Shorter Contributions to Paleontology and Stratigraphy

U.S. GEOLOGICAL SURVEY BULLETIN 1860

Shorter Contributions to Paleontology and Stratigraphy

Edited by WILLIAM J. SANDO

Studies of Ordovician and Silurian graptolites from Washington State and Devonian corals from Pennsylvania, West Virginia, Virginia, and New York

U.S. GEOLOGICAL SURVEY BULLETIN 1860

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE : 1989

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging in Publication Data

Shorter contributions to paleontology and stratigraphy.

(U.S. Geological Survey bulletin ; 1860 A–D

Supt. of Docs. no. : I 19.3:1860A–D
Bibliography: p.
1. Graptolites. 2. Paleontology—Ordovician. 3. Paleontology—Silurian.
4. Paleontology—Washington (State) 5. Corals, Fossil. 6. Paleontology—Devonian.
7. Paleontology—Middle Atlantic States. I. Sando, William Jasper. II. Series.
QE75.B9 no. 1860 A–D 557.3 s [563'.71] 88-600206
[QE840.5]

Shorter Contributions to Paleontology and Stratigraphy

Edited by WILLIAM J. SANDO

Studies of Ordovician and Silurian graptolites from Washington State and Devonian corals from Pennsylvania, West Virginia, Virginia, and New York

U.S. GEOLOGICAL SURVEY BULLETIN 1860

CONTENTS

Chapter A

A Middle Ordovician Graptolite Fauna from Near the Contact Between the Ledbetter Slate and the Metaline Limestone in the Pend Oreille Mine, Northeastern Washington State

By CLAIRE CARTER

Descriptions and illustrations of a rich and stratigraphically important graptolite fauna from Washington State

U.S. GEOLOGICAL SURVEY BULLETIN 1860

Shorter Contributions to Paleontology and Stratigraphy

CONTENTS

FIGURES

TABLE

A Middle Ordovician Graptolite Fauna from Near the Contact Between the Ledbetter Slate and the Metaline Limestone in the Pend Oreille Mine, Northeastern Washington State

By Claire Carter

Abstract

The nature of the contact between the Ledbetter Slate and the Metaline Limestone in northeastern Washington State has been the subject of some dispute. The presence of graptolites of the *Paraglossograptus tentaculatus* Zone (Middle Ordovician) on either side of the contact in the Pend Oreille Mine supports the interpretation of a conformable, depositional transition. Graptolites of *tentaculatus*-Zone age have not been reported or described previously from the State. The fauna, which can be closely correlated with *tentaculatus*-Zone faunas from New Zealand, Australia, Canada, and Alaska, consists of more than 30 species belonging to 18 different genera, including a new species (unnamed) of *Sinograptus* and a new subspecies of *Tetragraptus pendens* Elles.

INTRODUCTION

The Metaline district of northeastern Washington State (fig. 1) has yielded some 17 million tons of zinc-lead ore since mining began there in the early 1900's. Most of this ore has come from an irregularly stratiform zone of breccia (the Josephine unit of McConnel and Anderson (1968)) just below the contact between the Metaline Limestone and the overlying Ledbetter Slate. The nature of this contact has been the subject of some dispute. Where the contact is unfaulted, it has been interpreted as being conformable and gradational (Snook and others, 1981, p. 5), possibly disconformable (Park and Cannon, 1943, p. 20; Dings and Whitebread, 1965, p. 21), and even the result of prolonged subaerial exposure (Mills, 1977). In an effort to resolve the question, J.A. Morton of the GRC Exploration Co. has carefully examined the contact in the underground workings of the Pend Oreille Mine (fig. 1) and, in the process, has collected large numbers of well-preserved graptolites, which are the subject of this paper.

Acknowledgments

The author is grateful to Jack A. Morton for providing the graptolite specimens and for a guided tour of his collecting sites in the Pend Oreille Mine. Many thanks to J. Thomas Dutro, Jr., of the U.S. Geological Survey and Roger A. Cooper of the New Zealand Geological Survey for their comments and advice on the manuscript. Thanks also to J. Eric Schuster and Nancy L. Joseph of the Washington Division of Geology and Earth Resources.

GENERAL GEOLOGY

The Metaline Limestone consists of about 5,000 ft of thin-bedded limestone and shale, light-gray bedded dolomite, and gray massive limestone (Dings and Whitebread, 1965). The overlying Ledbetter Slate, predominantly black argillite and slate interbedded with minor amounts of limy argillite and limestone (Dings and Whitebread, 1965), is estimated to be between 2,000 and 4,500 ft thick. Both formations extend over much of Pend Oreille and Stevens Counties, Washington, and adjacent southeastern British Columbia. An undisturbed (unfaulted) contact between these formations is exposed in only a few places, one of which is in the Pend Oreille Mine near Metaline Falls, Wash.

During his study of the Ledbetter-Metaline contact, Morton collected graptolites from a shale unit in the Metaline Limestone as well as from a short interval of the Ledbetter Slate just above the contact. The fact that all of these graptolites are characteristic of the Middle Ordovician Zone of *Paraglossograptus tentaculatus* gives credence to Morton's interpretation of the contact as a depositional transition (J.A. Morton, written communication, 1986). Clearly, the age of this

Manuscript approved for publication May 16, 1988.

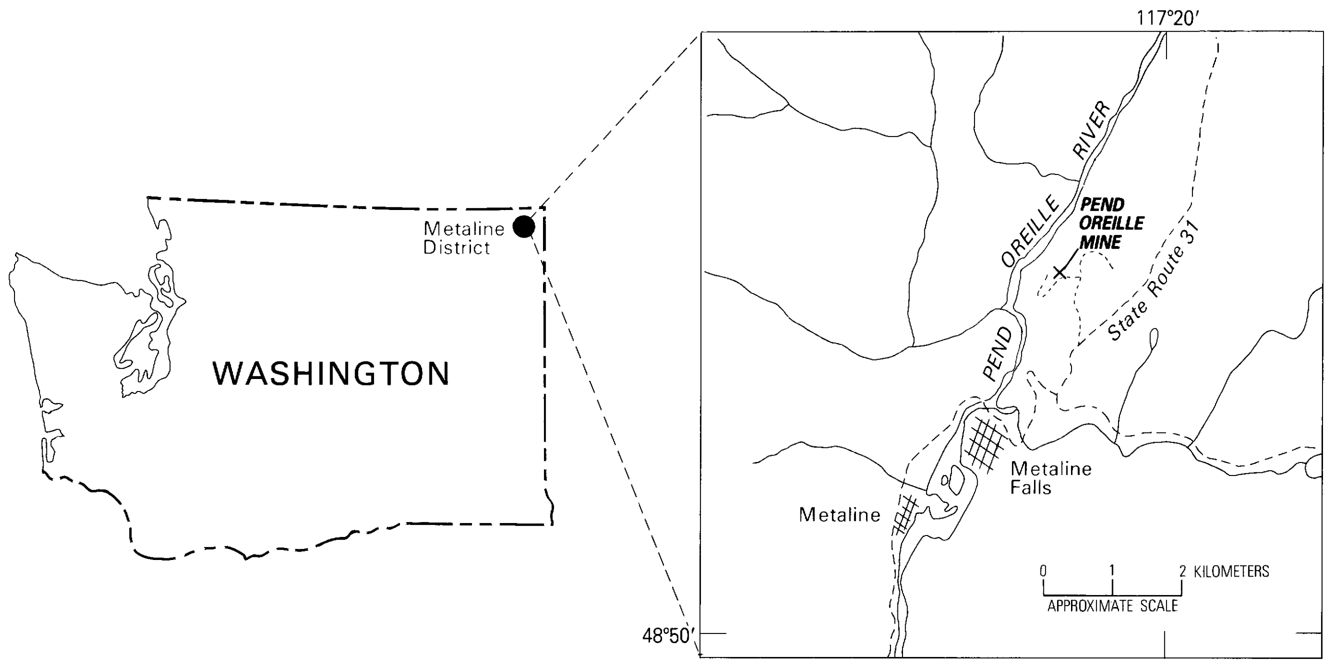


Figure 1. Location of Metaline district and the Pend Oreille Mine, Washington State. Solid lines, drainage; dashed lines, roads.

contact is not everywhere the same, because graptolites older than those of the *P. tentaculatus* Zone have been found in the Ledbetter Slate at other localities in the area.

THE GRAPTOLITE FAUNA

Graptolites have been known from the Ledbetter Slate in the Metaline Falls area since the early 1940's, when Park and Cannon (1943, p. 20–22) published Josiah Bridge's report on faunas ranging in age from "lower Deepkill" through "Normanskill." These collections, which I reexamined recently, were found to range from Early Ordovician (*Oncograptus* Zone) through Middle Ordovician (*Dicranograptus clingani* Zone) age. However, none of these collections is of the same age (*P. tentaculatus* Zone) as the fauna described herein from near the contact between the Ledbetter Slate and the Metaline Limestone. Ruedemann (1947, p. 111–112) listed a number of graptolite faunas from northeastern Washington and illustrated some of the forms (pl. 52, figs. 26, 27; pl. 55, fig. 19; pl. 64, figs. 20–22; pl. 68, figs. 11–13; pl. 72, figs. 50, 51; pl. 77, figs. 25, 38), but none was from the *P. tentaculatus* Zone. W.B.N. Berry (cited by Greenman and others, 1977) identified graptolites from the Ledbetter Slate in an area north of Metaline Falls, ranging in age from the Early Ordovician Zones of *Tetragraptus approximatus* or *T. fruticosus* through the Late Ordovician Zone of *Dicellograptus ornatus*. Again, none of the published fossil lists represents the *tentaculatus* Zone. In 1961, A.E. Weissenborn (U.S. Geological Survey) collected a *tentaculatus*-Zone fauna at the 1,700-ft level of the Pend Oreille Mine, from a shale lens in the Metaline Limestone about 40 ft below the Ledbetter-Metaline contact, but no descriptions or fossil list was ever published.

Three collections of graptolites, made by Morton from near the Ledbetter-Metaline contact in the Pend Oreille Mine, are included in the present description and discussion of the *P. tentaculatus*-Zone fauna. The stratigraphically lowest of the three (1085 A1 roadway, collection 2) is from various horizons in a roughly 40-ft thick lens or tongue of black shale in the Metaline Limestone, 60 to 80 ft stratigraphically below the Ledbetter-Metaline contact. The next-higher-up collection (1085 A1 crosscut, collection 3) is from an interval 0 to 5 ft stratigraphically above the contact; the highest collection (A4R crosscut, collection 1) is from an interval 0 to 7 ft stratigraphically above the contact.

CORRELATION

The graptolite fauna (table 1) from near the Ledbetter-Metaline contact is characterized by the presence of the following forms: *Loganograptus logani* (Hall), *Dichograptus* aff. *D. norvegicus* Harris and Thomas, numerous tetragraptids (including *T. quadribrachiatus* (Hall), *T.* cf. *T. pseudobigsbyi* Skevington, and *T. pendens liber* n.subsp.), *Pseudotrigonograptus ensiformis* (Hall), *Isograptus caduceus australis* Cooper, *I.* cf. *I. angulatus* Mu, Geh, and Yin, *Glossograptus echinatus* Ruedemann, *Paraglossograptus tentaculatus* (Hall), various cryptograptids (including *Cryptograptus* cf. *C. antennarius* (Hall) and *C.*? *inutilus* (Hall)), and *Undulograptus*? cf. *U.*? *intersitus* (Harris and Thomas). In addition, the highest collection (coll. 1) contains numerous sinograptids, including *Sinograptus rastritoides* Mu, *S.* n.sp., and *Holmograptus* cf. *H. spinosus* (Ruedemann), as well as *Climacograptus* cf. *C. riddellensis* Harris.

This fauna is correlated (fig. 2) with the *P. tentaculatus* Zone of New Zealand as described by Cooper (1979). In New Zealand, *P. tentaculatus* and *U.*? cf. *U.*? *intersitus* are restricted to this zone; they are found in association with the following species, which first appear in older zones: *L. logani*, *T. quadribrachiatus*, *Pseudotrigonograptus ensiformis*, and *Cryptograptus*? *inutilus*. In addition, sinograptids and pseudoclimacograptids first appear in the *tentaculatus* Zone. All of these species are found in the Ledbetter-Metaline fauna (see table 1). This fauna differs from the New Zealand *P. tentaculatus* zonal assemblage in its abundant isograptids and tetragraptids, most of which disappear at the end of the previous zone in New Zealand. A number of forms, including *Dichograptus*, ?*Zygograptus junori* Harris and Thomas, extensiform didymograptids, *I. caduceus australis*, and *I. victoriae divergens* Harris, which occur only in older zones in New Zealand, apparently extended their range into the *tentaculatus* Zone in northeastern Washington.

The *P. tentaculatus* Zone of New Zealand correlates with the Darriwillian (Da1–Da2) Zones of *U. austrodentatus* and *U.*? *intersitus* of Victoria, Australia (Cooper, 1979, table 13; VandenBerg, 1981), and the *Hallograptus etheridgei* (= *P. tentaculatus*) Zone of Texas (Berry, 1960).

Lenz and Jackson (1986) have established a Zone of *P. tentaculatus* for the Canadian Cordillera that can be divided into lower and upper parts. The whole zone is basically distinguished by the appearance of *P. tentaculatus* together with *L. logani* and the earliest biserial forms, including *Pseudoclimacograptus* spp. and *C.*? cf. *inutilus*. The upper part of the Canadian *tentaculatus* Zone contains *Diplograptus*? *decoratus* (Harris and Thomas), *Amplexograptus coelatus* (Lapworth), *Cryptograptus tricornis* (Carruthers) (all missing from the Ledbetter fauna), *C. riddellensis*, and abundant sinograptids such as *S. rastritoides*, *Tylograptus*, and *Holmograptus*?. The Ledbetter-Metaline fauna is correlatable for the most part with Lenz and Jackson's (1986) lower *P. tentaculatus* Zone, but the uppermost collection (coll. 1) contains elements (*S. rastritoides*, *Holmograptus*, and *C.* cf. *C. riddellensis*) indicative of the Canadian upper *tentaculatus* Zone. The Washington fauna lacks the phyllograptids and cardiograptids of its Canadian counterpart. Unlike the New Zealand *tentaculatus*-Zone fauna, the faunas of the *tentaculatus* Zone in Canada, Texas, and northeastern Washington contain several species of *Isograptus*.

Table 1. Graptolite fauna of the *Paraglossograptus tentaculatus* Zone, Ledbetter Slate and Metaline Limestone, Pend Oreille Mine, Washington State

Genus and species	Metaline Limestone, coll. 2	Ledbetter Slate: Coll. 3	Ledbetter Slate: Coll. 1
Loganograptus logani (Hall)	x		x
sp.			x
Trichograptus? sp.	x		
?*Zygograptus junori* Harris and Thomas			x
Dichograptus aff. *D. norvegicus* Harris and Thomas.	x		x
Tetragraptus cf. *T. minutus* Geh	x		
pendens liber n.subsp.	x	x	x
cf. *T. pseudobigsbyi* Skevington	x		x
quadribrachiatus (Hall)	x	cf. x	
cf. *T. zhejiangensis* Geh			x
Pseudotrigonograptus ensiformis (Hall)	x	x	x
Didymograptus cf. *D. cognatus* Harris and Thomas.			x
aff. *D. extensus* (Hall)	x	x	x
Xiphograptus sp.	x		
Isograptus caduceus australis Cooper	x	x	x
cf. *I. forcipiformis* (Ruedemann)	x		x
cf. *I. angulatus* Mu, Geh, and Yin	x	x	x
victoriae divergens Harris	x		
Pseudisograptus? aff. *P. manubriatus koi* Cooper and Ni.	x		
Sinograptus rastritoides Mu			x
n.sp.			x
Holmograptus cf. *H. lentus* (Törnquist)	x		x
cf. *H. spinosus* (Ruedemann)			x
Glossograptus echinatus Ruedemann	x		x
Paraglossograptus tentaculatus	x		x
Cryptograptus cf. *C. antennarius*	x		x
cf. *C. hopkinsoni* (Nicholson)		x	
? *inutilus* (Hall)	x		x
sp.	x		x
Climacograptus cf. *C. riddellensis* Harris			x
Pseudoclimacograptus sp.			x
Undulograptus? cf. *U.*? *intersitus* (Harris and Thomas.	x	x	x
?sp.			x

The *P. tentaculatus* Zone in the Baird Mountains of Alaska (Carter and Tailleur, 1984) has fewer species but is otherwise quite similar to the Ledbetter-Metaline fauna, especially in the presence of *I. caduceus australis* and *I. victoriae divergens*, as well as the usual forms (*Loganograptus*, *Tetragraptus quadribrachiatus*, *Pseudotrigonograptus ensiformis*, *P. tentaculatus*, *Undulograptus*, and *Cryptograptus*? *inutilus*).

Because the *P. tentaculatus* Zone is found in the Pacific graptolite province (see Barnes and others, 1981, p. 6), it is difficult to correlate with the classic British graptolite zones (Atlantic province). However, on the basis of the first appearance of diplograptids (*Undulograptus*), it can be correlated, in part, with the upper

System	Series	Unit	Northeastern Washington graptolite zones This paper Carter (Chapter B, this volume)	New Zealand graptolite zones Cooper (1979)	Australian series VandenBerg (1981) Cooper (1979)	Canadian Cordillera graptolite zones Lenz and Jackson (1986)	British series
ORDOVICIAN	Middle	Ledbetter Slate			Eastonian 4		
			Dicranograptus clingani		Eastonian 3 2 1		
			Climacograptus bicornis		Gisbornian		Caradocian
			Nemagraptus gracilis	*Dicellograptus*		*Diplograptus ? decoratus*	Llandeilan
			Diplograptus ? decoratus	*Diplograptus ? decoratus*	Darriwillian	*P. tentaculatus* upper	Llanvirnian
			Paraglossograptus tentaculatus	*Paraglossograptus tentaculatus*		*P. tentaculatus* lower	
	Lower	Metaline Limestone	*Oncograptus*	*Oncograptus*	Yapeenian	*Oncograptus* upper / lower	Arenigian

Figure 2. Correlation of graptolite faunas of the Ledbetter Slate with those of New Zealand, Australia, western Canada, and the British Isles.

Arenigian Zone of *Didymograptus hirundo* (see Jenkins, 1980, p. 290). Cooper (1979, table 13) has correlated it with the upper part of the *D. hirundo* Zone and the lower part of the Llanvirnian *D.* "*bifidus*" Zone.

SYSTEMATIC PALEONTOLOGY

The terminology and classification used herein are mainly from Bulman (1970). The synonymies are not always exhaustive; they represent, for the most part, only those citations with which I am personally acquainted. For more nearly complete synonymies, the reader should consult the later citations in each synonymy. Nearly all of the specimens described here are completely flattened, but they have undergone very little tectonic distortion. The repository of specimens is the U.S. National Museum of Natural History (USNM), Smithsonian Institution, Washington, D.C.

