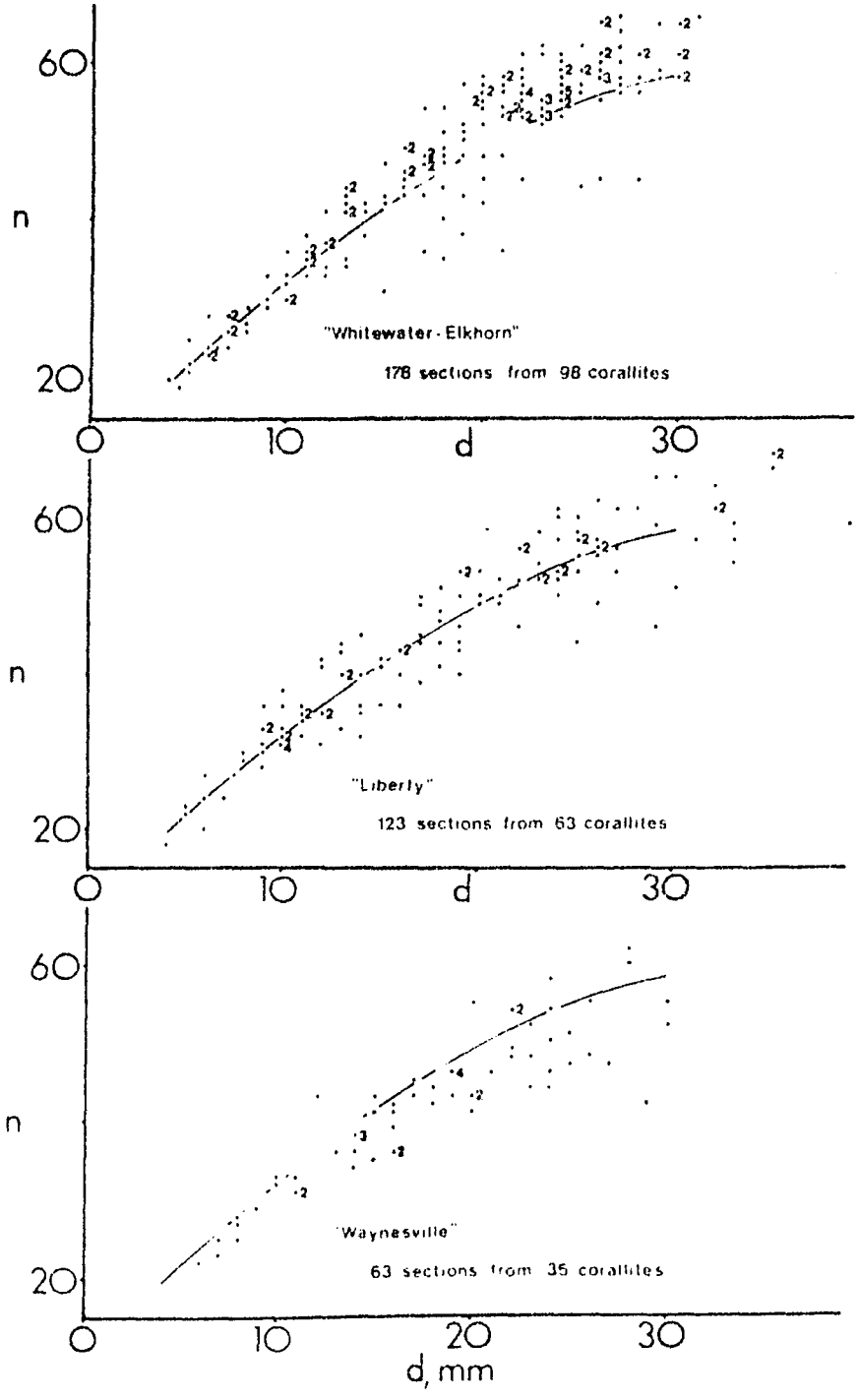
Intraspecific Variation: Number of Septa. A general increase in the number of major septa at a particular corallite diameter within Grewingkia canadensis of the Richmond Group in the Cincinnati Arch region is indicated by comparing values for known "Waynesville", "Liberty", and "Whitewater-Elkhorn" strata (Text-fig. 10). At section 1, however, there is no

Text-figure 10.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for three horizons in the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App. 8; Table 4). Curves are average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).

change throughout the Richmondian, and distributions at all horizons resemble those for "Liberty" strata elsewhere (Text-fig. 11). This is the only area in the Cincinnati Arch

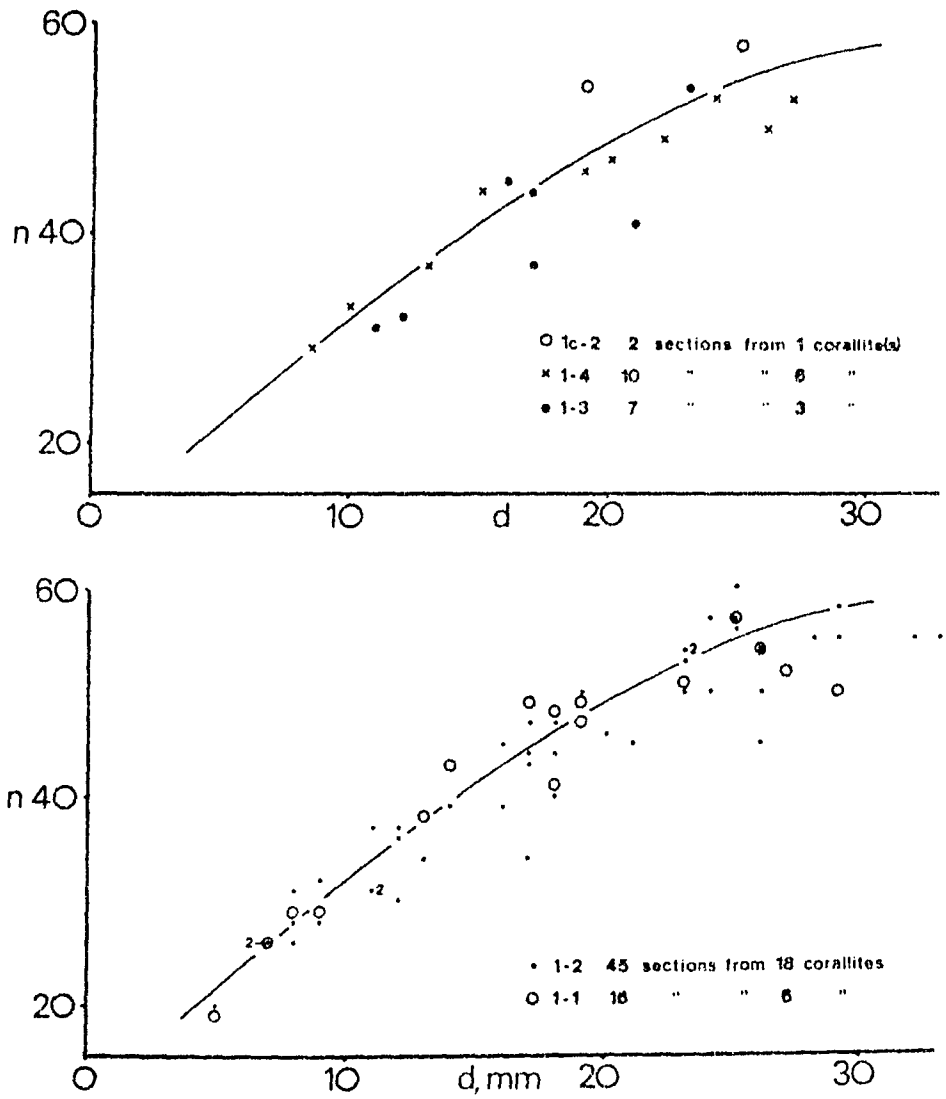
Text-figure 11.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for five collecting horizons at section 1, Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App. 8; Table 4). Curves are average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).

Text-figure 10.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for three horizons in the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App. 8; Table 4). Curves are average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).



Text-fig. 10

Text-figure 11.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for five collecting horizons at section 1, Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App. 8; Table 4). Curves are average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).



Text-fig. 11

region where there are no major lithologic changes within the Richmond Group, except for an upward increase in shale probably related to progradation of the Queenston delta (Text-fig. 3). The increase in the number of septa that occurred elsewhere must have been the result of environmental change. Perhaps it was related to a decrease in water depth, as suggested by "Waynesville", "Liberty", and "Whitewater-Elkhorn" lithologies (see Depositional Environments).

Axial Region. The degree of variation of the axial region in later ontogenetic stages within Grewingkia canadensis spans the genera Grewingkia, Helicelasma, and Borelasma (see Systematic Paleontology and Text-fig. 26a). Grewingkia is characterized by a complex axial structure. Helicelasma normally has a very simple axial structure, or the major septa may extend to the axis without forming a structure. The major septa do not reach the axis in Borelasma. In order to compare the axial region of corallites, a comparative scale was prepared using 21 corallites assigned values of 0, 5...100 on the basis of decreasing axial region complexity (Plate 4, figs. 33-53). Other corallites were assigned values using this scale. The axial region comparative scale value-frequency distribution for G. canadensis of the Richmond Group in the Cincinnati Arch region has a peak at 35, indicating that most corallites have moderately complex axial structures characteristic of Grewingkia (Text-fig. 12). Although

Text-figure 12.--Grewingkia canadensis (Billings, 1862): axial region comparative scale values for the Richmond Group and three horizons within it, Cincinnati Arch region (see Plate 4, figs. 33-53; App. 9).

relatively few values are available for the "Waynesville", the distribution has a peak at 35 with fairly low frequency below 25 and very low frequency above 45. The distribution for "Liberty" corallites has a pronounced peak at 35, and frequency below 25 and above 45 is low. For the "Whitewater-Elkhorn", the strongest peak is at 65. There was apparently a trend in G. canadensis toward predominantly simpler axial regions, although the total range in variability of the axial region remained approximately constant during the Richmondian. This trend, like the increase in the number of septa, may have been related to decreasing water depth. Too few data are available to determine if this trend also occurred in the vicinity of section 1.

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Text-figure 12.--Clewingkia canadensis (Billings, 1862): axial region comparative scale values for the Richmond Group and three horizons within it, Cincinnati Arch region (see Plate 4, figs. 33-53; App. 9).

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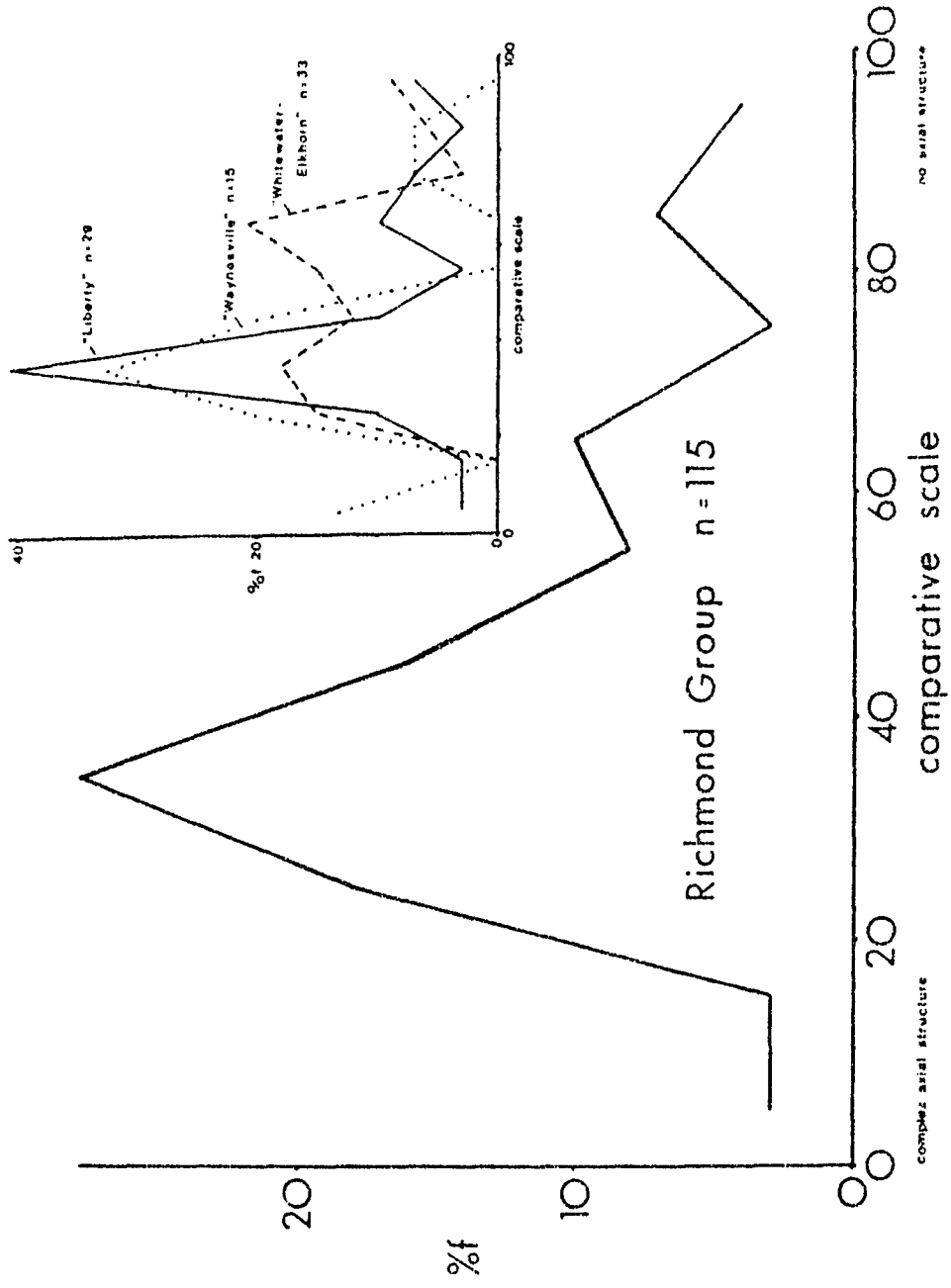

Text-fig. 12

B. Streptelasma divaricans (Nicholson, 1875)

Stratigraphic Distribution. The distribution of Streptelasma divaricans generally parallels that of Grewingkia canadensis, but this species is not as abundant (Text-fig. 3).

Orientation of Corallites. Whereas G. canadensis corallites formed a transported constituent within and on carbonate beds, S. divaricans was epifaunal on stabilized carbonate substrates during periods of non-deposition. Septal grooves and interseptal ridges are commonly preserved, indicating little abrasion (Plate 1, figs. 20, 27, 30, 33; Plate 2, figs. 1, 17s). Energy conditions remained low, and subsequent generally argillaceous sediments buried many corallites in an upright position, apparently in growth orientation (Plate 2, fig. 7). Some were deposited on their sides and a few at sections 12 and 13 are oriented with the calyx facing down, indicating transportation before final burial.

The attachment sites centered on the cardinal side of 59 corallites are as follows: 68 percent encrusting and branching bryozoans, 17 percent brachiopods (Plate 2, figs. 12, 13s, 14s), 8 percent Grewingkia canadensis corallites (Plate 2, fig. 16), 5 percent colonial corals (Plate 2, fig. 15), and 2 percent pelecypods (App. 10). Larvae frequently attached to living bryozoans, as demonstrated by

upward growth of bryozoans to surround corallites (Plate 2, fig. 9s). The corallite wall is sometimes absent at the site of attachment and septa are connected directly to the bryozoan (Plate 2, fig. 11). The septa of S. divaricans are generally undilated, but in UCGM 45018 and 45128 the septa are moderately dilated where the corallites are surrounded by bryozoans (Plate 1, figs. 42-45). Dilation may be a response to stress. The location of S. divaricans on brachiopods is shown in Table 1. Richards (1972, p. 401,

Table 1.--Streptelasma divaricans (Nicholson, 1875): attachment sites on brachiopods, Cincinnati Arch region (data from Richards, 1972, unless specimen number is given).

fig. 10) stated that "many of the corals are located [on Rhynchotrema dentatum and Lepidocyclus capax] so that the polyp would have been bathed by the exhalent current. Perhaps the coral fed on food of a size or type systematically rejected by the brachiopod". At horizon 4-2, S. divaricans corallites are situated at the uppermost points on colonial corals, some of which had been overturned before colonization. The species apparently favored elevated positions on stabilized substrates in low energy conditions. S. divaricans was not found in the Bull Fork Formation at section 1, although G. canadensis is common (Text-fig. 3). This is the only area in the Cincinnati Arch region where

Table 1.--*Streptelasma divaricans* (Nicholson, 1875): attachment sites on brachiopods, Cincinnati Arch region (data from Richards, 1972, unless specimen number is given).

TABLE 1

Rhynchotrema dentatum

9 on fold

5 off fold

Lepidocyclus capax

2 on brachial valve, anterior (UCGM 45066, USNM 40086)

8 on fold

Leptaena richmondensis

2 on geniculate part of pedicle valve

Rafinesquina alternata

1 on pedicle valve, anterior (USNM 135767)

Holtedahlina sulcata

1 on anterior

prominent lithologic changes are not present in the Richmond Group. Perhaps deposition was more continuous and uniform, not allowing S. divaricans an opportunity to colonize stabilized substrates.

S. divaricans corallites generally occur individually, but 26 percent form clusters of two or more (Text-fig. 13; Plate 1, fig. 27; Plate 2, figs. 1, 8s). The maximum

Text-figure 13.--Streptelasma divaricans (Nicholson, 1875): solitary corallites and number of corallites comprising pseudocolonies and colonies, Richmond Group, Cincinnati Arch region (see App. 10).

number of corallites seen in a single group is 13. Most clusters apparently represent pseudocolonies, with true coloniality being rare (see Systematic Paleontology). This gregarious habit is probably due to multiple selection of favorable attachment sites.

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Text-figure 13.--Streptelasma divaricans (Nicholson, 1875): solitary corallites and number of corallites comprising pseudocolonies and colonies, Richmond Group, Cincinnati Arch region (see App. 10).

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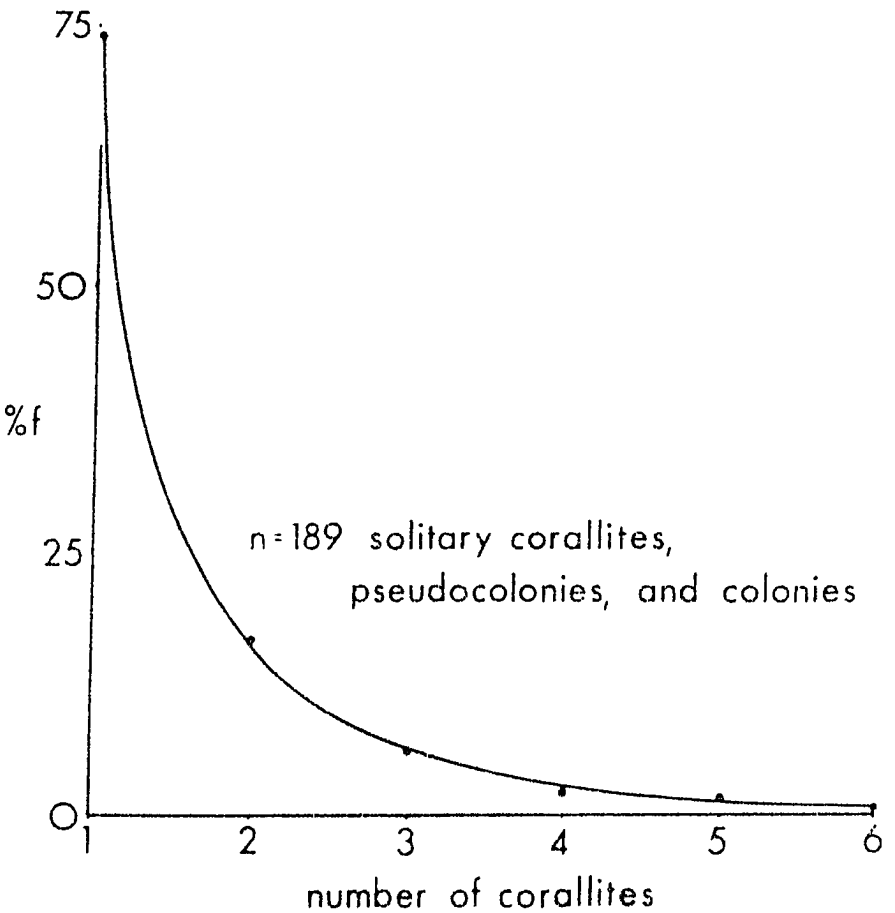


Text-fig. 13

Corallite Size. The length-frequency distribution for Streptelasma divaricans of the Richmond Group, Cincinnati Arch region, is shown in Text-fig. 14. Collecting bias is

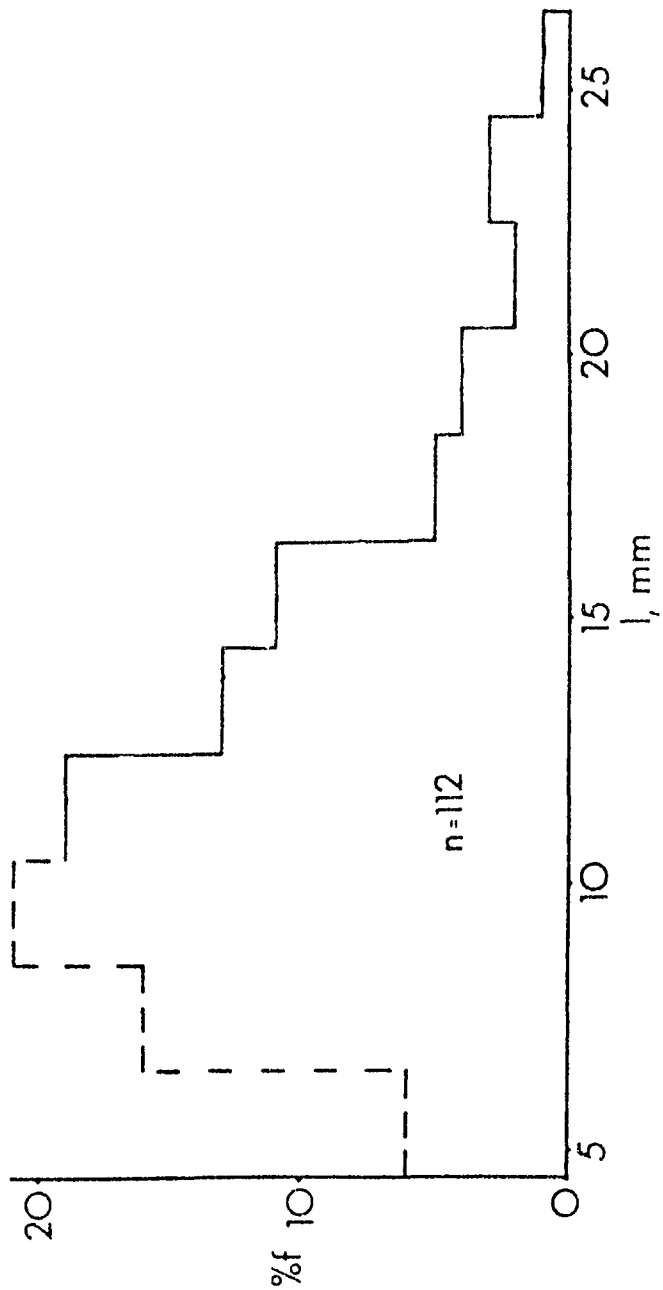
Text-figure 14.--Streptelasma divaricans (Nicholson, 1875): length of corallites (l), Richmond Group, Cincinnati Arch region (see App. 3). Collecting bias is thought to contribute, at least in part, to low frequencies below 10 mm.

thought to contribute, at least in part, to progressively lower frequencies below 10 mm. The effects of biologic factors such as birth rate, growth rate, and death rate are unknown. The distribution above 10 mm probably reflects the population because many corallites were preserved in growth position and few show signs of extensive transportation.

The longest corallites of S. divaricans occur at section 4 on the southwestern side of the Cincinnati Arch region. The significance of this is discussed in the Summary of the Cincinnati Arch region.

Epifauna. Epifaunal organisms are very rare on Streptelasma divaricans, probably because of small corallite size. Bryozoans occur on several larger corallites at horizons 4-3, 4-5, and 12a-9 (App. 5).

Text-figure 14.--*Streptelasma divaricans* (Nicholson, 1875): length of corallites (*l*), Richmond Group, Cincinnati Arch region (*see* App. 3). Collecting bias is thought to contribute, at least in part, to low frequencies below 10 mm.



Text-fig. 14

Endobiota. Vermiforichnus borings were seen in only two Streptelasma divaricans corallites at horizon 4-5 (App. 6). Microscopic algal borings are present in 32 of 45 corallites from the Cincinnati Arch region for which thin sections were examined (App. 7). Corallites without such borings are not restricted to the northern part of the region, as they are for Grewingkia canadensis. Algal borings are most weakly developed at sections 12, 13, and 14 in the northern Cincinnati Arch region, possibly reflecting greater water depth. The low frequency of endobiota in S. divaricans may be related to small corallite size and the fact that living bryozoans frequently surrounded the corallite soon after secretion, thereby protecting it.

Intraspecific Variation. The number of major septa at a particular corallite diameter is highly variable within Streptelasma divaricans of the Richmond Group, Cincinnati Arch region. Unlike Grewingkia canadensis, there is no apparent difference in values for corallites in "Liberty" and "Whitewater-Elkhorn" strata (Text-fig. 15).

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Text-figure 15.--Streptelasma divaricans (Nicholson, 1875): relation between number of major septa (n) and corallite diameter (d) for two horizons in the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App 8; Table 4). Curves are average for Richmond Group, Cincinnati Arch region (see Text-fig. 28).

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The degree of variation of the axial region in later ontogenetic stages within S. divaricans spans the genera Streptelasma and Grewingkia (see Systematic Paleontology and Text-fig. 26a). In Streptelasma, the major septa are withdrawn from the axis or extend to the axis without forming an axial structure. Grewingkia is characterized by a complex axial structure. In order to compare the axial region of corallites, a comparative scale similar to that for G. canadensis was prepared, using 19 corallites assigned values of 5, 10...95 on the basis of decreasing axial region complexity (Plate 1, figs. 1-19). Other corallites were

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Text-figure 15.--Streptelasma divaricans (Nicholson, 1875): relation between number of major septa (n) and corallite diameter (d) for two horizons in the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App. 8; Table 4). Curves are average for Richmond Group, Cincinnati Arch region (see Text-fig. 28).

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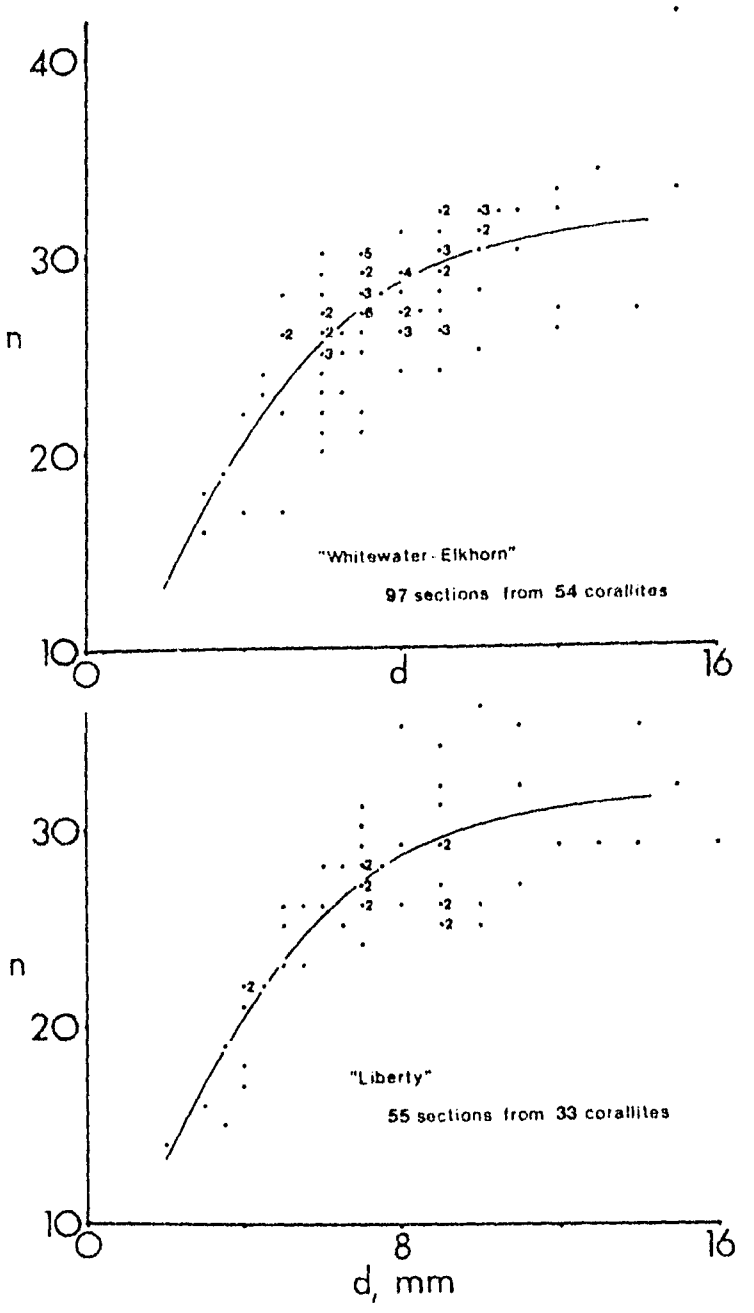


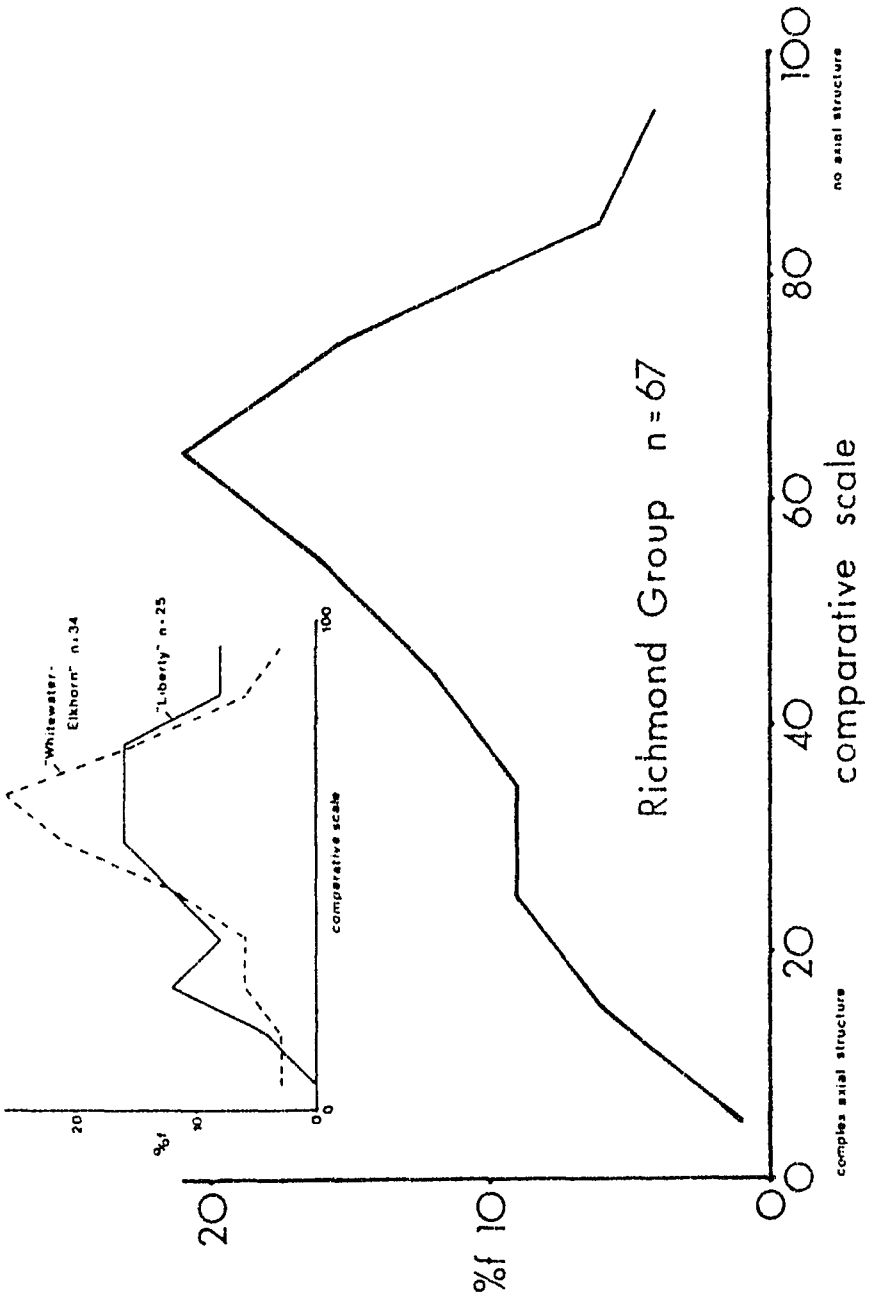
Text-fig. 15

assigned values using this scale. The axial region comparative scale value-frequency distribution for S. divaricans of the Richmond Group in the Cincinnati Arch region has a peak at 65, indicating that in most corallites the major septa extend to the axis without forming an axial structure, as is typical of Streptelasma (Text-fig. 16).

Text-figure 16.--Streptelasma divaricans (Nicholson, 1875): axial region comparative scale values for the Richmond Group and two horizons within it, Cincinnati Arch region (see Plate 1, figs. 1-19; App. 9).

The distribution for corallites of the "Liberty" has a broad peak centered about the value 65. For the overlying "Whitewater-Elkhorn", a sharp peak is present at 65 and frequencies at values below 40 are lower than in the "Liberty" distribution. As in G. canadensis, there was apparently a trend toward predominantly simpler axial regions, although the total range in variability of the axial region remained approximately constant through the Richmondian. The axial regions of corallites within pseudocolonies and colonies are the same or similar (App. 9). In the case of pseudocolonies, this could reflect the similar environment shared by the corallites. Similarity within colonies could be environmentally or genetically controlled. If the trend toward predominantly simpler

Text-figure 16.--Streptelasma divaricans (Nicholson, 1875): axial region comparative scale values for the Richmond Group and two horizons within it, Cincinnati Arch region (see Plate 1, figs. 1-19; App. 9).



Text-fig. 16

axial regions is environmentally controlled, it may be related to decreasing water depth.

Summary

In general, the Richmond Group of the Cincinnati Arch region represents a regressive sequence, possibly following a transgression near its base. Water depth became progressively greater northward, with depositional strike oriented east-west. The argillaceous, silty, and dolomitic sedimentary rocks of the south grade northward into interbedded shales and limestones. On the eastern side of the region nearest the Queenston delta, marine environments were more restricted and terrigenous input was greater than on the western side, which faced the main body of the epicontinental sea. In these less restricted environments, extensive development of colonial coral banks produced a temporary restricted lagoon in later Richmondian time. On the southwestern side of the Cincinnati Arch region, colonial coral zones are most prominent (Browne, 1964, p. 389), Grewingkia canadensis corallites are broadest, Streptelasma divaricans corallites are longest, and endofaunal algae are best developed. This area, on the shallow, open shelf edge of the Richmond Group carbonate belt, must have been an area of high productivity that was especially favorable for corals. The Cincinnati Arch was probably a subtle, broad platform sloping slightly to the north and influencing carbonate sedimentation and organic buildups during the Richmondian Stage.

Grewingkia canadensis (Billings, 1862) and Streptelasma divaricans (Nicholson, 1875) are the only solitary rugose

corals known from the Cincinnatian Series of the Cincinnati Arch region. They first appeared at the base of the "Waynesville" in the Richmond Group, suggesting introduction during a lower Richmondian transgression. Both species have a similar stratigraphic distribution, and favored "normal" marine waters of "intermediate" depth where calcium carbonate sediments accumulated and brachiopods and bryozoans thrived. G. canadensis probably lived in stable, low energy environments, but the corallites were transported in higher energy conditions before final deposition and rapid burial. Many corallites less than about 60 mm and especially about 35 mm long were removed from the region. Whereas G. canadensis corallites formed a clastic constituent within and on carbonate beds, S. divaricans was epifaunal on stabilized carbonate substrates during periods of non-deposition. The corals commonly attached to elevated areas especially on bryozoans. Energy conditions remained low, and subsequent generally argillaceous sediments often buried the corallites in growth position. In both G. canadensis and S. divaricans there was a trend toward predominantly simpler axial regions, although the total range in variability remained approximately constant. The average number of septa in G. canadensis generally increased during Richmondian time, but remained constant in the vicinity of section 1 where environmental conditions were apparently relatively uniform. These trends may be related to decreasing water depth. During the final

stages of regression of the epicontinental sea at the end of the Richmondian Stage, *C. canadensis* and *S. divaricans* became extinct.

2. BURKESVILLE, KENTUCKY

In the vicinity of Burkesville (Text-fig. 2, no. 2), the Richmond Group is represented by the 6 to 40 m thick Cumberland Formation, which is predominantly unfossiliferous, fine grained dolomite (Text-fig. 3). The dolomite is generally massive, but burrows and very fine laminae (? stromatolites) are also present. The formation was probably deposited in restricted, very shallow marine environments. Near the base, a thin zone of limestone with shale interbeds occurs locally. This was termed Burkesville limestone by Jillson (1951). Calcareous mudstone with birdseye structures is present, as well as wackestone containing a few brachiopods, branching bryozoans, and gastropods. This probably represents a brief "normal" marine incursion. Jillson (1951, p. 13, 14) listed a diverse fauna that pointed "rather conclusively to the Waynesville age of the Burkesville limestone". Near the top of the Cumberland Formation, local limestone lenses and shale interbeds are also present. At horizon 15b, one meter of limestone is overlain by 0.2 m of shale. The limestone includes wackestone with some branching bryozoans, brachiopods, and gastropods, and probably represents a short, "normal" marine interval. Also present is limestone pebble conglomerate and fine laminae suggesting very shallow marine to possibly subaerial conditions. Jillson (1953) described the Haggard limestone from this approximate interval at horizon 15d. He listed a solitary coral, the colonial

corals Favistina, Calapoecia, and Tetradium, as well as brachiopods, bryozoans, and a few other fossils that distinguish this limestone "indisputably as a correlative of the Liberty division of the Richmond" (Jillson, 1953, p. 9). All exposed bedrock seen at this horizon is unfossiliferous dolomite. Loose blocks of fossiliferous wackestone, packstone, and grainstone with brachiopods, bryozoans, and typical Richmond Group colonial corals were found. Solitary rugose corals were not seen, and the true identity of the specimens Jillson referred to as Streptelasma rusticum remains unknown. The presence of "Liberty" strata about 10 m below the top of the Cumberland Formation suggests that little was removed by post-Richmondian - pre-Devonian erosion.

Foerste (1912a, p. 447) reported solitary corals, colonial corals, and stromatoporoids east of Burkesville in Wayne County, Kentucky. He stated that this horizon probably correlates with the basal "Liberty".

3. GOODLETTSVILLE-GALLATIN, TENNESSEE

The Nashville Dome is known to have been periodically positive since the early Middle Ordovician (C.W. Wilson, 1935). It was uplifted above sea level during the late Maysvillian, and remained so except locally until the Mississippian. Richmondian sediments of the Arnheim and overlying Fernvale formations were deposited on the west and north sides of the dome (Bassler, 1932, p. 120-130; C. W. Wilson, 1949, p. 201-207, 212-215). Clastic and carbonate sediments forming the Sequatchie Formation to the east (C.W. Wilson, 1949, p. 209-211) intertongue with various horizons in the Arnheim-Fernvale on the north side of the Nashville Dome. The Richmond Group is overlain by the Middle Llandoverian (Lower Silurian) Brassfield Formation, which has abundant solitary corals at its base north of Gallatin (locality 16c).

In the Goodlettsville-Gallatin area north of Nashville (Text-fig. 2, no. 3), the Richmond Group varies from about 6 to 35 m in thickness (Text-fig. 3). The Arnheim Formation consists of rubbly bedded argillaceous limestone with gray shale interbeds. The fauna was discussed by Foerste (1912a, p. 446, 447), and listed by Bassler (1932, p. 124) and C.W. Wilson (1949, p. 207). Brachiopods are most abundant, and solitary corals are common. The Fernvale Formation consists of thicker and more evenly bedded crinoidal packstones, grainstones, and lesser finely laminated wackestone-mudstone,

with shale interbeds. Brachiopods and bryozoans are common, but solitary corals are rare. Fossils from the shale equivalent of the Fernvale were listed by C.W. Wilson (1949, p. 215). A western tongue of the Sequatchie Formation occurs at the top of the Richmond Group in the Goodlettsville-Gallatin area. It consists primarily of massive, unfossiliferous, argillaceous sandstone with occasional burrows and fine laminae. A few thin beds of wackestone and mudstone with birdseye structures and fine laminae are present locally. Several very thin lenses of fossils including common solitary corals and brachiopods occur in the sandstone.

The Richmondian sequence on the northern margin of the Nashville Dome appears to be regressive. The Arnheim was deposited in fairly low energy conditions, as indicated by the lithology (Howe, 1969, p. 1334). The Fernvale sediments suggest a higher energy shoal (Howe, 1969, p. 1333). The lithology and sedimentary structures of the Sequatchie tongue indicate very shallow marine to possibly occasionally subaerial environments.

Bassler (1932, p. 122, 124) noted that brachiopods of the Arnheim Formation of Tennessee are characteristic of the "Arnheim" in Ohio, but some of the brachiopods and other fossils are also typical of the "Waynesville". Howe (1969, p. 1335, 1336) stated that the fauna of the Arnheim Formation indicates a Richmondian age, but does not warrant precise correlation with the type Richmond of the Cincinnati Arch

region. On the basis of stratigraphic position, the Arnheim Formation of Tennessee may be equivalent to the "Arnheim-Waynesville". If the lower Arnheim Formation proves to be "Arnheim" in age, it contains the oldest solitary corals in the Richmond Group. The stratigraphic position and predominance of limestone in the Fernvale Formation near Goodlettsville suggest correlation with the "Liberty". The upper tongue of the Sequatchie Formation may correspond to the "Whitewater-Elkhorn". Howe (1969, p. 1335) found that diagnostic Richmond Group brachiopods occur in the Arnheim and basal Fernvale formations, whereas Maquoketa Group brachiopods are restricted to higher horizons.

Grewingkia canadensis (Billings, 1862) is the only solitary coral known from the Richmond Group in the Nashville Dome area. The corallites were abraded (Plate 6, fig. 7) and deposited on their sides before burial (App. 1). Epifaunal bryozoans are very rare, and were seen on only two of more than three dozen corallites (App. 5). Vermiforichnus borings are rare (App. 6). Microscopic algal borings were seen in only one of nine corallites for which thin sections were examined, but the stereozone is poorly preserved in specimens from this area (App. 7).

The length-frequency distribution for corallites in the Arnheim Formation suggests that most if not all were transported from elsewhere, as previously discussed under G. canadensis of the Cincinnati Arch region (Text-fig.

7). The source remains unknown because paleocurrent data are not available for this area. Distribution of the number of major septa at a particular diameter suggests that the corals lived in an environment similar to that during "Waynesville" time in the Cincinnati Arch region (Text-figs. 17, 10). Values for corallites in the Fernvale Formation are

Text-figure 17.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for four horizons in the Richmond Group, Goodlettsville-Gallatin area, Tennessee. Numbers indicate frequency of a point if greater than one (see Text-fig. 3; App. 8). Curve is average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).

similar to those in the "Liberty" of the Cincinnati Arch region.

Corallites in a thin, fossiliferous lens in the Sequatchie Formation (horizon 16b-2) are unusually long and broad (UCGM 45517, 45518, 45521). They exceed 60 mm in length, which is thought to be the maximum size of corallites that were removed by currents from an initial population (Text-fig. 7). These corals may have lived in the Goodlettsville area. Values for the number of major septa at a particular diameter are typical of the "Whitewater-Elkhorn" in the Cincinnati Arch region (Text-figs. 17, 10). Corallites in

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Text-figure 17.--*Crewingkia canadensis* (Billings, 1862): relation between number of major septa (*n*) and corallite diameter (*d*) for four horizons in the Richmond Group, Goodlettsville-Gallatin area, Tennessee. Numbers indicate frequency of a point if greater than one (*see* Text-fig. 3; App. 8). Curve is average for Richmond Group, Cincinnati Arch region (*see* Text-fig. 36).

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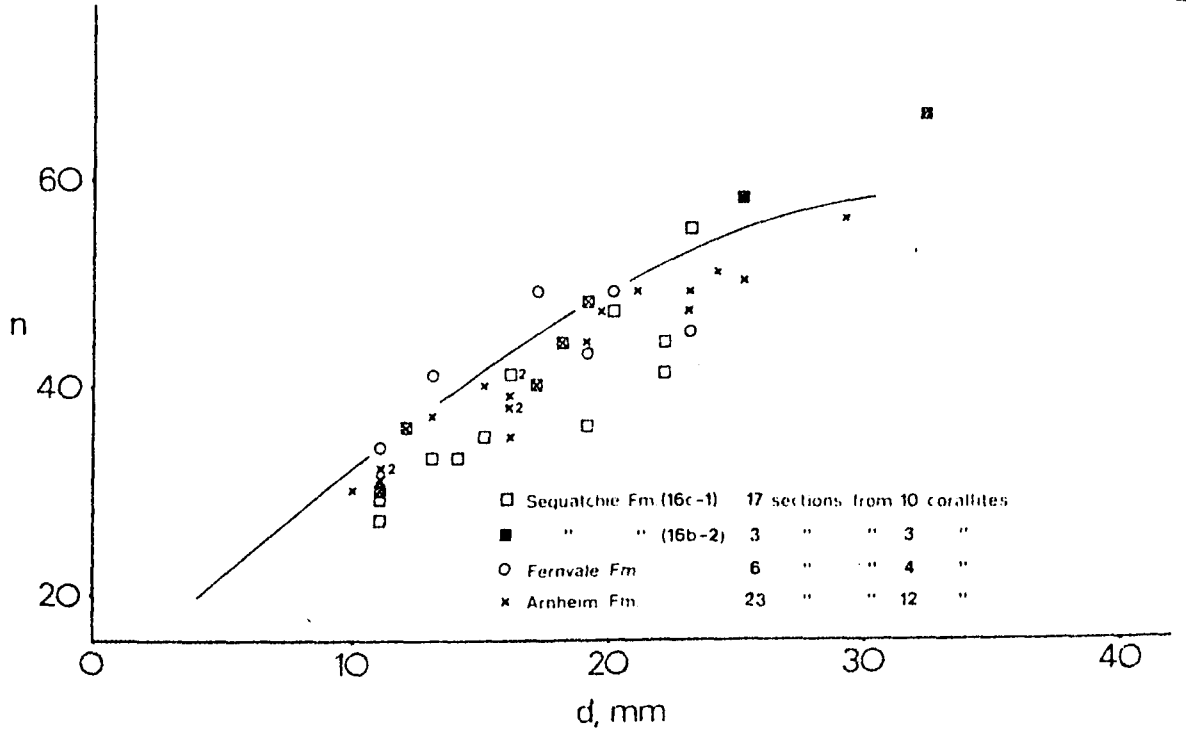


Text-fig. 17

another similar lens within the Sequatchie Formation (horizon 16c-1) have a length-frequency distribution suggesting they were transported from elsewhere, as previously discussed (Text-fig. 7). Two of the 16 corallites collected at this horizon have the stereozone completely removed, indicating extensive abrasion. Values for the number of major septa at a particular diameter are typical of the Arnheim Formation of Tennessee and "Waynesville" of the Cincinnati Arch region (Text-figs. 17, 10). These corallites may have been reworked and deposited in the clastic Sequatchie tongue. They are narrow, having a diameter-height ratio similar to those of the Arnheim Formation, and the northwestern and eastern Cincinnati Arch region (Text-fig. 8). One specimen (UCGM 45533) comprises three small corallites, but it is not known if these represent a pseudocolony or colony.

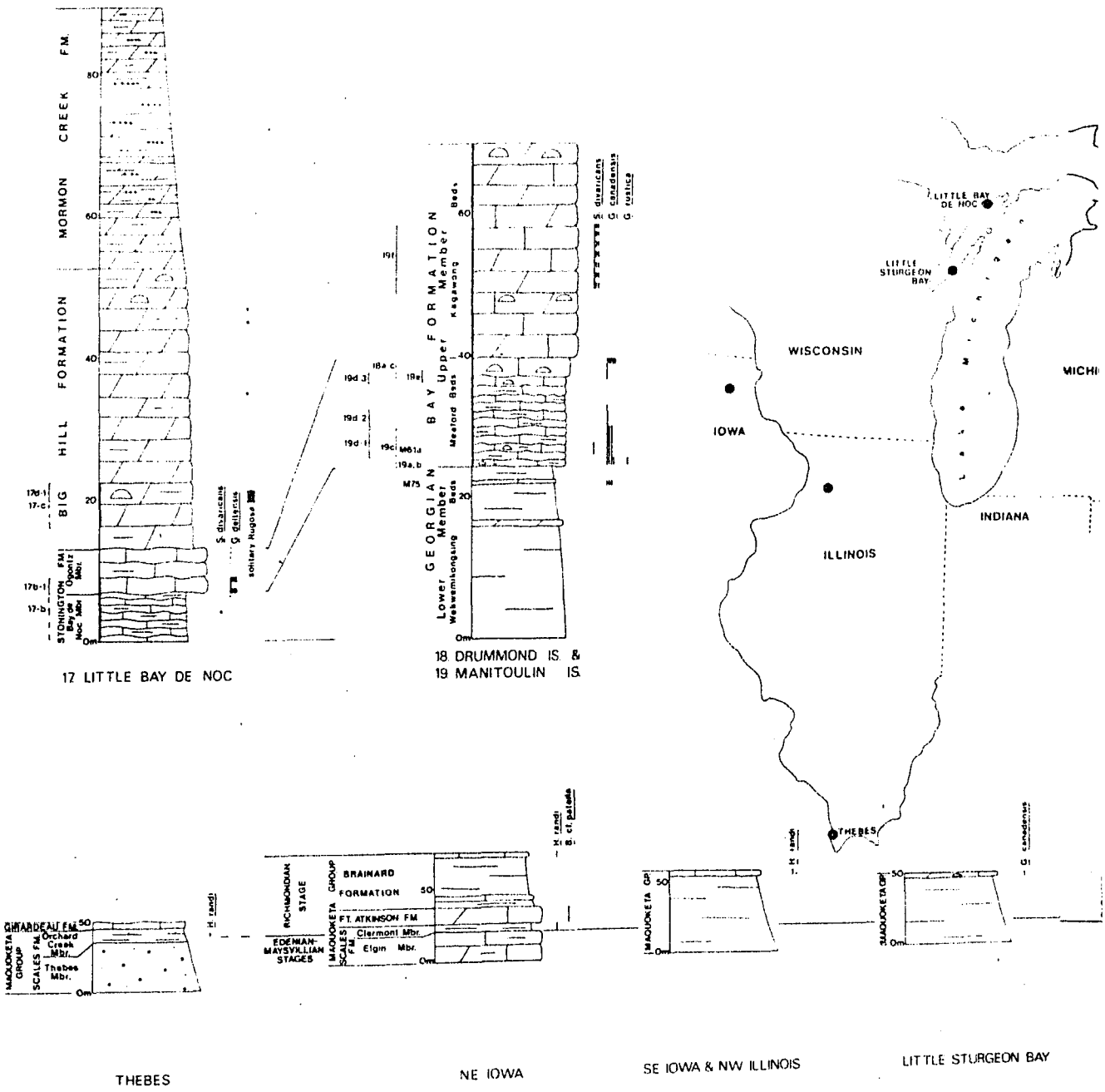
4. LITTLE STURGEON BAY, WISCONSIN

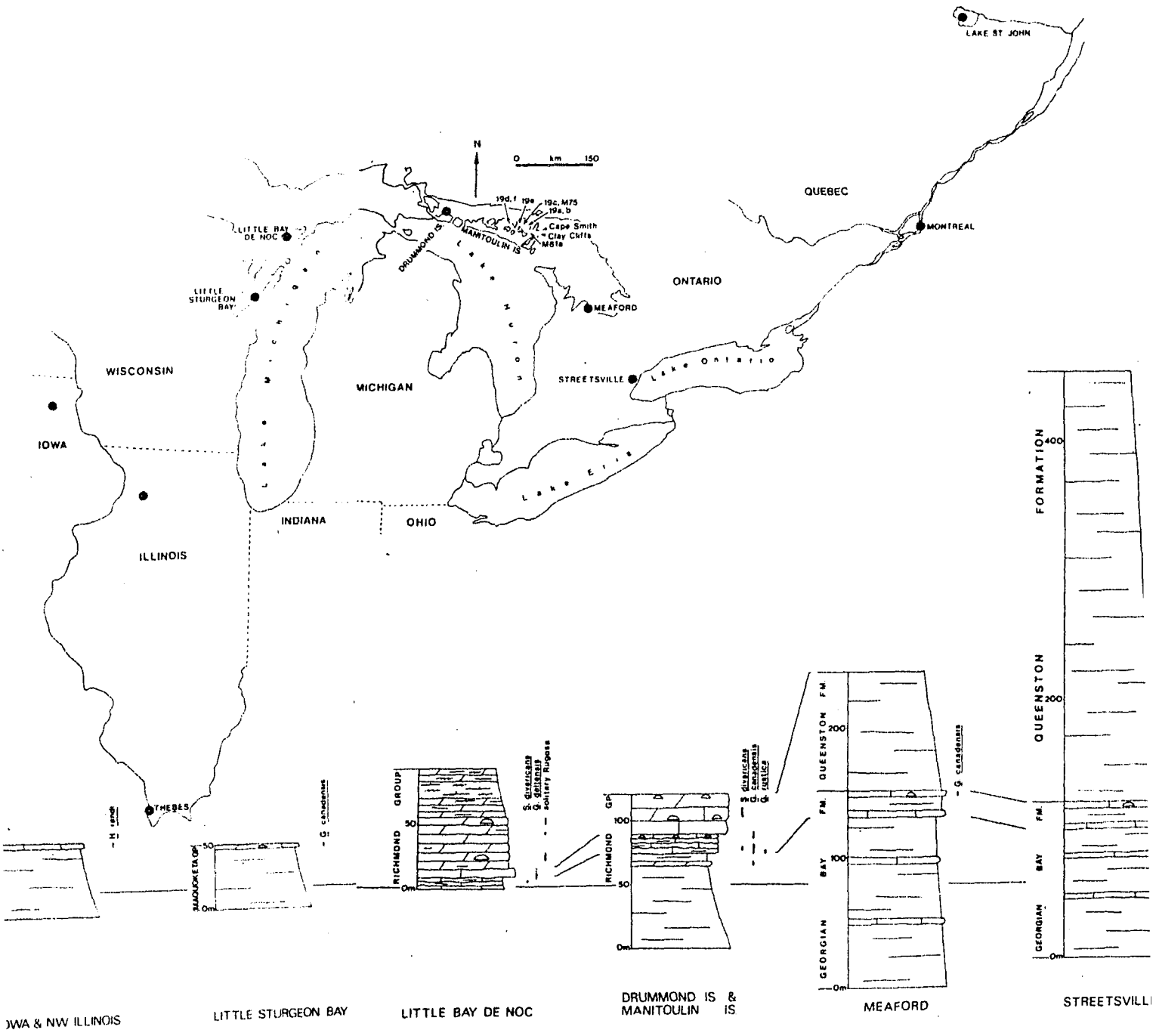
Silicified, poorly preserved corallites of Grewingkia canadensis (Billings, 1862) (USGS 347W) and typical Richmond Group colonial corals (USGS 433K) are present in dolomite at the top of the Maquoketa Group at Little Sturgeon Bay (Text-figs. 2, no. 4; 18). Chamberlin, et al

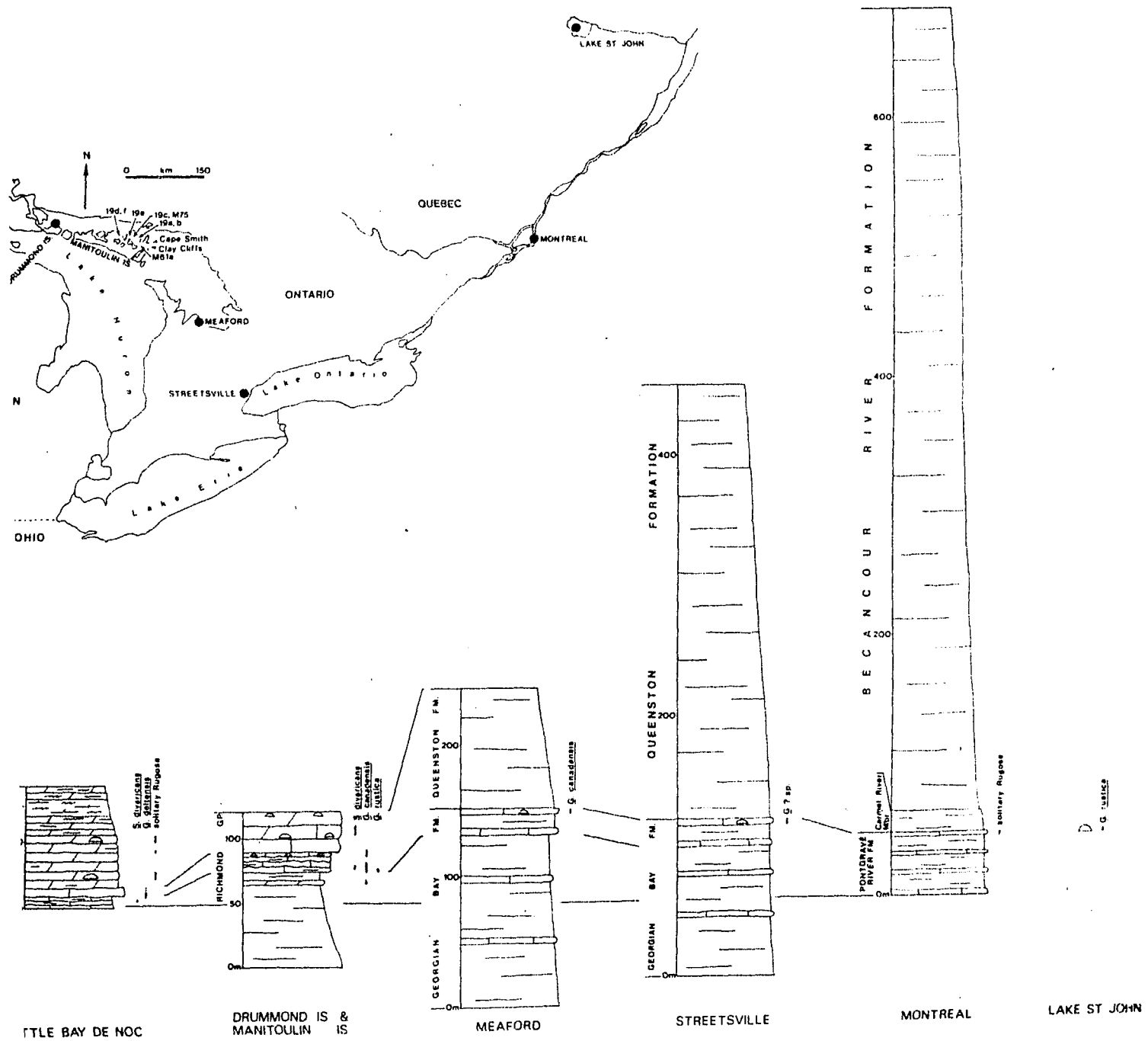
Text-figure 18.--Western and northern outcrops: Richmondian stratigraphic sections to scale and distribution of solitary rugose corals (Streptelasma, Helicelasma, Grewingkia, and Bighornia) (see Localities). For legend of symbols see Text-fig. 3.

(1883, p. 171) reported that carbonate beds in this area grade into shales toward the south and west. This zone appears to represent an incursion of the Richmond Group associated with final regression of the epicontinental sea at the end of the Richmondian Stage.

Text-figure 18.--Western and northern outcrops: Richmondian stratigraphic sections to scale and distribution of solitary rugose corals (Streptelasma, Helicelasma, Grewingkia, and Bighornia) (see Localities). For legend of symbols see Text-fig. 3.







