The *Foerstia* Zone of the Ohio and Chattanooga Shales

GEOLOGICAL SURVEY BULLETIN 1294-H

The *Foerstia* Zone of the Ohio and Chattanooga Shales

By J. M. SCHOPF *and* J. F. SCHWIETERING

CONTRIBUTIONS TO STRATIGRAPHY

GEOLOGICAL SURVEY BULLETIN 1294-H

An explanation for the stratigraphic zonation of the fossils and a report on a newly discovered occurrence of the Foerstia *zone in western Ohio*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 73-607393

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 30 cents (paper cover)

CONTENTS

ILLUSTRATIONS

[Plates follow references]

CONTRIBUTIONS TO STRATIGRAPHY

THE *FOERSTIA* ZONE OF THE OHIO AND CHATTANOOGA SHALES

By J. M. SCHOPF and J. F. SCHWIETERING[1]

ABSTRACT

Foerstia, long regarded as an inconspicuous problematic fossil, is allied with the pelagic algae. It is known to be present only in a zone within the Huron Member of the Ohio Shale (Upper Devonian) or its apparent time equivalents, principally in the Appalachian interior basin. *Foerstia* was restricted stratigraphically and geographically by its need for a suitable littoral environment for reproduction. Probably such an environment existed for a short interval during the Late Devonian along the southeastern shore of the transgressive epicontinental sea. The period during which *Foerstia* was fossilized probably coincided with the time during which the reproductive habitat persisted. Only about 20 *Foerstia* localities are known, but this fossil genus probably marks a consistent time zone in the Eastern United States. Its distribution may be related to tidal currents in the Late Devonian sea.

INTRODUCTION

Foerstia is a plant genus based on small abundant fossils that are commonly about the same size as common duckweed and superficially resemble it. We regard these fossils as remains of thallose algae. The fossils are found in a restricted zone of the Ohio and Chattanooga Shales (Upper Devonian), chiefly within the Appalachian region (Hass, 1956; Winslow, 1962). This paper suggests an explanation for the stratigraphic zonation of the fossils and reports a newly discovered occurrence of the *Foerstia* zone in western Ohio.

The fossils consist of small carbonaceous compressions[2] which are oval to bilobate in outline (pl. 1) and show a cancellate surface

[1] The Ohio State University, Columbus, Ohio.

[2] The coaly cell remains in this material differ slightly from land-plant compression material in their reaction to oxidative maceration. Some chemical differences may exist. Although resistant to maceration, the cell walls do not show a cuticle in section and seem not to be cutinized in any normal manner. Probably both algal cell-wall and mucilage materials contribute in altered condition to the coalified remains of the fossil algae. A discussion of the cell-wall chemistry of modern seaweeds is given by Kreger (1962) and by O'Colla (1962).

pattern or texture when viewed under a lens (see especially pl. 1, fig. 3). Fragments in cable-tool well cuttings can be identified by their characteristic surface texture, which is a reflection of the walls of cells that form a dense surficial layer (pl. 2, figs. 5–7). This layer is comparable to the surficial meristoderm that forms the toughest part of the thallus of many advanced types of modern seaweeds. Variation in gross outline of the thalli of the fossil *Foerstia,* aside from results of incidental breakage in preparation, seems to have been a function of balance between apical growth, periodically dichotomizing, and distal decay. Common floating forms of modern marine algae show a similar mode of vegetative propagation. No basal or holdfast parts of the foerstian thallus have ever been observed, and we believe that all the observed fossils originally were floating organisms. Juvenile stages, as yet not found as fossils, may well have had a holdfast attachment.

In Devonian black shale, *Foerstia* is associated with authigenic concretions containing Radiolaria (Foreman, 1959); with conodonts, fish plates, and other marine fossils (Hass, 1956; Winder, 1966); and with the disseminules of *Tasmanites. Tasmanites* is now recognized to be closely allied with the planktonic marine alga *Pachysphaera* (Wall, 1962), and *Tasmanites* is also widely distributed in other marine deposits (Winslow, 1962). These consistent associations, and lack of evidence to the contrary, leave no reasonable doubt that *Foerstia* represents marine vegetation.

EARLIER REPORTS

The fossils assigned to *Foerstia* have a long history of misinterpretation and confusion. Therefore, a brief review of earlier reports that relate to the naming and interpretation of *Foerstia* may be helpful. Considerable information can be gained from the older literature, if the vagaries in naming are correctly interpreted.

In referring to similar material, Arnold (1954) preferred to use the name *Protosalvinia* Dawson (1884) rather than *Foerstia* White (1923). However, we agree with Kräusel (1941) that the typical form of *Protosalvinia* from Brazil is generically distinct from the allied types found in the Ohio and Chattanooga Shales. Lang (1945) also substantially agreed with Kräusel, but he overlooked the fact that *Protosalvinia brasiliensis* Dawson (1884) is the type species of the genus and must therefore continue to bear the generic name. Lang, therefore, used *Protosalvinia* for the North American fossils and assigned the Brazilian ones to a new genus he called *Orvillea*. "*Orvillea*" can only be a synonym of *Protosalvinia,* but the relationship Lang was attempting to express, that the common types of the Brazilian and North American fossils are generically distinct, is apparently correct. Almost the same conclusion had been arrived at independently by White (in White and Stadnichenko, 1923) and probably constituted his reason for proposing the new genus *Foerstia.* He was, however, concerned with the plant materials as a source of oil and did not discuss taxonomy. Arnold (1954) suggested that White may not have known of Dawson's *Sporocarpon* paper (1888). White made no reference to it, and he did establish *F. ohioensis* White, 1923, as the type species of *Foerstia. F. furcata,* the species identified and misassigned by Dawson (as mentioned later), probably is synonymous with *F. ohioensis,* but *F. furcata* was not assigned to *Foerstia* until Pia did so (1927). White also continued to use the name *Protosalvinia* for some of the North American material, but Kräusel (1941) thought that this material should also be assigned to *Foerstia* as *F. ravenna* (White) Kräusel. We agree with Kräusel's principal conclusion but prefer to regard *F. ravenna* as a growth form of *F. ohioensis.* Without indulging in technicalities unnecessary for our present purpose, we may say that the genus *Foerstia* White, as employed by Kräusel (1941), seems to be a usable taxonomic concept that can be applied to nearly all thalloid material of this type in North America.