Class GRAPTOLITHINA Bronn, 1846
Order GRAPTOLOIDEA Lapworth, 1875
Suborder DIDYMOGRAPTINA Lapworth, 1880, emended by Bulman, 1970
Family DICHOGRAPTIDAE Lapworth, 1873
Genus *Loganograptus* Hall, 1868
Loganograptus logani (Hall)

Figures 3*A*, *F*

Graptolithus logani Hall, 1858, p. 115; 1859, p. 502–503, figs. 1–3; 1865, p. 100–102, pl. 9, figs. 1–9, pl. 11, fig. 7?

Graptolithus (*Loganograptus*) *logani* Hall, 1868, p. 208, figs. 6, 6a, 7.

Loganograptus logani Hall. Elles and Wood, 1901–18, p. 81–82, pl. 11, figs. 1a-g. Ruedemann, 1904, p. 631–633, pl. 9, figs. 3–6.

Loganograptus logani (Hall). Harris and Thomas, 1940, p. 130–131, text figs. 2, 3, pl. 2, figs. 7a, b. Ruedemann, 1947, p. 286–287, pl. 45, figs. 11–13. Mu, 1957, p. 416–417, pl. 1, figs. 1–6, text fig. 3a. Tsai, 1974, p. 42, pl. 2, fig. 9. Cooper, 1979, p. 56, pls. 4a, b.

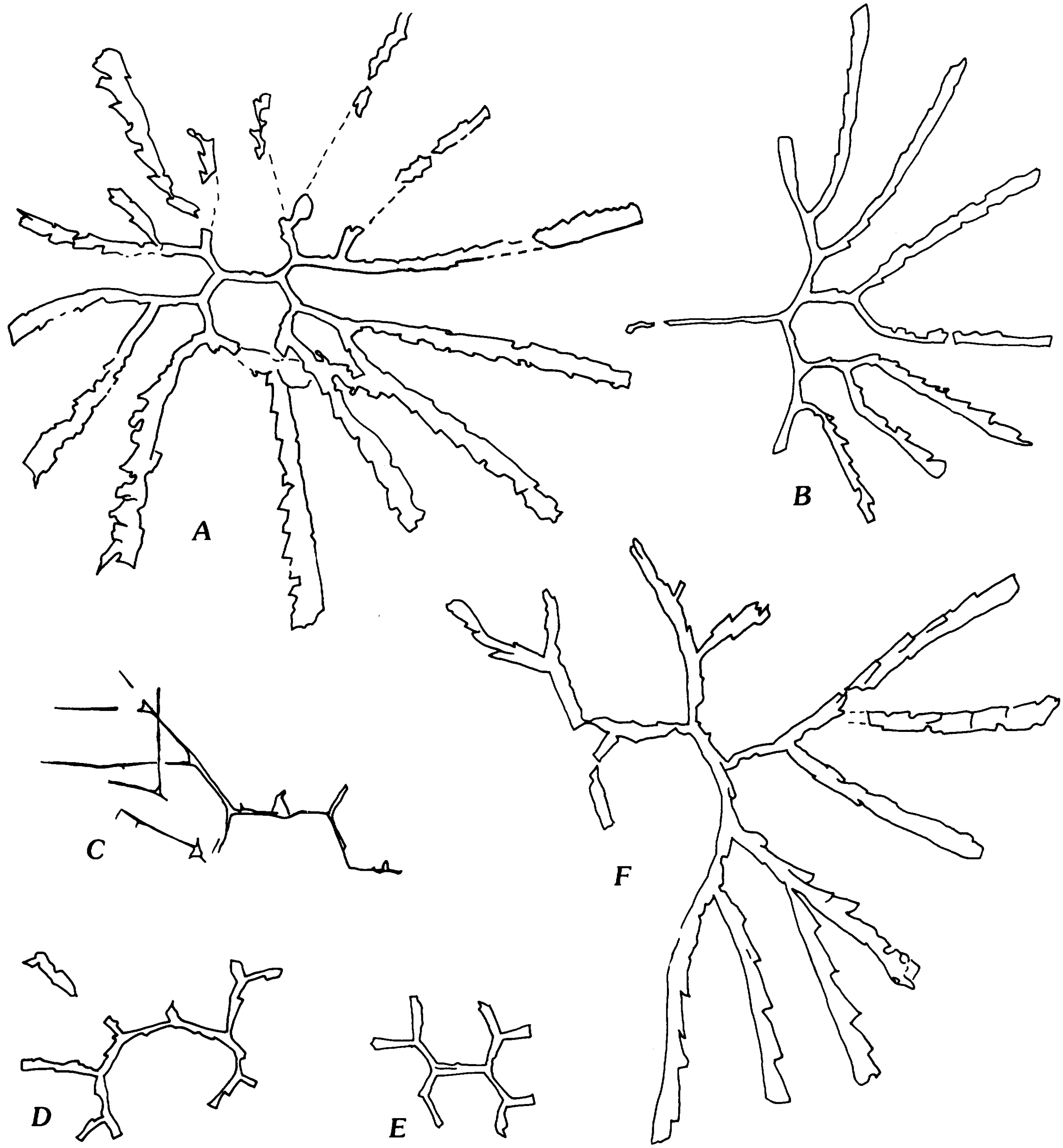


Figure 3. Dichograptidae. *A, Loganograptus logani* (Hall), USNM 406229, collection 2, Metaline Limestone, ×3.5. *B, ?Zygograptus junori* Harris and Thomas, USNM 406221, collection 1, Ledbetter Slate, ×5. *C, Trichograptus?* sp., USNM 406262, collection 2, Metaline Limestone, ×8. *D, Loganograptus?* sp., USNM 406247, collection 2, Metaline Limestone, ×5. *E, Loganograptus?* sp., USNM 406185, collection 1, Ledbetter Slate, ×5. *F, L. logani* (Hall), USNM 406196, collection 1, Ledbetter Slate, ×5.

Diagnosis.—Stipes of first, second, and third orders very short; long undivided stipes of fourth or fifth order widening to a maximum of about 1.6 mm. Thecae 8 to 10 per centimeter.

Discussion.—The Washington specimens have 16 or more fourth- or fifth-order branches and agree well with the foregoing diagnosis.

Horizon and locality.—*L. logani* is a well-known and widespread form and has been found in, among other places, the *P. etheridgei* (=*P. tentaculatus*) Zone of British Columbia (Larson and Jackson, 1966), the *P. tentaculatus* Zone (Fort Peña Formation) of Texas (Berry, 1960), and the Zones of *I. v. maximodivergens* and *P. tentaculatus* of New Zealand (Cooper, 1979). It

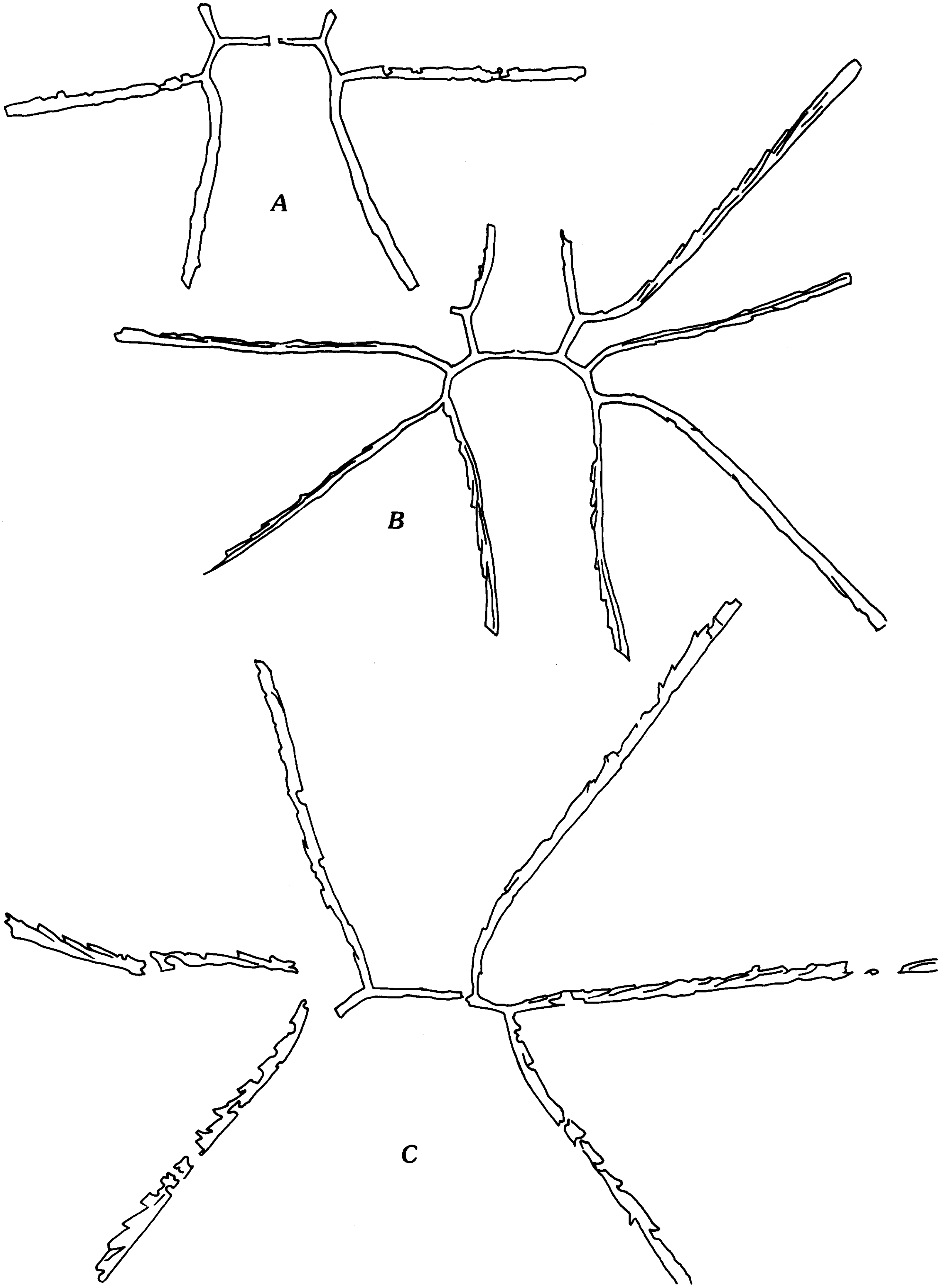


Figure 4. Dichograptidae. All ×5. *A*, *Dichograptus* aff. *D. norvegicus* Harris and Thomas, USNM 406249, collection 2, Metaline Limestone. *B*, *Loganograptus*? sp., USNM 406211, collection 1, Ledbetter Slate. *C*, *D.* aff. *D. norvegicus* Harris and Thomas, USNM 406201, collection 1, Ledbetter Slate.

is also present in China (Mu, 1957), the British Isles (Elles and Wood, 1901–18), and the U.S.S.R. (Tsai, 1974).

Loganograptus? sp.

Figure 4*B*

Discussion.—One specimen (fig. 4*B*) has the general appearance of *Loganograptus* but possesses only 10 undivided terminal stipes instead of the 16 or more typical of *L. logani*.

Genus *Trichograptus* Nicholson, 1876
Trichograptus? sp.

Figure 3*C*

Discussion.—The single specimen is not preserved well enough to be identified with certainty. It appears to branch in the manner of *Trichograptus* (undivided lateral branches from only one side of the main branches) and is very tentatively assigned to this genus. *Trichograptus* ranges from Arenigian through Llanvirnian in Europe, North and South America, and Australia (Bulman, 1970).

Genus *Zygograptus* Harris and Thomas, 1941
?*Zygograptus junori* Harris and Thomas

Figure 3*B*

?*Zygograptus junori* Harris and Thomas, 1941, p. 309, pl. 1, fig. 6, pl. 2, fig. 4. Cooper, 1979, p. 58, text fig. 23.

Diagnosis.—Sicula obscure; first-order stipes 4.5 to 6.0 mm long, forming straight funicle. Second- and third-order stipes relatively short, as in *Loganograptus*. Stipes thin (maximum width about 0.4 mm), with about 10 thecae per centimeter. Thecae parallel-sided tubes inclined at low angle (120°) to axis of stipe.

Discussion.—The single specimen (fig. 3*B*) presumably has half of the rhabdosome missing, but it matches the Australian form closely in size and mode of branching. Stipes are 0.25 to 0.5 mm wide, and thecae number about 12 per centimeter.

Horizon and locality.—Lower Darriwillian (Da1) in Victoria, Australia (Harris and Thomas, 1941); Zone of *D. protobifidus* (Chewtonian) in New Zealand (Cooper, 1979).

Genus *Dichograptus* Salter, 1863
Dichograptus aff. *D. norvegicus* Harris and Thomas

Figures 4*A*, *C*

aff. *Dichograptus norvegicus* Harris and Thomas, 1940, p. 130, pl. 1, figs. 4a–c, pl. 2, fig. 5.

Description.—The first-order branches form a funicle 4 mm long, from which the second-order branches diverge. One pair of second-order branches is itself unbranched, whereas the other pair is only about 1.2 mm long and gives rise to two third-order branches; thus, the rhabdosome consists of only six unbranched stipes instead of the usual eight that characterize the genus. One specimen (fig. 4*A*) possibly had eight stipes, but only six are preserved. The second- and third-order stipes are about 0.3 mm wide near their origin and widen to a maximum of 0.8 mm. The thecae number about 10 per centimeter.

Discussion.—*D. norvegicus* s.s. has six to eight unbranched stipes 0.25 to 1.5 mm wide, a funicle 3 mm long, and six to eight thecae per centimeter; it differs in detail from the Washington specimens but resembles them in general aspect, size, and mode of branching. *D. marathonensis* Berry, which occurs in the *P. tentaculatus* Zone in Texas (Berry, 1960), resembles the Washington specimens in its funicle length, relatively narrow stipes (0.5–1.2 mm), and number of thecae per centimeter (eight to nine); it may be a junior synonym of *D. norvegicus*.

Horizon and locality.—*D. norvegicus* s.s is found in the Chewtonian (Ch2) to Castlemainian (Ca2) of Victoria, Australia (Harris and Thomas, 1940). Cooper (1979) described *D.* cf. *norvegicus* from the *Oncograptus* Zone (Yapeenian) of New Zealand.

Genus *Tetragraptus* Salter, 1863
Tetragraptus cf. *T. minutus* Geh

Figure 5*A*

cf. *Tetragraptus minutus* Geh, 1964, p. 387, 400, pl. 4, fig. 12, text figs. 7a–b. Mu and others, 1979, p. 56, pl. 18, fig. 12.

Description.—The rhabdosome is small, with reclined stipes branching off a funicle 1.6 mm long. The stipes are nearly straight, about 7 mm long and 0.6 to 1.3 mm wide. The thecae are strongly denticulate and number 6 in 5 mm. They appear to overlap about half of their length.

Discussion.—The Washington specimen matches Geh's (1964) description of *T. minutus* very closely except for the length of the stipes, which are shorter (4.4 mm) and somewhat more dorsally curved. It also resembles *T.* sp. aff. *T. taraxacum* Ruedemann described by Cooper (1979) but lacks that form's conspicuous sicula. This form differs from *T. taraxacum* s.s. in its shorter funicle and the greater initial width of its stipes. It differs from *T. kindlei* Ruedemann in its shorter funicle, wider stipes, and greater number of thecae per centimeter.

Horizon and locality.—*T. minutus* occurs in the *Glyptograptus austrodentatus* Zone (Ningkuo Shale) of China (Geh, 1964). Mu and others (1979) list it from the *D. filiformis* Zone of southwestern China.

Tetragraptus pendens liber n.subsp.

Figures 5*C–E*

Holotype.—USNM 406181, from the Ledbetter Slate, collection 1.

Measured material.—USNM 406181, USNM 406252, USNM 406263, and six other specimens.

Name.—Liber, from the Latin for "child."

Description.—The sicula is 1.5 mm long and, in many specimens, is attached to a long (over 6 mm) virgula. The sicula gives rise to two short stipes, 0.8 to 1.0 mm long, each of which bifurcates to produce two

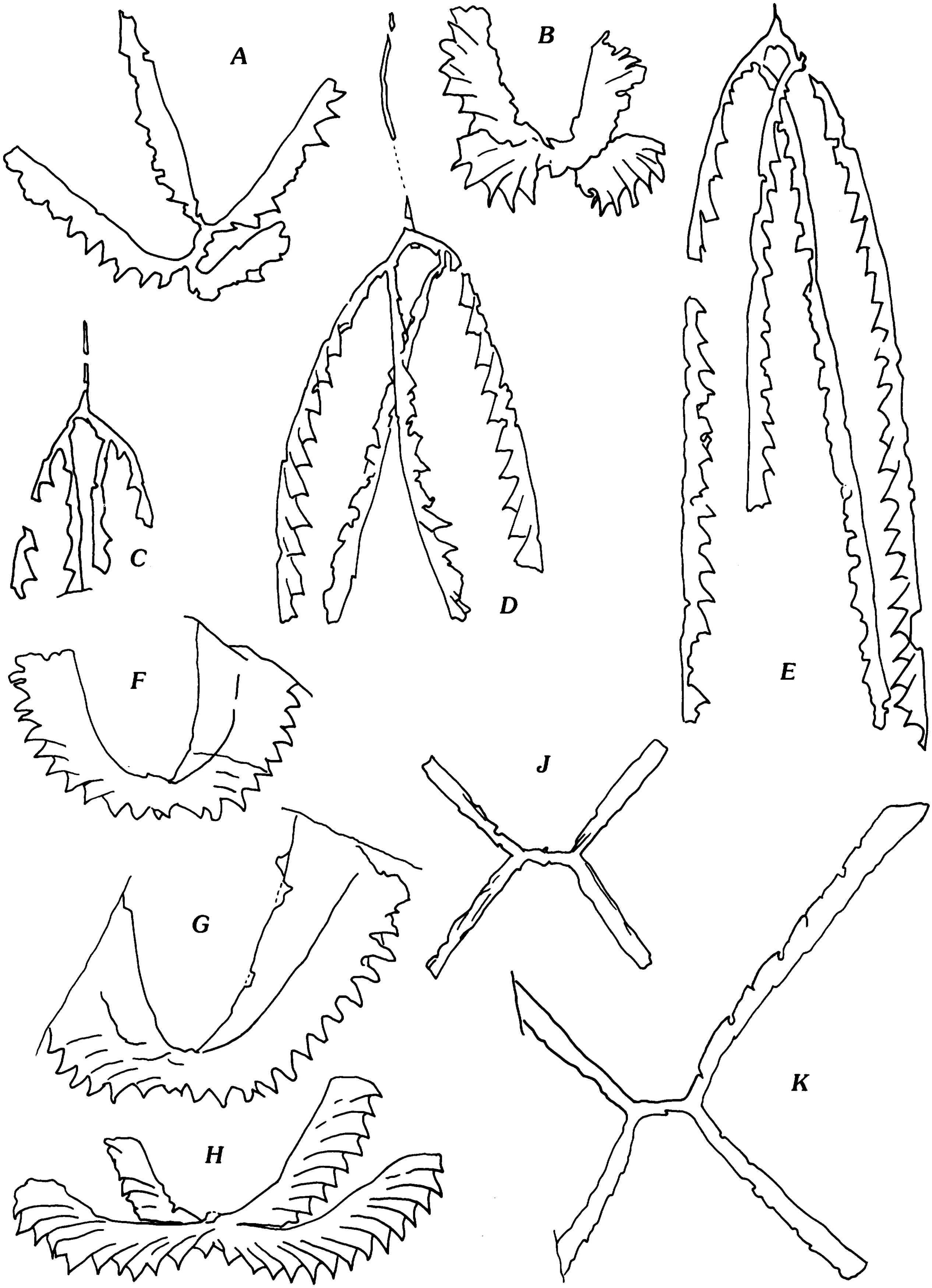


Figure 5. Dichograptidae. All X5. *A, Tetragraptus* cf. *T. minutus* Geh, USNM 406238, collection 2, Metaline Limestone. *B, T.* cf. *T. pseudobigsbyi* Skevington, USNM 406199, collection 1, Ledbetter Slate. *C, T. pendens liber* n. subsp., USNM 406263, collection 2, Metaline Limestone. *D, T. p. liber* n. subsp., USNM 406181, collection 1, Ledbetter Slate, holotype. *E, T. p. liber* n. subsp., USNM 406252, collection 2, Metaline Limestone. *F, T.* cf. *T. pseudobigsbyi* Skevington, USNM 406264, collection 2, Metaline Limestone. *G, T.* cf. *T. pseudobigsbyi* Skevington, USNM 406265, collection 2, Metaline Limestone. *H, T.* cf. *T. pseudobigsbyi* Skevington, USNM 406209, collection 1, Ledbetter Slate. *J, T. quadribrachiatus* (Hall), USNM 406232, collection 2, Metaline Limestone. *K, T. quadribrachiatus* (Hall), USNM 406180, collection 1, Ledbetter Slate.

pendent, inward-curving second-order stipes. The four second-order stipes are usually about 15 mm long but may attain a length of 25 mm. They increase rapidly from an initial width of 0.3 to 0.5 mm to a maxium width of 1.0 to 1.4 mm, which is maintained for most of their length. The thecae are nearly straight tubes, 1.2 to 2.0 mm (usually about 1.4 mm) long, inclined 25° to 30° to the stipe axis, overlapping one-third of their length or less, and numbering 8 to 10 per centimeter. The thecal apertures are located on the inward margins of the stipes; they are straight or slightly concave and are approximately perpendicular to the stipe axis.

