

The Fauna and Strata
of a Portion of the
Arnheim Formation
as Exposed in Stonelick Lake State Park,
Southwestern Ohio

Presented in Partial Fulfillment of the Re-
quirement for the degree Bachelor of Science

by

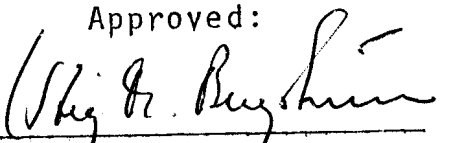
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Fig. 1. Portion of a seven and one-half minute topographic quadrangle map showing the location of Stonelick Lake State Park.

INTRODUCTION

Well preserved graptolites are rare in the Upper Ordovician (Cincinnatian) rocks in the Cincinnati region and only a few occurrences of such fossils have been reported in the literature (Rudemann, 1947; Berry, 1966; Erdtmann and Moor, 1973). In 1970, I discovered a previously unknown graptolite locality in this area and the purpose of this paper is to describe the graptolites collected from this locality and the rocks in which they occur, as well as to evaluate their age and environment of deposition.

The graptolite-bearing outcrop is located on the south side of Stone Lick Lake in Stone Lick State Park, about thirty miles east of Cincinnati, Ohio (Fig. 1). The park is in Wayne Township, Clermont County (Newtownsville seven and one-half foot Quadrangle Topographic Map). The outcrop lies just at the top of an old stream valley, now flooded by a man-made lake and is about two and one-half miles upstream from an exposure of the Corryville Member of the McMillan Formation (See Pulse, 1959), at an elevation of 875 feet above sea level. As indicated below, the exposed rocks belong to the Arnheim Formation of earliest Richmondian age.

The exposure is along a small creek dredged out during construction of two holding ponds for the park's sewage treatment plant (Fig. 2). Lithologically, the exposed beds consist of dominant shale

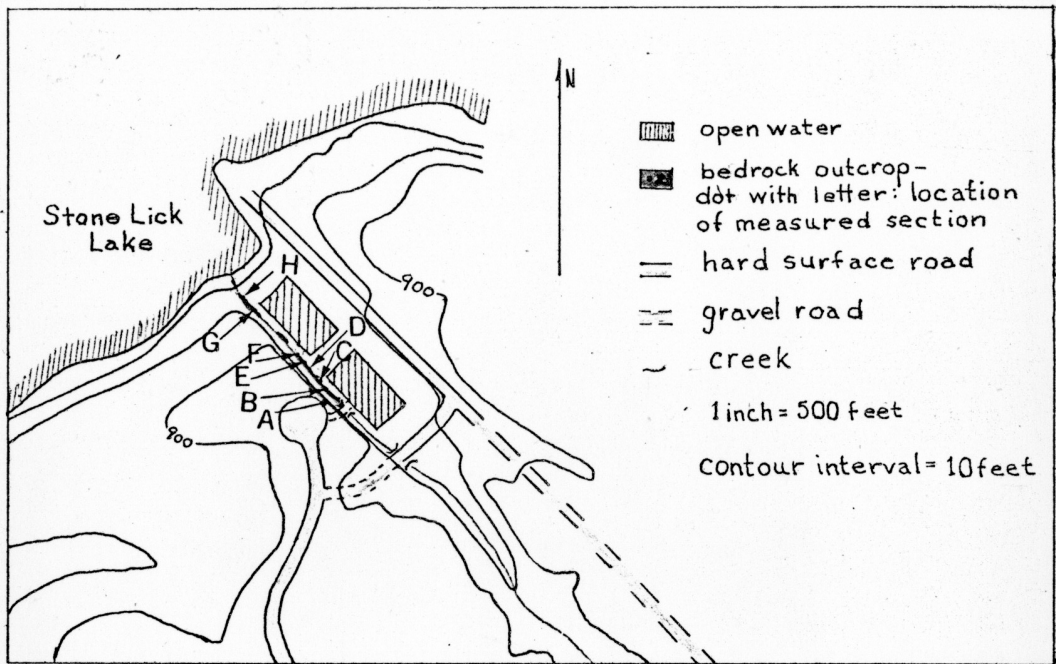


Fig. 2. Geographic location of the outcrop and the measured sections.

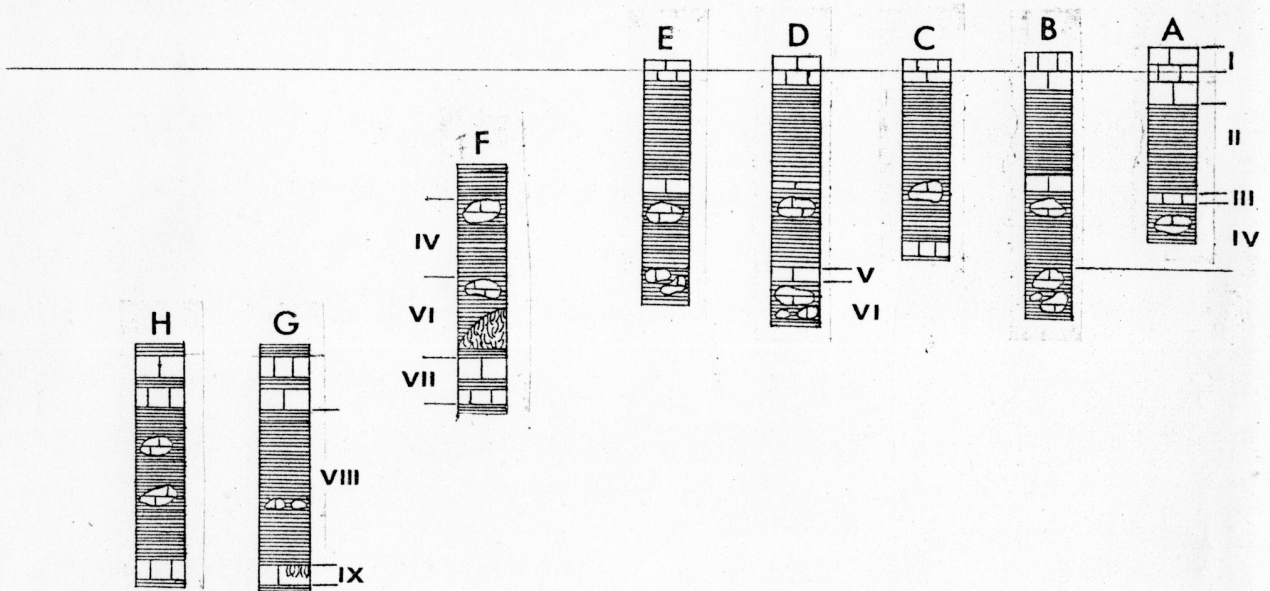


Fig. 3. Columnar sections of the measured sections. Distance from section A to Section B is 48 ft.; from B to C: 18 ft.; from C to D: 45 ft.; from D to E: 20 ft.; from E to F: 28 ft.; from F to G: 164 ft.; and from G to H: 46 ft. Vertical scale: 1 in. = 20 in.

with several beds of interbedded fossiliferous calcirudite packstone, calcareous argillaceous siltstone, and graptolite calcirudite wackestone and mudstone nodules, all of which are somewhat dolomitized. A fair variety of fossils occur in these rocks. They are best preserved in the wackestone nodules from which abundant three-dimensionally preserved graptolites have been obtained. A series of columnar sections, along a north-south cross-section through the study area are presented in Fig. 3.

LITHOLOGIC SEQUENCE

The rocks of the Stone Lick Lake exposure include siltstone, limestone, and shale. Beginning from the top of the sequence, Unit I is a fine-to-medium grained blue-gray mixed fossiliferous dolomitic calcirudite packstone. It is irregularly bedded and contains some beds of fine sand and silt. The principal skeletal grains are the remains of brachiopods, gastropods, bryozoans, and trilobite and crinoid fragments. There are also some compressed graptolites present. The thickness of the unit is two to six inches.

Unit II is a blue-gray fissile calcareous shale. It is fairly fossiliferous and also contains some compressed graptolites. The unit is eight to ten inches thick.

Unit III is a blue-gray sparsely fossiliferous calcareous siltstone. This unit is extensively burrowed. There are also abundant epichnial and hypichnial trace fossils on the surface of the bed. In this unit there are occasional but abundant occurrences of three-dimensionally preserved graptolites. The major mineralogic

constituents of this siltstone are quartz sand and silt, micrite (clay sized carbonate grains, probably calcite) and iron-rich dolomite. The unit is about one to one-and-one-half inches thick.

Unit IV is composed of shale and in that respect it is similar to Unit II. Unlike Unit II, however, Unit IV contains a layer of wackestone nodules about two inches from its top. These nodules are blue-gray in color, very fine grained and soft. They are extensively burrowed and abundantly fossiliferous. Three dimensionally preserved graptolites occur abundantly in some of the nodules. The nodules range in size from one to six inches along their greatest length. The thickness of the unit is seven to nine inches.

Unit V is a thin bedded blue-gray dolomitic mixed fossiliferous calcirudite packstone. The limestone of this unit is essentially the same as that in Unit I except that it is only one to one-and-one-half inches thick.

Unit VI is shale similar to that in Unit II and contains wackestone nodules identical to those found in Unit IV. The layer containing the nodules in Unit VI is, however, thicker than the layer in Unit IV. One inch from the base of Unit VI in section F, there is a lenticular limestone consisting almost exclusively of valves of the brachiopod Rafinesquina alternata stacked on edge. This bed is up to four inches thick and Unit VI is six to eight inches thick.

Unit VII consists of two beds of packstone like that in Unit I, separated by a one inch thick layer of shale. Both limestones in Unit VII are two inches thick.

Unit VIII is a very soft yellowish shale, which is sparsely fossiliferous. This unit contains two layers of soft yellow mudstone nodules. The nodules occasionally contain three-dimensionally preserved specimens of a dendroid graptolite. The thickness of the unit is fifteen inches and the nodules are up to four inches long.

Unit IX is a packstone and is again essentially the same as the packstone in Unit I. In some places, however, the upper part of the bed is composed of valves of Rafinesquina alternata stacked on edge. The thickness of the unit is one and one-half to three inches.

The various sections measured and their geographic locations are illustrated in Figs. 2 and 3.

OCCURRENCE OF FOSSILS

The packstones contain a great deal of large skeletal grains, the majority of which are the remains of brachiopods, bryozoans, gastropods, and molds of bivalves. There are also crinoid debris, trilobite and ostracode carapace remains and occasional cephalopods in the packstones. Upon acetic acid digestion, samples of the packstone yield conodonts, carbonized algal and graptolite fragments, chitinozoa, silicious sponge spiculae and scolecodonts.

The siltstones are by and large poorly fossiliferous and contain a few poorly preserved orthograptid graptolites, scolecodonts, and abundant trace fossils.

Washing of samples from the shales yielded brachiopods, bryozoans, crinoid columns, trilobites, ostracods^e, conodonts, small steinkerns of gastropods and bivalves, chitinozoans, and graptolite

fragments. Many of the fossils in the shales are wholly or partly pyritized. The conodonts are generally rather broken and the chitinozoans and graptolites are flattened. Some pieces of carbonized algae are also present.

The nodular wackestones contain essentially the same fossils as the shales with which they are intimately interbedded. The wackestones, however, also contain larger molds of bivalves and gastropods, and notably, in situ specimens of the inarticulate brachiopod Lingula sp. This lithology is especially suitable for the preservation of delicate structures and excellent specimens of trilobites, chitinozoans, conodonts, graptolites, and crinoids have been obtained from samples of this type of rock.

GENERAL REVIEW OF THE FAUNA

The fauna of the section is quite diverse with respect to the number of genera present and it includes representatives of most of the major invertebrate phyla (Table 1).

Brachiopods

Brachiopods are present throughout the section although their occurrence is apparently environmentally controlled. Specimens of Rafinesquina alternata, Hebertella occidentalis, and Leptaena richmondensis occur only in the packstone lithology. They could apparently not tolerate the mud and silt environments of the other lithologies. Specimens of Rafinesquina alternata also occur as almost the sole constituent of a lenticular bank-type deposit, just above

TABLE 1

Faunal list from the Stonelick Lake sections

Brachiopoda

Rafinesquina alternata Emmons
Hebertella occidentalis Hall
Leptaena richmodensis Foerste
Zygospira modesta (Say)

Lingula sp.