The essential distinction between the Brazilian *Protosalvinia* and North American *Foerstia* is that the thallus of *Protosalvinia* is virtually salverform (discoidal and naturally flattened), and has abundant conceptacles (craters) on the dorsal (upper) surface. Some thalli are bilobed (Dawson assigned these to a separate species[3]), but they are not bifurcate. *Foerstia* thalli are characteristically bifurcate, though end-on fossil compression of a very short (slow-growing?) tip (the "ravenna" type of growth) may simulate the discoidal appearance of the *Protosalvinia* thallus. The crowded abundance of dorsal conceptacles is never observed in thalli of *Foerstia* where conceptacles usually form inside the bifurcation. The individual conceptacles are similar in both genera and provide good evidence that the two are related and probably should be associated within the same taxonomic family.

Other names also have been applied somewhat indiscriminately to *Foerstia.* Dawson (1888) first identified material sent to him

[3] The senior author examined original material distributed by Dawson from Rio Curuá in Brazil, and now in collections at the New York State Museum, Albany. The author's findings confirm Kräusel's and Lang's general observations on *Protosalvinia braziliensis* and conflict with those of Sommer (1962). Some of the thalli shown on the New York Museum specimen also agree well with Dawson's illustration and description of *P. bilobata,* which Sommer said never occurs in mixture with *P. braziliensis.* The new material Sommer illustrated agrees with *Foerstia* more than it does with *Protosalvinia.*

by Edward Orton from Ohio with a problematical genus that Williamson (1878) had called *Sporocarpon.* Dawson thought that both Williamson's and the Ohio material might be allied with a type of free-floating water fern ("Rhizocarpalean"); it now seems improbable that either is so allied, and the two fossil types are evidently unrelated. However, in several papers and books, Dawson continued to speak about the rhizocarps of the Erian when he had reference to *Foerstia.*

Dawson and many others also considered that the disseminules of *Tasmanites* (usually then called *Sporangites*) represented the same plant as *Foerstia,* because *Tasmanites* seems always to be present wherever *Foerstia* is found. *Foerstia,* of course, is much more limited in its occurrence than *Tasmanites* is; however, on the basis of association, some authors were willing to draw a taxonomic conclusion, and some references to *Protosalvinia* only signify the presence of *Tasmanites* disseminules. Even if the sporelike *Tasmanites* disseminules were not linked up with *Foerstia,* a great many authors regarded them as spores of higher plants, lycopod megaspores, or almost anything but cysts of marine planktonic algae (Wall, 1962). Formerly, it was commonly believed that aquatic plants were incapable of producing sporelike microfossils that had resistant coats and that the presence of these "spores" indicated the presence of land plants. Independently, Kräusel (1941), Schopf (in Schopf and others, 1944), and Lang (1945) considered this complicated problem, and all agreed then (and it has become more evident since) that the association is only incidental. A summary review of these papers has been given by Schopf (1957, p. 712), in which Kräusel's assignment of the sporelike *Tasmanites* fossils to *Leiosphaera* Eisenack, a possible synonym, rather than to *Tasmanites* Newton, was discussed.

THE "SPORES" OF *FOERSTIA*

One reason Kräusel, Schopf, and Lang could be confident that *Tasmanites* had nothing to do with *Foerstia,* in spite of their general association, was that White and Stadnichenko (1923) and Kidston and Lang (1924) had independently demonstrated the presence of tetrads retained within conceptacles of *Foerstia* thalli (see pl. 2, fig. 6). The members of the tetrads are more sporelike than the disseminules of *Tasmanites,* for they show a contact configuration in addition to having a resistant coat.

The sporelike members of the *Foerstia* tetrads may have functioned both as true spores (haploid chromosome member; the initial stage of a gametophyte generation) and as egg cells, as in modern Fucales (Kylin, 1917, 1918; Smith, 1938; Caplin, 1968). The Fucales are basically heterosporous, having unilocular megasporangia producing megaspores that function as egg cells. The condition in *Foerstia* seems to suggest that this extreme condensation of the haploid generation (with the endogametophyte represented by only a single cell) may have persisted among brown algae since the Devonian. The fact that a distinctive spore coat was present at that time also suggests that a prior dispersal phase, possibly with spores that produced a free-growing external gametophyte which produced gametangia, might have been present in the early Paleozoic or even late Precambrian. Evidently the brown algae have a long history and are not given to rapid evolutionary changes.

It seems most likely to us that the tetrads functioned as a group of oospheres or aplanospores, as in *Fucus*, rather than as tetraspores, and that the fossils generally agree in structure and organization with modern members of the Fucales. The character of the meristoderm and conceptacles that contain the tetrads is exceedingly difficult to explain in alliance with any other group of organisms. Agreement with algal structure must be the deciding feature. If the plants represent an advanced type of algae, the tetrad members could not have served the same function as spores in the life cycle of vascular cryptogams or other land plants. Of course, interpretation of function is always difficult to prove from fossil material.

The senior author has studied much North American material and views the circumstantial evidence as follows: The most remarkable feature of these tetrads is that the members remain associated in the conceptacles on the thalli. Even where fertile specimens of *Foerstia* are relatively common, the tetrad members are almost never found dissociated. The tetrad members have not yet been reported in the course of normal palynologic studies, except when thallus fragments themselves were macerated or the members isolated by direct physical manipulation. Whether the tetrads functioned as spores or eggs or both, this repeated observation seems unusual. In view of the abundance of foerstian fossils, one would expect either spores or eggs to be dispersed from conceptacles if the well-formed tetrads were really functional. Certainly they could not function in any normal manner unless they were dispersed. Lack of any evidence of dispersal leads us to suspect that although eggs were matured (the unusually heavy coat may be an indication of over-maturity), they may not have been capable of functioning in a floating habitat. An incidental circumstance that fits the hypothesis of nonfunctionalism is that no structures have been discovered that resemble male sex organs (antheridia). Of course, many other reasons might be advanced to explain why fertilization was not completed, but no evidence from the available fossils indicates that the tetrad members actually fulfilled a generative function in the pelagic environment. We may refer to modern algae for a plausible explanation.