Discussion.—This form closely resembles *T. pendens pendens* Elles in the pendent habit of its stipes and the overall size and character of its rhabdosome. It is distinguished by wider stipes (in comparison with 0.6 mm wide in *T. p. pendens*) and more widely spaced thecae having less overlap (in comparison with 9 to 12 thecae per centimeter and an overlap of one-half to one-third in *T. p. pendens*). In addition, the thecae of *T. p. liber* are inclined to the stipe axis at 25° to 35°, whereas those of *T. p. pendens* are inclined at 15° to 20°.

According to R.A. Cooper (personal communication, 1986), *T. p. liber* might be related to a group of pendent dichograptids having a variable number of stipes, specifically the form described by Cooper (1979) as *Pterograptus*? sp.nov. from the Zone of *Diplograptus*? *decoratus*. In this form, one of the two primary stipes is unbranched. It is possible that *liber* is a similar form in which all dichotomies after the first (on each stipe) are suppressed. However, no variation in the number of stipes occurs in the Washington specimens.

Horizon and locality.—*T. p. pendens* has been found in the Zone of *Didymograptus nitidus* in the British Isles (Jackson, 1962) and in corresponding horizons in Texas (Berry, 1960), New Zealand (Cooper, 1979), Australia (Harris and Thomas, 1938), China (Mu and others, 1979), and Kazakhstan (Tsai, 1974). Larson and Jackson (1966) and Lenz and Perry (1972) reported *T. pendens* from western Canada occurring in the *Paraglossograptus etheridgei* (=*P. tentaculatus*) Zone; these forms may actually be *T. p. liber*. A form similar to *T. p. liber*, also from the *P. tentaculatus* Zone, is illustrated from Texas by Berry (1960, pl. 13, fig. 1).

Tetragraptus cf. *T. pseudobigsbyi* Skevington

Figures 5*B*, *F–H*

cf. *Graptolithus bigsbyi* Hall, 1865, pl. 16, figs. 22–24, 27, 28.

cf. *Tetragraptus pseudobigsbyi* Skevington, 1965, p. 8–9, fig. 2.

Description.—The four stipes are moderately to highly reclined and curved proximally but become straight distally (generally within 2–3 mm of their origin). They attain a maximum width (including denticles) of 2.3 to 3.0 mm. The thecae are curved, with prominent apertural denticles, and they are spaced 12 to 15 per centimeter.

Discussion.—These specimens resemble *T. pseudobigsbyi* in the general size and shape of the rhabdosome, but their thecae are somewhat more closely spaced (compared to 12–13 thecae per centimeter in *pseudobigsbyi*). They also resemble *T. serra* (Brongniart), which differs in having longer, straighter stipes and only 8 to 10 thecae per centimeter. Because *T. pseudobigsbyi* is not generally found in rocks this young, this form is probably a descendant of the true *pseudobigsbyi*.

Horizon and locality.—*T. pseudobigsbyi* s.s. is found in the Levis Shale of Quebec (Hall, 1865), the *Didymograptus hirundo* Zone (Ontikan Limestone) in Sweden (Skevington, 1965), the *D. bifidus* and *I. v. lunatus* Zone (Valhallfonna Formation) in Spitsbergen (Cooper and Fortey, 1982), and the *D. protobifidus* Zone (Phi Kappa Formation) at Trail Creek, Idaho (Carter and Churkin, 1977).

Tetragraptus quadribrachiatus (Hall)

Figures 5*J*, *K*, 6*B*

Graptolithus quadribrachiatus Hall, 1858, p. 125; Hall, 1865, p. 91–92, pl. 5, figs. 1–5, pl. 6, figs. 5, 6.

Tetragraptus quadribrachiatus (Hall). Elles and Wood, 1901–18, p. 57–58, pl. 5, figs. 1a–d, text fig. 34. Ruedemann, 1904, p. 645–647, text figs. 51, 52, pl. 11, figs. 1–4. Ruedemann, 1947, p. 307–308, pl. 50, figs. 15–17. Berry, 1960, p. 55, pl. 7, fig. 12. Cooper, 1979, p. 66, pls. 5b, 9b. Cooper and Fortey, 1982, p. 216, pl. 4, figs. 13, 14.

Tetragraptus (*Eotetragraptus*) *quadribrachiatus* (Hall). Tsai, 1974, p. 53–54, pl. 4, figs. 6–7.

Discussion.—The stipes of most of the Washington specimens are preserved in such a way that their profiles are obscured, so that thecal counts cannot be obtained, nor can their actual width be determined. In such cases, their width never exceeds about 1 mm. Where thecae can be seen, they number 8 to 12 per centimeter.

Horizon and locality.—*T. quadribrachiatus* is long ranging and geographically widespread. In addition to the occurrences cited by Ruedemann (1947, p. 308), it has been found in Alaska (Carter and Tailleur, 1984), Texas (Berry, 1960), western Canada (Lenz and Jackson, 1986), New Zealand (Cooper, 1979), Spitsbergen (Cooper and Fortey, 1982), and the Soviet Union (Tsai, 1974).

Tetragraptus cf. *T. zhejiangensis* Geh

Figures 6*C*, *D*

cf. *Tetragraptus zhejiangensis* Geh, 1964, p. 374, 393–394, pl. 1, figs. 1–8. Tsai, 1974, p. 55, pl. 4, fig. 8.

Description.—The rhabdosome is of the *quadribrachiatus* type, with very thin (0.1–0.3 mm wide), slightly flexuous second-order stipes that branch from a funicle 2.7 mm long. The second-order stipes are as much as 14 mm long and enclose an angle of 85° to 135°. The nature and spacing of the thecae are not revealed by the specimens at hand.

Discussion.—This form is distinguished by the extreme narrowness of the stipes. *T. zhejiangensis* s.s. has a funicle 2 to 3.4 mm long and 0.2 mm wide, seven to eight thecae per centimeter, and thin, slightly flexuous stipes less than 0.5 to 0.9 mm wide that enclose an angle of 90° to 110°. It occurs in the *Cardiograptus amplus* and *Glyptograptus austrodentatus* Zones (Ningkuo Shale) of China (Geh, 1964).

Horizon and locality.—*T. zhejiangensis* s.s. has been found in Kazakhstan in the upper part of the *Isograptus gibberulus-Didymograptus hirundo* Zone (Tsai, 1974). Lenz and Jackson (1986) reported the occurrence of *T.* cf. *zhejiangensis* in the lower *P. tentaculatus* Zone of western Canada.

Genus *Pseudotrigonograptus* Mu and Lee, 1958
Pseudotrigonograptus ensiformis (Hall)

Figures 6*E*, *F*

Graptolithus ensiformis Hall, 1858, p. 133.
Retiolites ensiformis (Hall). Hall, 1865, p. 114–115, pl. 14, figs. 1–5.
Trigonograptus ensiformis (Hall). Ruedemann, 1904, p. 727–729, pl. 17, figs. 1–9. Elles and Wood, 1901–18, p. 302–303, pl. 35, figs. 1a–c. Ruedemann, 1947, p. 447–448, pl. 76, figs. 49–57. Berry, 1960, p. 94, pl. 12, fig. 10, pl. 13, figs. 6, 7. Tsai, 1974, p. 67, pl. 6, figs. 1–5.
Pseudotrigonograptus ensiformis (Hall). Rickards, 1973, p. 599–602, figs. 1–3. Cooper and Fortey, 1982, p. 248, figs. 53a–d.
Tristichograptus ensiformis (Hall). Cooper, 1979, p. 91, pl. 19e, g, text fig. 83a.

Discussion.—This species is quite variable in size. The smallest Ledbetter specimen, considered to be immature, is 12 mm long and 2.0 mm wide (fig. 6*E*). The longest Ledbetter specimen is more than 4 cm long and 3.0 mm wide, and one specimen is as much as 4 mm wide.

Horizon and locality.—The Zones of *Isograptus caduceus* and *P. tentaculatus* in Texas (Berry, 1960), the *P. tentaculatus* Zone in British Columbia (Larson and Jackson, 1966), the *P. tentaculatus* Zone in the Baird Mountains of Alaska (Carter and Tailleur, 1984), and the *I. v. maximodivergens* and *P. tentaculatus* Zones in New Zealand (Cooper, 1979).

Genus *Didymograptus* M'Coy, 1851, sensu lato
Didymograptus cf. *D. cognatus* Harris and Thomas

Figures 6*K*–*N*

cf. *Didymograptus cognatus* Harris and Thomas, 1935, p. 291–292, fig. 1, nos. 4a–c, fig. 2, nos. 13, 14.
cf. *Acrograptus cognatus* (Harris and Thomas). Tsai, 1974, p. 85, pl. 7, fig. 16.

Description.—The sicula is 0.6 to 0.8 mm long and is generally quite conspicuous. The stipes are gently flexuous, more than 24 mm long and 0.2 to 0.3 mm wide initially and increasing gradually to a maximum width of 0.4 to 0.5 mm. They diverge from the sicula at an angle of 120° to 135°. The thecae are straight tubes, inclined at a very small angle and 1.2 to 1.5 mm long, overlap one-half to one-third of their length, and number 12 to 9½ thecae per centimeter.

Discussion.—*D. cognatus* s.s. has stipes not exceeding about 0.4 mm in width and diverging from the sicula at an angle of 140°. Its thecae number eight per centimeter and exhibit almost no overlap. One of the Ledbetter specimens (fig. 6*N*) matches these dimensions more closely than the rest (figs. 6*K*–*M*), but its stipes diverge at almost 180°. *D. cognatus* is distinguished by its very slender stipes and the characters of its thecae.

Horizon and locality.—*D. cognatus* s.s. is found in the Darriwillian (Da3) of Australia (Harris and Thomas, 1935; A.H.M. VandenBerg, unpublished report, 1981) and in the *Expansograptus hirundo* Zone of Kazakhstan (Tsai, 1974).

Didymograptus aff. *D. extensus* (Hall)

Figures 6*A*, *G*, *J*, *P*

aff. *Graptolithus extensus* Hall, 1858, p. 132. Hall, 1865, p. 80–81, pl. 2, figs. 11–16.
aff. *Didymograptus extensus* (Hall). Ruedemann, 1947, p. 331–332, pl. 55, fig. 16, pl. 56, figs. 1–2.

Description.—The long (as much as 10 cm), nearly straight stipes diverge at 180° from a broad sicula 1.0 to 1.2 mm long. Initially, the stipes are 0.6 to 0.8 mm wide, and they increase gradually (within about 3 cm) to a maximum width of 1.5 to 1.7 mm. The thecae number 4½ to 6 in 5 mm near the sicula and 8½ to 10 per centimeter distally; they overlap about one-half of their length.

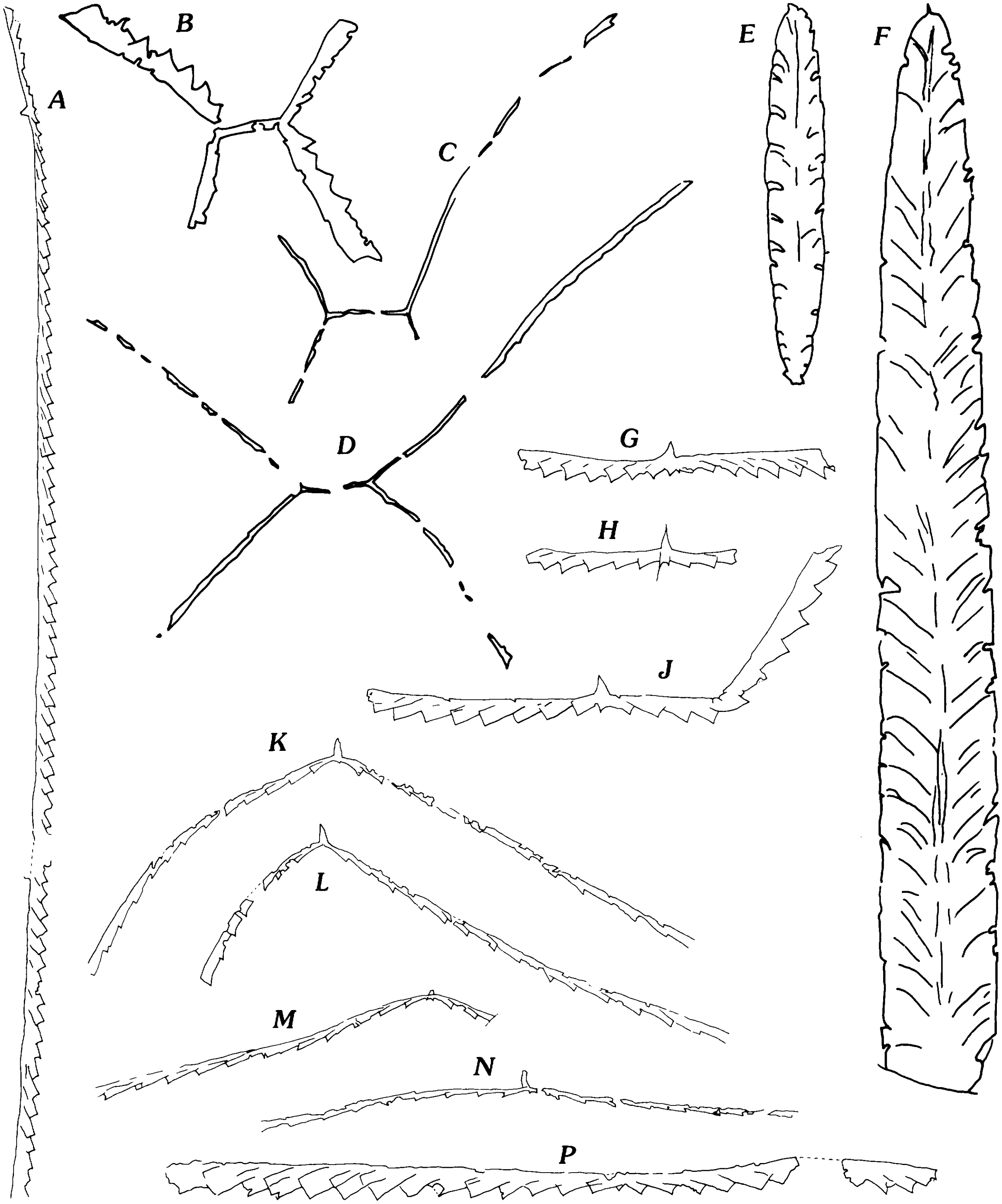


Figure 6. Dichograptidae. *A*, *Didymograptus* aff. *D. extensus* (Hall), USNM 406246, collection 2, Metaline Limestone, ×2.5. *B*, *Tetragraptus quadribrachiatus* (Hall), USNM 406260, collection 2, Metaline Limestone, ×5. *C*, *T.* cf. *T. zhejiangensis* Geh, USNM 406206, collection 1, Ledbetter Slate, ×5. *D*, *T.* cf. *T. zhejiangensis* Geh, USNM 406205, collection 1, Ledbetter Slate, ×5. *E*, *Pseudotrigonograptus ensiformis* (Hall), USNM 406261, collection 2, Metaline Limestone, ×5. *F*, *P. ensiformis* (Hall), USNM 406251, collection 2, Metaline Limestone, ×5. *G*, *D.* aff. *D. extensus* (Hall), USNM 406233, collection 2, Metaline Limestone, ×5. *H*, *Xiphograptus* sp., USNM 406241, collection 2, Metaline Limestone, ×5. *J*, *D.* aff. *D. extensus* (Hall), USNM 406202, collection 1, Ledbetter Slate, ×5. *K*, *D.* cf. *D. cognatus* Harris and Thomas, USNM 406194, collection 1, Ledbetter Slate, ×5. *L*, *D.* cf. *D. cognatus* Harris and Thomas, USNM 406182, collection 1, Ledbetter Slate, ×5. *M*, *D.* cf. *D. cognatus* Harris and Thomas, USNM 406224, collection 1, Ledbetter Slate, ×5. *N*, *D.* cf. *D. cognatus* Harris and Thomas, USNM 406184, collection 1, Ledbetter Slate, ×5. *P*, *D.* aff. *D. extensus* (Hall), USNM 406208, collection 1, Ledbetter Slate, ×5.

Discussion.—The Washington specimens match *D. extensus* in their angle of divergence but differ slightly in thecal spacing (9 to 10 per centimeter in *extensus*). They are distinguished from other didymograptids by their angle of divergence and straight, narrow stipes. *D. extensus* is restricted to the Zones of *Tetragraptus fruticosus* through *I. v. lunatus* in New Zealand (Cooper, 1979) and generally is found in the lower or middle Arenigian.

Genus *Xiphograptus* Cooper and Fortey, 1982

Xiphograptus sp.