Text-fig. 18

5. LITTLE BAY DE NOC, MICHIGAN

In northern Michigan, the Richmond Group is exposed in the peninsula between Little and Big Bay de Noc (Text-figs. 2, no. 5; 18). The basal beds of the 12 m thick Bay de Noc Member of the Stonington Formation are considered Maysvillian in age (Liberty and Shelden, 1968, fig. 8, p. 28). The Richmondian portion consists of rubbly bedded argillaceous limestone with gray shale interbeds (Hussey, 1926, p. 149; 1950, p. 16, 17). The carbonate content and frequency of fossils increase upward. At locality 17b, a few pelecypods and trilobites occur in the lower part, and brachiopods and some bryozoans are present in thin lenses and zones in limestone higher in the member. Hussey (1950, p. 17. 18) listed the fauna. Foerste (1918, p. 99) found a solitary coral, referred herein to Streptelasma divaricans (Nicholson, 1875), three meters below the top. The specimen consists of two adjacent corallites near the anterior margin of the pedicle valve of Rafinesquina (Plate 2, fig. 18s). Foerste also found solitary corals, referred herein to Grewingkia deltensis n. sp., at the top of the member. The Bay de Noc Member is probably a shallowing upward sequence deposited in a "normal" marine environment. Foerste (1918, p. 125, 126) suggested that fossils of the Bay de Noc Member (his "argillaceous Richmond limestone") "may represent a late stage of the Waynesville fauna or an early stage of the post-Waynesville". Hussey (1926, p. 144) noted that the presence of many "Waynesville"

and "Whitewater" fossils together with "Elkhorn" forms made positive correlation unwise, but suggested that the upper part of the Bay de Noc Member may be "Whitewater" in age. The position of the Bay de Noc Member at the base of the stratigraphic section, the general lithology and abundance of shale, and the rarity of solitary corals suggest it may correlate with the "Arnheim-Waynesville".

The overlying Ogontz Member of the Stonington Formation is 1 to 6 m thick and consists of cherty micritic limestone and wackestone with argillaceous material in irregular bands and lenses. An intraformational conglomerate of irregular nodules and thin slabs of Ogontz limestone is present near the top of the member (Hussey, 1926, p. 135-138; 1950, p. 17). Hussey (1950, p. 19, 20) listed the fauna. Corallites of Grewingkia deltensis are common on some surfaces of Ogontz limestone, where they tend to occur in groups in association with small gastropods and some brachiopods. The corallites were abraded and tips rounded before burial (Plate 6, figs. 35, 45). Two corallites were buried with the counter side up, six had an alar side up, and one had the cardinal side up (App. 1). G. deltensis corallites are trochoid, moderately curved, and attain large size. They resemble corallites of Grewingkia in the Red River Formation (late Middle or Upper Ordovician) of southern Manitoba, and were probably oriented during life with the convex cardinal side in the sediment and counter side facing upward (Elias,

1976, p. 31-34). None of the specimens collected had epifauna or Vermiforichnus borings. Both specimens for which thin sections were examined had Ordovician microscopic algal borings, and one also had similar Recent borings produced by algae in Lake Michigan (Plate 6, fig. 38; App. 7). The Ogontz Member was deposited in a shallow marine environment with little terrigenous influx, possibly in a sheltered lagoon as suggested by the micritic composition and common gastropods. The intraformational conglomerate may indicate a period of subaerial exposure near the end of Ogontz deposition. The relatively pure micritic limestone characterizing the Ogontz Member is not found elsewhere in the Richmond Group. Foerste (1918, p. 125) provisionally correlated the Ogontz (his "cherty Richmond limestone") with the "post-Waynesville" on the basis of fauna. Hussey (1926, p. 144) suggested that it may be equivalent to the "Whitewater". The position of the Ogontz Member in the stratigraphic sequence, the predominance of limestone, and the common occurrence of solitary corals suggest it may correlate with the "Liberty".

Overlying the Stonington Formation is the 38 m thick Big Hill Formation. It consists of dolomite with some shale partings (Ehlers, Kesling, and Slaughter, 1967, p. 225). In a quarry near the base of the formation at locality 17c, burrows and planar laminae are present. Hussey (1950, p. 21, 22) listed the fauna. Abundant colonial corals of Paleophyllum

and Catenipora and numerous bryozoans occur throughout (Ehlers, Kesling, and Slaughter, 1967, p. 228). Near the base, the typical Richmond Group colonial corals Calapoecia, Paleophyllum, Favistina, and Catenipora occur in abundance (Hussey, 1926, p. 145; 1950, p. 21). Near the top, Paleophyllum and Catenipora were reported (Ehlers, Kesling, and Slaughter, 1967, p. 225). Solitary corals are rare to common in association with colonial corals at locality 17d near the base of the formation, but are too poorly preserved for identification. Ehlers, Kesling, and Slaughter (1967, p. 225) reported solitary corals below the very fossiliferous colonial coral zone at the top of the formation. The lithology and sedimentary structures of the Big Hill Formation suggest deposition in periodically semi-restricted, shallow marine environments, perhaps frequently in lagoons behind colonial coral banks. The formation resembles the Saluda Dolomite Member of the western Cincinnati Arch region. Hussey (1926, p. 148-150) considered correlation of the Big Hill Formation uncertain, but suggested it may be near the "Whitewater-Elkhorn". Its stratigraphic position above the Ogontz Member but below the Mormon Creek Formation, the dolomitic composition, and the presence of colonial coral zones and solitary corals suggest correlation with the "Whitewater".

The 36 m thick Mormon Creek Formation overlies the Big Hill Formation (Kesling, 1975, p. 5-7). It consists of thinly bedded dolomite alternating with bands of shale, and

contains gypsum and occasional hopper-shaped halite molds. One species of ostracod is abundant on some bedding planes, and certain units contain trace fossils. Kesling (1975, p. 6) considered the formation to have been deposited in a brine-filled, restricted basin. Evaporite-producing environments did not occur elsewhere in eastern North America during the latest Ordovician. The position of the Mormon Creek Formation as the final stage in a regressive sequence at the top of the Richmondian stratigraphic section suggests that it may correlate with the "Elkhorn".

6. DRUMMOND ISLAND, MICHIGAN

The Richmond Group is exposed on the north shore of Drummond Island (Text-figs. 2, no. 6; 18). South of locality 18a, Hussey (1952, p. 49, 50) reported a stromatoporoid "reef" extending under the water, overlain by 2 m of sandy dolomitic limestone, followed by another stromatoporoid-colonial coral "reef". These "reefs" are equivalent to the stromatoporoid-colonial coral zones at the top of the Meaford beds on Manitoulin Island, Ontario. Hussey termed these strata "Whitewater member", and listed the fauna. At locality 18a, 0.5 m of rubbly limestone with uncommon to common solitary corals and a few brachiopods (horizon 18a-1) is overlain by a 0.3 m thick colonial coral zone with the typical Richmond Group colonial corals Favistina and Calapoecia (many overturned) and uncommon solitary corals (horizon 18a-2). This zone is overlain by 0.6 m of more massive limestone containing abundant solitary corals and sparse brachiopods at the top (horizon 18a-3). Orientation of the solitary corals is shown in Text-fig. 5. At locality 18b, the rubbly bedded argillaceous limestones and shales of the Meaford beds are exposed (Hussey, 1952, p. 50, 51). Near the base of the section, several fossiliferous surfaces with brachiopods, branching bryozoans, and uncommon to common solitary corals are present. The fauna was listed by Hussey (1952, p. 51). North of locality 18c, Hussey (1952, p. 50) reported Meaford beds and listed the fauna. At locality 18c,

massive, thickly bedded, vuggy dolomite with branching bryozoans represents the overlying Kagawong beds of Manitoulin Island. Solitary corals were not seen in this unit.

Grewingkia canadensis (Billings, 1862) is the only solitary rugose coral known from Drummond Island. The corallites were abraded before final burial (Plate 6, fig. 21). At horizons 18a-1 to 3 and 18b-1, sixteen of 19 corallites were oriented at the time of final burial with an alar side up, two had the counter side up, and one had the cardinal side up (App. 1). The length-frequency distribution is bimodal, suggesting that some corallites were removed from the area as previously discussed under G. canadensis of the Cincinnati Arch region (Text-fig. 7). Very long corallites are more common than usual in the solitary coral zone at horizon 18a-3. The diameter-height ratios are similar to those at the northwestern and eastern Cincinnati Arch region and Manitoulin Island (Text-fig. 7). The distribution of the number of major septa at a particular diameter for corallites from horizons 18a-1, 2, and 18b-1 in the upper Meaford beds of Drummond Island is similar to that for the "Waynesville" in the Cincinnati Arch region (Text-figs. 19, 10). Values in the horn coral zone

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Text-figure 19.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite

diameter (d) for horizons in the upper Meaford beds, upper member, Georgian Bay Formation, Drummond Island, Michigan (see App. 8). Curve is average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).

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(horizon 18a-3) tend to be higher, possibly reflecting shallower water conditions. Although too few axial region comparative scale values are available for accurate comparison, the frequency distribution peak at 35 is similar to that for the Richmond Group in the Cincinnati Arch region (Table 2; Text-fig. 12). Epifaunal bryozoans and

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Table 2.--Grewingkia canadensis (Billings, 1862): axial region comparative scale values for Meaford beds, upper member, Georgian Bay Formation, Drummond and Manitoulin Islands (see Plate 4, figs. 33-53; App. 9).

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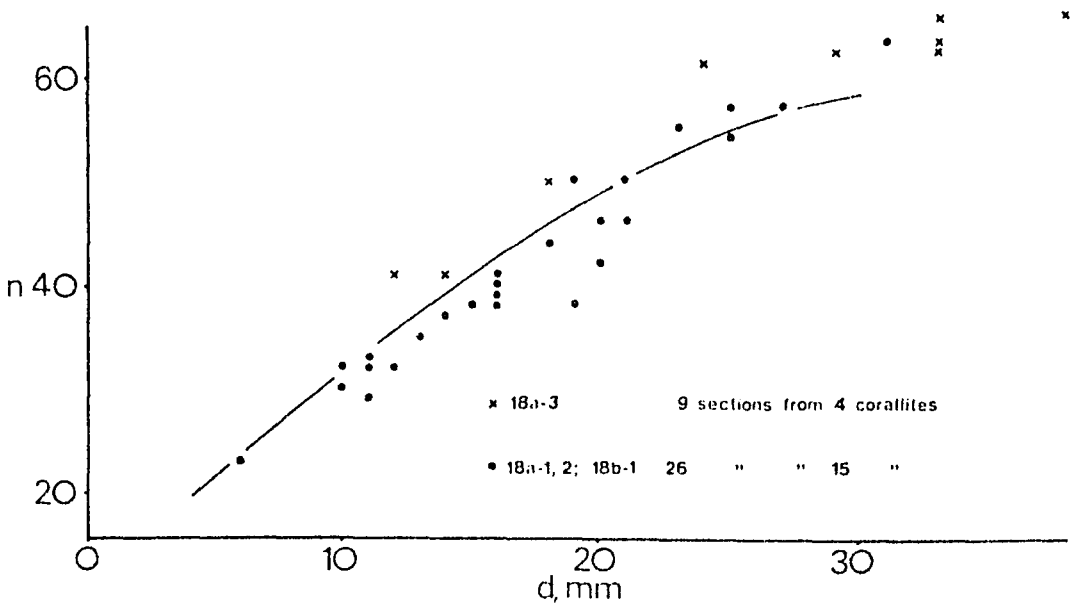
Vermiforichnus borings appear to be rare at Drummond Island (Apps. 5, 6). Microscopic algal borings are present in all five corallites for which thin sections were examined (App. 7).

Text-figure 19.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for horizons in the upper Meaford beds, upper member, Georgian Bay Formation, Drummond Island, Michigan (see App. 8). Curve is average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).



Text-fig. 19

Table 2.--Grewingkia canadensis (Billings, 1862): axial region comparative scale values for Meaford beds, upper member, Georgian Bay Formation, Drummond and Manitoulin Islands (see Plate 4, figs. 33-53; App. 9).

TABLE 2

Axial Region Complexity Comparative Scale Values:		0	10	20	30	40	50	60	70	80	90	100
Drummond Is., n=7	f:	-	-	1	3	2	-	-	-	1	-	
Manitoulin Is., n=9	f:	-	-	1	2	-	1	3	2	-	-	

7. MANITOULIN ISLAND, ONTARIO

The Richmondian stratigraphy and fauna of Manitoulin Island (Text-figs. 2, no. 7; 18) were described by Foerste (1912b; 1916, p. 97-127; 1924, p. 53, 54) and Caley (1936). The Georgian Bay Formation is Maysvillian through early Richmondian in age (Liberty and Shelden, 1968, p. 28, 30, 31; Liberty, 1969, p. 73-79). The upper, Richmondian portion of the 45 to 100 m thick lower member (Wekwemikongsing beds) consists of shale, with a few thin dolomite interbeds toward the top. Brachiopods, bryozoans, pelecypods, and gastropods are the dominant fossils. Solitary corallites of Grewingkia canadensis (Billings, 1862) occur in a dolomite bed near the top of the Wekwemikongsing beds at locality M75. The distribution of the number of septa at a particular corallite diameter is similar to that for "Liberty" strata of the Cincinnati Arch region (Text-figs. 20, 10). The lower member of the Georgian Bay Formation

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Text-figure 20.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for horizons in the Georgian Bay Formation, Manitoulin Island, Ontario. Numbers indicate frequency of a point if greater than one (see Text-fig. 18; App. 8). Curve is average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).

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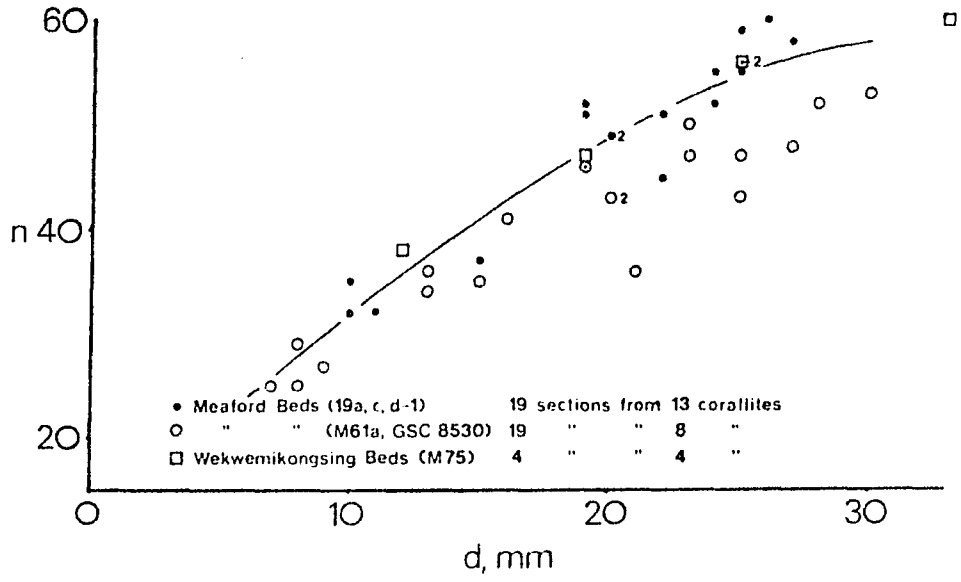
Text-figure 20.--Crewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) for horizons in the Georgian Bay Formation, Manitoulin Island, Ontario. Numbers indicate frequency of a point if greater than one (see Text-fig. 18; App. 8). Curve is average for Richmond Group, Cincinnati Arch region (see Text-fig. 36).



Text-fig. 20

appears to have been deposited in a "normal" marine environment, and the upward increase in the number of carbonate beds and fossils may indicate a shallowing sequence. The stratigraphic position of the upper portion of the lower member and the abundance of shale suggest it may correlate with the "Arnheim-Waynesville" of the Cincinnati Arch region.

The overlying Meaford beds of the upper member, Georgian Bay Formation, consist of about 15 m of rubbly bedded argillaceous limestone with gray shale interbeds. Brachiopods and branching bryozoans are the most common fossils. Typical Richmond Group colonial coral-stromatoporoid zones occur near the base and top of the unit. The fauna and lithology suggest deposition in a shallow, "normal" marine environment with colonial coral-stromatoporoid banks developing at the beginning and end of deposition. The upward increase in limestone at locality 19d may indicate a shallowing sequence. Foerste(1916, p. 104; 1924, p. 51) considered the fauna of the Meaford beds to be upper "Waynesville". The stratigraphic position and predominance of limestone suggest correlation with the "Liberty".

Grewingkia canadensis is rare to common at seven of ten Meaford bed exposures that were examined. Corallites occur most frequently near the base and top of the unit, and are usually associated with brachiopods and branching bryozoans. At horizon 19a they occur with gastropods and brachiopods.

Solitary corals are generally absent in colonial coral-stromatoporoid zones, but are rare in the Favistina zone at the top of the Meaford beds at horizon 19d-3. Epifaunal bryozoans and Vermiforichnus borings are not common (Apps. 5, 6). Microscopic algal borings are present in six of eight corallites for which thin sections were examined (App. 7). The corallites at localities 19a to e were abraded before final burial (Plate 6, fig. 30). The length-frequency distribution at these localities suggests that the corallites were transported from elsewhere, as previously discussed under G. canadensis of the Cincinnati Arch region (Text-fig. 7). The diameter-height distribution is similar to that for Drummond Island and the northwestern and eastern Cincinnati Arch region (Text-fig. 8). Distribution of the number of major septa at a particular diameter is similar to that for "Liberty" strata in the Cincinnati Arch region (Text-figs. 20, 10). Although too few axial region comparative scale values are available for accurate comparison, the frequency distribution peaks at 35 and 65 are similar to those for the Richmond Group in the Cincinnati Arch region (Table 2; Text-fig. 12).

Large corallites of G. canadensis generally showing little evidence of abrasion occur in the Meaford beds to the east of localities 19a to e at Manitowaning (locality M61a; GSC 8530, a, e-j), Clay Cliffs (GSC 8528, a-d; 8529b, c; 8573a-c), and Cape Smith (GSC 1982, a-g, i-l)

on Manitoulin Island (Plate 6, figs. 24, 29). These corallites are thought to be part of an initial population that did not undergo extensive transportation. The distribution of the number of major septa at a particular diameter for these corallites is similar to that for the "Waynesville" strata in the Cincinnati Arch region (Text-figs. 20, 10). These corallites may have lived in slightly deeper water than those elsewhere in the Meaford beds or in the uppermost Wekwemikongsing beds.

Except for a single, small specimen of Grewingkia rustica (Billings, 1858) found in the basal Meaford beds at locality 19b (Plate 7, fig. 15), the species is known only from Lake St. John, Quebec. The corallite may have been transported to Manitoulin Island from the east. Streptelasma divaricans (Nicholson, 1875) corallites attached to bryozoans are rare near the base of the Meaford beds at locality M61a (Plate 2, figs. 20s, 21s, 27). The absence of S. divaricans to the west could be accounted for if favorable substrates were seldom stabilized during periods of non-deposition.

Copper and Grawbarger (1978) studied the paleoecological succession leading to a lower Meaford biostrome on eastern Manitoulin Island. Solitary corals were not observed in the "level bottom" community occupying a muddy substrate, but were reported in the "wave baffle margin", "protected subtidal", and biostromal "wave baffle" communities where

carbonate sediments were deposited.

Overlying the Meaford beds, the Kagawong beds of the upper member, Georgian Bay Formation, consist of about 30 m of generally massive dolomite, dolomitic limestone, and limestone. Burrowed zones and branching bryozoan horizons are present. Cross-bedding, planar fine laminae, and gastropod-pelecypod zones are less common. Stromatoporoid-colonial coral zones occur near the base and top of the unit. Streptelasma divaricans is rare, and was found at only two of 15 Kagawong bed exposures examined. At locality 19f, in the middle of the unit, S. divaricans is rare to uncommon in association with branching bryozoans and brachiopods. One corallite was attached to a pelecypod. The lithology, fauna, and structures such as burrows and planar fine laminae suggest deposition in a periodically semi-restricted, shallow marine environment, perhaps occasionally behind colonial coral-stromatoporoid banks. Cross-bedded zones indicate periods of higher energy conditions. The association of brachiopods, bryozoans, and rare solitary corals suggests that more "normal" marine conditions existed during mid-Kagawong deposition. Foerste (1916, p. 104; 1924, p. 52) and Caley (1936, p. 43) considered the Kagawong beds to be "Saluda" or "Whitewater" in age on the bases of fauna and lithology. The stratigraphic position at the top of the Richmond Group suggests correlation with the "Whitewater-Elkhorn".

8. MEAFORD, ONTARIO

Fritz (1926) described the Ordovician stratigraphy and paleontology in the vicinity of Meaford (Text-figs. 2, no. 8; 18). Foerste (1916, p. 129, 130) listed solitary corals together with stromatoporoids and the colonial corals Tetradium, Favistina, and Calapoecia from the richly fossiliferous limestone and shale (Vincent Member of Fritz, 1926, p. 93, 94; upper Georgian Bay Formation of Liberty, 1969, p. 73-79) immediately beneath the Queenston Formation red shales. One of his specimens (GSC 8531) has been sectioned, and is Grewingkia canadensis (Billings, 1862). Bryozoans were epifaunal on GSC 8531a and endofaunal in GSC 8531b. ROM 12325 occurs in packstone, associated with bryozoans and brachiopods. Foerste considered this horizon to be "Waynesville" in age, but its position in the stratigraphic section and the presence of solitary and colonial corals suggest it may be equivalent to the "Liberty-Whitewater". The Queenston delta prograded over the Richmond Group in this area. Stratigraphic position of the Queenston Formation suggests it may correlate with the "Whitewater-Elkhorn". Liberty (1969, p. 81) noted a strong paleontological correlation with the highest "Whitewater" and Saluda.

On Bruce Peninsula northwest of Meaford, several colonial coral biostromes occur within the Queenston Formation (Liberty and Bolton, 1971, p. 25-28). These are

thought to correlate with the Kagawong beds of Manitoulin Island. Liberty and Bolton (1971, p. 126) listed solitary corals from several localities.

9. STREETSVILLE, ONTARIO

Dyer (1925a, b) described the Ordovician stratigraphy and paleontology in the vicinity of Streetsville, near Toronto (Text-figs. 2, no. 9; 18). Foerste (1916, p. 133) reported rare, very small solitary corals in a local incursion of Richmond Group limestone and shale (Columnaria reef, Meadowvale Member of Dyer, 1925b, p. 125; upper Georgian Bay Formation of Liberty, 1969, p. 73-79) a short distance beneath the Queenston Formation red shales. A small, poorly preserved corallite with dilated septa is herein referred to Grewingkia ? sp. (ROM 335HR). If these small corallites are G. canadensis, they may represent the smallest size fraction transported farthest toward shore from the initial population, as discussed previously under G. canadensis of the Cincinnati Arch region. Foerste also reported occasional specimens of the colonial coral Calapoecia, as well as bryozoans and gastropods. He stated that the fauna suggested "Whitewater" affinities to E.O. Ulrich. Dyer (1925b, p. 125) suggested correlation with the Saluda or "Whitewater". On the basis of stratigraphic position, this horizon may be equivalent to the "Liberty", with the "Whitewater-Elkhorn" represented by the Queenston Formation.

10. MONTREAL, QUEBEC

Richmondian stratigraphy in the vicinity of Montreal (Text-figs. 2, no. 10; 18) has been summarized by Clark and Stearn (1963, p. 40). The 48 m thick Pontgravé River Formation comprises calcareous marine shale and limestone. The overlying Décancour River Formation is more than 600 m thick, and consists of the basal 15 m thick Carmel River Member non-marine gray shale, with red and green non-marine shale and sandstone of the Queenston facies above.

Foerste (1916, p. 153, 155) reported solitary corals from the fossiliferous "Waynesville" beds (Pontgravé River Formation) beneath the Queenston red shales (Bécancour River Formation) at St. Hilaire and St. Hugues. At St. Hilaire, brachiopods, pelecypods, and gastropods were also listed. The corals are associated with brachiopods at St. Hugues, and occur in glacial erratics probably from a nearby source. Foerste (1916, p. 145) found one solitary coral associated with brachiopods in a sequence termed "Waynesville" (Pontgravé River Formation) in the Nicolet River section. Richmondian solitary corals from the vicinity of Montreal were referred to Streptelasma rusticum by Foerste, but their identity is uncertain because specimens have not been located for sectioning.

11. LAKE ST. JOHN, QUEBEC

At Snake Island, Lake St. John (Text-figs. 2, no. 11; 18) solitary rugose corals are "thrown up in great numbers by the waves from some [limestone] stratum below water-level" (Foerste, 1924, p. 69). Foerste (1916, p. 156-158) listed the fauna including solitary corals, the typical Richmond Group colonial corals Favistina, Calapoecia, Lyopora, and Tetradium, and stromatoporoids from in situ strata at water level.

Grewingkia rustica (Billings, 1858) is the only solitary coral known from Lake St. John. The species is externally very similar to G. canadensis, being ceratoid to trochoid and straight to very weakly curved in early to intermediate stages, and cylindrical in later stages (Plate 7, figs. 5, 9). The corallites are water-worn, but this may be at least partly of recent origin. Epifaunal bryozoans occur on five of 18 corallites, with four on the counter side, three on an alar side, and four on the cardinal side (App. 5). Vermiforichnus borings are present in seven of 18 corallites, and most are in the cardinal side (App. 6). Microscopic algal borings are present in all five corallites for which thin secions were examined (App. 7). They may be Ordovician and/or Recent in age (Plate 7, fig. 14). They are generally very fine, and appear to be different than those of the Cincinnati Arch region.

Foerste (1916, p. 156) provisionally correlated this horizon at Lake St. John with the "Whitewater".

II. MAQUOKETA GROUP

INTRODUCTION

The Maquoketa Group (Text-fig. 2) is Edenian through Richmondian in age (Templeton and Willman, 1963, p. 130, 131). This marine clastic wedge spread from the east, and rapidly thins from nearly 300 m in eastern Indiana (including the Richmond Group at the top) to about 60 m in western Indiana (Gray, 1972, p. 1, 4), Illinois (Willman and Buschbach, 1975, p. 82), and Iowa (Ladd, 1929, p. 331) (see Gutstadt, 1958, figs. 7-9). In Indiana, Gray (1972, fig. 4) recognized a deep basin facies in the southwest and shelf facies to the north and east. The Maquoketa Group is predominantly gray shale. Limestone occurs in the middle of the sequence in northeastern Illinois and northeastern Iowa. The group is almost completely shale in southeastern Iowa-northwestern Illinois, and eastern Wisconsin. Thin limestone beds are present in the upper Maquoketa in all these areas. The Neda Formation occurs locally at the top of the Maquoketa Group in Iowa (Agnew, 1955, p. 1717), Wisconsin, northern Illinois (Willman and Buschbach, 1975, p. 86), and possibly northeastern Indiana (Gray, 1972, p. 19). It is generally less than 3 m thick, and consists of red shale interbedded with oolitic hematite. A few Maquoketa species were reported from the formation by Savage and Ross (1916). The Neda is thought to be a western tongue of the Queenston delta (Willman and Buschbach, 1975, p. 86). Only the Edenian

through Maysvillian Scales Formation is present in southeastern Minnesota. Bayer (1965, p. 45) indicated that clastic material in the Elgin Member probably represents the western edge of detritus shed from the Taconic Mountains, while sand in the overlying Clermont Member carbonates was derived from an uplift of the Transcontinental Arch to the west (Bayer, 1965, p. 44; Austin, 1972, p. 470). The remainder of the group in Minnesota was eroded prior to deposition of the overlying Devonian (Austin, 1972, p. 470). Upper Ordovician strata become thinner and the clastic and carbonate content of the Maquoketa Group increases toward the Ozark Dome which was probably slightly positive, as seen in the vicinity of Thebes, southern Illinois (Templeton and Willman, 1963, p. 131; Bayer, 1965, p. 45). The Maquoketa is termed Sylvan Shale in Oklahoma (Ladd, 1929, p. 311, 407; Templeton and Willman, 1963, p. 192).

12. NORTHEASTERN IOWA

The stratigraphy and fauna of the Maquoketa Group in northeastern Iowa (Text-figs. 2, no. 12; 18) have been described by Savage (1905), Calvin (1906), and Ladd (1929). The lowermost Richmondian unit is the Clermont Member of the Scales Formation. This gray shale contains a fauna dominated by brachiopods. Ladd (1929, p. 391) listed a solitary coral from the Clermont Member, and described and figured a corallite possibly from the Clermont Member that he assigned to Streptelasma haysii (Ladd, 1929, p. 397, Pl. 4, figs. 1, 2). The latter specimen (SUI 2-050) has not been located, and so the identity remains uncertain. Another corallite probably from this unit is herein assigned to Helicelasma randi Elias, 1976. The overlying Fort Atkinson Formation consists of dolomite and limestone containing brachiopods and echinoderm fragments. Bighornia cf. patella (Wilson, 1926) occurs in this unit. One of the three known corallites has Vermiforichnus borings (Plate 8, fig. 26; App. 6). The Brainard Formation of the Maquoketa Group comprises gray shale with some limestone beds at the bottom and top. It contains bryozoans and brachiopods. One specimen of H. randi is known from the top of the formation in Clayton Co. at the southern extremity of this region. The septal grooves and interseptal ridges are preserved, indicating little abrasion prior to burial. Savage (1905, p. 487) listed solitary corals throughout the Maquoketa Group in

Fayette Co.

Templeton and Willman (1963, p. 132, 133) considered the Clermont Member similar in lithology and stratigraphic position to the "Arnheim" of the Richmond Group. They noted that the Fort Atkinson Formation and "Waynesville" are remarkably similar in fauna, lithology, and stratigraphic position. The Brainard Formation was correlated with the "Liberty-Whitewater-Elkhorn" primarily on the basis of lithology. Ladd (1929, p. 369, 370) considered highly probable the faunal correlation of the Brainard Formation and its uppermost Cornulites zone with the "Elkhorn".

13. SOUTHEASTERN IOWA-NORTHWESTERN ILLINOIS

In southeastern Iowa and northwestern Illinois (Text-figs. 2, no. 13; 18) the Maquoketa Group is predominantly gray shale, much of it unfossiliferous (Ladd, 1929, p. 330; Savage, 1925, p. 240-245; Willman and Buschbach, 1975, p. 86). Near the top, fossiliferous limestone interbeds with brachiopods and bryozoans are present. Ladd (1929, p. 371, 391-395) termed this the Cornulites zone and listed the fauna. Helicelasma landi Elias, 1976 occurs in these argillaceous limestone beds of the Brainard Formation at Sterling, Illinois, where stratigraphic sections were described and the fauna was listed by Savage (1925, p. 240-245). The septal grooves and interseptal ridges are generally preserved, indicating little abrasion prior to burial (Plate 4, figs. 1, 2, 5). Of the epifaunal bryozoans on eight corallites, six are on the counter side, seven on an alar side, and three are on the cardinal side (Plate 4, fig. 2; App. 5). Ladd (1929, p. 391) listed a solitary coral from the Cornulites zone of southeastern Iowa, and Savage (1925, p. 244) listed solitary corals as rare in fossiliferous limestone beds of the upper Maquoketa Group near Preston, Iowa.

14. THEBES, ILLINOIS

In the vicinity of Thebes (Text-figs. 2, no. 14; 18) the Maquoketa Group comprises the Thebes Sandstone and Orchard Creek Shale members of the Scales Formation. The Maquoketa is overlain by the Girardeau Limestone Formation (Willman and Buschbach, 1975, p. 86, 87, fig. 0-27). The Thebes Member has a maximum thickness of 48 m, and consists of silty, fine grained sandstone in medium to thick beds and local cross beds. Trace fossils occur in the upper part of the member. It grades or interfingues eastward and northward into the lower part of the Elgin Shale Member. The overlying Orchard Creek Member is 3 to 9 m thick and is predominantly gray shale. It may be equivalent to the Elgin Shale Member, but could be as young as the Brainard Shale (Willman and Buschbach, 1975, p. 86). The Orchard Creek fauna including brachiopods, molluscs, and trilobites occurs in calcareous layers, and was listed and described by Savage (1917b, p. 263, 264). Pryor and Ross (1962, p. 9) listed a graptolite. Only two solitary corallites of Helicelasma randi Elias, 1976 have been collected from the Orchard Creek (Mississippi River section of Pryor and Ross, 1962, fig. 3; section B of Satterfield, 1971, fig. 1). The member grades upward into the Girardeau Limestone, which is up to about 9 m thick (Satterfield, 1971, p. 266). It consists of unevenly bedded, fine grained to lithographic limestone with shale partings and siliceous interbeds and nodules. The Girardeau

Limestone may be equivalent to the Fort Atkinson Formation, but an age as young as or younger than the Brainard is presently favored (Willman and Buschbach, 1975, p. 87). The fauna including echinoderms, bryozoans, brachiopods, molluscs, and trilobites was described by Savage (1917a). Conodonts of the Girardeau indicate a very late Ordovician age (Satterfield, 1971).

III. UPPERMOST ORDOVICIAN OF OKLAHOMA-MISSOURI-ILLINOIS

INTRODUCTION

Thompson and Satterfield (1975) revised the stratigraphy and studied conodonts contiguous to the Ordovician-Silurian boundary in eastern Missouri (Text-fig. 2, nos. 16, 17). Their work indicated that strata previously included at the base of the Lower Silurian Edgewood Group of the Alexandrian Series (Savage, 1908, 1917a) are Late Ordovician in age. These strata comprise the Cyrene Formation and Noix Limestone in Pike Co., northeastern Missouri, and the Leemon Formation in Cape Girardeau Co. in the southeast (Text-fig. 21). The

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Text-figure 21.--Oklahoma-Missouri-Illinois: uppermost Ordovician stratigraphic sections and distribution of solitary rugose corals. For legend of symbols see Text-fig. 3.

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Noix Limestone lies disconformably on the Maquoketa Group and is disconformably overlain by Lower Silurian strata (Thompson and Satterfield, 1975, p. 89, 103). While the Noix was being deposited, Cyrene strata formed immediately to the west. The Leemon Formation was deposited on an eroded Maquoketa Group-Girardeau Formation surface, and was followed by a period of erosion before Lower Silurian deposition (Thompson and Satterfield, 1975, p. 101). A Late Ashgillian age for the Noix Limestone and Leemon

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Text-figure 21.--Oklahoma-Missouri-Illinois: uppermost Ordovician stratigraphic sections and distribution of solitary rugose corals. For legend of symbols see Text-fig. 3.

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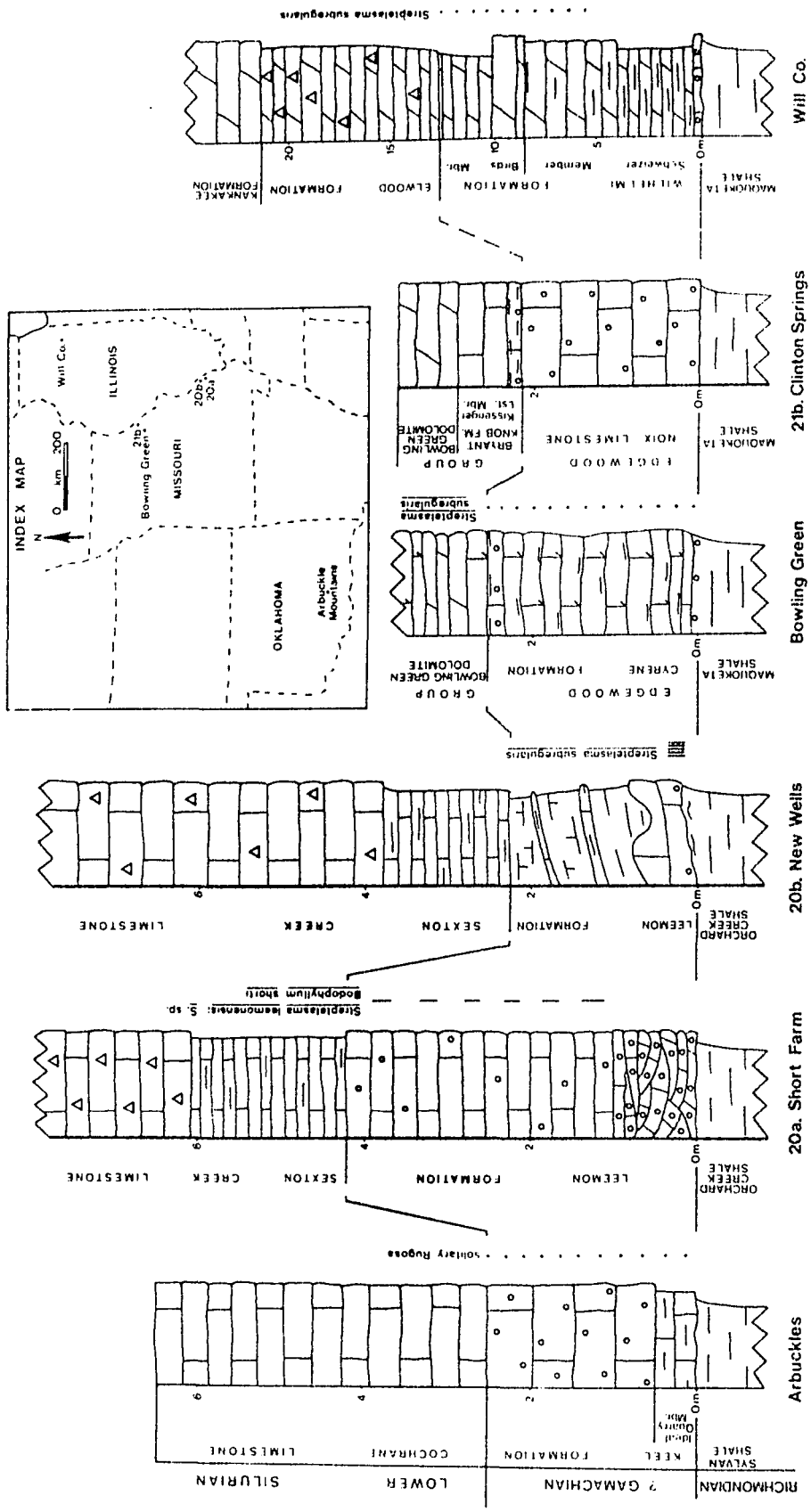

Text-fig. 21

Formation was supported by Amsden's (1974) study of the brachiopods.

The Keel Formation at the base of the Chimneyhill Subgroup in the Arbuckle Mountains of Oklahoma (Text-figs. 2, no. 15; 21) had been correlated with the Edgewood Group of Missouri, and was therefore placed in the Lower Silurian Alexandrian Series (Maxwell, 1936). It unconformably overlies the Sylvan Shale and is overlain, usually unconformably, by Silurian strata (Maxwell, 1936, p. 48; Amsden, 1974, p. 25). Amsden (1974, p. 26) found that all Keel brachiopods occur in the Noix Limestone and many are present in the Leemon Formation. He therefore tentatively correlated these three units, thereby assigning the Keel Formation to the Late Ashgill Series.

Savage (1910) recognized the Alexandrian Series in northeastern Illinois (Text-fig. 2, no. 18), and named the strata Channahon Limestone. He considered the fauna most closely related to the Edgewood of Missouri. Willman (1973, p. 12-14) proposed the Wilhelmi Formation, which includes the Channahon Limestone, for sediments deposited in channels eroded in the underlying Neda Formation and Brainard Shale of the Maquoketa Group (Text-fig. 21). These deposits are herein correlated with the Cyrene and Leemon formations of Missouri, as will be discussed in the section on Will Co., Illinois.

Amsden (1974, p. 26) noted that the Keel-Edgewood brachiopods have little in common with North American forms,

and the assemblage most closely resembles the Hirnantian fauna. The Hirnantian is presently considered the uppermost Ordovician stage of the Ashgill Series (Ingham and Wright, 1970) (Text-fig. 1). The characteristic brachiopod-dominated Hirnantian fauna has been widely recognized in Great Britain, Scandinavia, northwestern Europe, northern Africa, Kazakhstan, and Burma (Wright, 1968; Lespérance, 1974). In North America, the Hirnantian fauna may be present in siltstones near Ashland in Aroostook Co., Maine (R.B. Neuman, 1968, p. 44; Ingham and Wright, 1970, p. 240; Lespérance, 1974, p. 14). The typical brachiopod-dominated north European Hirnantian fauna occurs in mudstone in the Percé area of Quebec (Lespérance, 1974; Lespérance and Sheehan, 1976). Amsden (1974, p. 28) believed that the Keel-Edgewood brachiopod species were different from those of the Hirnantian fauna. He noted that the generic assemblages have similarities, but many genera of the Hirnantian are not present in the Keel-Edgewood, and vice versa. However, as Amsden pointed out, the Keel-Edgewood fauna occurs in a carbonate facies, whereas the Hirnantian fauna is almost everywhere in a mudstone facies. Amsden viewed the Hirnantian aspect of the Keel-Edgewood fauna with caution because most genera common to the two formations apparently have considerable ranges in the Late Ordovician-Early Silurian. Lespérance and Sheehan (1976, p. 719, 720) stated that the Edgewood fauna could be a latest Ordovician endemic fauna derived from the Hirnantian

fauna and other North European Province species, but considered more likely that the fauna is Silurian with a few hold-overs from the Late Ordovician North American Province. With the stratigraphic revision and conodont biostratigraphy of Thompson and Satterfield (1975), and the Ordovician elements in the Keel-Edgewood brachiopod fauna, evidence points to a very Late Ordovician age for the carbonate sequence of Oklahoma-Missouri-Illinois.

If the upper Maquoketa Group is equivalent to the "Elkhorn" of the Richmond Group, as discussed previously in the section on northeastern Iowa, it was deposited during latest Richmondian time. The uppermost Ordovician carbonate sequence in Oklahoma-Missouri-Illinois unconformably overlies the Maquoketa, suggesting it may be post-Richmondian in age. There is no evidence for comparable deposition above the Richmond Group, which is unconformably overlain by the Middle Llandoverian (Lower Silurian) Brassfield Formation. The Brassfield has been correlated with the Kankakee Formation of northeastern Illinois, the Sexton Creek Limestone of southwestern Illinois-southeastern Missouri (Willman and Atherton, 1975, p. 99), and the Cochrane Limestone of Oklahoma (Maxwell, 1936, fig. 4) (Text-fig. 21). Latest Ordovician and earliest Silurian carbonate sediments were probably deposited above the Maquoketa Group during the interval of non-deposition and/or erosion between Richmond and Brassfield time. Brachiopods of the

uppermost Ordovician units suggest this period of time may be equivalent to the Hirnantian Stage of Europe. Schuchert and Twenhofel (1910, p. 700, 701) proposed the Gamachian Stage to include the Ellis Bay Formation of Anticosti Island, Quebec, and all American Ordovician strata later in age than the youngest Richmondian of Ohio and Indiana. Unfortunately, the exact age of the Ellis Bay Formation is uncertain, and it has not been demonstrated to be post-Richmondian, as will be discussed in the section on Anticosti Island, Quebec. Nevertheless, the meaning of Gamachian as a post-Richmondian stage was made clear by Schuchert and Twenhofel, and has priority over Hirnantian if the two prove to be equivalent (Lespérance and Sheehan, 1976, p. 721). The Keel Formation of Oklahoma, the Leemon, Noix, and Cyrene formations of Missouri, and the Wilhelmi Formation of Illinois are tentatively considered to have been deposited during the Gamachian Stage.

The uppermost Ordovician deposits in Oklahoma-Missouri-Illinois represent the initial transgression of the middle Paleozoic carbonate sequence that formed in a shallow epicontinental sea covering a large area of the east-central United States (Amsden, 1974, p. 29). This transgression suggests that deglaciation began in the latest Ordovician rather than during the Llandovery (Lower Silurian) as previously thought (Berry and Boucot, 1973). The predominance of oolitic and bioclastic limestones and

presence of bioherms in the latest Ordovician indicate fairly high energy, shallow, "normal" marine conditions. Arenaceous detritus in southeastern Missouri suggests that the Ozark Dome may have been slightly positive at this time.

15. ARBUCKLE MOUNTAINS, OKLAHOMA

In the Arbuckle Mountain region (Text-figs. 2, no. 15; 21), the Keel Formation has a maximum thickness of about 4.5 m and comprises the lower Ideal Quarry Member (Hawkins Limestone of Maxwell, 1936, p. 45-49) and an upper "oolitic unit (Keel Limestone of Maxwell, 1936, p. 50-54) (Amsden, 1974, p. 25). The Ideal Quarry Member is locally present and consists of thinly bedded argillaceous limestone. Crinoid stems are common on bedding planes, but other fossils are rare. Maxwell (1936, table 1) listed solitary and colonial corals, a bryozoan, brachiopods, pelecypods, and a gastropod. The Ideal Quarry Member grades upward into the remainder of the formation, which consists of thickly bedded "oolitic limestone. Fossils are rare in the "oolite from which Maxwell (1936, table 2) listed solitary and colonial corals, brachiopods, and gastropods. Excluding crinoid fragments, brachiopods are the most abundant and diverse megafossils in the Keel Formation (Amsden, 1974, p. 26). Maxwell listed Streptelasma subregularis (Savage, 1913) from the Ideal Quarry Member and Streptelasma sp. from the "oolite. The identity of these corals is uncertain because specimens have not been located for sectioning.

16. CAPE GIRARDEAU COUNTY, MISSOURI

The Leemon Formation of southeastern Missouri is up to 7 m thick. At the type section in Cape Girardeau Co. (Text-figs. 2, no. 16; 21, locality 20a), the lower cross-bedded oölite with Girardeau-type limestone pebbles and fine quartz grains is overlain by thickly bedded, bioclastic and partly oölitic packstone and grainstone (Thompson and Satterfield, 1975, p. 76, 77; Amsden, 1974, p. 19). Except for abundant echinoderm debris, brachiopods strongly dominate the megafauna. Solitary and colonial corals and gastropods are rare. The following solitary corals are present in the upper part of the Leemon Formation at the type section: Streptelasma leemonensis n. sp., S. sp., and Bodophyllum shorti n. sp. All corallites were abraded and some were broken prior to burial (Plate 2, figs. 28-31; Plate 8, fig. 7). The only known specimen of B. shorti has a base of attachment on the cardinal side, and was epifaunal on a bryozoan (Plate 8, fig. 3).

The Leemon Formation is different to the north at locality 20b (Thompson and Satterfield, 1975, p. 79, 80; Amsden, 1974, p. 21, 22) (Text-figs. 2, no. 16; 21). Basal biohermal limestone mounds are up to 0.5 m high, with calcareous shale between and overlapping them. The mounds contain oöids (Plate 3, figs. 4, 8, 9), glauconite, phosphatic material, quartz grains, and fossils in a calcareous matrix. The most abundant fossils are branching

bryozoans apparently preserved in growth position. Brachiopods dominate the shelly fauna, some being attached to and partly overgrown by bryozoans. Amsden (1974, p. 22) considered this brachiopod fauna the most characteristic Late Ordovician assemblage in the uppermost Ordovician strata of Oklahoma-Missouri. Solitary corallites of Streptelasma subregularis (Savage, 1913) are abundant at the base of some mounds. They are randomly oriented, and are generally lying on an alar side, but some are oriented with the calyx facing down or up. Although corallites have moderately dilated septa in early stages, they were apparently quite fragile because of the very narrow stereozone, open axial region, and very widely spaced tabulae (Plate 3, figs. 3-16). Many had their tips broken off and some had the rim of the calyx broken before burial (Plate 3, figs. 4, 8). However, all specimens have growth lines preserved, indicating no abrasion (Plate 3, figs. 4, 8, 9, 12, 13). The corals may have been knocked over suddenly and buried near the site of growth, perhaps by a storm. The presence of S. subregularis at the base of the mounds suggests it may have been the initial species to colonize the eroded surface of the Orchard Creek Shale. The corallites are not associated with and did not form a framework structure, and were not hosts of epi- or endobiota. S. subregularis is very similar to many corallites of S. affinis, which is common in the Ellis Bay Formation

(? Gamachian) of Anticosti Island, and most closely resembles S. unicum Neuman, 1975, probably from the Hirnantian Dalmanitina beds of Sweden.

17. PIKE COUNTY, MISSOURI

The Noix Limestone occurs at the eastern margin of Pike Co. (Text-fig. 2, no. 17). It consists of massive and cross-bedded "ooids in a micritic matrix. Glauconite and phosphatic grains are present in the lower part (Thompson and Satterfield, 1975, p. 89-93; Amsden, 1974, p. 8, 9). At the type section (Text-fig. 21, locality 21b), Thompson and Satterfield (1975, fig. 12) included bed 9, bounded by shale interbeds at its base and top, in the 2 m thick Noix Limestone. It did not yield conodonts, and was presumably included because it contains "ooids. Solitary corals of the same species that is abundant at the base of their bed 10 (Kissinger Limestone Member of the Silurian Bryant Knob Formation) are present in bed 9. Bed 9 is herein included at the base of the Kissinger Limestone Member. The "ooids are probably reworked from the Noix Limestone. The fauna of the Noix Limestone in Pike Co. has been listed by Rowley (1908, p. 23), and by Savage (1917a, p. 82, 83) who also described new species. Rubey (1952, p. 170) listed the fauna in adjacent Calhoun Co., Illinois. Echinoderm debris is generally abundant. Brachiopods dominate the remainder of the megafauna, with bryozoans, trilobites, gastropods, pelecypods, corals, and tentaculitids making up a small fraction of the assemblage (Amsden, 1974, p. 12). Although solitary corals have been listed from the Noix Limestone, none were found at localities 21a or 21b.

To the west of the Noix Limestone belt, the Cyrene Formation occurs in the vicinity of Edgewood, Cyrene, and Bowling Green in Pike Co. (Thompson and Satterfield, 1975, p. 93-97, fig. 11) (Text-fig. 21). It is about 2 m thick at Bowling Green and consists of fine to medium grained, fossiliferous, dolomitic limestone. The Cyrene fauna near Edgewood was listed by Savage (1917a, p. 82, 83), who considered it very similar to that of the Noix Limestone. Conodonts of the Cyrene correlate with the Maquoketa Shale (Thompson and Satterfield, 1975, p. 96). Thompson and Satterfield (1975, p. 103) concluded that Cyrene strata were being deposited in the west, while the Noix Limestone formed to the east. The solitary coral Streptelasma subregularis (Savage, 1913) occurs in the Cyrene Formation. On the basis of this species, the Cyrene is correlated with the Leemon Formation at locality 20b in southeastern Missouri.

18. WILL COUNTY, ILLINOIS

Savage (1910) discussed the Channahon Limestone in Will Co. (Text-fig. 2, no. 18) and listed and described the fauna, which is dominated by brachiopods (Savage, 1917a, p. 84-86). The Wilhelmi Formation of Willman (1973, p. 12-14) includes the Channahon. It is up to 30 m thick in some channels but is absent or very thin between them. The formation comprises the very argillaceous dolomite and dolomitic shale of the Schweizer Member and the argillaceous dolomite of the overlying Birds Member (Text-fig. 21). A few thin, fossiliferous beds occur in the Schweizer Member, and some of the purer beds in the Birds Member are fossiliferous. C.A. Ross (1962) described graptolites suggesting an Early Llandoverian (Lower Silurian) age from 0.5 m below the first occurrence of a shelly fauna in the Wilhelmi Formation. Streptelasma subregularis (Savage, 1913), collected by Savage from the Channahon Limestone, occurs with this shelly fauna. Its presence indicates correlation with the Cyrene Formation of northeastern Missouri and the Leemon Formation at locality 20b in southeastern Missouri. The Wilhelmi Formation is herein considered latest Ordovician in age. The overlying Elwood Formation is cherty (Willman, 1973, p. 14, 15), as is the basal Silurian Sexton Creek Formation of southeastern Missouri and southern Illinois. Silicified corals are common in the Elwood, in the basal Silurian Bryant Knob Formation of northeastern Missouri, and in the basal Brassfield Formation near Gallatin, Tennessee.

IV. CONTINENTAL MARGIN

INTRODUCTION

North of the Taconic Mountains on the continental margin of North America, more than 1000 m of highly variable clastic rocks of Ashgillian age were deposited in northern Maine (Text-fig. 2, nos. 19, 20). The sequence indicates rapidly changing local tectonic controls (R.B. Neuman, 1968, p. 45). To the north, these clastic rocks grade into carbonates. The thinly bedded calcareous strata of the White Head Formation, Gaspé Peninsula (Text-fig. 2, no. 21), are Upper Caradocian through Ashgillian and Llandoverian (Lower Silurian) in age (Text-fig, 2, no. 21). This sequence represents deposition in a stable environment through a long period of time (R. B. Neuman, 1968, p. 45). On Anticosti Island (Text-fig. 2, no. 22), the Upper Ordovician is more than 1000 m thick in places, and consists of interbedded limestones and shales of the Vaureal and overlying Ellis Bay formations. The lithology, sedimentary structures, and fauna indicate deposition in a shallow marine environment (Twenhofel, 1928, p. 19-21). Twenhofel (1928, p. 18) believed the clastic sediments were derived from the north. The general upward increase in carbonate content and faunal diversity and abundance, and the presence of stromatoporoid-colonial coral bioherms toward the top may indicate a generally shallowing upward sequence accompanied by increased productivity. Microscopic algal borings are present in four of

19 solitary corals (21 percent) from the Vaureal Formation, and 18 of 40 corallites (45 percent) of the overlying Ellis Bay Formation (App. 7). The great thickness of the continental margin marine sequences compared with those of the epicontinental sea (Richmond and Maquoketa groups) is probably largely the result of more rapid subsidence. Also, sedimentation appears to have been continuous at the continental margin in uppermost Ordovician time, whereas the Richmond Group was followed by a period of non-deposition and/or erosion. The Hirnantian strata of Gaspé and possibly northern Maine, and the Ellis Bay Formation (?Gamachian) of Anticosti Island may have been deposited during this interval.

19. PENOBSCOT COUNTY, MAINE

Over 1000 m of Ashgillian strata including large amounts of coarse, bouldery, polymict conglomerate, pebbly siltstone, and other clastic rocks are present in Penobscot Co. (R.B. Neuman, 1978, personal communication) (Text-figs. 2, no. 19; 22). In addition to brachiopods and trilobites,

Text-figure 22.--Eastern continental margin: late Upper Ordovician stratigraphic sections to scale and distribution of solitary rugose corals.

on which the age assignment was made, colonial and solitary corals and gastropods are present in the sequence (R.B. Neuman, 1968, p. 44, 45). The assemblage and relatively high diversity of genera more closely resemble faunas of Europe than those elsewhere in North America (R.B. Neuman, 1968, p. 36). Solitary rugose corals in this clastic sequence are associated with carbonate debris and fossil fragments (Plate 8, figs. 1, 2, 8). The corallite exteriors are generally abraded, but the occasional preservation of septal grooves and interseptal ridges suggests they may have been transported a short distance from a nearby carbonate bank. Densigrewingkia ? sp. is rare 61 m above the base of the sequence. Solitary corals are more common 520 m above the base, where Streptelasma rankini n. sp., Grewingkia penobscotensis n. sp., and Bodophyllum neumani

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Text-figure 22.--Eastern continental margin: late Upper Ordovician stratigraphic sections to scale and distribution of solitary rugose corals.

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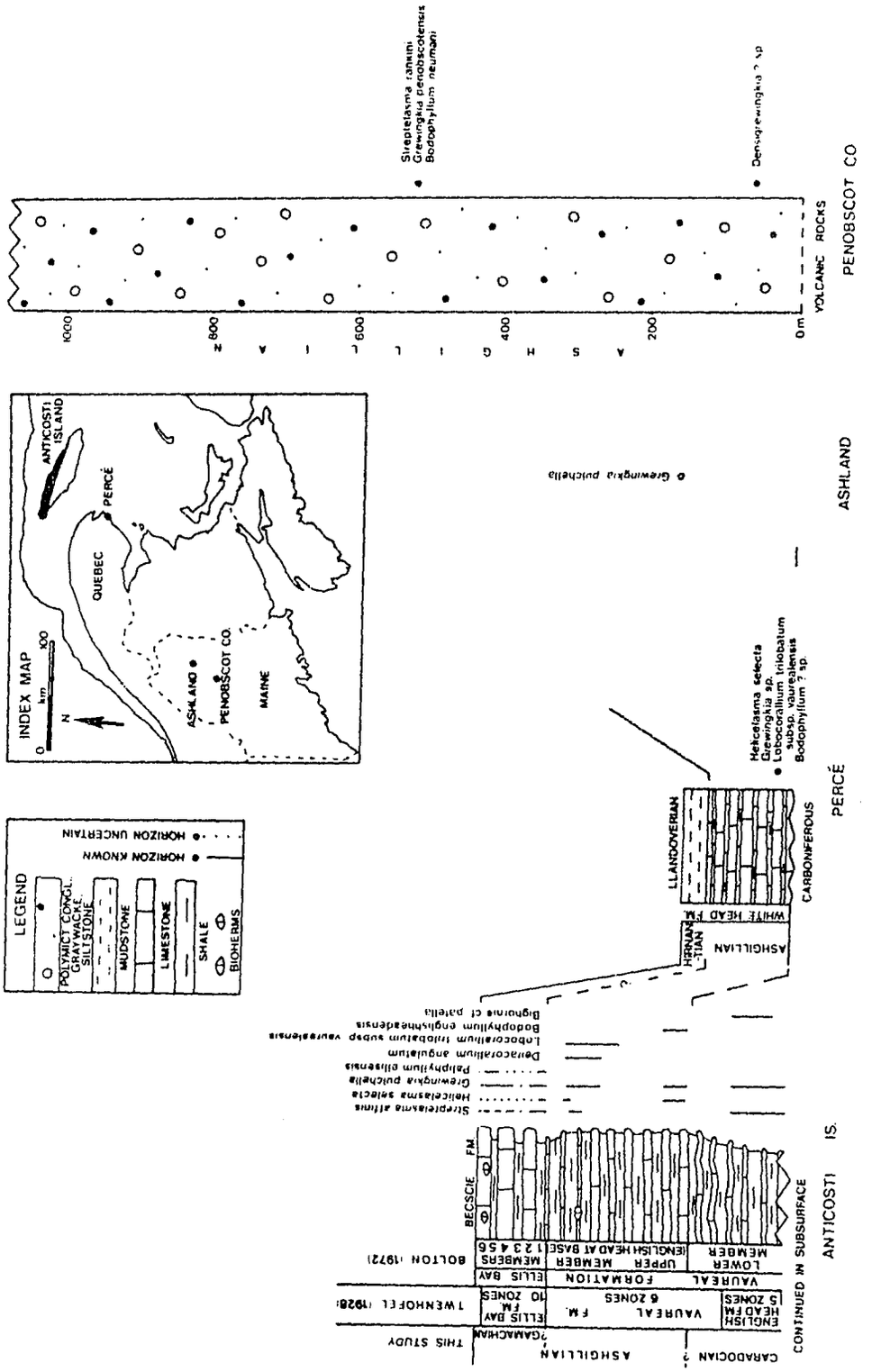

Text-fig. 22

n. sp. occur.

20. ASHLAND, MAINE

R.B. Neuman (1963) reported tuffaceous mudstone, basalt-limestone conglomerate, and other clastic rocks in a 45 m thick unnamed unit exposed in a gravel pit 9 km east of Ashland, Maine (Text-figs. 2, no. 20; 22). Brachiopods are by far the most common fossils in the sequence, followed by rugose and tabulate corals. Trilobites, gastropods, bryozoans, and graptolites are rare. The strata containing these fossils were deposited near the site of contemporaneous volcanism. Solitary rugose corals were found in bedrock exposures in the northeastern part of the gravel pit (R.B. Neuman, 1963, fig. 30.2). The abraded, apparently randomly oriented corallites occur in mudstone containing abundant volcanic fragments. The only species known from this locality, Grewingkia pulchella (Billings, 1865), also occurs in the Caradocian (?) through Ashgillian Vaureal and Ellis Bay formations of Anticosti Island, Quebec, indicating connection between the clastic and carbonate facies of the eastern continental margin.