In members of the Fucales, germination of fertilized eggs occurs in salt water along rocky coasts, where young plants find a suitable substrate for initial attachment (see Fritsch, 1945, p. 377). Eggs are extruded from conceptacles by an associated mucilaginous vehicle, following a change in turgor that is induced by altered salinity or, in the intertidal zone, by desiccation. Retention of tetrad members in fossil conceptacles of *Foerstia* might readily be explained by the presence of a gelatinous envelope that failed to expand. A mucilaginous deposit would be most difficult to identify specifically in fossil condition. The evidence available shows no disagreement with an algal reproduction cycle of the type exemplified by the modern genus *Sargassum.*

The life cycle of *Sargassum* is initiated by germination of egg cells along coasts, where the young plants become attached to a substrate. Some algae require a fairly specialized littoral environment for attachment and early growth. We suspect that this was true for *Foerstia.*

No juvenile stages of *Foerstia* are known, and the attached state is not known among these fossils. The specimen illustrated on plate 1, figures 9 and 10, is the smallest, and may possibly be the youngest, of any observed. In *Sargassum,* many attached plants break loose after a time and continue to grow vegetatively. The number of vegetative fragments increases by separation at dichotomies as the proximal parts decay, but sexual reproduction does not occur while the plant is in a free-floating condition. Essentially the same sort of free-floating vegetative growth and remission of sexual reproduction among the floating thalli is suggested by the fossil occurrences of *Foerstia.*

LITTORAL CONTROL

Some circumstantial confirmation of this interpretative account of *Foerstia* may be derived from its restricted stratigraphic occurrence. Although related forms (*Protosalvinia, Spongiophyton*) are abundant in Devonian rocks of Brazil (Kräusel, 1941, 1960), only one possible example of *Protosalvinia,* as far as we know, has been recognized in North America (Arnold, 1954, pl. 1, fig. 9). Regardless of how one chooses to interpret these fossils, they must have had ancestors, and if they are related to the modern Fucales, as we believe, they also had descendants. In general, the lack of fossil representation within a time zone in which such fossils occur is attributable to poor or intermittent opportunity for preservation, but the abundance of the foerstian fossils in only a single thin zone within the black shale of the Appalachian region poses a perplexing problem. The general facies uniformity of the black shale above and below the *Foerstia* zone is a sufficient indication that preservation was possible throughout the period of black-shale deposition, if a continuing abundance of plant remains had been available. In this particular instance, we must be dealing with an episodic proliferation of the plants themselves; that is, fossil occurrence depended on more than the mere opportunity for preservation.

The Devonian black shale has long been recognized as a generally transgressive phase of the Late Devonian epicontinental sea. Owing to its stratigraphic position, singular distribution, and distinctive lithology, it has been much referred to in discussons relating to the Devonian-Mississippian boundary. There is reason to believe that, during the period of Late Devonian time represented by the *Foerstia* zone, limestone formations may have been overlapped by the sea at the southeast margin of the broad epicontinental basin (Conant and Swanson, 1961). These paleogeographic relationships may have had a great deal to do with temporary proliferation of *Foerstia* and its distribution by sea currents for a limited time within the Appalachian interior basin.

If *Foerstia* is an alga, like *Sargassum,* that was dependent on a special type of littoral environment for completion of the sexual phase of its life cycle, exposure of the rocky margins of the basin may have been a critical factor for several reasons. Initially, rock exposures along the coast may have presented a favorable colonization habitat for migrant *Foerstia* washed in by the sea from distant areas. Later on, drowning of rocky ledges by the transgressing sea may just as effectively have cut off the favorable foerstian "spawning ground." Subsequent lack of a littoral site suitable for juvenile growth may have doomed the whole colony in this area of the sea. The specific causal mechanism may never be pinpointed, but littoral control of the occurrence of *Foerstia* within the black shale of the Appalachian basin seems plausible and consistent with algal alliance that is suggested by structural features of these plants. None of the alternative explanations we can think of is equally consistent with botanical considerations and with the associated paleoecologic indicators that are generally recognized as applying to the Upper Devonian black shale.

STRATIGRAPHIC OCCURRENCE OF *FOERSTIA*

Hass (1956), basing his opinion on conodonts, was inclined to regard the interval in which the foerstian fossils occur (specifically, see fig. 1, loc. 4, 6, 8, 9, 11–16) as correlative with the lower faunal zone of the Gassaway Member of the Chattanooga Shale (equivalent to part of the Huron Member of the Ohio Shale). Hass (1958) later discussed the more extensive correlation of this zone which he then called Zone III. Probably all the collections listed here are of the same age. Subsurface records are consistent with this age assignment and with other information obtained from plant microfossile (Winslow, 1962).

Known localities from which *Foerstia* has been collected are shown on the map in figure 1. Material from nearly all localities has been checked by the senior author. All but one collection (No. 13, Littlestone Mountain, Jefferson County, Va.) consists of thalli associated with the characteristic black or dark-gray shale matrix. The Littlestone Mountain collection is from a buff

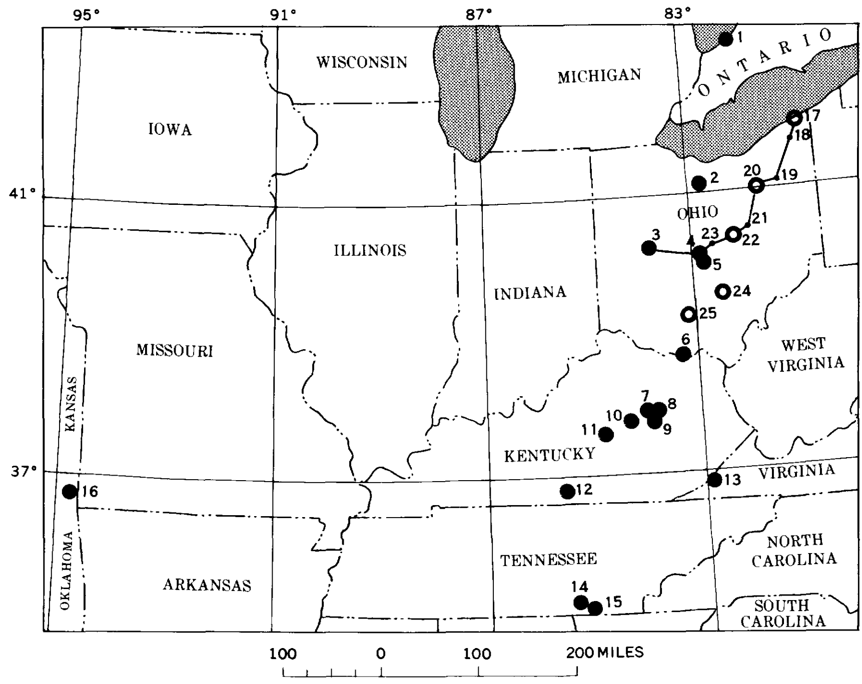


FIGURE 1.—Map showing *Foerstia* collection localities in North America. Solid circle, outcrop locality; open circle, subsurface locality; dot, gamma ray–neutron (GR–N) log. Localities, together with reference (in parentheses) or collector and date, are given in the explanation (facing page); numbers refer to Ohio Department of Natural Resources (ODNR) and to Ohio Division of Geological Survey (OGS) reference files.