Figure 6*H*

Description.—The single specimen has short, extensiform (horizontal) stipes and a sicula 1.3 mm long bearing a prominent virgella about 0.5 mm long. The stipes are 0.5 to 0.7 mm wide. The thecae are spaced approximately 12 per centimeter (extrapolated) and are inclined 15° to 25° to the stipe axis.

Discussion.—The presence of the virgellar spine is regarded by Cooper and Fortey (1982, p. 273, 289) as characteristic of the genus *Xiphograptus* and serves to distinguish it in flattened material from *Didymograptus* (*Expansograptus*). The Washington specimen has narrower stipes and fewer thecae per centimeter than *X.*? *elongatus* (Harris and Thomas). It has narrower stipes than any of the other species of *Xiphograptus* described by Cooper and Fortey (1982) do.

Horizon and locality.—*Xiphograptus* extends through the Arenigian to the Llanvirnian, mostly in the Pacific Province (Cooper and Fortey, 1982).

Genus *Isograptus* Moberg, 1892

Isograptus caduceus australis Cooper

Figures 7*A*–*E*

Isograptus caduceus australis Cooper, 1973, p. 74–77, text figs. 16a–e, h. Cooper, 1979, p. 74, pl. 13j, figs. 49a, b. Carter and Tailleur, 1984, p. 47–48, figs. 5K, L.

Diagnosis.—Rhabdosome medium sized, generally V shaped. Sicula 3.0 to 4.1 mm long, averaging 3.6 mm long. Stipes as much as 25 mm long, diverging at 330° to 360°, widest near the sicula, thereafter either parallel sided or gradually tapering. Proximal stipe width 1.3 to 2.5 mm (1.9 mm average); distal stipe width 1.6 to 2.2 mm (2.0 mm average). Thecae 9½ to 10½ per centimeter.

Discussion.—The Washington specimens exhibit all the characters and dimensions of *I. c. australis*. *I. c. caduceus* (Salter) has narrower stipes and fewer thecae per centimeter than *australis*.

Horizon and locality.—Yapeenian Zone of *Oncograptus* in New Zealand and Yapeenian (Ya1–Ya2) in Victoria, Australia (Cooper, 1973, 1979). Zones of *Oncograptus* and *P. tentaculatus* in the Baird Mountains of Alaska (Carter and Tailleur, 1984).

Isograptus cf. *I. forcipiformis* (Ruedemann)

Figures 7*Q*, *R*

cf. *Didymograptus forcipiformis* Ruedemann, 1904, p. 699–700, text fig. 91, pl. 15, figs. 10–13.
cf. *Isograptus forcipiformis* (Ruedemann). Cooper, 1971, p. 906, text figs. 3a–e.

Description.—The stipes diverge at an angle of almost 360°, so that they are nearly parallel. They are widest at their origin, tapering to a distal width of 1.5 mm. The sicula and first theca are 3.5 to 4.5 mm long, and the notch between them is almost nonexistent. The thecae number 11 to 10 per centimeter.

Discussion.—The Washington specimens resemble *I. forcipiformis* in general appearance (subparallel tapering stipes, no notch) and dimensions. They differ from *I. c. australis* mainly by having narrower stipes and a longer sicula.

Horizon and locality.—*I. forcipiformis* s.s. occurs in the *Glyptograptus dentatus* Zone at Mt. Merino, New York (Ruedemann, 1904), in beds of Darriwillian age in Victoria, Australia (VandenBerg, 1981), and in the *Paraglossograptus etheridgei* Zone in British Columbia (Larson and Jackson, 1966).

Isograptus cf. *I. angulatus* Mu, Geh, and Yin

Figures 7*F*–*J*, *L*, *M*, *P*

cf. *Isograptus angulatus* Mu, Geh, and Yin, *in* Mu, Lee, and Geh, 1962, p. 78–79, pl. 9, figs. 5–14, text fig. 10b.

Description.—The rhabdosome is small, with short, narrower stipes about 3 mm long. The sicula and first theca are 3.0 to 3.5 mm long; they have a supradorsal height of 0.4 to 0.9 mm, and the notch between their free ventral walls measures 0.9 to 1.0 mm in length. The stipes appear to grow outward at about 180° before they abruptly change direction and grow nearly straight upward; the area thus enclosed appears almost like three sides of a rectangle, the horizontal side of which is 1.5 to 2.2 mm long (2.0 mm average). The stipes are 1.6 to 1.9 mm wide at the level of their abrupt bend and 1.2 to 1.6 mm wide distally. The thecae are typically isograptid, with concave apertural margins that extend into pronounced ventral denticles. They number three to four in 2.5 mm (12–16 per centimeter).

Discussion.—The Washington form resembles *I. angulatus* in general size and shape, but its stipes are wider and not as nearly parallel distally as those of *angulatus*. In addition, the dorsal margins of the stipes

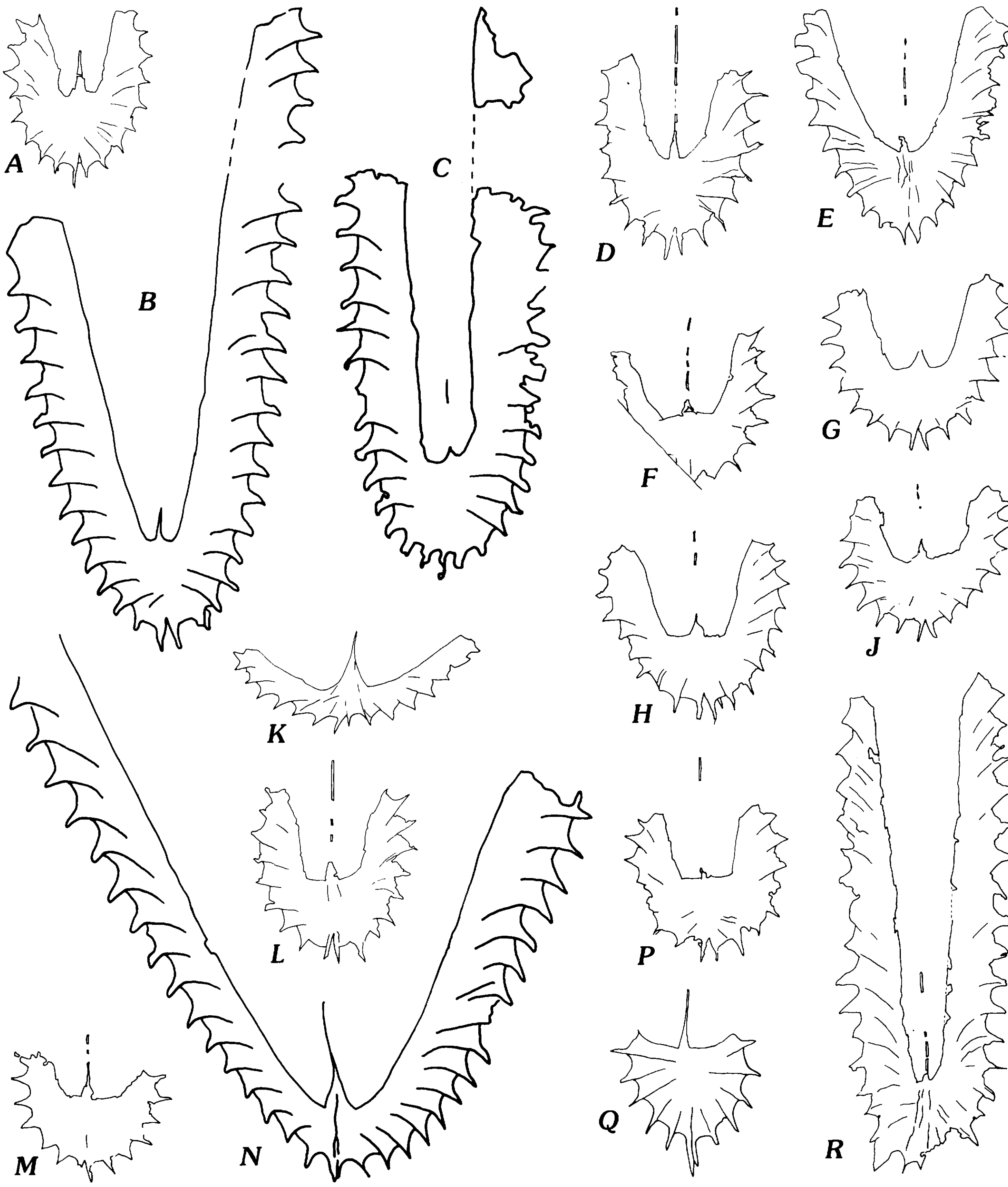


Figure 7. Dichograptidae. All ×5. *A, Isograptus caduceus australis* Cooper, USNM 406242, collection 2, Metaline Limestone. *B, I. c. australis* Cooper, USNM 406237, collection 2, Metaline Limestone. *C, I. c. australis* Cooper, USNM 406235, collection 2, Metaline Limestone. *D, I. c. australis* Cooper, USNM 406239, collection 2, Metaline Limestone. *E, I. c. australis* Cooper, USNM 406227, collection 1, Ledbetter Slate. *F, I.* cf. *I. angulatus* Mu, Geh, and Yin, USNM 406226, collection 1, Ledbetter Slate. *G, I.* cf. *I. angulatus* Mu, Geh, and Yin, USNM 406240, collection 2, Metaline Limestone. *H, I.* cf. *I. angulatus* Mu, Geh, and Yin,USNM 406267, collection 3, Ledbetter Slate. *J, I.* cf. *I. angulatus* Mu, Geh, and Yin, USNM 406213, collection 1, Ledbetter Slate. *K, Pseudisograptus*? aff. *P. manubriatus koi* Cooper and Ni, USNM 406258, collection 2, Metaline Limestone. *L, I.* cf. *I. angulatus* Mu, Geh, and Yin, USNM 406222, collection 1, Ledbetter Slate. *M, I.* cf. *I. angulatus* Mu, Geh, and Yin, USNM 406269, collection 3, Ledbetter Slate. *N, I. victoriae divergens* Harris, USNM 406244, collection 2, Metaline Limestone. *P, I.* cf. *I. angulatus* Mu, Geh, and Yin, USNM 406225, collection 1, Ledbetter Slate. *Q, I.* cf. *I. forcipiformis* (Ruedemann), USNM 406245, collection 2, immature specimen, Metaline Limestone. *R, I.* cf. *I. forcipiformis* (Ruedemann), USNM 406228, collection 1, Ledbetter Slate.

have a more abrupt and more angular bend than do the Chinese forms illustrated by Mu and others (1962, pl. 9, figs. 7–14). This form has the appearance of a pseudisograptid having a "flat" manubrium and, in fact, may actually belong in the genus *Pseudisograptus*. However, the specimens at hand do not reveal the details of this manubriumlike structure. In addition, the dorsal margins of the manubria in known species of *Pseudisograptus* slope downward from the sicula, whereas the dorsal margin of the "manubrium" in *I.* cf. *I. angulatus* is nearly straight and is perpendicular to the axis of symmetry of the rhabdosome.

I. angulatus s.s. is distinguished from all known isograptids by its small size and the nearly rectangular shape of the area defined by the dorsal margins of its stipes.

Horizon and locality.—Zone of *Paraglossograptus typicalis* (=*P. tentaculatus*) in Qilianshan, China (Mu and others, 1962).

Isograptus victoriae divergens Harris

Figure 7*N*

Isograptus caduceus var. *divergens* Harris, 1933, p. 91, text figs. 14–18.

Isograptus furcula Ruedemann, 1947, p. 353, pl. 57, fig. 48.

Isograptus victoriae divergens Harris. Cooper, 1973, p. 69–70, text figs. 13b–d. Cooper, 1979, p. 77, fig. 57. Carter and Tailleur, 1984, p. 49, fig. 6E.

Diagnosis.—Rhabdosome large and generally V shaped. Sicula 3.5 to 4.0 mm long; supradorsal portion 1.5 mm long. Stipes generally straight, widening gradually from a width of about 2 mm to about 4 to 5 mm wide distally. Angle of divergence about 340°. Thecae about nine per centimeter.

Discussion.—The stipes of the Washington specimens attain a distal width of only 3.0 mm and have 10 or 11 thecae per centimeter, but otherwise they fit the description of *I. v. divergens.*

Horizon and locality.—Glenogle Shale of British Columbia (Ruedemann, 1947), *Oncograptus* Zone in New Zealand (Cooper, 1973, 1979), Yapeenian and Darriwillian (Da1–Da3) in Victoria, Australia (VandenBerg, 1981), *P. tentaculatus* Zone in the Baird Mountains of Alaska (Carter and Tailleur, 1984), and upper *Oncograptus* and *P. tentaculatus* Zones in the Canadian Cordillera (Lenz and Jackson, 1986).

Genus *Pseudisograptus* Beavis, 1972
Pseudisograptus? aff. *P. manubriatus koi* Cooper and Ni

Figure 7*K*

aff. *Pseudisograptus manubriatus koi* Cooper and Ni, 1986, p. 332–339, pl. 24, figs. 1–6, 9–12, pl. 25, figs. 3, 4, text figs. 12, 13A–G, J.

Description.—The sicula and first three or four thecae appear to form a relatively slender "manubrium" that extends 1.0 to 1.2 mm above the dorsal margin of the stipes and measures about 1 mm across at its base. The sicula is 2.5 mm long and 0.6 mm wide at its aperture. The aperture of the first theca extends a little below that of the sicula and angles off to the side. The stipes diverge at about 230° and are gently dorsally curved near the sicula to nearly straight distally. They are as much as 3.5 mm long and 1.0 to 1.3 mm wide. The thecae are typically isograptid and spaced at a rate (extrapolated) of eight to seven in 5 mm.

Discussion.—This rare form superficially resembles *Didymograptus hemicyclus* Harris but differs in having a much larger sicula and a different arrangement of the proximal thecae. It has a longer sicula and wider stipes than *I. tenuis* Harris does. It resembles some of the small, slender-stiped examples of *P. manubriatus koi* Cooper and Ni illustrated by Cooper and Ni (1986, pl. 24, fig. 10, text fig. 12C) and is probably closely related to them. However, the Washington form has a shorter sicula, a shorter and narrower "manubrium," shorter thecae, and a smaller angle of stipe divergence. Because the specimens are flattened and do not reveal the true nature of the sicular region, this form is only tentatively assigned to the genus *Pseudisograptus*.

Family SINOGRAPTIDAE Mu, 1957
Genus *Sinograptus* Mu, 1957
Sinograptus rastritoides Mu

Figures 8*K–N*

Sinograptus rastritoides Mu, 1957, p. 403, 437, pl. 7, figs. 8–10, text fig. 20. Lenz, 1977, p. 1948–1950, pl. 2, figs. 1, 2, 7, 8.

Diagnosis.—Sicula 0.7 to 1.0 mm long. Stipes straight to gently flexed dorsally after initial divergence of 90° to 130°. Stipe width exclusive of spines 0.8 to 0.9 mm at first theca, increasing rapidly to a maximum of 1.9 to 2.4 mm. Dorsal (prothecal) folds 0.2 to 0.5 mm high; ventral folds (metathecae) 0.3 mm long proximally to 1.4 mm (average 1.0 mm) long distally. Thecae seven to five in 5 mm, bearing long dorsal spines (up to 1 mm) and shorter ventral spines.

Discussion.—Most of the Ledbetter specimens (except fig. 8*K*) might be placed in the species *S. typicalis* Mu because of the length of their metathecae. Mu (1957) and Lenz (1977) described *S. rastritoides* as having metathecae 1.2 to 1.35 mm long. However, *typicalis* has a much smaller angle of divergence than either the Ledbetter forms or the Chinese and Canadian

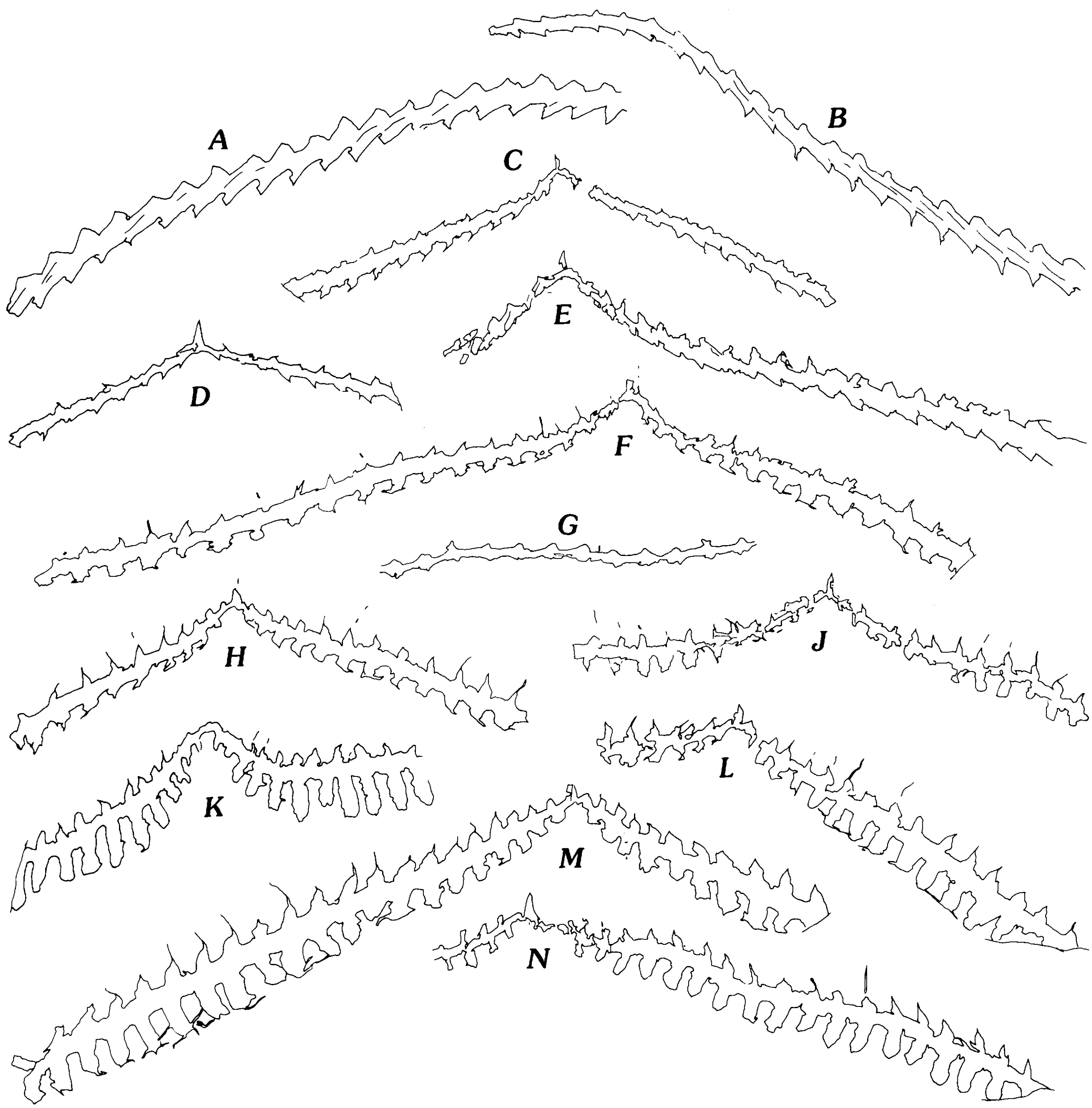


Figure 8. Sinograptidae. All ×5. *A*, *Holmograptus* cf. *H. spinosus* (Ruedemann), USNM 406200, collection 1, Ledbetter Slate. *B*, *H.* cf. *H. spinosus* (Ruedemann), USNM 406215, collection 1, Ledbetter Slate. *C*, *H.* cf. *H. spinosus* (Ruedemann), USNM 406188, collection 1, Ledbetter Slate. *D*, *H.* cf. *H. spinosus* (Ruedemann), USNM 406186, collection 1, Ledbetter Slate. *E*, *H.* cf. *H. spinosus* (Ruedemann), USNM 406216, collection 1, Ledbetter Slate. *F*, *Sinograptus* n.sp., USNM 406175, collection 1, Ledbetter Slate. *G*, *H.* cf. *H. lentus* (Törnquist), USNM 406259, collection 2, Metaline Limestone. *H*, *Sinograptus* n.sp., USNM 406214, collection 1, Ledbetter Slate. *J*, *Sinograptus* n.sp., USNM 406176, collection 1, Ledbetter Slate. *K*, *S. rastritoides* Mu, USNM 406177, collection 1, Ledbetter Slate. *L*, *S. rastritoides* Mu, USNM 406197, collection 1, Ledbetter Slate. *M*, *S. rastritoides* Mu, USNM 406178, collection 1, Ledbetter Slate. *N*, *S. rastritoides* Mu, USNM 406179, collection 1, Ledbetter Slate.

forms of *rastritoides*. Therefore, the Ledbetter forms are identified as *S. rastritoides*. *S. aequalis* Mu is distinguished from *rastritoides* by its lack of dorsal and ventral spines.