21. PERCÉ, QUEBEC

The White Head Formation in the vicinity of Percé (Text-fig. 2, no. 21) is Upper Caradocian through Ashgillian and Llandoverian in age (Lespérance, 1968b). The White Head fauna in general is similar to that of Europe (Schuchert and Cooper, 1930, p. 170; Cooper and Kindle, 1936, p. 349; Lespérance, 1968b, p. 812). At the type section, where the base is unconformably overlain by Carboniferous strata, the Ashgillian is 140 m thick (Lespérance, 1977, personal communication) (Text-fig. 22). The Lower and Middle Ashgillian consists of thinly bedded calcareous mudstones with argillaceous interbeds. At Grande Coupe, the solitary corals Helicelasma selecta (Billings, 1865), Grewingkia sp., Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928), and Bodophyllum ? sp. are associated with a diverse fauna including the colonial corals Paleofavosites, Catenipora, Propora, and Calapoecia, as well as bryozoans, gastropods, cephalopods, brachiopods, and trilobites (Schuchert and Cooper, 1930, p. 169; Cooper and Kindle, 1936, p. 350). Trilobites, which are the most abundant fossils, suggest a Lower Ashgillian age for this Stenopareia faunal zone (Lespérance, 1968b, p. 813, 815, table 1). L. trilobatum subsp. vaurealensis and H. selecta also occur on Anticosti Island, as will be discussed in the section on Anticosti Island, Quebec. All solitary corallites were abraded and some were broken prior to final burial (Plate 4, fig. 17).

The single specimen of Bodophyllum ? sp. has an area of attachment on the cardinal side, and was epifaunal on a brachiopod (Plate 8, figs. 14-16). Vermiforichnus borings are generally common, and are abundant in the cardinal side of a specimen of Grewingkia sp. (USNM 102390(4)). Of 94 borings in three corallites, 27 percent are in the counter side, 23 percent in an alar side, and 50 percent in the cardinal side (App. 6). The frequency distribution of bore diameters is shown in Text-fig. 9c. The average diameter of Vermiforichnus in the White Head Formation is smaller than in the Richmond Group, Cincinnati Arch region and the Selkirk Member, Red River Formation (late Middle or Upper Ordovician), southern Manitoba (Text-fig. 9a, b, d). Microscopic algal borings are present in corallites of the White Head Formation, but are not well preserved.

Solitary corals are not known from the overlying Remipyga faunal zone, which is Lower or Middle Ashgillian in age (Lespérance, 1968b, p. 815, 816). Lespérance (1968a, p. 151-153) found a close correspondence among trilobite faunas of the Remipyga faunal zone, the Richmond Group, and the Ellis Bay Formation of Anticosti Island.

Overlying the Remipyga faunal zone are 25 m of mudstone containing the typical brachiopod-dominated Hirnantian fauna (Lespérance, 1974; Lespérance and Sheehan, 1976). All species identified from Percé also occur in the Hirnantian

Stage of the Ashgillian Series in northern Europe, and the fauna is most closely related to that of Great Britain and Ireland (Lespérance and Sheehan, 1976, p. 721, 722). A few small colonial corals occur in the section (Lespérance and Sheehan, 1976, p. 720), but solitary rugose corals have not been found.

22. ANTICOSTI ISLAND, QUEBEC

Stratigraphy

Approximately 300 m of the Vaureal Formation are exposed on northern Anticosti Island (Text-figs. 2, no. 22; 22), and the formation is at least 1000 m thick in a well drilled near the center of the island (Bolton, 1972, p. 3, 5). The lower member of the exposed Vaureal Formation, including the north shore argillaceous English Head Formation of Twenhofel (1928), consists of gray shale and interbedded fine grained to dense limestone with intraformational conglomerate. The limestone beds increase in thickness upward and become nodular. The lower member continues in the subsurface, where the shale content increases with depth until a gray shale unit is distinguishable. The upper member of the Vaureal Formation is at least 180 m thick. It includes the type English Head of Twenhofel (1928) at or near its base in western exposures. The member consists of gray, fine grained to dense limestone with abundant intraformational conglomerate, fine cross-bedding and channel fills, and gray shale partings and lenses. Inland, it includes thinly to thickly bedded dense to fine grained limestone with shale interbeds and partings, and nodular limestone. Toward the top of the upper member, colonial coral-stromatoporoid bioherms are overlain by irregularly bedded, dense to granular limestone with shale partings. The upper beds of the Vaureal are thinly bedded, fine grained to granular limestone with

abundant intraformational conglomerate, and thin interbeds or lenses of dense to semilithographic limestone with argillaceous partings. The uppermost beds are argillaceous nodular limestone.

In the lower gray shale unit of the subsurface Vaureal Formation, Jansonius (1967, p. 357) recorded Lower to Middle Caradocian chitinozoans. The graptolites (Riva, 1969) and trilobites (Bolton, 1970) are characteristic of the Lorraine-Ashgill-Harjuan. In his English Head Formation, Twenhofel (1928, p. 31) noted that brachiopods are dominant and gastropods plentiful. He stated that rugose corals are rare compared to tabulates, and listed and described the diverse fauna. On the bases of the fauna and distribution of some species, Twenhofel (1928, p. 63, 64) correlated the English Head with the "Waynesville" of the Richmond Group. Sinclair (1956, p. 1734) considered the "English Head" to be slightly older, equivalent to "some part of the Covington of Ohio and the Lorraine of New York and southern Quebec". Bolton (1972, p. 8) noted that several genera are apparently confined to the Richmondian. Twenhofel (1928, p. 31) observed a greater abundance of corals higher in the section (his Vaureal Formation), and listed and described the large fauna. On the bases of the fauna and the vertical distribution of some species, he correlated his Vaureal with the "Liberty" through "Elkhorn" of the Richmond Group.(Twenhofel, 1928, p. 65). The upper member of the Vaureal Formation in the

subsurface contains a graptolite fauna intermediate between the youngest Ordovician and oldest Silurian (Riva, 1969, p. 551). These beds contain Upper Caradocian chitinozoans according to Jansonius (1967, p. 357). Graptolites of the surface Vaureal Formation suggest a post-Ashgillian - pre-Llandoverian age (Riva, 1969, p. 553).

The Vaureal Formation is conformably overlain by the Ellis Bay Formation, which is 50 to 95 m thick (Bolton, 1961, p. 6). It consists of gray shale with argillaceous limestone, and units of interbedded limestone and shale. Six members were described by Bolton (1972, p. 8). In member 6, bioherms with abundant colonial corals are up to 110 m long and 5 m high. The contact with the overlying Llandoverian (Lower Silurian) Becscie Formation is difficult to define because of the very gradual lithologic transition. Twenhofel (1928, p. 32) noted that the diverse Ellis Bay fauna is larger than that of the Vaureal (including his English Head), and contains almost 25 percent of the species in these earlier units as well as many new forms. Brachiopods are the most abundant faunal element, and corals are more common than in the Vaureal. The fauna has a decided Richmondian aspect, but some species suggest a Silurian age (Twenhofel, 1928, p. 68, 69). Schuchert and Twenhofel (1910, p. 700, 701) proposed the Gamachian Stage to include the Ellis Bay Formation and all American strata later in age than the youngest Richmondian of Ohio and

Indiana but below clearly recognizable Silurian strata (Twenhofel, 1914, p. 8; 1928, p. 35, 36). J.P. Ross (1960, p. 1060, 1061) found many bryozoans of the Vaureal and Ellis Bay formations to be closely related to those in the Richmond Group of Ohio and the Maquoketa Group of Iowa, and did not support the concept of the Gamachian Series. Riva (1969) considered the Ellis Bay graptolites (as well as those of the Vaureal) to be post-Ashgillian but pre-Llandoverian in age. Lespérance (1968a, p. 151-153) found a definite close correspondence among trilobite faunas of the Richmond Group, Ellis Bay Formation, and Lower or Middle Ashgillian Remipyga faunal zone of the White Head Formation at Percé, Quebec. The ostracods appear to be Late Ordovician (Copeland, 1970). Boucot (in Ayrton, et al, 1969, p. 462), however, located the Ordovician-Silurian boundary between the Vaureal and Ellis Bay formations or within the Ellis Bay. He considered the Ellis Bay to be Early Llandoverian on the basis of two brachiopod species. Bolton (1972, table 1) placed the Ellis Bay Formation in the Richmondian.

Eight solitary corals are recognized from the Vaureal and Ellis Bay formations (Text-fig. 22). Streptelasma affinis (Billings, 1865) and Grewingkia pulchella (Billings, 1865) occur in the lower and upper members of the Vaureal Formation and in the Ellis Bay Formation. Bighornia cf. patella (Wilson, 1926) is found in the lower member of the Vaureal. Helicelasma selecta (Billings, 1865) is present from the

base of the upper member, Vaureal Formation, through the Ellis Bay Formation. Bodophyllum englishheadensis n. sp. occurs at the base of the upper member of the Vaureal. Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928) and Deiracorallium angulatum (Billings, 1862) are known from the upper part of the upper member, Vaureal Formation. Paliphyllum ellisensis n. sp. is present in the Ellis Bay Formation.

The upper member of the Vaureal Formation of Anticosti Island is herein correlated with the Stenopareia faunal zone of the White Head Formation at Percé. Lobocorallium trilobatum subsp. vaurealensis occurs in both units, and the correlation is strengthened by the presence of Helicelasma selecta, although this species extends into the Ellis Bay Formation on Anticosti Island. The genus Bodophyllum, represented in the upper member of the Vaureal Formation, may also occur in the Stenopareia faunal zone (Text-fig. 22).

The presence of Lobocorallium trilobatum subsp. vaurealensis and Deiracorallium angulatum in the upper Vaureal Formation and the former in the Stenopareia faunal zone of the White Head Formation indicate correlation with the Gunn and Penitentiary members of the Stony Mountain Formation, southern Manitoba, in which Lobocorallium trilobatum (Whiteaves, 1895) and a species of Deiracorallium probably conspecific with D. angulatum occur. The upper Vaureal and Stenopareia faunal zone would be slightly older

if L. trilobatum subsp. vaurealensis was the immediate ancestor of L. trilobatum, but the two could have been contemporary geographic variants (see Systematic Paleontology). Twenhofel (1928, p. 66, 67) considered the fauna in his zones 3-5 of the Vaureal Formation to indicate fairly positive correlation with the Stony Mountain Formation. The upper Vaureal Formation and Stony Mountain Formation are Lower Ashgillian if the age assignment of the Stenopareia faunal zone is correct (Lespérance, 1968b, p. 813, 815, table 1). The lower Vaureal Formation and the Red River Formation of southern Manitoba, which underlies the Stony Mountain, may therefore be Caradocian in age. Bighornia cf. patella occurs in both units, but is widespread geographically and stratigraphically (see Systematic Paleontology).

Three of the six solitary coral species in the upper member of the Vaureal Formation extend through the Ellis Bay Formation, indicating its Ordovician age. Streptelasma affinis, which is common in the Ellis Bay, most closely resembles S. primum (Wedekind, 1927) of the Ashgillian Division 5a of Norway and Boda Limestone of Sweden. It is similar to S. subregularis (Savage, 1913) of the latest Upper Ordovician (? Gamachian) in Missouri and Illinois, and S. unicum Neuman, 1975, probably from the Hirnantian Dalmanitina beds of Sweden. Paliphyllum ellisensis represents a genus found in member no. 3 of the Chasm Creek Formation, Churchill River Group, northern Manitoba, which correlates with the

upper Stony Mountain Formation of southern Manitoba (Nelson, 1963, fig. 2). Paliphyllum is also known from the Upper Ordovician of Sweden, Estonia, and Siberia, and the Llandoverian (Lower Silurian) of Estonia. The Ellis Bay may in part correlate with the Lower or Middle Ashgillian Remipyga faunal zone of the White Head Formation at Percé, as suggested by the stratigraphic position and trilobites (Lespérance, 1968a, p. 151-153). Strata equivalent to the Upper Ashgillian Hirnantian mudstones of the White Head could also be represented in the Ellis Bay Formation, but the Hirnantian fauna has not been recognized in the carbonate facies on Anticosti Island. If the Ellis Bay Formation proves to be at least partly post-Richmondian and of the same age as the Hirnantian, the term Gamachian Stage (Schuchert and Twenhofel, 1910, p. 700, 701) has priority (Lespérance and Sheehan, 1976, p. 721).

Solitary Rugose Corals

Streptelasma affinis occurs in the Vaureal Formation, and is common in the Ellis Bay Formation. Corallites show little evidence of pre-depositional abrasion, and apparently lived in low energy environments (Plate 3, figs. 21-23). Corallites are ceratoid to trochoid and very weakly to moderately curved in early stages, becoming cylindrical in late stages (Plate 3, figs. 17, 27). Talons are sometimes present in early stages (Plate 3, figs. 17, 21). Corallites attain very large size in the upper Vaureal Formation (GSC 1987), and in Twenhofel's (1928) zones 5 (YPM 555a) and 9 (YPM 3063/57k) of the Ellis Bay Formation. Epifaunal organisms are fairly common (Plate 3, fig. 21; App. 5). In the Vaureal Formation they include stromatoporoids, bryozoans, and colonial corals. In Twenhofel's zone 5 of the Ellis Bay Formation, bryozoans, stromatoporoids, and cornulitids occur as epifauna, and in zones 7 and 9, epifaunal bryozoans and stromatoporoids are present. Coarse rugae are regularly spaced on some corallites in the lower Vaureal and Twenhofel's zones 5 and 9 of the Ellis Bay Formation (Plate 3, fig. 21; App. 11). Environmental conditions must have been stable and very favorable for organisms during deposition of the Vaureal and Twenhofel's zones 5 and 9 of the Ellis Bay Formation. *Vermiforichnus* borings are very rare, being present in two of 29 specimens (App. 6). Microscopic algal borings are present in eight

of 16 corallites for which thin sections were examined (App. 7). Those in YPM 556b are considered Recent in age because they penetrate secondary calcite crystals.

Helicelasma selecta is uncommon in Twenhofel's collection. Almost all corallites were abraded prior to final burial, indicating transportation in relatively high energy conditions (Plate 4, fig. 11). They occur in argillaceous wackestone and packstone. Epifauna were not observed. Vermiforichnus borings are present in one of ten corallites (App. 6). Microscopic algal borings occur in four of five corallites for which thin sections were examined (App. 7).

Corallites of Deiracorallium angulatum are extremely well preserved and were not abraded prior to final burial, indicating that they lived in very low energy conditions (Plate 4, figs. 20s, 21s, 24s, 25s). The species appears to be generally sparse, but is quite abundant in argillaceous limestones of the Potatoe River area (Bolton, 1977, personal communication). Epifauna and borings are not present in the 33 corallites examined.

Grewingkia pulchella appears to be the most abundant solitary coral on Anticosti Island. Corallites are generally not abraded, and presumably lived in low energy environments (Plate 7, figs. 24, 25, 28, 32). They occur in argillaceous limestones in association with bryozoans and brachiopods. YPM 551 was collected in a bioherm within

the Ellis Bay Formation. The frequency distribution of corallite lengths in Twenhofel's collection is shown in Text-fig. 23. The distribution above 15 mm is thought to

Text-figure 23.--Grewingkia pulchella (Billings, 1865): length of corallites (l) (see App. 3). Collecting bias is thought to contribute, at least in part, to low frequencies below 15 mm.

reflect the population. Collecting bias probably contributes, at least in part, to the progressively lower frequencies of smaller corallites. The effects of biologic factors such as birth rate, growth rate, and death rate are unknown. The distribution resembles that for Streptelasma divaricans (Text-fig. 14). Only one of more than 100 G. pulchella corallites has epifaunal bryozoans (App. 5). Vermiforichnus borings are not present. Microscopic algal borings occur in ten of 19 corallites for which thin sections were examined (App. 7).

Lobocorallium trilobatum subsp. vaurealensis is rare. These large, trilobate corallites were abraded in relatively high energy conditions prior to burial (Plate 7, fig. 43s). YPM 20482 occurs in argillaceous limestone with abundant brachiopods, bryozoans, and arthropod fragments. At GSC locality 36157, corallites are present in coarse grained packstone. Epifauna and boring algae are not present. YPM

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Text-figure 23.--Grewingkia pulchella (Billings, 1865): length of corallites (l) (see App. 3). Collecting bias is thought to contribute, at least in part, to low frequencies below 15 mm.

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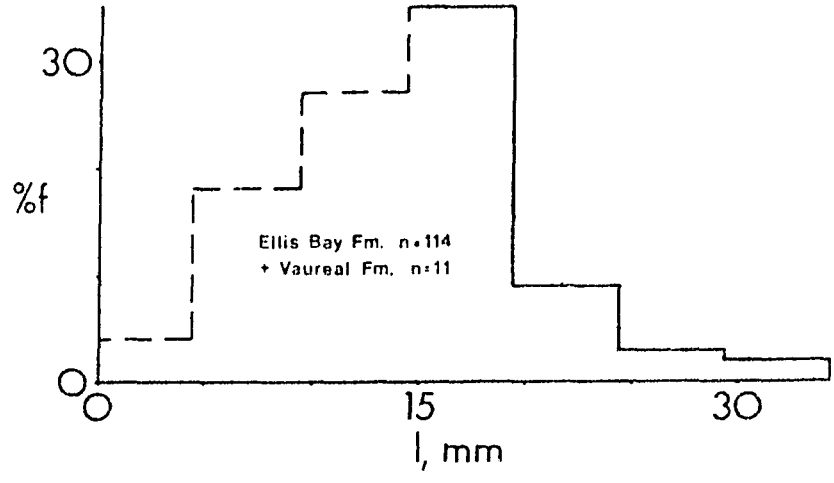


Text-fig. 23

20482 has abundant Vermiforichnus borings (Plate 7, fig. 43s; App. 6).

Corallites of Bodophyllum englishheadensis are rare. They have a base of attachment centered on the cardinal side, and YPM 3019/2c was epifaunal on a bryozoan (Plate 8, figs. 18, 21). The corallites were abraded before burial, indicating relatively high energy condition. YPM 3063/15a, b occur in wackestone with brachiopods and arthropod fragments, and YPM 3019/2a, c are in echinodermal packstone. Epifauna and borings are not present in the five corallites examined.

Bighornia cf. patella is rare. Corallites have spoon-shaped areas of attachment on the concave cardinal side near the tip (Plate 8, fig. 38). The species presumably lived in low energy environments and corallites were not abraded before burial. Epifauna and borings are not present.

Paliphyllum ellisensis is uncommon. Several corallites were collected from an Ellis Bay bioherm (YPM 573, a). A few were slightly abraded before burial. The corallites are cylindrical and some have regularly spaced coarse rugae (Plate 8, fig. 51; App. 11). The species probably lived in a fairly low energy, stable environment. Epifaunal bryozoans occur on five of 26 corallites (App. 5). Borings are not present.

LATE UPPER ORDOVICIAN SOLITARY RUGOSE CORAL PROVINCES OF EASTERN NORTH AMERICA

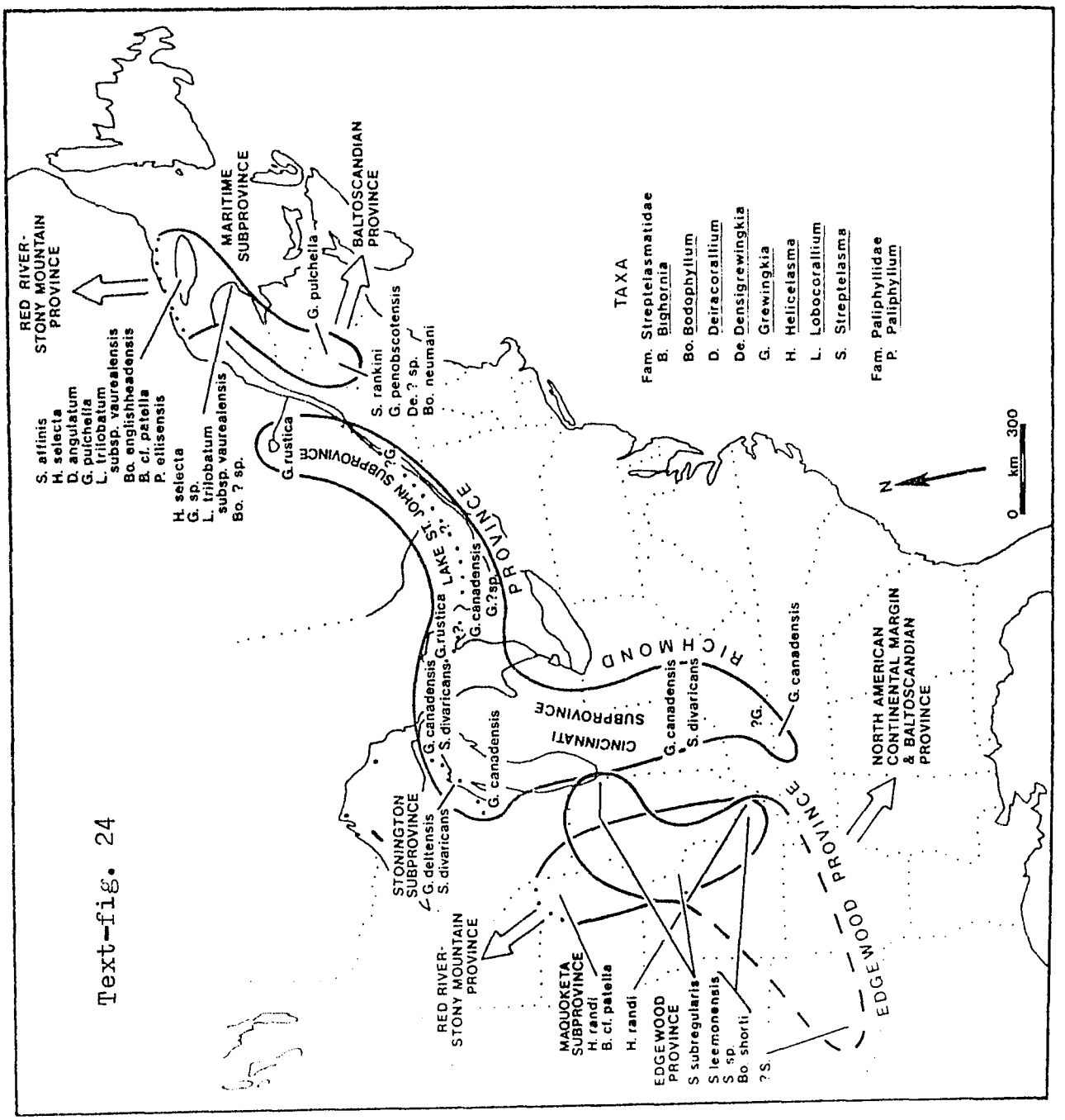
INTRODUCTION

Late Upper Ordovician solitary corals of eastern North America are assigned to three provinces distinguished on the bases of assemblages and characteristic species (Text-fig. 24). The distribution of these provinces corresponds

Text-figure 24.--Late Upper Ordovician solitary rugose coral provinces of eastern North America.

closely to paleogeography and lithofacies (Text-fig. 2). The Richmond Province coincides with the Richmond Group. Solitary corals of the Maquoketa Group and eastern continental margin belong to the Red River-Stony Mountain Province of central North America. Those in the uppermost Ordovician carbonate sequence of Oklahoma-Missouri-Illinois are assigned to the Edgewood Province.

Text-figure 24.--Late Upper Ordovician solitary rugose coral provinces of eastern North America.



Text-fig. 24

I. RICHMOND PROVINCE

The Richmond Province is characterized by very low diversity (Text-fig. 24). The genera Grewingkia and Streptelasma are represented by G. canadensis, G. rustica, G. deltensis, and S. divaricans. G. canadensis occurs in Tennessee, the Cincinnati Arch region, Wisconsin, Drummond and Manitoulin Islands, and at Meaford, Ontario. S. divaricans is present in the Cincinnati Arch region, northern Michigan, and at Manitoulin Island. The large central area of the Richmond Province where G. canadensis and often S. divaricans occur is termed the Cincinnati Subprovince. In the Little Bay de Noc region of northern Michigan, S. divaricans and G. deltensis are present. The latter species is unique to this area, which is termed the Stonington Subprovince. G. rustica occurs at Lake St. John, Quebec, and a single corallite found at Manitoulin Island was transported from an unknown source. The area of the Richmond Province occupied by G. rustica is termed the Lake St. John Subprovince. Its exact boundary with the Cincinnati Subprovince is uncertain because corallites in the vicinity of Montreal, Quebec, and Streetsville, Ontario, are not known at the species level.

Origin. Solitary corals of the Richmond Province first appeared in carbonate beds at the base of the "Waynesville" horizon in the Richmond Group. Those in the lower Arnheim Formation of Tennessee may also be of "Waynesville" age.

Solitary corals are not known in Upper Ordovician strata underlying the Richmond Group. They may have been introduced to this geographic region during an early Richmondian transgression. The source probably lay to the west, where solitary corals occur in Edenian-Maysvillian strata of the Maquoketa Group. Solitary corals in the Trentonian-Early Cincinnatian of Minnesota, described as Streptelasma corniculum and S. rusticum in Winchell and Schuchert (1895, p. 90, 91, 93, Pl. G, figs. 20-23) resemble Grewingkia canadensis and G. rustica externally, and the Trentonian S. (?) parasiticum Ulrich (in Winchell and Schuchert, 1895, p. 89, 90, fig. 6) is remarkably similar in growth form to S. divaricans. A detailed study of the late Middle-early Upper Ordovician solitary corals of eastern North America is required to determine if the Richmond Group contains recurrent Black River-Trenton forms (see Foerste, 1924, p. 43-45).

G. canadensis and G. rustica are virtually identical externally. A single G. rustica corallite was found on Manitoulin Island at the base of the Meaford beds in which G. canadensis occurs. It was transported from an unknown source, but suggests close relation in space and time between the two species. It is possible that both were derived from a common ancestor, or G. rustica may have arisen from G. canadensis in the eastern digitation of the Richmond Group by geographic speciation very soon after

introduction from the west.

Grewingkia deltensis, which occurs in micritic limestone of the Ogontz Member, Stonington Formation, northern Michigan, has the trochoid, moderately curved form and large size typical of species of Grewingkia in massive carbonates of the Selkirk Member, Red River Formation (late Middle or Upper Ordovician), southern Manitoba (Elias, 1976). G. deltensis occurs in the digitation of the Richmond Province nearest Manitoba. Selkirk Member corals of different genera occur in the Maquoketa Group to the southwest, indicating that migration across the Transcontinental Arch was possible. G. deltensis may have arisen from Red River species. It was unable to migrate farther into the Richmond Province because suitable environments resulting in Ogontz-type deposition did not occur elsewhere.

Fate. Following introduction into the belt of Richmond Group sedimentation, solitary corals migrated laterally as favorable environments became more widespread. They attained their maximum geographic range during "Liberty-early Whitewater" time. Migration out of and into the Richmond Group was restricted shoreward by the Queenston delta, the positive Nashville Dome, and the Canadian Shield, which was probably slightly positive (Copper and Grawbarger, 1978, p. 1990). Seaward of the carbonate platform, deeper waters in which the Maquoketa shale was deposited proved to be an

impenetrable barrier.

Progradation of the Queenston delta eliminated corals from the Montreal, Streetsville, and Meaford areas during Richmondian time (Text-fig. 18). Extinction of Richmond Province species resulted from withdrawal of the eastern North American epicontinental sea at the close of the Richmondian Stage, possibly due to a glacioeustatic sea-level drop. An incursion of the Richmond Group at the top of the Maquoketa Shale at Little Sturgeon Bay, Wisconsin, reflects this final westward retreat.

II. RED RIVER-STONY MOUNTAIN PROVINCE

The Red River-Stony Mountain Province is characterized by corallites having peculiar external form (Elias, 1976). Grewingkia includes forms that are circular, compressed, triangulate, and trilobate in cross-section. Species of Deiracorallium are compressed, and Lobocorallium is trilobate. Bighornia is distinct in having the cardinal septum on the concave side of the depressed corallite. Diversity in the carbonate facies of the Red River-Stony Mountain Province is generally high.

A. MAQUOKETA SUBPROVINCE

The Maquoketa Subprovince is characterized by the paucity and very low diversity of solitary corals in carbonate beds within the Maquoketa Group, which is predominantly shale (Text-fig. 24). Helicelasma randi occurs in the Maquoketa Group in northeastern Iowa-northwestern Illinois, and southwestern Illinois. It is also present in the Selkirk Member, Red River Formation (late Middle or Upper Ordovician) of southern Manitoba. In the Maquoketa Subprovince, Bighornia cf. patella is known only from the Fort Atkinson Formation in northeastern Iowa. This species also occurs in the Red River and Stony Mountain formations of southern Manitoba and at other localities in the Red River-Stony Mountain Province (see Systematic Paleontology). The presence of identical species on both sides of the Transcontinental Arch indicates that migration

across this slightly positive structure took place at least periodically during the late Middle to Upper Ordovician. H. randi and B. cf. patella became extinct in the Maquoketa Subprovince when the eastern North American epicontinental sea withdrew at the end of the Richmondian.

B. MARITIME SUBPROVINCE

A diverse assemblage of solitary corals occurs at the continental margin (Text-fig. 24). Bighornia cf. patella, a characteristic Red River-Stony Mountain species of wide geographic and considerable stratigraphic range, occurs with Streptelasma affinis and Grewingkia pulchella in the lower member of the Vaureal Formation on Anticosti Island. Deiracorallium angulatum of the upper member is probably conspecific with the form in the Stony Mountain Formation of southern Manitoba and the correlative Churchill River Group of northern Manitoba. Lobocorallium trilobatum subsp. vaurealensis is very close to L. trilobatum of the Stony Mountain Formation. Also present in the upper member of the Vaureal Formation are S. affinis, Helicelasma selecta, G. pulchella, and Bodophyllum englishheadensis. In the Stenopareia faunal zone of the White Head Formation at Percé, L. trilobatum subsp. vaurealensis occurs with H. selecta, Grewingkia sp., and Bodophyllum ? sp. S. affinis, H. selecta, and G. pulchella of the Vaureal Formation extend into the Ellis Bay Formation of Anticosti Island. Also present is Paliphyllum ellisensis, representing a genus

found in the Red River-Stony Mountain Province in northern Manitoba. G. pulchella, apparently the most abundant species at Anticosti Island, also occurs in the clastic facies near Ashland, Maine. In Penobscot Co., Maine, S. rankini, G. penobscotensis, Bodophyllum neumani, and Densigrewingkia ? sp. are present. Although the species are unique to this locality, the generic assemblage resembles that at Percé and Anticosti Island.

Presence of the characteristic genera Lobocorallium, Deiracorallium, and Bighornia indicates that the carbonate facies of the Anticosti-Percé region is part of the Red River-Stony Mountain Province. Correspondence at the species level, especially with southern Manitoba, indicates communication via the northern Canadian Shield during the Upper Ordovician. Although characteristic Red River-Stony Mountain taxa are not known from Maine, the presence of G. pulchella on Anticosti Island and at Ashland, Maine, indicates connection of the carbonate and clastic facies. The generic assemblage comprising Streptelasma, Grewingkia, Bodophyllum, Helicelasma, and Paliphyllum is typical of the late Upper Ordovician Baltoscandian Province (Table 3). Although Grewingkia, Helicelasma, and Paliphyllum

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Table 3.--Ashgillian solitary rugose coral genera of Scandinavia (compiled from B. Neuman, 1968, 1969, 1975). Division 5b and the Dalmanitina beds contain the characteristic Hirnantian fauna. The Boda Limestone, which

comprises reef core and flank deposits, probably corresponds in part to the Dalmanitina facies. It does not contain the typical Hirnantian fauna, but more characteristic elements occur in increasingly shaly beds to the south (Lespérance, 1978, personal communication).

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are also represented in the continental interior of the Red River-Stony Mountain Province, Streptelasma and Bodophyllum are unknown. The Maritime Subprovince at the North American continental margin is characterized by Red River-Stony Mountain species in association with genera typical of the Baltoscandian Province.

Table 3.--Ashgillian solitary rugose coral genera of Scandinavia (compiled from B. Neuman, 1968, 1969, 1975). Division 5b and the Dalmanitina beds contain the characteristic Hirnantian fauna. The Boda Limestone, which comprises reef core and flank deposits, probably corresponds in part to the Dalmanitina facies. It does not contain the typical Hirnantian fauna, but more characteristic elements occur in increasingly shaly beds to the south (Lespérance, 1978, personal communication).

TABLE 3

LOCATIONS	HORIZONS \ TAXA	Fam. Streptelasmatidae							Fam. Tryplasmatidae	Fam. Paliphyllidae
		Streptelasma	*Grewingkia*	*Bodophyllum*	*Helicelasma*	*Densigrewingkia*	*Borelasma*	*Ullernelasma*	*Tryplasma*	*Paliphyllum*
Norway	Division 5b			X		X		X		
	Division 5a	X	X	X		X				
Sweden	*Dalmanitina* beds	X		X	X		X			
	Boda Limestone	X	X	X					X	X

III. EDGEWOOD PROVINCE

Solitary corals of the uppermost Ordovician carbonate sequence in Illinois, Missouri, and probably Oklahoma constitute the Edgewood Province (Text-fig. 24). They are different from corals of the Red River-Stony Mountain and Richmond provinces of the continental interior. Streptelasma subregularis, S. leemonensis, Streptelasma sp., and Bodophyllum shorti form an assemblage resembling those of the North American continental margin and the Baltoscandian Province. S. subregularis is similar to S. affinis of Anticosti Island, and most closely resembles S. unicum of Sweden. B. shorti is the only representative of the genus known from the continental interior of North America.

The uppermost Ordovician transgression that marked the beginning of Middle Paleozoic carbonate deposition in the east-central United States may be related to deglaciation. The transgression probably proceeded from the south, and brought with it an assemblage previously restricted to the continental margin. This introduction foreshadowed the cosmopolitan Silurian fauna (Kaljo and Klaamann, 1973). Laub (1975; 1976, p. 51) found that corals of the Middle Llandoverian (Lower Silurian) Brassfield Formation of the Cincinnati Arch region show greatest similarity to the eastern North American continental margin fauna.

UPPER ORDOVICIAN SOLITARY RUGOSE CORALS OF NORTH AMERICA

BIOGEOGRAPHY

INTRODUCTION

Three Upper Ordovician solitary coral provinces, the Red River-Stony Mountain, Richmond, and Edgewood, are presently recognized in North America (Text-fig. 25). The

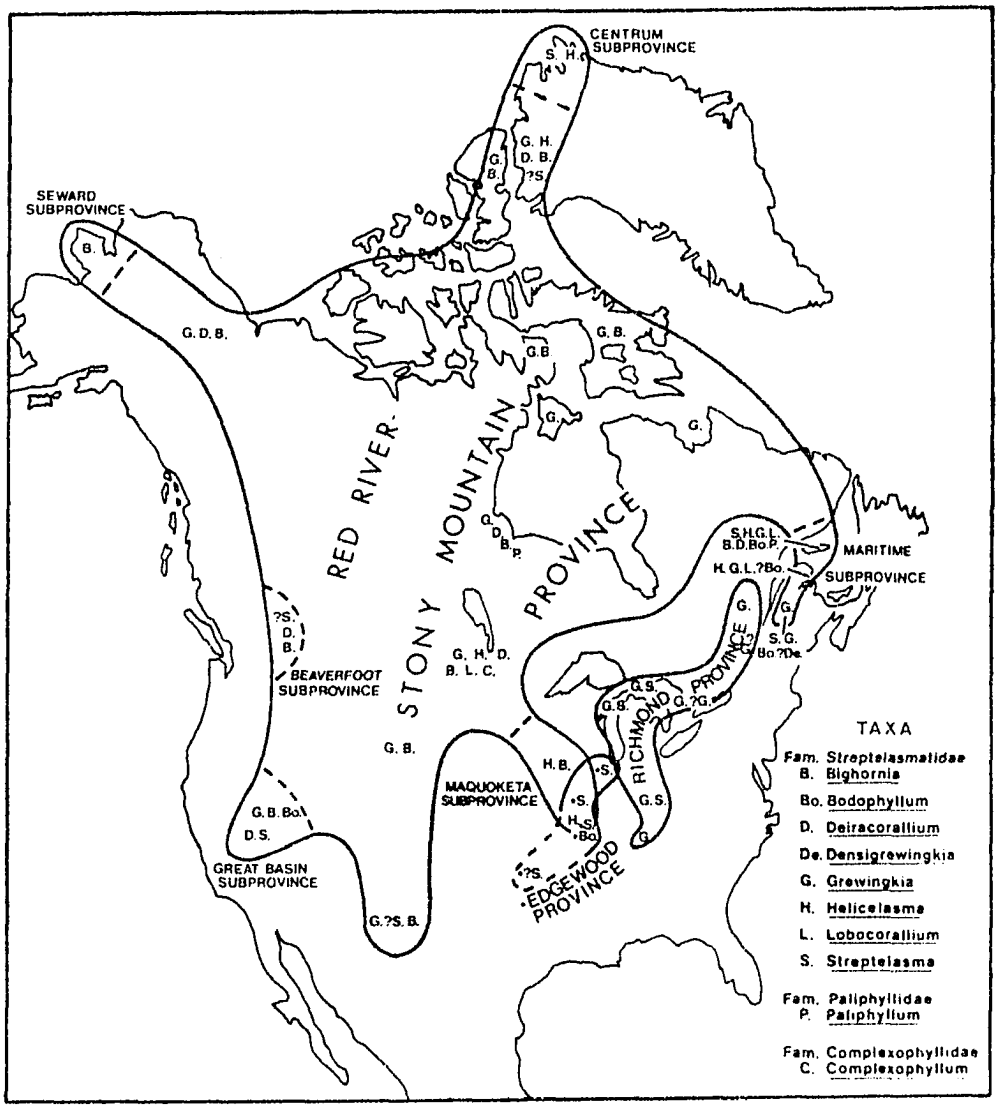
Text-figure 25.--Upper Ordovician solitary rugose coral provinces of North America.

geographic and stratigraphic distribution of taxa characterizing them was determined by regional environmental parameters related to paleogeography. The late Middle through Upper Ordovician Red River-Stony Mountain Province is by far the most extensive.

I. RED RIVER-STONY MOUNTAIN PROVINCE

Continental Interior. The vast continental interior portion of the Red River-Stony Mountain Province was occupied by shallow, interconnected epicontinental seas centralized in large areas of subsidence such as the Williston and Hudson Bay basins. Remarkably similar massive carbonate deposits formed throughout the area, indicating widespread, stable, uniform environmental conditions (Flower, 1965, fig. 5). This region corresponds to the North America brachiopod province (Sheehan, 1975) and Midcontinent conodont province,

Text-figure 25.--Upper Ordovician solitary rugose coral provinces of North America.



Text-fig. 25

thought to have been characterized by raised temperatures and salinity (Barnes and Fåhraeus, 1975). Solitary coral assemblages dominated by Grewingkia are similar throughout the region, although there is some differentiation at the species level from basin to basin (Elias, 1976, p. 48-52). Diversity is generally high -- nine species representing five genera are present in the Selkirk Member, Red River Formation, of southern Manitoba (Elias, 1976). Corallites are often trochoid, generally moderately curved, and frequently attain large size. External variation within some species is great. Grewingkia robusta corallites vary from circular in cross-section to weakly triangulate to weakly trilobate. All solitary corals of the continental interior have strongly to completely dilated septa in early stages and sometimes throughout ontogeny. An axial structure is present, or major septa extend to the axis. There is generally little intraspecific variation in the number of septa at a particular cross-sectional area (Elias, 1976, fig. 3).

Continental Margin. Carbonate and clastic sediments were deposited in digitations of the Red River-Stony Mountain Province at the continental margins of North America. These areas correspond to the North European brachiopod province (Sheehan, 1975) and North Atlantic conodont province, thought to have been characterized by normal Ordovician open marine environments (Barnes and Fåhraeus, 1975).

Large bioherms developed at Anticosti Island and in Arctic Canada. Solitary coral diversity can be higher at the generic level than in the continental interior. Eight genera are known from Anticosti Island, each represented by a single species. Corallites are usually of small size, although some species such as Streptelasma affinis attain very large size. There is generally relatively little intraspecific variation. Streptelasma and Bodophyllum, both unknown in the continental interior, are often associated with characteristic Red River-Stony Mountain forms. These two genera have undilated to weakly dilated septa, and Streptelasma generally has an open axial region.

II. RICHMOND PROVINCE

The Richmond Province corresponds to a carbonate platform at the margin of an epicontinental sea receiving clastic sediments from the Queenston delta. A wide variety of environments were present, ranging from open waters of the platform margin where colonial coral banks developed, to restricted hypersaline lagoons. As would be expected in an area of clastic sedimentation, solitary coral diversity is very low. Grewingkia canadensis and Streptelasma divaricans are present in the relatively large central area of the province, whereas G. deltensis and G. rustica occur in digitations at the margin. What the assemblage lacks in taxonomic diversity is offset by an incredible degree of intraspecific variability in G. canadensis and S. divaricans. The number of septa at a particular corallite diameter is highly variable. Variation in the axial region within these species spans several genera, as they are presently defined.

The Richmond Province was separated paleogeographically from the Red River-Stony Mountain Province by the Canadian Shield to the north and Taconic upland to the east. On the west, the deeper waters in which Maquoketa shale was deposited proved to be an impenetrable barrier for solitary corals. The Nashville Dome formed the southern boundary of the Richmond Province. To account for the different assemblages in these two provinces, Flower (1946, p. 127) and Nelson (1959a) suggested that the Red River-Stony

Mountain fauna was tropical whereas the eastern (Richmond) fauna was temperate. This widely cited climatic influence need not be invoked, especially when it is seen that the Red River-Stony Mountain Province occurs on opposite sides and ends of the Richmond Province. Paleogeography and the related type of sedimentation are the primary factors that determined the nature and extent of these provinces.

III. EDGEWOOD PROVINCE

The Edgewood Province corresponds to the carbonate sequence deposited during a latest Upper Ordovician transgression into the continental interior. Normal Ordovician open marine environments are indicated by the development of oölite shoals and small bioherms. As would be expected, the solitary corals (and brachiopods) resemble those previously restricted to the continental margin. Streptelasma subregularis is widely distributed, occurring in northeastern Illinois and north- and southeastern Missouri. The corallites vary from trochoid to ceratoid in external form, but there is little internal variation. Streptelasma leemonensis, Streptelasma sp., and Bodophyllum shorti are present in southeastern Missouri.

BIOSTRATIGRAPHY

Upper Ordovician solitary rugose coral provinces of North America have relatively large central areas containing geographically widespread diagnostic taxa, and smaller marginal digitations in which different taxa are often associated with these characteristic forms. This distribution permits correlation within provinces. For example, Grewingkia robusta of the continental interior, Red River-Stony Mountain Province, occurs in the Red River Formation of southern Manitoba and the correlative Bad Cache Rapids Group of northern Manitoba and Melville Peninsula (Elias, 1976; Bolton, 1977). Lobocorallium trilobatum is present in the Stony Mountain Formation of southern Manitoba, and L. trilobatum subsp. vaurealensis is known from the continental margin in the Vaureal Formation of Anticosti Island and White Head Formation of Percé, Quebec. Correlations must be made with caution, however. Helicelasma randi occurs in the Selkirk Member of the Red River Formation, southern Manitoba, and in the upper Brainard Formation of Iowa and Illinois, which is almost certainly younger. Grewingkia pulchella has a long stratigraphic range on Anticosti Island, extending from the lower Vaureal to upper Ellis Bay formations.

Accurate correlation between provinces is impossible because the species and assemblages are different. Consequently, strata outside the Richmond Province cannot be correlated, using solitary corals, with the North American

Upper Ordovician type section of the Cincinnati Arch region. The compressed, triangulate, and trilobate taxa characteristic of the Red River-Stony Mountain Province are unknown elsewhere in the world. Although assemblages on the eastern and southwestern continental margin of the Red River-Stony Mountain Province, the Baltoscandian Province, and the latest Ordovician Edgewood Province are somewhat similar, they have no species in common. The solitary corals in these assemblages reflect similar normal Ordovician open marine environments, and do not necessarily indicate close genetic relationship, geographic proximity, or contemporaneity.

MORPHOLOGY AND TAXONOMY

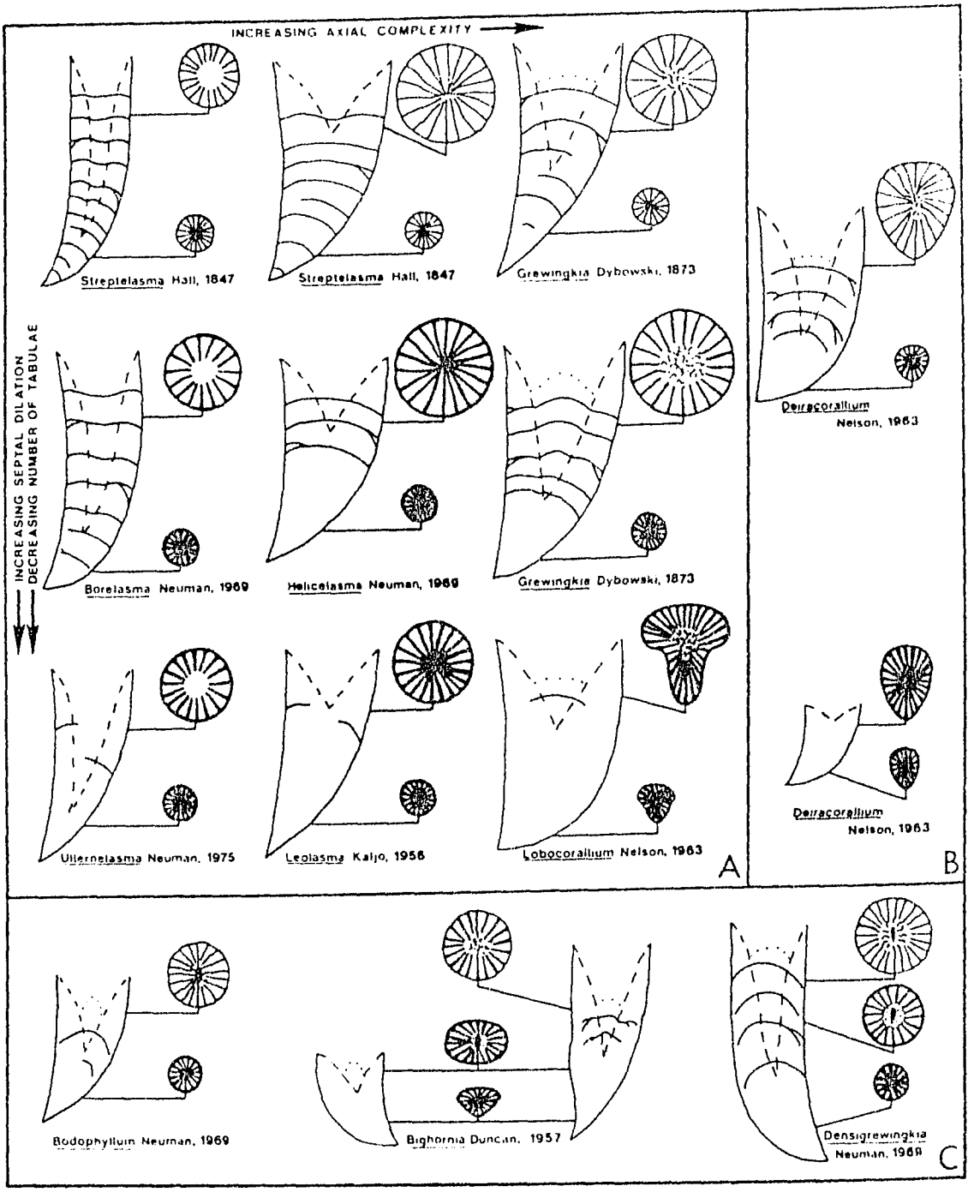
Virtually all Upper Ordovician solitary rugose corals of North America possess a septal stereozone and belong to the Family Streptelasmatidae Nicholson in Nicholson and Lydekker, 1889. A single corallite of Complexophyllum leithi Elias, 1976 is known from the Selkirk Member, Red River Formation, southern Manitoba, and represents the Family Complexophyllidae Elias, 1976. It has major septa inserted in eight positions rather than four as is typical of the Rugosa. Paliphyllum ellisensis (Twenhofel, 1928) of the Ellis Bay Formation, Anticosti Island, Quebec, and P. stummi (Nelson, 1963) of the Chasm Creek Formation, northern Manitoba, possess a dissepimentarium. They represent the Family Paliphyllidae Soshkina, 1955. The phylogenetic relationship of these families is uncertain.

Upper Ordovician solitary streptelasmatid genera are distinguished primarily on the bases of the nature of the axial region, the degree of septal dilation, and degree of development of tabulae (Text-fig. 26). Most occupy positions

Text-figure 26.--The conceptual bases for Upper Ordovician solitary streptelasmatid coral "genera" (some illustrations adapted from B. Neuman, 1969, 1975).

within the field of variability shown in Text-fig. 26a. In order to evaluate the validity of these genera, the

Text-figure 26.--The conceptual bases for Upper Ordovician solitary streptelasmatid coral "genera" (some illustrations adapted from B. Neuman, 1969, 1975).



Text-fig. 26

following points must be considered [all species used as examples are figured in B. Neuman (1969), Elias (1976), and herein]:

1. Streptelasma includes species having an open axial region as in S. subregularis (Savage, 1913) and S. primum (Wedekind, 1927), species such as S. leemonensis n. sp. in which septa extend to or almost to the axis, and species having a weak axial structure, for example S. eccentricum Neuman, 1969. However, Borelasma and Helicelasma, and Ullernelasma and Leolasma are considered distinct.

2. The axial region in corallites of Streptelasma divaricans (Nicholson, 1875) varies from open, to those in which major septa extend to the axis, to corallites with an axial structure of complexity comparable to Grewingkia.

3. An axial region is not present in some corallites of Helicelasma randi Elias, 1976, but in others it is as large as that of Grewingkia and a weak axial structure is developed.

4. The axial region in corallites of Grewingkia canadensis (Billings, 1862) varies from open as in Borelasma, to those resembling Helicelasma in having major septa that extend to the axis, to corallites with simple to complex axial structures characteristic of Grewingkia.

5. Streptelasma includes species such as S. divaricans in which major septa are undilated in early stages, and S. subregularis and S. corniculum Hall, 1847 having moderately dilated septa. However, species with strongly dilated septa are referred to Borelasma and Helicelasma.

6. Grewingkia includes species such as G. penobscotensis n. sp. and G. anguinea (Scheffen, 1933) having weakly dilated major septa in early stages, to G. rustica (Billings, 1858) in which dilation is complete in early stages and very strong even in later stages.

7. Species of Helicelasma such as H. selecta (Billings, 1865), in which septa are completely dilated until the latest stages and tabulae are rare, approach Leolasma.

8. The following continuous morphologic sequence between Grewingkia and Lobocorallium is recognized, and involves an increase in the degree of trilobation and septal dilation, and a decrease in the number of tabulae: G. robusta (Whiteaves, 1896) → G. haysi (Meek, 1865) → L. trilobatum subsp. vaurealensis (Twenhofel, 1928) → L. trilobatum (Whiteaves, 1895).

9. Deiracorallium differs from Grewingkia in that the corallites are generally compressed and the axial structure is finer and smaller (Text-fig. 26b). However, G. robusta and G. haysi are sometimes compressed, and both D. delicatum

Elias, 1976 and G. robusta can be triangulate to weakly trilobate. D. delicatum, a large species, is strongly to completely dilated in early stages, but in weakly dilated later stages an axial structure and tabulae develop. D. angulatum (Billings, 1862), a small species, resembles Leolasma. Septa are strongly to completely dilated until immediately below the calyx where dilation decreases except around the axis, and tabulae are not developed.

10. Bodophyllum is characterized by a dilated median septal lamella which is the prominent element in the axial structure (Text-fig. 26c). However, Grewingkia bilateralis Neuman, 1969, Helicelasma lamellosa Elias, 1976, and some corallites of Streptelasma cyrtum Neuman, 1969 also have a median lamella. In late stages of Bodophyllum shorti n. sp., the axial structure resembles Grewingkia because the median lamella is weakly dilated and irregular, and other septal lobes and lamellae are present.

11. Bighornia is very similar to Bodophyllum, but the cardinal septum is on the concave side of the corallites (Text-fig. 26c). Corallites of Bighornia are generally subcalceoloid in form, as is Bodophyllum duncanae (Spjeldnaes, 1961). In an unusually long corallite of Bighornia cf. patella (Wilson, 1926), the axial structure in the latest stage resembles Grewingkia (Elias, 1976, Pl. 17, fig. 13).

12. In Densigrewingkia the cardinal septum is on the concave

side and the dilated median septal lamella is enclosed in stereoplasmatic deposits until the latest stage, when the axial structure very much resembles Grewingkia (Text-fig. 26c). In some species of other genera having strongly dilated septa, such as Lobocorallium trilobatum subsp. vaurealensis, the strongly dilated axial structure can be dense because of stereoplasmatic deposits, and the axial structure resembles Grewingkia.

It is apparent that the generic classification of streptelasmatid corals is to a large extent artificial and arbitrary. Genera for which the most species are known (Streptelasma and Grewingkia) have been expanded to include the broadest ranges in the field of variability shown in Text-fig. 26a. "Voids" between all genera are being (or have been) filled as more species and their intraspecific variation are described. Similarly, as the ranges of an increasing number of genera that first appeared in the Ordovician are being extended into the Silurian, it is becoming apparent that many "Ordovician" and "Silurian" genera may be indistinguishable. For example, McLean (1974, p. 39, 43) suggested that Streptelasma, Porfirieviella Ivanovsky, 1963, and Dinophyllum Lindström, 1882 may prove to be gradational, and that Bighornia, Bodophyllum, Dalmanophyllum Lang and Smith, 1939, and Ditoecholasma Simpson, 1900 could be synonymous.

In order to evaluate the significance of the morphology of these streptelasmatid corals, the following points must be considered [morphologic variability in Baltoscandian species was discussed by B. Neuman (1974)]:

1. In Streptelasma divaricans and Grewingkia canadensis, decreasing axial region complexity may be related to decreasing water depth. This trend is accompanied by an increase in the number of septa at a particular cross-sectional area in G. canadensis. A decrease in complexity of the axial structure from G. robusta to G. dilata to G. paucisepta of the Selkirk Member, Red River Formation, southern Manitoba, is accompanied by a decrease in the number of major septa at a particular cross-sectional area (Elias, 1976, fig. 3). In the continental interior of the Red River-Stony Mountain Province, corals having axial structures such as Grewingkia are predominant, and those with open axial regions are unknown. Corals with open axial regions such as Streptelasma are present in normal open marine environments at the continental margins.

2. Species that lived in stable environments where clean carbonate sediments accumulated generally have little variability in the number of septa at a particular cross-sectional area. Examples are species in the Selkirk Member, Red River Formation, southern Manitoba (Elias, 1976, fig. 3), and Grewingkia deltensis of the Ogontz Member in the Richmond

Group at Little Bay de Noc, Michigan (Text-fig. 37). Species inhabiting variable environments, such as G. canadensis and Streptelasma divaricans of the Richmond Group, show great variability in the number of septa (Text-figs. 36, 28).

3. In most corallites of Grewingkia rustica, the major septa form a counterclockwise whorl when viewed from the calyx (Plate 7, figs. 12, 18). Major septa in Streptelasma divaricans sometimes twist in a counterclockwise direction (Plate 1, fig. 17). Development of this feature is rare in some stages of small S. affinis corallites. The significance of axial torsion is unknown (Laub, 1978).

4. The significance of a median septal lamella in the axial region is unknown. It occurs in numerous genera and species, as previously discussed.

5. The mode of septal insertion in the following species is the same as in corals of Grewingkia, Helicelasma, Deiracorallium, and Bighornia in the Selkirk Member, Red River Formation, southern Manitoba (Elias, 1976, p. 44, 45, fig. 7): Streptelasma subregularis, Helicelasma randi, H. selecta, Deiracorallium angulatum, Grewingkia canadensis, G. deltensis, G. rustica, G. pulchella, Lobocorallium trilobatum subsp. vaurealensis, and Bodophyllum shorti.

6. The degree of development of the cardinal fossula is highly variable within genera. For example, Streptelasma subregularis, Grewingkia deltensis, and Helicelasma randi have broad fossulae. In S. affinis, G. penobscotensis, and H. lamellosa, the cardinal fossula is narrow or undeveloped.

7. In the continental interior of the Red River-Stony Mountain Province, corals have strongly to completely dilated major septa at least in early ontogenetic stages. Corals with undilated and weakly dilated septa, such as Streptelasma, are present at the continental margins. The degree of septal dilation can be highly variable within a genus, an example being Grewingkia. Within Helicelasma randi of the Selkirk Member, Red River Formation, southern Manitoba, septal dilation in early stages varies from extremely weak to complete. In Grewingkia contexta Neuman, 1969, strong septal dilation on the cardinal side where a fixing structure is present probably served to strengthen the corallite (B. Neuman, 1969, p. 33, 34). G. paucisepta, G. robusta, G. europaea hosholmensis (Kaljo, 1961), and H. randi lack fixing structures but often have stronger dilation on the cardinal side. In these cases it may have served to increase stability of the corallites, which lay with the cardinal side in the sediment, by adding weight to the lower side (Elias, 1976, p. 33). Septal dilation in Streptelasma

divaricans may be a response to the stress of bryozoans encroaching on the corallite. Although septal dilation almost always decreases during ontogeny, the maximum degree of dilation in H. randi often occurs at some height above the tip. If elements of the axial structure are completely dilated, the axial region will appear dense, as in some stages of Grewingkia pulchella and Lobocorallium trilobatum subsp. vaurealensis.

8. Tabulae cannot be present if interseptal chambers are absent due to complete dilation of major septa. It is not surprising, therefore, that a characteristic of Ullernelasma, Leolasma, Lobocorallium, and small corallites of Deiracorallium and Bighornia is the rarity or absence of tabulae. In large corallites or species of Deiracorallium and Bighornia having less strongly dilated septa in later stages, tabulae are present. The degree of dilation and spacing of tabulae is highly variable. Within a single corallite of Streptelasma affinis they may be thin to moderately thick and very closely to widely spaced. Tabellae are developed in the septal region of large species of Grewingkia, Helicelasma, and Deiracorallium occurring in the continental interior, and in Lobocorallium which occurs at the continental margin as well.

9. All late Middle and Upper Ordovician streptelasmatid genera have similar microstructure. The outermost portion

of the wall consists of tiny fibers or clusters of fibers oriented approximately perpendicular to the exterior, and appears to be structurally continuous with the septa (Plate 1, figs. 55, 56). The microstructure of the septa, axial structure, tabellae, and tabulae is similar. When very thin or in undilated stages, they appear structureless in plane light (Plate 1, fig. 56), and trabeculae are not distinguishable in longitudinal sections of septa. If thick or dilated, well developed fibers are visible in transverse sections (Plate 1, fig. 55), and trabeculae inclined up toward the axis are distinguishable in longitudinal sections of septa. U-shaped lamellae are developed in the stereozone when septa are not in lateral contact due to dilation or close spacing (Plate 1, fig. 56). The microstructure seen in these solitary corals is dependent to a large extent on the degree of septal dilation.

10. Most genera include species in which an area of attachment is developed. Streptelasma divaricans inhabited stabilized carbonate surfaces, and all corallites possess a base of attachment. The larvae preferentially selected bryozoans as a substrate. Bodophyllum englishheadensis and most corallites of Bighornia cf. patella have bases of attachment. In most solitary coral species, however, the larvae attached to particles so small that no visible record was preserved on the corallite. A tiny area of attachment

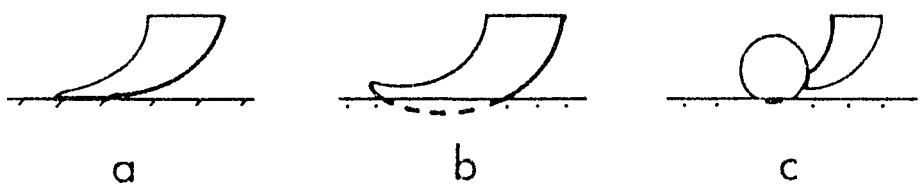
is rarely present on Grewingkia pulchella. A single corallite of Helicelasma randi having an area of attachment on a bryozoan is known, but all others were unattached. The nature and degree of development of this structure is determined by preference of the larva for a particular substrate, and substrate availability.

11. In all corallites possessing a base of attachment, the structure is centered on the cardinal side. Curved corallites that did not possess a base of attachment are thought to have been oriented during life with the cardinal side in contact with the substrate (Elias, 1976, p. 31-34). Growth was directed away from the substrate, resulting in some degree of curvature (Text-fig. 27a, b). In Bighornia,

Text-figure 27.--Growth orientation of solitary rugose corals, cardinal side (heavy line) in contact with substrate. a, Corallite attached to upper surface; b, unattached in sediment; c, attached to underside of object.

the shape of the area of attachment suggests that some corallites may have been fixed to a cylindrical surface, such as a cephalopod shell (Elias, 1976, p. 30) (Text-fig. 27c). Upward growth resulted in corallites having concave rather than the usual convex cardinal sides. Perhaps the larvae of all corals possessing concave cardinal sides (Bighornia, Densigrewingkia) settled in protected areas on

Text-figure 27.--Growth orientation of solitary rugose corals, cardinal side (heavy line) in contact with substrate. a, Corallite attached to upper surface; b, unattached in sediment; c, attached to underside of object.