or tawny siltstone and signifies that preservation of the algae did not depend entirely on the black-shale facies. Possibly this locality may be closest to the area of foerstian reproduction. *Tasmanites* is associated with foerstian remains at all the localities.

On the basis of these occurrences and stratigraphic studies carried out by the junior author, other possible occurrences may be predicted. The *Foerstia* zone should be present about 600 to 800

EXPLANATION FOR FIGURE 1

1. Kettle Point, Ontario (Winder, 1966)
2. Frink Run, south of Monroeville, Huron County, Ohio; Thomas Schopf, 1958
3. Bristol Ridge, east of Zanesfield, Logan County, Ohio; J. F. Schwietering, 1968
4. Glen Mary, Flint Park, The Narrows, 1–3 miles north of Worthington, Franklin County, Ohio; J. M. Schopf, 1951–3
5. 4th Street and 17th Avenue, Columbus, Franklin County, Ohio (Orton Museum, Ohio State University)
6. Vanceburg, Lewis County, Ky.; David White, 1923
7. 10 miles southeast of Winchester, Clark County, Ky. (Bharadwaj and Venkatachala, 1960)
8. Clay City, Powell County, Ky.; David White, 1923
9. Ravenna and Irvine, Estil County, Ky.; David White, 1923
10. 3 miles west of Berea, Madison County, Ky.; J. M. Schopf, 1963
11. Junction City, Boyle County, Ky.; David White, 1923
12. Burkesville, Cumberland County, Ky. (Hass, 1956)
13. Littlestone Mountain, Jefferson County, Va.; W. H. Hass, 1953
14. Glendale, Hamilton County, Tenn. (Hass, 1956)
15. Apsion, Hamilton County, Tenn. (Hass, 1956)
16. Spavinaw Dam, Delaware County, Okla. (Hass, 1956)
17. Kaiser-Pinney 1 (cable-tool well cutting), Ashtabula County, Ohio; depth 135–215 ft.; Schwietering, 1969; samples studied 115–305 ft. (ODNR P–16; OGS S–615)
18. Horizon Oil–Rhoa 1 (GR–N log), Trumbull Township, Ashtabula County, Ohio (ODNR P–191)
19. Atlas Minerals—Kemmery-Smith 1 (GR–N log), Suffield Township, Portage County, Ohio (ODNR P–419)
20. Barberton Core Test, Norton Township, Summit County, Ohio; depth 1436.5–1519 ft. (interval 82.5 ft.) (Winslow, 1962) ; (OGS S–955)
21. Natol-H. Johnson 1 (GR–N log), Monroe Township, Coshocton County, Ohio (ODNR P–1330; OGS S–821)
22. Pure-Dalier 3 (cable-tool well cutting), Newcastle Township, Coshocton County, Ohio, *Foerstia* zone depth 1640–1740 ft. (sample description, Winslow, 1962; OGS S–493)
23. Kin-Ark Oil–Boyd-Young Unit 1 (GR–N log), Harlem Township, Delaware County, Ohio (ODNR P–251)
24. Logan (cable-tool well cutting), Hocking County, Ohio, *Foerstia* zone depth 1430–1571 ft. (Winslow, 1962)
25. Chillicothe core test, Ross County, Ohio, *Foerstia* zone depth 320–376.7 ft. (Winslow, 1962)

feet above the top of the Dunkirk Shale Member of the Perrysburg Formation in northwestern Pennsylvania and western New York. This estimate has been based on eastward projection of the base of the Huron Member of the Ohio Shale, as correlated from gamma ray–neutron well logs from test drilling in Ohio, recognition of the *Foerstia* zone by Winslow (1962) in the core record at Barberton, Ohio, and the new identification of the *Foerstia* zone in the shallow subsurface from cable-tool well cuttings in the city of Ashtabula, Ohio. The relations of the *Foerstia* zone to Upper Devonian and Lower Mississippian formations in central and