Horizon and locality.—Upper *P. tentaculatus* Zone (Road River Formation) in western Canada (Lenz, 1977; Lenz and Jackson, 1986). *Amplexograptus confertus* Zone (Ningkuo Shale) in China (Mu, 1957).

Sinograptus n.sp.

Figures 8*F*, *H*, *J*

Description.—The stipes are straight or gently flexuous, diverging initially at an angle of 100° to 120° from a sicula 0.8 mm long. The angle of divergence generally increases distally to about 130° to 160°. The longest stipe measured is 19 mm long; stipe width increases rapidly from 0.5 to 0.6 mm near the sicula to a maximum of 1.4 mm about 8 to 10 mm from the sicula. The thecae are of the sinograptid type and strongly sigmoidal and form dorsal folds 0.2 to 0.5 mm high and ventral folds (metathecae) 0.2 to 0.6 mm long. The thecae number 6 to 7½ in 5 mm proximally and 9 to 12 per centimeter distally. The dorsal folds bear short (less than 0.5 mm) but conspicuous spines; spines on the metathecae are even shorter.

Discussion.—This form is distinguished from all other known species of *Sinograptus* by the shortness of its folded metathecae. However, it has not been named, because poor preservation has obscured the details of its thecal morphology.

Genus *Holmograptus* Kozlowski, 1954
Holmograptus cf. *H. lentus* (Törnquist)

Figures 8*G*, 9*A*, *B*

cf. *Didymograptus lentus* Törnquist, 1911, p. 430, pl. 5, figs. 10–15.
cf. *Didymograptus callotheca* Bulman, 1932, p. 16–19, text figs. 2–5.
cf. *Holmograptus lentus* (Törnquist). Jaanusson, 1960, p. 341–342, pl. 5, fig. 11; Skevington, 1965, p. 41–44, figs. 47–50.

Description.—The sicula is 0.9 mm long, and the straight to gently flexed stipes diverge at an angle of about 115°. Stipe width (measured across the thecal apertures) increases from 0.25 mm at the first theca to about 0.6 mm 1 cm from the sicula. Maximum width of distal fragments is 0.75 mm (usually averages 0.5–0.6 mm). The thecae number about 6 in 5 mm proximally and 9½ to 10 per centimeter distally; they have small but distinct (0.15–0.2 mm high) unspined prothecal folds. The free ventral margin of each theca nearly parallels the stipe axis except in the region of the aperture, where it abruptly curves ventrally, so that the apertural portion is expanded into a "knob." The apertural "knobs" are located opposite the prothecal folds, so that the stipe almost has the appearance of beads strung widely apart on a thick string. Details of the thecal apertures are difficult to determine in these flattened specimens.

Discussion.—The Washington specimens have the same dimensions and thecal spacing as *H. lentus* s.s. does, but the thecae of *lentus* appear to be more inclined to the stipe axis.

Horizon and locality.—*H. lentus* is found in the *D. bifidus* Zone of Öland, Sweden (Bulman, 1932; Jaanusson, 1960; Skevington, 1965).

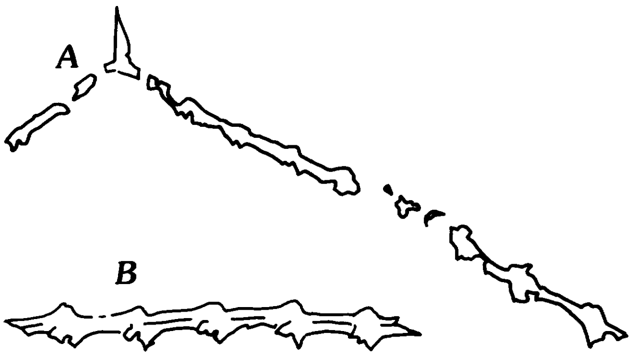


Figure 9. Sinograptidae. *Holmograptus* cf. *H. lentus* (Törnquist), U.S. Geological Survey collection D913–CO, at the 1,700-ft level of the Pend Oreille Mine, from a lens in the Metaline Limestone about 40 ft below the Ledbetter-Metaline contact. Collected by A.E. Weissenborn, 1961. *A*, USNM 413742; *B*, USNM 413744, distal fragment.

Holmograptus cf. *H. spinosus* (Ruedemann)

Figures 8*A*–*E*

cf. *Didymograptus spinosus* Ruedemann, 1904, p. 688–689, text figs. 84, 85, pl. 14, figs. 30–32. Ruedemann, 1947, p. 348, pl. 54, figs. 40–48.
cf. *Didymograptus nodosus* Harris, 1926, p. 56, pl. 1, figs. 1–3 (not pl. 1, fig. 4). Harris and Thomas, 1935, p. 295, fig. 1, no. 7, fig. 2, no. 27.
cf. *Holmograptus spinosus* (Ruedemann). Archer and Skevington, 1973, p. 44–48, pls. 1, 2, text figs. 1a–e. Carter and Tailleur, 1984, p. 52, fig. 7A.

Description.—From a sicula 0.6 to 0.8 mm long, two straight or gently flexed stipes diverge at an initial angle of 90° to 104°. Specimens with a smaller initial angle of divergence (90°–120°) always increase to 125° to 140° distally. Stipe width (measured across thecal apertures) increases from 0.3 to 0.5 mm at the first theca through about 1.0 mm at 10 mm from the sicula to a maximum distal width of about 1.3 mm. The longest measured stipe is more than 20 mm long. The thecae have very prominent dorsal (prothecal) folds (0.15 mm high proximally, 0.4 mm high distally) and apertures with lateral lappets and, in some cases, a denticle on the ventral margin (fig. 8*B*). Thecae number 6 to 7 in the first 5 mm of stipe and 10 to 11 per centimeter distally.

Discussion.—The Ledbetter specimens conform to the dimensions of *H. spinosus* s.s. except for the greater width of some of the longer stipes. In addition, they lack the prominent dorsal and ventral spines characteristic of *spinosus*, although some specimens exhibit a few spinelike projections (fig. 8*D*). *H. lentus* similarly lacks spines but has narrower stipes and less prominent dorsal folds than either *H. spinosus* or this form. *Tylograptus intermedius* Mu, as described by Lenz (1977) from western Canada, resembles the Ledbetter form in its lack of spines but has a shorter sicula (0.5 mm), straighter, narrower stipes (0.25–1.0 mm), and thecae exhibiting strongly introverted apertures.

Horizon and locality.—*H. spinosus* s.s. is found in the Zone of *Diplograptus*? *decoratus* in the Baird Mountains of Alaska (Carter and Tailleur, 1984), the *D. dentatus* Zone in New York State (Ruedemann, 1947; Archer and Skevington, 1973), the Lower Ordovician (Rosroe Grits) in Ireland (Archer and Skevington, 1973), and the *D.*? *decoratus* Zone (Da3) in Victoria, Australia (VandenBerg, 1981).

Suborder GLOSSOGRAPTINA Jaanusson, 1960
Family GLOSSOGRAPTIDAE Lapworth, 1873
Genus *Glossograptus* Emmons, 1855
Glossograptus echinatus Ruedemann

Figures 10*A–E*

Glossograptus echinatus Ruedemann, 1904, p. 725-726, text fig. 102, pl. 16, figs. 30–32. Larson and Jackson, 1966, pl. 3, fig. 9.

Lasiograptus (*Hallograptus*) *echinatus* (Ruedemann). Ruedemann, 1947, p. 462–463, pl. 77, figs. 9–12, 14 (not pl. 77, fig. 13).

Diagnosis.—Rhabdosome up to 20 mm long, wider in middle (3 mm excluding spines) than at ends. Thecae 12 per centimeter, with apertural margins drawn out into stout spines about 1.5 mm long.

Discussion.—The Washington specimens range in maximum width from 2.0 to 3.5 mm (excluding spines), and some have seven thecae in 5 mm proximally. Their apertural spines are generally only about 1.0 to 1.3 mm long. Some specimens (figs. 10*A*, *B*, *E*) possess a few extra-long (up to 5.5 mm long), slender spines presumed to be septal spines.

G. echinatus is wider than *G. fimbriatus* (Hopkinson), and its apertural spines are shorter and stouter than those of *G. ciliatus* Emmons. It has shorter spines than *G. acanthus* Elles and Wood, and its thecae are more closely spaced.

Horizon and locality.—*D. dentatus* Zone at Deepkill, N.Y. (Ruedemann, 1904, 1947), *P. etheridgei* Zone (Glenogle Formation) in British Columbia (Larson and Jackson, 1966).

Genus *Paraglossograptus* Mu (in Hsu, 1959)
Paraglossograptus tentaculatus (Hall)

Figures 10*F–H*

Graptolithus tentaculatus Hall, 1858, p. 134.

Retiograptus tentaculatus (Hall). Hall, 1865, p. 116–117, pl. 14, figs. 6–8. Ruedemann, 1904, p. 733–734, pl. 16, figs. 33–35. Ruedemann, 1947, p. 460–461, pl. 80, figs. 1–10.

Lasiograptus (*Thysanograptus*) *etheridgei* Harris, 1924, p. 98–99, pl. 7, figs. 3–7. Harris and Thomas, 1935, p. 306, fig. 2, nos. 28, 29.

Hallograptus etheridgei (Harris). Berry, 1960, p. 95, pl. 12, figs. 6, 9b, pl. 13, fig. 4.

Paraglossograptus tentaculatus (Hall). Rickards, 1972, p. 102–109, figs. 1, 2a, b, 3. Cooper, 1979, p. 82–83, pl. 16 d, e, j, text figs. 66a-g. Carter and Tailleur, 1984, p. 53, figs. 7G, H.

Diagnosis.—Rhabdosome about 20 to 30 mm long, 3 to 4 mm wide (excluding spines and lacinial processes). Thecae 9 to 14 per centimeter, with apertural spines 2.0 mm long.

Discussion.—This species is readily recognized by the ladderlike lacinial meshworks on either side of the rhabdosome (see Rickards, 1972, for a full description and discussion). Its rhabdosome is wider than that of *P. tricornis* Mu, Geh, and Yin, and it differs from *P. proteus* (Harris and Thomas) by having outwardly directed spines on the lacinia.

Horizon and locality.—This well-known and widespread species occurs in, among other places, the *P. etheridgei* Zone in British Columbia (Larson and Jackson, 1966), the *P. tentaculatus* Zone in the Baird Mountains of Alaska (Carter and Tailleur, 1984), the *P. tentaculatus* Zone in Texas (Berry, 1960), the *P. tentaculatus* Zone (Da1–Da2) in New Zealand (Cooper, 1979), and the Zones of *G. austrodentatus* through *D.*? *decoratus* (Da1–Da3) in Victoria, Australia (VandenBerg, 1981).

Family CRYPTOGRAPTIDAE Hadding, 1915, emended by Bulman, 1970
Genus *Cryptograptus* Lapworth, 1880
Cryptograptus cf. *C. antennarius* (Hall)

Figures 11*H*, *J*, *L*

cf. *Climacograptus antennarius* Hall, 1865, p. 112–113, pl. 13, figs. 11–13. Ruedemann, 1904, p. 731–732, pl. 16, figs. 21–26.

cf. *Cryptograptus*(?) *antennarius* (Hall). Elles and Wood, 1901–18, p. 300–301, pl. 32, figs. 14a–e.

cf. *Cryptograptus antennarius* (Hall). Ruedemann, 1947, p. 444–445, pl. 76, figs. 9–13, ?1–8, ?14–18.

Description.—The rhabdosome is as much as 15.5 mm long and widens from 1.1 to 1.7 mm just above the

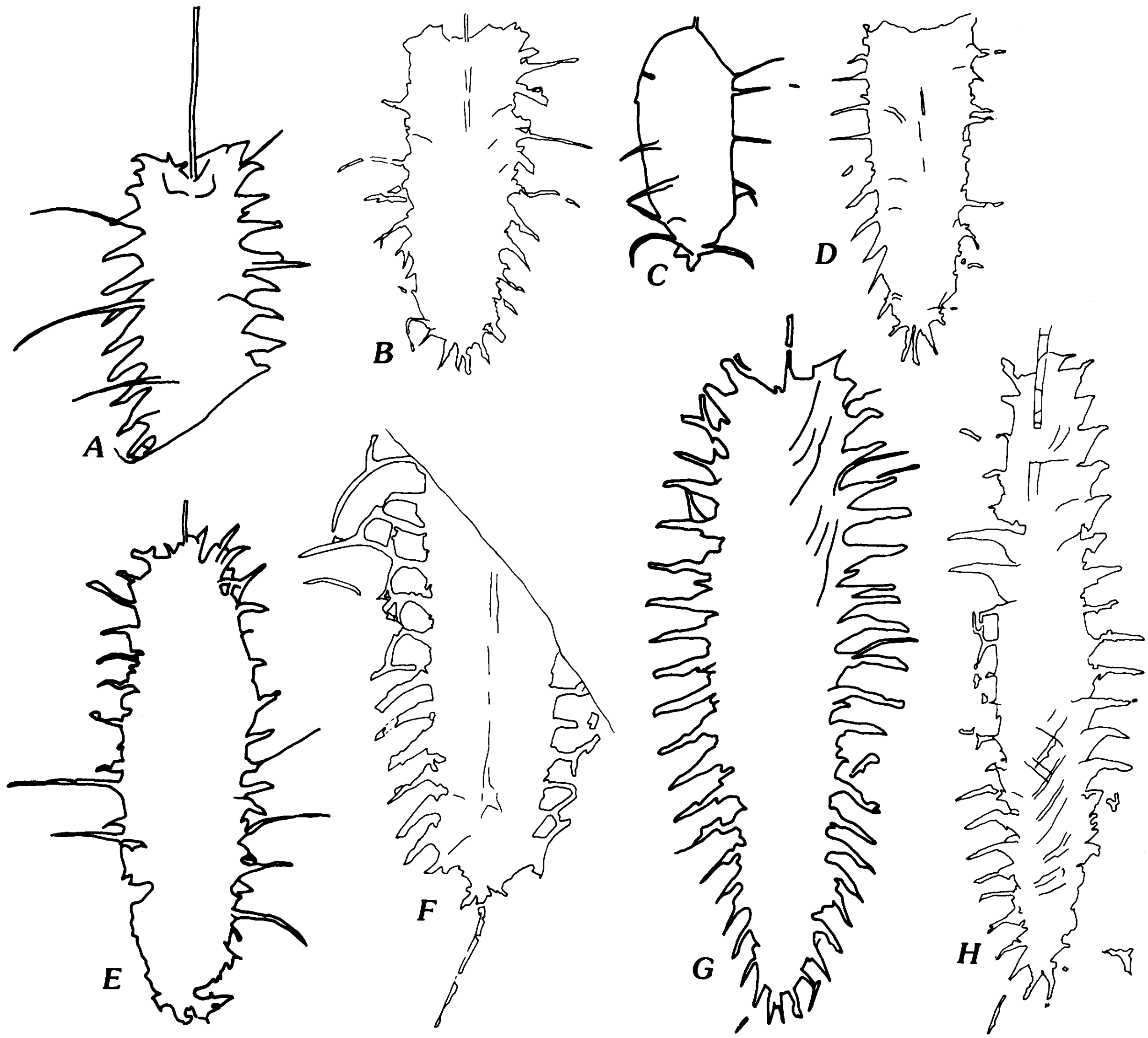


Figure 10. Glossograptidae. All ×5. *A*, *Glossograptus echinatus* Ruedemann, USNM 406254, collection 2, Metaline Limestone. *B*, *G. echinatus* Ruedemann, USNM 406217, collection 1, Ledbetter Slate. *C*, *G. echinatus* Ruedemann, USNM 406253, collection 2, scalariform view, Metaline Limestone. *D*, *G. echinatus* Ruedemann, USNM 406203, collection 1, Ledbetter Slate. *E*, *G. echinatus* Ruedemann, USNM 406250, collection 2, Metaline Limestone. *F*, *Paraglossograptus tentaculatus* (Hall), USNM 406218, collection 1, Ledbetter Slate. *G*, *P. tentaculatus* (Hall), USNM 406189, collection 1, Ledbetter Slate. *H*, *P. tentaculatus* (Hall), USNM 406223, collection 1, Ledbetter Slate.

basal spines to a maximum width of 1.9 to 2.5 mm in scalariform view. The proximal end is pointed in the manner of *C. tricornis* (Carruthers) and bears two long, slender lateral spines measuring as much as 4.4 mm long. The nature and spacing of the thecae cannot be determined because of the scalariform preservation of the specimens. The virgula is somewhat thickened, usually measuring 0.3 to 0.5 mm wide.

Discussion.—*C. antennarius* s.s. is 2 to 3 mm wide and has long, stiff basal spines 4 to 8 mm long or longer. Some of the Washington specimens having shorter basal spines (fig. 11*H*) may actually be scalariform views of *C.*? *inutilus* (Hall). However, some of them have such long basal spines that they are here compared to *C. antennarius*.