Mollusca

Bivalvia

Byssonychia robusta (Miller)
B. radiata (Hall)
Pterinea demissa (Conrad)
Lyrodesma major (Ulrich)
Modiolopsis sp. cf. M. modiolaris Conrad
Cyrtodontula rugatina (Ulrich)
Cuneamya sp. cf. C. scapha (Hall and Whitfield)
Anomalodonta sp. aff. A. gigantea (Miller)

Gastropoda

Cyclonema bilix Conrad
Cyrtolites ornatus Conrad
Schizolopha sp.?

Cephalopoda

Nautiloid cephalopod indet.

Echinodermata

Crinoidea

Iocrinus subcrassus (Meek and Worthen)

Arthropoda

Trilobita

Flexicalymene meeki (Foerste)
Isotelus maximus (Locke)

Ostracoda

Aechmina sp. cf. A. richmondensis
 (Ulrich and Bassler)
Warthina nodosa (Ulrich)
Bollina persulcata Ulrich

Bryozoa

Trepostomata

Hallopora subnodosa (Ulrich)

Porifera

siliceous spiculae indet.

TABLE 1
(cont.)

Annelida

Polychaetia
scolecodonts indet.

Protista

Pyrrophyta
acritarchs indet.

Conodonta

Phragmodus undatus Branson and Mehl
Plectodina sp.
Drepanoistodus suberectus (Branson and Mehl)

Chitinozoa

Conochitina sp. (two forms)
C. micracantha capitata Eisenack
C. sp. cf. C. seriespinosa Jenkins
Desmochitina sp. cf. D. lata Schallreuter
D. minor typica Eisenack

Graptolithina

Dendroidea
Mastigograptus sp. cf. M. tenuiramosus
(Walcott)

Graptoloidea

Orthograptus amplexicaulis (Hall) n.ssp.

Unit VII in section F, in which the shells are stacked on edge. Specimens of Zygospira modesta are present in all carbonate ^{rocks} in about equal numbers. They appear to have been indifferent to the mud content of the sediment. Shells of Lingula sp. are found only in the nodular wackestones of Units IV, V, and VI.

Bivalves

Bivalves occur throughout the section. They are most abundant, however, in the packstones and nodular wackestones. Specimens of Byssonychia sp. cf. B. robusta are very common as internal molds on the surfaces of the packstones and also occur in the nodular wackestones. Pterinea demissa is the only bivalve of those present that is found with the shell material preserved. It occurs in more or less equal numbers in all the carbonate lithologies and in the shales. A variety of bivalves not seen elsewhere in the section were found in the nodular wackestones. These are Byssonychia radiata, Lyrodesma major, Modiolopsis sp. cf. M. modiolaris, Cyrtodontula rugatina, Cuneamya sp. cf. C. scapha and Anomalodonta sp. aff. A. gigantea, as well as a representative of another large ambonychiid bivalve which has proved to be unidentifiable to genus. As previously mentioned, all of the bivalves in the section except Pterinea demissa occur as internal molds. This tends to make their identification somewhat more difficult and less reliable than it might be otherwise, since they had to be identified by form and such readily visible characters as muscle scars, type of hinge line, size and spacing of costae, presence of a byssal gap, etc. Unfortunately, the dentition is not

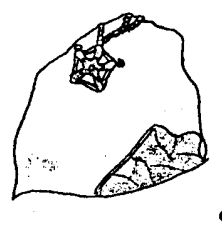
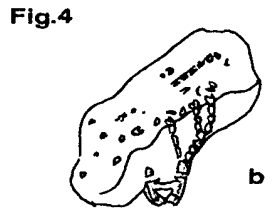
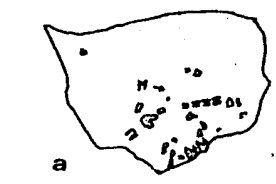
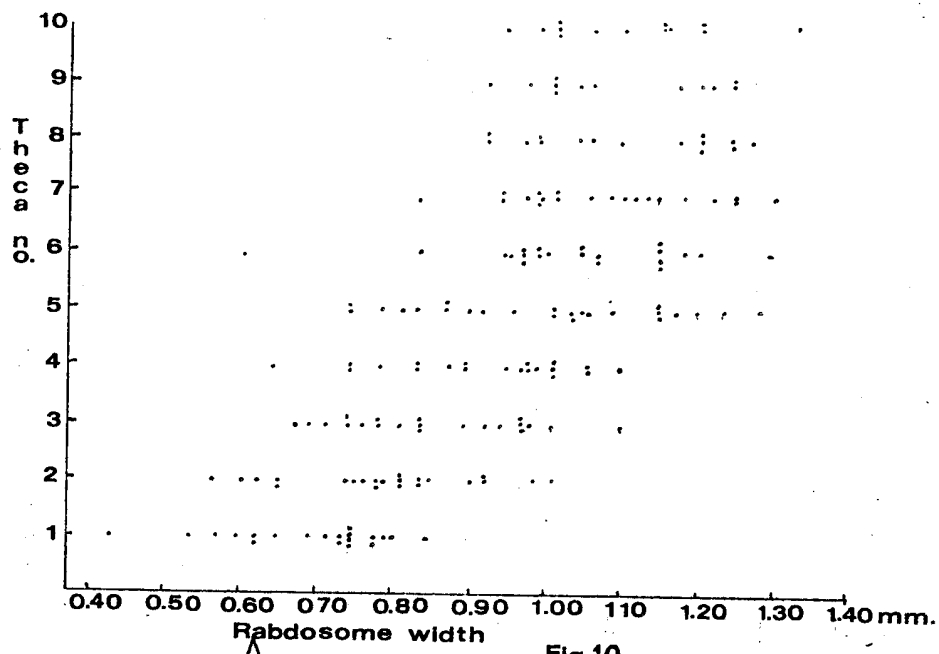


Fig. 4



Fig. 10

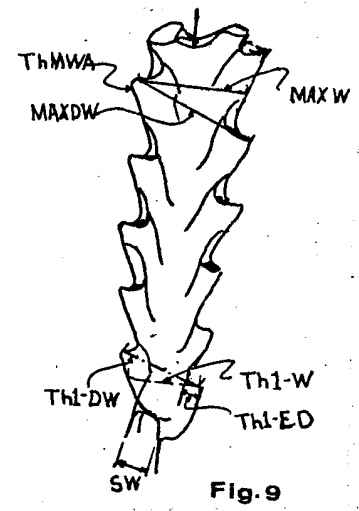


Fig. 9

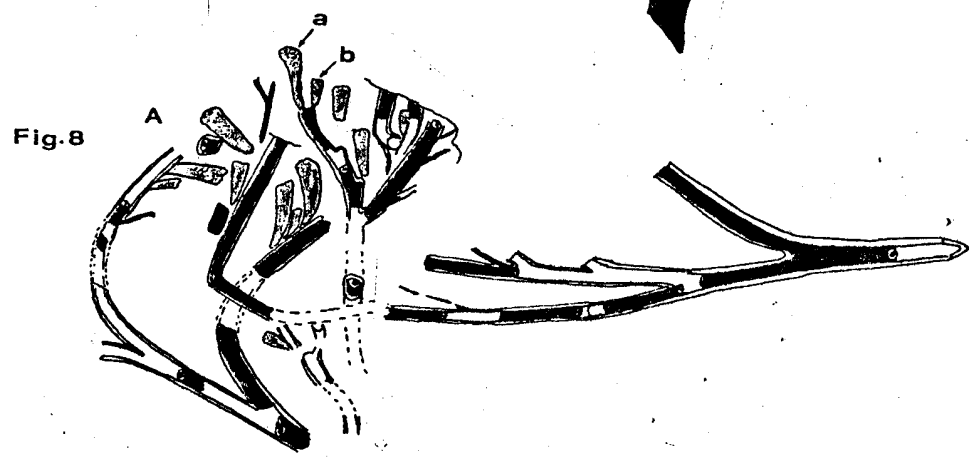
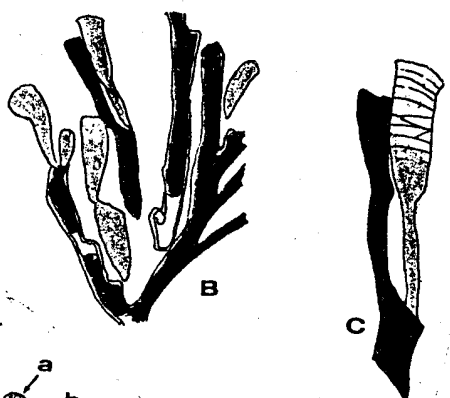


Fig. 8

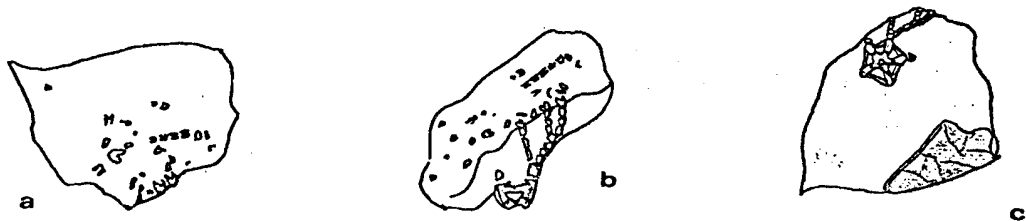


Fig. 4a. Top view of the specimen of Iocrinus subcrassus.
Natural size.

4b. Lateral view of same specimen.

4c. Aboral view of same specimen.

visible in any of the specimens.

Gastropods

Representatives of the gastropod Cyclonema bilix occur with the shell material replaced by calcite in the packstones and as steinkerns in the nodular wackestones and shales. Also present in the same beds are specimens of Cyrtolites ornatus, which occur only as steinkerns and which are very commonly encrusted by bryozoans. If the bryozoans are chipped off, fine growth laminae are revealed. A large quantity of tiny steinkerns of Cyclonema and Cyrtolites with only one or two whorls has been observed in the washed residues from the shales. There is also a third gastropod species present in the section. It occurs in the nodular wackestones and is particularly common in Unit VI, section D. It is a medium-spined conical form with a prominent keel on each whorl. It may be related to the genus Schizolopha. It has altered shell material preserved but no specimens were found free enough of the matrix to be positively identified.

Cephalopods A few poorly preserved specimens of a straight nautiloid cephalopod have been found in the packstone and nodular wackestone.

Crinoids

Crinoid debris is fairly common in the limestones and shales, particularly in the packstones. The debris consists primarily of columnals and fragments of the pinnules. One calyx was found in Unit VIII, section H in a mudstone nodule. It appears to represent Iocrinus subcrassus. The specimen is very well preserved although the majority of it is embedded in the matrix. It seems to be in

living position and has the arms spread out projecting up through the sediment (Fig. 4).

Trilobites

Specimens of two trilobite species have been found in the section. They are Flexicalymene meeki and Isotelus maximus. Fragments of representatives of both genera are extremely common throughout the section and many excellent specimens of the former have been collected by the author, some of which are in resting position rather than enrolled. I have also obtained several nearly complete, though small, specimens of Isotelus maximus from the nodular wackestones, as well as a meraspis stage not more than one-half an inch across the cephalon. The well preserved specimens of both genera are most common in Unit IV, sections A and B.

Bryozoans

Bryozoans are very common in the rocks of the section and both ramose and encrusting forms are present. Although I have made no serious attempt to identify the forms present, the majority appear to be Trepostomes. Specimens of Hallopora subnodosa have been seen in two of the thin sections made for petrographic purposes.

Sponges

Siliceous sponge spiculae have been seen in acid residues of the packstone in Unit VII. Several forms are present, including fusiform oxeas types, tetra × ons, and a relatively smooth, many-branched desma type. Sponge spiculae have not been found in any other

unit of the section studied.