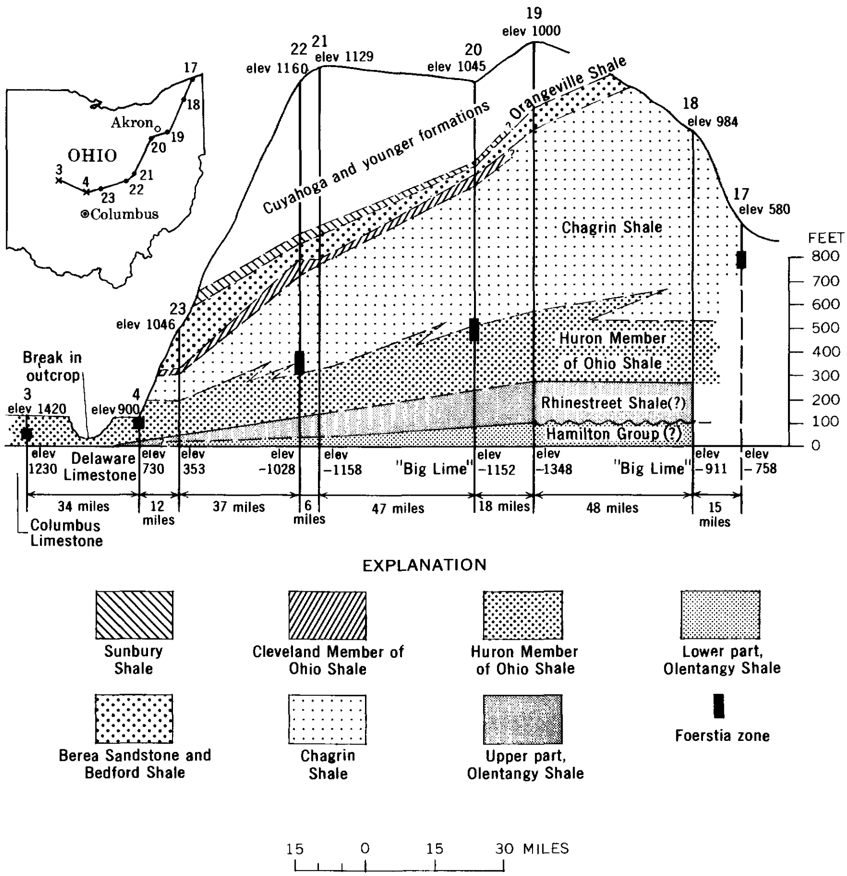


FIGURE 2.—Geologic cross section across central and northeastern Ohio showing occurrences of the *Foerstia* zone. Datum taken at the top of the thick Middle Devonian carbonate deposit (Delaware and Columbus Limestones and "Big Lime"); not a structure cross section. Based on published records, outcrop and sample study, and gamma ray–neutron log interpretation by J. F. Schwietering, July 1969. Locality numbers and locations as given for figure 1.

northeastern Ohio is shown in the geologic cross section in figure 2. Further investigations of stratigraphic relationships are being carried out by the junior author. It is most desirable, of course, to record additional occurrences of the *Foerstia* zone as a means of testing this and further possible hypotheses that attempt to account for the singular ditribution of these fossils.

Apparently all material reported in the literature is included in the list of localities (fig. 1). Kidston and Lang (1924) studied one shale specimen sent by J. W. Dawson and another sent by Professor H. S. Williams of Cornell. Presumably that transmitted by Dawson may have originally been given him by Edward Orton. Kidston and Lang said only that the material was from the Upper Devonian shales, Columbus, Ohio. Kräusel's (1941) North American material was all listed as Upper Devonian, Ohio, or Columbus, Ohio, and was derived from several sources, all of which may refer to the Columbus locality. Labels on material in the Orton Museum at The Ohio State University refer to a excavation near 4th Street and 17th Avenue in Columbus, a few blocks east of the university, but no collector's name or date is given. Abundant material from several related localities probably became available from time to time. Arnold (1954) listed no specific locality for his material, but in a letter (Mar. 13, 1969) he stated that associated museum material indicates that all this material probably came from a few miles north of Columbus where we have repeatedly collected it (our loc. 4).

The only *Foerstia* species that seems clearly distinguished from *Foerstia ohioensis* is that named *Protosalvinia arnoldii* by Bharadwaj and Venkatachala (1960). The species is here reassgined to *Foerstia* as *Foerstia arnoldii* n. comb. The type material came from the black-shale outcrop zone 10 miles southeast of Winchester, Ky., and about 12 miles north-northwest of *Foerstia* locality at Irvine and Ravenna. In 1952, the senior author found what is apparently *F. arnoldii* at an outcrop in Glen Echo Park, at a horizon a short distance above the main *Foerstia* zone in Columbus; and about 4 miles north of there at a similar level at Flint Park, about 2 miles north of Worthington. Although the botanical interpretation of this species seems less certain, its association with the same stratigraphic interval seems definite.

It must be emphasized that although generalized locality designations may lead to the assumption that foerstian remains are ubiquitous in the Devonian black shale of the Eastern United States, such is not the case. *Foerstia* occurs in a variable, but relatively thin, zone in the lower part of the shale sequence and is not present elsewhere. A characteristic part of its range is illustrated on the geologic cross section shown in figure 2. Its geographic occurrence also seems limited, although in several places the inconspicuous fossils have probably been misidentified or overlooked. Except for one locality in northeastern Oklahoma, where it was collected by H. D. Miser of the U.S. Geological Survey (Hass, 1956), *Foerstia* has not been reported west of the Cincinnati arch. If our interpretation of a littoral control of the occurrence of these fossils is approximately correct, the geographic distribution of the fossils may provide additional information about tidal currents in the Late Devonian epicontinental sea.

The same variations in thickness of the *Foerstia* zone may signify differences in rate of deposition; some may also signify distance from the source of the foerstian remains. The absence of *Foerstia* from the Indiana-Illinois embayment suggests that a barrier along the line of the Cincinnati arch interfered with westward distribution of these algae. However, relations of the section near Bellefontaine (see below) do not suggest that the arch at this time was subaerially exposed. An effective barrier could have consisted chiefly of tidal currents. After all, the only noteworthy occurrence of floating *Sargassum* is in the Sargasso Sea, but its modern distribution is much more extensive (Setchell, 1935).

A NEW *FOERSTIA* LOCALITY

The farthest west in Ohio that *Foerstia* has been found is at a locality in the Bellefontaine outlier at Bristol Ridge, east of Zanesfield. Here the zone is thin, only about 5 feet thick. The following is a description of the black shale section as measured by the junior author in September 1968. The section extends along a ravine on the south side of the ridge from a point about 2.25 miles east of Zanesfield, Jefferson Township, Logan County, Ohio.

	Thickness (feet)
1. Shale, dark-brown to black, thinly laminated and fissile, weathering papery, alternating visible lamellae, silty and micaceous; two soft blocky gray mudstone beds; each about 1.5 feet thick at base and 6 feet above base	14.5
2. Shale; as above, containing five thin (0.1–0.2-ft. thick) cone-in-cone brown limestone layers interspersed at intervals of 6–25 feet. A few pyritic nodules present in the lower part. Base of unit at lowest cone-in-cone layer observed	63.9
3. Shale; as above	34.1
4. Shale; as above, including numerous *Foerstia* specimens scattered along bedding planes. (*Foerstia* zone)	5.0
5. Shale; as above, containing large carbonate and septarian concretions 8–15 feet above base, scattered smaller concretions elsewhere	41.9

	Thickness (feet)
6. Mudstone, blocky, gray to brown, mostly hard, pyritic; three dark shale interbeds, 0.3–1.0 foot thick, that have "worm tubes" with gray silty filling; shale otherwise as described above. Base of unit at lowest mudstone layer observed	5.6
7. Shale; as described for units 1–5 above, including one 2-foot covered interval near the top	24.5
8. Sandstone, gray, iron-stained on weathering, medium- to coarse-grained, pyritic, argillaceous; containing a scattering of scolecodonts. (Base of Ohio Shale)	.3
9. Sandstone, carbonate-cemented; with brachiopods (equivalent to Columbus Limestone)	1.0+

SUMMARY

Foerstia is a problematic type of plant fossil that has a confusing scientific history. These fossils occur within a zone in the Huron Member of the Ohio Shale (Upper Devonian) and in correlative beds in the Eastern United States. *Foerstia* is regarded as an advanced type of pelagic alga that depends on an association with a particular type of littoral environment for its reproduction. Its limited stratigraphic and geographic distribution may be explained as a result of edaphic change that rendered the environment only temporarily accessible, a condition dependent on interaction between the variable character of the littoral zone and transgression of an epicontinental sea.