Horizon and locality.—*C. antennarius* s.s. is found in the Quebec Group at Point Levis, Quebec (Hall, 1865), the *D. dentatus* Zone in New York (Ruedemann, 1947), and the *D. hirundo* Zone (Skiddaw Group) in the British Isles (Jackson, 1962).

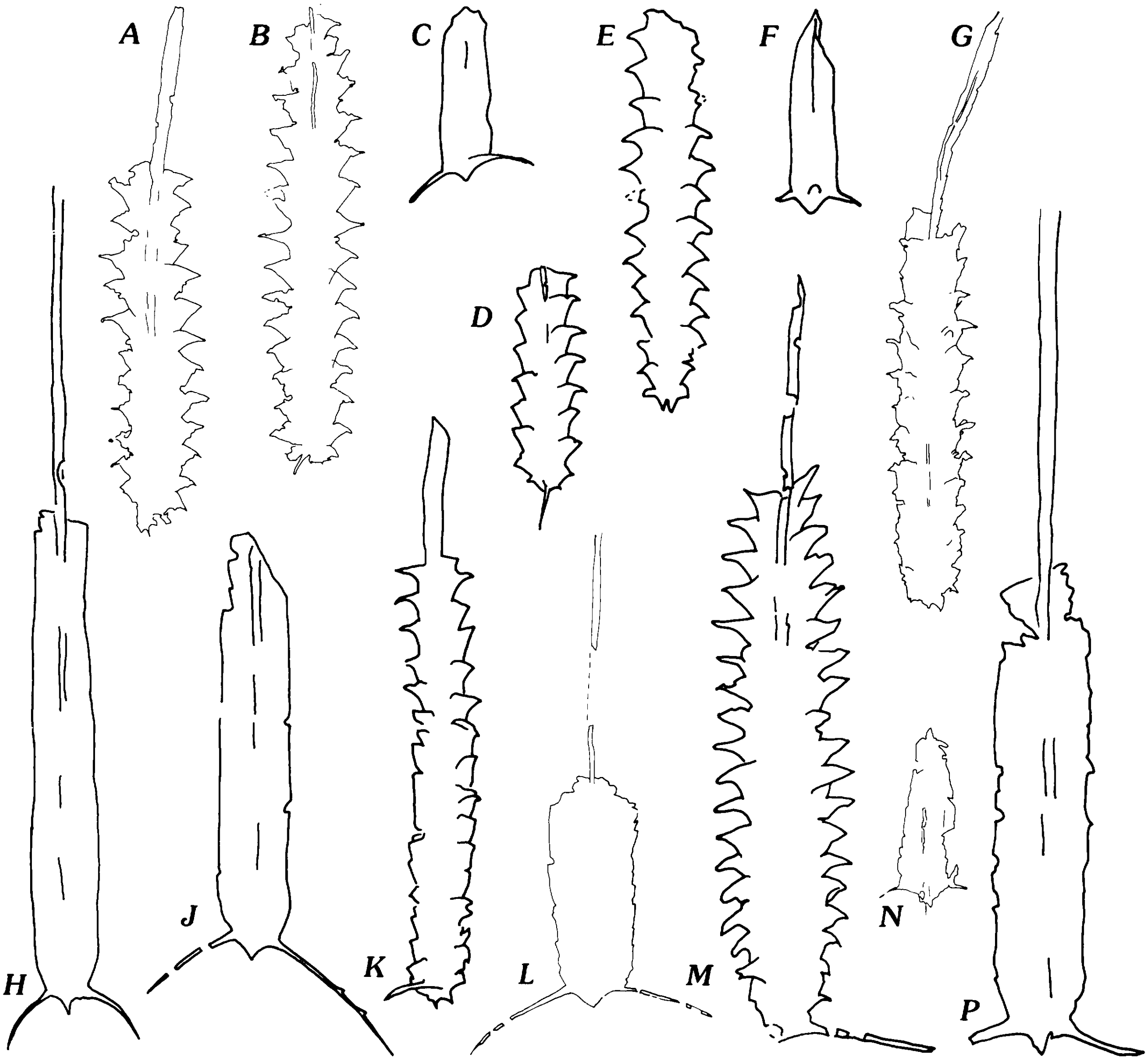


Figure 11. Cryptograptidae. All ×5. *A, Cryptograptus? inutilus* (Hall), USNM 406204, collection 1, Ledbetter Slate. *B, C.? inutilus* (Hall), USNM 406195, collection 1, Ledbetter Slate. *C, Cryptograptus* sp., USNM 406257, collection 2, scalariform view, Metaline Limestone. *D, C.? inutilus* (Hall), USNM 406248, collection 2, Metaline Limestone. *E, C.? inutilus* (Hall), USNM 406243, collection 2, Metaline Limestone. *F, Cryptograptus* sp., USNM 406256, collection 2, Metaline Limestone. *G, C.? inutilus* (Hall), USNM 406193, collection 1, Ledbetter Slate. *H, C.* cf. *C. antennarius* (Hall), USNM 406255, collection 2, scalariform view, Metaline Limestone. *J, C.* cf. *C. antennarius* (Hall), USNM 406231, collection 2, scalariform view, Metaline Limestone. *K, C.? inutilus* (Hall), USNM 406236, collection 2, Metaline Limestone. *L, C.* cf. *C. antennarius* (Hall), USNM 406198, collection 1, Ledbetter Slate. *M, C.* cf. *C. hopkinsoni* (Nicholson), USNM 406271, collection 3, Ledbetter Slate. *N, Cryptograptus* sp., USNM 406191, collection 1, scalariform view, Ledbetter Slate. *P, C.* cf. *C. hopkinsoni* (Nicholson), USNM 406272, collection 3, scalariform view, Ledbetter Slate.

Cryptograptus cf. *C. hopkinsoni* (Nicholson)

Figures 11*M*, *P*

cf. *Diplograptus hopkinsoni* Nicholson, 1869, p. 234, pl. 11, fig. 7

cf. *Cryptograptus hopkinsoni* (Nicholson). Elles, 1898, p. 520. Elles and Wood, 1901–18, p. 299–300, pl. 32, figs. 15a, b.

Description.—The rhabdosome is as much as 16 mm long, increases from about 1.5 mm wide proximally to a maximum width of 4.0 mm (1.6–2.7 mm wide in scalariform view), and decreases distally to 2.3 mm wide. The thecae number 12 to 11 per centimeter. Their apertural margins are straight or somewhat convex, approximately perpendicular to the rhabdosome axis, and drawn out into prominent denticles. The virgula is long and stout, as much as 0.5 mm wide. The proximal end bears two long (as much as 3.6 mm long), stout lateral spines.

Discussion.—Elles and Wood's (1901-18) largest figured specimen attains a width of 3.3 mm; thus, the Ledbetter specimens are considerably wider, and their proximal spines are longer and straighter. *C. hopkinsoni* s.s. is distinguished by the form of its thecae, the width of its rhabdosome, and its proximal spines.

Horizon and locality.—*C. hopkinsoni* s.s. is found in the *I. gibberulus* and *D. hirundo* Zones (Skiddaw Group) in the British Isles (Elles and Wood, 1901-18; Jackson, 1962).

Cryptograptus? *inutilus* (Hall)

Figures 11*A*, *B*, *D*, *E*, *G*, *K*

Diplograptus inutilus Hall, 1865, p. 111, pl. 13, fig. 14. Ruedemann, 1904, p. 721, pl. 16, figs. 13, ?12.

Cryptograptus? *inutilus* (Hall). Cooper, 1979, p. 80-81, pl. 15e, text figs. 64a, b.

Diagnosis.—Rhabdosome as much 15 mm long; width increases from 1.0 to 1.5 mm at first thecal pair to a maximum of 2.2 to 2.9 mm. Thecae 14 to 10 per centimeter, with straight or concave ventral walls and apertural margins drawn out into prominent denticles. Proximal end bears a pair of slender lateral spines. Virgula often conspicuous and thickened to a width of about 0.5 mm.

Discussion.—This species is distinguished from *C. tricornis* (Carruthers) and *C. schaeferi* Lapworth by the shape of its thecae and from *C. hopkinsoni* by its narrower rhabdosome.

Horizon and locality.—Zones of *Oncograptus* and *P. tentaculatus* in New Zealand (Cooper, 1979), horizon with *D. dentatus* in New York (Ruedemann, 1947), mixed assemblage of *Oncograptus* and *P. tentaculatus*-Zone forms in the Baird Mountains of Alaska (Carter and Tailleur, 1984), Zone of *P. tentaculatus* in the Terra Cotta Mountains of Alaska (Claire Carter, unpublished data, 1980).

Cryptograptus sp.

Figures 11*C*, *F*, *N*

Description and discussion.—A number of small (5.5 mm long, 1.5 mm wide proximally, narrowing to 1.2 mm wide or less distally) specimens of *Cryptograptus* preserved in scalariform view are present in the collections. They resemble *C. tricornis* (Carruthers) except for being generally shorter than that species, and they also resemble *C. insectiformis* in size and shape except for having shorter proximal spines. Possibly, they are simply immature individuals of one or more of the previously described species of *Cryptograptus*.

Suborder DIPLOGRAPTINA Lapworth, 1880, emended by Bulman, 1970
Family DIPLOGRAPTIDAE Lapworth, 1873
Genus *Climacograptus* Hall, 1865
Climacograptus cf. *C. riddellensis* Harris

Figures 12*F*, *G*

cf. *Climacograptus riddellensis* Harris, 1924, p. 100-101, pl. 8, figs. 11, 12. Berry, 1960, p. 82, pl. 14, figs. 9, 10. Berry, 1966, p. 439-440, pl. 50, figs. 1-5.

Description.—The rhabdosome is over 30 mm long; it is 1.0 to 1.25 mm wide at the first pair of thecae and increases to a maximum width of 1.8 to 2.7 mm. The thecae number 6 to 7 in the proximal 5 mm and 9 to 10 per centimeter distally; apertural lappets(?) give the appearance of pouch-shaped apertural "excavations." The virgella is 0.5 to 2.0 mm long.

Discussion.—The Ledbetter form resembles *C. riddellensis* s.s. in the shape and spacing of the thecae and the distinctive pouch-shaped apertural excavations. It differs in being considerably wider; *riddellensis* is only 0.6 to 0.9 mm wide at the first pair of thecae, and its maximum width is 1.7 to 2.0 mm.

Horizon and locality.—*C. riddellensis* s.s. is found in the Zone of *Glyptograptus teretiusculus* (Da4) in Victoria, Australia (Berry, 1966; VandenBerg, 1981), in the *D.*? *decoratus* Zone in the Terra Cotta Mountains of Alaska (Claire Carter, unpublished data, 1980), and in the Zones of *G. teretiusculus* and *Nemagraptus gracilis* in Texas (Berry, 1960).

Genus *Pseudoclimacograptus* Přibyl, 1947
Pseudoclimacograptus sp.

Figures 12*A*, *B*

Description.—The rhabdosome does not exceed 7 mm long and increases from a width of 0.8 to 1.1 mm at the first thecal pair through 1.3 to 1.5 mm at the fifth thecal pair to a maximum width of 1.5 to 1.7 mm. The thecae are of the *Pseudoclimacograptus* type, with convex supragenicular walls and narrow, slitlike apertural excavations, and they are spaced seven to six in 5 mm.

Discussion.—Although the nature of the median septum cannot be determined in these flattened specimens, they are placed in the genus *Pseudoclimacograptus* because of the shape of their thecae and apertural excavations. They are slightly wider and much shorter than *P. angulatus angulatus* (Bulman), and they lack its pouch-shaped apertural excavations.

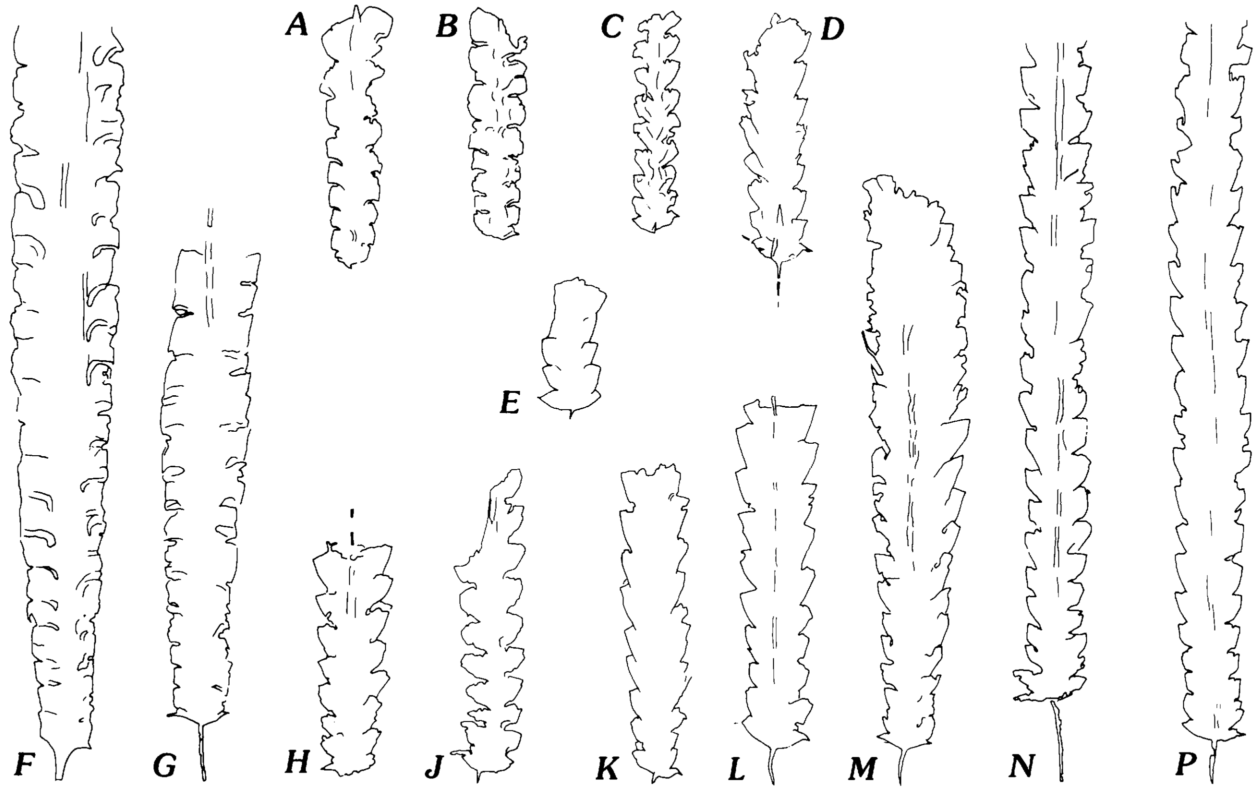


Figure 12. Diplograptidae. All ×5. *A*, *Pseudoclimacograptus* sp., USNM 406207, collection 1, Ledbetter Slate. *B*, *Pseudoclimacograptus* sp., USNM 406183, collection 1, Ledbetter Slate. *C*, *Undulograptus*? sp., USNM 406212, collection 1, Ledbetter Slate. *D*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406190, collection 1, Ledbetter Slate. *E*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406234, collection 2, proximal fragment, Metaline Limestone. *F*, *Climacograptus* cf. *C. riddellensis* Harris, USNM 406219, collection 1, Ledbetter Slate. *G*, *C.* cf. *C. riddellensis* Harris, USNM 406187, collection 1, Ledbetter Slate. *H*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406192, collection 1, Ledbetter Slate. *J*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406210, collection 1, Ledbetter Slate. *K*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406220, collection 1, Ledbetter Slate. *L*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406270, collection 3, Ledbetter Slate. *M*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406230, collection 2, Metaline Limestone. *N*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406266, collection 3, Ledbetter Slate. *P*, *U*.? cf. *U*.? *intersitus* (Harris and Thomas), USNM 406268, collection 3, Ledbetter Slate.

Horizon and locality.—*Pseudoclimacograptus* spp. indet. are found in the *P. tentaculatus* Zone in New Zealand (Cooper, 1979).

Genus *Undulograptus* Bouček, 1973 emended by Jenkins, 1980 *Undulograptus*? cf. *U*.? *intersitus* (Harris and Thomas)

Figures 12*D*, *E*, *H–N*, *P*

cf. *Diplograptus* (*Glyptograptus*) *intersitus* Harris and Thomas, 1935, p. 296–297, fig. 1, nos. 11a–e, fig. 3, nos. 6–10.

cf. *Glyptograptus intersitus* Harris and Thomas. Mu and others, 1979, p. 136, pl. 48, fig. 12.

?*Glyptograptus* sp. cf. *G. intersitus* Harris and Thomas. Cooper, 1979, p. 89, pl. 18h, text fig. 80.

Description.—The rhabdosome is as much as 30 mm long (commonly 8–20 mm); it widens from about 1.2 to 1.8 mm at the first thecal pair through 1.4 to 2.0 mm wide at the fifth thecal pair to a maximum width of 1.8 to 2.5 mm. The thecae number 6 to 7 in 5 mm proximally and 8 to 11 per centimeter distally; their ventral walls show varying degrees of curvature, depending on preservation, but generally appear only gently curved. The apertural margins are mostly straight and nearly perpendicular to the rhabdosome axis, but a few appear to have a ventral apertural "lip" similar to that of *U. austrodentatus americanus* (Bulman), although much less pronounced.

Discussion.—The Washington specimens attain a greater maximum width than does *U*.? *intersitus* s.s. (2.0 mm wide), but, otherwise, they appear to be quite similar. In their greater width, they agree with *G.* sp. cf. *G. intersitus* as described by Cooper (1979). They are longer and wider than *U. austrodentatus* (Harris and Keble) and its subspecies, and their thecae are much less closely spaced than those of *U. oelandicus* (Bulman). *U. cumbrensis* (Bulman) is similar in size to the Washington specimens but has distinctly introverted apertural margins.

Jenkins (1980, p. 290) omitted *G. intersitus* Harris and Thomas from his emendation of *Undulograptus*, stating that it "is more allied in its form to *Glyptograptus dentatus*." However, the proximal end of *intersitus* clearly resembles that of *U. austrodentatus* in that the first two thecae appear (in flattened specimens) to grow outward from the rhabdosome axis and only slightly upward near their apertures. In contrast, the first two thecae of *G. dentatus* present a very different appearance, th1^2 growing mostly upward rather than outward. It is not possible in our flattened specimens to detect which theca is dicalycal and whether the median septum is undulose, so they are only questionably referred to *Undulograptus*.

Horizon and locality. — *U. ?intersitus* s.s. is found from the upper *U. austrodentatus* Zone to midway through the *D.? decoratus* Zone (Da1–Da3) in Victoria, Australia (VandenBerg, 1981), the *P. tentaculatus* Zone in Texas (Berry, 1960), and the *Didymograptus* cf. *artus* Zone in southwestern China (Mu and others, 1979). *U.?* sp. cf. *U.? intersitus* is found in the *P. tentaculatus* Zone in New Zealand (Cooper, 1979).

Undulograptus? sp.