Text-fig. 27

the underside of objects.

12. Species in the Red River Formation and its correlatives in the continental interior are large, trochoid, and generally moderately curved. Species in the Richmond and Edgewood provinces, and at the continental margin of the Red River-Stony Mountain Province are seldom large, range from trochoid to ceratoid or are exclusively ceratoid, and are generally weakly curved. Corallites becoming cylindrical in later stages are extremely rare in the Red River Formation (Elias, 1976, p. 20). In the Richmond Province, however, Grewingkia canadensis and G. rustica generally become cylindrical. At the continental margin, Streptelasma affinis becomes cylindrical and corallites of Bodophyllum englishheadensis sometimes become cylindrical. External form can be highly variable within a species. For example, corallites of Helicelasma randi in the Selkirk Member, Red River Formation, southern Manitoba, vary from generally trochoid to rarely ceratoid, and conical to strongly curved (Elias, 1976, p. 91). In the Selkirk Member, the more strongly curved corallites may have lived in higher energy environments than uncurved or weakly curved corallites (Elias, 1976, p. 33, 34). Corallites of G. canadensis are broadest (ie. most trochoid) on the shallow, open, highly productive shelf edge of the Richmond Group carbonate platform. Solitary rugose

corals are generally circular in cross-section. In the Red River-Stony Mountain Province, however, depressed (Bighornia), compressed (Deiracorallium), triangulate (some species of Grewingkia and Deiracorallium), and trilobate (Lobocorallium and some species of Grewingkia) corallites occur. Cross-sectional shape can be highly variable within a species. For example, G. robusta in the Selkirk Member, Red River Formation, southern Manitoba, varies from circular to weakly triangulate to weakly trilobate. The unusual external forms developed by these polyps could have served to increase stability of the corallites, which lay with the cardinal side in the sediment. This ability may have been in part genetically controlled because it is restricted to the Red River-Stony Mountain Province during the Ordovician (Elias, 1976, p. 35-39). Depressed and compressed solitary rugose corals appeared a number of times later in the Paleozoic, but triangulate and trilobate forms are unique to this province.

It is apparent that the significance of the morphology of these streptelasmatid corals is poorly understood. Many structures are inter-related, and all are determined directly or indirectly by environmental factors. Their genetic and phylogenetic significance is questionable. The only known continuous sequence of morphotypes that may represent a phylogenetic lineage is Grewingkia robusta → G. haysi → Lobocorallium trilobatum subsp. vaurealensis →

L. trilobatum in the Red River-Stony Mountain Province. The sequence is characterized by an increase in trilobation and septal dilation (Elias, 1976, p. 38, 39). G. robusta and G. haysi occur together in the Selkirk Member, Red River Formation, southern Manitoba, and so it is not known that the former gave rise to the latter. L. trilobatum subsp. vaurealensis of Anticosti Island, Quebec, and L. trilobatum, which occurs in southern Manitoba, could be comtemporary geographic variants. The relation between G. haysi and L. trilobatum is uncertain. L. trilobatum is known from the Stony Mountain Formation of southern Manitoba, but G. haysi occurs in the correlative Churchill River Group of northern Manitoba. The two forms may be geographic variants.

The present generic classification of Ordovician solitary streptelasmatid corals is to a large extent artificial and arbitrary, and is based on environmentally controlled morphologic features of questionable phylogenetic significance. A phylogenetic classification will be possible only if these corals prove to furnish valid phylogenetic criteria, and if lineages can be traced to their origin. This requires, among other things, a knowledge of the virtually unstudied Middle Ordovician solitary rugose corals.

The major source of difficulty in classification of solitary Rugosa at the species level is intraspecific

variation. A sample large enough to reveal the extent of morphologic variability within a species must be examined to ensure that variants are not assigned to different taxa, and different taxa are not interpreted as variants of a single species. Because the degree of variability and available sample size differ greatly from species to species, there will always be uncertainty in this regard. In many cases where several species occur together stratigraphically, the morphologic "gaps" separating them are so great that they can be readily distinguished. Examples are Streptelasma divaricans (Nicholson, 1875) and Grewingkia canadensis (Billings, 1862) of the Richmond Group, and S. affinis (Billings, 1865), Helicelasma selecta (Billings, 1865), G. pulchella (Billings, 1865), Deiracorallium angulatum (Billings, 1862), and Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928) from the upper part of the upper member, Vaureal Formation, Anticosti Island. In some cases, however, "gaps" between species are relatively small and involve subtle differences among populations. An example is the Selkirk Member of the Red River Formation, southern Manitoba, in which Grewingkia paucisepta Elias, 1976, G. dilata Elias, 1976, G. robusta (Whiteaves, 1896), and G. haysi (Meek, 1865) have been recognized (Elias, 1976). An examination of more specimens might indicate that these are in fact subspecies (if the populations overlap slightly), or synonyms (if a single

population is present). The species recognized within the scope of this study are considered valid because they are separated from all others by morphologic "gaps".

SYSTEMATIC PALEONTOLOGY

INTRODUCTION

Morphological terminology and biometrical methods used herein were discussed by Elias (1976, p. 11-13, 15-20). Many morphological features are described qualitatively (for example, "weakly curved", "moderately convex", "closely spaced"). Relative terms such as these are used to compare specimens within the scope of this study, and their meaning is made clear by an examination of the plates.

The uncertain or questionable validity of Ordovician solitary streptelasmatid genera, as they are presently understood, is discussed for each "genus". The term is placed in quotation-marks in recognizance of this problem. Unfortunately, our knowledge of these corals is insufficient to satisfactorily resolve these problems at the present time.

The species recognized herein are considered valid because they are separated from all others by morphologic "gaps".

Order Rugosa Milne-Edwards & Haime, 1850

Suborder Streptelasmatina Wedekind, 1927

Superfamily Zaphrentoidea Milne-Edwards & Haime, 1850

Family Streptelasmatidae Nicholson in
Nicholson and Lydekker, 1889

"Genus" Streptelasma Hall, 1847

1969. Streptelasma B. Neuman, p. 8-10.

1974. Streptelasma McLean, p. 38-41.

Discussion: The present concept of Streptelasma is based on Neuman's (1969, p. 8-11) study of the type species S. corniculum Hall, 1847, from the Middle Ordovician Trenton Limestone of New York. The "genus" includes solitary corals having undilated to moderately dilated major septa normally fused into a weak axial structure in early to intermediate ontogenetic stages. In later stages, the major septa are undilated and comparatively short, normally not forming an axial structure (Text-fig. 26a).

McLean (1974, p. 39) discussed the uncertain relationships of Streptelasma, Porfirieviella Ivanovskiy, 1963, and Dinophyllum Lindström, 1882, and stated that "future study of a larger variety of material may reveal that differences between these two genera and Streptelasma are merely gradational, in which case they should all be considered synonymous". The following points must be noted in establishing the relationships of Streptelasma, Borelasma Neuman, 1969, Helicelasma Neuman, 1969, and Grewingkia Dybowski, 1873 (Text-fig. 26a):

1. Streptelasma includes corals having undilated and moderately dilated major septa in early stages. However, otherwise similar forms with strongly dilated septa are

assigned to Borelasma and Helicelasma.

2. The single species S. divaricans (Nicholson, 1875) is highly variable and includes corallites having an open axial region (as in Streptelasma), those in which major septa extend to the axis (also considered Streptelasma), and forms with an axial structure of complexity comparable to Grewingkia.

Further study will probably demonstrate the gradational nature of these "genera". A knowledge of variation within S. corniculum is vital to this problem, but at present only the lectotype is known (Neuman, 1969, p. 10, 11).

Streptelasma divaricans (Nicholson, 1875)

Plate 1, figs. 1-56; Plate 2, figs. 1-27

1875b. Palaeophyllum divaricans Nicholson, p. 220, 221, Pl. 22, figs. 10, 10a, 10b.

1882. Palaeophyllum divaricans Nicholson. Hall, p. 377, 378, Pl. 52, fig. 4.

1908. Streptelasma divaricans (Nicholson). Cumings, p. 707, 708, Pl. 1, figs. 6, 6a.

1909. Streptelasma divaricans (Nicholson). Foerste, p. 307, 308, Pl. 10, figs. 4a-e.

1909. Streptelasma divaricans-angustatum Foerste, p. 308, Pl. 9, fig. 6a, 6b.

1918. Streptelasma cf. divaricans (Nicholson). Foerste, p. 99, Pl. 4, fig. 2.

1924. Streptelasma divaricans (Nicholson). Foerste, p. 67, Pl. 2, figs. 5a-d.

Lectotype (designated herein): The specimen represented by Nicholson, 1875b, on Pl. 22, fig. 10, is designated as the lectotype. It was said to be in the collection of U.P. James, and the horizon and locality were given as the "Cincinnati Group, Cincinnati, Ohio". It has not been located.

Paralectotype (designated herein): The specimen represented by Nicholson, 1875b, Pl. 22, fig. 10a, is designated as the paralectotype. It was said to be in the collection of U.P.

James, and the horizon and locality were given as the "Cincinnati Group, Cincinnati, Ohio". It has not been located.

Other specimens: UCGM 45000-45143, 45611, 45646; Richmond Group; Cincinnati Arch region, Ohio-Indiana-Kentucky (see Text-fig. 3 for stratigraphic horizons and locations); Elias collection. UCGM 45144, 45145; "Whitewater" strata, Richmond Group; entrance to Hueston Woods Park, Oxford, Ohio; Elias collection. USNM 70024 (1 of 3 specimens); "Waynesville" strata (base of Clarksville), Richmond Group; near Clarksville, Ohio. USNM 70211 (2 specimens); "Waynesville" (Blanchester) strata, Richmond Group; near Clarksville, Ohio. USNM 135761; "Waynesville" (Blanchester) strata, Richmond Group; SW of Blanchester, Ohio. USNM 40086; "Whitewater" strata, Richmond Group; Oxford, Ohio. USNM 42517; middle Richmond Group; Oxford, Ohio. USGS loc. 4343-CO (3 specimens); "Whitewater" strata, Richmond Group; B&O railroad cut (Cincinnati, Indianapolis, and Western R.R., NE¼, sec. 21, T5N, R1E, College Corner topo sheet) just NW of Oxford, Ohio; Boardman collection. USNM 135767; "Whitewater" strata, Richmond Group; Richmond, Indiana. USNM 84868 (2 syntypes of S. divaricans-angustatum Foerste, 1909); "Whitewater" strata, Richmond Group; Osgood, Indiana. USNM 84869 (4 specimens); "Whitewater" strata, Richmond Group, 3-4.5 m below Brassfield Formation; Osgood, Indiana. USNM 50816; Richmond Group; Bardstown, Kentucky. USNM 78449 (S. cf. divaricans of Foerste, 1918);

Bay de Noc Member, Stonington Formation; Stonington, Delta Co., Michigan; Stratton collection. UCGM 45146-45152; Kagawong beds, upper member, Georgian Bay Formation; locality 19f-1, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location); Elias collection. LU M61a-1, 4; Meaford beds, upper member, Georgian Bay Formation; locality M61a, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location).

Occurrence: Upper Ordovician (Richmondian): "Waynesville" strata to top of Richmond Group; Cincinnati Arch region, Ohio-Indiana-Kentucky. Meaford and Kagawong beds, upper member, Georgian Bay Formation; Manitoulin Island, Ontario. Bay de Noc Member, Stonington Formation; Delta Co., Michigan.

Diagnosis: Corallites generally ceratoid, weakly curved, of small size, and possess a base of attachment. Epitheca with septal grooves and interseptal ridges. Calyx deep, sometimes with very weakly convex calicular boss. Corallites generally solitary, but also occur as pseudocolonies and rarely as colonies resulting from lateral and peripheral increase.

In late stages axial region varies from complex structure of septal lobes and lamellae, to septal lobes only, to septa extending to axis, to septa withdrawn from

axis -- septa most commonly extend to axis. Major septa generally undilated throughout ontogeny and wavy. Cardinal septum indistinct, fossula not developed. Minor septa confined to or extend a short distance beyond a generally narrow stereozone. Tabulae mostly complete, moderately convex upward, with complementary plates.

Description of corallites: The length of corallites is shown in Text-fig. 14. The distribution above 10 mm is thought to represent the population, as discussed in the text. The longest corallite examined (UCGM 45013) has a length of 32 mm and a diameter of 15 mm immediately below the calyx where 32 major septa are present.

The corallites are generally ceratoid, but sometimes trochoid. They rarely become cylindrical in late stages (UCGM 45025; USNM 84868). Most are weakly curved, but they vary from uncurved to moderately curved. The cardinal-counter surface is often slightly curved or twisted.

The corallites have a relatively small to large base of attachment generally centered on the cardinal side, but sometimes toward an alar side. Basal extensions or talons are sometimes present. The corallites are usually attached to bryozoans, as discussed in the text under Cincinnati Arch Region. A wall is sometimes absent at the site of attachment and the septa are connected directly to the bryozoan. Septal grooves and interseptal ridges are present on the epitheca.

Corallites generally occur individually, but 26 percent of 189 specimens occur in clusters of two or more in lateral contact (Text-fig. 13). The most corallites seen in a single cluster is 13 (USNM 84869, Foerste, 1909, Pl. 10, fig. 4e). Most of these clusters apparently represent pseudocolonies. Often the tips are separate and the corallites expand into lateral contact soon after. Less commonly, the tips are in contact or the tip of one corallite is attached to another corallite, but separating walls are present with no evidence of increase. In only two specimens has lateral and peripheral increase resulting in true coloniality been demonstrated (see "Blastogeny" below). In USGS loc. 4343-CO(a), the walls separating two corallites opened in late stages. Two specimens show attempted rejuvenation in later stages (UCGM 45070; USGS loc. 4343-CO(b)).

The calyx has a depth between 0.35 and 0.55 of the corallite length. The calicular boss, when developed, is very weakly convex.

Ontogeny and internal structures: In early stages the major septa generally extend to or almost to the axis. Above this, a moderately complex axial structure of septal lobes and lamellae may develop, or a few septal lobes only may appear, or the major septa may extend to the axis, or the major septa may become withdrawn from the axis. There is a complete spectrum of variation from corallites with

complex axial structures to those with an open axial region (Plate 1, figs. 1-19; Text-fig. 16). Corallites with major septa extending to the axis are most frequent.

The number of major septa at a particular diameter is shown in Text-fig. 28. The septa are generally undilated.

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Text-figure 28.--Streptelasma divaricans (Nicholson, 1875): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) for the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curve is visual fit of class averages. USNM 84868, (x), cotype of S. divaricans-angustatum Foerste, 1909, "Whitewater" strata, Richmond Group, Osgood, Indiana; USNM 78449, (o), S. cf. divaricans of Foerste (1918), Bay de Noc Mbr., Stonington Fm., Stonington, Michigan (see App. 8).

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In a few corallites the septa are weakly to moderately dilated, especially in early stages (UCGM 45018, 45128). The major septa are generally wavy and sometimes twist in a counterclockwise direction. The cardinal septum is indistinct, and a fossula is not developed. The minor septa are confined to or extend a short distance beyond the stereozone, which is generally narrow.

Tabulae first appear in very early stages. They are mostly complete and moderately convex upward. Complementary

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Text-figure 28.--Streptelasma divaricans (Nicholson, 1875): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) for the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curve is visual fit of class averages. USNM 84868, (x), cotype of S. divaricans-angustatum Foerste, 1909, "Whitewater" strata, Richmond Group, Osgood, Indiana; USNM 78449, (o), S. cf. divaricans of Foerste (1918), Bay de Noc Mbr., Stonington Fm., Stonington, Michigan (see App. 8).

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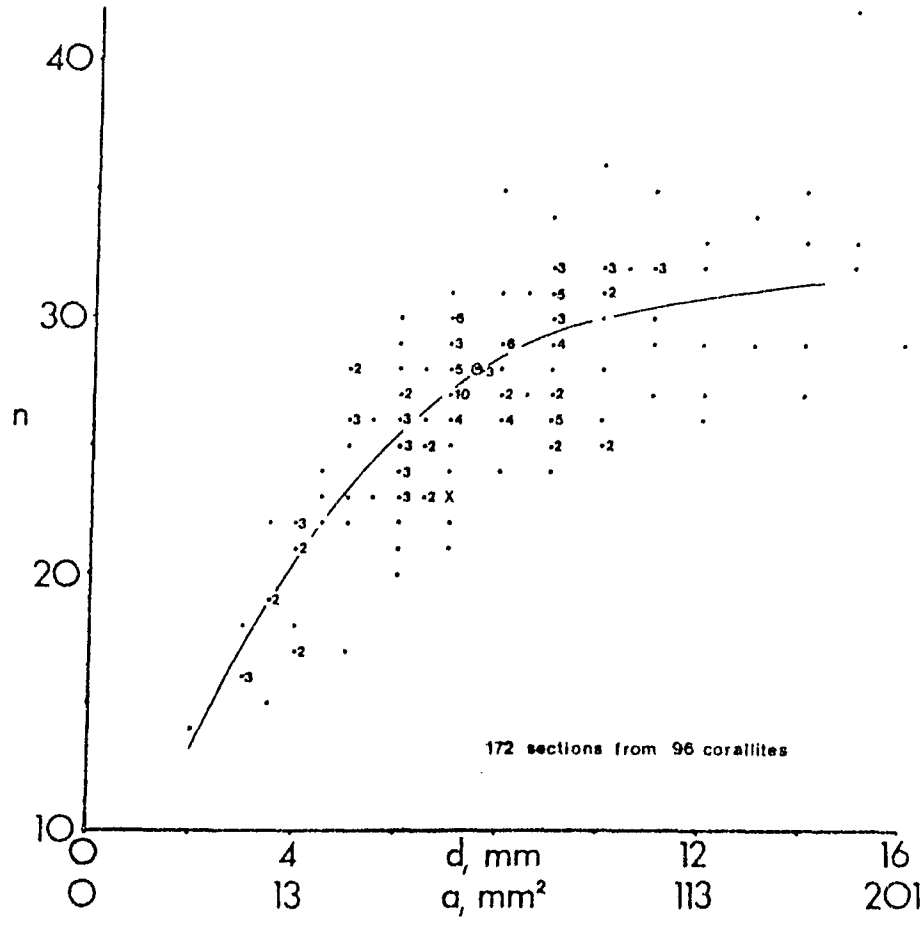


Text-fig. 28

plates are present in the septal region.

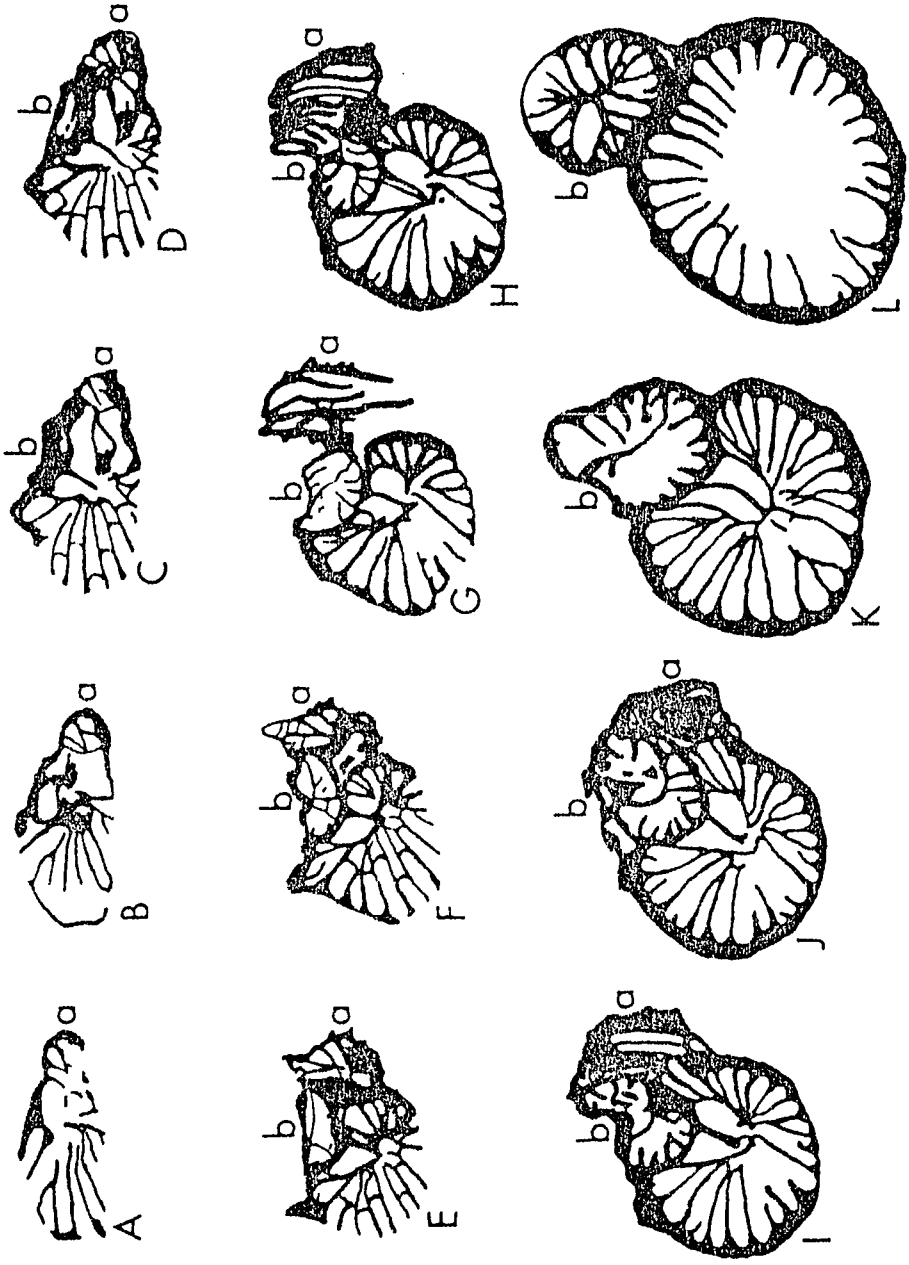
Blastogeny: In UCGM 45646, one offset resulted from lateral increase and another arose by peripheral increase (Text-fig. 29).

Text-figure 29.--*Streptelasma divaricans* (Nicholson, 1875): blastogeny in UCGM 45646 (x5). a, Offset resulting from lateral increase; b, offset resulting from peripheral increase (see Plate 2, fig. 1).

a) lateral increase -- The offset (a) developed in a lateral protuberance of the elongate protocorallite. The parent septa were initially withdrawn from this region -- it is not known if the septa in the offset represent their peripheral ends left behind. A wall separating the protocorallite and offset appears as a dense region in Text-fig. 29e, and is better defined in f. This offset was short lived, and is absent after j.

b) peripheral increase -- The offset (b) developed in a thickened portion of the protocorallite wall (Text-fig. 29c, d). The offset initially expanded inward at the expense of the protocorallite (e-j), as is typical of peripheral increase. Later, however, the offset

Text-figure 29.--*Streptelasma divaricans* (Nicholson, 1875): blastogeny in UCGM 45646 (x5). *a*, Offset resulting from lateral increase; *b*, offset resulting from peripheral increase (*see* Plate 2, fig. 1).



Text-fig. 29

curved away from the protocorallite (Plate 2, fig. 1). This is unusual because peripheral increase is generally parricidal (Fedorowski and Jull, 1976, p. 41). The septal arrangement is irregular until 1.

Increase in UCGM 45093 is indicated by an incomplete wall partially separating two corallites in early stages and becoming complete in later stages. Lateral increase probably occurred in UCGM 45036.

Microstructure: Septal fibers are well developed only in dilated stages (Plate 1, fig. 55). Trabeculae are inclined slightly up toward the axis. Lamellae in the stereozone are well developed only in undilated stages when the septa are relatively far apart (Plate 1, fig. 56). The outer wall of the corallite is composed of fibers oriented perpendicular to the interseptal ridges (Plate 1, figs. 55, 56).

Discussion: This species, described from the Cincinnati Arch region, was referred to Palaeophyllum by Nicholson (1875b) and Hall (1882), and to Streptelasma by later workers. Foerste (1909) distinguished S. divaricans-angustatum on the basis of its cylindrical form. However, it has been found to lie within the variability of S. divaricans, both externally and internally. S. cf. divaricans of Delta Co., Michigan, was described from

external morphology by Foerste (1918). The specimen has been sectioned and Foerste's comparison is vindicated. The species also occurs in the upper member of the Georgian Bay Formation on Manitoulin Island.

The degree of variation of the axial region within S. divaricans spans the "genera" Streptelasma and Grewingkia. The species is referred to Streptelasma because in the majority of corallites an axial structure is not developed. S. divaricans is distinct in often forming pseudocolonies and rarely colonies by lateral and peripheral increase. S. (?) parasiticum Ulrich in Winchell and Schuchert (1895, p. 89-90, fig. 6) from the Trentonian of Minnesota also forms pseudocolonies or colonies attached to bryozoa, but the corallites are only several mm long -- internal structures are unknown. S. ostrogothicum Neuman (1969, p. 21-23, fig. 13b, c) from the Upper Ordovician of Sweden commonly produces several intracalicular offsets by peripheral increase.

Streptelasma leemonensis n. sp.

Plate 2, fig. 28

Etymology: The specific name refers to the town of Leemon, Girardeau Co., Missouri, near which the species occurs.

Holotype: UCGM 45614; Elias collection.

Paratype: UCGM 45615; Elias collection.

Occurrence: Upper Ordovician (? Gamachian): Leemon Formation; locality 20a-1, Cape Girardeau Co., Missouri.

Diagnosis: Corallites ceratoid, very weakly curved, and of small size. Major septa undilated and extend to or almost to axis. Cardinal septum indistinct, fossula not developed. Minor septa very long, sometimes extending more than half the corallite radius. Stereozone moderately broad. Tabulae present.

Description of corallites: The holotype is of small size and has 32 major septa at a diameter of 9 mm. The paratype has 24 major septa at a diameter of 7 mm. The corallites are ceratoid and very weakly curved.

Ontogeny and internal structures: The major septa extend to or almost to the axis, where they meet in several groups. They are undilated. The cardinal septum is indistinct, and a cardinal fossula is not present. The minor septa are very long, extending more than half the radius of the

corallite in the paratype. The stereozone is moderately broad. Tabulae are present.

Microstructure: The microstructure of these partially silicified corallites is unknown.

Discussion: Streptelasma leemonensis resembles corallites of S. divaricans (Nicholson, 1875) with major septa that extend to the axis. However, S. leemonensis is distinct in having very long minor septa.

Streptelasma sp.

Plate 2, figs. 29-31

Specimen: UCGM 45616; Elias collection.

Occurrence: Upper Ordovician (? Gamachian): Leemon Formation; locality 20a-1, Cape Girardeau Co., Missouri.

Description: In this small corallite the major septa extend to or almost to the axis, where they meet in several groups. They are moderately dilated in early stages and undilated in later stages. The minor septa appear to be confined to the stereozone. Tabulae are present.

Microstructure: The major septa appear to be fibrous, and lamellae are developed in the stereozone.

Discussion: This corallite resembles Streptelasma leemonensis n. sp. and S. divaricans (Nicholson, 1875) in that the major septa extend to or almost to the axis, where they meet in several groups. However, in this corallite the septa are more strongly dilated. The minor septa are much shorter than in S. leemonensis. This single specimen is poorly preserved because of secondary dissolution of the periphery, and a specific name is therefore not assigned.

Streptelasma subregularis (Savage, 1913)

Plate 3, figs. 1-16

1913. Zaphrentis subregularis Savage, 1917a[1], p. 113, Pl. 5, fig. 5, Pl. 9, fig. 1.

1913. Zaphrentis ambigua Savage, 1917a, p. 149, Pl. 9, fig. 2.

Holotype (by original designation): UI X-851; Cyrene Formation, Edgewood Group; near Edgewood, Missouri; Savage collection.

Other specimens: UI X-926 (2 specimens); Wilhelmi Formation (Channahon Limestone of Savage); Will Co., Illinois; Savage collection. UI X-947 (type specimens of Z. ambigua; one slab with 5 specimens plus a single specimen); Wilhelmi Formation (Channahon Limestone of Savage); near Channahon, Illinois; Savage collection. UCGM 45618-45634; locality 20b-1, Cape Girardeau Co., Missouri; Elias collection.

Occurrence: Upper Ordovician (? Gamachian): Wilhelmi Formation; Will Co., Illinois. Cyrene Formation, Edgewood Group; Pike Co., Missouri. Leemon Formation; Cape Girardeau Co., Missouri.

Diagnosis: Corallites trochoid to generally ceratoid, uncurved to weakly curved, and of moderate size. Epitheca

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[1] Savage (1917a, p. 67) stated: "The first publication of the new species of fossils noted herein was in this extract that was distributed in November, 1913". Therefore, all references to Savage's descriptive paleontology are cited as 1913 (see Amsden, 1974, p. 4).

with prominent septal grooves and interseptal ridges. Calyx deep, without calicular boss.

Major septa withdrawn from axis, moderately dilated in early stages and undilated in later stages, and wavy. Cardinal septum short in later stages, cardinal fossula prominent. Minor septa generally very short, stereozone very narrow. Tabulae complete, thin, very widely spaced and somewhat irregular, convex upward in septal region and horizontal to concave upward in axial region, and strongly depressed in cardinal fossula.

Description of corallites: The largest corallite examined (UCGM 45629) is 65 mm long, with a diameter of 29 mm in the calyx where 37 major septa are present. The corallites are trochoid (UCGM 45618, UI X-851) to usually ceratoid (UCGM 45619, UI X-947), and uncurved to weakly curved. Prominent septal grooves and interseptal ridges are present. Growth lines are preserved, and rugae are sometimes present. The calyx has a depth equal to 0.4 (UCGM 45618) to 0.5 of the corallite length (UCGM 45622). A calicular boss is not present.

Ontogeny and internal structures: In early stages the major septa extend to or almost to the axis, where they meet in several groups. In later stages they extend about half way to the axis. The septa are wavy.

The number of major septa at a particular diameter is

shown in Text-fig. 30. The major septa are moderately

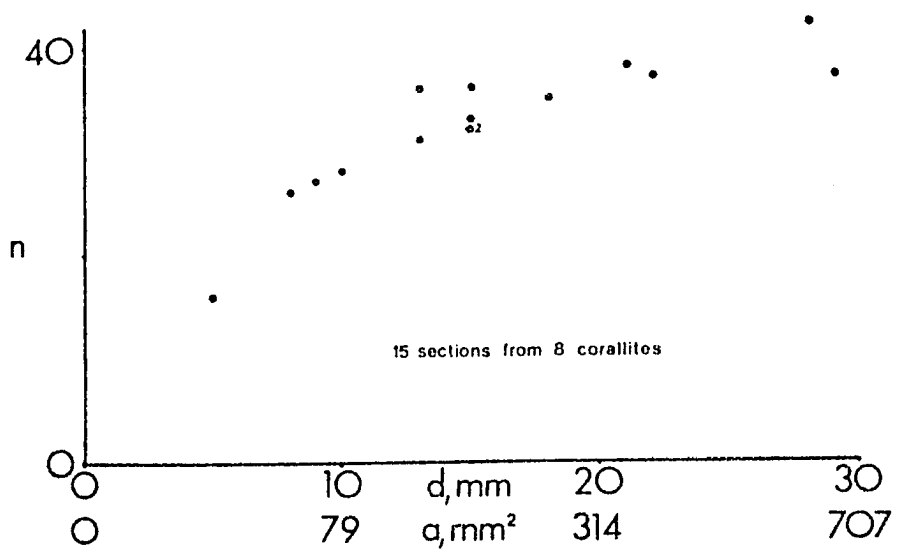
Text-figure 30.--Streptelasma subregularis (Savage, 1913): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).

dilated in early stages and undilated in later stages. The cardinal septum becomes short in later stages, when a prominent cardinal fossula is present. The minor septa are generally very short, and the stereozone is very narrow. The tabulae are complete, thin, very widely spaced, and somewhat irregular. They are convex upward in the septal region and horizontal to concave upward in the axial region. The tabulae are strongly depressed in the cardinal fossula (UI X-851).

Microstructure: The major septa are clearly fibrous. Trabeculae are inclined up toward the axis. Lamellae appear to be present in the stereozone in undilated stages.

Discussion: Savage (1917a) distinguished Zaphrentis subregularis and Z. ambigua primarily on the basis of external form, but recognized that they were similar internally. Z. subregularis was trochoid, whereas Z. ambigua was ceratoid. In the Leemon Formation, a complete gradation from trochoid to

Text-figure 30.--Streptelasma subregularis (Savage, 1913): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).



Text-fig. 30

ceratoid forms with similar internal structure is seen. Therefore, Z. ambigua is a synonym of Z. subregularis, herein placed in Streptelasma.

Streptelasma subregularis resembles the lectotype of S. corniculum Hall, 1847 from the upper Middle Ordovician Trenton Limestone of New York (B. Neuman, 1969, p. 10-11, figs. 4-6) in having moderately dilated septa in early stages, major septa that are withdrawn from the axis, short minor septa, and tabulae that are concave upward axially. However, S. corniculum does not appear to have a short cardinal septum in a prominent fossula. S. affinis (Billings, 1865) from the Caradocian(?) through Ashgillian Vaureal and Ellis Bay formations of Anticosti Island, is often very similar to S. subregularis externally and internally. S. subregularis is distinct in having a short cardinal septum in a prominent fossula, and very short minor septa.

S. subregularis most closely resembles S. unicum Neuman, 1975 from the Ashgillian (Hirnantian Stage) Dalmanitina beds or lowermost Llandoverian (Lower Silurian) beds, Östergötland, and probably from the Dalmanitina beds, Siljan district, Sweden. However, S. subregularis has more strongly dilated septa, more widely spaced tabulae, and slightly fewer septa at a particular diameter (see B. Neuman, 1975, fig. 17).

Streptelasma rankini n. sp.

Plate 2, figs. 32-34

Etymology: The species is named for D.W. Rankin, whose field work for a Ph.D. at Harvard University resulted in recognition of Upper Ordovician rocks in Penobscot Co., Maine.

Holotype: USGS 6344a-c; Neuman collection.

Paratypes: USGS 6262a, b; 6332a-c; 6335a, b; 6337a, b; 6340a, b; 6341a, b; 6345a, b; 6346a; 6347a, b; 6350a, b; 6355a, b; Neuman collection.

Occurrence: Upper Ordovician (Ashgillian): About 520 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot Co., Maine.

Diagnosis: Corallites ceratoid, usually uncurved, and attain moderate size. Major septa generally slightly withdrawn from axis, undilated, and wavy. Cardinal septum indistinct, fossula not developed. Minor septa usually extend a moderate distance beyond a moderately broad stereozone. Tabulae mostly complete, steeply convex upward at margins but almost horizontal or slightly concave upward axially.

Description of corallites: The specimens are poorly preserved and incomplete. The largest corallite examined (USGS 6262b) has a diameter of 22 mm and 42 major septa at an unknown distance below the calyx. The corallites are ceratoid. All but USGS 6355 appear to be uncurved. USGS 6332c may have a base of attachment.

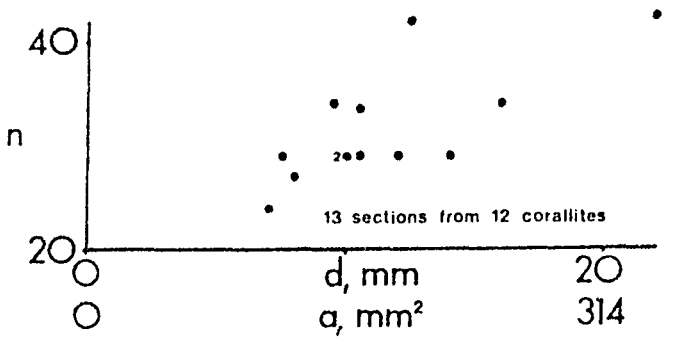
Internal structures: The number of major septa at a particular diameter is shown in Text-fig. 31. The major

Text-figure 31.--*Streptelasma rankini* n. sp.: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).

septa are generally slightly withdrawn from the axis. They are undilated and wavy. The cardinal septum is indistinct, and a fossula is not developed. Minor septa generally extend a moderate distance beyond the stereozone, but they may be very long (USGS 6335b). The stereozone is moderately broad. The tabulae are thin and mostly complete. They are steeply convex upward at the margins, but become almost horizontal or are slightly concave upward axially. Complementary plates are sometimes present.

Microstructure: The corallites are poorly preserved. Septal fibers cannot be distinguished, but weakly developed trabeculae that are very slightly inclined up toward the

Text-figure 31.--*Streptelasma rankini* n. sp.: relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (*see* App. 8).



Text-fig. 31

axis are possibly present.

Discussion: Streptelasma rankini resembles some corallites of S. affinis (Billings, 1865) and S. primum (Wedekind, 1927) in growth form and in having major septa withdrawn from the axis. However, S. rankini is distinct in having tabulae that are much more steeply convex upward at the margins.

Streptelasma affinis (Billings, 1865)

Plate 3, figs. 17-31

1865. Zaphrentis affinis Billings, p. 430.

1865. Zaphrentis bellistriata Billings, p. 430, 431.

1866. Zaphrentis affinis Billings, p. 7.

1866. Zaphrentis bellistriata Billings, p. 8.

1901. Zaphrentis affinis Billings. Lambe, p. 118, 119, Pl. 7, figs. 6, a, b.

1928. Zaphrentis affinis Billings. Twenhofel, p. 114, 115.

Lectotype (designated herein): GSC 1987, c-e; upper member, about 30+ m below top of Vaureal Formation; Wreck Point, Anticosti Island, Quebec; T.C. Weston collection, 1865.

Paralectotypes (designated herein): GSC 1987a, b; 1987g, i; 1987f, h; upper member, about 30+ m below top of Vaureal Formation; Wreck Point, Anticosti Island, Quebec; T.C. Weston collection, 1865.

Other specimens (all from Anticosti Island, Quebec; Twenhofel collection unless otherwise stated): GSC 2244, a, b (syntype of Zaphrentis bellistriata); upper member, about 30+ m below top of Vaureal Formation; Wreck Point; T.C. Weston collection, 1865. YPM 556a, b; lower member,

Vaureal Formation (Twenhofel's English Head Formation); reef at little cliff between Bear Cape and Cape Eagle. YPM 517a; lower member, Vaureal Formation (Twenhofel's zone 4, English Head Formation); Carleton Point. YPM 538a; Ellis Bay Formation; cliff 1.2 km east of Junction Cliff. YPM 145; Ellis Bay Formation; Prinstie Bay. YPM 574; Ellis Bay Formation; near Junction Cliff. YPM 3063/45a; Ellis Bay Formation; west side of Prinstie Bay. YPM 3063/52a; Ellis Bay Formation; west side of Ellis Bay. YPM 3063/44b; Ellis Bay Formation; Prinstie Bay. YPM 548a; Twenhofel's zone 1, Ellis Bay Formation; west side of Ellis Bay. YPM 3019/3063/35a, e, f, i, j; Twenhofel's zone 1, Ellis Bay Formation; Junction Cliff. YPM 515b; Twenhofel's zone 2, Ellis Bay Formation; coral and Beatricea zones, Lousey Cove. YPM 3063/36b-e; Twenhofel's zone 2, Ellis Bay Formation; Junction Cliff. YPM 555a; Twenhofel's zone 5, Ellis Bay Formation; Ellis Bay. YPM "Ellis Bay zone 7"; Twenhofel's zone 5, Ellis Bay Formation; Ellis Bay. YPM 3063/56a; Twenhofel's zone 7 (Hormotoma gigantea zone), Ellis Bay Formation; Ellis Bay. YPM 3019/3063/57j, k; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay.

Occurrence: Upper Ordovician: Lower member (? Caradocian) and upper member (Lower Ashgillian), Vaureal Formation, and Ellis Bay Formation (Ashgillian, ? Gamachian); Anticosti Island, Quebec.

Diagnosis: Corallites ceratoid to trochoid, cylindrical in late stages, very weakly to moderately curved, and attain very large size. Epitheca with prominent septal grooves and interseptal ridges, and rugae. Calyx deep to very deep, without calicular boss.

Major septa generally withdrawn from axis, undilated to usually moderately dilated in early stages and undilated in later stages, and wavy. Cardinal septum indistinct, fossula not developed. Minor septa generally long, extending well beyond a narrow to moderately broad stereozone. A few tabellae in septal region. Tabulae complete and incomplete, thin to moderately thick, very closely to widely spaced, and convex upward in septal region, and concave upward in axial region.

Description of corallites: The largest corallite examined (GSC 1987g, i) is a fragment 120 mm long, with a maximum diameter of 55 mm and a diameter of 37 mm at the incomplete base. YPM "Ellis Bay zone 7" has 70 major septa at a diameter of 43 mm. The corallites are ceratoid to trochoid in early stages, and become cylindrical in later stages. Curvature is very weak to moderate, and the corallites are generally uncurved in cylindrical stages. Prominent septal grooves and interseptal ridges are present. Coarse rugae are often developed, and on some corallites are regularly spaced at an interval of 8 to 13 mm (App. 11). Talons are sometimes present in early stages. The calyx has a depth equal to 0.3 (YPM "Ellis Bay zone 7") to 0.6 of the

corallite length (GSC 1987, c-e). The base of the calyx is generally concave upward.

Ontogeny and internal structures: In early stages the major septa extend to or almost to the axis. In intermediate and late stages they may extend almost to the axis where a few septal lobes are sometimes present (YPM 3019/3063/57k), but are generally withdrawn and may extend less than half way to the axis (YPM 3019/3063/35i). The septa are generally wavy.

The number of major septa at a particular diameter is shown in Text-fig. 32. The major septa are usually

Text-figure 32.--Streptelasma affinis (Billings, 1865): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).

moderately dilated in early stages, but may be undilated. They are undilated in later stages. The major septa rarely twist in a counterclockwise direction in small corallites when viewed from the calyx (YPM 517a, 3063/36d, 3063/56a). The cardinal septum is indistinct, and a cardinal fossula is not developed. The minor septa are usually long and extend well beyond the stereozone. The stereozone is generally narrow, but ranges from very narrow

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Text-figure 32.--Streptelasma affinis (Billings, 1865): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).

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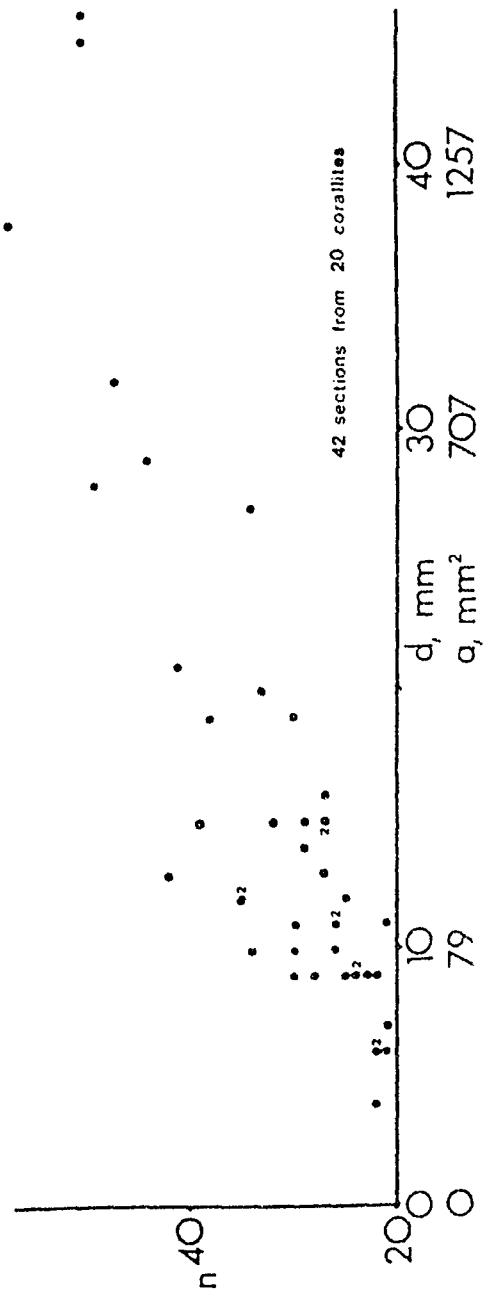


Text-fig. 32

(YPM 517a, 548a) to broad (YPM 555a).

A few thin tabellae inclined up toward the axis are present in the septal region. Complete and incomplete tabulae are developed. Within a corallite, they may vary from thin to moderately thick, and be very closely to widely spaced. They are convex upward in the septal region and concave upward in the axial region.

Microstructure: Septal fibers are distinguishable only in dilated stages. The weakly developed trabeculae are inclined slightly up toward the axis. In undilated stages, lamellae are developed in the stereozone.

Discussion: GSC 1987, c-e is selected from Billings' syntypes as the lectotype of Streptelasma affinis because the specimen has been cross-sectioned. Paralectotype GSC 1987a was figured by Lambe (1901, Pl. 7, figs. 6, a), but has not been cross-sectioned. The source of Lambe's cross-section in fig. 6b is unknown.

A cross-section and longitudinal section of a syntype of Zaphrentis bellistriata (GSC 2244, a, b) indicate that it is a junior synonym of S. affinis, as noted by Lambe (1901) and Twenhofel (1928).

S. affinis resembles S. primum (Wedekind, 1927) (see B. Neuman, 1969, p. 11-17) from the Ashgillian of Norway in growth form and in having short major septa and tabulae that are concave upward axially. S. affinis is distinct in

attaining larger size and in having long minor septa.

"Genus" Helicelasma Neuman, 1969

1969. Helicelasma B. Neuman, p. 28, 29.

1976. Helicelasma Elias, p. 86-90.

Discussion: Helicelasma was proposed by Neuman (1969) to include solitary corals having strongly to completely dilated major septa extending to the axis in early and intermediate ontogenetic stages. In later stages the major septa are less strongly dilated and normally join into a loosely built axial structure (Text-fig. 26a). The diagnosis was based primarily on the type species H. simplex Neuman, 1969.

The uncertain relationship between Helicelasma and Streptelasma Hall, 1847 was discussed under the latter "genus". The following points suggest that differences among Helicelasma, Grewingkia Dybowski, 1873, Leolasma Kaljo, 1956, and Borelasma Neuman, 1969 are gradational (Text-fig. 26a):

1. An axial region is not present in some corallites of H. randi Elias, 1976, but in others it is as large as that of Grewingkia and a weak axial structure is developed. In H. lamellosa Elias, 1976, the degree of development of the axial structure varies during ontogeny, and spans the "genera" Helicelasma and Grewingkia.
2. Species of Helicelasma such as H. selecta (Billings, 1865), in which septa are completely dilated until the

latest stages and tabulae are rare, approach Leolasma.

3. Streptelasma includes corals having a weak axial structure, those in which septa extend to or almost to the axis, and forms having an open axial region. However, Helicelasma is distinguished from Borelasma, which has an open axial region in later ontogenetic stages but is otherwise similar.

Helicelasma randi Elias, 1976

Plate 4, figs. 1-8

1976. Helicelasma randi Elias, p. 91-96, Pl. 13, figs. 1-15, Pl. 14, figs. 1-20.

Specimens: SUI 57-'24; probably Clermont Member, Scales Formation, Maquoketa Group; SW¼, sec. 21 or NW¼, sec. 28, Clermont Township, Fayette Co., Iowa. USNM 42535, a, b; Brainard Formation, Maquoketa Group; Sterling, Illinois. USGS 206S, a, b; Brainard Formation, Maquoketa Group; Sterling, Illinois; Ulrich and Bassler collection. USGS 206T (3 specimens); Brainard Formation, Maquoketa Group; Sterling, Illinois; Ulrich and Bassler collection. USNM acc. 306219 (2 specimens); Brainard Formation, Maquoketa Group; SE¼, SE¼, sec. 35, T91N, R6W, Clayton Co., Iowa; Gerk collection. SIU 4200, 4201; Orchard Creek Member, Scales Formation, Maquoketa Group; bank of Mississippi River, 1.6 km N of Thebes, sec. 5, T15S, R3W, Alexander Co., Illinois; Guensburg collection.

Occurrence: Late Middle (?) and Upper Ordovician: The types occur in the Selkirk Member, Red River Formation (late Middle or Upper Ordovician); Garson, Manitoba. Probably Clermont Member, Scales Formation (Richmondian), Maquoketa Group; Fayette Co., Iowa. Brainard Formation (Richmondian), Maquoketa Group; Clayton Co., Iowa, and Sterling, Illinois.

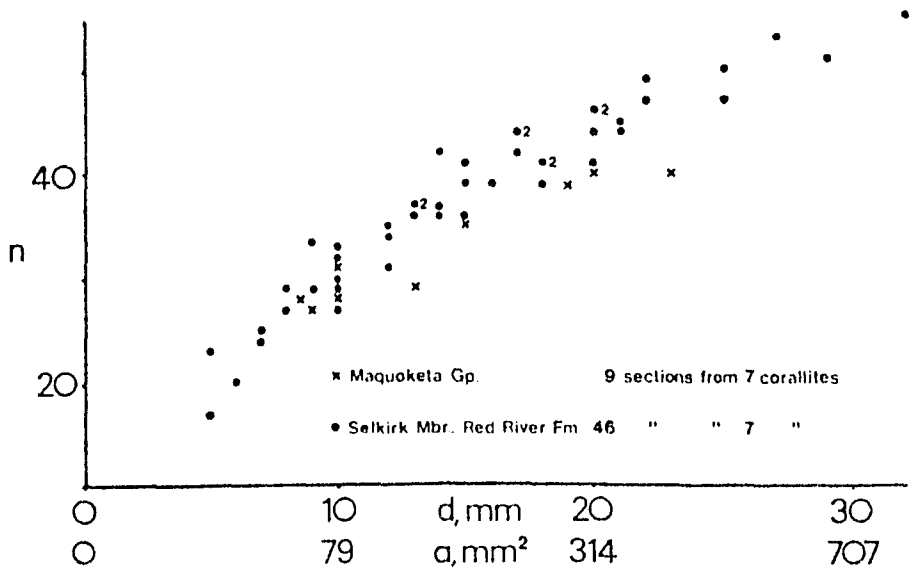
Description of corallites: The largest corallite examined (USGS 206Sa) has a length of 63 mm and a diameter of 23 mm immediately below the calyx where 40 major septa are present. The corallites are trochoid, and uncurved to weakly curved. Septal grooves and interseptal ridges are present on the epitheca. The calyx has a depth equal to 0.3 of the corallite length (USGS 206T). The calicular boss is strongly convex (USGS 206T).

Ontogeny and internal structures: In early stages the major septa extend to or almost to the axis. In intermediate and late stages a few septal lobes and lamellae develop in the axial region. Groups of two or more major septa often converge near the axis. The number of major septa at a particular diameter is shown in Text-fig. 33. In early

Text-figure 33.--Helicelasma randi Elias, 1976: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) for the Selkirk Mbr., Red River Fm., southern Manitoba (see Elias, 1976, fig. 12b) and Maquoketa Gp. (see App. 8). Numbers indicate frequency of a point if greater than one.

stages, septal dilation is complete (USGS 206Sa) to moderate (USNM 42535b). Dilation near the axis sometimes produces a halo around the axial region (USNM 42535b; SUI 4200). The cardinal septum is long and less strongly

Text-figure 33.--*Helicelasma randi* Elias, 1976: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) for the Selkirk Mbr., Red River Fm., southern Manitoba (see Elias, 1976, fig. 12b) and Maquoketa Gp. (see App. 8). Numbers indicate frequency of a point if greater than one.



Text-fig. 33

dilated than the other major septa. The cardinal fossula is moderately broad. Minor septa are confined to or extend a short distance beyond the moderately broad stereozone. In later stages the tabulae are complete, relatively widely spaced, and moderately strongly convex upward.

Microstructure: The microstructure is unknown because of poor preservation.

Discussion: These corallites from the Maquoketa Group of Iowa and Illinois cannot be distinguished morphologically from Helicelasma randi of the Selkirk Member, Red River Formation, southern Manitoba. The number of major septa at a particular diameter is similar in both units, although corallites from the Maquoketa tend to have slightly lower values (Text-fig. 33). The specimen from Clermont Township, Iowa, probably from the Clermont Member of the Scales Formation, has a larger axial region than those from the Brainard Formation.

Helicelasma selecta (Billings, 1865)

Plate 4, figs. 9-19

1865. Petraia selecta Billings [partim], p. 429.

1866. Petraia selecta Billings [partim], p. 7.

1901. Streptelasma selectum (Billings) [partim]. Lambe, p. 113, Pl. 6, figs. 8, a.

1928. Streptelasma selectum (Billings) [partim]. Twenhofel, p. 113.

Lectotype (designated herein): GSC 1989a, b; upper member, 27-30 m below top of Vaureal Formation; west end lighthouse, Anticosti Island, Quebec; Richardson collection, 1856.

Paralectotypes (designated herein): GSC 1989, g; 1989c, d; 1989f; upper member, about 27-30 m below top of Vaureal Formation; west end lighthouse, Anticosti Island, Quebec; Richardson collection, 1856 (the following belong to Grewingkia pulchella: GSC 1989e; 1989h; 1989i, j; 1989k; 19891; 1989m, 1989n).

Other specimens (all from the Twenhofel collection, Anticosti Island, unless otherwise stated): YPM 508a; upper member (English Head facies), Vaureal Formation; English Head. YPM 518c; upper member (English Head facies), Vaureal Formation; West Bay. YPM 514a; Ellis Bay Formation; Cape James. YPM 543; Ellis Bay Formation; zone 21 of

Twenhofel's Vaureal River section. YPM 539a; basal unit, Ellis Bay Formation; zone 10 of Twenhofel's Vaureal River section. YPM 515a; Twenhofel's zone 2, Ellis Bay Formation; coral and Beatricea zones, Lousey Cove. USNM 102390(2, 3) and YPM "Grande Coupe, Percé, Quebec"(a); Stenopareia faunal zone of Lespérance (1968b), White Head Formation; Grande Coupe, 2.4 km N of Percé, Quebec.

Occurrence: Upper Ordovician: Upper member (Lower Ashgillian), Vaureal Formation, and Ellis Bay Formation (Ashgillian, ? Gamachian); Anticosti Island, Quebec. White Head Formation (Lower Ashgillian); Percé, Quebec.

Diagnosis: Corallites trochoid, weakly curved, and attain moderate size. Calyx deep, calicular boss not developed. Small axial structure of a few dilated septal lobes and lamellae. Septa generally completely dilated except in late stages immediately below calyx. Cardinal septum thin and generally short in late stages, in moderately broad fossula. Minor septa moderately long and sometimes extend a short distance beyond the moderately broad stereozone in weakly dilated late stages. Tabulae rare.

Description of corallites: The longest specimen observed (YPM 514a) is incomplete, and has a length of 50 mm. The broadest specimen (YPM 515a) has a diameter of 27 mm. The maximum number of septa observed is 44 at a diameter of 25 mm (USNM 102390(3)). The corallites are trochoid and

weakly curved. Weakly developed septal grooves and interseptal ridges are sometimes present (GSC 1989, g). The calyx has a depth equal to 0.4 of the corallite length (GSC 1989a, b; 1989c, d).

Ontogeny and internal structures: In early stages the major septa extend to the axis. In intermediate stages, a few completely dilated septal lobes are present at the axis, and in late stages a few dilated septal lamellae sometimes develop in the small axial structure. The number of major septa at a particular diameter is shown in Text-fig. 34.

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Text-figure 34.--Helicelasma selecta (Billings, 1865): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) (see App. 8).

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The septa are generally completely dilated except in late stages immediately below the calyx, where septa are weakly (USNM 102390(3)) to usually strongly dilated. In late stages the cardinal septum is thin and generally very short. The cardinal fossula is moderately broad. The minor septa are moderately long and sometimes extend a short distance beyond the moderately broad stereozone in weakly dilated late stages. A few tabulae are sometimes present (GSC 1989a, b).

Microstructure: Septal fibers are well developed and

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Text-figure 34.--*Helicelasma selecta* (Billings, 1865): relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (*a*) (*see* App. 8).

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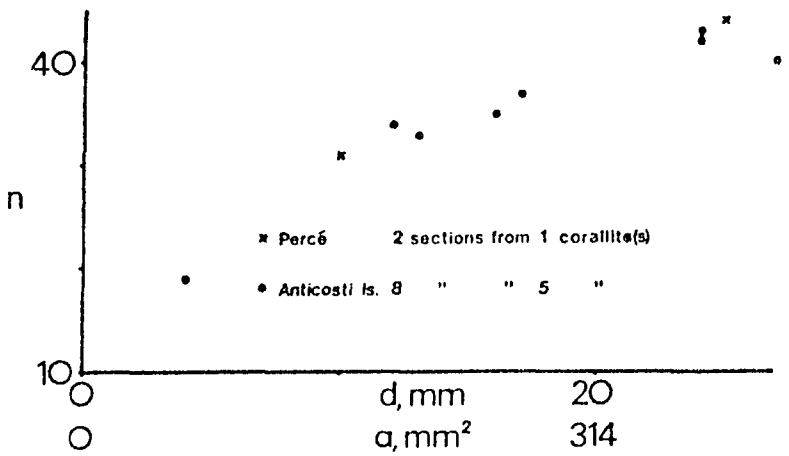


Text-fig. 34

the trabeculae are weakly inclined up toward the axis. Lamellae are generally present in the stereozone.

Discussion: GSC 1989, a-n are probably the syntypes used by Billings in his original description. However, two species are represented in this collection. One is Grewingkia pulchella. The other is considered to be Helicelasma selecta, from which the lectotype and paralectotypes are herein designated. Billings' Petraia pulchella was considered a synonym of P. selecta by Lambe (1901) and Twenhofel (1928), but two species are definitely involved.

In the latest ontogenetic stages, H. selecta resembles H. randi Elias, 1976. Both species have a small axial structure of a few dilated septal lobes and lamellae, and the thin cardinal septum occurs in a moderately broad fossula. However, H. selecta is distinct in having completely dilated septa except in late stages immediately below the calyx, and in generally possessing fewer septa than H. randi at a particular corallite diameter (Text-figs. 33, 34).

"Genus" Deiracorallium Nelson, 1963

1963. Deiracorallium Nelson, p. 37.

1976. Deiracorallium Elias, p. 102-106.

Discussion: Deiracorallium was proposed by Nelson (1963) to include solitary corals having a markedly angulate convex cardinal side and strongly dilated major septa that extend to the axis without twisting. This diagnosis was based on the small type species D. manitobense Nelson, 1963. This species is probably conspecific with D. angulatum (Billings, 1862) of Anticosti Island, a possibility recognized by Nelson (1963, p. 38) and discussed under the species herein. D. giganteum Nelson, 1963 is of moderate size and has major septa that twist in the axial region. D. delicatum Elias, 1976 attains moderately large size and in later ontogenetic stages has weakly dilated major septa and an axial structure of septal lobes and lamellae. Therefore, the genus was expanded by Elias (1976) to include forms with an axial structure.

The following points must be considered in evaluating the relationships of Deiracorallium, Grewingkia Dybowski, 1873, and Leolasma Kaljo, 1956 (Text-fig. 26a, b):

1. Large species of Deiracorallium such as D. delicatum differ from Grewingkia in that the corallites are generally compressed and the axial structure is finer and smaller. However, G. robusta (Whiteaves, 1896) and G.

haysi (Meek, 1865) are sometimes compressed, and both D. delicatum and G. robusta can be triangulate to weakly trilobate. The significance of external form as a diagnostic generic trait is questionable. Variability in the complexity and size of the axial structure in Grewingkia is great, as will be discussed under that "genus".

2. Except for external form, small species such as D. angulatum resembles Leolasma. The major septa are strongly to completely dilated until immediately below the calyx where dilation decreases except around the axis, and tabulae are not developed.

Deiracorallium angulatum (Billings, 1862)

Plate 4, figs. 20-32

1862. Petraia angulata Billings, p. 103, figs. 90a, b.

1901. Streptelasma angulatum (Billings). Lambe, p. 112.

1928. Streptelasma angulatum (Billings). Twenhofel, p. 111, 112, Pl. 3, fig. 5.

1937. "Streptelasma angulatum (Billings)". Cox, p. 4, Pl. 1, fig. 5.