Scolecodonts

Scolecodonts are very abundant throughout the sequence. They are most prevalent in the nodular wackestones which are commonly extensively burrowed. A number of different scolecodont elements are present but no attempt has been made to identify them. The most common burrows are of the Chondrites type. There is also a larger endichnial type present, as well as abundant epichnial and hypichnial forms.

Acritarchs

A few acritarchs were discovered while picking chitinozoan residues.

Ostracods

At least six different species of ostracods^e were obtained from washing shales from Unit II. Three were sufficiently distinctive to be readily identified. These are Aechmina sp. cf. A. richmondensis (very common); Warthina nodosa (formerly called Ulrichia nodosa [common]); and Bollina persulcata (rare). Specimens of Warthina nodosa are known to be common only from the middle of the Arnheim Formation through the Waynesville Formation. For purposes of the study, the other forms mentioned are of no particular stratigraphic significance.

Conodonts

The conodonts present in the acid residues of the limestones and in the washed residues of the shales are all simple cones, bars,

and blades. No platform elements were discovered. It was hoped that a valuable stratigraphic indicator could be found among the conodonts but, unfortunately, it did not prove to be the case. A number of different elements are present which are assignable to three multi-element genera. Specific determination was possible only in the case of two of the genera. The conodonts present in the section are ^wPragmodus undatus, Drepanoistodus suberectus, and Plectodina sp. The state of the taxonomy for Plectodina is such that assigning of species names to my specimens is not meaningful. The Plectodina forms present are similar to those that have been called P. furcata, P. robusta, and P. aculeata. Representatives of the forms present in the sections are figured on Plate 1.

Chitinozoans

Chitinozoans were obtained from acid residues of the nodular wackestones and the packstone in Unit VII. Abundances in samples from this Unit were between 100 and 200 specimens per 50 g. sample and the shales in Unit III yielded near 100 specimens per 25 g. sample. Preservation varies from specimen to specimen in the wackestone and packstone samples, whereas those from the shales were universally flattened. Many of the specimens are compressed and many are distorted and ruptured by the growth of pyrite framboids within the vesicles. A few specimens are preserved in undistorted condition.

Two genera with a total of four identifiable species were recognized in samples from the section. These are Conochitina micracantha capitata, Eisenack, 1962; Conochitina sp. cf. C. seriespinosa,

Jenkins, 1969; Desmochitina sp. cf. D. lata, Schallreuter, 1963; Desmochitina minor typica, Eisenack, 1931; and two other forms of Conochitina which are unidentifiable to species.

The specimens assigned to Conochitina seriespinosa (Pl. 2, Figs. 2 and 3) resemble this form in their proportions and general shape as well as in the character of their spines (they have spines with two or three bases). However, the overall dimensions are only about two-thirds of those of the types (total length -- 105μ ; oral tube diameter -- 25μ ; and max. diameter -- 50μ for the specimens on hand; and 163μ , 41μ , and 75μ as an average in Jenkins' specimens). Also, the spines are considerably shorter in the forms at hand than in the types.

The types of Desmochitina lata differ from the present specimens only in the absence of the scattered nodose globular spines(?) seen in the Stone Lick Lake material (Pl. 2, Fig. 10).

The short conical form of Conochitina sp. (Pl. 2, Fig. 1) is badly ~~distorted~~ by the growth of pyrite framboids within the vesicle. This caused the lumpy appearance of the surface. The neck is also broken off.

The long forms of Conochitina sp. (pl. 2, Figs. 5 and 6) resemble representatives of the Group C. micracantha in vesicle shape but the former lacks the typical spines present in all forms of that species.

STRATIGRAPHIC AGE

As previously mentioned, the Stone Lick Lake section is at an

elevation of 875 feet and that of the nearby Corryville exposure examined by Pulse (1959) is around 800 feet. This Corryville outcrop is stratigraphically 57 feet below the base of the Richmond Group (W. C. Sweet personal communication, 1975), based on regional conodont correlations. The difficulty of relating differences in elevation to stratigraphic thickness makes accurate stratigraphic placement of the section by this method impossible; however, it does suggest that the Stone Lick Lake section must lie in the Arnheim Formation of earliest Richmondian age.

Paleontologic evidence corroborates this conclusion. According to Foerste (1912), the basal member of the Arnheim Formation, the Sunset Member, is for the most part unfossiliferous on the east side of the Cincinnati arch, and those fossils it does contain are of the same types as those present in the Mt. Auburn below it. The upper member, the Oregonia Member, is, in contrast, abundantly fossiliferous and it exhibits the first appearance of typical Richmond fossils. The base of the Oregonia Member is marked by a horizon in which specimens of the brachiopod Retrorsirostra carleyi (formerly called Dinorthis carleyi) are abundant. Representatives of Leptaena richmondensis are also first seen at this level. Wolford (1927) cites Anomalodonta gigantea and Cyclonema bilix as characteristic Richmond fossils that first appear in the Oregonia Member.

DEPOSITIONAL ENVIRONMENT

Deposition in this area took place in a shallow and dominantly

quiet water environment. The substrate was a fine silty mud from both basinal (carbonate) and terrigenous sources with a large amount of organic matter incorporated into it. The high proportion of mud and fine silt-sized particles indicates that the energy level prevailing during deposition must have been low. Changes in the lithologies were for the most part caused by changes in the amount of clastic material supplied to the area, as well as by minor fluctuations in the energy level. This latter fact is evidenced by the presence of several packstones, the matrix of which is still composed primarily of micrite. The siltstone in Unit III was probably deposited during only slightly higher energy conditions, since it also contains a large amount of mud. This bed is occasionally ripple marked with ripples exhibiting a wave length of about three inches and an amplitude of three-eighths to one-half inch.

It is possible that benthic animals could influence the environment and/or the sediment in such a way as to decrease the energy level of the water during sedimentation. Sessile benthic organisms such as crinoids and bryozoans are known to form baffles which inhibit current action and, thus, trap fine-grained sediment. It does not appear, however, that in this case, either of these organisms was present in great enough numbers to have influenced the environment of deposition. In addition, burrowing organisms (especially sediment feeders) and boring algae contribute to the size reduction (micritization) of carbonate grains. Worm burrows(?) of the Chondrites type are very common in the siltstone and nodular wackestone lithologies. The organism which produced this type of burrow

is believed to have been a sediment feeder and it may have, indeed, contributed significantly to the micritization of the carbonate grains. Micrite borders, which are the result of the activity of boring algae, were not seen on any of the grains examined in thin section and so this factor can safely be omitted as a significant contributor of micrite. Accordingly, micritization activities of these types could not produce or enhance the quantity of terrigenous clays found in the rocks.

The excellence of the preservation of many elements of the fauna suggests a quiet environment of deposition. This is most strikingly shown by the following examples. In the case of the dendroid graptolite Mastigograptus sp. cf. M. tenuiramosus, not only are the individual branches of the rhabdosome preserved in relief, but the entire colony remains for the most part undisturbed, retaining its original three-dimensional character (Pl. 4, Fig. 2). The specimen of Iocrinus subcrasus obtained from the same beds (Unit VIII) is preserved in situ with the arms projecting up through the sediment (Fig. 4) in a more or less vertical position. Several specimens of the trilobite Flexicalymene meeki preserved completely articulated and in an extended horizontal position have been collected by the author in Units IV, V, and VI. Specimens of Orthograptus amplexicaulis ^{n.} ssp. obtained from these beds and even from the siltstones are very commonly preserved with the delicate virgula, antivirgular spines, and long nema intact. The presence of many delicate fossils in situ indicates that they were buried in the absence of any strong currents which might have winnowed them from the sediment.

In the author's opinion, these examples also provide evidence for rapid deposition of the fossil-bearing strata. The vulnerable un-enrolled trilobites would have been quickly disarticulated by scavengers had they not been buried rapidly. This is also true in the case of the crinoid. It was most certainly dead by the time the calyx was covered with sediment, at which point the arms would still have been projecting up into the water and, thus, would have been vulnerable to damage by current action or predators. Providing the arms were not destroyed by these agents, they would have been disarticulated as soon as the supporting flesh rotted away.

Unfortunately, there has not been time enough for the detailed study of the nodular wackestones in order to determine the way they were formed. In the author's opinion, this would be a very interesting problem for further study.

The thanatocoenosis of Rafinesquina alternata which forms a up to four inches thick, bank-type lenticular deposit in Unit VI, section F is apparently one case in which there was a strong current acting along the bottom. The presence of micrite in the matrix indicates a lack of winnowing and, thus, suggests deposition by a current of short duration, perhaps caused by a storm.

According to Simpson (1972), the presence of the Chondrites-type burrows indicates both rapid sedimentation, which is necessary to fill the burrows before they collapse, and quiet water.

In modern seas, the brachiopod Lingula is known to inhabit a shallow marine environment of depths down to twenty fathoms, although exceptionally, it may be found as deep as 50 fathoms. Davidson

(1886-1888) states that specimens of Lingula are most abundant at depths of seven to ten fathoms. While most forms of Lingula are burrowers, there are some that live attached to floating plants and are, thus, secondarily planktic. This explains the occurrence of Lingula in deep water sequences.

In the Stone Lick Lake section, specimens of Lingula occur in the nodular wackestones in fair numbers and in some cases they appear to be preserved in situ. This indicates that the rocks of the section were deposited within the depth range of Lingula during the late Ordovician. It is not possible to assign any reliable depth figures to its range at that time but other occurrences seem to indicate that the Paleozoic Lingula species had approximately the same depth range as the recent ones.

In summary, the depositional environment of the studied sequence appears to have been low energy shallow, normal marine with a moderate terrigenous clastic influx. This, coupled with a high rate of organic productivity, produced a rapid sedimentation rate.

PALEOECOLOGY AND FOSSIL COMMUNITIES

The megafossils of the section may be distributed among three groups. One of these, which occurs throughout the section, includes Zygospira modesta, Flexicalymene meeki, Isotelus maximus, Cyclonema bilix, Cyrtolites ornatus, Pterinea demissa, Mastigograptus tenuiramosus, crinoids, nautiloid ^Pcephalopods, and several trepostomatid bryozoans. The second group, found only in the packstone, is composed of Rafinesquina alternata, Hebertella occidentalis, Lepteana richmondensis,

and Byssonychia robusta. The third group is restricted to the shales and the nodular wackestones. It includes Lingula sp., Lyrodesma major, Modiolopsis modiolaris, Cyrtodontula rugatina, Cuneamya sp. cf. C. scapha, Byssonychia radiata, Anomalodonta sp. aff. A. gigantea and Schizolopha sp.

The change in energy level from that of the environment of the packstone to that of the shales and nodular wackestone with the attendant increase in the mud content of the sediment and the water residence time must have been a major controlling factor in the distribution of the two latter species groups. The species of the first group are apparently little sensitive to the relative amount of mud in their environment. The organisms of this group are all epifaunal or nectic. The mobility of the vagrant benthos may have aided them in coping with the variations in the mud content. Forms such as Pterinea demissa (due to its shape) and Zygospira modesta (because of its size) may have been able to float on the soft substrate while stalked forms such as the crinoids, the dendritic graptolites and the bryozoans were, for the most part, not affected by the presence of mud bottoms as long as the water was not too turbid and they had a firm place to anchor themselves. The packstone association was also epifaunal but the elements were probably too heavy to live on the sediment surface or may have been otherwise unable to prevent themselves from being buried. Large brachiopods such as specimens of Rafinesquina may have been more sensitive to turbidity than the smaller forms which had a much less complex lophophore arrangement. Conversely, the faunal elements restricted to the lower energy lithologies were

dominantly infaunal and presumably required an environment low enough in energy so that the substrate would not be constantly eroded away from around them. Also, since they were burrowers, they should have been able to keep up with the rate of sedimentation, provided it was not too rapid.

All of the epifaunal elements except for the trilobites and gastropods (deposit feeders, scavengers and browsing herbivores^e?) were filter feeders utilizing the suspended plankton. Among the infaunal elements, there are filter feeders (Lingula, Lyrodesma, Modiolopsis, Cuneomya, and Cyrtodontula) and sediment feeders (worms and the Chondrites animal). The graptolite Orthograptus amplexicaulis n. ssp. was most likely planktic or nectic and was also a filter feeder.