Figure 12*C*

Description. — The single specimen (fig. 12*C*) is 5.8 mm long and 1.2 mm wide across the first pair of thecae and maintains that width throughout its length. The thecae number 7½ in the first 5 mm and appear to be of the sigmoidal undulograptid type; apertural excavations are relatively conspicuous. The proximal end, though not well preserved, also appears to be of the undulograptid type.

Discussion. — This rare form is much smaller than the associated form *U.?* cf. *intersitus*. Its dimensions and thecal spacing are the same as those of *U. austrodentatus americanus* (Bulman), but it lacks that form's conspicuous ventral apertural "lip."

REFERENCES CITED

Archer, J.B., and Skevington, D., 1973, The morphology and systematics of "*Didymograptus*" *spinosus* Ruedemann, 1904, and allied species from the Lower Ordovician: Geological Magazine, v. 110, p. 43–54, pls. 1–2.

Barnes, C.R., Norford, B.S., and Skevington, D., 1981, The Ordovician System in Canada: International Union of Geological Sciences Publication 8, 27 p.

Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Bureau of Economic Geology Publication 6005, 179 p., 20 pls.

——— 1966, A discussion of some Victorian Ordovician graptolites: Proceedings of the Royal Society of Victoria, v. 79, p. 415–448, pls. 44–50.

Bulman, O.M.B., 1932, On the graptolites prepared by Holm: Arkiv för Zoologi, v. 24A, nos. 8–9, 75 p., 18 pls.

——— 1970, Treatise on invertebrate paleontology, pt. V, Graptolithina (2d ed.): Boulder, Colo., Geological Society of America, 163 p.

Carter, C., and Churkin, M., Jr., 1977, Ordovician and Silurian graptolite succession in the Trail Creek area, central Idaho — A graptolite zone reference section: U.S. Geological Survey Professional Paper 1020, 37 p., 7 pls.

Carter, C., and Tailleur, I.L., 1984, Ordovician graptolites from the Baird Mountains, western Brooks Range, Alaska: Journal of Paleontology, v. 58, p. 40–57.

Cooper, R.A., 1971, The identity of *Isograptus caduceus* (Salter) sensu stricto: Journal of Paleontology, v. 45, p. 902–909.

——— 1973, Taxonomy and evolution of *Isograptus* Moberg in Australasia: Palaeontology, v. 16, pt. 1, p. 45–115.

——— 1979, Ordovician geology and graptolite faunas of the Aorangi Mine area, north-west Nelson, New Zealand: New Zealand Geological Survey Paleontological Bulletin 47, 127 p., 19 pls.

Cooper, R.A., and Fortey, R.A., 1982, The Ordovician graptolites of Spitsbergen: Bulletin of the British Museum (Natural History), Geology, v. 36, no. 3, p. 157–302, pls. 1–6.

Cooper, R.A., and Ni Yunan, 1986, Taxonomy, phylogeny, and variability of *Pseudisograptus* Beavis: Palaeontology, v. 29, pt. 2, p. 313–363, pls. 24–27.

Dings, M.G., and Whitebread, D.H., 1965, Geology and ore deposits of the Metaline zinc-lead district, Pend Oreille County, Washington: U.S. Geological Survey Professional Paper 489, 109 p., 6 pls.

Elles, G.L., 1898, The graptolite fauna of the Skiddaw Slates: Quarterly Journal of the Geological Society of London, v. 54, p. 463–539.

Elles, G.L., and Wood, E.M.R., 1901–18, A monograph of British graptolites: London, Palaeontographical Society of London, 526 p., 52 pls.

Geh Mei-yu, 1964, Some species of *Tetragraptus* from the Ningkuo Shale (Lower Ordovician) of Zhejiang (Chekiang): Acta Palaeontologia Sinica, v. 12, p. 367–410, 4 pls.

Greenman, C., Chatterton, B.D.E., Boucot, A.J., and Berry, W.B.N., 1977, Coarse Silurian(?) and Devonian detrital rocks in northeastern Washington: Evidence of Silurian(?) and Devonian tectonic activity, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States; Pacific Coast Paleogeography Symposium 1, Bakersfield, CA: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 467–479.

Hall, J., 1858, Descriptions of Canadian graptolites: Geological Survey of Canada Report of Progress for 1857, p. 111–145.

——— 1859, Natural history of New York, v. 3, Paleontology (containing descriptions and figures of the organic remains of the lower Helderberg Group and the Oriskany Sandstone): Albany, Geological Survey of New York, 532 p.

——— 1865, Graptolites of the Quebec Group, *in* Figures and descriptions of Canadian organic remains, Decade II: Ottawa, Ont., Geological Survey of Canada, p. 1-151, pls. A, B, 1-21.

——— 1868, Introduction to the study of the Graptolitidae, *in* 20th annual report: Albany, New York State Museum of Natural History, p. 201-275.

Harris, W.J., 1924, Victorian graptolites (new series), pt. I: Proceedings of the Royal Society of Victoria, v. 36 (new series), pt. II, p. 92-106, pls. 7, 8.

——— 1926, Victorian graptolites (new series), pt. II: Proceedings of the Royal Society of Victoria, v. 38 (new series), p. 55-61, pls. 1, 2.

——— 1933, *Isograptus caduceus* and its allies in Victoria: Proceedings of the Royal Society of Victoria, v. 46 (new series), pt. I, p. 79-114.

Harris, W.J., and Thomas, D.E., 1935, Victorian graptolites (new series), pt. III: Proceedings of the Royal Society of Victoria, v. 47 (new series), pt. II, p. 288-313.

——— 1938, Victorian graptolites (new series), pt. V: Mining and Geological Journal of Victoria, v. 1, no. 2, p. 70-81.

——— 1940, Victorian graptolites (new series), pt. VII: Mining and Geological Journal of Victoria, v. 2, no. 2, p. 128-136.

——— 1941, Victorian graptolites (new series), pt. IX, *Zygograptus*—A new genus of graptolites: Mining and Geological Journal of Victoria, v. 2, no. 5, p. 308-310.

Jaanusson, V., 1960, Graptolites from the Ontikan and Viruan (Ordovician) limestones of Estonia and Sweden: Bulletin of the Geological Institute of the University of Uppsala, v. 38, pts. 3-4, p. 289-366.

Jackson, D.E., 1962, Graptolite zones in the Skiddaw Group in Cumberland, England: Journal of Paleontology, v. 36, p. 300-313.

Jenkins, C., 1980, *Maeandrograptus schmalenseei* and its bearing on the origin of the diplograptids: Lethaia, v. 13, p. 289-302.

Larson, M.L., and Jackson, D.E., 1966, Biostratigraphy of the Glenogle Formation (Ordovician) near Glenogle, British Columbia: Bulletin of Canadian Petroleum Geology, v. 14, p. 486-503.

Lenz, A.C., 1977, Some Pacific faunal province graptolites from the Ordovician of northern Yukon, Canada: Canadian Journal of Earth Sciences, v. 14, p. 1946-1952.

Lenz, A.C., and Jackson, D.E., 1986, Arenig and Llanvirn graptolite biostratigraphy, Canadian Cordillera, *in* Hughes, C.P., and Rickards, R.B., eds., Palaeoecology and biostratigraphy of graptolites: Geological Society (London) Special Publication 20, p. 27-45.

Lenz, A.C., and Perry, D.G., 1972, The Neruokpuk Formation of the Barn Mountains and Driftwood Hills, northern Yukon; its age and graptolite fauna: Canadian Journal of Earth Sciences, v. 9, p. 1129-1138.

McConnel, R.H., and Anderson, R.A., 1968, The Metaline District, Washington, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933-1967 (Graton-Sales vol.): New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, v. II, p. 1460-1480.

Mills, J.W., 1977, Zinc and lead ore deposits in carbonate rocks, Stevens County, Washington: Washington Division of Geology and Earth Resources Bulletin 70, 171 p.

Mu, A.T., 1957, Some new or little known graptolites from the Ningkuo Shale (Lower Ordovician) of Changshan, western Chekiang: Acta Palaeontologica Sinica, v. 5, p. 369-438, 8 pls.

Mu, A.T., Lee, C.K., and Geh, M.Y., 1962, Geology of Qilianshan, pt. 2, Paleontology: Beijing, Science Press, Academia Sinica, 168 p., 32 pls.

Mu Enzhi, Ge Meiyu, Chen Xu, Ni Yunan, and Lin Yaokun, 1979, Lower Ordovician graptolites of southwest China: Palaeontologia Sinica, whole no. 156, new series B, no. 13: Beijing, Science Press, 192 p., 48 pls.

Nicholson, H.A., 1869, On some new species of graptolites: Annals and Magazine of Natural History, v. 4, p. 231-242.

Obut, A.M., and Sennikov, N.V., 1984, Lower Ordovician graptolites and zonal subdivisions of the Gorny Altai, *in* Stratigrafiya i fauna nizhnego ordovika gornogo altaya: Akademiya Nauk SSSR Sibirskoe Otdelenie, v. 565, p. 53-106, pls. 6-21 (in Russian).

Park, C.F., and Cannon, R.S., Jr., 1943, Geology and ore deposits of the Metaline quadrangle, Washington: U.S. Geological Survey Professional Paper 202, 81 p., 34 pls.

Rickards, R.B., 1972, The Ordovician graptolite genus *Paraglossograptus* Mu: Geological Magazine, v. 109, p. 99-113.

——— 1973, The Arenig graptolite genus *Pseudotrigonograptus* Mu and Lee, 1958: Acta Geologica Polonica, v. 23, p. 597-603.

Ruedemann, R., 1904, Graptolites of New York, pt. I, Graptolites of the lower beds: New York State Museum Memoir 7, p. 457-803, 17 pls.

——— 1947, Graptolites of North America: Geological Society of America Memoir 19, 652 p., 92 pls.

Snook, J.R., Lucas, H.E., and Abrams, M.J., 1981, A cross section of a Nevada-style thrust in northeast Washington: Washington Division of Geology and Earth Resources Report of Investigations 25, 9 p.

Skevington, D., 1965, Graptolites from the Ontikan Limestones (Ordovician) of Öland, Sweden, pt. II, Graptoloidea and Graptovermida: Bulletin of the Geological Institute of the University of Uppsala, v. 43, p. 1-74.

Törnquist, S.L., 1911, Graptolitologiska bidrag., 3-7: Geologiska Föreningens i Stockholm Förhandlingar, v. 33, no. 6, p. 421-438, pls. 5, 6.

Tsai, D.T., 1974, Graptolity rannego Ordovika Kazakhstana: Moscow, Akademia Nauk SSSR, 127 p., 11 pls.

VandenBerg, A.H.M., 1981, Victorian stages and graptolite zones, *in* Webby, B.D., ed., The Ordovician System in Australia, New Zealand, and Antarctica: Correlation chart and explanatory notes: International Union of Geological Sciences Publication 6, p. 2-7, fig. 2.

Chapter B

Ordovician-Silurian Graptolites from the Ledbetter Slate, Northeastern Washington State

By CLAIRE CARTER

Descriptions and illustrations of some new or unusual graptolite species

U.S. GEOLOGICAL SURVEY BULLETIN 1860

Shorter Contributions to Paleontology and Stratigraphy

CONTENTS

PLATE

FIGURES

Ordovician-Silurian Graptolites from the Ledbetter Slate, Northeastern Washington State

By Claire Carter

Abstract

Between 1934 and 1975, the U.S. Geological Survey obtained 39 collections of Early and Middle Ordovician graptolites and one of late Early Silurian graptolites from the Ledbetter Slate and adjacent formations in northeastern Washington State. All of these collections have been examined recently by the author, and previously published fossil lists have been revised. Two species first described by Rudolf Ruedemann in 1947 are revised on the basis of this material: *Syndeograptus bridgei* Ruedemann = *Pterograptus elegans* Holm and *Dicellograptus perspinosus* Ruedemann = *Kalpinograptus ovatus* (T.S. Hall). The Ordovician graptolite faunas of northeastern Washington are strikingly similar to those of Australasia, Alaska, and the Canadian Cordillera. Twenty-eight species, including 2 new but unnamed species, are described and illustrated, and an additional 31 species are illustrated only.

INTRODUCTION

Graptolites have been collected by geologists of the U.S. Geological Survey (USGS) from the Ledbetter Slate of northeastern Washington State since 1934. Some of the 39 collections made over the years have been identified and listed (Park and Cannon, 1943; Snook and others, 1981), and a few of the forms collected by C.F. Park, Jr., were described and illustrated by Ruedemann (1947). Most of these graptolites, however, have remained unstudied. This work describes and illustrates the diagnostic species as well as the unusual ones in these collections, which are almost all from the Ledbetter Slate and range in age from Early through Middle Ordovician to Early Silurian.

The Ledbetter Slate is a black, fine-grained unit, commonly cleaved and noncalcareous (Yates, 1970). It is underlain by the Cambrian and Early Ordovician Metaline Limestone, a thick unit of limestone and dolomite that has been locally mineralized with lead-zinc deposits. The Ledbetter is apparently overlain by carbonate rocks that are distinguished from it mainly by the presence of Silurian and Devonian fossils (Dings and Whitebread, 1965, p. 27). More detailed descriptions of the geology of northeastern Washington have been given by Park and Cannon (1943), Dings and Whitebread (1965), Yates (1970), and Greenman and others (1977).

BIOSTRATIGRAPHY

The oldest graptolite fauna from the Ledbetter Slate in USGS collections consists of scraps of possible anisograptid-type graptolites (collections 2178–CO, 2179–CO, 2180–CO, 1071, and D508–CO). Anisograptids are relatively advanced, siculate, regularly branched dendroids that range in age from Early Ordovician (Tremadocian) through Middle(?) Ordovician (Bulman, 1970). One collection (D1450–CO) contains species of *Tetragraptus* possibly indicative of the Lancefieldian and Bendigonian (early Arenigian) zones of *Tetragraptus approximatus* and *T. fruticosus* of New Zealand (Cooper, 1979).

The oldest graptolite zone (fig. 1) to which the Ledbetter can be assigned with certainty is the *Oncograptus* Zone (Yapeenian; late Arenigian) of New Zealand (Cooper, 1979). The Ledbetter fauna (collections B–458a, D354–CO, and D1450a) correlates very well with the New Zealand fauna, even though it lacks *Oncograptus* itself. In this respect (lack of *Oncograptus*), the Ledbetter fauna is similar to the *Oncograptus* Zone faunas from the Baird Mountains of Alaska (Carter and Tailleur, 1984), the Terra Cotta Mountains of southwestern Alaska (Claire Carter, unpublished data, 1980), and the northern part of the Canadian Cordillera (Lenz and Jackson, 1986). Typical *Oncograptus*-Zone species found in northeastern Washington include *Isograptus victoriae divergens* Harris, *Pseudisograptus dumosus* (Harris), *P. manubriatus koi*

Manuscript approved for publication May 16, 1988.

System	Series	Unit	Northeastern Washington graptolite zones This paper	New Zealand graptolite zones Cooper (1979)	Australian series VandenBerg (1981) Cooper (1979)	Canadian Cordillera graptolite zones Lenz and Jackson (1986)	British series
ORDOVICIAN	Middle	Ledbetter Slate			Eastonian 4 3		Caradocian
ORDOVICIAN	Middle	Ledbetter Slate	*Climacograptus spiniferus*		Eastonian 2 1		Caradocian
ORDOVICIAN	Middle	Ledbetter Slate	?		Eastonian 2 1		Caradocian
ORDOVICIAN	Middle	Ledbetter Slate	*Climacograptus bicornis* Subzone (*Nemagraptus gracilis*)		Gisbornian		Caradocian
ORDOVICIAN	Middle	Ledbetter Slate	*Nemagraptus gracilis* Subzone (*Nemagraptus gracilis*)	*Dicellograptus*	Gisbornian	*Diplograptus ? decoratus*	Llandeilan
ORDOVICIAN	Middle	Ledbetter Slate	*Diplograptus ? decoratus*	*Diplograptus ? decoratus*	Darriwillian	*P. tentaculatus* upper	Llanvirnian
ORDOVICIAN	Middle / Lower	Ledbetter Slate	*Paraglossograptus tentaculatus*	*Paraglossograptus tentaculatus*	Darriwillian	*P. tentaculatus* lower	Llanvirnian / Arenigian
ORDOVICIAN	Lower	Ledbetter Slate / Metaline Limestone (part)*	*Oncograptus*	*Oncograptus*	Yapeenian	*Oncograptus* upper / lower	Arenigian
ORDOVICIAN	Lower	Metaline Limestone (part)*					Arenigian

*Overall unit age is Late(?) Cambrian and Early Ordovician(?)

Figure 1. Correlation of graptolite sequences in northeastern Washington, New Zealand, and the Canadian Cordillera with the Australian and British Series.

Cooper and Ni, *P. manubriatus harrisi* Cooper and Ni, *Cardiograptus morsus* Harris and Keble, *Didymograptus v-deflexus* Harris, *Phyllograptus nobilis* Harris and Keble, and ?*Apiograptus* cf. *A. crudus* (Harris and Thomas).

The next higher zone within the Ledbetter Slate graptolite succession is the *Paraglossograptus tentaculatus* Zone (early Darriwillian; late Arenigian–early Llanvirnian), represented by a single collection (D913–CO). It is correlated (fig. 1) with the New Zealand zone of the same name, as used by Cooper (1979), on the basis of the presence of *Loganograptus logani* Hall, *P. tentaculatus* (Hall), *Cryptograptus*? *inutilus* (Hall), *Pseudotrigonograptus ensiformis* (Hall), and *Undulograptus*? cf. *U.*? *intersitus* (Harris and Thomas). Graptolites of the *P. tentaculatus* Zone have also been found in the Baird and Terra Cotta Mountains of Alaska, in the Canadian Cordillera, in New York and Quebec, and the Marathon region of Texas (Berry, 1960). The fauna of this zone from the Pend Oreille Mine, near Metaline Falls, Wash., has been fully described and illustrated elsewhere (Carter, this volume).

Collection B–458b is correlated with the *Diplograptus*? *decoratus* Zone (late Darriwillian; late Llanvirnian) of New Zealand (Cooper, 1979), on the basis of the presence of *Pterograptus*, *Cryptograptus schaeferi* Lapworth, and *Climacograptus riddellensis* Harris, the first appearance of *Glossograptus ciliatus* Emmons (= *G. hincksii*), and the absence of dicellograptids and dicranograptids. The *D. decoratus* Zone of the Canadian Cordillera (Lenz and Jackson, 1986) is somewhat younger than the New Zealand *decoratus* Zone. Collection B–458b also contains a species originally described by Ruedemann (1947) as *Dicellograptus perspinosus* that should now be referred to the genus *Kalpinograptus*. Ruedemann established another new species from this collection, *Syndeograptus bridgei*, which I believe to be a species of *Pterograptus*.

Several collections (B–459, 65WCn 91, and 66Y–200) represent the *Nemagraptus gracilis* Subzone of the *N. gracilis* Zone (early Caradocian; Gisbornian) as defined by Finney (1986) and contain typical *gracilis* Zone forms such as *N. gracilis* (Hall), *Dicellograptus sextans* (Hall), *Glyptograptus euglyphus* (Lapworth), *Pseudoclimacograptus scharenbergi* (Lapworth), *Reteograptus geinitzianus* Hall, and *Azygograptus*.