1943. [?] Streptelasma trilobatum (Whiteaves). Okulitch, Pl. 1, figs. 13, 14.

1959b. [?] "Streptelasma angulatum (Billings)". Nelson, Pl. 4, figs. 2a, b.

1963. [?] Deiracorallium manitobense Nelson, p. 37, 38, Pl. 13, figs. 1, 2a, b.

1963. [?] Deiracorallium manitobense var. churchillense Nelson, p. 38, Pl. 13, figs. 3a, b.

Lectotype (designated herein): GSC 1984, a; upper member, about 30+ m below top of Vaureal Formation; west end camp, Anticosti Island, Quebec; Richardson collection, 1856.

Other specimens: GSC loc. 84419 (28 specimens); upper

member, 60+ m below top of Vaureal Formation; main highway section on upper elevation east of Potatoe River crossing, Anticosti Island, Quebec; Bolton collection. YPM 506a-d; Twenhofel's zone 5, upper member, Vaureal Formation; Anticosti Island, Quebec; Twenhofel collection.

Occurrence: Upper Ordovician (Lower Ashgillian): upper member, Vaureal Formation; Anticosti Island, Quebec.

Diagnosis: Corallites ceratoid to trochoid, weakly to moderately curved, compressed, triangulate, and of small size. Calyx deep, without calicular boss. Major septa extend to axis and are very strongly to completely dilated until immediately below calyx where dilation decreases except around the axis. Cardinal septum short and thin in latest stages, when fossula is long and narrow. Minor septa confined to or may extend well beyond the moderately wide stereozone in latest stages. Tabulae absent.

Description of corallites: The largest corallite examined has a length of 23 mm. The maximum number of major septa observed is 36 at a height of 9 mm (GSC loc. 84419(b)). The corallites are ceratoid to trochoid. They are weakly to moderately curved, strongly compressed, and triangulate in early stages. Later, curvature decreases, corallite expansion decreases or ceases, and compression and triangulation decrease. Weakly developed septal grooves and interseptal ridges are present on the epitheca. The

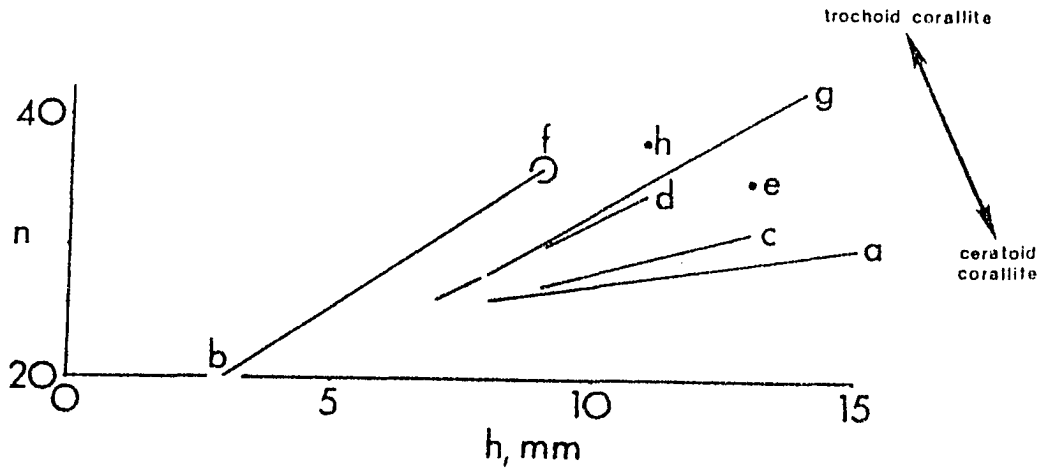
calyx has a depth equal to 0.3 of the corallite length. A calicular boss is not developed.

Ontogeny and internal structures: The major septa extend to or almost to the axis throughout ontogeny. The number of major septa at a particular height is shown in Text-fig. 35. As would be expected, trochoid corallites have more

Text-figure 35.--Deiracorallium: relation between number of major septa (n), corallite height (h), and corallite form. a-d, GSC loc. 84419a-d, D. angulatum (Billings, 1862), Vaureal Fm., Anticosti Is., Quebec; e, GSC 10846, paratype of D. manitobense Nelson, 1963, mbr. no. 1, Caution Creek Fm., northern Manitoba; f, GSC 10847, holotype of D. manitobense var. churchillense Nelson, 1963, mbr. no. 1, Chasm Creek Fm., northern Manitoba; g, h, UM 266, 346, Deiracorallium sp., Gunn Mbr., Stony Mountain Fm., Stony Mountain, Manitoba (see App. 8).

septa at a particular height than ceratoid forms. The septa are very strongly to completely dilated until immediately below the calyx where dilation decreases except around the axis. The cardinal septum is short and thin in late stages, and the cardinal fossula is narrow. In late stages immediately below the calyx, the minor septa may be confined to (GSC loc. 84419(a)) or extend well beyond the moderately broad stereozone (GSC loc. 84419(b)). Tabulae

Text-figure 35.--Deiracorallium: relation between number of major septa (n), corallite height (h), and corallite form. a-d, GSC loc. 84419a-d, D. angulatum (Billings, 1862), Vaureal Fm., Anticosti Is., Quebec; e, GSC 10846, paratype of D. manitobense Nelson, 1963, mbr. no. 1, Caution Creek Fm., northern Manitoba; f, GSC 10847, holotype of D. manitobense var. churchillense Nelson, 1963, mbr. no. 1, Chasm Creek Fm., northern Manitoba; g, h, UM 266, 346, Deiracorallium sp., Gunn Mbr., Stony Mountain Fm., Stony Mountain, Manitoba (see App. 8).



Text-fig. 35

are not developed.

Microstructure: Septal fibers are well developed and the trabeculae are weakly inclined up toward the axis. Lamellae are not present in the stereozone.

Discussion: Billings' original description was based on three syntypes, one of which was figured. Twenhofel (1928) listed and figured the holotype as GSC 1984 and listed one paratype as GSC 1984a. Cox (1937) listed and figured the holotype as GSC 1984a, the original of Billings' figure. The specimen represented in Billings' figure is presently unknown. GSC 1984 is the specimen figured by Twenhofel, and GSC 1984a is a thin section of GSC 1984. This is the only known syntype, and is herein designated as the lectotype of Deiracorallium angulatum.

Specimens of Deiracorallium in the Stony Mountain Formation of southern Manitoba were assigned to Streptelasma trilobatum by Okulitch (1943), to "S. angulatum" by Nelson (1959b), and to D. manitobense by Nelson (1963). Similar specimens from the Caution Creek and Chasm Creek Formations of northern Manitoba were assigned to D. manitobense and D. manitobense var. churchillense by Nelson (1963). These corals from Manitoba are probably conspecific with D. angulatum, a possibility recognized by Nelson (1963, p. 38). All have similar numbers of septa at a particular height (Text-fig. 35). Definite assignment must await further

sectioning and study of the forms from Manitoba.

Deiracorallium angulatum resembles Leolasma Kaljo, 1956 (see B. Neuman, 1975, p. 337) in having a solid axial structure of fused major septa in later stages. However, Deiracorallium is compressed and triangulate, and larger species such as D. delicatum Elias (1976, p. 107-111) develop a fine axial structure in late stages.

"Genus" Grewingkia Dybowski, 1873

1969. Grewingkia B. Neuman, p. 33-36.

1974. Grewingkia McLean, p. 42-44.

1976. Grewingkia Elias, p. 54-60.

Discussion: Until Neuman's (1969) examination of variability within Grewingkia, diagnoses of the "genus" were based almost entirely on characteristics of the type species G. buceros (Eichwald, 1856) alone. Neuman (1969, p. 33) noted that the degree of septal dilation and nature of the axial structure are the most variable morphologic features. As presently understood, the "genus" includes species such as G. penobscotensis n. sp. and G. anguinea (Scheffen, 1933) having weakly dilated major septa in early ontogenetic stages, to G. rustica (Billings, 1858) in which dilation is complete in early stages and very strong even in later stages. In general, the axial structure of Grewingkia is relatively large and consists of numerous septal lobes and lamellae in later stages.

The uncertain relationships of Grewingkia, Streptelasma Hall, 1847, Helicelasma Neuman, 1969, and Deiracorallium Nelson, 1963 were discussed under the latter three "genera". The following points suggest that the sequence Borelasma Neuman, 1969 → Helicelasma → Grewingkia → Lobocorallium Nelson, 1963 is gradational (Text-fig. 26a):

1. The single species G. canadensis (Billings, 1862) is

highly variable and includes corallites having an open axial region as in Borelasma, those resembling Helicelasma in having major septa that extend to the axis, and forms with simple to complex axial structures characteristic of Grewingkia.

2. The following continuous morphologic sequence between Grewingkia and Lobocorallium is recognized, and involves an increase in the degree of trilobation and septal dilation, and a decrease in the number of tabulae: G. robusta (Whiteaves, 1896) → G. haysi (Meek, 1865) → L. trilobatum subsp. vaurealensis (Twenhofel, 1928) → L. trilobatum (Whiteaves, 1895).

Grewingkia canadensis (Billings, 1862)

Plate 4, figs. 33-53; Plate 5, figs. 1-46;
Plate 6, figs. 1-34

1851. Streptelasma corniculum Hall [partim]. Milne-Edwards and Haime, p. 398, 399, Pl. 7, figs. 4, a, b.

1862. Zaphrentis canadensis Billings, p. 105, 106, figs. 93a-c.

1863. Petraia canadensis Billings. Geol. Surv. Can., fig. 205, p. 208.

1875a. Streptelasma corniculum Hall [partim]. Nicholson, p. 26, 27.

1875b. Streptelasma corniculum Hall [partim]. Nicholson, p. 218, 219.

1876. Streptelasma corniculum Hall [partim]. Rominger, p. 142, 143, Pl. 51, upper tier [partim].

1882. Streptelasma corniculum Hall [partim], p. 376, Pl. 51, figs. 2-4.

1901. Streptelasma rusticum (Billings) [partim]. Lambe, p. 110-112, Pl. 7, figs. 2, a, 3.

1908. Streptelasma rusticum (Billings) [partim]. Cumings, p. 708, 709, Pl. 2, figs. 2, a, b.

1909. Streptelasma vagans Foerste, p. 305, 306, Pl. 11, figs. 1a-c.

1909. Streptelasma insolitum Foerste, p. 306, Pl. 10, fig. 3.

1909. Streptelasma dispandum Foerste, p. 307, Pl. 9, figs. 4a, b.

1924. Streptelasma rusticum (Billings) [partim]. Foerste, p. 65, 66, Pl. 1, figs. 1a-c, 2a-c, Pl. 2, figs. 6a-c.

1924. Streptelasma dispandum Foerste, p. 66, 67, Pl. 2, fig. 4.

1932. Streptelasma rusticum (Billings). Bassler, Pl. 24, figs. 16, 17.

1937. Streptelasma rusticum (Billings) [partim]. Cox, p. 11-13, Pl. 2, figs. 11, 12a-c, 13a-d.

1948. Streptelasma rusticum (Billings). C.W. Wilson, Pl. 19, figs. 26, 27.

1949. Streptelasma rusticum (Billings). C.W. Wilson, Pl. 19, figs. 26, 27.

1963. Streptelasma arcticum drummondense Stumm, p. 27, Pl. 2, figs. 4-7.

1964. Grewingkia rustica (Billings). Liberty, Pl. 6, fig. 8.

1967. Grewingkia rustica (Billings). Simmons and Oliver, p. F9-F10.

1967. "Streptelasma" spp. A-E and angulatum (Billings). Simmons and Oliver, p. F10.

1972. Grewingkia rustica (Billings). Bolton and

Copeland, Pl. B, figs. 9, 11.

Lectotype (designated herein): GSC 1983h, i; upper member, Georgian Bay Formation; Drummond Island, Michigan; Murray collection, 1847.

Paralectotypes (designated herein): GSC 1983, a; 1983b, c, e; 1983d; 1983f, g; upper member, Georgian Bay Formation; Drummond Island, Michigan; Murray collection, 1847.

Other specimens: UCGM 45153-45500; Richmond Group; Cincinnati Arch region, Ohio-Indiana-Kentucky (see Text-fig. 3 for stratigraphic positions and location); Elias collection. USNM 70024 (2 of 3 specimens); "Waynesville" strata (base of Clarksville), Richmond Group; near Clarksville, Ohio. USNM 70487 (4 specimens); "Waynesville" strata (lower 1 m of Clarksville), Richmond Group; Stony Hollow, Clarksville, Ohio. USNM 78749 (syntype of S. vagans Foerste, 1909); "Liberty" strata, Richmond Group; Tate's Hill, Dayton, Ohio. USNM 84871 (2 specimens); "Liberty" or "Whitewater" strata, Richmond Group; Tate's Hill, Dayton, Ohio. USNM 78742 (5 syntypes of S. dispandum Foerste, 1909); "Waynesville" (Blanchester) strata, Richmond Group; Moore's Hill, Indiana. USNM 84870 (holotype of S. insolitum Foerste, 1909); "Whitewater" strata, Richmond Group; SE of Westport, Indiana. USNM 9719 (9 specimens); "Waynesville" strata, Richmond Group; railroad cut, Madison, Indiana. USNM 15587; "Whitewater"

strata, Richmond Group; Connersville, Indiana. Otter Creek coral bed, Preachersville Member, Drakes Formation (see Simmons and Oliver, 1967): USGS loc. 4662-CO (4 specimens), Lancaster quad., Lincoln Co., Kentucky; USGS loc. D1370-CO (26 specimens), Richmond North quad., Madison Co., Kentucky; USGS loc. 5308-CO (1 specimen), Union City quad., Madison Co., Kentucky; USGS loc. 4468-CO (11 specimens), Palmer quad., Estill Co., Kentucky; USGS loc. 4545-CO (6 specimens), Palmer quad., Madison Co., Kentucky; USGS loc. 4760-CO (6 specimens), Palmer quad., Clark Co., Kentucky. UCGM 45501-45536; Richmond Group; Goodlettsville-Gallatin area, Tennessee (see Text-fig. 3 for stratigraphic positions and locations); Elias collection. USNM 102371 (7 specimens); Arnheim Formation (Rhynchotrema dentatum bed, middle division of Richmond Group); 6.4 km NE of Goodlettsville, Tennessee. USNM 42512 (21 specimens); 6.4 km NE of Goodlettsville, Tennessee. USGS 370U (6 specimens); Bassler's bed 5, Richmond Group; near Bakers, Tennessee. USNM 80609; Arnheim Formation; near Bakers, Tennessee. USNM 42515 (13 specimens); Arnheim Formation; 0.8 km S of Dismukes, Sumner Co., Tennessee. USGS 347W; colonial coral bed at top of Maquoketa Group; NW¼, sec. 17, T27N, R24E, Little Sturgeon Bay, Wisconsin; Ulrich collection. USGS 433K (G. cf. canadensis, 6 specimens); colonial coral bed at top of Maquoketa Shale; Little Sturgeon Bay, Wisconsin; Ulrich and Mesler collection. UCGM 45537-45562, 45612; upper Meaford beds, upper member, Georgian Bay Formation;

Drummond Island, Michigan (see Text-fig. 18 for stratigraphic positions and locations); Elias collection. UMMP 26927, 45353, 45354 (holotype and paratypes of S. arcticum drummondense Stumm, 1963); upper Meaford beds, upper member, Georgian Bay Formation; S side of Potaganissing Bay, Poe Point, Drummond Island, Michigan; Hussey collection. UCGM 45563-45591; Meaford beds, upper member, Georgian Bay Formation; Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic positions and locations); Elias collection. LU M75-1 to 7 (plus 6 specimens); upper Wekwemikongsing beds, lower member, Georgian Bay Formation; locality M75, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location). LU M61a-2, 3, 5-7 (plus 8 specimens); Meaford beds, upper member, Georgian Bay Formation; locality M61a, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location). GSC 8530, a-c, e-j (10 specimens); Meaford beds, upper member, Georgian Bay Formation; gully N of lighthouse, Manitowaning, Manitoulin Island, Ontario; Foerste collection. GSC 8529, b-d (4 specimens); 8528, a-d (5 specimens); 8573a-c (3 specimens); GSC loc. 6259 (1 specimen); Meaford beds, upper member, Georgian Bay Formation; Clay Cliffs, Manitoulin Island, Ontario; Foerste collection. GSC 1982, a; b, c; d, e; f, g; i; k, l (6 specimens); Meaford beds, upper member, Georgian Bay Formation; Cape Smith, Manitoulin Island,

Ontario; Bell collection, 1859. GSC 8531; upper Georgian Bay Formation; 3.2 km NW of Meaford on road to Cape Rich, Ontario; Foerste collection.

Occurrence: Upper Ordovician (Richmondian): "Waynesville" strata to top of Richmond Group; Cincinnati Arch region, Ohio-Indiana-Kentucky. Throughout the Richmond Group; Goodlettsville-Gallatin area, Tennessee. Meaford beds, upper member, Georgian Bay Formation; Drummond Island, Michigan. Top of lower member (Wekwemikongsing beds), and Meaford beds of upper member, Georgian Bay Formation; Manitoulin Island, Ontario. Top of Georgian Bay Formation; Meaford, Ontario. Top of Maquoketa Group; Little Sturgeon Bay, Michigan.

Diagnosis: Corallites ceratoid to trochoid and usually become cylindrical in late stages, generally very weakly curved, and attain large size. Calyx deep with moderately convex calicular boss when axial structure is developed.

Axial structure generally of moderate size and moderately complex consisting of septal lobes and lamellae, but varies from very complex with many septal lamellae to simple with only a few septal lobes or none at all. Major septa completely dilated in early stages, strongly to completely dilated in intermediate stages, and undilated to weakly dilated in late stages. Cardinal and counter septa generally distinct in being long throughout ontogeny and

often having very strongly dilated lobes in intermediate stages. Cardinal fossula in late stages narrow and expands at the axial region. Minor septa generally confined to the moderately broad stereozone in late stages. Tabellae in septal region. Tabulae in axial region mostly complete, moderately spaced, and generally moderately convex upward.

Description of corallites: The corallites can attain lengths in excess of 130 mm, and diameters greater than 40 mm. The length of specimens is shown in Text-fig. 6 and discussed in the text. The corallites vary from ceratoid to trochoid, and usually become cylindrical in late stages. They are generally very weakly curved in early to intermediate stages and are uncurved in late stages. Moderately curved corallites are uncommon. Septal grooves and interseptal ridges are weakly developed on the epitheca. Corallites in lateral contact are very rare (USNM 15587; UCGM 45438, 45307, 45533, 45577). Increase has not been demonstrated in these cases. The calyx commonly has a depth equal to about 0.35 of the corallite length, but varies from 0.3 to 0.5 (App. 12). The calicular boss is moderately convex when an axial structure is developed.

Ontogeny and internal structures: In early stages the major septa extend to or almost to the axis. In intermediate stages the small axial structure is composed of a few very strongly dilated septal lobes, and the cardinal and counter

septal lobes are often especially prominent. In late stages the axial region is highly variable. The axial structure is generally of moderate size and complexity, consisting of septal lobes and lamellae, but it varies from very complex with many fine septal lamellae to simple with only a few septal lobes. Septal elements are sometimes completely lacking in the axial region (Plate 4, figs. 33-53; Text-fig. 12).

The number of major septa at a particular diameter is shown in Text-fig. 36. The major septa are completely

Text-figure 36.--Grewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) for the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curve is visual fit of class averages. USNM 78749, (△), cotype of Streptelasma vagans Foerste, 1909, "Liberty" strata, Dayton, Ohio; USNM 78742, (□), cotype of S. dispandum Foerste, 1909, "Waynesville" strata, Moore's Hill, Indiana; USNM 84870, (o), holotype of S. insolitum Foerste, 1909, "Whitewater" strata, Westport, Indiana (see App. 8).

dilated in early stages, strongly to completely dilated in intermediate stages, and undilated to weakly dilated in late stages. The cardinal and counter septa are generally

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Text-figure 36.--Crewingkia canadensis (Billings, 1862): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) for the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curve is visual fit of class averages. USNM 78749, (△), cotype of Streptelasma vagans Foerste, 1909, "Liberty" strata, Dayton, Ohio; USNM 78742, (□), cotype of S. dispandum Foerste, 1909, "Waynesville" strata, Moore's Hill, Indiana; USNM 84870, (o), holotype of S. insolitum Foerste, 1909, "Whitewater" strata, Westport, Indiana (see App. 8).

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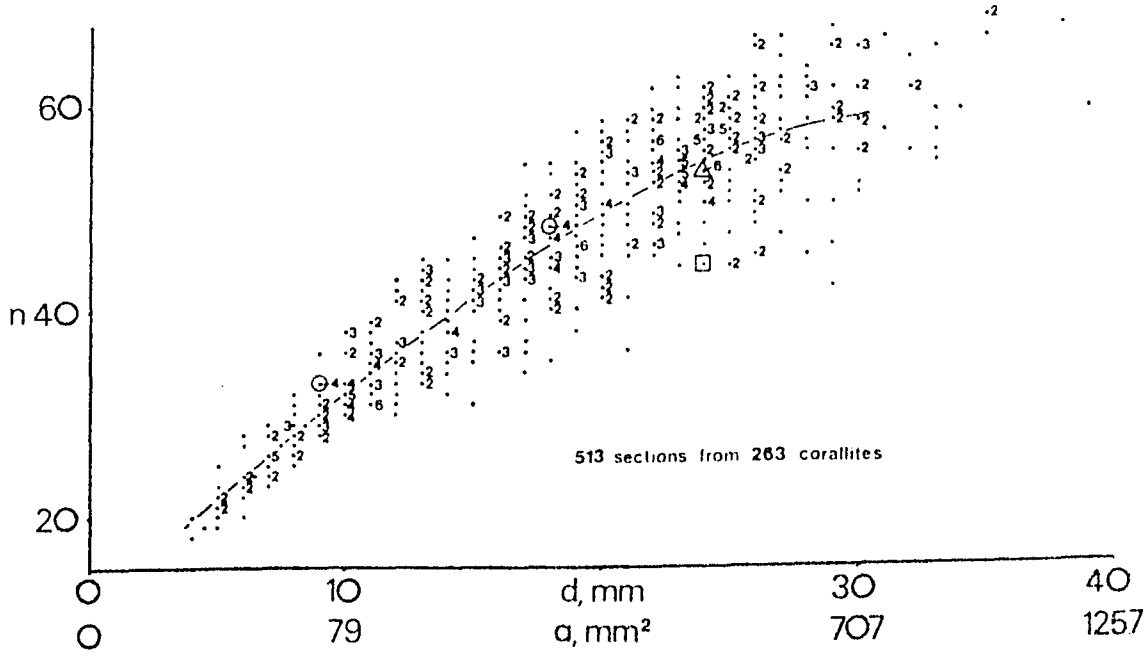


Text-fig. 36

distinct in being longer than the other septa throughout ontogeny. The cardinal fossula in late stages is narrow and expands at the axial region. The minor septa are generally confined to the moderately broad stereozone in late stages.

Tabellae occur in the septal region in incompletely dilated stages. They are steeply to moderately inclined up toward the axis in intermediate stages and become less steeply inclined with increased height in the corallites. The tabulae in the axial region are mostly complete and generally moderately spaced. In intermediate stages they are steeply to moderately convex upward, and in late stages are usually moderately convex upward.

Microstructure: The major septa are clearly fibrous, especially when dilated. Trabeculae are inclined slightly up toward the axis. The stereozone in incompletely dilated sections is composed of lamellae. The epitheca is composed of small groups of fibers generally oriented perpendicular to the exterior surface.

Discussion: The syntypes of Grewingkia canadensis are from Drummond Island, where corals are unfortunately not as well preserved as elsewhere in the Richmond Province. However, these and other specimens from Drummond Island are indistinguishable from specimens at Manitoulin Island, the Cincinnati Arch region, and the Nashville Dome. GSC 1983h,

i from Billing' syntypes is designated as the lectotype because it is an originally figured specimen and cross-sections have been prepared.

The solitary corals from Drummond Island were referred to Streptelasma corniculum by Nicholson (1875b) and Rominger (1876), to S. rusticum by Lambe (1901) and Cox (1937), and to G. rustica by Liberty (1964) and Bolton and Copeland (1972). The solitary corals from Manitoulin Island were referred to S. corniculum by Nicholson (1875a), S. rusticum by Lambe (1901), Foerste (1924), and Cox (1937), and G. rustica by Bolton and Copeland (1972). These are G. canadensis. Stumm (1963) named S. arcticum drummondense from Drummond and Manitoulin Islands. His holotype, which has been sectioned, and figured paratypes are G. canadensis. The large solitary corals from the Cincinnati Arch region were referred to S. corniculum by Milne-Edwards and Haime (1851), Nicholson (1875b), Rominger (1976), and Hall (1882), and to S. rusticum by Cumings (1908) and Cox (1937). Foerste (1909) named S. vagans, S. insolitum, and S. dispandum, distinguishing them primarily on the basis of external form. In 1924 he synonymized S. vagans with S. rusticum and reported S. dispandum from Manitoulin Island. His types have been sectioned, and are G. canadensis. Simmons and Oliver (1967) reported G. rustica, "Streptelasma" spp. A-E and "S." angulatum. These specimens have been examined, and represent various growth

stages and variations of G. canadensis. Bassler (1932) and C.W. Wilson (1948, 1949) referred specimens from the Nashville Dome to S. rusticum. These are G. canadensis. Foerste (1924) referred a specimen from Meaford, Ontario, to S. rusticum. This specimen has been sectioned and is G. canadensis. Specimens from Little Sturgeon Bay are silicified and poorly preserved, but USGS 347W is G. canadensis.

The degree of variation of the axial region in later ontogenetic stages within G. canadensis spans the "genera" Borelasma, Helicelasma, and Grewingkia. The species is referred to Grewingkia because the majority of corallites have the moderately complex axial structure characteristic of that 'genus'. G. canadensis is distinct in having long cardinal and counter septa that have very strongly dilated lobes in intermediate stages. This species resembles those of the 'genus' from the Red River Province in having well developed tabellae in the septal region.

Grewingkia deltensis n. sp.

Plate 6, figs. 35-45

1918. Streptelasma rusticum (Billings). Foerste, p. 99, Pl. 4, fig. 1.

1963. Streptelasma rusticum (Billings) [partim]. Stumm, p. 26, 27, only Pl. 2, figs. 1-3.

Etymology: The specific name is derived from Delta Co., Michigan, where the species occurs.

Holotype: UCGM 45602; Ogontz Member, Stonington Formation; locality 17b-1, Delta Co., Michigan; Elias collection.

Paratypes: UMMP 26911; Bay de Noc Member, Stonington Formation; locality 17b, Delta Co., Michigan. UCGM 45593-45601, 45603, 45604; Ogontz Member, Stonington Formation; locality 17b-1, Delta Co., Michigan; Elias collection.

Occurrence: Upper Ordovician (Richmondian): Bay de Noc and Ogontz members, Stonington Formation; Delta Co., Michigan.

Diagnosis: Corallites trochoid, moderately curved, and attain large size. Epitheca with septal grooves and interseptal ridges. Calyx of moderate depth with weakly convex calicular boss.

Large, coarse axial structure of a few generally thin

septal lobes and lamellae. Major septa almost completely dilated near tip and undilated in late stages. Short cardinal septum and numerous tabellae in prominent fossula in late stages. Minor septa poorly developed and confined to a narrow stereozone. Tabulae mostly complete, very closely to widely spaced, weakly convex upward within septal and axial regions but concave upward at junction of the two regions. A few complementary plates present.

Description of corallites: The longest corallite examined (UCGM 45604) has a length of 85 mm and a diameter of 33 mm immediately below the calyx where 59 major septa are present. UMMP 26911 is 81 mm long and has a diameter of 37 mm immediately below the calyx where 62 major septa are present. The corallites are trochoid and moderately curved. The epitheca has septal grooves and interseptal ridges (UCGM 45594). The calyx has a depth equal to 0.3 of the corallite length (UMMP 26911; UCGM 45602, 45604). The calicular boss is weakly convex (UCGM 45602).

Ontogeny and internal structures: Near the tip some major septa extend to the axis. In intermediate stages a few long septal lobes arising primarily from septa on the cardinal side extend to the axis. In late stages the major septa become short and the large axial region contains a coarse structure of relatively few generally thin septal lobes and lamellae.

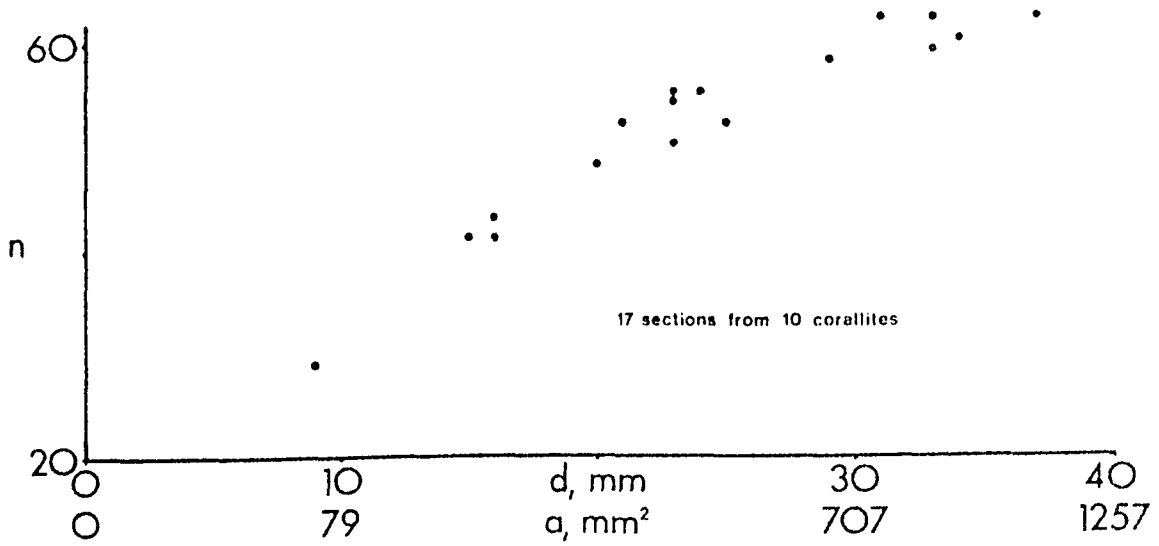
The number of major septa at a particular diameter is shown in Text-fig. 37. Near the tip the major septa are

Text-figure 37.--Grewingkia deltensis n. sp.: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) (see App. 8).

almost completely dilated. Dilation decreases upward. Septa are sometimes more strongly dilated on the cardinal side than on the counter side. In early stages the cardinal septum is long and more strongly dilated than the other septa. In intermediate stages it becomes thinner than the other septa and the fossula is narrow. In late stages the cardinal septum becomes short, and a prominent fossula with numerous tabellae develops. In early to intermediate stages the major septa on the cardinal side tend to impinge on the cardinal septum or fossula, and the septa on the counter side tend to impinge on the long alar septa. The minor septa are poorly developed and confined to the narrow stereozone.

Tabulae first appear when the axial region begins to develop. They are mostly complete and very closely to widely spaced. They are weakly convex upward within the septal and axial region, but are concave upward at the junction of the two regions. A few complementary plates are present.

Text-figure 37.--*Crewingkia deltensis* n. sp.: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) (see App. 8).



Text-fig. 37

Microstructure: Septal fibers are well developed, and the trabeculae are slightly inclined up toward the axis. Lamellae are rarely present in the stereozone.

Discussion: Foerste (1918) reported this species as Streptelasma rusticum in the Ogontz Member and immediately beneath in the Bay de Noc Member of the Stonington Formation. Stumm (1963) described and illustrated a single specimen from the Bay de Noc Member and referred it to S. rusticum. These specimens are Grewingkia deltensis.

G. deltensis is distinguished from other species of the "genus" by its prominent cardinal fossula with short cardinal septum and numerous tabellae, and tabulae that are convex upward within the septal and axial regions but concave upward at the junction of the two regions.

Crewingkia rustica (Billings, 1858)

Plate 7, figs. 1-18

1858a. Petraia rustica Billings, p. 168, 169.

1858b. Petraia rustica Billings, p. 422, 423.

1901. Streptelasma rusticum (Billings) [partim]. Lambe, p. 110-112, Pl. 7, figs. 2, a, 3.

1908. Streptelasma rusticum (Billings) [partim]. Cumings, p. 708, 709, non Pl. 2, figs. 2, a, b.

1924. Streptelasma rusticum (Billings) [partim]. Foerste, p. 65, 66, non Pl. 1, figs. 1a-c, 2a-c, Pl. 2, figs. 6a-c.

1937. Streptelasma rusticum (Billings) [partim]. Cox, p. 11-13.

1963. Streptelasma rusticum (Billings) [partim]. Stumm, p. 26, 27, only Pl. 2, figs. 8-10.

Lectotype (designated herein): GSC 5822b, c; Snake Island, Lake St. John, Quebec; Richardson collection, 1857.

Paralectotype (designated herein): GSC 5822, a; Snake Island, Lake St. John, Quebec; Richardson collection, 1857.

Other specimens: GSC 8527, a, c, e, f, h, j-s and UMMP 45351, 45352; Snake Island, Lake St. John, Quebec; Foerste collection. UCGM 45592; Meaford beds, upper member,

Georgian Bay Formation; Manitoulin Island, Ontario; Elias collection.

Occurrence. Upper Ordovician (Richmondian): Richmond Group; Snake Island, Lake St. John, Quebec. Meaford beds, upper member, Georgian Bay Formation; Manitoulin Island, Ontario.

Diagnosis: Corallites ceratoid to trochoid and become cylindrical in later stages, straight to very weakly curved, and attain large size. Epitheca with septal grooves and interseptal ridges. Calyx deep with weakly convex calicular boss.

Complex axial structure of numerous septal lobes and lamellae in late stages. Major septa completely dilated in early stages and very strongly dilated in later stages until immediately below calyx when dilation of septa and axial structure decreases. In later stages cardinal septum less strongly dilated, fossula narrow. Minor septa confined to or extend a short distance beyond a stereozone of moderate width. Tabulae mostly complete, moderately to widely spaced, and weakly concave upward axially to strongly convex upward.

Description of corallites: The largest corallite examined (GSC 5822b,c) has a length of 65 mm but is incomplete at both ends. It has a diameter of 30 mm immediately below the calyx where 54 major septa are present. The corallites

are ceratoid to trochoid, and become cylindrical in later stages. They are uncurved to very weakly curved. Septal grooves and interseptal ridges are present on the epitheca. The calyx has a depth equal to 0.4 of the corallite length (GSC 58271, n). The sides of the calyx are steep and the boss is weakly convex (GSC 5827a).

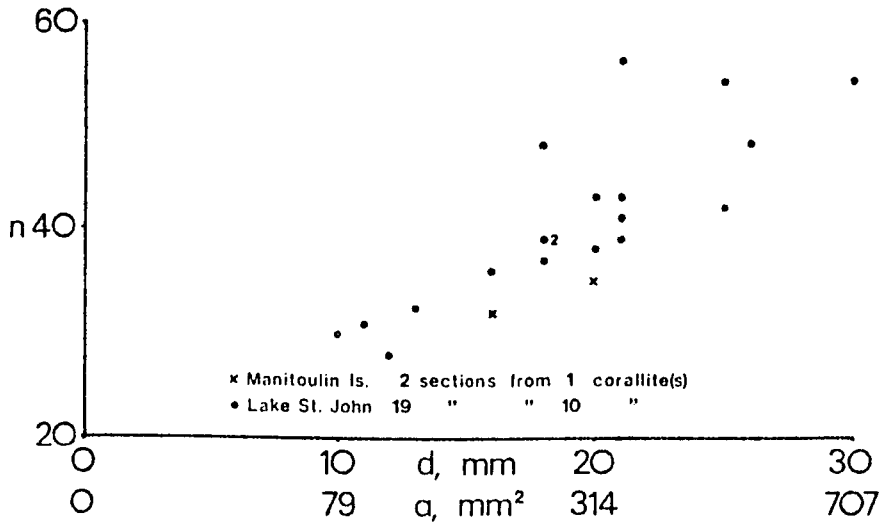
Ontogeny and internal structures: In early stages the major septa extend to or almost to the axis. A few strongly dilated septal lobes soon appear, followed by septal lamellae. A large, complex axial structure of numerous septal lobes and lamellae is developed in later stages in the less strongly dilated zone immediately below the calyx.

The number of major septa at a particular diameter is shown in Text-fig. 38. The major septa are completely

Text-figure 38.--Grewingkia rustica (Billings, 1858): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).

dilated in early stages and remain very strongly dilated in intermediate stages. Dilation of the septa and axial structure decreases immediately below the calyx in later stages. In early stages the cardinal septum is long and generally broader than the other major septa. In

Text-figure 38.--*Crewingkia rustica* (Billings, 1858): relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (*a*). Numbers indicate frequency of a point if greater than one (*see* App. 8).



Text-fig. 38

intermediate and late stages it becomes less strongly dilated and a narrow fossula develops. In most specimens the major septa form a counterclockwise whorl in early to intermediate stages. In later stages the minor septa are confined to or extend a short distance beyond the moderately broad stereozone.

Tabulae, first appearing in intermediate stages, are mostly complete and moderately to widely spaced. They vary from slightly depressed axially (UMMP 45352) to weakly convex upward (GSC 5822, a) to strongly convex upward (GSC 8527j). A few complementary plates are present.

Microstructure: Septal fibers are well developed, and trabeculae are weakly inclined up toward the axis. Lamellae are not present in the stereozone.

Discussion: This species was first listed from Snake Island, Lake St. John, as Streptoplasma corniculum by Richardson (1858, p. 89). Billings (1858a, b) described Richardson's collection as a new species, Petraia rustica, but did not figure it. Lambe (1901) examined the types and figured two specimens which were collected from Snake Island by Richardson in 1857. Because it is probable that these were Billings' syntypes, they are herein designated as the lectotype and paralectotype. Only those portions of the descriptions and illustrations by Lambe (1901), Cumings (1908), Foerste (1924), Cox (1937), and Stumm (1963)

dealing with specimens from Snake Island are synonymous with Grewingkia rustica. Their other material and all references to this species not included in the synonymy belong to other species. Except for one specimen from the base of the Meaford beds on Manitoulin Island, G. rustica is known only from Lake St. John, Quebec.

G. rustica generally has fewer major septa at a particular diameter than G. canadensis (Billings, 1862), but the two species are similar in external form and may be related. G. rustica is distinct in having completely to very strongly dilated septa until immediately below the calyx in late stages when dilation decreases and a complex axial structure develops.

Grewingkia penobscotensis n. sp.

Plate 7, figs. 19-23

Etymology: The specific name refers to Penobscot Co., Maine, where the species occurs.

Holotype: USGS 6268a-c; Neuman collection.

Paratypes: USGS 6333a-c; 6334a-c; 6336a, b; 6339a, b; 6342a, b; 6343a, b; 6261a, b; 6266a, b; 6267a, b; Neuman collection.

Occurrence: Upper Ordovician (Ashgillian): About 520 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot Co., Maine.

Diagnosis: Corallites ceratoid to trochoid, weakly curved, and attain moderate size. Prominent calicular boss. Coarse axial structure of a few moderately dilated septal lobes and lamellae. Major septa weakly dilated in early stages. Cardinal septum indistinct, fossula not developed. Minor septa extend a short to moderate distance beyond a stereozone of moderate width. Tabulae mostly complete, moderately convex upward, somewhat irregular.

Description of corallites: The specimens are poorly preserved and incomplete. The largest corallite examined (USGS 6268) has a diameter of 25 mm and 51 major septa in the calyx. The corallites are ceratoid to trochoid and

weakly curved. The calicular boss is prominent.

Internal structures: A coarse axial structure of a few moderately dilated septal lobes and lamellae appears early in ontogeny. The number of major septa at a particular diameter is shown in Text-fig. 39. The major septa are

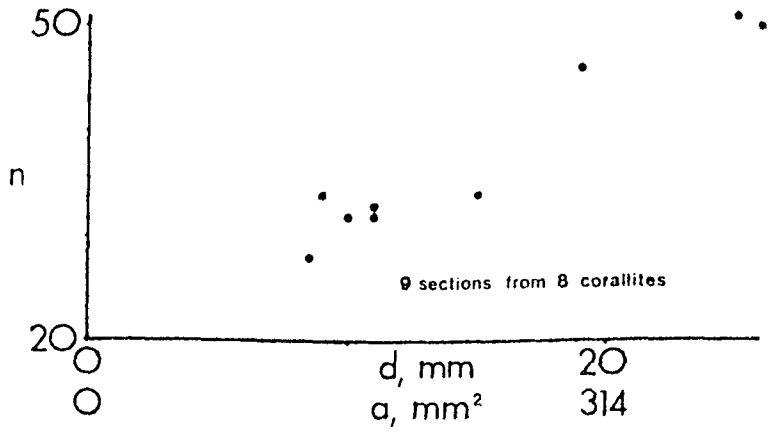
Text-figure 39.--Grewingkia penobscotensis n. sp.: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) (see App. 8).

undilated to weakly dilated. The cardinal septum is indistinct and a fossula is not developed. The minor septa extend a short to moderate distance beyond the stereozone, which is of moderate width. The tabulae are somewhat irregular, mostly complete, and moderately convex upward. USGS 6268 is the only specimen in which the tabulae are concave upward at the periphery of the corallite. Complementary plates are sometimes present.

Microstructure: The specimens are poorly preserved, but some weakly developed septal fibers can be distinguished, and weak trabeculae are inclined up toward the axis.

Discussion: Grewingkia penobscotensis is distinct in having undilated to weakly dilated septa, a coarse axial structure of a few septal lobes and lamellae, an indistinct cardinal septum, and no fossula.

Text-figure 39.--*Grewingkia penobscotensis* n. sp.: relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (*a*) (*see* App. 8).



Text-fig. 39

Grewingkia pulchella (Billings, 1865)

Plate 7, figs. 24-28

1865. Petraia pulchella Billings, p. 429.

1865. Petraia selecta Billings [partim], p. 429.

1866. Petraia pulchella Billings, p. 33.

1866. Petraia selecta Billings [partim], p. 7.

1901. Streptelasma selectum (Billings) [partim]. Lambe, p. 113, Pl. 6, figs. 8, a.

1928. Streptelasma selectum (Billings) [partim]. Twenhofel, p. 113.

Lectotype (designated herein): GSC 2243, a; Ellis Bay Formation; Ellis Bay, Anticosti Island, Quebec; Weston collection, 1865.

Other specimens (all from Twenhofel collection, Anticosti Island, Quebec, unless otherwise stated): YPM 558a; lower member (Twenhofel's English Head Formation), Vaureal Formation; cliff between Bear Cape and Cape Eagle. YPM 533a; lower member (Twenhofel's English Head Formation), Vaureal Formation; Cape Eagle. YPM 506e; Twenhofel's zone 5, upper member, Vaureal Formation; zone 8 of Twenhofel's Vaureal River section. GSC 1989e; h; i, j; k; l; m; n; upper member, 27-30 m below top of Vaureal Formation; west end lighthouse; Richardson collection, 1856 (probably syntypes of Petraia selecta). YPM 518a, b;

upper member (English Head facies), Vaureal Formation; West Bay. YPM 3063/41a-c; Ellis Bay Formation; Cape James Bay. YPM 3063/45b, c; Ellis Bay Formation; west side of Prinstie Bay. YPM 3063/52b-d; Ellis Bay Formation; west side of Ellis Bay. YPM 538b; Ellis Bay Formation; cliff 1.2 km east of Junction Cliff. YPM 3063/44a; Ellis Bay Formation; Prinstie Bay. YPM 537a; Ellis Bay Formation; Twenhofel's zone 13 at Cape James. YPM 546a; Ellis Bay Formation; zone 15 of Twenhofel's Vaureal River section. YPM 532a; Ellis Bay Formation; zone 22 of Twenhofel's Vaureal River section. YPM 3063/55a; Ellis Bay Formation; Twenhofel's zone D, west side of Ellis Bay. YPM 539b; basal unit, Ellis Bay Formation; zone 10 of Twenhofel's Vaureal River section. YPM 3019/3063/35b-d, g, h; Twenhofel's zone 1, Ellis Bay Formation; Junction Cliff. YPM 548b; Twenhofel's zone 1, Ellis Bay Formation; west side of Ellis Bay. YPM 3063/36a; Twenhofel's zone 2, Ellis Bay Formation; Junction Cliff. YPM 529a-c; Twenhofel's zone 2, Ellis Bay Formation; Junction Cliff. YPM 547a; Twenhofel's zone 2, Ellis Bay Formation; west side of Ellis Bay. YPM "Ellis Bay zone 6"; Twenhofel's zone 6, Ellis Bay Formation; east of Junction Cliff. YPM 3063/56c; Twenhofel's zone 7 (Hormotoma gigantea zone), Ellis Bay Formation; Ellis Bay. YPM 541a, b; Twenhofel's zone 8, Ellis Bay Formation; west side of Ellis Bay. YPM 536; Twenhofel's zone 9, Ellis Bay Formation; reef at

Ellis Bay. YPM 551; Twenhofel's zone 9, bioherm at base of Bolton's member 6, Ellis Bay Formation; Raspberry Point. YPM 3019/3063/57e-g; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay. YPM 540a; Twenhofel's zone 10, Ellis Bay Formation; west side of Ellis Bay. USGS loc. 4112-CO(a-f, + 13 other identifiable specimens); unnamed unit; 9 km E of Ashland, Maine; Neuman collection.

Occurrence: Upper Ordovician: Lower member (? Caradocian) and upper member (Lower Ashgillian), Vaureal Formation, and Ellis Bay Formation (Ashgillian, ? Gamachian); Anticosti Island, Quebec. Unnamed unit (probably Ashgillian); 9 km E of Ashland, Maine.

Diagnosis: Corallites ceratoid to trochoid, weakly curved, and small. Epitheca with prominent septal grooves and interseptal ridges. Calyx deep with moderately to strongly convex calicular boss.

Axial structure generally dense in intermediate stages and composed of a few septal lobes and lamellae in late stages. Major septa completely dilated in early stages and weakly to moderately dilated in late stages. Cardinal septum generally indistinct, fossula narrow. Minor septa extend a short distance beyond the narrow to moderately broad stereozone in late stages. Tabulae in later stages sparse, incomplete, and irregular.

Description of corallites: The length of corallites is shown in Text-fig. 23 and discussed in the text. The longest corallite examined (YPM 541b) has a length of 30 mm and is 13 mm in diameter immediately below the calyx where 32 major septa are present. The corallites are ceratoid to trochoid and generally weakly curved. A tiny area of attachment at the tip on the cardinal side is rarely present (YPM 3019/3063/35g, h). The epitheca has prominent septal grooves and interseptal ridges. The calyx has a depth equal to 0.4 of the corallite length (YPM 538b). The calicular boss is moderately to strongly convex.

Ontogeny and internal structures: In early stages the major septa extend to the axis. In intermediate stages the axial structure is generally dense, consisting of completely dilated septal lobes. In late stages a few moderately to strongly dilated septal lobes and lamellae comprise the axial structure.

The number of major septa at a particular diameter is shown in Text-fig. 40. In early stages the septa are

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Text-figure 40.--Crewingkia pulchella (Billings, 1865): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).

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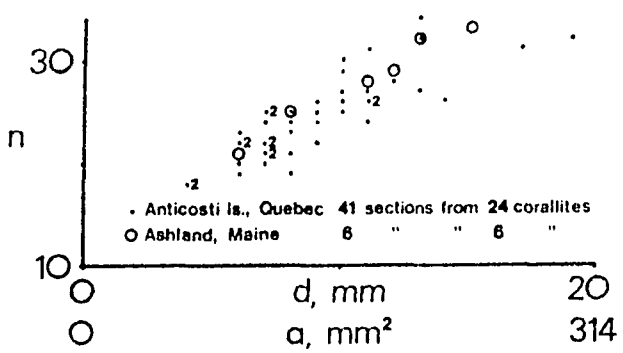
Text-figure 40.--Crewingkia pulchella (Billings, 1865): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a). Numbers indicate frequency of a point if greater than one (see App. 8).



Text-fig. 40

completely dilated. They are generally strongly but sometimes completely dilated in intermediate stages. In late stages they are weakly to moderately dilated. The cardinal septum is generally indistinct and the cardinal fossula is narrow. The minor septa extend a short distance beyond the narrow to moderately broad stereozone in late stages. Tabulae are sparse in late stages, and are incomplete and irregular in development.

Microstructure: Septal fibers are well developed and trabeculae are weakly inclined up toward the axis. Lamellae are present in the stereozone in incompletely dilated stages.

Discussion: Billings based this species on two corallites. One of these was figured as Streptelasma selectum by Lambe (1901) and is herein designated as the lectotype of Grewingkia pulchella. The other specimen is unknown. Several of the probable syntypes of Petraia selecta are G. pulchella. Billings' P. pulchella was considered a synonym of P. selecta by Lambe (1901) and Twenhofel (1928), but two species are definitely involved.

G. pulchella is distinct in having a dense axial structure of completely dilated septal lobes in intermediate stages, and a few moderately to strongly dilated septal lobes and lamellae in late stages.

Grewingkia sp.

Plate 7, figs. 39-42

Specimens: YPM "Grande Coupe, Percé, Quebec"(b); USNM 102390(4).

Occurrence: Upper Ordovician (Lower Ashgillian): Stenopareia faunal zone of Lespérance (1968b), White Head Formation; Grande Coupe, 2.4 km north of Percé, Quebec.

Description: The corallites attain moderate size. In early stages the major septa extend to the axis. In intermediate stages the major septa are withdrawn from the axis and a few septal lobes and short lamellae form a small, very weak axial structure. In late stages the moderately small axial structure consists of moderately dilated septal lobes and lamellae. The major septa are undilated to weakly dilated. The cardinal septum is indistinct and a fossula is not developed. The minor septa are short and generally confined to the stereozone, which becomes broad in late stages. Tabulae are present.

Microstructure: The septa appear to be weakly fibrous, and lamellae are present in the stereozone.

Discussion: These two specimens are distinct in having the major septa withdrawn from the axis in intermediate stages where a few septal lobes and lamellae form a small, very

weak axial structure. Assignment to a probably new species must await the discovery of more specimens from which additional information can be obtained.

"Genus" Lobocorallium Nelson, 1963

1963. Lobocorallium Nelson [partim], p. 34, 35.

Type species (by original designation): Streptelasma rusticum var. trilobatum Whiteaves, 1895.

Diagnosis: Corallites solitary, trochoid, weakly to moderately curved, and attain very large size. Cross-section trilobate. Calyx of moderate depth with very weakly convex calicular boss.

Cardinal septum on convex side of corallite. Major septa completely dilated until immediately below calyx. Minor septa poorly developed. Axial structure in latest stage comprises a few strongly to completely dilated septal lobes or lobes and lamellae. Tabellae in septal region. Tabulae in axial region mostly complete and slightly concave upward axially to weakly convex upward.

Species and occurrence: Lobocorallium is known from the Upper Ordovician of North America. The following species are included in the genus:

1895. Streptelasma rusticum var. trilobatum (= L. trilobatum) Whiteaves, p. 113.
Upper Ordovician: Stony Mountain Formation; southern Manitoba.

1928. Zaphrentis vaurealensis (= L. trilobatum subsp. vaurealensis) Twenhofel, p. 116, 117, Pl. 3,

fig. 1.

Upper Ordovician: Vaureal Formation (Ashgillian); Anticosti Island, Quebec. White Head Formation (Ashgillian); Percé, Quebec.

Discussion: Lobocorallium was proposed to include the trilobate corals Streptelasma rusticum var. trilobatum, S. goniophylloides, and L. trilobatum var. major. The last two species have ontogenies and axial structures characteristic of Grewingkia, and have been referred to G. haysi (Elias, 1976, p. 83). Trilobation appears within several species of Grewingkia and Deiracorallium, and cannot be considered a generic trait. Lobocorallium is presently considered distinct in having completely dilated septa until immediately below the calyx, where an axial structure of a few strongly to completely dilated septal lobes or lobes and lamellae is developed in late stages. G. haysi and L. trilobatum subsp. vaurealensis are intermediate forms linking Grewingkia and Lobocorallium, as discussed previously under the former "genus".

Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928)

Plate 7, figs. 43-49

1928. Zaphrentis vaurealensis Twenhofel, p. 116, 117, Pl. 3, fig. 1.

Holotype (by original designation): YPM 20482; Twenhofel's zone 5, upper member, Vaureal Formation; zone 7 of Twenhofel's Vaureal River section, Anticosti Island, Quebec; Twenhofel collection.

Other specimens: GSC loc. 36157(1, 2): upper member, about 50 m below top of Vaureal Formation; main highway section, cut approximately 10.4 km from Port Menier, Anticosti Island, Quebec; Bolton collection. USNM 102390(1); Stenopareia faunal zone of Lespérance (1968b), White Head Formation; Grande Coupe, 2.4 km north of Percé, Quebec.

Occurrence: Upper Ordovician (Lower Ashgillian): upper member, Vaureal Formation; Anticosti Island, Quebec. White Head Formation; Percé, Quebec.

Diagnosis: Corallites trochoid, weakly to moderately curved, trilobate, and attain very large size. Calyx of moderated depth with very weakly convex calicular boss.

Axial structure of strongly dilated septal lobes and lamellae in latest stages. Septa completely dilated until immediately below calyx. Cardinal septum long, fossula not

developed. Minor septa poorly developed. Tabellae in septal region. Tabulae in axial region mostly complete, often dilated, moderately spaced, and approximately horizontal.

Description of corallites: The largest corallite examined (YPM 20482) has a length of 150 mm. GSC loc. 36157(2) has 71 major septa at a cross-sectional area of 1025 mm^2. The corallites are trochoid and weakly to moderately curved. They are compressed throughout their length -- the maximum cross-sectional length-width ratio is 1.3 (USNM 102390(1)). In cross-section the corallites vary from weakly to strongly trilobate. Trilobation is strongest several cm above the tip, and decreases upward. The calyx has a depth equal to 0.2 of the corallite length (YPM 20482). The calicular boss is very weakly convex.

Ontogeny and internal structures: In early stages the major septa extend to the axis. A few completely dilated septal lobes and lamellae appear in intermediate stages. In the latest stages the axial structure consists of very strongly dilated septal lobes and lamellae.

The number of major septa at a particular cross-sectional area is shown in Text-fig. 41. The septa

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Text-figure 41.--Lobocorallium trilobatum (Whiteaves, 1895), Stony Mountain Fm., Stony Mountain, Manitoba; L. trilobatum

subsp. vaurealensis (Twenhofel, 1928), Vaureal Fm., Anticosti Is., Quebec (see App. 8); Grewingkia haysi (Meek, 1865), Manitoba, Northwest Territories, northwestern Greenland (see Elias, 1976, fig. 11b): relation between number of major septa (n) and corallite cross-sectional area (a).

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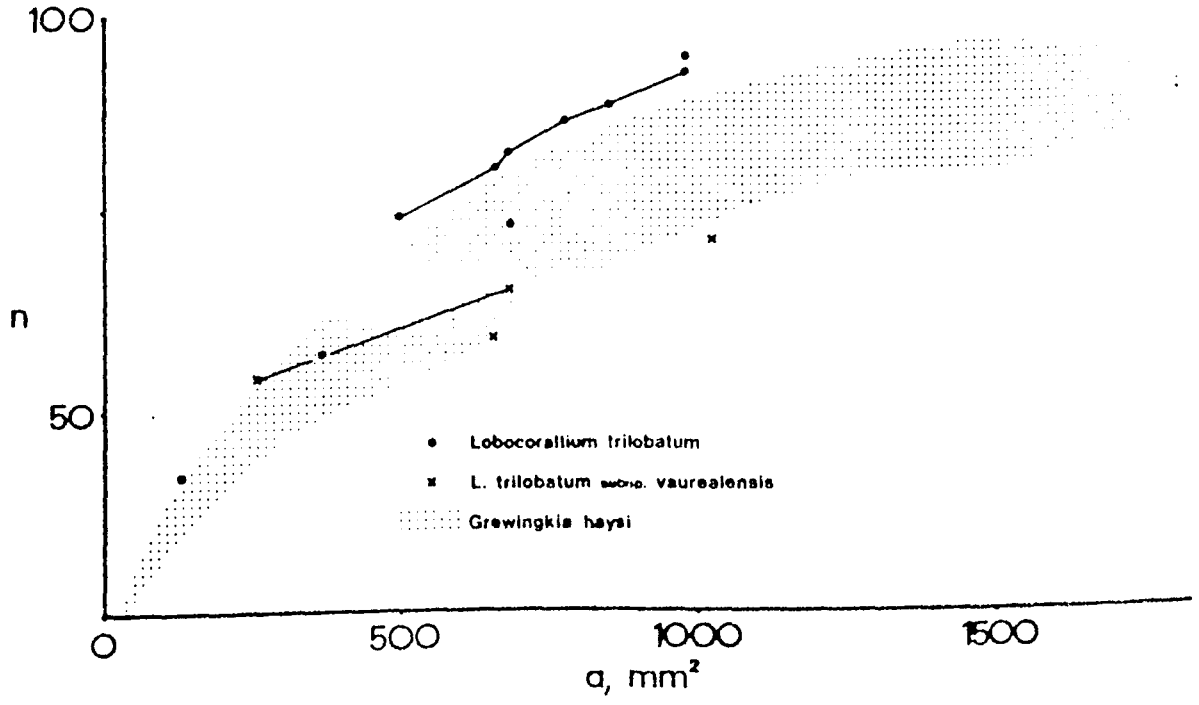
are completely dilated until immediately below the calyx. The cardinal septum is long, and a cardinal fossula is not developed. In early to intermediate stages the major septa on the cardinal side tend to impinge on the cardinal septum, and the septa on the counter side tend to impinge on the long alar septa. Minor septa are poorly developed because of the completely dilated major septa.

Convex upward tabellae are present in the septal region. They are inclined up toward the axis in early stages and become less steeply inclined with increased height in the corallite. They are oriented horizontally in late stages. Tabulae in the axial region are mostly complete, moderately spaced, often dilated, and approximately horizontal.

Microstructure: Septal fibers are well developed, and lamellae are present in the stereozone.

Discussion: The following specimens of Lobocorallium trilobatum (Whiteaves, 1895) from the Gunn and Penitentiary Members of the Stony Mountain Formation at Stony Mountain,

Text-figure 41.--*Lobocorallium trilobatum* (Whiteaves, 1895), Stony Mountain Fm., Stony Mountain, Manitoba; *L. trilobatum* subsp. *vaurealensis* (Twenhofel, 1928), Vaureal Fm., Anticosti Is., Quebec (see App. 8); *Grewingkia haysi* (Meek, 1865), Manitoba, Northwest Territories, northwestern Greenland (see Elias, 1976, fig. 11b): relation between number of major septa (*n*) and corallite cross-sectional area (*a*).



Text-fig. 41

southern Manitoba, have been examined (Elias, 1976, p. 59): GSC 6825 (collected by T.C. Weston in 1884; this specimen is probably a syntype), UM 252, 260, 261, 265, 268, 269, 272, 274, 282, and 336. L. trilobatum subsp. vaurealensis differs from the species sensu stricto in having less pronounced trilobation, a slightly less dilated and better developed axial structure in the latest stage, and fewer major septa at a particular cross-sectional area (Text-fig. 41). If L. trilobatum subsp. vaurealensis is the immediate ancestor of L. trilobatum, it can be added to the possible evolutionary sequence Grewingkia robusta → G. haysi → L. trilobatum subsp. vaurealensis → L. trilobatum (Elias, 1976, p. 38, 39). L. trilobatum subsp. vaurealensis could also be a geographic variant of the contemporary L. trilobatum. It is closer to L. trilobatum than to G. haysi, which is generally less strongly trilobate and has less strongly dilated septa and a better developed axial structure. It is therefore included in Lobocorallium, and is not considered sufficiently different from L. trilobatum to constitute a separate species.