Pojeta (1971, p. 33) states that, "the Ambonychiids are both the ecological and morphological homeomorphs of the recent Mytilids." He goes on to say that forms such as Byssonychia, which have retained the anterior lobe, probably had life habits like those of the Modiolus-like Mytilaceans and could have lived either on a hard substrate raised above the bottom or semi-infaunally on a soft bottom. Considering the muddy condition of the substrate in the study area, Byssonychia was, in this case, probably semi-infaunal.

In his work on the Upper Ordovician fossil communities of the Central Appalachian area, Bretsky (1969) found that his fauna could be separated into three communities, which he named according to the dominant genera of each group. These are the Sowerbyella-Onniella; the Orthorhynchula-Ambonychia; and the Zygospira-Hebertella communities. Within the second group there is a faunal assemblage composed of

infaunal bivalves and Lingula sp. which occurs in muddy siltstones, silty sandstones, and coarser sandstones. Bretsky (op. cit.) interprets the environment of this assemblage as inner infralittoral to intertidal (infralittoral = depths from 100 meters to intertidal). The Orthorhynchula-Ambonychia Community intimately overlaps the Zygospira-Hebertella Community in the southern part of Bretsky's area. The latter community is dominated by epifaunal suspension feeders. It includes forms such as Hebertella sinuata, Zygospira recurvirostra, Pterinea demissa, Rafinesquina alternata, Modiolopsis modiolaris, several treptostomate bryozoans, and a gastropod. The dominant lithologies are regularly bedded clay shale, calcisiltite, and calcilutite. The environmental setting given by Bretsky for this community is both inner and outer infralittoral and possibly some lagoonal and tidal flat occurrences.

The similarities between these two communities and the one being examined in this paper are obvious. Not only are the elements similar from an ecological standpoint, but the communities share genera and species and occur in similar lithologies. It is the author's opinion, therefore, that the fauna at hand is ecologically equivalent to mixture of the Orthorhynchula-Ambonychia and the Zygospira-Hebertella Communities described by Bretsky. As such, it represents a quiet inner-infralittoral environment of very nearly, if not normal, salinity, located some distance from any major clastic source. The environment must have supported a high level of organic activity, with a rich and diverse fauna.

The common presence of Lingula sp. in situ and the low diversity of the conodonts tend to indicate shallow water. This is not contradicted by the high diversity among the faunal elements similar to those of the Zygospira-Hebertella Community since Bretsky has found that this group maintains its high level of diversity until very near the shallow limit of its range. It is quite possible that there may have been some lowering of sea level during the time of deposition of the shales, allowing the encroachment of the Lingula assemblage into an area dominated by a community of the Zygospira-Hebertella type, but this could not account for the low diversity of the conodonts throughout the Stone Lick Lake sequence.

The Orthograptid graptolite, Orthograptus amplexicaulis (Hall) n. sp., appears in the section at the level of Unit VII and occurs scarcely and in compressed condition from there to the top of the section, except in the nodular wackestones of Units IV and VI and in the siltstones of Units III and V. According to Berry and Boucot (1972), graptolites occurring in the upper depth zones of the sea are now regarded as having been pelagic. They also state that according to their observations, scandent biserial graptolites do not occur in the Silurian of the Midcontinent in deposits shallower than their third depth zone, the Pentamerus benthic zone, and that no graptolites occur in the Lingula benthic zone. The graptolites found in the Stone Lick Lake section not only lived at depths probably somewhat less than that cited by Berry and Boucot for the Silurian biserial graptolites, but they also occur in the same beds in which specimens

of Lingula sp. commonly are found. The depth at which these beds were deposited is probably within Berry and Boucot's first, or possibly second, benthic zones (the Lingula and Eocoelia benthic zones, respectively).

There is little doubt that specimens of O. amplexicaulis n. ssp. were indigenous to the area where they are found. It is improbable that they could have been transported there by currents since this would have separated the tiny growth stages (which occur abundantly along with the adult rhabdosomes) from the larger and more developed specimens. The alleged sessile benthic Mastigograptus sp. cf. M. tenuiramosus, was certainly native to the Stone Lick Lake area if it was, indeed, attached to the bottom. However, there is a possibility that it may have been attached to floating sea weed.

Fox (1968) studied the limestones of the Tanner's Creek Formation (basal Richmond) in Indiana from an ecological standpoint. He divided the fauna into five assemblage zones based on more or less consistent fossil abundances and associations. The assemblage zones were further subdivided into a number of fossil communities on the basis of statistical correlation. Zone A, Rafinesquina-Zygospira assemblage zone, is characterized by specimens of Rafinesquina and Zygospira. Other brachiopods present are Resserella, Retrorsirostra, Platystrophia, Leptaena, Strophomena, and Hebertella. Crinoid fragments are common throughout the zone as are representatives of the trilobites Flexicalymene and Isotelus. Also significant is the absence of specimens of the cup coral Streptelasma, which are very common in the higher portions of the formation. Cephalopods are present but are

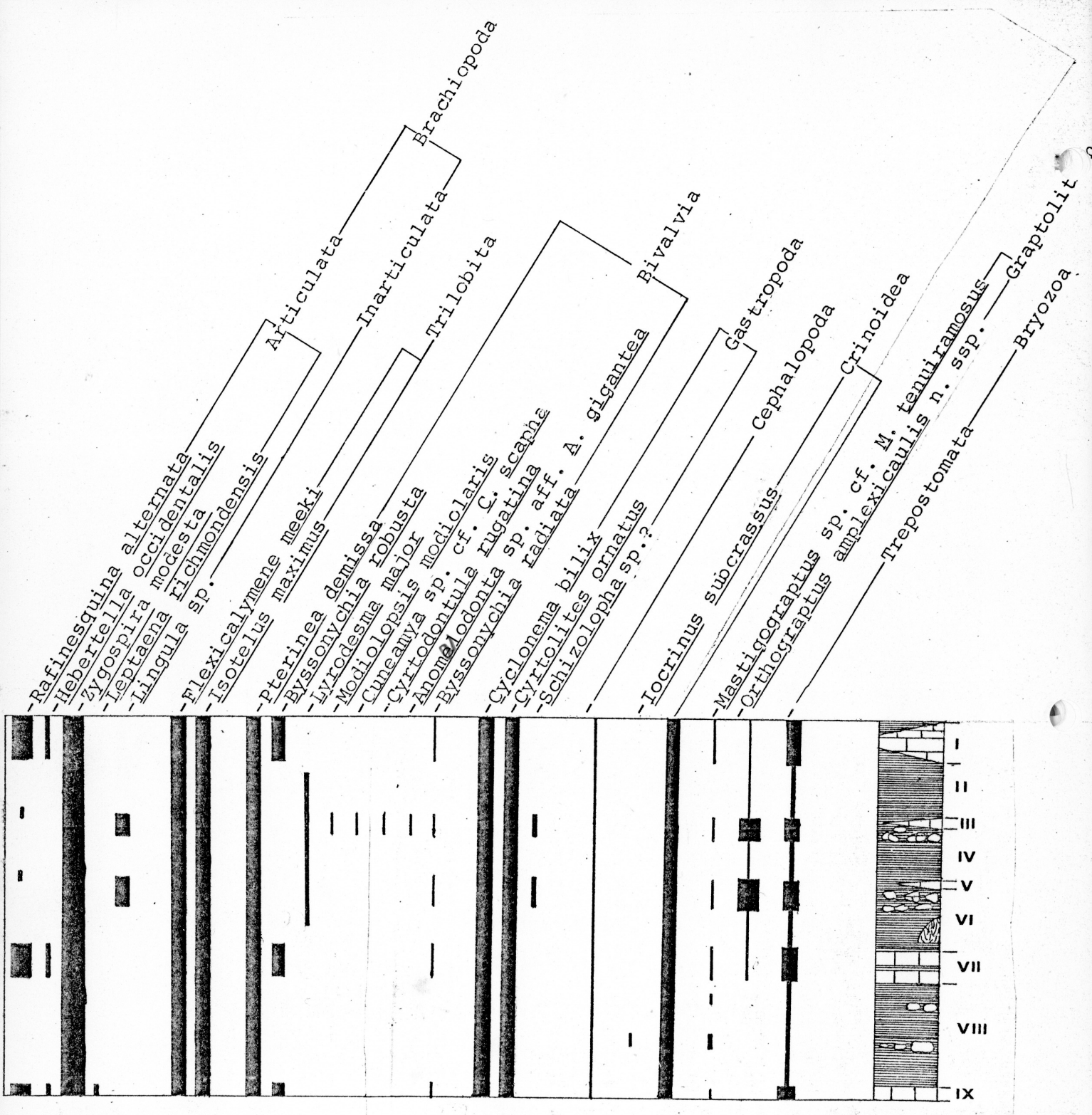


Fig. 5. Distribution and abundance of the major megafossils in the section studied. Width of the bars indicates relative abundance of a particular fossil.

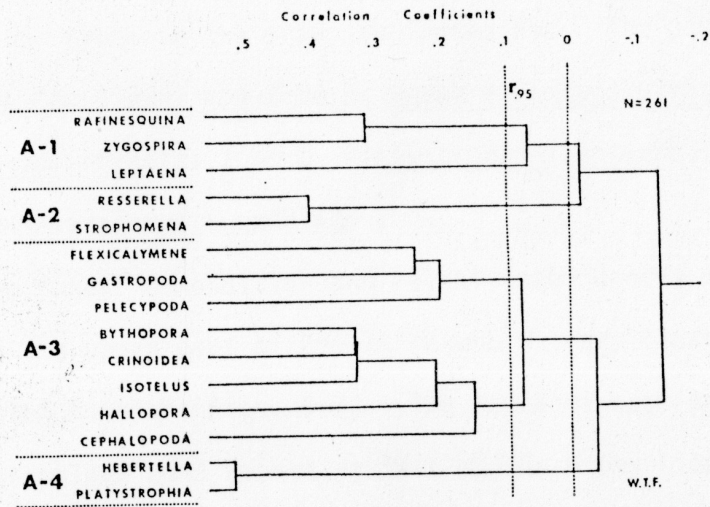


Fig. 6—Dendrogram of fossil associations A-1 through A-4 in the *Rafinesquina-Zygospira* Assemblage Zone, Zone A. (From Fox, 1968)

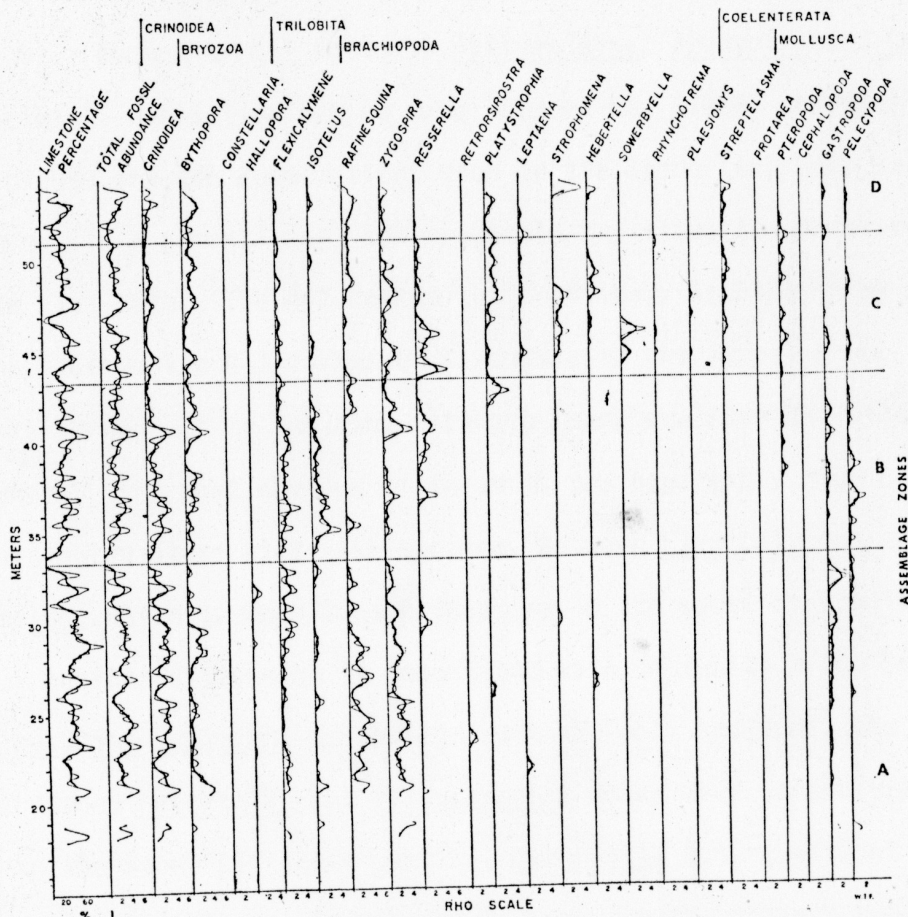


Fig. 7—Time-trend curves for fossil abundance 20-53 m. above the base of the Tanners Creek Formation measured on Dry Fork. (From Fox, 1968)

scarce, while gastropods and bivalves are somewhat more common. This zone is 33 m. thick in the area studied by Fox. The other zones recognized by Fox (1968) are Zone B, Resserella-Zygospira; Zone C, Resserella-Sowerbyella; Zone D, Platystrophia-Leptaena; and Zone E, Rhychotrema-Plaesiomys assemblage zone.