Examples of *Foerstia* from several localities, including several growth forms, have been illustrated. Most of these previously studied seem to have come from Ohio and probably are best identified with the type species that David White named *Foerstia ohioensis*. *Foerstia* should be distinguished from *Protosalvinia* Dawson, but the two genera are related and probably belong in the same family. *Protosalvinia* occurs most abundantly and typically in Brazil. Both genera probably should be assigned to the Order Fucales, which also includes many advanced types of modern seaweeds.

According to the hypothesis of littoral control that is advocated herein, it is reasonable to expect *Foerstia* to be easily recognized over a large area as an excellent guide to a thin stratigraphic zone related to a particular level of the ancient sea. *Foerstia* can be identified both in cuttings and in outcrop. Its geographic distribution may signify the course of tidal currents. Further studies should aid in testing the littoral control theory for foerstian occurrence, and, if confirmed, the localities should outline in detail the paleogeography of at least a part of the black-shale basin through a restricted interval of time.

REFERENCES CITED

Arnold, C. A., 1954, Fossil sporocarps of the genus *Protosalvinia* Dawson, with special reference to *P. furcata* (Dawson) comb. nov.: Svensk Bot. Tidskr., v. 48, no. 2, p. 292–300.

Bharadwaj, D. C., and Venkatachala, B. S., 1960, On *Protosalvinia arnoldii* n. sp. from Upper Devonian of Kentucky, U.S.A.: Senckenbergiana Lethaea, v. 41, no. 1–6, p. 27–35, 2 pls., 1 fig.

Caplin, S. M., 1968, The *Fucus* life cycle; time to correct textbooks: Bioscience, v. 18, no. 3, p. 193.

Conant, L. C., and Swanson, V. E., 1961, Chattanooga Shale and related rocks of central Tennessee and nearby areas: U.S. Geol. Survey Prof. Paper 357, 91 p., 17 pls., 18 figs.

Dawson, J. W., 1884, On rhizocarps in the Palaeozoic period [abs.]: Am. Assoc. Adv. Sci. Proc., v. 32, p. 260–264.

———1888, On sporocarps discovered by Prof. E. Orton in the Erian shale of Columbus, Ohio: Canadian Rec. Sci., v. 3, no. 3, p. 137–140, 1 fig.

Foreman, H. P., 1959, A new occurrence of Devonian Radiolaria in calcareous concretions of the Huron Member of the Ohio Shale: Jour. Paleontology, v. 33, no. 1, p. 76–80, pl. 15, 1 fig.

Fritsch, F. E., 1945, The structure and reproduction of the algae: London, Cambridge Univ. Press, 2 v. (Repr. 1959.)

Hass, W. H., 1956, Age and correlation of the Chattanooga Shale and the Maury Formation: U.S. Geol. Survey Prof. Paper 286, 47 p., 5 pls., 1 fig.

———1958, Upper Devonian conodonts of New York, Pennsylvania, and interior states: Jour. Paleontology, v. 32, no. 4, p. 765–769.

Kidston, Robert, and Lang, W. H., 1924, On the presence of tetrads of resistant spores in the tissue of *Sporocarpon furcatum* Dawson from the Upper Devonian of America: Royal Soc. Edinburgh Trans., v. 53, pt 3, no. 28, p. 597–601, 1 pl.

Kräusel, Richard, 1941, Die Sporokarpien Dawsons, eine neue Thallophyten-Klasse des Devons: Palaeontographica, v. 86, sec. B, pt. 4–6, p. 113–133, pls. 28–34, 3 figs.

———1960, *Spongiophyton* nov. gen. (Thallophyta) e *Haplostigma* Seward (Pteridophyta) no Devoniano Inferior do Paraná: Brazil, Div. Geologia e Mineralogio Mon. 15, 41 p., 11 pls.

Kreger, D. R., 1962, Cell walls, *in* Lewin, R. A., ed., Physiology and biochemistry of algae: New York and London, Academic Press, p. 315–335, 3 figs.

Kylin, Harald, 1917, Über die Entwicklungsgeschichte und die systematische Stellung der Tilopterideen: Deutsche bot. Gesell., Ber. v. 35, no. 29, p. 298–310.

———1918, Über den Generationswechsel der Phaeophyceen, *in* Studien über die Entwicklungsgeschichte der Phaeophyceen: Svensk Bot. Tidskr., v. 12, no. 1. p. 40–59.

Lang, W. H., 1945, *Pachytheca* and some anomalous early plants *(Prototaxites, Nematothallus, Parka, Foerstia, Orvillea* n. g.): Linnean Soc. London Jour., Botany, v. 52, no. 347, p. 535–552, pls. 22–25.

O'Colla, P. S., 1962, Mucilages, *in* Lewin, R. A., ed., Physiology and biochemistry of algae: New York and London, Academic Press, p. 337–356, 5 figs.

Pia, Julius, 1927, Algae incertae sedis, *in* Hirmer, Max, Handbuch der Paläobotanik: Munich and Berlin, R. Oldenbourg, v. 1, p. 109.

Schopf, J. M., 1957, "Spores" and problematic plants commonly regarded as marine—annotated bibliography, *in* Hedgpeth, J. W., and Ladd, H. S., eds., Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, v. 2, p. 709–718.

Schopf, J. M., Wilson, L. R., and Bentall, Ray, 1944, An annotated synopsis of Paleozoic fossil spores and the definition of generic groups: Illinois State Geol. Survey Rept. Inv. 91, 73 p., 3 pls., 5 figs.

Setchell, W. A., 1935, Geographic elements of the marine flora of the North Pacific Ocean: Am. Naturalist, v. 69, no. 725, p. 560–577, 12 figs.