"Genus" Densigrewingkia Neuman, 1969

1969. Densigrewingkia B. Neuman, p. 50, 51.

Discussion: Densigrewingkia, known from the Upper Ordovician of Norway and a questionable occurrence in Maine, is presently considered distinct in having a concave cardinal side and an ontogeny similar to Grewingkia, except with stereoplasmatic deposits connecting elements of the axial structure at least until the latest ontogenetic stage. The relationship of Densigrewingkia with Bighornia Duncan, 1957 is uncertain (Text-fig. 26b). Bighornia also has a concave cardinal side and a strongly dilated median septal lamella in the axial region. In an unusually long corallite of B. cf. patella (Wilson, 1926), the axial structure in the latest stage also resembles Grewingkia (Elias, 1976, Pl. 17, fig. 13). It is uncertain whether the position of the cardinal septum on the concave side is generically significant, as discussed in the text under "Morphology and Taxonomy". The significance of stereoplasmatic deposits in Densigrewingkia is questionable. In some species of other genera having strongly dilated septa, such as Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928), the strongly dilated axial structure can be dense because of stereoplasmatic deposits.

Densigrewingkia ? sp.

Plate 8, figs. 1, 2

Specimens: USGS 6257a, b; 6258a, b; Neuman collection.

Occurrence: Upper Ordovician (Ashgillian): About 61 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot Co., Maine.

Description of corallites: The largest corallite examined (USGS 6257) has a diameter of 18 mm and 37 major septa at an unknown distance below the calyx.

Ontogeny and internal structures: In early stages the major septa extend to the axis. In later stages, a dense, solid axial structure of a few strongly dilated septal lobes and lamellae enclosed in stereoplasmatic deposits is present. In early stages, the septa are completely dilated. The major septa are strongly dilated in later stages, where the cardinal septum appears to be shorter than the others. Minor septa are confined to the stereozone.

Microstructure: The microstructure is unknown because the specimens are poorly preserved.

Discussion: These two incomplete specimens appear to have the ontogeny and axial structure characteristic of

Densigrewingkia, but assignment to the "genus" remains questionable until the ontogeny is more completely known and it can be determined that the cardinal side is concave.

"Genus" Bodophyllum Neuman, 1969

1969. Bodophyllum B. Neuman, p. 54-56.

Discussion: Bodophyllum, as presently understood, is characterized by a dense to solid axial structure composed of septal lobes and very few lamellae, with an often prominent median lamella joining the cardinal and counter septa and forming a calicular boss. B. Neuman (1969, p. 56) reported this Upper Ordovician "genus" from Sweden and Norway, and probably Scotland and North America. In North America it occurs in the late Upper Ordovician of the eastern Great Basin (Budge, 1977), in the Ashgillian of Anticosti Island, Quebec, and Maine, questionably in the Lower or Middle Ashgillian at Percé, Quebec, and in the Gamachian (?) of Missouri.

The uncertain relationship of Bodophyllum with other "genera" is demonstrated by the following points (Text-fig. 26a, c):

1. Bodophyllum is very similar to Bighornia Duncan, 1957, but has the cardinal septum on the convex rather than concave side. It is uncertain whether the position of the cardinal septum is generically significant, as discussed in the text under "Morphology and Taxonomy". Corallites of Bighornia are generally subcalceoloid in form, as is Bodophyllum duncanae (Spjeldnaes, 1961).
2. The significance of a dilated median septal lamella in

the axial structure is uncertain. Grewingkia bilateralis Neuman, 1969, Helicelasma lamellosa Elias, 1976, and some corallites of Streptelasma cyrtum Neuman, 1969 also have a median lamella. In late ontogenetic stages of Bodophyllum shorti n. sp., the axial structure resembles Grewingkia because the median lamella is weakly dilated and irregular, and other septal lobes and lamellae are present.

McLean (1974, p. 43) suggested that Bodophyllum, Bighornia, Dalmanophyllum Lang and Smith, 1939, and Ditoecholasma Simpson, 1900 may be synonymous.

Bodophyllum shorti n. sp.

Plate 8, figs. 3-7

Etymology: The species is named for the former owner of the farm on which this coral was found at the type section of the Leemon Formation.

Holotype and only specimen: UCGM 45613; Elias collection.

Occurrence: Upper Ordovician (? Gamachian): Leemon Formation; locality 20a-1, Cape Girardeau Co., Missouri.

Diagnosis: Corallite small, uncurved, with base of attachment and deep calyx. Axial structure solid in early stages, in intermediate stages prominent dilated median septal lamella connects with long cardinal and counter septa, in late stages median lamella weakly dilated, irregular, and not connected to cardinal or counter septa, and a few septal lobes and lamellae present. Major septa undilated. Minor septa long, extending well beyond the narrow stereozone. Tabulae present.

Description of corallite: The corallite is about 15 mm long and has a diameter of 8 mm a short distance below the calyx where 34 major septa are present. The corallite is uncurved. The base of attachment is on the cardinal side, and the corallite was attached to a bryozoan. The calyx has a depth equal to about 0.4 of the corallite length.

Ontogeny and internal structures: The axial structure is solid in early stages. In intermediate stages a prominent dilated median septal lamella is connected to the long cardinal and counter septa and a few dilated septal lobes and rare septal lamellae are present. In late stages the elements of the axial structure are weakly dilated. The median lamella is irregular and discontinuous, and is not connected to the cardinal or counter septa. A few other septal lamellae and septal lobes are present. The major septa are weakly dilated in early stages, and undilated in later stages. A cardinal fossula is not developed. The minor septa are long, extending well beyond the narrow stereozone. Tabulae are present.

Microstructure: Septal fibers are present, but lamellae are apparently not developed in the stereozone.

Discussion: Bodophyllum shorti differs from other species of the "genus" in having very long minor septa, and a weakly dilated axial structure in later stages with an irregular median septal lamella. It resembles Streptelasma leemonensis n. sp., from the same locality, in having long minor septa.

Bodophyllum neumani n. sp.

Plate 8, figs. 8-13

Etymology: The species is named for Robert B. Neuman, U.S. Geological Survey, who collected the specimens.

Holotype: USGS 6264a, b; Neuman collection.

Paratypes: USGS 6260a, b; 6269a, b; 6270a, b; 6271a, b; 6338a, b; 6351a, b; Neuman collection.

Occurrence: Upper Ordovician (Ashgillian): About 520 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot Co., Maine.

Diagnosis: Corallites ceratoid, uncurved, and of small size. Epitheca with septal grooves and interseptal ridges. Axial structure of a dilated median septal lamella and a few septal lobes. Major septa undilated. Minor septa extend a short distance beyond the narrow stereozone. Tabulae mostly complete, moderately convex upward.

Description of corallites: The largest corallite examined (USGS 6269) has a diameter of 13 mm and 30 major septa at an unknown distance below the calyx. The corallites are ceratoid and uncurved. Septal grooves and interseptal ridges are present on the epitheca.

Internal structures: The axial structure consists of a dilated median septal lamella joining the cardinal and counter septa, and a few septal lobes originating from other major septa. The number of major septa at a particular diameter is shown in Text-fig. 42. The major septa are

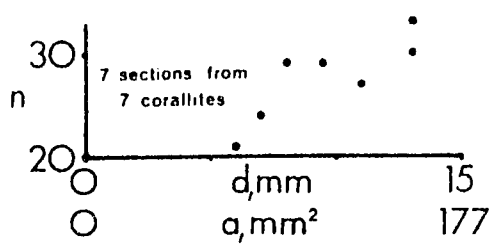
Text-figure 42.--Bodophyllum neumani n. sp.: relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) (see App. 8).

undilated. The minor septa extend a short distance beyond the narrow stereozone. The tabulae are mostly complete and moderately convex upward. Complementary plates are sometimes present.

Microstructure: The microstructure is unknown because of poor preservation.

Discussion: Bodophyllum shorti n. sp. differs from B. neumani in having longer minor septa and a median lamella that is weakly dilated and irregular in late stages. B. neumani is distinct in having a more elongate and prominent median lamella than other species of the "genus".

Text-figure 42.--*Bodophyllum neumani* n. sp.: relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (*a*) (*see* App. 8).



Text-fig. 42

Bodophyllum ? sp.

Plate 8, figs. 14-16

Specimen: YPM "Grande Coupe, Percé, Quebec"(c).

Occurrence: Upper Ordovician (Lower Ashgillian): Stenopareia faunal zone of Lespérance (1968b), White Head Formation; Grande Coupe, 2.4 km north of Percé, Quebec.

Description: The small corallite has an area on the cardinal side where it was attached to a brachiopod. In early stages a few septal lobes are present. In intermediate and late stages a moderately dilated median septal lamella joins the cardinal and counter septa, and a few septal lobes originate from other major septa. In the late stage, 25 major septa are present. The major septa are undilated. The minor septa are confined to the moderately broad stereozone. Tabulae are present.

Microstructure: Septal fibers are not distinguishable, and lamellae are developed in the stereozone.

Discussion: This specimen resembles Bodophyllum in having a median septal lamella, but the assignment is questionable because the axial structure is not as dilated as is typical of the genus. A new species is not erected because only a single incomplete specimen is known.

Rodophyllum englishheadensis n. sp.

Plate 8, figs. 17-23

Etymology: The specific name refers to English Head, Anticosti Island, Quebec, where the species has been collected.

Holotype: YPM 3063/7; English Bay; Twenhofel collection.

Paratypes: YPM 3019/3063/2a, c; English Head; Twenhofel collection. YPM 3063/15a, b; White Cliff; Twenhofel collection.

Occurrence: Upper Ordovician (Lower Ashgillian): upper member (English Head facies), Vaureal Formation; Anticosti Island, Quebec.

Diagnosis: Corallites ceratoid and sometimes cylindrical in late stages, straight to weakly curved, of moderate size, and possess a base of attachment. Epitheca with septal grooves and interseptal ridges. Calyx deep.

Axial structure dense, consisting of a dilated median septal lamella connected to the long cardinal and counter septa, and dilated axial ends of septa and septal lobes. Major septa weakly dilated. Minor septa confined to the stereozone which becomes very broad in late stages. Tabulae mostly complete, moderately spaced, weakly convex upward, with complementary plates.

Description of corallites: The largest complete corallite examined (YPM 3063/15b) is 20 mm long and has a diameter of 14 mm immediately below the calyx where 43 major septa are present. The corallites are ceratoid and sometimes become cylindrical in late stages (YPM 3063/2a, YPM 3063/7). They are uncurved to weakly curved. The base of attachment is centered on the cardinal side. In YPM 3019/2c, two corallites attached to a bryozoan near one another and grew into lateral contact. The epitheca has septal grooves and interseptal ridges, and coarse rugae are sometimes present (YPM 3063/15a, 3063/2a). The calyx has a depth equal to 0.4 of the corallite length (YPM 3063/15b). A calicular boss does not appear to be developed in YPM 3063/2a.

Ontogeny and internal structures: In early stages the major septa extend to the axis where they are dilated, forming a dense axial region. In intermediate and late stages a dilated median lamella connecting the long cardinal and counter septa is the dominant element in the axial structure. It is surrounded by the dilated axial ends and septal lobes of other major septa, forming a dense axial region.

The number of major septa at a particular diameter is shown in Text-fig. 43. The major septa are weakly dilated

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Text-figure 43.--*Bodophyllum englishheadensis* n. sp.: relation between number of major septa (*n*) and corallite

diameter (d) or cross-sectional area (a) (see App. 8).

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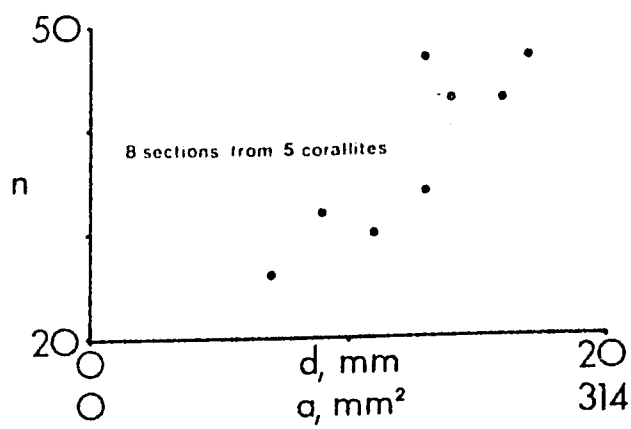
to undilated. A distinct fossula is not developed. The minor septa are almost always confined to the stereozone, which is moderately broad in early stages and becomes very broad in late stages. The tabulae appear in early stages and are mostly complete, weakly convex upward, and moderately spaced. Complementary plates are present.

Microstructure: The septal fibers are well developed, and the trabeculae are inclined slightly upward toward the axis. The stereozone is composed of lamellae.

Discussion: Bodophyllum englishheadensis is distinct in having a very broad stereozone, far broader than in B. euthum Neuman, 1969. In early stages of B. englishheadensis the major septa are dilated in the axial region, whereas in B. euthum they are very strongly dilated throughout their length.

Text-figure 43.--*Rodonhyllum englishheadensis* n. sp.: relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (*a*) (*see* App. 8).



Text-fig. 43

"Genus" Bighornia Duncan, 1957

1957. Bighornia Duncan, p. 608-611.

1963. Bighornia Nelson, p. 39, 40.

1976. Bighornia Elias, p. 112-117.

Discussion: As presently understood, Bighornia includes solitary corals having a concave cardinal side, major septa that are generally completely dilated in early ontogenetic stages and sometimes strongly dilated even in later stages, and an axial structure with a prominent, strongly dilated median lamella. The uncertain relationships of Bighornia, Densigrewingkia Neuman, 1969, and Bodophyllum Neuman, 1969, were discussed previously under the latter two "genera".

Bighornia cf. patella (Wilson, 1926)

Plate 8, figs. 24-42

1928. [?] Streptelasma aff. breve Ulrich in Winchell and Schuchert. Troedsson, p. 109, Pl. 26, figs. 6, 7.

1929. Lindströmia solearis Ladd, p. 397-399, Pl. 4, figs. 6-12.

1943. Holophragma anticonvexa Okulitch, p. 68, 69, Pl. 1, figs. 11, 12.

1956. "Holophragma" Lindström. Duncan, Pl. 22, figs. 1a-c.

1957. "Holophragma" sp. Lindström. R.J. Ross, Pl. 37, figs. 3, 5-7.

1957. Bighornia parva Duncan, p. 611-614, Pl. 70, figs. 1-18.

1959b. Bighornia patella (Wilson). Nelson, Pl. 4, figs. 1a-d.

1963. Bighornia patella (Wilson). Nelson, p. 40, 41, Pl. 11, figs. 1a-c, 2, 3a-d.

1963. Bighornia solearis (Ladd). Nelson, p. 41, Pl. 11, figs. 4a-d.

1976. Bighornia cf. patella (Wilson). Elias, p. 118-123, Pl. 17, figs. 1-22.

A. Iowa

Specimens: SUI 2-051 (holotype of L. solearis Ladd); Thomas collection. SUI 2-052 (paratype of L. solearis); Ivson collection. USNM 71926 (paratype of L. solearis); Tysor collection.

Occurrence: Upper Ordovician (Richmondian): Fort Atkinson Formation, Maquoketa Group; NW¼, sec. 15, T96N, R8W, 1.2 km southwest of Ossian, Winneshiek Co., Iowa.

Description of corallites: The largest corallite examined (USNM 71926) has a length of 23 mm. SUI 2-051 has the maximum number of major septa -- 49 in the calyx at a height of 19 mm. The cardinal side is concave. The corallites are trochoid and weakly curved. They are depressed throughout their length, especially in early stages. In intermediate stages the cross-sectional length-width ratio is 1.4 (SUI 2-052). In late stages the ratio is 1.2 (USNM 71926; SUI 2-051). SUI 2-051 and USNM 71926 have a spoon-shaped depression on the cardinal side near the tip. SUI 2-051 also has a depression on the counter side in early stages. SUI 2-052 is triangulate in cross-section, but in late stages the corallites become oval (SUI 2-051; USNM 71926). The calyx has a depth equal to 0.3 of the corallite length (SUI 2-051). The calicular boss is moderately convex and a prominant columella elongate in the cardinal-counter plane is present (SUI

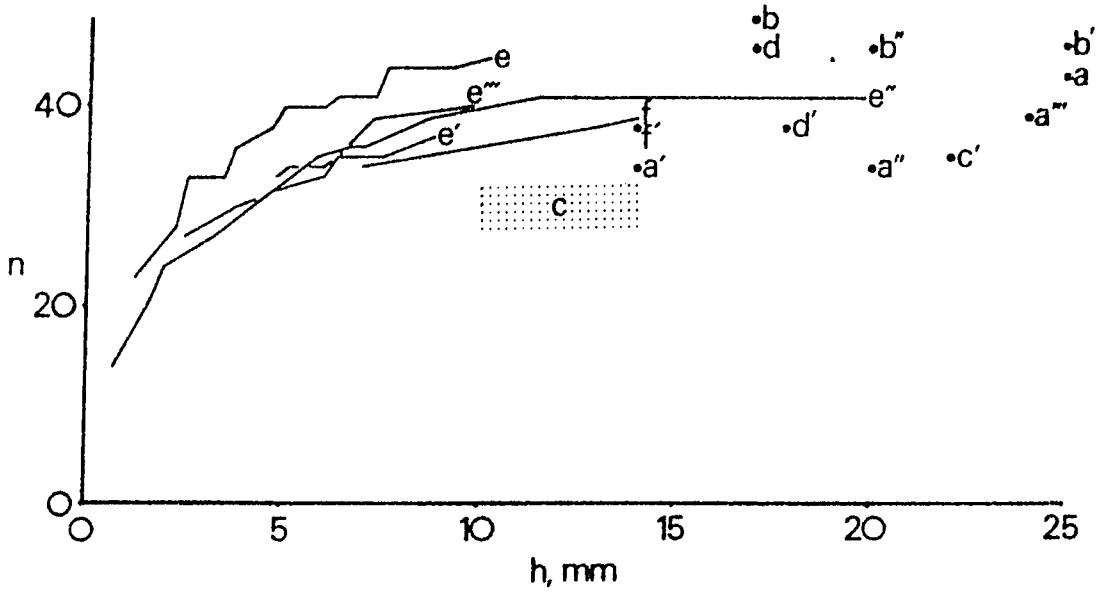
2-051; USNM 71926).

Internal structures: In intermediate and late stages the axial structure consists of a conspicuous, strongly dilated median lobe that is an extension of the counter septum, and a few other septal lobes and rare lamellae.

The number of major septa at a particular height is shown in Text-fig. 44. The major septa are moderately

Text-figure 44.-- Bighornia patella (Wilson, 1926) and B. cf. patella: relation between number of major septa (n) and corallite height (h). B. patella: a, GSC 6732, Beaverfoot Fm., near Golden, southeastern British Columbia. B. cf. patella: a', GSC 10872, [B. patella], mbr. no. 1, Caution Creek Fm., northern Manitoba; a", GSC 10873, [B. patella], mbr. no. 1, Chasm Creek Fm., northern Manitoba; b, SUI 2-051 and b', USNM 71926, [Lindströmia solearis], Fort Atkinson Fm., Ossian, Iowa; b", GSC 10870, [B. solearis], mbr. no. 1, Chasm Creek Fm., northern Manitoba; c, Okulitch, 1943, and c', Nelson, 1963, [Holophragma anticonvexa], Gunn Mbr., Stony Mountain Fm., Stony Mountain, Manitoba; d, USNM 127574 and d', USNM 124801, [B. parva], upper Bighorn Dolomite, Bighorn Mountains, Wyoming; e-e", UM 214, 216, 331, and 335, respectively, Selkirk Mbr., Red River Fm., Garson, Manitoba; f, YPM 505a, lower mbr., Vaureal Fm., Anticosti Is., Quebec, and f', YPM 3063/17, Anticosti Is., Quebec (a-e from Elias, 1976, fig. 15; for f see App. 8).

Text-figure 44.-- Bighornia patella (Wilson, 1926) and B. cf. patella: relation between number of major septa (n) and corallite height (h). B. patella: a, GSC 6732, Beaverfoot Fm., near Golden, southeastern British Columbia. B. cf. patella: a', GSC 10872, [B. patella], mbr. no. 1, Caution Creek Fm., northern Manitoba; a", GSC 10873, [B. patella], mbr. no. 1, Chasm Creek Fm., northern Manitoba; b, SUI 2-051 and b', USNM 71926, [Lindström ia solearis], Fort Atkinson Fm., Ossian, Iowa; b", GSC 10870, [B. solearis], mbr. no. 1, Chasm Creek Fm., northern Manitoba; c, Okulitch, 1943, and c', Nelson, 1963, [Holophragma anticonvexa], Gunn Mbr., Stony Mountain Fm., Stony Mountain, Manitoba; d, USNM 127574 and d', USNM 124801, [B. parva], upper Bighorn Dolomite, Bighorn Mountains, Wyoming; e-e"', UM 214, 216, 331, and 335, respectively, Selkirk Mbr., Red River Fm., Garson, Manitoba; f, YPM 505a, lower mbr., Vaureal Fm., Anticosti Is., Quebec, and f', YPM 3063/17, Anticosti Is., Quebec (a-e from Elias, 1976, fig. 15; for f see App. 8).



Text-fig. 44

dilated in the calyx. The cardinal septum is short in the calyx, and the cardinal fossula is narrow. Minor septa are confined to or extend a very short distance beyond the stereozone.

Microstructure: The microstructure is not preserved in these silicified specimens.

B. Anticosti Island

Specimens: YPM 505a, b; lower member (zone 4 of Twenhofel's English Head Formation), Vaureal Formation; Girard Harbour, Anticosti Island, Quebec; Twenhofel collection. YPM 3063/17; Anticosti Island, Quebec; Twenhofel collection.

Occurrence: Upper Ordovician (? Caradocian): lower member, Vaureal Formation; Anticosti Island, Quebec.

Description of corallites: The largest corallite examined (YPM 505a) has a length of 28 mm. YPM 505b has the maximum number of major septa -- 42 at a height of about 12 mm immediately below the calyx. The cardinal septum is on the concave side of the corallite. The corallites are trochoid and weakly curved. They are depressed throughout their length, especially in early stages. The maximum cross-sectional length-width ratio varies from 1.5 at a height of 7 mm (YPM 505a) to 2.7 at a height of about 3 mm

(YPM 505b). The corallites become triangulate during ontogeny. All specimens have a concave spoon-shaped area of attachment on the cardinal side near the tip. Growth lines and weak septal grooves and interseptal ridges are preserved on the epitheca. The calyx has a depth equal to 0.2 (YPM 505a) to 0.3 of the corallite length (YPM 505b). The calicular boss is moderately convex.

Ontogeny and internal structures: Up to a height of several mm the major septa extend to the axis. Above this the axial structure consists of a conspicuous, strongly dilated median lobe that is an extension of the counter septum, and a few other septal lobes.

The number of major septa at a particular height is shown in Text-fig. 44. The major septa are completely dilated in early stages and moderately dilated immediately below the calyx. Dilation is strongest on the cardinal side. The cardinal septum becomes short in the calyx. The cardinal fossula is narrow in moderately dilated stages. Minor septa are confined to the moderately broad stereozone. A few thin, irregular, incomplete tabulae are present in YPM 505a.

Microstructure: The septal fibers are well developed, and weak trabeculae are present. Lamellae cannot be distinguished in the stereozone.

Discussion: Bighornia from Iowa and Anticosti Island cannot be distinguished from the other species listed in synonymy, as discussed in detail by Elias (1976, p. 120, 121). This species, referred to as B. cf. patella (A.E. Wilson, 1926) is definitely known to occur in the following units and localities: Selkirk Member, Red River Formation (late Middle or Upper Ordovician), Garson, Manitoba; members no. 1 and 3 and upper member of Caution Creek Formation, and member no. 1 of Chasm Creek Formation (Upper Ordovician), northern Manitoba; Gunn Member, Stony Mountain Formation (Upper Ordovician), Stony Mountain, Manitoba; shaly beds at top of Bighorn Dolomite (Upper Ordovician), Johnson Co., Wyoming; lower member, Vaureal Formation (? Caradocian), Anticosti Island, Quebec; and Fort Atkinson Formation (Richmondian), Maquoketa Group, Ossian, Iowa. The species possibly occurs in the Cape Calhoun Formation (late Middle or Upper Ordovician), Cape Calhoun, northwestern Greenland, and in the Beaverfoot Formation (Upper Ordovician), near Golden, southeastern British Columbia. This species is apparently long-lived and widely distributed in North America.

Family Paliphyllidae Soshkina, 1955

Genus Paliphyllum Soshkina, 1955

1968. Paliphyllum B. Neuman, p. 230, 231.

Discussion: Paliphyllum is characterized by a broad axial structure composed of septal lobes and lamellae with a median lamella at least in some stages, and a dissepimentarium of a few series of medium or large dissepiments.

B. Neuman (1968, p. 231) reported the genus from the Upper Ordovician of Siberia, Estonia, and Sweden, and from the Llandoverian of Estonia. The following species are known from North America:

1963. Phaulactis stummi Nelson, p. 43, 44, Pl. 13, figs. 7, 8a-c, 9-12.
Upper Ordovician: Member no. 3, Chasm Creek Formation, Churchill River Group; northern Manitoba.

1928. Cyathophyllum ellisense Twenhofel, p. 119, Pl. 2, figs. 10-13.
Upper Ordovician (Ashgillian, ? Gamachian): Ellis Bay Formation; Anticosti Island, Quebec.

Paliphyllum ellisensis (Twenhofel, 1928)

Plate 8, figs. 43-53

1928. Cyathophyllum ellisense Twenhofel, p. 119, Pl. 2, figs. 10-13.

Holotype (by original designation): YPM 10388A; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay, Anticosti Island, Quebec; Twenhofel collection.

Paratype (by original designation): The specimen represented by Twenhofel (1928, Pl. 2, fig. 11); Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay, Anticosti Island, Quebec; Twenhofel collection.

Other specimens (all from Twenhofel's Anticosti Island collection): YPM 3063/52e, f; Ellis Bay Formation; west side of Ellis Bay. YPM 3063/58a, b; Ellis Bay Formation; Cape Henry. YPM 572; near base of Ellis Bay Formation; coral zone above Vaureal Falls. YPM 10388B; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay. The specimen represented by Twenhofel (1928, Pl. 2, fig. 12); Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay. YPM 573a, b; bioherm at base of Bolton's member 6, Ellis Bay Formation; Raspberry Point. YPM 3019/3063/57a-d, h, i; Twenhofel's zone 9, Bolton's member 6, Ellis Bay Formation; Ellis Bay.

Occurrence: Upper Ordovician (Ashgillian, ?Gamachian): Ellis Bay Formation; Anticosti Island, Quebec.

Diagnosis: Corallites cylindrical, uncurved, and attain moderate size. Epitheca with septal grooves and interseptal ridges, and prominent rugae. Axial structure varies from simple with few septal lobes to moderately complex with septal lobes and lamellae. In early stages a dilated median lamella is sometimes present. Minor septa very long. In early stages the stereozone is narrow to moderately broad. In later stages dissepimentarium consists of one to three series of large dissepiments, with narrow stereozone on axial side of dissepimentarium. Tabulae mostly complete, very thin, closely spaced, slightly concave upward axially to moderately convex upward, with complementary plates.

Description of corallites: The corallites are all incomplete at both ends. The longest fragment (YPM 10388A) is 40 mm long, and the broadest (YPM 3019/3063/57h) is 28 mm in diameter. The maximum number of major septa observed is 42 at a diameter of 21 mm (YPM 3019/3063/57a). The corallites are cylindrical and uncurved. Coarse rugae are common, and are sometimes regularly spaced at an interval of 6 to 11 mm. Septal grooves and interseptal ridges are present on the epitheca. In one specimen (YPM 10388B), seven offsets resulted from peripheral increase.

Ontogeny and internal structures: In early to intermediate stages the axial structure consists of a few dilated septal lobes and lamellae, sometimes with a median lamella (YPM 3019/3063/57d). In later stages the major septa may extend almost to the axis with only a few septal lobes (YPM 572), but usually a moderately complex axial structure of septal lobes and lamellae develops.

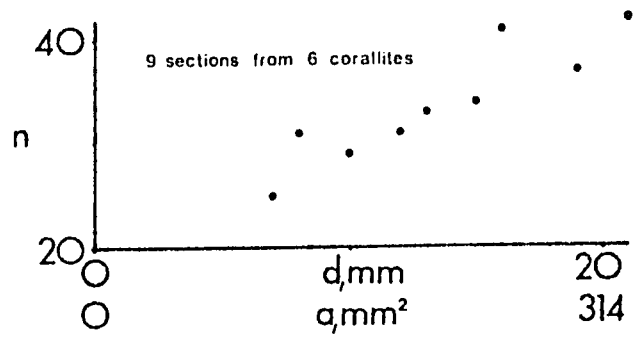
The number of major septa at a particular diameter is shown in Text-fig. 45. The major septa are undilated. The

Text-figure 45.--Paliphyllum ellisensis (Twenhofel, 1928): relation between number of major septa (n) and corallite diameter (d) or cross-sectional area (a) (see App. 8).

cardinal septum is indistinct, and a fossula is not developed. The minor septa are very long. Septa are occasionally interrupted in the dissepimentarium. In early stages the stereozone is narrow to moderately broad. In later stages a dissepimentarium consisting of one to three series of large dissepiments develops, with a narrow stereozone on its axial side.

The tabulae are mostly complete, very thin, closely spaced, and slightly concave upward axially (YPM 3019/3063/57a) to moderately convex upward (YPM 3019/3063/57i). Complementary plates are present.

Text-figure 45.--*Paliphyllum ellisensis* (Twenhofel, 1928): relation between number of major septa (*n*) and corallite diameter (*d*) or cross-sectional area (*a*) (*see* App. 8).



Text-fig. 45

Microstructure: The septal fibers are well developed, and the trabeculae are weakly inclined up toward the axis. Lamellae are not present in the stereozone.

Discussion: Paliphyllum ellisensis differs from other species of the genus in having larger dissepiments. P. stummi (Nelson, 1963) is distinct in having a moderately broad cardinal fossula, many series of small dissipiments, and a smaller, less complex axial region. P. ellisensis and P. suecicum Neuman, 1968 have similar tabulae, but the latter species has a finer axial structure.

LOCALITIES

The localities examined in this study are listed below. Locations and stratigraphic-paleontologic data are shown in Text-figs. 3, 18, and 21. The stratigraphic position of collecting horizons in the Richmond Group, Cincinnati Arch region is presented in Table 4.

Table 4.--Stratigraphic position of collecting horizons, Richmond Group, Cincinnati Arch region. For each horizon, the first number refers to the locality and the second to the stratigraphic interval (see Text-fig. 3).

Table 4.--Stratigraphic position of collecting horizons, Richmond Group, Cincinnati Arch region. For each horizon, the first number refers to the locality and the second to the stratigraphic interval (see Text-fig. 3).

TABLE 4

"Waynesville"	"Liberty"	"Whitewater-Elkhorn"	
11b-1	3-1	5b-1	12a-8
11b-2	3-2	5b-2	12a-9
14b-1	3-3	5b-3	12b-1
14b-2	4-2	5b-4	12b-2
USNM Coll.	4-3	5b-5	12b-3
	4-4	12a-1	13-1
	4-5	12a-2	13-2
	5b-6	12a-3	13b-3
	5b-7	12a-4	14-3
	5b-8	12a-5	14-4
	5b-9	12a-6	14-5
	6-1	12a-7	14-6
	7-2		
	11-1		
	12c-1		
	12d-1		
	13b-1		
	13b-2		
	14-1		
	14-2		
	USGS Otter Cr. Coll.		

A. Cincinnati Arch Region, Ohio-Indiana-Kentucky

1(a). $^{42}77^{800}$N, $^{2}70^{850}$E to $^{42}78^{450}$N, $^{2}70^{450}$E: Orangeburg and Maysville East Quads., Mason Co., KY. Type section of Bull Fork Fm. Roadcuts on E side of Hwy. 1443, 1.45 to 2.3 km N of junction with Hwy. 984, 3 km E of Springdale. Refer to USGS Quad. Maps GQ-588 and GQ-1006, and Peck (1966, p. B19, 26-29).

1b. $^{42}90^{250}$N, $^{2}73^{500}$E: Manchester Islands Quad., Adams Co., OH. Streamcut in Isaacs Cr. just W of Hwy. 136, 1.8 km S of intersection with Hwy. 41 at Bentonville. Refer to Kohut and Sweet (1968, p. 1459, 1460, loc. 14).

1c. $^{43}00^{300}$N, $^{2}82^{600}$E: West Union Quad., Adams Co., OH. Roadcut on W side of Hwy. 41, 5.45 km NE of junction with Hwy. 247 N in West Union. For nearby section refer to Schmidt, et al (1961, p. 281-283), and Kohut and Sweet (1968, p. 1459).

2. $^{42}73^{750}$N, $^{6}50^{250}$E to $^{42}73^{300}$N, $^{6}49^{600}$E: Bedford Quad., Trimble Co., KY. Roadcuts on N and S sides of Hwy. 42, 3.5 to 4.4 km E of Bedford. Refer to USGS Quad. Map GQ-1409, and Hattin, et al (1961, p. 307-314, stop 3).

3. $^{42}21^{800}$N, $^{6}28^{650}$E to $^{42}21^{800}$N, $^{6}28^{350}$E: Jeffersontown Quad., Jefferson Co., KY. Roadcuts and quarry on N side of

Brush Run Rd., 0.25 to 0.65 km E of junction with Hwy. 1819, about 1.5 km WNW of Seatonville. Refer to USGS Quad. Map GQ-999, and Browne (1964, p. 388, 390, 391, loc. 6a, b).

4. 37°46'2"N, 85°21' 20"W to 37°46'24"N, 85°21'31"W: Maud Quad., Nelson Co., KY. Includes type section of Bardstown Mbr., Drakes Fm. Roadcut on W side of Hwy. 150, 1.15 to 1.9 km NW of bridge over Beech Fork R., about 2 km NW of Fredericktown. Refer to USGS Quad. Map GQ-1043, Browne (1964, p. 388, 390, loc. 1), Hatfield (1968, Pl. 1, key sec. 6), Kohut and Sweet (1968, p. 1459, loc. 5), and Peterson (1970).

5a. SE¼, sec. 16, T9N, R2W: Mount Carmel Quad,, Franklin Co., IN. Roadcut on N side of Hwy. 101 at Bon Well Hill about 2 km NE of Brookville. Refer to Hay (1975), and Hay (1977, p. I-23 to 26).

5b. SE¼ and NE¼, sec. 36, T10N, R2W: Mount Carmel Quad., Franklin Co., IN. Roadcuts on both sides of Hwy. 101 about 9.5 km NE of Brookville. Refer to Hay (1975), and Hay (1977, p. I-18 to 22).

5c. SE¼SE¼, sec. 17, T9N, R2W: Brookville Quad., Franklin Co., IN. Cut at Brookville Dam Spillway about 2 km N of Brookville. Refer to Hay (1975, p. 12) and Hay (1977, p. I-27).

6a. 37°34'15"N, 84°36'57"W to 37°34'24"N, 84°36'50"W: Lancaster Quad., Lincoln Co., KY. Type section of Ashlock Fm. Roadcuts on both sides of Hwy. 27 for 0.4 km N of Dix R., about 6 km SW of Lancaster. Refer to USGS Quad. Map GQ-888, Weir, Greene, and Simmons (1965, p. D9, 24, 25), and Kohut and Sweet (1968, p. 1459, loc. 2).

6b. 37°32'N, 84°29'48"W: Paint Lick Quad., Garrard Co., KY. Type section of Drakes Fm. Roadcuts about 0.4 km S of East Fork, Drakes Cr., on E side of road leading NW from Vanhock Cemetery, about 3 km E of Preachersville. Refer to USGS Quad. Map GQ-800, and Weir, Greene, and Simmons (1965, p. D17, 30, 31).

6c. 37°30'4"N, 84°30'53"W: Lancaster Quad., Lincoln Co., KY. Type section of Preachersville Mbr., Drakes Fm. Roadcuts on E side of Hwy. 39, 3.7 to 3.95 km SE of Preachersville. Refer to USGS Quad. Map GQ-888, Weir, Greene, and Simmons (1965, p. D33-35), Simmons and Oliver (1967), and Kohut and Sweet (1968, p. 1459, loc. 4).

7a. 37°48'10"N, 84°11'13"W to 37°48'3"N, 84°11'16"W: Union City Quad., Madison Co., KY. Roadcuts on both sides of Hwy. 974, 0.8 to 1.25 km NE of Union City. Refer to USGS Quad. Map GQ-585, and Simmons and Oliver (1967).

7b. 37°47'36"N, 84°14'7"W to 37°47'25"N, 84°14'20"W: Union City Quad., Madison Co., KY. Roadcut on E side of road, 0.8

to 1.3 km NE of junction with Hwy. 974, about 3.5 km W of Union City. Refer to USGS Quad. Map GQ-585.

8. 37°44'30"N, 84°14'56"W: Moberly Quad., Madison Co., KY. Includes type section of Terrill and Reba Mbrs., Ashlock Fm. Roadcuts on both sides of Hwy. 52, about 3 km E of Richmond. Refer to USGS Quad. Map GQ-664, and Weir, Greene, and Simmons (1965, p. D27-29).

9. 41_{99}^{800}N, 7_{56}^{200}E to 41_{98}^{900}N, 7_{56}^{550}: Hedges Quad., Clark Co., KY. Railroad cuts on Louisville and Nashville R.R., 1.4 to 2.4 km N of Howard Cr., 1.2 to 0.2 km SE of Agawam. Refer to USGS Quad. Map GQ-1235, Weir, Greene, and Simmons (1965, p. D18, 19), and Kohut and Sweet (1968, p. 1460, loc. 16).

10a. 38°17'32"N, 83°42'21"E: Hillsboro Quad., Fleming Co., KY. Roadcut on E side of road along Buttermilk Branch, 1.6 km NW of Sunset. Refer to USGS Quad. Map GQ-876.

10b. 38°17'26"N, 83°42'E: Hillsboro Quad., Fleming Co., KY. Roadcut on E side of road along Buttermilk Branch, 1.1 km NW of Sunset. Refer to USGS Quad. Map GQ-876.

10c. 38°18'22"N, 83°42'12"E: Hillsboro Quad., Fleming Co., KY. Roadcut on N side of road 1.5 km S of junction of Locust Cr. and Hillsboro Branch, 4 km WNW of Hillsboro. Refer to USGS Quad. Map GQ-876.

10d. 38°18'8"N, 83°40'11"E: Hillsboro Quad., Fleming Co., KY. Stream cut in tributary just S of road on N side of Hillsboro Branch, 1.35 km NW of Hillsboro. Refer to USGS Quad. Map GQ-876.

10e. 38°19'2"N, 83°41'10"E: Hillsboro Quad., Fleming Co., KY. Roadcut on N side of road 0.6 km S of Locust Cr., 3.6 km NW of Hillsboro. Refer to USGS Quad. Map GQ-876.

10f. 38°19'8"N, 83°39'41"E: Hillsboro Quad., Fleming Co., KY. Roadcut on E side of Hwy. 111, 3 km N of Hillsboro. Refer to USGS Quad. Map GQ-876.

11(a). NW¼SE¼ and NE¼SE¼, sec. 12, T7N, R11E: Milan Quad., Ripley Co., IN. Roadcut on E and W sides of Hwy. 50, 1.1 to 1.5 km W of Laughery Cr. at Versailles. Refer to Hattin, et al (1961, p. 334, 347-349), and Hatfield (1968, Pl. 1, key sec. 2).

11b-1. NE¼SE¼, sec. 6, T7N, R12E: Milan Quad., Ripley Co., IN. Stream cut on S side of Falling Timber Cr., 0.4 km upstream from Laughery Cr., about 2.3 km NE of Versailles.

11b-2. SW¼NW¼, sec. 5, T7N, R12E: Milan Quad., Ripley Co., IN. Stream cuts on S and N sides of Falling Timber Cr., 1.1 to 1.2 km upstream from Laughery Cr., about 2.8 km NE of Versailles.

11b-3. SE¼NW¼, sec. 5, T7N, R12E: Milan Quad., Ripley Co.,

IN. Stream cut on N side of Falling Timber Cr., 1.4 to 1.5 km upstream from Laughery Cr., about 3.1 km NE of Versailles.

12a. SW¼SE¼, sec. 29, T14N, R1W: Richmond Quad., Wayne Co., IN. Stream cut at Thistlewaite Falls on West Fork of Whitewater R. just S of bridge in Spring Grove. Refer to Cumings (1908, p. 662), and Hay (1975, p. 23).

12b. SW¼ and SE¼, sec. 21 and SW¼ and NW¼, sec. 22, T13N, R1W: Richmond and New Paris Quads., Wayne Co., IN. Stream cuts along Elkhorn Cr. between Straight Line Rd. and Hwy. 227, about 6 km S of Richmond. Refer to Cumings (1908, p. 657, 658, 660), and Hay (1975, p. 26).

12c. NE¼NE¼, sec. 23, T13N, R2W: Richmond Quad., Wayne Co., IN. Stream cuts at Blue Clay Falls on creek just S of Hunt Rd., 0.55 km W of Salisbury Rd., about 7 km SW of Richmond. Refer to Hay (1975, p. 20).

12d. NE¼SW¼, sec. 2, T12N, R2W: Liberty Quad., Wayne Co., IN. Roadcut on E side of Smithfield Rd., 0.1 to 0.25 km N of intersection with Potter Shop Rd., 0.4 km E of Abington. For nearby section refer to Hay (1975, p. 19).

13(a). SE¼SW¼, sec. 7, T2, R8: Fairborn Quad., Greene Co., OH. Railroad cut primarily on S side of New York Central R.R. 0.1 km N of Wright Bros. Memorial, about 6 km SW of Fairborn. Refer to Utgaard and Perry (1964, p. 35, loc.

21), and Kohut and Sweet (1968, p. 1459, loc. 10).

13b. SE¼SW¼, sec. 7, T2, R8: Fairborn Quad., Greene Co., OH. Cut on S bank of Mad R., 0.1 km SW of Huffman Dam, about 6 km SW of Fairborn. Refer to Kohut and Sweet (1968, p. 1459, loc. 10).

14(a). $^{43}64^{100}$N, $^{2}47^{700}$E to $^{43}63^{700}$N, $^{2}47^{900}$E: Clarksville Quad., Clinton Co., OH. Cut on N side of Cowan Cr., 0.2 to 0.75 km downstream from Cowan L. spillway, about 4.7 km ESE of Clarksville.

14b. $^{43}66^{700}$N, $^{7}49^{400}$E to $^{43}66^{500}$N, $^{7}49^{200}$E: Oregonia Quad., Warren Co., OH. Roadcuts primarily on W side of road just S of Hwy. I71 leading to picnic area on Little Miami R., about 1.7 km NW of Ft. Ancient State Memorial. Refer to Wolford (1930, p. 304-307), and Kohut and Sweet (1968, p. 1459, loc. 11).

B. Burkesville, Kentucky

15a. 36°46'21"N, 85°22'43"W: Waterview Quad., Cumberland Co., KY. Roadcut on E side of Hwy. 61, 1.3 km S of junction with Hwy. 90 at Burkesville. Refer to USGS Quad. Map CQ-286, and for nearby section refer to Jillson (1951).

15b. 36°47'45"N, 85°23'20"W: Waterview Quad., Cumberland Co., KY. Roadcut on S side of new Hwy. 90, 2.2 km E of junction with Hwy. 691, about 1.3 km NW of Burkesville.

Refer to USGS Quad. Map GQ-286.

15c. 36°47'48"N, 85°23'11"W: Waterview Quad., Cumberland Co., KY. Roadcut on N side of new Hwy. 90, 2.4 km E of junction with Hwy. 691, about 1.2 km NW of Burkesville. Refer to USGS Quad. Map GQ-286.

15d. 36°47'38"N, 85°24'40"W: Waterview Quad., Cumberland Co., KY. Outcrop just E of Cary house, 0.4 km N of junction of Hwys. 90 and 691, about 3.5 km W of Burkesville. Refer to USGS Quad. Map GQ-286, and Jillson (1953).

C. Goodlettsville-Gallatin, Tennessee

16a. 36°21'57"N, 86°42'57"W and 36°22'4"N, 86°42'51"W: Goodlettsville Quad., Sumner Co., TN. Roadcuts on W and E sides of Hwy. I65, 2.4 km N of Goodlettsville interchange. For nearby sections refer to Bassler (1932, p. 122), and Wilson (1949, p. 234, 236, sec. 5).

16b. 36°22'33"N, 86°42'48"W: White House Quad., Sumner Co., TN. Roadcut on W side of Hwy. I65, 3.45 km N of Goodlettsville interchange. For nearby sections refer to Bassler (1932, p. 122), and Wilson (1949, p. 234, 236, sec. 5).

16c. 36°27'54"N, 86°25'54"W: Gallatin Quad., Sumner Co., TN. Roadcut on W side of Dobbins Pike, 2.75 km S of Graball. For nearby sections refer to Bassler (1932, p.

127).

D. Little Bay de Noc, Michigan

17b. SE¼, sec. 26, T39N, R22W: Peninsula Point Quad., Delta Co., MI. Outcrop on E shore of Little Bay de Noc just W of road, 2.3 km N of Stonington. Refer to Foerste (1918, p. 98, Rheinholdson sec.), Hussey (1926, p. 116, 117, 133, 142, loc. 17), and Hussey (1950, p. 16-20, stop 7).

17c. SE¼SW¼, sec. 11, T39N, R21W: Rapid River Quad., Delta Co., MI. Federal Forest Quarry No. 2 just W of Co. Hwy. 511, 0.5 km S of Stonington Lookout tower. Refer to Kesling (1975, p. 8, loc. 4, Pl. 1, figs. 3, 4, p. 27, map 1), and for nearby section refer to Hussey (1926, p. 116, 117, 146, loc. 11), and Hussey (1950, p. 21, 22, stop 8).

17d. NW¼ and NE¼, sec. 11, T39N, R21W: Rapid River Quad., Delta Co., MI. Outctops on E and W side of road, 0.4 km N of intersection by Stonington Lookout tower. Refer to Hussey (1926, p. 116, 117, 145, 146, loc. 12).

E. Drummond Island, Michigan

18a. SE¼ and SW¼, sec. 29, T43N, R7E: Drummond SE Quad., Drummond Is., MI. Samples collected at exposure on shore 0.3 km SE of Raynolds Point; paleocurrent data collected on shore in NE part of Raynolds Bay, 0.3 km SW of Raynolds Pt. For nearby section refer to Hussey (1952, p. 49, 50).

18b. SW¼, sec. 24, T43N, R6E: Drummond Quad., Drummond Is., MI. Exposure on shore 0.3 km E of Poe Point. Refer to Hussey (1952, p. 50, 51).

18c. NE¼, sec. 30, T43N, R6E: Drummond Quad., Drummond Is., MI. Exposure on shore at Hay Point, 0.65 km S of Chippewa Pt. For nearby section refer to Hussey (1952, p. 50).

F. Manitoulin Island, Ontario

19a. 45°52'40"N, 81°52'54"W: Little Current area, Manitoulin Is., Ont. Roadcuts on both sides of Hwy. 68, 4.9 km SE of Sheguiandah. Refer to ODM Map 2247.

19b. 45°52'36"N, 81°51'17"W: Little Current area, Manitoulin Is., Ont. Roadcut on Hwy. 68, 7.1 km SE of Sheguiandah. Refer to ODM Map 2247.

19c. 45°53'46"N, 81°58'54"W: Little Current area, Manitoulin Is., Ont. Roadcut on S side of road, 4.5 km W of Sheguiandah. Refer to ODM Map 2247.

19d. 45°54'21"N, 82°15'29"W: Kagawong area, Manitoulin Is., Ont. Roadcut on W side of road into Kagawong, 0.3 km N of junction with Hwy. 540. Refer to ODM Map 2246, Foerste (1916, p. 110, loc. 40), and Liberty and Shelden (1968, p. 7, stop 1).

19e. 45°53'55"N, 82°6'10"W: Kagawong area, Manitoulin Is., Ont. Roadcut on E side of Hwy. 540, 1.4 km N of Honora.

Refer to ODM Map 2246.

19f. 45°53'45"N, 82°15'5"W: Kagawong area, Manitoulin Is., Ont. Roadcut on N and S sides of Hwy. 540, 1 km SE of junction with road into Kagawong. Refer to ODM Map 2246, and for nearby section refer to Foerste (1916, p. 108, 109, loc. 38).

M61a. 45°45'3"N, 81°48'45"W: Little Current area, Manitoulin Is., Ont. Laurentian Univ. collection. Refer to ODM Map 2247.

M75. 45°52'40"N, 81°57'36"W: Little Current area, Manitoulin Is., Ont. Laurentian Univ. collection at ditch on SE corner at intersection of E-W road and N-S road, 1 km E of Pike Lake. Refer to ODM Map 2247.

G. Missouri

20a. SE¼NE¼SW¼, sec. 21, T32N, R13E: Cape Girardeau Quad., Cape Girardeau Co., MO. Type section of Leemon Formation. Outcrop in gully behind barn of Short's farm. Refer to Amsden (1974, p. 19-21, loc. K), and Thompson and Satterfield (1975, p. 76, 77, loc. 3).

20b. NW¼SE¼SE¼, sec. 9, T33N, R13E: Neelys Landing Quad., Cape Girardeau Co., MO. Outcrops on Blue Shawnee Creek, 0.8 km E of New Wells. Refer to Amsden (1974, p. 20-22, loc. U), and Thompson and Satterfield (1975, p. 79, 80, loc. 4).

21a. NW¼, sec. 9, T53N, R1E: Nebo Quad., Pike Co., MO. Roadcut on west side of Hwy. 79, N edge of Clarksville. Refer to Amsden (1974, p. 6, 9, loc. E), and Thompson and Satterfield (1975, p. 91, loc. 6).

21b. SW¼NE¼NW¼, sec. 20, T54N, R1W: Bowling Green Quad., Pike Co., MO. Type section of Noix Limestone. Outcrop at Clinton Springs, S edge of Louisiana. Refer to Amsden (1974, p. 6, 9, loc. D), and Thompson and Satterfield (1975, p. 90, loc. 7).

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PLATES

Exterior views are of specimens coated with ammonium chloride. "S" in a figure number denotes a stereopair. Transverse and longitudinal sections are negatives of thin sections unless otherwise stated. Transverse sections are oriented as they appear looking from the top of the corallite towards the tip. A line and small number beside an exterior view or longitudinal section refers to the position and figure number of a transverse section illustrated on the same plate, unless otherwise stated. When the horizon of a specimen is given, the first number indicates the locality and the second designates the stratigraphic interval (see "Localities"; Text-figs. 3, 18, 21).

EXPLANATION OF PLATE 1

Figure

1-56. *Streptelasma divaricans* (Nicholson, 1875) (Richmond Group; Cincinnati Arch region)

1-19. Axial region comparative scale and values (small numbers 5, 10...95), x2 (refer to p. 81 in text). 1, UCGM 45072, horizon 12a-1. 2, UCGM 45061, horizon 11b-1. 3, UCGM 45014, horizon 4-2. 4, UCGM 45037, horizon 5b-2. 5, UCGM 45137, horizon 13b-2. 6, UCGM 45004, horizon 2-1. 7, UCGM 45133, horizon 13b-1. 8, UCGM 45074, horizon 12a-1. 9, UCGM 45028, horizon 5b-1. 10, UCGM 45054, horizon 5b-9. 11, UCGM 45084, horizon 12a-2. 12, UCGM 45008, horizon 3-2. 13, UCGM 45611, horizon 13-1. 14, UCGM 45018, horizon 4-3. 15, UCGM 45057, horizon 10-1. 16, UCGM 45020, horizon 4-4. 17, UCGM 45086, horizon 12a-2. 18, UCGM 45034, horizon 5b-2. 19, UCGM 45019, horizon 4-3.

20-22. UCGM 45072, horizon 12a-1. 20, alar view, cardinal side left, x1. 21, 22, cardinal side down, x2.

23-26. UCGM 45074, horizon 12a-1. 23, alar view, cardinal side right, x1. 24-26, cardinal side down, x2.

27-29. UCGM 45084, horizon 12a-2. 27, x1. 28, 29, x2.

30-32. UCGM 45018, horizon 4-3. 30, x1. 31, 32, x2.

33-36. UCGM 45086, horizon 12a-2. 33, cardinal side left, x1. 34-36, cardinal side down, x2.

37-41. UCGM 45034, horizon 5b-2. 37, alar view, cardinal side left, x1. 38-41, cardinal side down, x2.

42-45. UCGM 45128, horizon 13-2, x2.

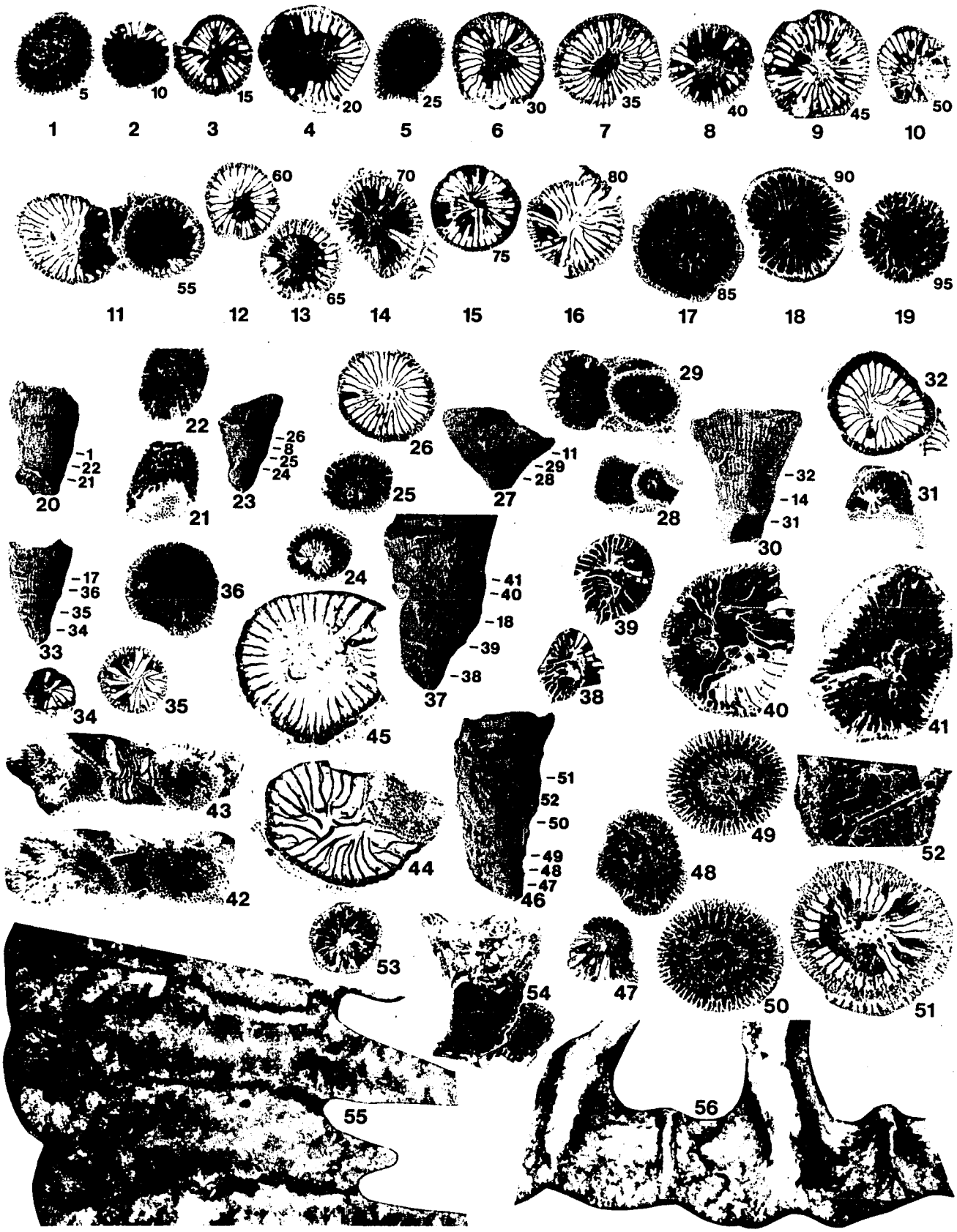
46-52. UCGM 45013, horizon 4-2. 46, alar view, cardinal side left, x1. 47-51, cardinal side down, x2. 52, cardinal side left, x2.

53. USNM 84868a, (syntype of S. divaricans-angustatum Foerste, 1909), "Whitewater" strata, Osgood, Indiana, x2.

54. UCGM 45145, "Whitewater" strata, Hueston Woods Park, Oxford, Ohio, x2.

55. UCGM 45024, horizon 4-5, transverse photomicrograph, late ontogenetic stage, dilated major and minor septa in lateral contact in stereozone, x31.

56. UCGM 45080, horizon 12a-2, transverse photomicrograph, late ontogenetic stage, undilated major and minor septa separated by U-shaped lamellae in stereozone, x31.



EXPLANATION OF PLATE 2

Figure

1-27. *Streptelasma divaricans* (Nicholson, 1875)
(Richmond Group: 1-17, Cincinnati Arch region; 18, 19, Little Bay de Noc, Michigan; 20-27, Manitoulin Island, Ontario)

1. UCGM 45646, horizon 12a-5, x1 (blastogeny shown in Text-fig. 29)

2, 3. UCGM 45093, horizon 12a-4, x2. 2, increase demonstrated by incomplete wall between two corallites on left. 3, corallites separated later in ontogeny.

4, 5s. USGS loc. 4343-CO(a), "Whitewater" strata, NW of Oxford, Ohio. 4 (USGS 6798a), opening in wall developing between two central corallites, x2. 5s, complete connection between two central corallites later in ontogeny, x1.

6s. USGS loc. 4343-CO(b), "Whitewater" strata, NW of Oxford, Ohio, rejuvenance in calyx of right corallite, x1.

7. UCGM 45121, horizon 13-1, bedding surface, corallites in growth position on brachiopod fragment (upper right) and on bryozoan (lower right), x1.

8s. USNM 50816, Bardstown, Kentucky, cluster of

corallites, x1.

9s. USNM 70211, "Waynesville" strata, near Clarksville, Ohio, cluster partly overgrown by host bryozoan, x1.

10, 11. UCGM 45100, horizon 12a-5. 10, corallite with large base of attachment on bryozoan, x1. 11, corallite wall not developed at site of attachment to bryozoan, x2.

12. UCGM 45066, horizon 11b-3, corallite attached to Lepidocyclus capax, x1.

13s. USNM 40086, "Whitewater" strata, Oxford, Ohio, corallites attached to L. capax, x1.

14s. USNM 135767, "Whitewater" strata, Richmond, Indiana, corallites attached to Rafinesquina alternata, x1.

15. UCGM 45012, horizon 4-2, corallites attached to colonial coral, x1.

16. USNM 42517, Oxford, Ohio, bedding surface, some corallites attached to large Grewingkia canadensis corallite, x1.

17s. USNM 84869, "Whitewater" strata, Osgood, Indiana, note talons on right corallite, x1.

18s, 19. USNM 78449, a, Bay de Noc Mbr., Stonington Fm., Stonington, Michigan. 18s, corallites attached to Rafinesquina, x1. 19, x2.

20s-26. LU M61a-4, Meaford beds, upper mbr.,

Georgian Bay Fm., horizon M61a. 20s, alar view, cardinal side right, x1. 21s, alar view, cardinal side left, x1. 22-26, cardinal side down, x2.