The faunal composition and relative abundances of the various fossils in the upper part of Zone A resemble very closely those found in my section (compare Figs. 5-7). The fauna of each successively younger assemblage zone resembles that of the Stone Lick Lake section less and less with respect to their major elements. Zone A includes four groups of fossil associations referred to as communities (see Fig. 6). Community A-1 includes Rafinesquina, Zygospira and Leptaena. No critical comparison can be made between Fox (1968) correlation coefficients and the associations seen in the Stone Lick Lake section. However, in a general way, they resemble the situation observed at Stone Lick Lake. The A-2 community is entirely lacking in my collections. Community A-3 corresponds roughly to the faunal group which occurs throughout my section, although there are some definite differences. The most obvious of these is the apparently high correlation, in the Stone Lick Lake section, between Flexicalymene and Isotelus, which is much less pronounced in the sections studied by Fox. Another difference is associated with community A-4. In the Rafinesquina-Zygospira assemblage zone of Fox's sections, the brachiopods Hebertella and Platystrophia occur very commonly together, but in the Stone Lick Lake section, Hebertella occurs without Platystrophia. Yet, this may not be very important since Hebertella

is found only rarely in the Stone Lick Lake section.

It should be noted that there are faunal elements present in each of the sections that are not present in the other, but on the whole, the fauna of the upper 15-20m. of Zone A of Fox (1968) resembles fairly well the fauna of Stone Lick Lake section. This makes it likely that the interval represented by the Stone Lick Lake section is equivalent to some part of the upper half of the Rafinesquina-Zygospira assemblage zone of the Tanner's Creek Formation of Fox (1968).

Fox interprets the rock sequence studied by him as being primarily a regressive sequence deposited in a "carbonate basin." He bases his conclusions on the average spar to micrite ratio of the limestones in his sections. The low value of this ratio in Zone A is, in his opinion, indicative of low energy conditions, in an environment below wave base, and the steadily increasing spar to micrite ratio up section is evidence of a regression, with increasingly high energy levels as the water became shallower. The problem with this interpretation is that it assumes that deposition in the Late Ordovician sea of this region fits the clastic basinal model of sedimentation, where facies are arranged in more or less concentric bands and the sediment becomes progressively finer with increasing distances from the shore. This, however, was most likely not the case. Deposition in the Cincinnati region during the Late Ordovician took place on a broad shallow platform, most of which was probably at or near wave base. The topography was undoubtedly irregular with shoals and troughs, with no really extensive shoreline anywhere nearby. This



Fig. 8A. *Mastigograptus* sp. cf. *M. tenuiramosus*. Portion of same specimen as shown in Pl. 4, figs. 1,2. a: autotheca; b: bitheca. 7X.

8B. Same species and specimen. Detail shown at higher magnification after some additional preparation. 15X.

8C. Same at still higher magnification. Note growth lines. 30X.

8D. Same specimen, another portion of the rhabdosome. 7X.

type of geography is much more similar to that in areas characterized by deposition of the type described by the carbonate water circulation model, such as the modern Grand Bahama Bank or the platform behind the Florida Keys. In this model, a drop in sea level tends to produce a decrease of the water circulation, which favors organisms that can tolerate less well oxygenated, more saline and warmer water-- such as those of the Lingula Community, and a drop, rather than increase, in the energy level. This is a result of the wave energy being dissipated rapidly at the platform margin, which may have been as distant as in Tennessee, where there are Ordovician bryozoan reefs. If it is true that the water circulation model is actually the more appropriate one for my area, then the conclusions of Fox (1968) regarding the regressive-transgressive phases and the water depth are wrong and Zone A is the shallowest of the Tanner's Creek assemblage zones.

SYSTEMATIC PALEONTOLOGY

Class Graptolithina Brown, 1846
 Order Uncertain
 Family Uncertain
 Genus Mastigograptus Ruedemann, 1908

Mastigograptus sp. cf. M. tenuiramosus (Walcott)

(Pl. 3, figs. 1, 2; Text-Fig. 8)

1881. Dendrograptus tenuiramosus Walcott, Albany Inst. Proc.

Vol. 10. p. 21, Pl. 1, fig. 4.

1908. Mastigograptus tenuiramosus (Walcott), Ruedemann,

New York State Mus. Mem. 11, p. 216-218, Text-fig. 114,

Pl. 9, Figs. 2,3; Pl. 11, Figs. 2-4; Pl. 12, Figs. 1-2.

Description

The form of the rhabdosome is that of a multi-branched dendroid of bush-like appearance. The stipes (stolothecae?) are rather thick-walled and in the specimens examined, heavily carbonized and fractured. In all cases where the stipes have retained their three-dimensional shape, the hollow center of the stipe is filled with crystalline calcite and its exterior is also usually surrounded by the same material. In cross-section the uncompressed stipes are circular to ovoid, especially near points of branching. Branching follows two general patterns; one is an unequal monopodial branching of the stipe producing a smaller branch inclined at a high angle (up to 50°) to the primary axis from which the branch arises; the second is an equal bifurcation of the main axis at a low angle (10° to 20°). The width of the stipe varies considerably, ranging from 0.04 mm. in the thinnest distal branches to 0.48 mm. in the proximal part of the main axis. The thickness of the stipe walls also varies in the same way.

The thecae are conical and thin-walled. Autothecae are about two to three times as large as the bithecae (up to 1.13 mm. and 0.48 mm., respectively). The arrangement of the thecae is uncertain since they are seldom preserved, but they appear to arise in triads (stolothecae, bithecae, and autothecae), the bitheca being located just below the autotheca with the pair always arising on the same side of the stipe. Both the autothecae and the bithecae are sub-parallel to inclined to the axis of the stipe up to about 40° and are attached to the stipe only at their base with both the dorsal and ventral walls free distally. The thecae tend to curve in toward the stipe in their

apertural region and in this way become sub-parallel to the stipe. The aperture of the autothecae flares out in a bell shape manner.

Occasionally, there are circular rimmed pits on the stipe. They are of two sizes; one is about half the width of the stipe while the other is somewhat smaller. They also appear to occur only on one side of the stipe, as do the thecae, but the two sizes do not seem to be associated with one another in the manner exhibited by the thecae.

The fusellar tissue (as illustrated in Text-fig. 8) appears to consist of complete rings with diagonal sutures more or less randomly arranged.

Discussion

Several well-preserved three-dimensional specimens were obtained from the nodular mudstones in Unit VIII. Fragments of stipes were also observed in the acid residues of samples from the other carbonate lithologies in the section.

Several thin sections of the stipe were examined in order to try to determine the nature and origin of the crystalline calcite found in association with the stipes. Using a petrographic microscope equipped with a cathodo-luminescence device, it was observed that the sparry core was of a type similar to that typical of void fillings and that the spar surrounding the stipe was of two types. The spar closest to the stipe was essentially identical to that filling the center. The growth of these crystals had apparently continued once the void had been filled as a replacement of the calcareous matrix.

This fact is proved by the nibbled edge of the sparry zone and the abundant inclusions of fine particulate material in the crystals of the outer zone, while those of the inner zone were essentially clear. Calcite had also replaced the carbonaceous material of the stipe to a small extent. It is the author's opinion that the spar adjacent to the exterior of the stipes is at least, in part, a void filling and represents a layer of organic material which surrounded the stipes and decayed after burial. It is, however, also possible that this void space was the result of shrinkage of the organic matter of the stipe during carbonification due to the loss of water and other volatiles. If this shrinkage included a longitudinal component, this could also account for the abundant transverse fractures, which often have spaces between the fracture surface, that can be seen in this material.

From a stratigraphic standpoint, this occurrence of M. cf. M. tenuiramosus (Walcott) is much closer to that reported by Ruedemann (1947) for M. perexilis Ruedemann than for M. tenuiramosus. The latter is known in the Cincinnati region from the lower one-third of the Eden shale near Covington, Kentucky and from the "lower Utica shale" near Cincinnati, Ohio. The former is reported from the Waynesville Formation of the Richmond near Clarksville, Ohio (the "Lyrodesma major beds"), which is about twenty-five miles north of Stone Lick Lake and about ninety feet higher up in the section. The form at hand, however, differs from M. perexilis Ruedemann in that the stipes are wider (at least proximally) and that they possess conical thecae and circular rimmed pits, neither of which have been reported in M. perexilis.

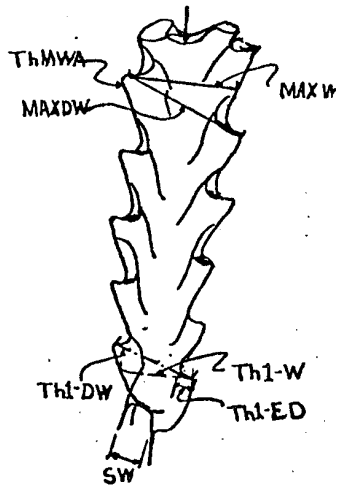


Fig. 9. Sketch of a specimen of Orthograptus amplexicaulis (Hall) n. ssp. showing location of measurements taken. SW: sicular width at its aperture; Th1-ED: depth of apertural excavation of Th1¹; Th1-W: width of the rhabdosome at the level of the Th1¹ aperture measured perpendicular to the axis of the rhabdosome; Th1-DW: diagonal width of the rhabdosome measured between the outer margins of the Th1¹ and Th1² apertures; MAXW: maximum width of the rhabdosome measured perpendicular to the axis of the rhabdosome; MAXDW: maximum diagonal width of the rhabdosome measured between the outer margins of the thecal apertures of a pair of thecae; ThMWA: the theca at which the maximum width is attained.

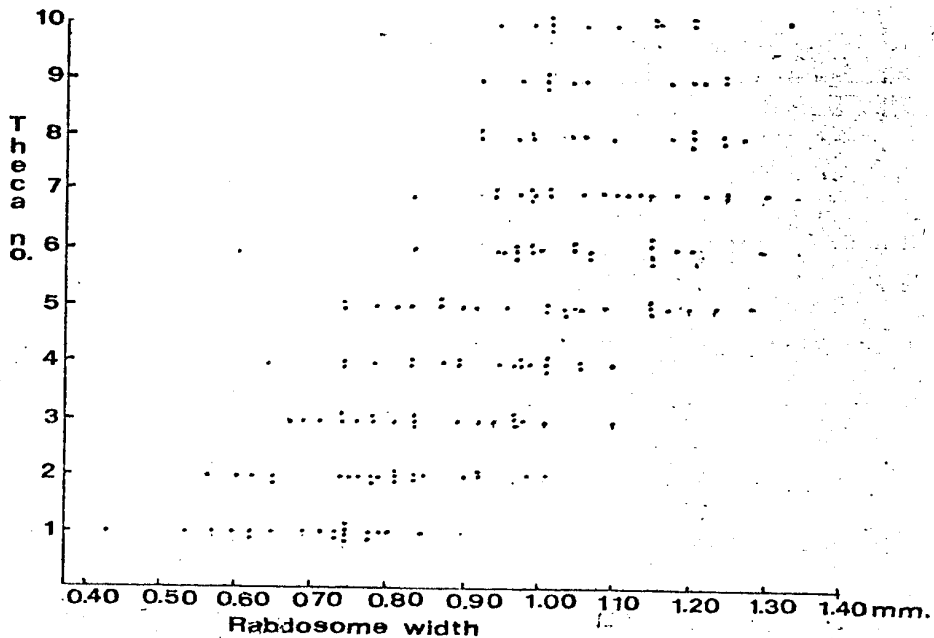


Fig. 10. Scatter diagram showing the relationship between the width of the rhabdosome and the thecal number.