Smith, G. M., 1938, Algae and fungi, volume 1 *of* Cryptogamic botany: New York, McGraw-Hill Book Co., 545 p., 299 figs. 2d ed., 1955.

Sommer, F. W., 1962, On *Protosalvinia bilobata* Dawson from the Devonian of Pará and its taxonomic situation: Acad. Brasileira Ciências, Anais, v. 34, no. 4, p. 465–475, 2 pls., 1 fig.

Wall, David, 1962, Evidence from Recent plankton regarding the biological affinities of *Tasmanites* Newton 1875 and *Leiosphaeridia* Eisenack 1958: Geol. Mag., v. 99, no. 4, p. 353–362, pl. 17, 8 figs.

White, David, and Stadnichenko, Taisia, 1923, Some mother plants of petroleum in the Devonian black shales: Econ. Geology, v. 18, no. 3, p. 238–252, 5 pls.

Williamson, W. C., 1878, On the organization of the fossil plants in the Coal-Measures, Part IX: Royal Soc. London Philos. Trans., v. 169, pt. 3, p. 319–364.

Winder, C. G., 1966, Conodont zones and stratigraphic variability in Upper Devonian rocks, Ontario: Jour. Paleontology, v. 40, no. 6, p. 1275–1293, pl. 156, 9 figs.

Winslow, M. R., 1962, Plant spores and other microfossils from Upper Devonian and Lower Mississippian rocks of Ohio: U.S. Geol. Survey Prof. Paper 364, 93 p., 27 pls., 12 figs.

PLATES 1 AND 2

PLATE 1

[All fossils photographed with unidirectional illumination. Specimens have been entirely separated from matrix by HF treatment]

FIGURES 1–10. *Foerstia ohioensis* White.

1, 3. Top (fig. 1, × 5) and bottom (fig. 3, × 10) of large thallus from *Foerstia* zone, Bristol Ridge. Fig. 3 shows pattern of meristoderm cells radiating from ragged proximal margin.

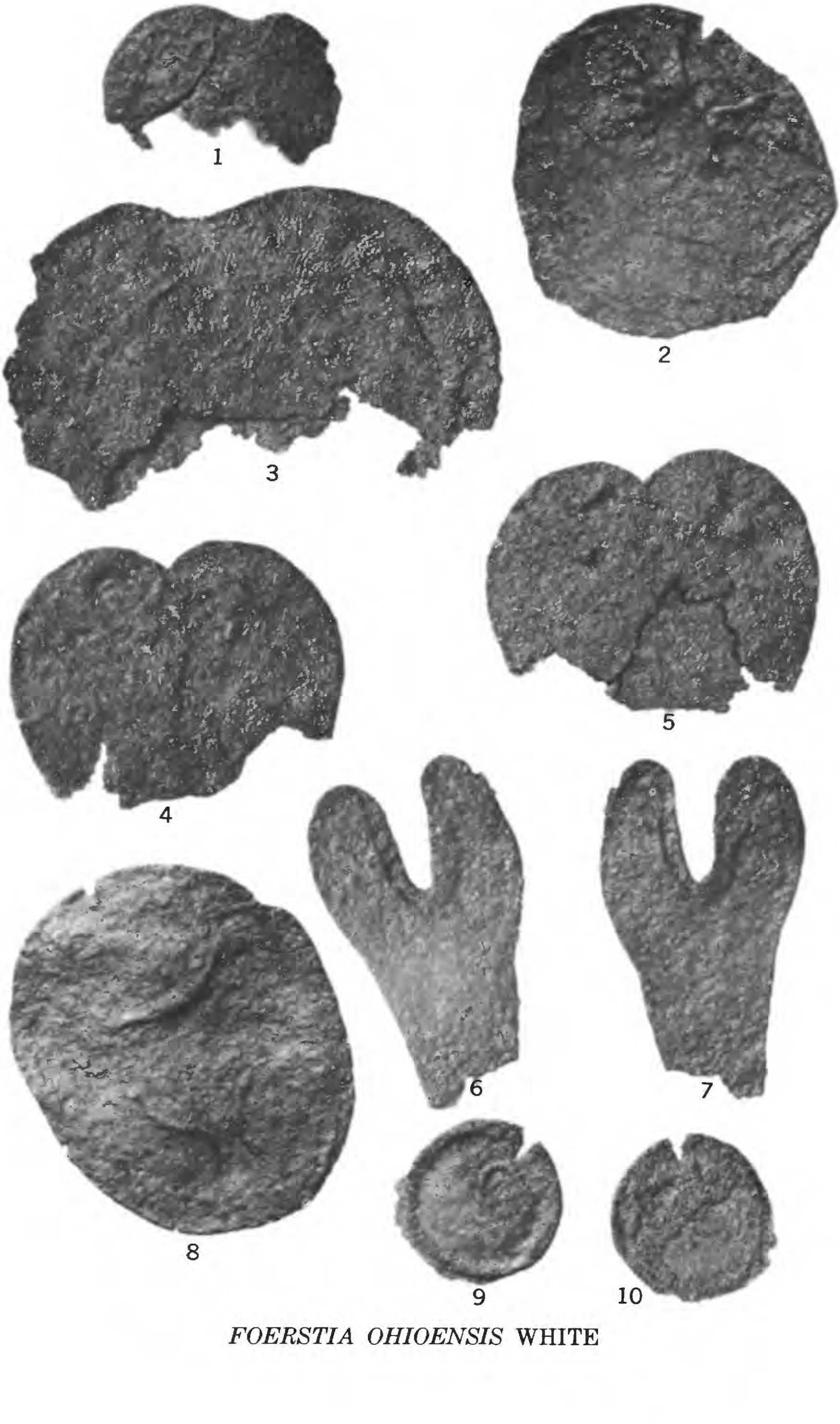
2. Discoidal thallus with acute apical lobes. Orton Museum specimen, collected at former exposure of *Foerstia* zone near 4th Street and 17th Avenue in Columbus, Ohio. × 10.

4, 5. Top and bottom of characteristic bilobed form of thallus, *Foerstia* zone, Bristol Ridge. Proximal margin in fig. 5 is partly indicated by black line. × 10.