27. LU M61a-1, Meaford beds, upper mbr., Georgian Bay Fm., horizon M61a, corallite attached to bryozoan, x1.

28. Streptelasma leemonensis n. sp.

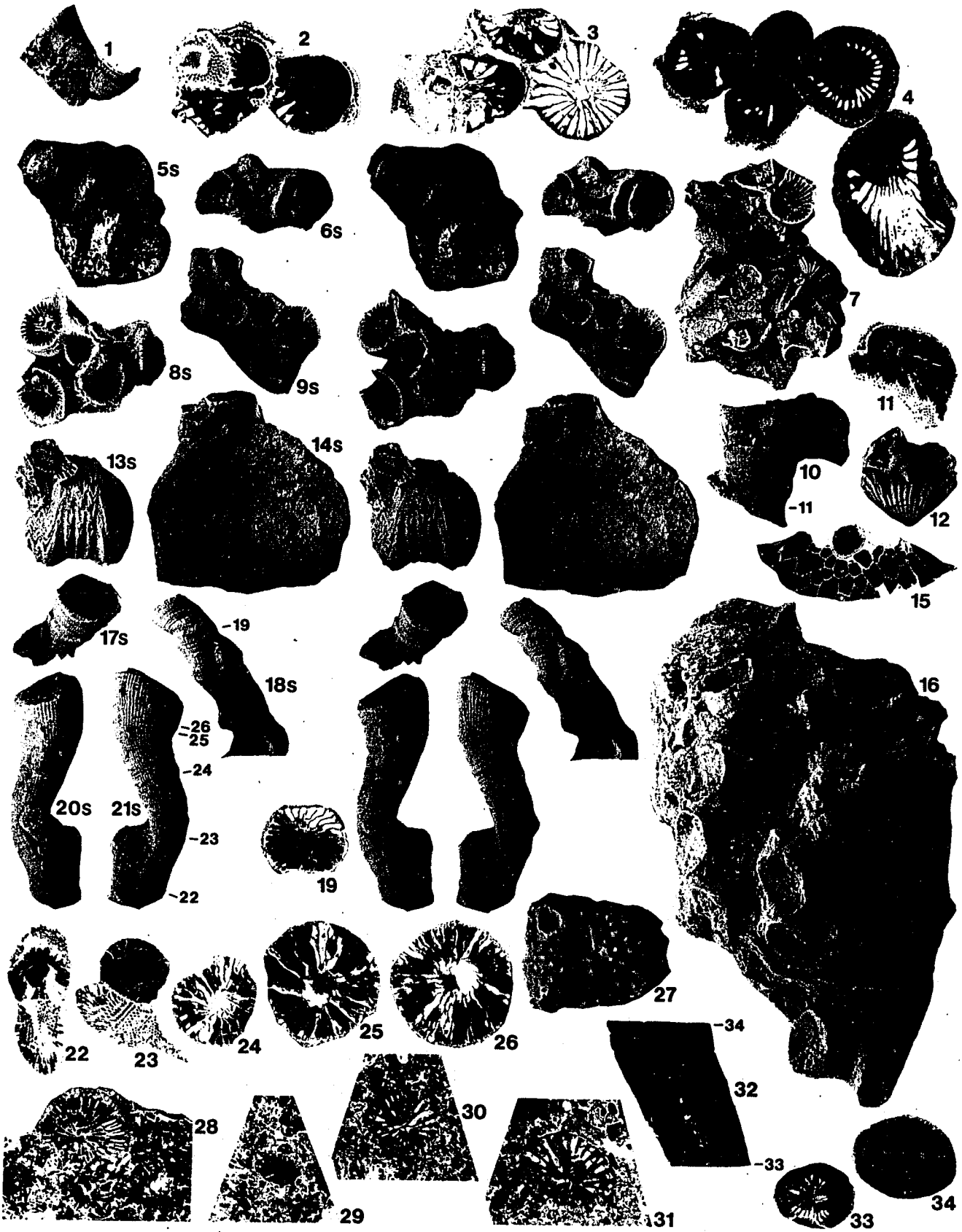
28. UCGM 45614 (holotype), Leemon Fm., horizon 20a-1, Cape Girardeau Co., Missouri, x2.

29-31. Streptelasma sp.

29-31. UCGM 45616, Leemon Fm., horizon 20a-1, Cape Girardeau Co., Missouri, x2.

32-34. Streptelasma rankini n. sp.

32-34. USGS 6344a, c, b (holotype), unnamed Ashgillian formation, Penobscot Co., Maine, x2.



EXPLANATION OF PLATE 3

Figure

1-16. *Streptelasma subregularis* (Savage, 1913)
(1s, 2, Cyrene Fm., near Edgewood, Missouri; 3-16, Leemon Fm., horizon 20b-1, Cape Girardeau Co., Missouri)

1s, 2. UI X-851 (holotype), x1. 1s, calyx, cardinal side down. 2, counter side showing tabulae where broken.

3. UCGM 45628, cardinal side left, x1.

4-8. UCGM 45619, x1. 4, alar view, cardinal side left. 5, 6, cardinal side down. 7, cardinal side left. 8, cardinal view.

9-12. UCGM 45622, x1. 9, alar view, cardinal side right. 10, 11, cardinal side down. 12, cardinal view.

13-16. UCGM 45618, x1. 13, counter view. 14-16, cardinal side down.

17-31. *Streptelasma affinis* (Billings, 1865)
(Ellis Bay Fm., Anticosti Island, Quebec)

17-20. YPM "Ellis Bay zone 7", x1. 17, polished section, cardinal side left. 18-20, cardinal side down.

21. YPM 555a, note talons near base on right side and coarse rugae, x1.

22-26. YPM 3016/3063/35j, x1. 22, cardinal view. 23,

alar view, cardinal side right. 24-26, cardinal side down.

27-31. YPM 3019/3063/57k, x1. 27, alar view, cardinal side right. 28-31, cardinal side down.

EXPLANATION OF PLATE 4

Figure

1-8. *Helicelasma randi* Elias, 1976

(Maquoketa Group: 1-7, Brainard Fm., Sterling, Illinois; 8, probably Clermont Mbr., Scales Fm., Fayette Co., Iowa)

1-4. USNM 42535b. 1, cardinal view, x1. 2, alar view, cardinal side right, x1. 3, 4, cardinal side down, x2.

5. USGS 206S, x1.

6. USGS 206Sa, cardinal side down, x2.

7. USGS 206T, cardinal side left, x2.

8. SUI 57-'24, cardinal side down, x2.

9-19. *Helicelasma selecta* (Billings, 1865)

(9-16, Anticosti Island, Quebec; 17-19, White Head Fm., Percé, Quebec)

9, 10. GSC 1989a (lectotype), upper mbr., Vaureal Fm. 9, alar view, cardinal side left, x1. 10, cardinal side down, x2.

11-13. YPM 539a, Ellis Bay Fm. 11, alar view, cardinal side left, x1. 12, 13, cardinal side down, x2.

14, 15. YPM 514a, Ellis Bay Fm., cardinal side down, x1.

16. YPM 543, Ellis Bay Fm., cardinal side down, x1.

17-19. USNM 102390(3). 17, alar view, cardinal side left, x1. 18, 19, cardinal side down, x2.

20-32. Deiracorallium angulatum (Billings, 1862) (upper mbr., Vaureal Fm., Anticosti Is., Quebec)

20s-23. GSC loc. 84419(a). 20s, cardinal view, x1. 21s, alar view, cardinal side left, x1. 22, 23, cardinal side down, x2.

24s-28. GSC loc. 84419(c). 24s, cardinal view, x1. 25s, alar view, cardinal side left, x1. 26-28, cardinal side down, x2.

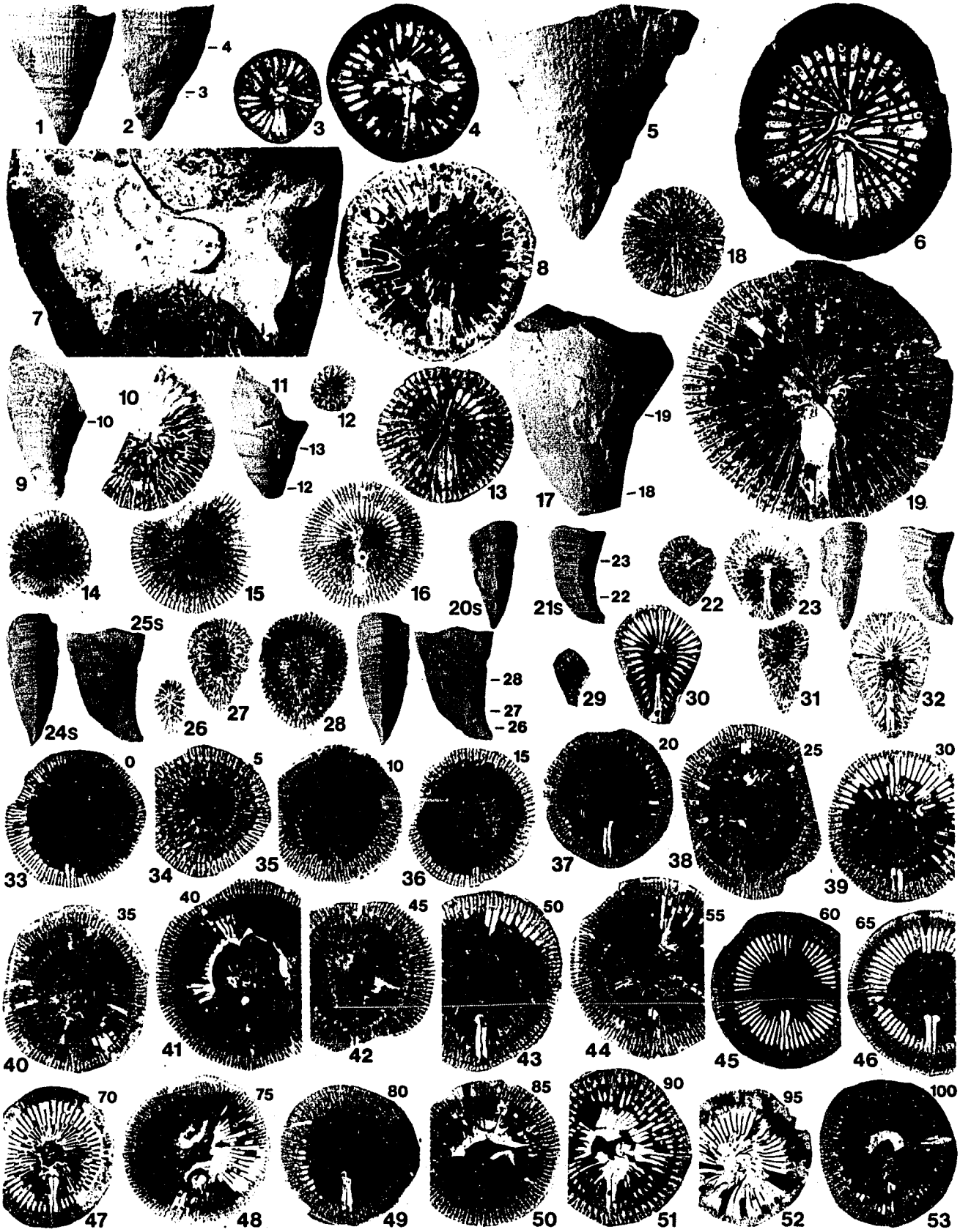
29, 30. GSC loc. 84419(b), cardinal side down, x2.

31, 32. GSC loc. 84419(d), cardinal side down, x2.

33-53. Grewingkia canadensis (Billings, 1862) (Richmond Group, Cincinnati Arch region)

33-53. Axial region comparative scale and values (small numbers 0, 5...100), cardinal side down, x1 (refer to p. 66 in text). 33, UCGM 45334, horizon 11b-2. 34, UCGM 45230, horizon 4-4. 35, UCGM 45156, horizon 1-1. 36, UCGM 45279, horizon 5b-9. 37, UCGM 45390, horizon 12a-4. 38, UCGM 45206, horizon 3-1. 39, UCGM 45315, horizon 11b-1. 40, UCGM 45446, horizon 13b-1. 41, UCGM 45226, horizon 4-4. 42, UCGM 45394, horizon 12a-5. 43, UCGM 45191, horizon 2-1. 44, UCGM 45193, horizon 2-1. 45, UCGM 45220, horizon 4-1. 46, UCGM 45357, horizon 12a-1. 47, UCGM 45272,

horizon 5b-6. 48, UCGM 45355, horizon 12a-1. 49, UCGM 45183, horizon 1-4. 50, UCGM 45344, horizon 11b-3. 51, UCGM 45228, horizon 4-4. 52, UCGM 45260, horizon 5b-2. 53, UCGM 45413, horizon 12b-2.



EXPLANATION OF PLATE 5

Figure

1-46. *Grewingkia canadensis* (Billings, 1862)
(Richmond Group, Cincinnati Arch region)

Note: 4/ refers to fig. in Pl. 4.

1-6. UCGM 45334, horizon 11b-2, x1. 1, alar view, cardinal side left. 2-4, cardinal side down. 5, 6, cardinal side left.

7-10. UCGM 45390, horizon 12a-4, x1. 7, alar view, cardinal side left. 8-10, cardinal side down.

11-16. UCGM 45446, horizon 13b-1, x1. 11, 12, cardinal side down. 13, 14, cardinal side left. 15, cardinal view. 16, alar view, cardinal side left.

17-22. UCGM 45193, horizon 2-1, x1. 17, alar view, cardinal side left. 18-21, cardinal side down. 22, cardinal side left.

23-31. UCGM 45355, horizon 12a-1, x1. 23, cardinal view. 24, alar view, cardinal side left. 25-29, cardinal side down. 30, 31, cardinal side left.

32-34. UCGM 45413, horizon 12b-2, x1. 32, alar view, cardinal side left. 33, 34, cardinal side down.

35-38. UCGM 45310, horizon 11b-1. 35, cardinal view, x1. 36-38, cardinal side down, x2.

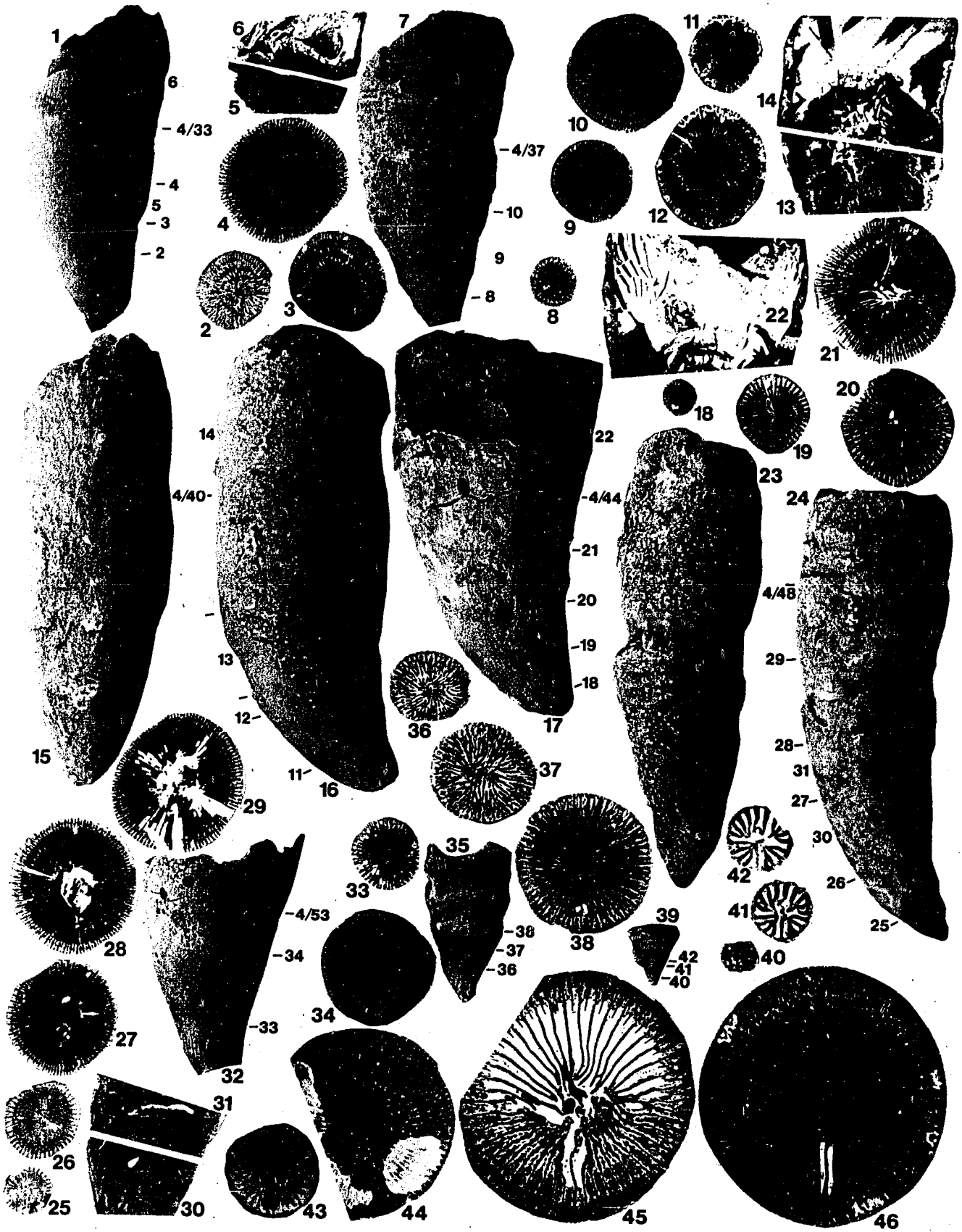
39-42. UCGM 45259, horizon 5b-1. 39, alar view,

cardinal side left, x1. 40-42, cardinal side down, x3.

43, 44. USNM 84870b, a (holotype of Streptelasma insolitum Foerste, 1909), "Whitewater" strata, SE of Westport, Indiana, cardinal side down, x2.

45. USNM 78742a (syntype of S. dispandum Foerste, 1909), "Waynesville" strata, Moore's Hill, Indiana, cardinal side down, x2.

46. USNM 78749a (syntype of S. vagans Foerste, 1909), "Liberty" strata, Dayton, Ohio, cardinal side down, x2.



EXPLANATION OF PLATE 6

Figure

1-34. Grewingkia canadensis (Billings, 1862)
(Richmond Group: 1-6, Cincinnati Arch region; 7-13, Goodlettsville-Gallatin area, Tennessee; 15-23, Drummond Island, Michigan; 24-33, Manitoulin Island, Ontario; 34, Meaford, Ontario. Maquoketa Group: 14, Little Sturgeon Bay, Michigan)

1s. UCGM 45311, horizon 11b-1, calyx, cardinal side down, x1.

2s. UCGM 45340, horizon 11b-3, calyx, cardinal side down, x1.

3. USNM 15587, "Whitewater" strata, Connersville, Indiana, bedding surface, corallites in growth position, x1.

4. UCGM 45469, horizon 14b-1, alar view, cardinal side left, note epifaunal bryozoans upper left and boring bryozoans lower left, x1.

5. UCGM 45226, horizon 4-4, transverse photomicrograph, Ordovician algal borings in outer corallite wall and penetrating septa from interseptal chambers, x31.

6. UCGM 45302, horizon 10-2, transverse photomicrograph, Recent algal borings in outer corallite wall and penetrating secondary calcite filling Vermiforichnus boring on right side, x31.

7-11. UCGM 45505, horizon 16a-1, x1. 7, alar view, cardinal side left. 8-11, cardinal side down.

12. UCGM 45519, horizon 16b-2, cardinal side down x1.

13. UCGM 45518, horizon 16b-2, cardinal side down, x1.

14. USGS 347W, top of Maquoketa Group, cardinal side down, x2.

15-17. GSC 1983h, i (lectotype), upper mbr., Georgian Bay Fm., x1. 15 (1983h), polished section, cardinal side left. 16, 17 (1983i), cardinal side down.

18-20. UCGM 45540, horizon 18a-1, cardinal side down, x1.

21-23. UMMP 26927 (holotype of Streptelasma arcticum drummondense Stumm, 1963), upper Meaford beds, upper mbr., Georgian Bay Fm., Potaganissing Bay, Poe Point, x1. 21, alar view, cardinal side right. 22, 23, cardinal side down.

24-29. LU M61a-7, horizon M61a, x1. 24, alar view, cardinal side left. 25-28, cardinal side down. 29, cardinal view.

30-33. UCGM 45585, horizon 19d-1, x1. 30, alar view, cardinal side left. 31-33, cardinal side down.

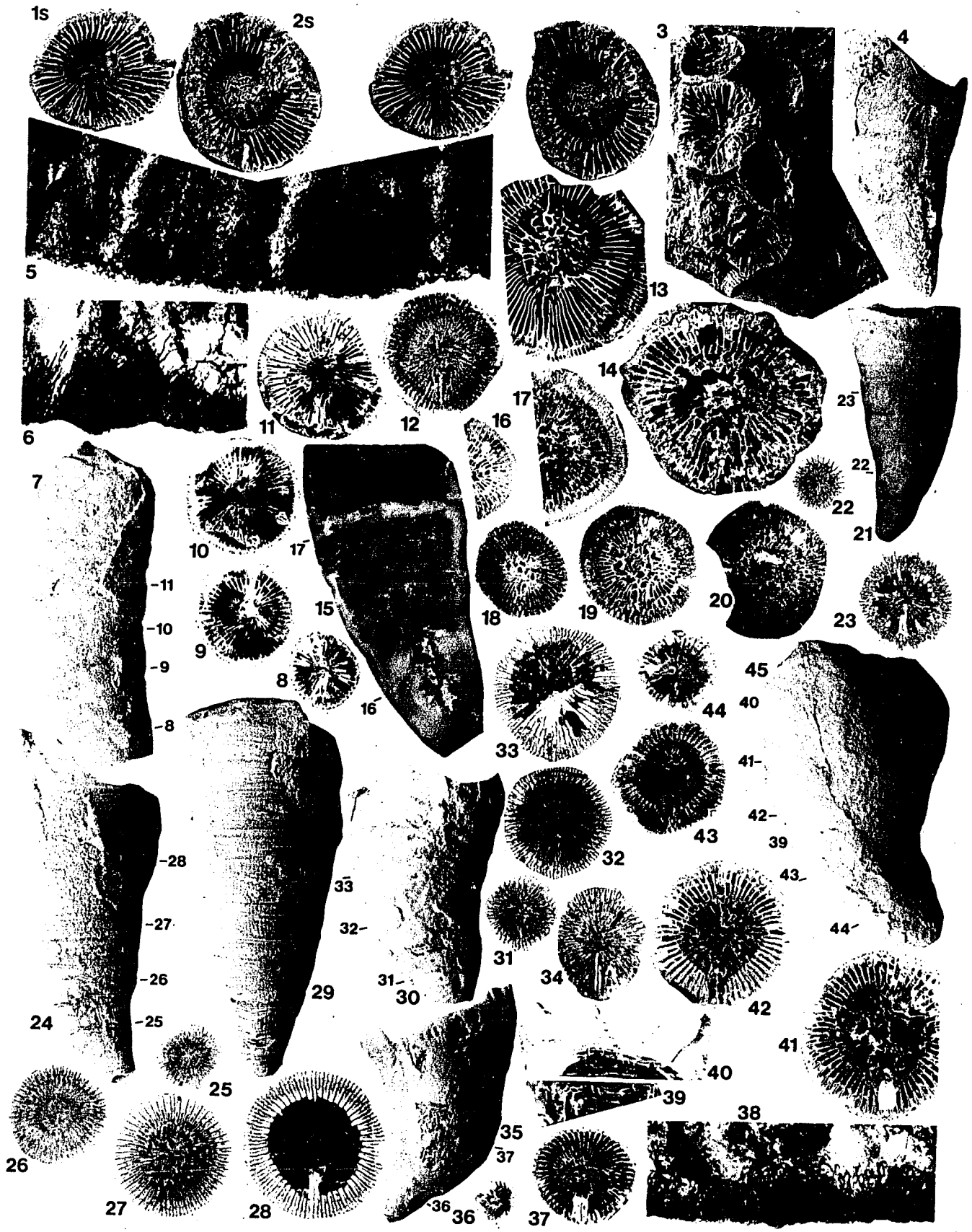
34. GSC 8531, upper Georgian Bay Fm., cardinal side

down, x1.

35-45. Grewingkia deltensis n. sp.
(Ogontz Mbr., Stonington Fm., horizon 17b-1, Delta Co., Michigan)

35-37. UCGM 45596 (paratype), x1. 35, alar view, cardinal side right. 36, 37, cardinal side down.

38-45. UCGM 45602 (holotype). 38, transverse photomicrograph, Recent algal borings in outer corallite wall, x31. 39, 40, cardinal side left, x1. 41-44, cardinal side down, x1. 45, alar view, cardinal side left, x1.



EXPLANATION OF PLATE 7

Figure

1-18. *Grewingkia rustica* (Billings, 1858)

(Richmond Group: 1-14, Snake Island, Lake St. John, Quebec; 15-18, Manitoulin Island, Ontario)

1. GSC 5822c (lectotype), polished section, cardinal side down, x1.

2-4. GSC 8527j, x1. 2, cardinal side right. 3, 4, cardinal side down.

5-8. GSC 8527c, x1. 5, alar view, cardinal side right. 6-8, cardinal side down.

9-12. GSC 8527n, x1. 9, alar view, cardinal side right. 10-12, cardinal side down.

13s. GSC 8527a, calyx, cardinal side down, x1.

14. GSC 8527c, transverse photomicrograph, age of algal borings in outer corallite wall uncertain, x31.

15-18. UCGM 45592, horizon 19b-1, x1. 15, alar view, cardinal side left. 16-18, cardinal side down.

19-23. *Grewingkia penobscotensis* n. sp.

(unnamed Ashgillian formation, Penobscot Co., Maine)

19, 20. USGS 6336a, b (paratype), x2.

21-23. USGS 6268a, c, b (holotype), x2.

24-28. Grewingkia pulchella (Billings, 1865)

(24-36, Anticosti Island, Quebec; 37, 38, unnamed unit, near Ashland, Maine)

24-27. GSC 1989h, upper mbr., Vaureal Fm. 24, cardinal view, x1. 25, alar view, cardinal side left, x1. 26, 27, cardinal side down, x2.

28-31. YPM 3063/41a, Ellis Bay Fm., x1. 28, alar view, cardinal side right. 29-31, cardinal side down.

32-35. YPM 3063/41c, Ellis Bay Fm. 32, alar view, cardinal side left, x1. 33-35, cardinal side down, x2.

36. YPM 538b, Ellis Bay Fm., cardinal side right, x2.

37, 38. USGS loc. 4112-CO(a), cardinal side down, x2.

39-42. Grewingkia sp.

(White Head Fm., Percé, Quebec)

39-41. YPM "Grande Coupe, Percé, Quebec"(b), x2.

42. USNM 102390(4), x2.

43-49. Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928)

(43-48, upper mbr., Vaureal Fm., Anticosti Island, Quebec; 49, White Head Fm., Percé, Quebec)

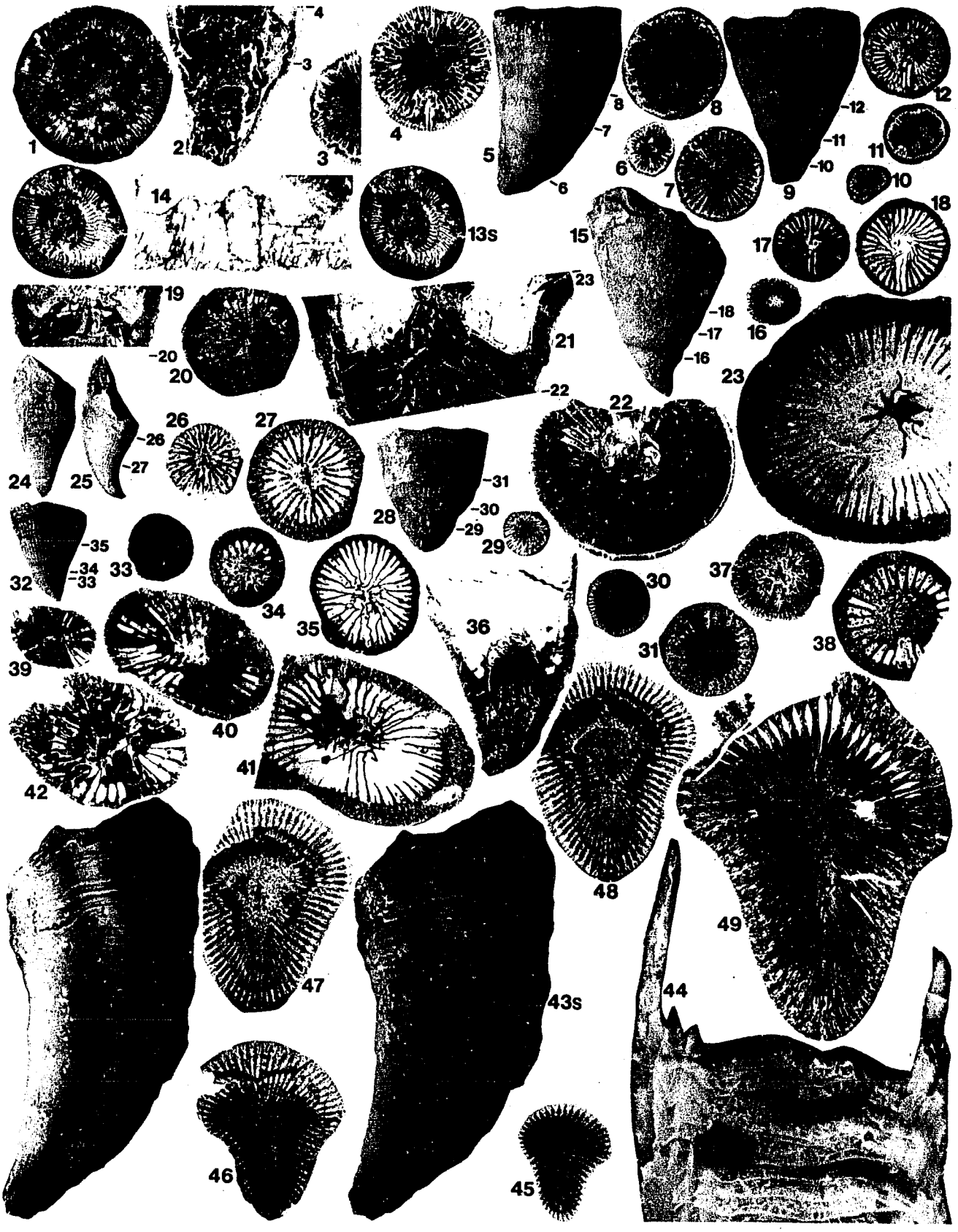
43s, 44. YPM 20428 (holotype). 43s, alar view,

cardinal side right, x0.5. 44, polished section, cardinal side left, x1.

45, 46. GSC loc. 36157(1), cardinal side down, x1.

47, 48. GSC loc. 36157(2), cardinal side down, x1. 48, immediately below calyx, several mm above 47.

49. USNM 102390(1), cardinal side down, x2.



EXPLANATION OF PLATE 8

Figure

1, 2. *Densigrewingkia* ? sp.

(unnamed Ashgillian formation, Penobscot Co., Maine)

1. USGS 6258a, x2.

2. USGS 6257a, cardinal side probably down, x2.

3-7. *Bodophyllum shorti* n. sp.

3-7. UCGM 45613 (holotype), Leemon Fm., horizon 20a-1, Cape Girardeau Co., Missouri, cardinal side down, x2.

8-13. *Bodophyllum neumani* n. sp.

(unnamed Ashgillian formation, Penobscot Co., Maine)

8, 9. USGS 6264b, a (holotype), x2. 8, cardinal or counter side down.

10, 11. USGS 6269a, b (paratype), x2. 11, cardinal or counter side down.

12. USGS 6271b (paratype), cardinal or counter side down, x2.

13. USGS 6260b (paratype), cardinal or counter side down, x2.

14-16. *Bodophyllum* ? sp.

14-16. YPM "Grande Coupe, Percé, Quebec"(c), White Head Fm., Percé, Quebec, cardinal side probably down, x2.

17-23. Bodophyllum englishheadensis n. sp.
(upper mbr., Vaureal Fm., Anticosti Island, Quebec)
17-20. YPM 3063/7 (holotype), x2. 17, cardinal side left. 18-20, cardinal side down.
21-23. YPM 3019/2c (paratype), cardinal side probably down, x2.

24-42. Bighornia cf. patella (Wilson, 1926)
(24-31, Fort Atkinson Fm., Maquoketa Group, Winneshiek Co., Iowa; 32-42, lower mbr., Vaureal Fm., Anticosti Island, Quebec)
24s-27. SUI 2-051 (holotype of Lindströmia solearis Ladd, 1929), x1. 24s, calyx, cardinal side down. 25, alar view, cardinal side left. 26, cardinal view. 27, counter view.
28s-30. USNM 71926 (paratype of L. solearis Ladd, 1929), x1. 28s, calyx, cardinal side down. 29, alar view, cardinal side right. 30, cardinal view.
31s. SUI 2-052 (paratype of L. solearis Ladd, 1929), calyx, cardinal side down, x1.
32-37. YPM 505a. 32, alar view, cardinal side right, x1. 33-36, cardinal side down, x2. 37, cardinal side right, x2.
38-42. YPM 505b. 38, cardinal view, x1. 39, alar view, cardinal side right, x1. 40-42, cardinal side down, x2.

43-53. Paliphyllum ellisensis (Twenhofel, 1928)
(Ellis Bay Fm., Anticosti Island, Quebec)

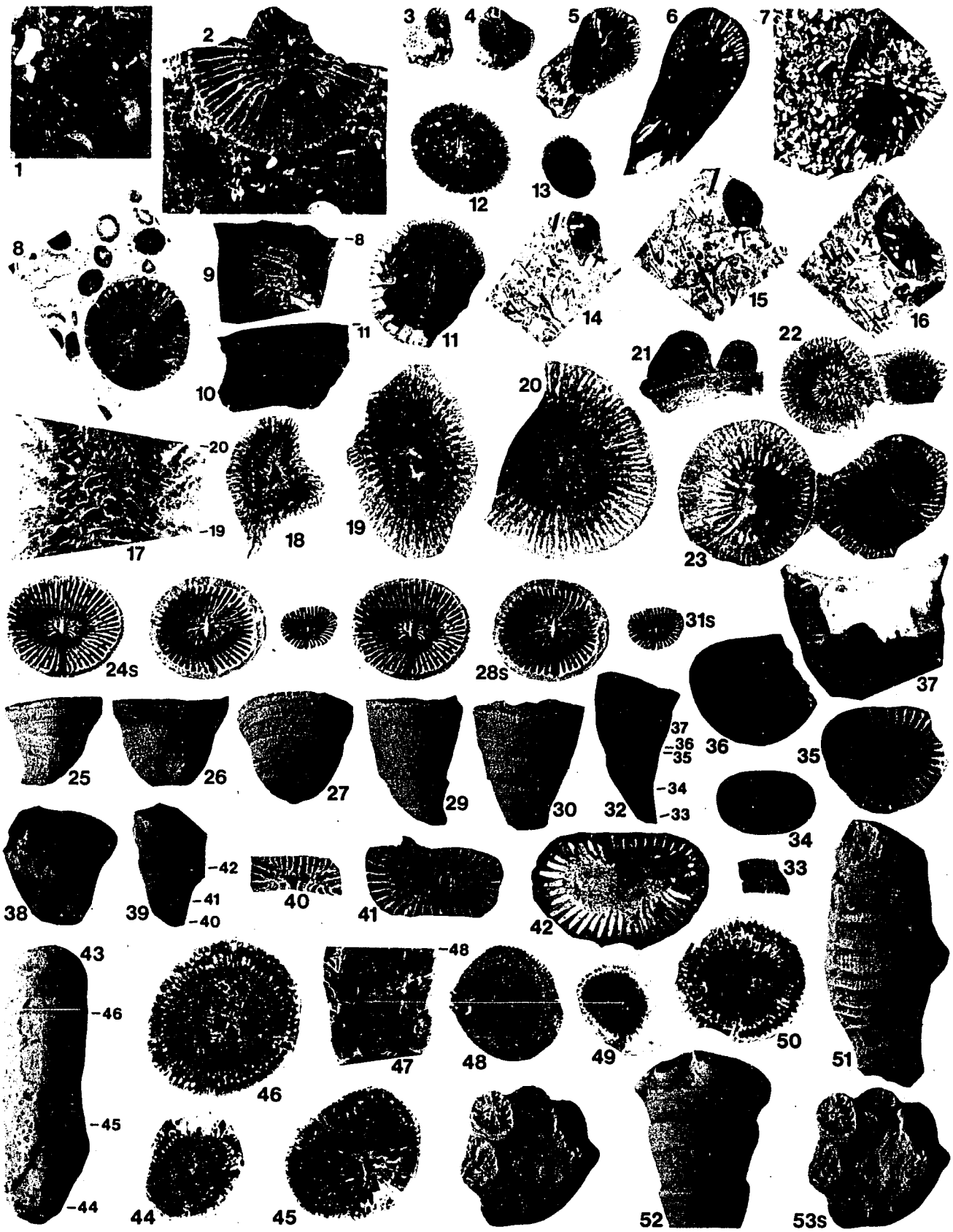
43-46. YPM 3019/3063/57b. 43, x1. 44-46, x2.

47, 48. YPM 3019/3063/57a, x1.

49, 50. YPM 3019/3063/57d, cardinal side probably down, x2.

51. YPM 573b, note coarse rugae, x1.

52, 53s. YPM 10388B, x2. 52, lateral view. 53s, calyx with offsets resulting from peripheral increase.



Appendix 1.--Grewingkia canadensis (Billings, 1862) and G. deltensis n. sp.: frequency of side facing up on bedding surface (K = counter, A = alar, C = cardinal).

A. Grewingkia canadensis

Horizon	K	A	C
1--1	2	4	2
1-2	3	15	3
1-3	1	-	-
2-1	3	3	2
3-1	-	2	-
4-1	-	1	-
4-4	3	7	-
5b-1	-	3	-
5b-2	-	2	-
5b-6	-	4	-
10-2	-	1	-
11b-2	-	6	1
12a-1	1	7	3
12a-2	1	6	-
12a-3	1	9	1
12a-4	-	2	-
12a-5	1	2	-
12a-6	-	5	-
12a-8	1	1	-
12b-1	-	7	-
12b-2	1	2	1
12d-1	-	2	-
13b-1	-	5	-
13b-2	-	2	-
13b-3	1	3	-
14-2	1	-	-
14-3	1	2	-
14-4	1	3	-
14-5	-	2	-
16a-1	-	2	-
18a-1	-	4	-
18a-2	1	1	-
18a-3	1	8	1
18b-1	-	3	-

B. Grewingkia deltensis

17b-1	2	6	1

Appendix 2.--*Crewingkia canadensis* (Billings, 1862): directional orientation of corallites (calyx faces direction indicated).

Horizon	Orientation
1b	N03E, N09E, N13E, N36E, N45E, N56E, N62E, N68E, N69E, N69E, N69E, N70E, N78E, N80E, S87E, S87E, S83E, S75E, S62E, S57E, S56E, S31E, S25E, S23E, S12E, S21W, S26W, S40W, S58W, S72W, S78W, S80W, N21W, N20W, N17W.
4-4	N04E, N27E, N34E, N35E, N43E, N44E, S63E, W, N35W, N22W, N20W, N17W, N08W, N05W, N05W.
5b-1	N25E, N37E, N47E, S04E, S56W, N55W, N37W.
5b-2	N18E, S08W, S32W, S38W, S42W, S51W, S75W, N06W.
5b-6	S22E, S18W, N50W, N30W.
11b-2	N, N04E, N22E, S37E, S40W, S75W, N82W, N72W, N42W, N40W, N15W, N06W.
12a-1	N15E, N20E, N78E, S82E, S65E, S30E, S07E, S05E, S55W, S60W, S70W, S70W, S80W, S82W, S85W, N65W, N40W, N30W, N30W.
12a-2	N05E, S87E, S52E, S50E, S35E, S30E, S25E, S15E, S08E, S36E, S43E, S80W, N70W, N54W, N53W, N43W.
12a-3	N15E, N43E, N51E, N56E, N63E, N83E, S88E, S45E, S30E, S25W, S50W, N85W, N77W, N76W, N57W, N40W, N08W, N05W.
12a-4	N41E, N80E, S40W, W.

12a-5 N87E, S62E, S07E, S41W, S44W, S84W, N76W, N70W, N20W.

12a-6 N45E, S46E, S15E, S82W, S85W, S86W, N43W, N37W, N37W, N30W, N24W, N05W.

12a-8 N65E, S38W, N65W.

12b-1 N10E, S41E, S30E, S02W, S03W, S20W, S22W, S30W, N87W, N73W, N72W, N48W, N43W.

12b-2 N05E, S85E, S74E, S70E, S66E, S59E, S56E, S14W, S16W, S18W

13b-1 N28E, N51E, N75E, N82E, N86E, N86E, S79E, S74E, S63E, S49W, N85W, N77W, N17W, N14W, N11W.

13b-3 S88E, S57E, S52E, S43E, S33E, S02W, S04W, S83W, N74W, N13W.

14-2 S30E, N13W.

14-3 N75E, S52E, S38W, N13W.

14-4 N11E, N13E, S64E, S56E, S31E.

14-5 N, N, N06E, N13E, S48E, N34W.

14-6 N29E, S54W, N30W.

18a-3 N01E, N04E, N12E, N15E, N17E, N37E, N49E, N75E, N85E, S89E, S80E, S34E, S17E, S16W, S24W, S25W, S37W, S55W, S76W, S85W, N58W, N57W, N48W, N01W.

Appendix 3.--Length of corallites

A. Grewingkia canadensis (Billings, 1862)

Horizon	Length (mm)
1-1	22, 38, 38, 43, 56, 58, 60, 73.
1-2	13, 34, 37, 42, 46, 48, 50, 51, 51, 52, 52, 52, 54, 55, 55, 59, 60, 63, 66, 68, 70, 70, 82, 85, 90, 90, 93.
1-3	33, 46.
1-4	23, 32, 35, 36, 59, 62.
1b-1	130.
1c-2	61.
2-1	25, 26, 33, 40, 42, 44, 50, 50, 50, 58, 62, 65, 75, 78.
3-1	11, 21, 22, 40, 41, 45, 45, 50, 68, 71, 80.
3-2	30.
4-1	29, 63.
4-4	13, 19, 25, 39, 46, 49, 57, 63, 66, 66, 70.
5b-1	17, 24, 32, 32, 42, 48, 52, 56.
5b-2	21, 30, 60, 71.
5b-5	16, 60.
5b-6	13, 13, 45, 60.
5b-9	14, 18, 27, 33, 62, 63.
6-1	58.
7-2	27.
9-1	32.

10-2 49.

11b-1 15, 16, 19, 20, 23, 24, 28, 29, 31, 32, 33, 35, 38, 40, 42, 45, 46, 54, 63, 74.

11b-2 43, 58, 59, 76.

11b-3 21, 23, 28, 40, 45, 46, 49, 51, 51, 57, 58, 58, 62, 64, 70.

12a-1 23, 34, 43, 53, 71, 77, 80, 87, 91.

12a-2 22, 29, 41, 43, 53, 61, 65, 68.

12a-3 11, 13, 14, 18, 20, 20, 28, 33, 38, 46, 59, 59, 67, 68.

12a-4 20, 59, 63, 65.

12a-5 20, 21, 71, 125.

12a-6 16, 30, 40, 75.

12a-8 35.

12b-1 18, 28, 72.

12b-2 13, 36, 40, 57.

12d-1 51, 86.

13-2 15, 15, 23, 40, 47, 49, 55, 58.

13b-1 24, 28, 32, 39, 50, 53, 55, 94.

13b-2 52.

13b-3 13, 19, 23, 40, 57, 90.

14-1 15.

14-2 19, 57.

14-3 15, 22, 50, 69.

14-4 24, 64, 69, 75.

14-5 13, 45, 46, 48, 59, 66.

14-6 18, 29, 40, 44.

14b-1 57.

16a-1 13, 32, 33, 35, 37, 40, 41, 41, 66.

16b-2 very large corallites not collected intact.

16c-1 17, 18, 20, 22, 22, 30, 34, 35, 37, 41, 43, 45, 48, 57.

18a-1 33.

18a-2 58, 75.

18a-3 20, 22, 50, 67, 84, 96, 106.

18b-1 11, 42, 54, 66.

19a-1 30, 48

19b-1 35.

19c-1 9, 10, 21, 28, 43, 43.

19d-1 27, 33, 37, 40, 57.

19d-2 23.

19e-1 35.

B. Streptelasma divaricans (Nicholson, 1875)

2-1 9, 10, 11.

3-2 12, 15.

4-2 15, 32.

4-3 10, 25.

4-4 24.

4-5 21, 23.

5b-1 9, 10, 11, 12, 13, 15, 18, 20, 21.

5b-2 9, 10, 12, 13, 14, 14, 15, 20, 23.

5b-4 11.

5b-7 6, 8, 8.

5b-9 6, 8, 9.

11b-1 5, 6, 9, 10, 10, 10, 10, 11, 12, 12, 13.

11b-3 8, 9, 16, 17, 17.

12a-1 7, 7, 7, 7, 8, 8, 8, 8, 11, 12, 12, 15, 15, 16, 17, 19.

12a-2 10, 12, 13, 13, 14, 16, 19.

12a-3 7, 9, 10.

12a-4 14.

12a-5 10, 12, 12, 14.

12a-9 11, 16, 18.

12b-1 7, 18.

12c-1 10.

12d-1 8.

13-1 5, 7, 11, 14.

13-2 5, 6, 8, 9, 11, 11, 13, 13.

13b-1 8, 10, 12, 13, 16.

13b-2 9, 16.

13b-3 10.

14-3 13.

14-5 12.

C. Grewingkia deltensis n. sp.

17b-1 30, 38, 40, 53, 54, 57, 63, 69, 85.

UMMP 26911: 81.

D. Grewingkia pulchella (Billings, 1865)

Vaureal Fm.: 22, 15, 19, 19, 8, 9, 18, 18, 16, 7, 16.

Ellis Bay Fm.: 20, 16, 16, 18, 20, 17, 9, 16, 16, 5, 8, 14,
4, 4, 2, 5, 4, 4, 14, 11, 12, 14, 14, 9, 10, 12,
6, 11, 13, 13, 13, 9, 10, 6, 6, 11, 11, 13, 16, 19,
22, 17, 12, 14, 12, 9, 12, 15, 19, 14, 18, 14, 15,
16, 15, 12, 19, 18, 15, 19, 13, 16, 21, 11, 17, 15,
5, 17, 14, 7, 6, 7, 12, 20, 16, 19, 17, 20, 16, 17,
18, 14, 17, 18, 13, 10, 17, 13, 8, 23, 30, 11, 30,
16, 30, 25, 13, 29, 17, 29, 12, 12, 20, 20, 8, 9,
6, 8, 17, 9, 19, 19, 20, 18, 25, 12, 22, 8, 19.

Appendix 4.--Crewingkia canadensis (Billings, 1862): corallite diameter (d, mm) at a particular height (h, mm).

Number	Horizon	h	d
UCCM 45156	1-1	45	27
45154	"	50	27
45165	1-2	50	32
45173	"	55	25
45161	"	55	33
45171	"	45	25
45164	"	50	29
45167	"	40	28
45164	"	50	29
45174	"	45	28
45166	"	50	31
45175	"	50	27
45169	"	50	29
45185	1-4	50	25
45183	"	45	27
45186	"	50	28
45198	2-1	35	26
45194	"	50	35
45196	"	40	33
45197	"	35	30
45191	"	55	39
45193	"	55	37
45192	2-1	50	35
45202	3-1	50	33
45206	"	50	37
45207	"	40	28
45203	"	45	33
45208	"	40	28
45220	4-1	50	36
45225	4-4	50	40
45226	"	50	36
45230	"	50	31
45229	"	50	35
45227	"	50	31
45228	"	50	33
45254	5b-1	40	24
45247	"	45	32
45244	"	50	28
45260	5b-2	50	27
45261	"	40	29
45279	5b-9	50	33
45280	"	45	27
45289	6-1	45	31
45302	10-2	40	25

45318	11b-1	40	26
45315	"	45	28
45330	11b-2	50	26
45334	"	45	25
45335	"	50	23
45336	"	45	25
45350	11b-3	40	28
45348	"	40	25
45340	"	45	28
45345	"	40	28
45346	"	45	26
45347	"	45	26
45358	12a-1	55	29
45356	"	55	30
45359	"	50	25
45355	"	55	26
45357	"	55	30
45365	12a-2	50	25
45368	"	35	25
45364	"	45	27
45387	12a-4	40	23
45395	12a-5	55	24
45394	"	55	26
45399	12a-6	50	28
45409	12b-1	55	30
45414	12b-2	45	29
45421	12d-1	55	34
45422	"	40	27
45428	13-2	45	27
45429	"	40	25
45431	"	40	25
45446	13b-1	55	32
45442	"	40	24
45443	"	45	28
45444	"	40	23
45455	13b-2	45	22
45459	13b-3	40	32
45457	"	55	29
45480	14-3	45	26
45477	"	50	29
45483	14-4	55	32
45487	14-5	40	25
45492	"	40	21
45490	"	40	23
45493	"	55	30
45496	14-6	40	26
45469	14b-1	45	24
45536	16c-1	45	27
45525	"	40	28
45542	18a-2	50	26
45543	"	40	23

45548	18-3	50	29
45550	"	50	30
45551	"	55	32
45567	19a-1	40	29
M61a-6	M61a	50	26
M61a-7	"	50	27
M75-1	M75	50	30

UMMP 26927	40	21
CSC 1983b	50	33
1983g	50	30
1983h	55	29
8528a	55	28
8528b	55	25
8528d	40	23
8529b	55	31
8529c	55	26

Appendix 5.--Location of epifauna on corallites (K = counter side, A = alar side, C = cardinal side).

A. Grewingkia canadensis (Dillings, 1862)

1. Bryozoans

Horizon		Location on Corallite
1-1	1.	K
"	2.	K A C
"	3.	K
"	4.	K A C
"	5.	A
"	6.	K A C
"	7.	A
"	8.	A
1-2	1.	K C
"	2.	A C
"	3.	K A
"	4.	K A C
"	5.	K C
"	6.	K
"	7.	K A
"	8.	A
"	9.	K
"	10.	K A
"	11.	K A
1-2	12.	K
"	13.	K A
"	14.	K A C
"	15.	K A
"	16.	K A C
"	17.	K
"	18.	K
"	19.	K C
"	20.	A
"	21.	K
"	22.	C
"	23.	A
"	24.	A
"	25.	A C
"	26.	C
"	27.	K C
"	28.	A
"	29.	A C
"	30.	C
"	31.	C
"	32.	A
1-2	33.	K
"	34.	A C
"	35.	A
"	36.	C
"	37.	A
"	38.	K A
"	39.	A
"	40.	K A
"	41.	C
"	42.	K
"	43.	C
"	44.	C
1-3	1.	A
"	2.	A
1-4	1.	C
1c-2	1.	K A
2-1	1.	K
"	2.	A
"	3.	K A C
"	4.	A
"	5.	K A

2-1	6.	C
"	7.	A
"	8.	K
"	9.	K A C
"	10.	K
"	11.	K
"	12.	K A
3-1	1.	K
"	2.	K A
"	3.	A
"	4.	A C
"	5.	K
"	6.	A
"	7.	K
"	8.	A
"	9.	K A
"	10.	A
"	11.	A
"	12.	K
4-4	1.	K
"	2.	A
"	3.	A
"	4.	A
"	5.	K C
"	6.	A
"	7.	C
4-4	8.	K A C
"	9.	A
"	10.	K A C
"	11.	A
"	12.	K C
"	13.	K C
4-5	1.	K
5b-1	1.	K
"	2.	K
"	3.	K
"	4.	A
"	5.	A
"	6.	A
"	7.	K A
"	8.	A
"	9.	K
"	10.	A
"	11.	K A C
5b-2	1.	K A
"	2.	K A
"	3.	K
5b-5	1.	A
"	2.	K A C
"	3.	K A C
5b-6	1.	K
"	2.	K
5b-9	1.	K A C
"	2.	K A C
"	3.	K A C
"	4.	K A C
"	5.	K A
"	6.	K
"	7.	A
"	8.	A
"	9.	K A C
"	10.	K A C
10-2	1.	A
11b-1	1.	K A C
"	2.	K A C
"	3.	K A C
"	4.	K
"	5.	K A C
"	6.	K A C
"	7.	K A
"	8.	K
"	9.	A
"	10.	K A C
"	11.	K A
"	12.	K A C
"	13.	C
"	14.	K
"	15.	K A C

11b-1	16.	K	A	C	11b-3	1.		A		12a-1	9.	K	A	
"	17.		A		"	2.	K	A		"	10.	K	A	
"	18.	K	A		"	3.			C	"	11.	K	A	C
"	19.		A		"	4.	K			"	12.	K	A	C
"	20.		A		"	5.	K	A	C	12a-2	1.	K	A	C
"	21.	K	A		"	6.		A		"	2.	K	A	C
"	22.	K	A		"	7.	K			"	3.	K	A	C
"	23.	K			"	8.			C	"	4.			C
"	24.		A		"	9.	K			"	5.	K	A	C
"	25.	K	A		"	10.	K	A	C	"	6.	K		
"	26.	K		C	"	11.			C	"	7.	K	A	C
"	27.	K		C	"	12.		A		"	8.	K	A	C
"	28.	K			"	13.	K	A	C	"	9.	K		
"	29.	K		C	"	14.	K	A		"	10.			C
"	30.	K	A	C	"	15.		A		"	11.		A	
"	31.	K			"	16.		A		"	12.	K	A	
"	32.		A	C	"	17.	K			"	13.	K	A	C
"	33.	K			11-1	1.		A	C	"	14.	K	A	C
11b-2	1.	K	A	C	12a-1	1.	K	A	C	12a-3	1.	K	A	C
"	2.		A		"	2.	K	A	C	"	2.	K	A	
"	3.	K	A		"	3.	K	A		"	3.	K	A	C
"	4.	K	A		"	4.	K	A	C	"	4.	K	A	C
"	5.		A		"	5.	K	A	C	"	5.		A	
"	6.	K	A	C	"	6.	K	A	C	"	6.	K	A	
"	7.	K			"	7.	K	A	C	"	7.	K	A	C
"	8.	K	A	C	"	8.	K	A		"	8.	K	A	C

12a-3	9.	K	A	C	12b-1	4.	K	A		13b-3	3.		A	
"	10.			C	12b-2	1.	K	A		"	4.	K		C
"	11.		A		"	2.	K	A		14-3	1.	K		
"	12.	K	A	C	"	3.			C	14-4	1.	K	A	C
"	13.	K	A	C	12d-1	1.		A	C	14-5	1.		A	
"	14.	K			"	2.	K		C	"	2.	K		
12a-4	1.	K	A	C	"	3.			C	"	3.	K		
"	2.	K	A		"	4.	K			14b-1	1.	K	A	
"	3.	K	A	C	13-1	1.	K	A	C	"	2.	K	A	
"	4.	K	A	C	"	2.			C	"	3.	K	A	C
"	5.	K	A		13-2	1.	K	A	C	USGS 370u	1.	K		C
12a-5	1.	K	A	C	"	2.	K	A	C		2.	K		
"	2.	K	A	C	"	3.			C	18a-1	1.	K		
"	3.	K	A	C	"	4.	K	A	C	18a-3	1.	K		C
"	4.	K	A	C	"	5.	K	A	C	18b-1	1.	K		
"	5.	K	A	C	"	6.	K	A	C	19a-1	1.		A	
"	6.	K			"	7.		A		19b-1	1.	K	A	
12a-6	1.	K	A	C	"	8.	K	A	C	19c-1	1.		A	
"	2.	K	A	C	"	9.	K	A	C	"	2.	K		C
"	3.	K	A		13b-1	1.	K	A		19d-1	1.	K	A	
"	4.	K	A	C	"	2.		A	C	"	2.	K	A	C
"	5.	K	A	C	"	3.	K	A		"	3.	K		
12a-8	1.	K	A	C	"	4.	K	A	C	"	4.	K		
12b-1	1.		A		"	5.	K			M61a	1.		A	
"	2.	K			13b-3	1.	K	A	C	"	2.	K	A	
"	3.	K			"	2.	K		C	"	3.	K	A	C

M61a	4.	K A C	M61a	8.	A	M75	1.	K	C
"	5.	K	"	9.	A C	"	2.	K	
"	6.	K A	"	10.	A C	"	3.		A C
"	7.	K				"	4.	K A	

2. Streptelasma divaricans

Number	Horizon	Side	Position Along Corallite	Condition
UCGM 45246	5b-1	K	lower half	
45249	"	K	top	
45251	"	K	top	
45253	"	K	top	worn before burial
45359	12a-1	C	lower half	
45361	"	A	rim of calyx	not worn
45444	13b-1	A	middle	worn before burial

3. Colonial coral

UCGM 45364	12a-2	K	

B. Streptelasma divaricans (Nicholson, 1875)

UCGM 45018	4-3	bryozoan
45025	4-5	"
45026	"	"
45108	12a-9	"

C. Grewingkia rustica (Billings, 1858)

GSC 5822b, c	bryozoan	K	A	C	(mostly C)
8527a	"	K		C	

GSC 8527j	bryozoan		A	C	
8527k	"	K	A	C	
8527s	"	K			

D. Helicelasma randi Elias, 1976

USGS 206S	1. bryozoan		A		
	2. "	K	A	C	
	3. "	K	A	C	
206T	1. "	K	A		
	2. "	K			
USNM 42535	1. "		A		
	2. "	K	A	C	
	3. "	K	A		

E. Grewingkia pulchella (Billings, 1865)

GSC 2243, a	bryozoan		A		

F. Streptelasma affinis (Billings, 1865)

GSC 1987a	colonial coral on C
1987g, i	stromatoporoids
YPM 556	bryozoans and stromatoporoids
555	bryozoans, minor stromatoporoids all around, cornulitids
EB7	especially bryozoans, stromatoporoids
3063/57	stromatoporoids and bryozoans all around

G. Paliphyllum ellisensis (Twenhofel, 1928)

YPM 3063/57	bryozoans on 4 corallites

YPM 3019/52 bryozoans on 1 corallite

Appendix 6.--*Vermiforichnus* cf. *V. clarkei* Cameron, 1969a: size and location of borings in corallites (K = counter side, A = alar side, C = cardinal side).

A. *Grewingkia canadensis* (Billings, 1862) (unless otherwise indicated)

Horizon	Side of corallite and diameter (mm) of boring
1-1	1. K1.0, K0.7, K2.6, K0.4, K2.5, K2.3, K1.8, K2.1, K3.9, K1.1, K1.8, K2.1, K1.7, K0.6, K1.3, A1.7, A0.5, A0.8.
"	2. K0.8, K2.1, K1.3, K0.6, K0.6, K0.5, A2.5, C2.0.
"	3. K0.5, K0.9, A1.1, A0.4, A0.5, A0.6, A0.7, A0.5, C2.2.
"	4. A1.8, C0.8.
"	5. K0.9, K1.0, K1.7, K0.5, K2.3, K0.8, K1.2, K0.7, K0.7, K0.9, K0.8, K1.1, K0.7, K1.6, K1.2, A0.8, A1.8, A1.8, A1.7, A1.6, A1.6, A1.7, A2.2, A0.7.
"	6. K0.7, K1.0, A1.1, A1.5, A1.2, A1.9, A0.9, A1.7, A0.7, A0.6, C1.5, C0.6, C0.8, C1.3, C0.8, A0.7.
1-2	1. A0.8, A0.4, A0.4.
"	2. K2.0, K0.7, K0.8, A0.4, A2.1, C0.8, C0.4.
"	3. K0.3, K0.4, A0.3.
"	4. K1.9, K0.4, K1.5, A0.6, A0.8, A0.7, A3.6, A0.4.
"	5. K0.3, A1.0, A1.2.
"	6. K0.4, K0.5.
"	7. K0.6, K0.5, A1.1, A0.8, C0.8.
"	8. K2.7, K2.3, K0.9, A1.8, A2.0, A2.2, A2.1, A2.9,

A1.6, A1.7, A1.8, A2.1, A1.6, A1.4.

1-2 9. K0.8, A2.0, A0.5, A0.4, A0.7, A0.6, A0.6, A0.7, A0.5, C0.5.

" 10. K2.6, K0.9, K0.9, K0.7, K2.0, K3.2, A0.9, A0.5, A0.7, A0.6, A0.6, A0.5, A1.0, A0.7, A0.3, C0.5, C0.5, C2.2, C0.6.

" 11. K2.9, K1.5, K1.7, K2.6, K2.6, A0.8, A0.8, C0.5, C0.2.

" 12. K0.5, A1.1, A0.9, A1.0, A0.9, C0.9, C1.0.

" 13. K0.3, K0.5, K0.4, K1.2, K0.8, K0.4, K0.6, K1.4, A1.4, A0.4, A0.3, A0.3.

" 14. K1.4, K1.9, K2.8, K2.3, K0.6, A2.5, A0.6, A0.7, A1.1, A1.3, A0.9, A0.4, A3.3, C1.9, C1.0, C0.9, C0.5.

1-4 1. K1.0, A1.0, A1.8, A0.5, A0.5, A0.6.

" 2. K1.3, K2.3, K0.8, K0.4, A0.5, A0.8, A1.7, A1.4, A1.8.

" 3. C0.5, C0.8.

1c-2 1. A0.9, A1.4, A0.8.

2-1 1. A0.8.

" 2. A1.0.

" 3. K3.0, K0.9.

" 4. A0.4.

" 5. K1.1, C0.6.

" 6. K0.5, K1.1, K1.9, K1.8, K1.8, K1.7, K1.2, C0.9, C0.8, C1.2, C1.5, C1.0.