It is possible that the specimens described here are identical to the form Ruedemann described as M. perexilis, but the description he provides is not detailed enough that the species can be objectively and reliably recognized. On this basis, and on that of the close morphological similarities with M. tenuiramosus (Walcott), my specimens are included with the latter species.

Material

Several mudstone nodules containing specimens of M. cf. M. tenuiramosus were collected from Unit VIII, sections G and H. The complete colony was never observed.

Class Graptolithina Brown, 1846
 Order Graptoloidea Lapworth, 1875
 Family Diplograptidae Lapworth, 1873
 Genus Orthograptus Lapworth, 1873

Orthograptus amplexicaulis (Hall) n. ssp.
 (pl. 3, Figs. 1-14; pl. 4, pl. 5)

Description

Several hundred isolated rhabdosomes were studied and measurements were taken on twenty specimens (Fig. 10 and Table 1). The longest observed rhabdosomes were slightly over 1 cm. in length. The specimens widen from an average of 0.66 mm. (0.43-0.84 mm.) at the level of the Th 1¹ aperture to an average of 1.09 mm. (0.75-1.45 mm.) maximum width which is attained at the level of Th5¹ or Th6¹. However, in some specimens the rhabdosome may widen very slowly and not attain the maximum width until Th10¹ with all variations in between.

This maximum width is usually maintained but some specimens show a tendency to narrow for a few thecal pairs. The rhabdosome is aseptate, the thecae alternate with seven to nine pairs in the proximal 5 mm. and fifteen to eighteen in the proximal 10 mm.; they overlap slightly more than $3/10$ (32%) of their length, proximally to $2/5$ (44%) distally and are inclined 20° to 30° to the axis of the rhabdosome with the larger inclination typically distally. Thecae are semi-circular to slightly quadrangular in cross-section and are straight to gently sigmoidal but without a definite geniculum, as in the glyptograptid type. The free ventral wall is restricted in this latter form just above the aperture of the preceding theca. This portion of the free ventral wall is almost always concave, forming a nearly circular aperture with the preceding theca. Further up, the free ventral wall reverts to its usual convex configuration. In obverse view the apertural margin ranges from perpendicular to the axis of the thecae to an inclination of 45° to the axis of the rhabdosome. The apertural margin usually intersects the free ventral wall at an acute angle. In lateral view, it has the appearance of an inverted U with the open end directed proximally. The apertural margin has a selvage rimming it which merges with the fusellar tissue of the wall of the next theca. On $Th1^1$ this selvage often develops into a small lip on the outer part of the margin. The apertural excavation of $Th1^1$ is rather shallow (0.10-0.18 mm), but it becomes two to three times deeper in the distal thecae. The sicula is short, as an average 1.2 mm. (the maximum length observed is 1.35 mm.), and

is partially exposed on the obverse side of the rhabdosome. The sicular aperture is moderately concave and the ventral apertural region extends somewhat beyond the most proximal portion of Th1². The sicula bears a virgella about 0.3 mm. long and two antivirgular spines which are only slightly shorter. The rhabdosome is ovoid in cross-section but may be compressed to varying degrees. A thin nema may extend beyond the distal end of the rhabdosome for a distance of more than 5 mm.

Discussion

With respect to the general morphology, shape, and relative proportions of the rhabdosome, the described form resembles a host of similar orthograptids referable to the Orthograptus amplexicaulis group, including O. truncatus, Diplograptus foliaceus, and D. peosta. All of these forms have essentially the same morphology and differ primarily in size and thecal spacing.

The specimens on hand differ from the above forms and from O. gracilis, which they resemble in their ontogenic development and the tendency to widen slowly, in that it has a considerably narrower rhabdosome (Stone Lick Lake specimens: 0.66 mm. proximally, 1.09 mm. distally; O. amplexicaulis: 0.8 mm. to 1.0 mm., 2.0 mm. to 3.5 mm.; O. truncatus intermedius Ellis and Wood: 2.5 mm. average distally; O. peosta Hall: 1.4 mm., 2.6 mm.; O. gracilis Romer: 1.2 mm., 1.6 mm.; O. amplexicaulis var. pertenuis Ruedemann: 1.2 mm., 1.6 mm.). It also lacks the mesial spine common to all the above forms and has closer thecal spacing (Stone Lick Lake specimens: 15 to 18 in the proximal 10 mm.;

O. amplexicaulis Hall: 12 to 16; O. truncatus intermedius: 10 to 14;
O. peosta: 11 to 13; O. gracilis: 10 to 11; O. amplexicaulis pertenuis:
 13 to 14).

In a recent paper Riva (1974, p. 32) states,

The specimens of O. truncatus differ from those of O. amplexicaulis only in degree: they have less closely spaced thecae and a longer sicula...than those of O. amplexicaulis, but otherwise are indistinguishable. Such differences may be of sub-specific value...

It is the author's opinion that the differences in thecal spacing, rhabdosome width, and the lack of the Th1¹ mesial spine indicate that the Stone Lick Lake specimens represent at least a separate sub^ospecies distinguishable from O. amplexicaulis amplexicaulis as well as O. amplexicaulis pertenuis, and other similar sub-species of that species described previously.

It should also be noted that the Stone Lick Lake specimens are from a younger stratigraphic interval than previously known occurrences of specimens of the O. amplexicaulis group, except for O. truncatus richmondensis Ruedemann, which has been described from the Arnheim Formation in the vicinity of Oxford, Ohio (Berry, 1966). Other known occurrences are the Trenton Limestone, the Canajoharie shales, the Snake Hill Shale, the Utica Shale and Lorraine Shale of New York, and their equivalents in Canada, England, and the Marathon District of Texas.

Abnormalities

There was only one abnormality observed among the specimens

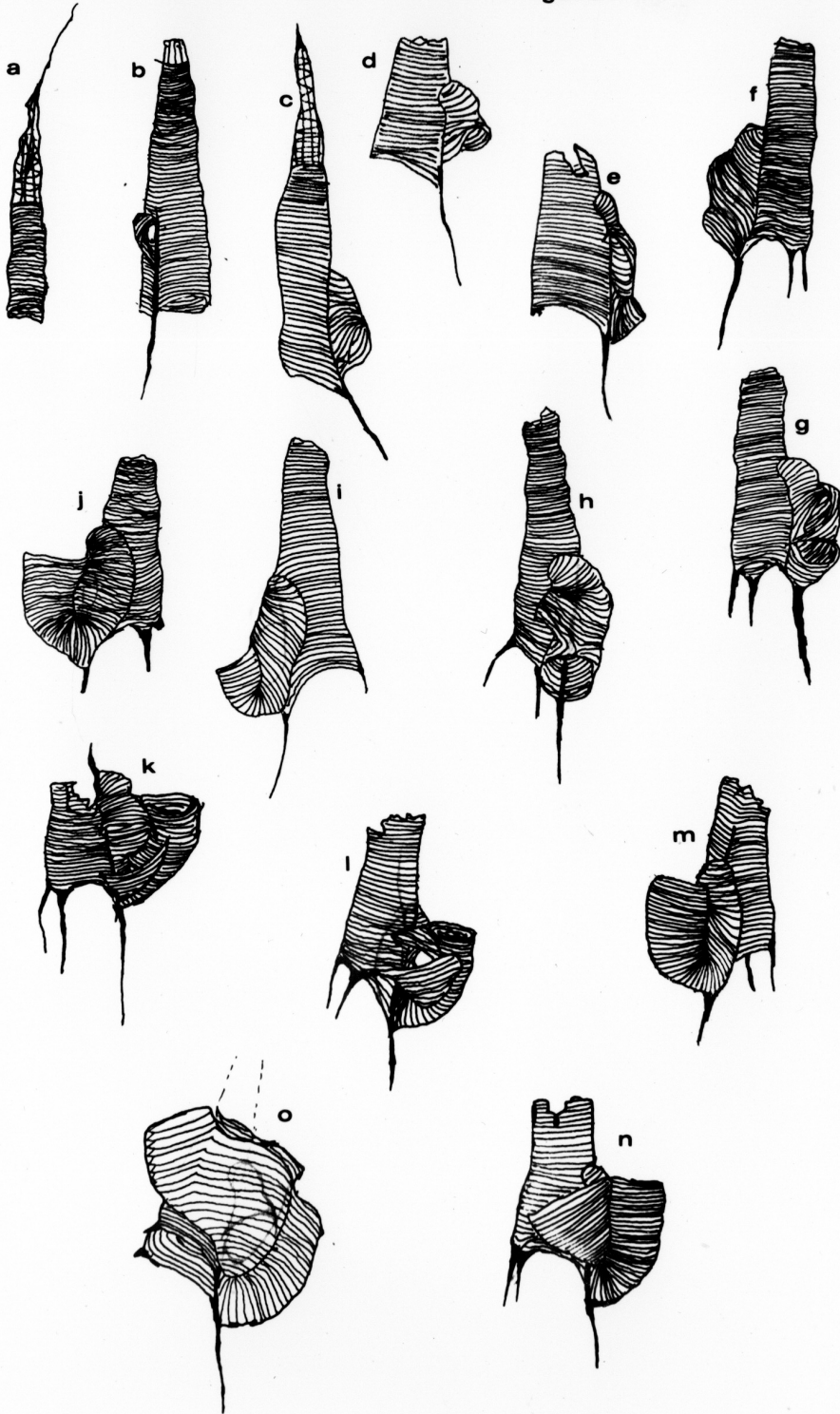
examined, and it was seen only in two specimens. It consists of a bifurcation of a ThX^1 theca at an early stage in such a way that at a mature growth stage there are two separate thecae in very close association on the same side of the rhabdosome at the same level. The abnormality appears to persist in subsequent generations of thecae and ThX^1 migrates to the center of the reverse side of the rhabdosome while it simultaneously increases to a size very nearly equal to that of the normal thecae. In this way, a third row of thecae is established which gives the rhabdosome a triserial appearance. This triserial thecae arrangement persists for five thecal pairs (triads) at which point the specimens are broken. Much work needs to be done before this unique abnormality can be understood and explained, but additional specimens are required for such a study.

Ontogeny

A great number of young growth stages of this form were found in the acid residues of samples from the nodular wackestone lithology. They range in stage of development from prosicula to forms with four thecae, but non-adult forms with more than Th^1 developed were rare. Fully-developed siculae representing the stage just before and just after the formation of the foramen and the initial bud are by far the most common ones in my collection. This apparently was a critical period in their growth.

Specimens of the prosicular stage are about 0.4 mm. long and very thin-walled. They are provided with longitudinal threads of varying length, some of which run the entire length of the prosicula

Figure 11



Orthograptus amplexicaulis (Hall) n. ssp.
early growth stages.

and other begin one-third to one-half the way down the prosicula toward its aperture. The four or five longer threads unite at the apex of the prosicula to form an extremely slender nema (pl. 5, Figs. 1, 2, Text Fig. H, a) that may reach a length of 0.5 mm. prior to the formation of the rhabdosome. Following the prosicula is a metasicula, composed of half rings of fusellar tissue, which comprises the remaining part of the complete sicula, which is 1.2 mm. long as an average.

The first indication of the development of the virgella is a down-warping of the growth lines of the aperture, forming a pronounced prolongation of the apertural margin of the sicula (pl. 5, Figs. 3, 4). This is followed by a thickening of the fusellar tissue at the apex of the prolongation and the formation of the virgella as a rod of corticular tissue layer down along the base (pl. 5, Fig 5). The formation of the anti-virgellar spines follows the same general pattern and begins at about the time of the formation on the $Th1^2$ foramen.