6, 7. Top and bottom of compressed, strongly bilobed thallus. Note the similar infolding of apical grooves on the two surfaces. From collections submitted by W. H. Hass from Glendale Locality (see Hass, 1956, loc. 225, p. 35), Hamilton County, Tenn. × 10.

8. Discoidal thallus showing asymmetrical dichotomous apical lobing (not to be confused with trilete apical segments of lycopsid megaspores). Orton Museum specimen, The Ohio State Univ., collected at former exposure of *Foerstia* zone near 4th Street and 17th Avenue in Columbus, Ohio. For reverse surface, see pl. 2, fig. 3. × 10.

9, 10. Top and bottom view of smallest (youngest?) whole thallus noted. From *Foerstia* zone, Bristol Ridge section. × 10.



FOERSTIA OHIOENSIS WHITE

PLATE 2

FIGURES 1–7. *Foerstia ohioensis* White.

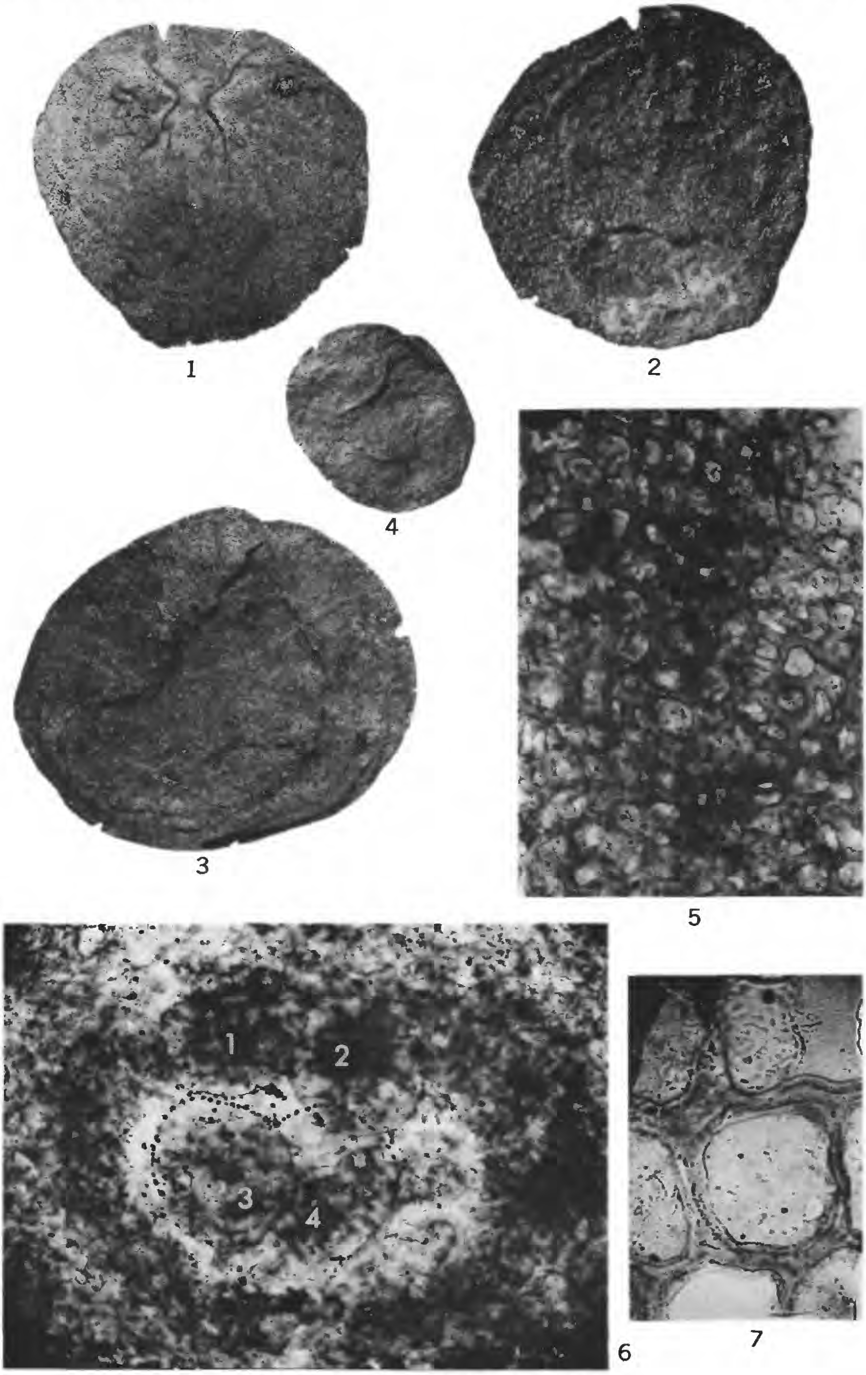
1, 2. Top and bottom surfaces of compressed whole thallus. The "bumps" near the apical lobes of fig. 1 are impressions of mineral grains; photographed with Ultropak (cone of incident light); for view with unidirectional lighting, see pl. 1, fig. 2. Fig. 2, with unidirectional lighting, shows the proximal opening clearly. × 10.

3, 4. Bottom (fig. 3, × 10) and top (fig. 4, × 5) surfaces of discoidal compressed whole thallus; unidirectional illumination. Note proximal opening shown in fig. 3. See pl. 1, fig. 8, for enlarged view of top surface. Orton Museum specimen, 4th Street and 17th Avenue, Columbus, Ohio.

5. Cellular pattern of double thickness of meristoderm; focus on the upper layer. Specimen cleared and mounted in balsam; photographed by transmitted light. Specimen from *Foerstia* zone, Bristol Ridge section. × 100.

6. A single conceptacle with four contained oospheres (margins dotted, numbered 1–4). Overlap of oospheres by the margin of the crater suggests that the uncompressed conceptacle originally had much greater depth. Source and lighting as for fig. 5. × 100.

7. A few cells of the meristoderm (single thickness). Source and lighting as for fig. 5. × 300.



FOERSTIA OHIOENSIS WHITE

Contributions to Stratigraphy, 1969

GEOLOGICAL SURVEY BULLETIN 1294

This volume was published as separate chapters A–H

UNITED STATES DEPARTMENT OF THE INTERIOR
WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY
William T. Pecora, *Director*

CONTENTS

[Letters designate the separately published chapters]

☆U.S. GOVERNMENT PRINTING OFFICE. 1970 O—383-286