2-1 7. C2.3.

" 8. C1.6.

" 9. K2.4, K3.1, A2.2.

" 10. K0.7, K0.4, K0.9, K1.1, K1.2, K0.5, K1.4, K1.1, K1.0, K3.3, K0.4, K0.6, K0.6, K0.5, K0.9, K0.6, K0.7, K1.0, K0.9, K0.6, K1.8, K1.8, K0.8, K1.2, A0.6, A1.2, A0.7, A0.4, A1.1, A0.6, C0.5, C1.4, C1.0.

" 11. K1.0, K0.5, K0.9, K0.7, A0.7, A1.2, A0.6, A0.8, A0.8, A2.2, A0.8, A1.1, A0.7, A0.5, A0.7, C1.2, C0.9, C0.8, C0.8, C1.0, C1.3.

3-1 1. A0.5, A0.6, A0.5, A0.4, A0.5, A0.6, A0.4, A0.5.

" 2. K0.8, K1.4, K0.7, K0.7, K0.6, K0.8, K0.4, A2.0, A0.4, A1.5, A0.6, A0.5, A0.7, A0.6, A0.3.

" 3. K1.0, K1.4, C0.9, C1.7, C0.7.

" 4. A0.5, A0.6.

" 5. A1.2.

" 6. K1.6, K1.7, K1.9.

" 7. A1.3, A1.3, A1.5.

" 8. K1.5, A0.5, A0.4, A0.4, A0.5.

4-1 1. A0.8.

4-4 1. K0.6, K0.8, A0.8, A0.7, A0.8, A0.5, C0.5, C0.3, C0.8.

" 2. A0.8, A0.6, A0.8, A0.8, A0.7.

" 3. A0.8, A0.6, A0.5, A1.0, A0.5.

" 4. K0.5.

4-4 5. K2.1, A0.6, A0.5, A1.9.

" 6. A0.4, A0.8.

" 7. A0.5, A0.4, A0.5.

" 8. K0.7.

" 9. K0.5, K0.5.

4-5 1. 0.6, 0.6, 0.6 [in Streptelasma divaricans (Nicholson, 1875)].

" 2. 1.4 [in Streptelasma divaricans (Nicholson, 1875)].

" 3. 2.5, 1.1, 0.9, 1.2.

5b-1 1. A0.6, A0.6, C0.6, C0.9.

" 2. K0.7, C1.1, C0.4.

" 3. A1.5

" 4. A1.7.

" 5. K0.4

" 6. A3.3

5b-2 1. A0.7, A0.5, A0.5.

5b-4 1. A0.8, A0.4, A0.7, C1.5, C0.5.

5b-5 1. A1.2, A1.4, A0.5, A0.7, A1.4, C2.3, C1.3.

" 2. 0.7, 0.5, 0.7, 1.2, 0.7, 1.0, 0.7, 0.9, 1.2.

5b-6 1. K1.1, K0.6, A0.6, A1.3, A0.8, A0.9, C1.2.

" 2. K0.7, K1.2, K0.7, K0.7, K0.8, A0.7, A0.5.

5b-9 1. A0.8.

" 2. A1.1, A1.1, A0.7, A2.3, A1.1, A0.7, A0.7, A0.4, C0.3, C0.9.

" 3. K3.7, K0.6, K0.9, K0.8, K0.5, K0.3, K1.0, K0.5,

K0.6, K0.8, K0.6, K0.5, K0.7, A1.0, A1.1, A0.8, A0.4, A0.8, A1.0, C0.9, C0.8, C0.8, C0.9, C2.6, C0.7.

5b-9 4. C0.8.

" 5. A0.6.

" 6. K1.2, K0.8, K0.5.

9-1 1. 1.9, 1.4, 0.7, 0.5, 0.7, 0.5, 1.2, 0.4, 1.1, 0.6, 0.4, 1.6, 0.7.

11-1 1. K0.5, K1.1, A0.6.

11b-1 1. K0.2, K0.2, K0.5, K0.7, K0.8, K0.4, K0.4, A0.5, A0.6, A0.6, A0.6, C0.6, C1.0, C1.2, C0.6, A0.5.

" 2. K0.8, K1.0, K0.5, K0.8, K0.9, A0.7, A0.5, C1.0.

" 3. A0.7, A0.6, A0.5, A0.5, A0.5, A0.5, A0.7, A0.7, A0.6.

" 4. K1.6, K0.5, K0.7, K0.6, K0.5, K0.7, K0.5, K1.0, A1.0, A0.7, A1.6.

" 5. K0.8, K1.4, K0.6, K0.5, A0.6, A0.9, A0.5, A0.6, A0.9, A1.0, A0.7, A0.6, C1.2, C1.4.

" 6. K0.7, K0.9, K0.5, K0.4, K0.9, A0.7, A1.1, A0.8, C0.8, C0.5, C0.8, C0.5, C0.5, C0.5.

" 7. A0.8, A0.5, A0.5, A0.6, A0.6.

" 8. A0.5, A0.4, A0.6, A0.3, A0.1, A0.1, A0.2, A0.2, C0.9, C1.2.

" 9. K0.6, K0.5, K0.6, K0.5, K0.5.

11b-2 1. A0.7, A0.9, A0.5.

" 2. K0.6, A1.4, A0.8, C0.6.

11b-2	3.	A1.0, A0.9, A1.0, A0.6, A0.5, A0.7.
"	4.	K1.1, K0.4, K0.4, K0.3, A0.7.
"	5.	A3.5, A0.9.
11b-3	1.	K0.4, K0.2, K0.2, K0.5, K0.5, K0.7, A0.5, A0.2, A0.2, A0.4, C0.4, C0.7, C0.5.
"	2.	K0.6, K0.9, K0.9, K2.1, A0.7, C0.9.
"	3.	K1.0, A0.5, A0.6, C0.2, C0.7, C0.5, C0.3, C0.6, C0.7, C0.8.
"	4.	C0.8, C1.3, C0.7, C0.5, C0.6.
"	5.	K0.6, K0.8, K0.5, K0.7, K0.6, A0.5.
"	6.	A0.8, A1.4, A0.3, C0.4, C0.4, C0.6, C2.0.
"	7.	K0.7, K0.7, K0.6, K0.5, K0.8, K0.8, A0.7, A0.5, A0.4, A0.9.
"	8.	A1.1, A1.3, A0.8, A1.0, A1.4.
"	9.	K0.4, K0.6, K0.5, K0.6, A0.3, A0.7, A0.2, A0.9, A0.3, C2.1, C0.4, C0.5.
"	10.	K3.0, K2.1, A0.8, A0.6, A1.5, A0.6, A0.5, A0.9.
"	11.	K0.4, K1.1, K0.5, K0.7, K0.5, K1.0, A0.8, A0.4, A0.7, A0.8.
"	12.	K0.8, K0.6, K0.5, A0.6, A0.7, C0.7, C0.4, C0.5, C3.3.
12a-1	1.	A2.3, A0.8, A0.4, A0.6.

12a-1 2. A0.7.

" 3. K0.9.

" 4. A1.3, A0.3.

" 5. A1.2, A0.7.

" 6. A1.0.

" 7. K1.1, A1.7, A1.7.

" 8. A1.2, A1.7.

12a-2 1. A0.9, A0.4, A1.9, A0.8.

" 2. K1.3, K0.9, K1.3, K0.5, A0.9, A1.9, A1.7, A1.8, A2.5, A2.0, A0.7, A1.4, A1.4, A0.9, A0.8, A1.4, A1.6, A2.0, C1.6, C1.5, C0.9.

" 3. A0.7, A0.7.

" 4. K1.4, K1.6.

" 5. A1.7.

" 6. K1.5, K1.2, K2.0, K0.5, K2.3, A0.6, A0.6, A0.9.

" 7. A1.4, A0.5, A0.8, A0.8.

" 8. K0.7.

12a-3 1. K1.6, K1.7, K1.4, K1.7, K1.9, A1.2, A0.5, A1.5, A1.3, A1.6.

" 2. K0.5, K1.0, K0.6, K0.7, A1.0, A1.3, A1.3, A1.9, A1.1.

" 3. A2.0, A0.9, A1.2.

" 4. K0.6, K0.5, K1.0.

12a-3 5. K2.7, K2.4, C1.2, C0.9.
" 6. A1.5, A1.1.
" 7. K1.9, K0.5, K0.5, A1.8.
12a-4 1. K1.8.
" 2. K1.8, K1.3.
12a-5 1. K2.0, K1.7, K2.1, K0.6, K0.4, K0.4, K0.3, K0.3, K1.8, A1.4, A0.6, A1.9, C1.3, C2.4.
" 2. K1.9, K1.6, A1.1, A1.0.
12a-6 1. A1.2, C1.4.
" 2. A1.0, A2.3, A1.0, C1.8, C0.9.
" 3. A1.3.
" 4. A1.9, A1.4.
12a-8 1. K1.3, K1.0, K0.7, K1.9, A0.5, A1.7, C0.8.
" 2. A1.8.
12a-9 1. K1.4.
12b-1 1. K0.9, K0.5, K0.4.
" 2. K0.8, A0.5, A0.7, A1.0, A1.7, C0.9.
12b-2 1. K0.8, K0.7, A0.9, A0.8, A1.4, A1.1, A0.7, C1.2.
" 2. K1.5, K0.9, K0.9, K1.4, K1.6, K0.7, K0.6, K0.5, K0.5, K0.4, K0.4, A1.1, A0.9, A1.8, C1.0.
" 3. A1.3, A1.3, A1.8, C0.3, C0.5, C0.7, C0.4, C0.4, C0.5, C1.5, C0.6.
" 4. K1.1, K0.5, K1.0.
" 5. K1.2, A1.5.
12d-1 1. A1.8.
" 2. K1.7, K1.7, A3.5, A1.3, A1.1, C0.6.

12d-1	3. K0.7, K1.0, K0.6, K1.2, K1.5, A1.3, A0.7, A1.7, A1.5, A1.2, A1.8, A0.7, A1.1, A1.4, A1.2, A1.7, C0.8, C0.5, C0.6, C0.8, C1.8, C0.8, C1.0.
13-2	1. A1.3.
"	2. K0.8, K1.4, K0.6, K1.2, A2.4.
"	3. 0.8, 0.7, 0.6.
"	4. K0.9, K0.6, C0.6, C0.5, C1.6.
"	5. K0.9, K2.0, K2.2, K0.6, A1.3, A1.8, A0.6, A0.7, A0.6, A0.6.
"	6. K0.8, K1.3, A1.3, A0.9, A0.9, A1.8.
"	7. K1.7, K1.2, K1.2, K1.5, A1.7, A1.7, A1.1, C1.4, C1.0. C1.3.
"	8. A0.5, A1.1, A1.9, A1.8, A1.6.
13b-1	1. K3.3, K2.3, K2.0, A0.9, A2.5, A2.1, A3.1, A3.1, A1.4, A2.4, A1.3, A2.2, A2.2.
"	2. A1.7, A1.5, A1.3, A0.6, A1.2.
"	3. K1.7, A1.6, A1.3, A0.9, A1.8.
"	4. K2.3.
"	5. K1.5, K0.7, K1.0, A1.0, A0.8.
13b-2	1. K1.7, K0.7, A2.2, A1.0, A1.4, A2.3, A2.1, A1.6.
13b-3	1. A1.0, A2.1, A0.5, A0.4, A0.2, A0.3, A0.4, A0.5, A0.6, A0.9, A0.8.
"	2. K0.6, K1.8, K1.5, K2.0.
"	3. K1.6, K0.6, K0.5, K0.4.
"	4. K1.9, K0.4, K0.2, A1.9, A2.6, A2.2, A1.7, A1.6, A1.1, C0.9, C0.7, C1.0, C0.4.

13b-3 5. A1.6, A2.0, A2.5, A1.3, A1.7, A0.7, C0.8, C2.3, C1.2, C2.1, C1.2.

" 6. K1.1, K0.4, K1.2, K1.5, K0.6, K1.9, A0.9.

14-2 1. K1.2, K1.7, K2.2, K1.6, K1.4, A1.2, A1.5, A1.3, A1.4, A1.6, A2.0, C2.7.

14-3 1. K1.9, K0.9, K0.6, K0.5, K0.4, K1.1, A1.3, A1.7, A1.0, A1.2, A1.2, A1.8, A1.1, A0.8, A1.0.

" 2. K0.4, K1.5, K1.9, K0.6, A2.1, A0.4, A1.3.

" 3. K2.3, K1.8, K2.4, K1.9, K2.5, A1.5, A2.0, A0.6, A2.2, A2.2, A2.4, A1.5, A1.2, A1.6, A1.2, A2.0, A2.0, C2.3, C2.2, C1.3.

14-4 1. K1.5, K1.3, A1.5, A2.3, A1.2, C1.3.

" 2. K2.6, A1.6, A1.3, A2.3, A1.6, A1.9, A0.8, A1.6, A1.2, C2.0, C1.6, C2.4, C1.8, C2.0, C1.6, C2.3, C1.9, C1.6, C1.8, C2.4, C2.1, C1.8, C1.5, C1.7.

" 3. A1.2, A1.4.

14-5 1. A0.5, A1.0, A1.6, A1.0, A1.7, C1.0.

" 2. K2.0, K2.8, A1.7, A2.2, A0.7, C0.8.

" 3. K1.1, A1.0, A0.8, A1.2.

" 4. A2.0.

14b-1 1. A1.2, A2.5, A0.5, A0.9, A0.5, A0.4, A0.6, A2.0, C0.4, C0.7, C1.0, C0.8.

" 2. K0.6, K0.7.

14b-2 1. K1.9.

USGS 370U 1. K1.5, K0.5, K1.0, K0.6, K1.0, A1.5, A1.1.

USGS 370U	2. K1.2, K1.4, K0.4, K0.2.
"	3. A0.7, A0.5.
USNM 42512	1. A1.6.
"	2. K2.0.
"	3. K1.4.
"	4. C2.2.
"	5. A1.1, A1.0, A0.8, A0.4.
"	6. C2.4.
"	7. K0.8, K0.8, K1.0.
USNM 102371	1. C1.5, C1.3, C1.5.
18a-3	1. A1.3, A1.1, A2.2.
"	2. K0.6, K2.4.
"	3. A1.4, A2.5.
18b-1	1. A1.1, A1.1.
"	2. K1.0, A1.8, A1.2.
19a-1	1. A1.0.
"	2. K0.7, K0.7.
19c-1	1. K0.6, K0.5, K0.5, A0.5, A0.6, A0.5.
19d-1	1. A1.9, C1.3.
"	2. K1.3, A1.9.
19d-3	1. A1.4.
M75	1. C1.6.
"	2. A1.4.
"	3. A1.1, C0.9, C0.8.
"	4. A0.7.

B. Lake St. John, Quebec

Grewingkia rustica (Billings, 1858)

GSC 5822b, c	K	A	C (mostly K, numerous)
5822, a	K	A	C (mostly C, numerous)
8527f			C (sparse)
8527h	K		C (numerous)
8527j			C (sparse)
8527k			C (sparse)
8527s			C (sparse)

C. Maquoketa Group

Bighornia cf. patella (Wilson, 1926)

USNM 71926 C0.7, C1.2, C1.5.

D. Percé, Quebec

Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928)

USNM 102390(1) K1.4, K0.5, K0.5, K3.0, A2.2, A0.5.

Helicelasma selecta (Billings, 1865)

102390(2) K1.2, K0.3, K0.3, K0.3, A0.4, A0.3, A0.2, A0.3, A0.3, A0.5, A0.4, A1.0, A0.5, A0.3, A0.5, A0.2, A0.4, C1.4, C1.3, C0.5, C0.5, C1.0.

102390(3) K0.1, K0.2, K0.3, K0.3, K0.4, K0.4, K0.4, K0.3, K0.3, K0.9, K0.3, K0.3, K0.3, K0.4, K0.4, K0.8, K0.3, A0.4, A0.3, A0.3, A0.2, A0.2, A0.3, A2.7, C0.3, C0.2, C0.1, C0.3,

C0.8, C0.4, C0.3, C0.1, C0.2, C0.4, C0.3, C0.1, C0.1, C0.4, C0.4, C0.4, C0.4, C0.5, C0.3, C0.2, C0.2, C0.9, C0.6, C0.4, C0.4, C0.4, C0.4, C0.4, C0.4, C0.4, C0.4, C0.4, C0.4, C0.4, C0.3, C0.3, C0.3, C0.3, C0.3, C0.2, C0.2.

Grewingkia sp.

USNM 102390(4) 0.4, 0.8, 1.2, 0.3, 1.0, 0.2, 0.3, 0.3, 0.2, 0.2, 0.9, 1.3, 0.3, 0.3, 0.3, 0.4.

E. Anticosti Island, Quebec

Streptelasma affinis (Billings, 1865)

GSC 1987i 1.7, 1.3, 1.4.

YPM 555 1.6.

Helicelasma selecta (Billings, 1865)

YPM 543 0.4, 0.4, 0.7, 0.6, 0.5, 1.4.

Lobocorallium trilobatum subsp. *vaurealensis* (Twenhofel, 1928)

YPM 20482 1.9, 0.4, 0.5, 0.6, 0.6, 1.2, 0.6, 0.6, 0.5, 0.6, 0.6, 0.3, 0.6, 0.5, 0.2, 0.6, 0.7, 1.9, 0.3, 0.6, 0.8, 0.4, 0.3, 0.5, 0.6, 0.7, 0.6, 0.5, 0.4, 1.0, 0.4.

Appendix 7.--Microscopic endofaunal algae (x = all ontogenetic stages, K = counter side, A = alar side, C = cardinal side, l = long, m = intermediate, s = short).

A. Richmond Group

1. Grewingkia canadensis (Billings, 1862)

Number	Horizon	Occurrence in Corallite: Ontogenetic Stages	Sides	Size	Development	Remarks
UCGM 45158	1-1	x	all	l	moderate	
45156	"	x	all	l	good	
45174	1-2	x	all, esp. C-A	l	sparse	
45166	"	x	all	m	sparse	
45172	"	x	all	m	fair	
45176	"			m	v. sparse	
45177	"	x	all	m	moderate	
45180	1-3	x	all	m	fair	
45184	1-4			m	rare	
45185	"	x	all	m		

45183	1-4	x	all	s	fair	
45193	2-1	x	all	m	fair	
45191	"	x	all, esp. K-A	l	good	large "cysts"
45199	"	x	all	m	moderate	
45200	"			m	rare	(septal grooves present)
45206	3-1	x	A	s, l		
45202	"	x	all	l	moderate	
45203	"	x	all	m	sparse	(septal grooves present)
45212	"			m	v. sparse	in interseptal chambers in late stage
45215	3-2			m	sparse	
45216	"			m	v. rare	
45214	"	x			v. rare	
45220	4-1	x, esp. late	all, esp. A	l	fair	
45230	4-4	x, esp. early	esp. K	s, l		
45234	"	x	all	l	moderate	
45226	"	x, esp. early	all, esp. K	l		in interseptal chamber and around Vermiforichnus

45232	4-4			f, m	present	
45228	"	x	all	m	fair	
45259	5b-1		C-A		poor	
45248	"	x	all	s		
45244	"	x			v. sparse	
45260	5b-2	x	esp. C	s	moderate	
45261	"	x		m	v. sparse	
45263	"				absent	
45272	5b-6	x	esp. C	l		
45277	5b-8	x	all	s	sparse	
45279	5b-9			s	rare	(septal grooves present)
45280	"	x	all	s	fair	
45302	10-2	x	all	m		fine recent borings penetrate micrite and calcite crystals in Vermiforichnus
45315	11b-1	x	esp. A	m	sparse	
45307	"	x	all	s		
45310	"	x	esp. K			
45334	11b-2		esp. K	l		some in bryozoan

45344	11b-3		x	esp. A	l		
45355	12a-1		x	esp. C	m, s	v. sparse	
45357	"			all	s		(septal grooves present)
45392	12a-4				s	v. rare	
45390	"					absent	(septal grooves present)
45394	12a-5		x	esp. C-A	l, s		(septal grooves present)
45413	12b-2	early-intermediate		C	m	poor	
45435	13-2					absent	
45434	"					absent	(septal grooves present)
45446	13b-1		x			sparse	
45457	13b-3		x	all	m	sparse	
45485	14-4					v. sparse	
45469	14b-1		x	esp. K	l	fair	
45466	"				m	v. rare	(septal grooves present)
45506	16a-1					? present	
45505	"		x	all	m	weak	
45515	16a-2					? absent	
45516	16b-1					? present	

45519	16b-2				absent	worn
45518	"				absent	not well preserved
45533	16c-1				? absent	
45540	18a-1				present	
GSC 1983i					present	
UMMP 26927					sparse	
45354				m	present	
45353				m, l	good	
UCGM 45565	19a-1				absent	
45577	19c-1		all	m	present	
45585	19d-1	x	all, esp. K	m	fairly good	
M61a-7	M61a				absent	
M61a-2	"			m	present	
M75-4	M75			m	present	
GSC 8530c				m	v. rare	
8530G				m	v. rare	

2. Streptelasma divaricans (Nicholson, 1875)

Number	Horizon	Size	Development	Remarks
UCGM 45003	2-1	m	present	
45005	"	s	sparse	
45004	"		absent	(sparse in brachiopod corallite is attached to)
45002	"	m	present	
45008	3-2	s, m	present	
45014	4-2		absent	
45013	"	s	fairly common	
45012	"		absent	
45018	4-3		sparse	
45020	4-4	s	present	
45025	4-5		v. rare	
45023	"	s	fairly common	
45028	5b-1	m	present	(large in a nearly brachiopod)
45038	5b-2		sparse	
45043	"	m, s	present	
45034	"	s	present	

45036	5b-2		present
45037	"		sparse
45048	5b-7	s	uncommon
45054	5b-9	l	abundant
45057	10-1	s	present
45061	11b-1		absent
45064	11b-3	s	sparse
45074	12a-1		v. rare
45072	"		sparse
45069	"		absent
45080	12a-2		absent
45084	"	s	rare
45086	"		moderately good
45090	12a-3	m	sparse
45092	"	m	rare
45093	12a-4		v. rare
45098	12a-5		absent
45611	13-1	m	present

45133	13b-1		absent	
45134	"	s	rare	
45135	"	s	sparse	also in calyx
45137	13b-2		absent	
45139	"		absent	
45138	"		sparse	
45136	"		absent	
45140	13b-3		absent	
45141	14-3	s	sparse	
45142	14-5	s	sparse	
45143	14-6		absent	

3. Grewingkia deltensis n. sp.

45596	17b-1	s, l	present	
45602	"	s	rare	abundant coarse recent borings do not enter oxidized zones

4. Grewingkia rustica (Billings, 1858)

GSC 85271		s	A, in one section	
8527n		s	sparse	

GSC 8527c	s	A
8527	s, ?m	present
UMMP 45351	m	K

B. Percé, Quebec

All specimens		present, but not well preserved
YPM (Percé)	m	in H. selecta

C. Anticosti Island

1. Streptelasma affinis (Billings, 1865)

YPM 3063/57j, k	Ellis Bay	zone	9		absent
EB7	"	"	7		rare
3063/56a	"	"	7		present
555 a	"	"	5		rare
3063/36b	"	"	2		absent
3063/36c	"	"	2		absent
3063/36d	"	"	2		absent
3063/36e	"	"	2	s	present
3063/35e	"	"	1	m	present

3063/35f	Ellis Bay zone 1			present	
548 a	" " "	1	m	present	
3063/35a	" " "	1		absent	
538 a	" "			absent	
145	" "			absent	
556b	Lower Vaureal			?	abundant in K probably recent - enter calcite crystals, possibly green, water worn
556a	" "			absent	
517 a	" "			rare	

2. Helicelasma selecta (Billings, 1865)

515a	Ellis Bay zone 2			poor
539 a	Basal Ellis Bay			poor
543	Ellis Bay		s	rare
514 a	" "			poor
508 a	Upper Vaureal			absent

3. Deiracorallium angulatum (Billings, 1862)

4 specimens	Vaureal			absent

4. Crewingkia pulchella (Billings, 1865)

YPM 3063/57g	Ellis Bay zone		9	l, m	present
3063/57f	"	"	9		absent
3063/57e	"	"	9	l	present
541a	"	"	8		absent
3063/56c	"	"	7		absent
3063/56b	"	"	7	m	A
EB6	"	"	6	m	all sides
3063/35b	"	"	1		absent
3063/35c	"	"	1		absent
3063/35d	"	"	1		absent
3063/52d	"	"			absent
538b	"	"		s	K
3063/41a	"	"		s	K-A
3063/41b	"	"			absent
3063/41c	"	"		s, m, l	all sides
518a	Upper Vaureal			s	present
518b	"	"			absent

GSC 1989a	Vaureal	m	present
1989h	"	s	present

5. Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928)

2 specimens	Vaureal	absent

6. Bodophyllum englishheadensis n. sp.

4 specimens	Upper Vaureal	absent

7. Bighornia cf. patella (Wilson, 1926)

2 specimens	Lower Vaureal	absent

8. Paliphyllum ellisensis (Twenhofel, 1928)

7 specimens	Ellis Bay	absent

Appendix 8.--Biometrical data (d = corallite diameter, mm; n = number of major septa; d_a = axial region diameter, mm).

1. Streptelasma divaricans (Nicholson, 1875)

Number	Horizon	d	n
UCGM 45000	1c-1	6.5	23
45003	2-1	3	16
		6	23
45004	"	4	21
		6	24
		8	29
		9	31
		11	32
45005	"	7	27
		9	31
45008(a)	3-2	7	30
" (b)		2	14
		4	17
		7	27
45013	4-2	11	32
		15	32
45016	"	10	25
45017	"	9	29
45015	"	8	26
45014	"	3.5	15
		8	29
		9	29
45012	4-2	7	26
45018	4-3	9	25
		12	29
45019	"	9	26
45020	4-4	9	26
		11	27
45024	4-5	5.5	23
		9	25
		13	29
45026	"	10	26
45025	"	14	29
		16	29
45023	"	11	35
		14	35
45022	"	9	32
45032	5b-1	8	28
45028	"	7	30
		10	31
45030	"	10	32
45034	5b-2	10.5	32

		13	34
		15	42
45038(a)	5b-2	4.5	23
		6.5	26
		8	27
"	(b)	9	27
45039	"	7	30
45032(a)	"	6.5	25
		9	26
		10	32
		12	32
"	(b)	3	16
		6	21
45037	"	3	18
		5	17
		6.5	23
		8.5	27
		10	30
45040	"	11	32
45042	"	7	27
45043	"	4	22
		5	26
		7	30
45052	5b-7	6	28
45048	"	3	16
		4	18
		6.5	25
		9	27
45046	5b-7	7	28
45053	5b-9	3.5	19
		4.5	22
		6	26
45055	"	9	31
45054(a)	"	7	24
	(b)	5	23
45057	10-1	3.5	22
		7.5	28
		8.5	31
		14	33
45058	"	11	29
45061	11b-1	6	24
		7	27
45067	11b-3	7	26
45064	"	5	28
		9	31
45077	12a-1	7	28
45071	"	7	28
		9	30
45076	"	5	26
		8	29
45075	"	6	25
		7	29

45073	12a-1	6	23
		10	32
45074	"	6	25
		9	29
45072	"	7	25
		8	26
45086	12a-2	4	17
		6	20
		9	26
		11	30
45082	"	7	27
45088	"	6	28
45087	"	9	31
		12	33
45081	"	7	27
45083	"	9	30
45085	"	6	25
		9	30
45084(a)	"	4.5	24
	"	7	28
		9	29
	(b)	3.5	19
		6	26
		7	30
45092	12a-3	5	22
		7	26

45091	12a-3	6	22
		9	28
45090	"	7	21
		9	24
		12	26
		14	27
45095	12a-4	9	26
45094	"	8	29
45093	"	7	22
		8	24
45646	12a-5	8	29
45100	"	10	25
		12	27
45103	12a-6	10	28
45108	12a-9	6	27
		9	32
45106	"	9	32
45110	12b-1	7	29
45113	12c-1	7	27
45114	"	9	34
45611	13-1	6	24
		7.5	28
45119	"	8	26
45120	"	7	27
45118	"	8	27
45122	"	6	26

45126	13-2	7	27
45125	"	5	28
		7	30
45124	"	6	29
45128	"	15	33
45132	13b-1	5	26
45135	"	4	21
		6.5	28
45133	"	7	31
		8	35
		10	36
45134	"	4	22
		7	28
45137	13b-2	4	22
		7.5	28
45139	"	7	26
45136	13b-2	5.5	26
		7	29
45138	"	5	25
45140	13b-3	6	27
		8	29
45141	14-3	8	26
45142	14-5	6	30
		8	31
45143	14-6	7	27
		10	31
USNM 84868		7	23
M61a-4	M61a	5	21
		7	23
		9	24
		12	33
USNM 78449		7.5	28

2. Streptelasma leemonensis n. sp.

UCGM 45614	20a-1	9	32
45615	20a-1	7	24

3. Streptelasma subregularis (Savage, 1913)

UCGM 45618	20b-1	10	28
		18	35
		28	42
45619	"	15	33
		21	38
45622	"	8	26
		15	36
45621	20b-1	15	32
45624	"	13	36
45620	"	9	27
		15	32
45630	"	5	16

45629 20b-1	13	31
	22	37
	29	37

4. Streptelasma rankini n. sp.

USGS 6344b	10	29	6345b	7	24
6344c	7.5	29	6346a	10.5	33
6332b	10	29	6347b	12	29
6335b	14	29	6350b	12.5	42
6337b	8	27	6355b	10.5	29
6340b	16	34	6262b	22	42
6341b	9.5	34			

5. Streptelasma affinis (Billings, 1865)

YPM 517a	7	21		15	27
	11	26	3019/3063/35f	9	24
556a	38	57	548a	6	22
556b	12	35		9	24
	21	41	145	4	22
	29	44		9	28
538a	10	34		11	30
	13	42		15	32
3063/36b	9	30	3019/3063/35i	6	21
3063/36c	15	27		9	23
3063/36d	9	22		12	25
	11	26		15	29
3019/3063/35e	11	21		20	33

3019/3063/57j	9	25	3063/56a	10	26
	19	30		13	27
3019/3063/57k	12	35	515b	6	22
	28	49		16	27
	45	50	3063/44b	14	29
555a	19	38	3063/52a	10	30
	32	47		15	39
	46	50	GSC 2244	27	34

6. Helicelasma randi Elias, 1976

SUI 57-'24	19	39	USNM acc. 306219	10	31
USNM 42535a	20	40	SIU 4200	10	28
42535b	8.5	28		9	27
	15	35	SIU 4201	13	29
USGS 2065a	23	40			

7. Helicelasma selecta (Billings, 1865)

YPM 543	24	43	515a	16	35
539a	4	19		27	40
	13	33	508a	12	34
514a	17	37	USNM 102390(3)	10	31
	24	42		25	44

8. Deiracorallium angulatum (Billings, 1862)
(h = height, mm)

Number	h	n			
GSC loc. 84419a	8	26	GSC loc. 84419b	3	20
	15	30		9	36

GSC loc. 84419c		9	27	GSC 10847		9	36
		13	31	UM 266		8	28
	84419d	7	26			14	42
		11	34	UM 346		11	38
GSC 10846		13	35				

9. Grewingkia canadensis (Billings, 1862)

Number	Horizon	d	n	da					
UCGM 45156	1-1	8	29				23	53	5
		14	43				32	55	13
		19	49		45176	1-2	13	34	
		20		4	45177	"	5	20	
		26	54	8			7	26	
45157	"	13	38				8	31	
		17	49		45161	"	12	37	
		25	57	7			23	50	
45155	"	18	48				29	55	5
45159	"	18	41				33	55	10
		29	50		45170	"	9	28	
45154	"	19	47		45171	"	11	31	
		23	51				17	47	
		27	52	9			22		6
45158	"	5	19				23	54	
		7	26		45167	"	9	32	
		9	29				17	43	
45166	1-2	16	39				24	50	

45164	1-2	11	31	
		21	45	
		26	54	5
45168	"	11	37	
		23	54	5
		28	55	7
45169	"	16	45	
		25	57	10
45165	"	20	46	
45175	"	18	47	
		25	56	8
		29	58	11
45173	"	8	28	
		14	39	
		19	50	
		25	60	11
45172	"	7	26	
		18	44	
		24		9
		26	50	11
45174	"	8	26	
		18	40	
		23		5
		26	45	8
45163	"	24	57	10
45162	"	12	30	
		17	34	
45178	1-2	12	36	
		17	44	
45179	1-3	17	44	
		23	54	8
45180	"	12	32	
		17	37	
		21	41	5
45181	"	11	31	
		16	45	
45183	1-4	20	47	2
		26	50	5
45188	"	10	33	
45187	"	15	44	
45185	"	19	46	
		24	53	10
45186	"	22	49	
		27	53	5
45184	"	8.5	29	
		13	37	
45189	1c-2	19	54	
		25	58	
45191	2-1	18	47	
		24	50	
		34	59	11
45193	"	7	29	

		15	45	
		22	58	
		28	63	4
		33	65	8
		38	67	
45199	2-1	10	30	
45192	"	11	31	
		21	49	
		23		2
		30	55	9
45194	"	13	45	
		18	53	
		26	66	3
		29	67	7
45198	"	11	38	
		17	51	
		23	59	
45197	"	16	44	
		23	56	
45196	"	11	33	
		19	45	
		25	52	4
45195	"	10	38	
		18	49	
45200	"	5	21	
		10	32	
45202	3-1	12	42	
		19	53	
		24	61	5
		29	65	7
45206	"	10	31	
		18	48	
		24	60	
		30	65	10
45207	"	19	50	
		24	57	5
45212	"	9	31	
		12	35	
45203	"	10	32	
		18	41	
		25	44	0
		29	46	
45205	"	10	38	
		17	50	
		22	56	3
45204	"	17	45	
		23	58	
		27	61	
45209	"	8	30	
		14	40	
		16	43	
45210	"	12	31	

		15	36	
45214	3-2	9	33	
		13	40	
		17	49	
		23	54	4
45216	"	6	24	
		11	34	
45215	"	5	22	
45220	4-1	23	53	
		29	61	6
45221	"	13	33	
45222	"	11	39	
45234	4-4	13	33	
45228	"	25	53	
		29	59	8
45230	"	24	50	8
		30	51	
		31		10
45227	"	22	52	
		25	57	
45229	"	10	31	
		21	52	
		26	57	
45226	"	25	60	5
		30		9
		35	68	15

45225	4-4	12	35	
		24	53	
		32	64	11
45231	"	18	44	
45224	"	12	41	
		22	56	
		32	61	8
45258	5b-1	5	21	
		6.5	24	
45259	"	4.5	19	
		6	23	
45257	"	10	32	
45245	"	12	37	
		15	42	
45248	"	19	50	
		23	53	
45252	"	26	58	
45247	"	18	44	
		24	53	
45253	"	13	42	
		22	57	
45251	"	26	55	6
45246	"	20	48	
45256	"	14	38	
45254	"	18	48	
		24	56	

45260	5b-2	19	43	
		22	45	3
		26	45	5
		28	45	7
45261	"	11	36	
		17	47	
		25	59	6
45263	"	6	24	
		9	29	
		11	35	
45266	5b-4	20	52	
45269	5b-5	18	40	
		23	52	9
		27	56	11
45268	"	25	44	3
45270	"	8	26	
45274	5b-6	19	46	
45273	"	20	49	
		22		3
		26	56	5
45272	"	25	57	5
45271	"	17	39	
		22	46	
		26	49	1
45275	"	7	24	
		10	33	

45276	5b-6	4	18	
		8	29	
45277	5b-8	9	33	
		16	40	4
45280	5b-9	9	30	
		15	41	
		23	52	9
45279	"	11	36	
		16	43	4
		26	62	8
45286	"	11	35	
45284	"	11	35	
		19	43	
45289	6-1	21	50	
		24	52	
		27	56	
45294	7-2	14	35	
45296	9-1	21	53	
45295	"	11	39	
45299	10-1	14	36	
		20	42	
45302	10-2	10	30	
		20	50	
		22	52	3
		24	53	5
45353	11-1	14	36	

		19	44	
45310	11b-1	8	28	
		11	31	
		14	34	
45309	"	8	25	
		11	31	
45313	"	13	36	
45327	"	19	46	
45320	"	15	35	
45321	"	14	38	
		18	42	
45314	"	20	55	
45325	"	16	39	
45324	"	11	33	
		16	36	
45326	"	15	41	
		19	46	
		24	50	7
45328	"	23	44	
45311	"	12	43	
45323	"	16	41	
		21	46	
45316	"	16	36	
		20	41	
		28		4
		29	42	
45317	11b-1	20	43	
		26	48	
		30	52	12
45318	"	18	44	
		22	49	
		25	51	
45315	"	22	54	
		24		3
		28	60	10
45306	"	7	25	
45312	"	6	22	
		9	29	
45305	"	7	23	
		10	32	
45331	11b-2	14	36	
45332	"	14	38	
45330	"	19	46	
		25	47	
		27	47	
45333	"	20	43	
		24	46	5
45334	"	19	43	
		24	54	9
		26	55	13
45336	"	17	45	
		23	52	6

45338	11b-3	10	32	
		18	45	
45349	"	15	42	
		18	45	
45351	"	20	41	
45339	"	24	52	8
45347	"	20	50	
		25	55	8
45346	"	18	45	
		24	48	
45343	"	15	37	
		22	46	10
45344	"	21	46	
		22		5
		28	50	10
45345	"	19	51	
		26	56	
45342	"	15	41	
		25	50	9
45348	"	17	41	
		23	47	
45340	"	15	40	
		22	46	
		26	51	11
45350	"	22	48	
		27	51	
45352	11b-3	20	50	
45341	"	9	31	
45359	12a-1	15	43	
		21	53	
		24	55	6
45356	"	19	52	
		27	62	6
		30		10
		31	66	
45358	"	23	55	
		29	58	6
45360	"	18	54	
		26	59	8
45357	"	14	41	
		23	54	
		28	61	9
		30	65	9
45355	"	16	46	
		21		6
		22	56	
		26	60	8
		28	61	10
45361	"	20	54	
45364	12a-2	20	56	4
		24	59	
		25		6

45371	12a-2	12	41	
45366	"	24	61	4
45368	"	22	56	
45382	12a-3	8	27	
45381	"	7	28	
		11	36	
		13	41	
45376	"	23		6
		24	59	
45378	"	26	65	6
45375	"	25	57	
45374	"	15	47	
		22	56	
45379	"	16	49	
		22	61	
45383	"	11	38	
45384	"	10	36	
45389	12a-4	22	56	
		26	61	6
45391	"	16	45	
		23	55	
45390	"	10	30	
		16	44	
		23	53	3
		26	58	7
45387	"	17	43	
		23	53	
45388	12a-4	18	49	
		22	55	
45392	"	7	26	
		10	30	
		12	34	
45396	12a-5	21	53	
		30	61	6
45395	"	22	53	
		24	55	
45394	"	9	33	
		19	48	
		24	56	3
		27	58	5
		30	58	10
		28	58	7
		29	59	9
45397	"	11	33	
45399	12a-6	20	57	
		29	65	3
45400	"	20	55	
45403	"	7	24	
45405	12a-8	23	61	
45404	"	17	47	
45407	"	20	56	
45410	12b-1	20	45	

45409	12b-1	22	58	
		27	64	
		30	65	9
45412	"	5	25	
45414	12b-2	27	60	5
45413	"	21	56	
		26	65	7
45416	"	20	58	
45415	"	21	48	
45417	"	6	28	
45420	"	8	29	
45420	"	8	29	
45422	12d-1	25	58	
45423	"	19	40	
45421	"	28	61	
		35	68	12
45425	13-1	11	35	
45433	13-2	22	54	8
45430	"	23	55	
45431	"	18	51	
		24	56	
45429	"	21	57	
45434	"	15	31	
		21	36	
45428	"	19	51	
		24	56	

45432	13-2	14	42	
45439	"	5	22	
		7	28	
45435	"	4	20	
		7	26	
		10	33	
45441	13b-1	27	53	
		33	54	8
45442	"	17	44	
		23	52	
45443	"	18	47	
		26	56	
45444	"	13	44	
		19	53	
45446	"	15	42	
		24	53	
		31	57	11
45450	"	18	51	
45445	"	6	20	
45447	"	9	36	
		14	45	
45449	"	13	40	
45451	"	9	28	
45448	"	7.5	27	
		11	32	
45453	13b-2	10	31	

		16	36	
45454	13b-2	10	36	
		13	43	
45455	"	20	50	
45458	13b-3	21	58	
		27	66	
45457	"	16	46	
		24	57	5
		30	61	8
45459	"	18	47	
		25	56	
45460	"	21	58	
		25	62	
45462	"	13	41	
45471	14-1	5	23	
		10	32	
45473	14-2	6	27	
		10	31	
45478	14-3	12	33	
45476	"	17	48	
45477	"	17	48	
		22	53	
		27	57	
45480	"	16	49	
		25	59	
45481	"	12	37	
45475	14-3	9	30	
45483	14-4	21	54	
		26	61	
45484	"	13	44	
		20	55	
45485	"	22	54	
		30	58	9
45494	14-5	24	60	
45487	"	13	43	
		24	58	
45488	"	13	35	
		20	42	
45490	"	17	54	
		22	59	
45491	"	13	44	
		19	57	
		23	62	
45493	"	16	43	
		24	56	
		28	56	
45489	"	6	23	
45497	14-6	17	36	
45496	"	18	35	
45498	"	13	34	
		19	38	
45466	14b-1	19	46	

			22	54	5	UCGM	45505	16a-1	13	37
			24	58	8				19	48
	45467	14b-1	8	27					21	49
			14	38					24	51
			17	43			45503	"	18	44
	45468	"	15	43					25	50
	45469	"	16	42			45509	"	15	40
			22	48	7				23	49
	45470	14b-2	10	33			45506	"	16	39
USNM	84870		9	33					23	47
			18	48			45504	"	12	36
	78742		24	44					16	38
	9719a		28	62			45507	"	11	30
	9719b		23	48					16	35
	70024		30	55			45508	"	11	32
	78749		24	53					19	44
USGS	2366c		33	57	14		45511	"	11	31
	2369c		25	55	6				16	38
	2372b		21	49	0		45502	"	11	32
	2378a		14	32					17	40
	2413b		20	53			45512	"	10	30
	2416c		32	61			45513	16a-2	19	43
	2419b		35	66	12		45514	"	13	41
	2421a		26	55	8				20	49
	2421c		33	59	11		45515	"	11	34
	2422c		39	59	13				23	45

	45516	16b-1	17	49		21	46
	45521	16b-2	32	66	45540	18a-1	19	50
	45518	"	42	77			23	55
	45519	"	25	58			27	57
	45523	16c-1	12	36	45541	"	11	32
			19	48			15	38
			23	55	45543	18a-2	20	46
	45524	"	11	30	45542	"	18	44
			18	44	45548	18a-3	12	41
			20	47			18	50
	45536	"	11	27			24	61
			16	41			29	62
			22	44			33	63
	45526	"	19	36	45550	"	33	62
	45527	"	16	41	45551	"	33	65
	45535	"	13	33			38	65
			22	41	45552	"	14	41
	45533	"	11	29	45555	18b-1	10	30
	45530	"	17	40			12	32
	45531	"	15	35			14	37
	45529	"	14	33	45556	"	16	38
USNM	42512		29	56			20	42
	102371		19.5	47	45557	"	31	63
UCGM	45538	18a-1	10	32	45558	"	13	35
			16	39			16	40
	45539	"	16	41	45559	"	21	50

			25	54
	45560	18b-1	6	23
	45562	"	11	33
UMMP	45354		25	57
	26927		11	29
			19	38
UCGM	45564	19a-1	25	56
	45565	"	19	52
			26	60
	45566	"	25	59
	45567	"	19	51
			25	56
	45570	19c-1	22	45
	45571	"	22	51
	45575	"	11	32
	45572	"	10	35
	45579	19d-1	10	32
			15	37
	45580	"	19	46
		--	24	52
	45582	"	24	55
	45583	"	20	49
	45585	"	20	49
			25	55
			27	58
	45586	19d-2	13	36
	45589	19e-1	18	38
	45590	"	18	41
M61a-2		M61a	7	25
			9	27
M61a-3		"	8	29
			13	34
M61a-5		"	15	35
			21	36
M61a-6		"	20	43
			25	47
			27	48
M61a-7		"	13	36
			19	46
			23	50
			28	52
M75-4		M75	33	60
M75-5		"	25	56
M75-6		"	19	47
M75-7		"	12	38
GSC 8530c			8	25
			16	41
			20	43
			23	47
	8530		30	53
	8530g		25	43

10. Grewingkia deltensis n. sp.

UCGM 45595	17b-1	9	29			29	58
		16	43			33	62
45596	"	21	52	45599	17b-1	31	62
		23	55	45600	"	25	52
45598	"	34	60	45601	"	15	41
45604	"	23	50			20	47
		33	59	45603	"	24	55
45602	"	16	41	UMMP 26911		37	62
		23	54				

11. Grewingkia rustica (Billings, 1858)

GSC 5822c		30	54	85271		10	30
8527		20	43			16	36
		26	48			20	38
8527c		11	31	8527n		13	35
		18	37			18	39
		21	41	UMMP 45351		18	48
		25	42			21	56
8527a		21	39	UCGM 45592	19b-1	12	28
8527j		25	54			16	32
8527m		21	43			20	35
8527p		18	39				

12. Grewingkia penobscotensis n. sp.

USGS 6268b		25	51	6333c		10	32
6268c		19	46	6334c		8.5	28

6336b	11	33
6339b	11	32
6342b	9	34
6343b	15	34
6267b	26	50

13. Grewingkia pulchella (Billings, 1865)

YPM 3019/3063/57e	6	22
	10	30
3019/3063/57f	6	23
	11	31
3063/56c	7	22
520	7	25
	12	28
518a	14	26
518b	6	20
	8	24
	9	26
3063/36a	4	18
	8	23
551	7	24
	10	29
EB6	10	26
536	7	20
3019/3063/57g	7	25
	13	34
541a	9	24
541b	7	21
	13	32
3019/3063/35b	8	19
3019/3063/35c	4	18
	9	22
3019/3063/35d	7	21
3063/41a	9	25
	13	27
	17	31
	19	32
3063/41b	10	27
3063/41c	8	21
	11	24
GSC 1989h	7	22
	11	27
YPM 3063/44a	10	25
3063/52b	8	25
3019/3063/52c	6	19
	11	26
540 a	6	22
	11	26
USGS 4112-CO a	12	29

4112-COb	15	33	4112-COe	8	25
4112-COc	11	28	4112-COf	13	32
4112-COd	6	21			

14. Lobocorallium trilobatum (Whiteaves, 1895)
(a = corallite cross-sectional area, mm^2)

Number	a	n			
UM 252	497	74		977	92
	657	80	UM 272	977	94
	680	82	UM 268	367	57
	776	86	UM 265	132	42
	848	88	UM 336	684	73

15. Lobocorallium trilobatum subsp. vaurealensis (Twenhofel, 1928)

GSC loc. 36157(1)	684	65	36157(2)	1025	71
	258	54	USNM 102390(1)	658	59

16. Bodophyllum shorti n. sp.

Number	d	n			
UCGM 45613 20a-1	6	25		8	34
	7	29			

17. Bodophyllum neumani n. sp.

USGS 6260b	6	21	6271b	9.5	29
6264b	11	27	6338b	8	29
6269b	13	30	6351b	13	33
6270b	7	24			

18. Bodophyllum englishheadensis n. sp.

YPM 3063/15b	14	43	3019/2c (a)	7	26
3063/2a	15	43		11	30
3063/7	13	47	3019/2c (b)	9	32
	17	47		13	34

19. Bighornia cf. patella (Wilson, 1926)

Number	h	n			
YPM 505a	7	34		14	39
	13	38	3063/17	14	38

20. Paliphyllum ellisensis (Twenhofel, 1928)

Number	d	n			
YPM 573b	19	37		15	34
572	16	41	3019/3063/57c	8	31
3019/3063/57a	21	42	3019/3063/57d	7	25
3019/3063/57b	10	29		12	31
	13	33			

Appendix 9.--Grewingkia canadensis (Billings, 1862) and Streptelasma divaricans (Nicholson, 1875): A = axial region comparative scale values.

A. Grewingkia canadensis

Number	Horizon	A	Number	Horizon	A	Number	Horizon	A
UCGM 45156	1-1	10	45186	1-4	42	45223(b)	4-4	39
45157	"	37	45189	1c-2	43	45223(c)	"	38
45154	"	34	45191	2-1	50	45260	5b-2	95
45159	"	38	45190(a)	"	37	45261	"	28
45153(a)	"	17	45190(b)	"	37	45266	5b-4	68
45153(b)	"	27	45193	"	55	45269	5b-5	36
45153(c)	"	46	45194	"	28	45268	"	98
45161	1-2	24	45192	"	22	45272	5b-6	70
45171	"	43	45196	"	28	45273	"	71
45164	"	43	45206	3-1	25	45279	5b-9	15
45174	"	41	45202	"	44	45280	"	53
45169	"	36	45207	"	42	45292	6-1	26
45172	"	88	45214	3-2	67	USGS 2401c		37
45173	"	37	45220	4-1	60	2416c		24
45163	"	21	45230	4-4	5	2433b		88
45168	"	22	45226	"	40	2366c		37
45175	"	2	45228	"	90	2367c		96
45166	"	33	45224	"	29	2369c		68
45179	1-3	42	45225	"	36	2370c		37
45183	1-4	80	45223(a)	"	33	2319b		37

	2421c		61
	2422c		39
UCGM	45297	10-1	59
	45315	11b-1	30
	45326	"	29
	45317	"	37
	45318	"	24
	45303(a)	"	48
	45303(b)	"	33
	45334	11b-2	0
	45330	"	3
	45333	"	47
	45336	"	26
	45344	11b-3	85
	45339	"	38
	45347	"	23
	45343	"	33
	45344	"	69
	45345	"	41
	45342	"	36
	45340	"	27
	45350	"	88
	45357	12a-1	65
	45355	"	75
	45359	"	61
	45356	"	29
	45358	12a-1	41
	45360	"	37
	45364	12a-2	67
	45365	"	68
	45363	"	39
	45376	12a-3	57
	45378	"	53
	45375	"	83
	45377	"	42
	45390	12a-4	20
	45389	"	36
	45394	12a-5	45
	45396	"	63
	45409	12b-1	36
	45413	12b-2	100
	45416	"	71
	45422	12d-1	34
	45433	13-2	26
	45441	13b-1	31
	45446	"	35
	45457	13b-3	84
	45458	"	54
	45477	14-3	28
	45480	"	53
	45485	14-4	42
	45483	"	38
	45494	14-5	52
	45466	14b-1	83
	45469	"	43
USNM	70024		36
	9719a		39
	9719b		78
UCGM	45505	16a-1	23
	45503	"	25
	45509	"	41
	45514	16a-2	37
	45521	16b-2	39
	45518	"	42
	45536	16c-1	97
	45534	"	43
	45525	"	83
	45540	18a-1	39
	45545	18a-3	88
	45548	"	21
	45549	"	49
	45551	"	39
	45559	18b-1	32
UMMP	45354		44
UCGM	45565	19a-1	35
	45566	"	37
	45572	19c-1	68
	45582	19d-1	67

45585	19d-1	76	M61a-6	M61a	53	GSC 8530c	79
45589	19e-1	68	M61a-7	M61a	24		

B. Streptelasma divaricans

Number	Horizon	A	Comparison of axial regions within pseudocolonies and colonies
UCGM 45000	1c-1	37	pseudocolony, 2 similar
45003	2-1	44	
45004	"	30	
45005	"	18	
45008	3-2	65	pseudocolony, 2 same
45009	3-3	23	
45014	4-2	15	
45015	"	81	
45016	"	71	
45012	"	52	
45017	"	65	
45018	4-3	70	
45019	"	95	
45020	4-4	80	
45025	4-5	92	
45028	5b-1	45	
45030	"	51	
45031	"	62	
45037	5b-2	20	
45038	"	64	pseudocolony, slightly different
45043	"	62	

45034	5b-2	90	
45036	"	64	colony, 2 same
45042	"	63	
45046	5b-7	57	
45048	"	71	
45052	"	28	
45054	5b-9	50	
45053	"	64	
45055	"	63	
45057	10-1	75	
45061	11b-1	10	
45064	11b-3	29	
45067	"	63	
45072	12a-1	5	
45074	"	40	
45071	"	76	
45076	"	43	
45075	"	53	
45073	"	56	
45084	12a-2	55	pseudocolony, 2 same
45086	"	85	
45082	"	76	
45088	"	36	
45087	"	37	
45083	"	69	
45090	12a-3	63	

45093	12a-4	51	colony, 3 similar
45100	12a-5	79	
45646	"		colony, 2 same
45108	12a-9	13	
45112	12b-3	59	
45113	12c-1	46	
45116	12d-1	54	
45611	13-1	60	pseudocolony, 3 same
45119	"	77	
45122	"	62	
45126	13-2	43	
45133	13b-1	35	
45134	"	47	
45132	"	31	
45137	13b-2	25	
45136	"	78	
45139	"	41	
45140	13b-3	27	
45141	14-3	77	pseudocolony, 2 similar
45142	14-5	56	
45143	14-6	82	

Appendix 10.--*Streptelasma divaricans* (Nicholson, 1875): solitary corallites and number of corallites comprising pseudocolonies and colonies (#), and attachment sites.

Number	Horizon	#	Attachment Site	Pseudocolony or Colony
UCCM 45000	1c-1	2		pseudocolony
45001	2-1	1		
45005	"	1	bryozoan	
45004	"	1	brachiopod	
45002	"	1		
45003	"	1		
45006	3-2	3	bryozoan	
45007	"	2	bryozoan	
45008	"	2	bryozoan	pseudocolony
45009	3-3	1		
45010	4-2	1	colonial coral	
45014	"	1	bryozoan	
45015	"	3		
45016	"	1		
45013	"	1		
45017	"	1	bryozoan	
45012	"	3	colonial coral	
45011	"	1	colonial coral	
45019	4-3	1		
45018	"	2	bryozoan	
45020	4-4	1	bryozoan	

45021	4-5	2	bryozoan	
45126	"	1		
45024	"	1	bryozoan	
45023	"	1	bryozoan	
45022	"	1	bryozoan	
45025	"	1		
45027(a)	5b-1	2	bryozoan	pseudocolony
45027(b)	"	1	brachiopod	
45027(c)	"	1		
45027(d)	"	1	brachiopod	
45029	"	1	bryozoan	
45246	"		G. canadensis	
45251	"		G. canadensis	
45028	"	1	brachiopod	
45030	"	1		
45032	"	1		
45031	"	1		
45033(a)	5b-2	1		
45033(b)	"	1		
45033(c)	"	1		
45033(d)	"	2	bryozoan	
45034	"	1		
45038	"	3		pseudocolony
45039	"	1		
45036	"	2		colony
45035	"	numerous		

45037	5b-2	3		
45040	"	1		
45042	"	1		
45043	"	1		
45044	5b-3	9, 5	bryozoan	
45045	5b-4	2	bryozoan	pseudocolony
45050	5b-7	1	brachiopod	
45049	"	1		
45052	5b-7	1		
45048	"	2		
45051	"	2		
45046	"	1		
45054	5b-9	4	bryozoan	
45053	"	1	bryozoan	
45055	"	1		
45057	10-1	1		
45058	"	1		
45059(a)	11b-1	1	bryozoan	
45059(b)	"	1		
45059(c)	"	2		
45059(d)	"	1	bryozoan	
45059(e)	"	1	bryozoan	
45059(f)	"	1		
45059(g)	"	1		
45059(h)	"	1	brachiopod	
45062	"	2	bryozoan	pseudocolony

45060	11b-1	1	brachiopod
45061	"	1	
45063	11b-3	1	bryozoan
45064	"	1	
45067	"	1	
45065	"	1	
45066	"	1	brachiopod
45068(a)	12a-1	1	
45068(b)	"	4	bryozoan
45068(c)	"	4	bryozoan
45068(d)	"	1	
45068(e)	"	1	
45068(f)	"	1	
45068(g)	"	1	
45068(h)	"	2	
45068(i)	"	1	
45069	"	1	
45356	"		G. canadensis
45361	"		G. canadensis
45078	"	1, 1	bryozoan
45077	"	1	
45071	"	1	
45076	"	1	
45075	"	1	
45073	"	1	
45074	"	1	

45072	12a-1	1	bryozoan	
45079(a)	12a-2	1		
45079(b)	"	3		
45079(c)	"	1		
45079(d)	"	5		
45079(e)	"	2		
45079(f)	"	3		
45079(g)	"	1		
45079(h)	"	1		
45079(i)	"	2		
45086	12a-2	1		
45084	"	2		pseudocolony
45082	"	1	bryozoan	
45088	"	1		
45087	"	1		
45081	"	1		
45080	"	1	bryozoan	
45083	"	2		
45085	"	2		pseudocolony
45089	12a-3	1		
45092	"	2		
45091	"	2		pseudocolony
45090	"	1		
45095	12a-4	1		
45094	"	1	bryozoan	
45096	"	1		

45093	12a-4	3		colony
45098	12a-5	4		pseudocolony
45097(a)	"	1		
45097(b)	"	1		
45646	"	2		colony
45099	"	numerous		
45100	"	1	pelecypod	
45101(a)	12a-6	1		
45101(b)	"	1		
45103	"	1		
45102	"	2		
45104	12a-7	12	bryozoan	
45105	12a-9	1		
45107	"	1		
45108	"	1		
45106	"	1		
45109	12b-1	1		
45110	"	1		
45111	12b-2	2	bryozoan	
45112	12b-3	1		
45113	12c-1	1	bryozoan	
45114	"	1		
45115	12d-1	1		
45116	"	2		
45117(a)	13-1	1		
45117(b)	"	1		

45117(c)	13-1	3		
45117(d)	"	5		
45117(e)	"	1		
45119	"	1		
45120	"	1		
45121(a)	"	6	bryozoan	
45121(b)	"	2	brachiopod	
45611	"	3		pseudocolony
45118	"	1		
45122	"	1		
45123(a)	13-2	1		
45123(b)	"	1		
45123(c)	"	1	bryozoan	
45123(d)	"	1		
45123(e)	"	1		
45123(f)	"	1		
45123(g)	"	1		
45123(h)	"	2		
45123(i)	"	1		
45123(j)	"	1		
45128	"	1	bryozoan	
45126	"	1	bryozoan	
45129	"	1	bryozoan	
45125	"	1		
45127	"	1		
45124	"	1		

45130	13-2	2	bryozoan	
45131(a)	13b-1	1		
45131(b)	"	1		
45131(c)	"	1		
45131(d)	"	1		
45131(e)	"	1	brachiopod	
45132	"	2		
45444	"		G. canadensis	
45135	"	2		
45133	"	1		
45134	"	1		
45137	13b-2	1		
45139	"	1		
45138	"	1		
45136	"	1		
45140	13b-3	2		
45141	14-3	3		pseudocolony
45142	14-5	1		
45143	14-6	1		
M61a-1	M61a	1	bryozoan	
M61a-4	"	1	bryozoan	
UCGM 45148	19f	1		
45147	"	1	pelecypod	
45149	"	3		
45150	"	1		
45151	"	2		

45152 19f 1

Appendix 11.--*Streptelasma affinis* (Billings, 1865) and *Paliphyllum ellisensis* (Twenhofel, 1928): intervals (mm) between regularly spaced rugae.

A. *Streptelasma affinis*

Number	Interval
GSC 1987b	10, 12, 13
YPM 555 (one specimen in lot)	8, 10, 10, 10, 12, 12, 12
YPM 555 (one specimen in lot)	8, 8, 11
YPM 3063/57 (one specimen in lot)	8, 9, 10, 10, 10, 10, 11, 12

B. *Paliphyllum ellisensis*

YPM 10388A	7, 7, 11
YPM 3063/57 (one specimen in lot)	7, 7
YPM 3063/57 (one specimen in lot)	7, 7
YPM 3063/52	10, 10, 11
YPM 3063/58	6, 7, 8, 8

Appendix 12.--*Crewingkia canadensis* (Billings, 1862): corallite length (*l*, mm) and depth of calyx (d_c, mm).

Number	*l*	d_c	d_c/l
UCGM 45161	80	30	0.38
45164	60	20	0.33
45169	65	30	0.46
45185	65	18	0.28
45191	73	22	0.30
45192	65	27	0.42
45220	78	27	0.35
45289	53	28	0.53
45318	60	21	0.35
45358	62	22	0.35