The development of the rhabdosome begins with the restoration of an oval-shaped hole (foramen) in the wall of the sicula next to the virgella at a point on the reverse side of the sicula about two-thirds the length of the metasicula, as measured from its top (pl. 5, Fig. 6). $Th1^1$ grows from here across the line of the virgella toward the obverse side of the sicula and downward toward the aperture (pl. 5, Figs. 7-9, Text Fig. 11, b). After about 0.1 mm., an embayment begins to form in the theca by the growth of its reverse side as a narrow ridge along the sicula and of its obverse side as a wide

flange, while growth of the central part of the theca temporarily stops (pl. 5, Fig. 10, 11; Text Fig 11 c, d). A little further down the sicula these two sides fuse to form a foramen (pl. 5, Fig 13, Text Fig 11 e, g, h). The growth of $Th1^1$ continues on down the sicula and beyond the aperture along the virgella for a short distance (pl. 5, Fig. 15, Text Fig. 11 f, g). It then begins to curve up and toward the reverse side of the sicula and is no longer attached to the sicula but grows back along itself and out around the $Th1^2$ foramen (pl. 5, Figs. 16, 17; Text Fig. 11 i, j). It continues growing in this way until it is complete. $Th1^2$ proper begins as a flange near the base of $Th1^1$ and grows up on the sicula and the side of $Th1^1$ while simultaneously a hood develops over the foramen left in $Th1^1$ and grows down (pl. 5, Fig. 18, Text Fig. 11 k, l). The growth of the hood appears to stop shortly and the flange continues to grow completely around the reverse side and out over the hood without fusing with it as it does in *O. gracilis* (Bulman, 1932) (pl. 5, Fig. 19, Text Fig. 11 n). Just below the level of the $Th1^1$ aperture, which is fully formed some time during the early stages of growth of $Th1^2$, the $Th1^2$ metatheca is differentiated from the protheca and formation of the inter-thecal septum begins (Text Fig. 11 o). $Th2^1$ begins its growth as the $Th1^2$ nears completion. Initially, it is an undifferentiated protheca from which $Th2^1$ develops, followed shortly by $Th2^2$ in an alternating fashion. There appears to have been a greater time lag between the initiation of the second theca in a pair and the first theca in the following pair than between the two thecae of the same pair. This resulted in a slightly shorter distance (both diagonally and

parallel to the axis of the rhabdosome) between the level of the apertures of, for instance, Th2¹ and Th2² than between those of Th2² and Th3¹. This fact makes it possible to distinguish the ThX¹ and ThX² sides of the rhabdosome, even if the proximal end is not preserved (and consequently, also the obverse and reverse sides since ThX¹ is always on the left, if one orients the specimens with the proximal end down in obverse view). Further development of the rhabdosome follows this pattern. By the time the second thecal pair is fully developed the protheca has fused on the obverse side of the sicula, which is not exposed subsequently.

Material

The several hundred excellently preserved adult and immature specimens examined in this study were obtained by acid preparation of several wackestone nodules from Units IV and VI.

CONCLUSIONS

The stratigraphic position of the Stone Lick Lake section is determined to be within the Oregonia Member of the Arnheim Formation on the basis of its topographic relations to a nearby section dated by conodonts and on the basis of the presence of characteristic Richmond fossils.

The environment of deposition of these beds represents an area of quiet water carbonate sedimentation with a moderate input of terrigenous clastics in the clay to fine sand range and a fairly high rate of deposition. The water was probably shallow and normal marine

with low turbidity. The strata investigated contain a diverse fauna of bryozoans, brachiopods, crinoids, moluscs, trilobites, ostracodes, chitinozoans, conodonts, graptolites, sponges, scolecodonts, acritarchs and algae. Ecologically the fauna was heavily dominated by filter feeders of various types. Excellent preservation is shown by many of the fossils present in the nodular rocks of the wackestone to mudstone lithology, the deposition of which was the result of some unusual but currently poorly understood conditions.

There are certain discrepancies between the depth zonation and faunal associations of graptolites worked out by Berry and Boucot (1972) and the data from the Stone Lick Lake section. For instance, in my section graptolites occur with a species of Lingula which, according to their work on the relation of Silurian graptolites to brachiopod depth zones, should not be the case. However, their work concerns Silurian faunas and their results may not be valid in the Ordovician.

The Stone Lick Lake fauna appears to be a mixture of the Lingula faunal assemblage and the Orthorhynchula-Ambonychia Community and the Zygospira-Hebertella Community of Bretsky (1971) and to represent the inner infralittoral zone. The fauna also appears to be very similar to the upper part of the Rafinesquina-Zygospira assemblage zone (Zone A) of Fox (1962). Paleogeographic data, which necessitates the application of a different model of sedimentation than the one assumed by Fox for deposition in the Cincinnati region, seem to indicate that his regressive-transgressive sequence may be in error.

Representatives of two species of graptolites are present in the section. Mastigograptus sp. cf. M. tenuiramosus (Walcott) of

uncertain affinities at the order and family level, is represented by well preserved specimens only in the mudstone nodules in Unit VIII. Specimens of a new sub-species of the diplograptid graptoloid Orthograptus amplexicaulis occur abundantly in the nodular wackestones. Two specimens of this form show a previously undescribed thecal abnormality resulting in a triserial appearance. Abundant growth stages of this form were also found which made it possible to work out its previously undescribed ontogeny in detail.

ACKNOWLEDGMENTS

I would like to thank Dr. Stig M. Bergström for his advice and patience throughout this long-lasting project; Robert S. Wilkinson for his generous help with the photography; Dr. K. Stanley for his advice on petrographic and sedimentologic problems; the department of Geology and Mineralogy at the Ohio State University and Robert F. Markley for access to the Scanning Electron Microscope; the Friends of Orton Hall Fund for economic support; and last but not least Deborah for her moral support which kept me going.

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PLATE 1

All figures are 59X

Phragmodus undatus Branson and Mehl

Figs. 4, 7, 15. Dichognathiform elements.

Figs. 12, 14. Phragmodiform elements.

Fig. 18. Oistodiform element.

Plectodina sp.

Figs. 1, 2. Trichonodelliform elements.

Figs. 3, 9. Prioniodiniform elements.

Figs. 5, 8. Cordylodiform elements.

Fig. 6. Zygognathiform element.

Fig. 11. Cyrtoniodiform element.

Drepanoistodus suberectus (Branson and Mehl)

Figs. 10, 17, 19. Drepanodiform elements.

Figs. 13, 16. Oistodiform elements.

All illustrations are reflected light photographs.

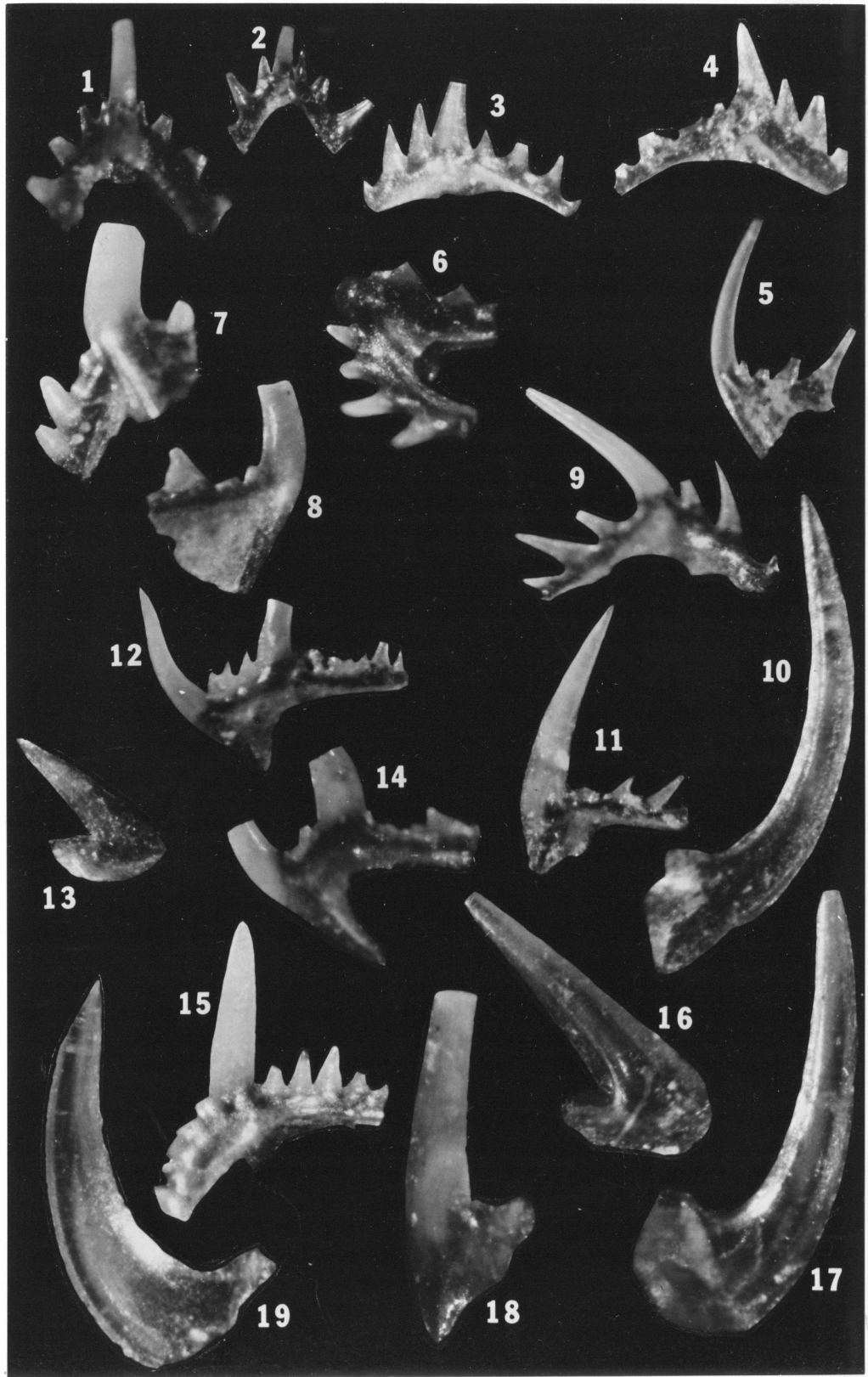


PLATE 2

Conochitina sp.

Fig. 1. Basal part of specimen with neck broken off. Note distortion caused by the growth of pyrite framboids within the vesicle. Slightly inclined view. 325X.

Conochitina sp. cf. C. seriespinosa Jenkins

Figs. 2, 3. Complete vesicle. Note the spines. Lateral view.
Fig. 2: 322X. Fig. 3: 330X

Conochitina sp.

Fig. 4. Enlargement of aboral end of same specimen as in Fig. 5. Note absence of spines. 465X.

Fig. 5. Complete vesicle. Slightly inclined view. 230X.

Conochitina micracantha capitata Eisenack

Fig. 7. Almost complete specimen with broken aperture. Lateral view. 90X.

Fig. 10. Enlargement of aboral end. Note the spines. 450X.

Desmochitina minor typica Eisenack

Fig. 6. Almost complete specimen with broken aperture. Lateral view. 450X.

Desmochitina sp. cf. D. lata Eisenack

Fig. 8. A two-specimen chain. The lower specimen is flattened. Lateral view. 290X.

Fig. 9. Almost complete specimen. Note the nodose globular spines. View at approximately 30 inclination. 625X.

All illustrations are Scanning Electron Microscope micrographs .

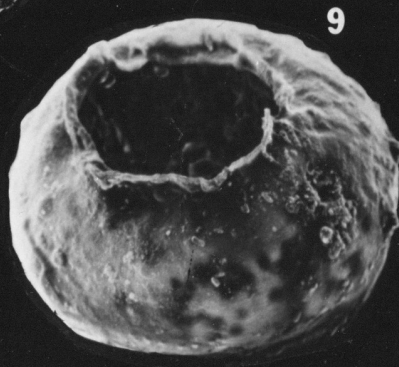
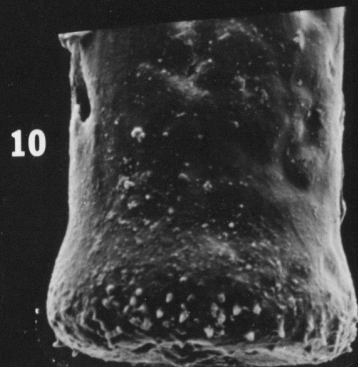
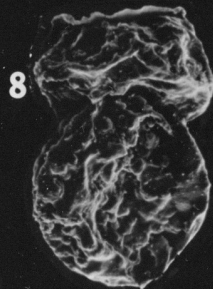
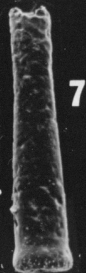
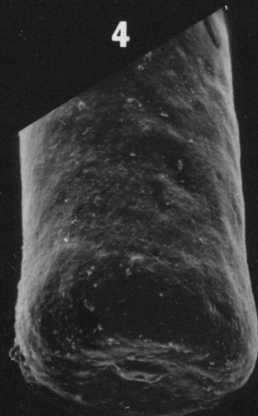
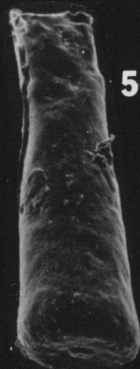
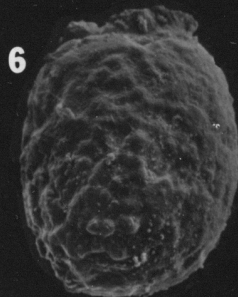
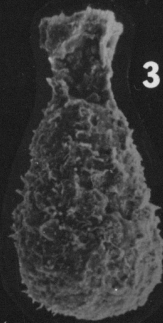
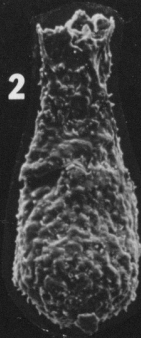
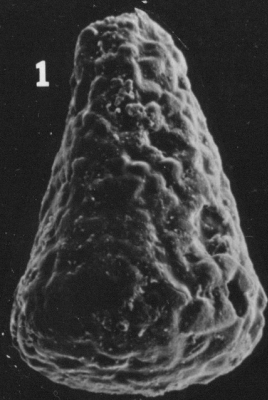


PLATE 3

Mastigograptus sp. cf. M. tenuiramosus (Walcott)

Figs. 1, 2. Specimen in matrix of a mudstone nodule from Unit VIII. Nodule broken perpendicular to bedding. Fig. 1 is lower left portion of Fig. 2 at higher magnification. 19X. Fig. 2. 2X.

Orthograptus amplexicaulis (Hall) n. ssp.

Figs. 3-14. Specimens isolated from matrix. Note variation in thecal shape and spacing. 8X.

Fig. 15. Etched wackestone nodule with specimens partly imbedded in matrix. Nodule from Unit IV. Note the roughly circular distribution of randomly oriented specimens. Natural size.

All figures are reflected light photographs.

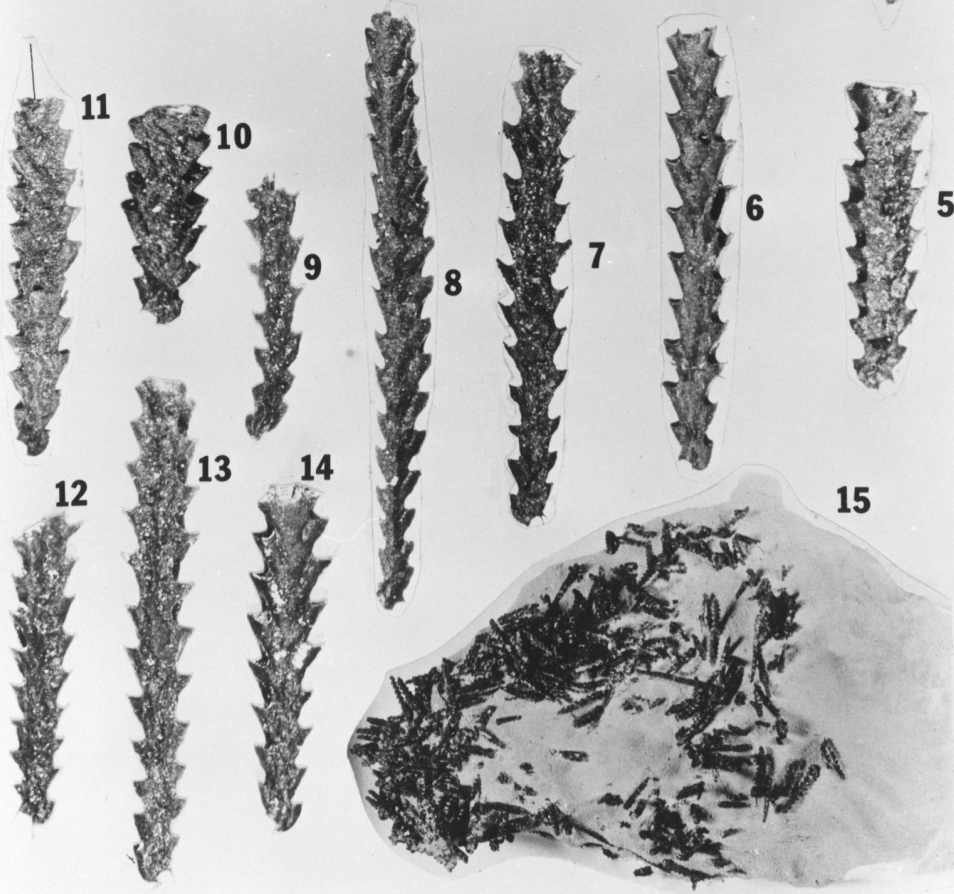
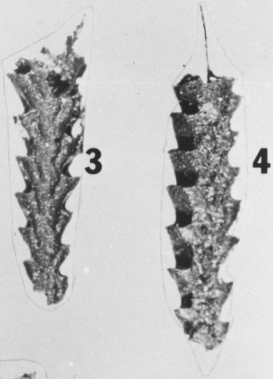
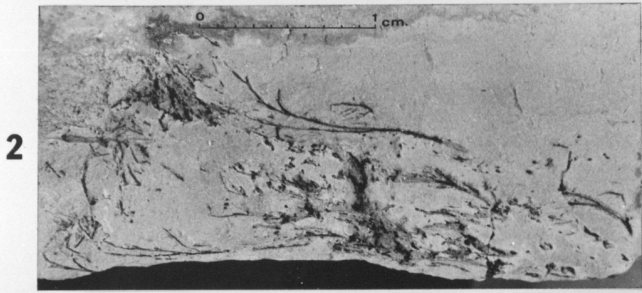
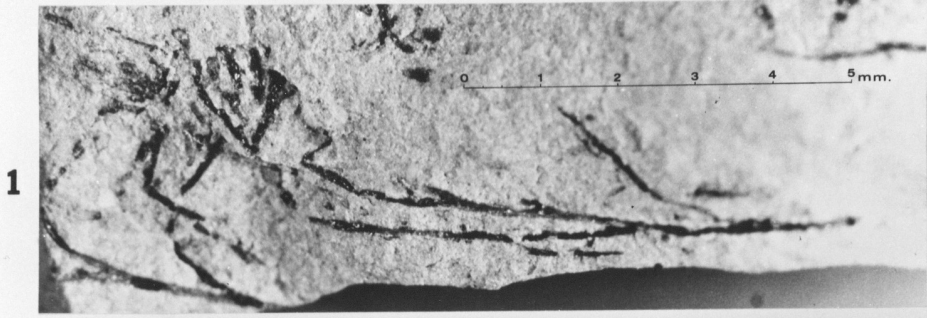


PLATE 4

Orthograptus amplexicaulis (Hall) n. ssp.

Fig. 1. Distal end of specimen illustrated in Fig. 6. Note shape of thecal apertures and apertural excavation. 28X.

Fig. 2. Right lateral view of ThX¹ side of rhabdosome showing abnormal development of thecae. 26X.

Fig. 3. Same specimen as in Fig. 2., obverse view. Note position of abnormal thecae. 13X.

Figs. 4, 7-11. All are views of specimen illustrated in Fig. 11.

Fig. 4. Inclined end on view of distal portion of the specimen. 24X.

Fig. 7. Near axial view. Note origin of inter-thecal septum. 24X.

Fig. 8. Right lateral view of proximal end of specimen. Note complete lack of any vestige of mesial spine on Th1¹. 120X.

Fig. 9. Obverse view of Th7¹ aperture. Note the selvage along the thecal margin. 225X.

Fig. 10. Distal end of specimen in obverse view. Note configuration of growth lines in immature Th9² and Th10 protheca. 18X.

Fig. 11. Obverse view of complete specimen. Note the very gradual change in rhabdosome width. 9X.

Fig. 5. Inclined end on view of the obverse side of the proximal portion of a specimen. Early growth stages of Th1¹ visible. 55X.

Fig. 6. Distal portion of rhabdosome. Note closeness of thecal spacing. 14X.

All figures are Scanning Electron Microscope micrographs.



PLATE 5

All figures are 36.5X

Orthograptus amplexicaulis (Hall) n. ssp.

Fig. 1. Prosicula. Note longitudinal and spiral threads.

Fig. 2. Prosicula and immature metasicula with nema.

Fig. 3. Metasicula. Note down-warping of growth lines.

Fig. 4. Metasicula. Growth lines drawn out further preparatory to the formation of the virgella.

Fig. 5. Sicula. Note thickening of fusellar tissue to form a beginning of virgella.

Fig. 6. Mature sicula showing resorbed foramen. Note termination of half rings at edge of foramen.

Fig. 7. Sicula showing very early prothecal stage of $Th1^1$

Fig. 8. Slightly later $Th1^1$ prothecal stage. Note variation in position of origin of $Th1^1$ relative to the sicular aperture. Compare with Figs. 7, 9, 14.

Fig. 9. Sicula showing elongation of half rings of $Th1^1$ protheca down the sicula.

Fig. 10. Sicula showing very early stage of formation $Th1^2$ foramen. Note the bell-shape of the protheca at this point.

Fig. 11. Specimen showing continued suppression of half rings in central part of the protheca producing a notch. Note the wedging out of half rings in notch (cf. Fig. 10) Also note the flange on the obverse side of the protheca.

Fig. 12. Obverse view of a growth stage after formation of the $Th1^2$ foramen is completed. $Th1^1$ is beginning its turn toward the reverse side.

Fig. 13. Same stage as in fig. 12. but is reverse view.

Fig. 14. Obverse view of a stage during the upward curving of $Th1^1$. Note the wedging out of the half rings along the inside of the curve.

Fig. 15. Left lateral view of a specimen at same stage of development as in Fig. 14. Note migration of $Th1^1$ as it grew down the obverse side of the sicula and $Th1^1$'s growth beyond the sicular aperture along the virgella.

PLATE 5
(cont.)

Fig. 16. Obverse view of specimen at stage of growth of Th1¹ upwards back upon itself.

Fig. 17. Same as Fig. 16, but slightly more mature.

Fig. 18. Specimen with growth of Th1¹ complete. Growth of Th1² initiated as a flange around and up the sicula. Note that Th2 protheca is joining Th1¹ and the sicular wall.

Fig. 19. Reverse view of a specimen at a growth stage just three half rings after the differentiation of Th1² from the protheca. Note the shadow exhibited by the hood formed over the Th1² foramen in Th1¹. Also note that the hood has not fused with the Th1² protheca.

Fig. 20. Obverse view of a specimen with Th1² nearly complete (on right) and Th2 protheca developing.

Fig. 21. Reverse view of a specimen of nearly the same age as that in Fig. 20. but Th2 protheca is more developed than it is in Fig. 20.

The photographs were made on a Leitz Orthoplan petrographic microscope equipped with a Leitz Orthomat camera device using infrared sensitive film and a Kodak #25 red filter. The scale on the plate in hundredths of a millimeter (the smallest increments).

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