The *Climacograptus bicornis* Subzone of the *N. gracilis* Zone (Finney, 1986) is differentiated from the underlying *gracilis* Subzone mainly by the additional presence of *C. bicornis* (Hall). Several Ledbetter collections (B-456, D511-CO, D543-CO, and 65WCn 92) represent this zone. Graptolite faunas from the *C. bicornis* Subzone have been found in Alaska (Terra Cotta Mountains, Prince of Wales Island area), Idaho (Carter and Churkin, 1977), the northern Canadian Cordillera (Lenz and Chen, 1985), and Texas (Berry, 1960). Taken together, the *N. gracilis* Subzone and the *C. bicornis* Subzone are roughly equivalent to the *N. gracilis* Zone of Finney and Bergström (1986). The *N. gracilis* Zone is well known and widespread, occurring in Alaska, Idaho, Texas, Alabama, the Canadian Cordillera, New York, Quebec, and elsewhere. John Riva (written communication, 1987) believes that the *N. gracilis* and *C. bicornis* Subzones of Finney (1986) are equivalent only to the *N. gracilis* Zone of Britain (Elles and Wood, 1901-18). The main difference between the British *N. gracilis* Zone and the overlying *Diplograptus multidens* Zone (= the *C. peltifer* and *C. wilsoni* Zones of Elles and Wood (1901-18)) is the absence of nemagraptids in the upper zone. *C. bicornis* and a number of other species, including *Dicellograptus divaricatus salopiensis*, *Cryptograptus tricornis*, *Orthograptus calcaratus acutus*, and *Glossograptus ciliatus* (= *G. hincksii*), range through both zones. Therefore, the Ledbetter collections (B-456, D511-CO, and D543-CO) that contain the above species but no *N. gracilis* are possibly equivalent, at least in part, to the British *D. multidens* Zone (but not to the *D. multidens* Zone of Riva (1974)).

The next higher zone, here called the *Climacograptus spiniferus* Zone, is represented by eight collections (65WCn 102, B-86, B-88, B-89, B-458c, B-462, D770-CO, and D1502-CO) and is correlated with the *Climacograptus baragwanathi* Zone (Early Eastonian Ea2) of Australia (VandenBerg, 1981; VandenBerg and Stewart, 1983), on the basis of the presence of *Dicranograptus hians hians* T.S. Hall, *Dicellograptus flexuosus* Lapworth, *Climacograptus spiniferus spiniferus* Ruedemann, *C. caudatus* Lapworth, *C.* cf. *C. baragwanathi* T.S. Hall, *Orthograptus quadrimucronatus* sensu lato, and *Neurograptus margaritatus* (Lapworth). It can also be correlated with the upper Caradocian Zone of *Dicranograptus clingani* in the British Isles (Elles and Wood, 1901-18; Williams, 1982), the *C. spiniferus* Zone of eastern North America (Riva, 1974) and, in part, the *Climacograptus tubuliferus* Zone of Trail Creek, Idaho (Carter and Churkin, 1977). None of the Ledbetter collections correlates with the earliest Eastonian Zone of *C. spiniferus* n.subsp. as defined by VandenBerg and Stewart (1983).

Several poorly preserved and (or) sparsely fossiliferous collections (B-91, B-92, B-94, D510-CO, D-914, D1451-CO, D1470-CO, 2181, 2182, and 65WCn 112) are lumped into the category of "approximately Middle Ordovician."

One collection (65WCn 111) contains late Llandoverian graptolites indicative of the *Monograptus spiralis* Zone of the northern Canadian Cordillera (Lenz, 1979). Thus, there is a gap in the zonal succession between the youngest Ordovician graptolites of the Ledbetter Slate and this late Early Silurian fauna, amounting to about 3 Ordovician graptolite zones and more than 10 Silurian zones. Greenman and others (1977) listed a fauna from the Ledbetter of latest Ordovician age and, from their Silurian "Unit A," several faunas of the *M. spiralis* Zone and above. For some reason, most of the Llandoverian graptolite succession in northeastern Washington is either missing or simply has not been identified yet.

SYSTEMATIC PALEONTOLOGY

In recent years, various authors, including Cooper and Fortey (1982), Cooper and Ni (1986), and Rigby (1986), have made useful and needed revisions of parts of Bulman's (1970) classification scheme. As much as possible, these revisions have been utilized herein. The synonymies are not always exhaustive but instead represent, for the most part, only those citations that I have verified. Most of the specimens described here are flattened, but some have been pyritized and preserved in three dimensions. Varying degrees of tectonic distortion are present and have been noted in the individual descriptions.

The repository of specimens is the U.S. National Museum of Natural History (USNM), Smithsonian Institution, Washington, D.C.

Order GRAPTOLOIDEA Lapworth, 1875
Family DICHOGRAPTIDAE Lapworth, 1873, sensu lato
Genus *Pterograptus* Holm, 1881
Pterograptus elegans Holm

Figures 6*B*, *C*, 7*A*–*C*

Pterograptus elegans Holm, 1881, p. 77–80, figs. 1–4. Benson and others, 1936, p. 380–381, text figs. 5a–c. Skwarko, 1962, p. 221, text fig. 4, fig. 1. Berry, 1964, p. 82–84, pl. 1, figs. 1–3.

Syndeograptus bridgei Ruedemann, 1947, p. 374-375, pl. 61, figs. 24, 25, 26?, 27?, 28.

Diagnosis.—Sicula about 0.5 mm long, giving off two slender, declined primary stipes that enclose an angle of about 60° to 80°. Distally, main stipes become pendent and subparallel. Each primary stipe gives rise to about seven unbranched secondary stipes that branch off alternately right and left from plane of primary stipe; all 0.4 mm wide, measured across thecal apertures.

Discussion.—The Ledbetter specimens were described by Ruedemann (1947) as a new species of *Syndeograptus*, but, in *Syndeograptus*, the primary stipes are reclined, and the secondary branches are paired instead of alternating. The Ledbetter form agrees almost entirely with *P. elegans*, although its stipes are a bit wider (0.3-0.5 mm wide). The rhabdosome as a whole is 25 mm or more in length and as much as 15 to 20 mm in width. *P. elegans* is distinguished from other species of *Pterograptus* by the number of its secondary branches and its lensoid shape.

Horizon and locality.—Ledbetter Slate, collection B-458b, *Diplograptus*? *decoratus* Zone. The *Glyptograptus teretiusculus* Zone (upper Darriwillian) in New Zealand (Benson and others, 1936; Skwarko, 1962), the *Didymograptus murchisoni* Zone in Norway (Berry, 1964), and the *P. elegans* Zone in south-central China (Wang and Jin, 1977). *P.* cf. *P. elegans* (which has wider stipes) occurs in the lower *D.*? *decoratus* Zone in the Terra Cotta Mountains of Alaska (Claire Carter, unpublished data, 1980).

Genus *Tetragraptus* Salter, 1863, emended by Cooper and Fortey, 1982
Subgenus *Tetragraptus* Salter, 1863
Tetragraptus (*Tetragraptus*) cf. *T.* (*T.*) *bigsbyi* (Hall)

Figure 2*G*

cf. *Graptolithus bigsbyi* Hall, 1865, (parts) p. 86-88, pl. 16, figs. 25-26, 29, 30 (not figs. 22-24, 27, 28).

cf. *Tetragraptus bigsbyi* (Hall). Skevington, 1965, p. 4-8, figs. 1, 3, 5, 6. Cooper, 1979, p. 62, pl. 8b, e, fig. 30.

cf. *Tetragraptus* (*Tetragraptus*) *bigsbyi* (Hall). Cooper and Fortey, 1982, p. 199.

Description.—The rhabdosome is 13.5 mm long with nearly straight and highly reclined to nearly scandent second-order stipes. The second-order stipes are widest near their origin (as much as 3.0 mm wide), and they taper distally to about 2.3 mm wide (including apertural denticle). The thecae are curved throughout their length and number 10 to 11 per centimeter.

Discussion.—The Ledbetter specimen matches *T. bigsbyi* s.s. in size and general appearance but has fewer thecae per centimeter and its stipes do not converge distally, as they do in *bigsbyi*.

Horizon and locality.—Ledbetter Slate, collection D354-CO, *Oncograptus* Zone. *T. bigsbyi* occurs in the *Tetragraptus fruticosus* through *Isograptus victoriae maximo-divergens* Zones (Bendigonian-Castlemainian) in New Zealand (Cooper, 1979). In other regions (Scandinavia, North America, and Britain), it occurs in rocks of Arenigian age.

Tetragraptus (*Tetragraptus*) n.sp.

Figures 6*F*, *H*

Description.—The rhabdosome measures as much as 13 mm in length and 8.5 mm in width. The first-order stipes are relatively slender and of undetermined length. The second-order stipes widen from an initial width of about 0.7 mm at the aperture of the first theca to a maximum width of 2.0 mm at the level of the eighth to tenth theca, which is maintained thereafter. The stipes are strongly reclined to nearly scandent and even converge to meet distally, in the manner of *T. bigsbyi* s.s. The thecal apertures and free ventral walls form prominent denticles. The thecae number 14 to 12 per centimeter.

Discussion.—This form differs from most other reclined tetragraptids in the distal convergence of its stipes and from *T. bigsbyi* in the initial slenderness of its second-order stipes. It differs from *T. erectus* Mu, Geh, and Yin in the greater distal width of its stipes. However, because only two specimens have been found, it has not been named.

Horizon and locality.—Ledbetter Slate, collection B-458b, *D.*? *decoratus* Zone.

Subgenus *Pendeograptus* Bouček and Přibyl
Tetragraptus (*Pendeograptus*) *pendens liber* Carter

Figure 4*A*

Tetragraptus pendens liber Carter, this volume, p. A7, figs. 5*C*–*E*.

Diagnosis.—Sicula 1.5 mm long, giving rise to two first-order stipes 0.8 to 1.0 mm long, each of which gives rise to two pendent, inward-curving second-order stipes 15 to 25 mm long. Stipes initially 0.3 to 0.5 mm wide, increasing rapidly to maximum width of 1.0 to 1.4 mm. Thecae straight, inclined 25° to 30° to stipe axis, overlapping one-third or less, numbering 8 to 10 per centimeter.

Discussion.—*T. pendens liber* has wider stipes, fewer thecae per centimeter, less thecal overlap, and greater thecal inclination than *T. pendens pendens* Elles and Wood does.

Horizon and locality.—Metaline Limestone, collection D913-CO, *P. tentaculatus* Zone.

Genus *Phyllograptus* Hall, 1858, sensu lato
Phyllograptus? sp.

Figure 2*E*

Description.—The single pyritized specimen is 5.5 mm long and 5.5 mm wide. The sicula is about 4 mm long. The thecae grow outward from the rhabdosome axis proximally and increasingly upward in the distal part of the rhabdosome; they are spaced 6 to 8 in 5 mm.

Discussion.—This specimen does not clearly exhibit the trace of the thecal series along the median line of the rhabdosome that is diagnostic of the genus *Phyllograptus* s.l., and it possesses a virgula, something rarely seen in phyllograptids. However, it lacks the proximal pendent thecae of *Cardiograptus* and *Oncograptus*.

Horizon and locality.—Ledbetter Slate, collection B-458a, *Oncograptus* Zone.

Genus *Didymograptus* M'Coy, 1851
Subgenus *Didymograptellus* Cooper and Fortey, 1982
Didymograptus (*Didymograptellus*) sp.

Figure 2*F*

Description.—The stipes are less than 1 cm long and increase in width from 0.6 mm at the aperture of $th1^2$ to 1.2 mm about 7 mm from the sicula. They diverge at an initial angle of about 90° but soon curve inward to become subparallel. The sicula is slender and 1.7 mm long; it gives rise to $th1^1$ about one-third of the way down its length. The thecae are spaced 14 to 15 per centimeter; mature thecae are about 2 mm long, 0.3 to 0.4 mm wide, and inclined 30° or less to the stipe axis and overlap about three-fourths of their length.

Discussion.—The single Ledbetter specimen is preserved as a pyritized internal mold. It differs from most pendent didymograptids in the slenderness of its stipes. It is distinguished from narrow-stiped forms such as *D. nanus* Lapworth mainly by the much greater overlap and smaller inclination of its thecae. *D. bifidus* (Hall) has a shorter sicula (1.1-1.5 mm) and greater thecal inclination (40°-50°).

Horizon and locality.—Ledbetter Slate, collection B-458a, *Oncograptus* Zone.

Genus *Didymograptus* M'Coy, 1851, sensu lato
Didymograptus serratulus (Hall)

Figure 6*N*

Graptolithus serratulus Hall, 1847, p. 274, pl. 74, figs. 5a, b.

Didymograptus serratulus (Hall). Ruedemann, 1908, p. 251-253, text figs. 156-159, pl. 14, fig. 4. Ruedemann, 1947, p. 346, pl. 54, figs. 49-51.

Diagnosis.—Stipes long (8 cm or more), 0.5 mm wide proximally, increasing gradually to a maximum width of 1.2 mm distally, declined, diverging at 140° to 155°. Sicula long (about 2.5 mm) and conspicuous. Proximal thecae slender, numbering about 10 in 10 mm, overlapping about one-fourth of their length and inclined 15° to 20° to stipe axis. Distal thecae number seven to eight in 10 mm, overlap one-half of their length, and are inclined at an angle of 25° to 30°.

Discussion.—This species is known mostly from distal fragments. The Ledbetter collections contain a number of wide distal fragments and one specimen having a sicula 0.7 mm long and stipes 5.5 cm long that diverge at an angle of 140°. The stipes increase in width from 0.4 mm proximally to 1.0 mm distally. The distal fragments are as much as 3 mm wide and have 7½ thecae per centimeter. These distal thecae overlap one-half to two-thirds of their length and are inclined at an angle of 30° to 35°. *D. serratulus* differs from the similar form *D. superstes* Lapworth in its more gradual increase in width and smaller number of thecae per centimeter distally.

Horizon and locality.—Ledbetter Slate, collection B-458b, *D.*? *decoratus* Zone. Normanskill Shale (*Nemagraptus gracilis* Zone) in New York (Ruedemann, 1908, 1947).

Genus *Azygograptus* Nicholson, 1875
Azygograptus cf. *A. canadensis* Ruedemann

Figures 8*A*, *B*

cf. *Azygograptus canadensis* Ruedemann, 1947, p. 357, pl. 58, figs. 9-11.

Description.—The sicula is about 1.0 mm long. The first theca originates about 0.5 mm above the sicular aperture and grows downward along the virgella to about 0.2 mm below the sicular aperture, where it turns outward. The first thecal aperture is about 1.2 mm from the sicula. The stipe is 3 or 4 cm long and strongly curved; the ventral margin is concave. It widens rapidly from 0.3 mm at the first thecal aperture to a maximum width of 0.7 to 0.8 mm, which is maintained for most of its length. The thecae are long and slender, 9 to 5 in 10 mm, and inclined very little.

Discussion.—The Ledbetter specimens have longer stipes, shorter siculae, and fewer thecae per centimeter than those described from the Glenogle Formation by Ruedemann (1947). However, they match *A. canadensis* in rhabdosome shape and the growth habit of the first theca. *A. incurvus* Ekström is similar in its curved stipe, sicula, and first theca but is narrower and shorter and has more thecae per centimeter. In addition, its stipe grows upward from the sicula and is more strongly curved than that of the Ledbetter form.

Horizon and locality.—Ledbetter Slate, collection B-459, *N. gracilis* Subzone. *A. canadensis* is also found in the *N. gracilis* Zone (Glenogle Formation) in British Columbia (Ruedemann, 1947).

Genus *Kinnegraptus* Skoglund, 1961
Kinnegraptus? sp.

Figure 4*G*

Description.—The single specimen is fragmentary but exhibits the extremely slender stipes and spinelike thecal processes characteristic of *Kinnegraptus*. Its stipes are about 0.2 mm wide between thecal apertures and 0.5 to 0.8 mm wide at the thecal apertures. The interthecal distance (measured from one aperture to the next) varies between 0.6 to 0.9 mm (16½–11 thecae per centimeter). No sicula is visible; the stipes appear to be reclined but are probably broken or twisted into a reclined relationship.

Discussion.—The Washington specimen has a wider stipe, shorter thecal processes, and more thecae per centimeter than *K. kinnekullensis* Skoglund does. Its thecae are more closely spaced than those of *K.*? *gracilis* Chen.

Horizon and locality.—Metaline Limestone, collection D913-CO, *P. tentaculatus* Zone. *Kinnegraptus* occurs in older beds (*Phyllograptus densus* to *Didymograptus hirundo* Zones) in Sweden (Skoglund, 1961) and Norway (Bulman and Cowie, 1962) and in the Canadian Cordillera (*T. fruticosus* Zone) (Lenz and Jackson, 1986). *K.*? *gracilis* is found in the *Glyptograptus sinodentatus* Zone in southwestern China (Mu and others, 1979).

Family ISOGRAPTIDAE Harris, 1833, sensu Cooper and Ni, 1986
Genus *Cardiograptus* Harris and Keble, in Harris, 1916
Cardiograptus morsus Harris and Keble

Figure 2*H*

Cardiograptus morsus Harris and Keble, *in* Harris, 1916, pl. 1, figs. 1–4. Harris, 1924, p. 95–96. Berry, 1960, p. 66, pl. 11, figs. 13, 14. Cooper, 1973, text fig. 24h. Beavis and Beavis, 1974, p. 208, figs. 15a–j. Cooper, 1979, p. 72, pls. 14c, f, figs. 46a, b.

Diagnosis.—Rhabdosome biserial, 18 to 24 mm long from proximal end to base of distal emargination and 3 mm wide proximally, broadening to a maximum width of about 11 mm wide. Thecae 9 to 11 per centimeter, pendent proximally, in contact for almost their whole length; long apertural denticles. Sicula 2 mm long.

Discussion.—If allowance is made for the fact that the Ledbetter specimens have been tectonically distorted, they appear to fall within the dimensional limits of *C. morsus*. The proximal end of *C. folium* Ruedemann is wider and blunter than that of *C. morsus*, and *Bergstroemagraptus crawfordi* (Harris) is much smaller.

Horizon and locality.—Ledbetter Slate, collection D354-CO, *Oncograptus* Zone. *Oncograptus* Zone in Canadian Cordillera (Lenz and Jackson, 1986), *Oncograptus* Zone (Yapeenian) in New Zealand (Cooper, 1979), and *C. morsus* to *Glyptograptus austrodentatus* Zones (Ya2–Da1) in Victoria, Australia (Beavis and Beavis, 1974; VandenBerg, 1981).

Genus *Isograptus* Moberg, 1892
Isograptus sp.

Figure 3*B*

Description.—Tectonic distortion of the single specimen makes true dimensions difficult to determine. The sicula and first theca were probably a bit shorter than their apparent length of 3 mm; the supradorsal height was about 1 mm, and the ventral notch depth was about 0.9 mm. The rhabdosome was broadly U shaped, and the stipes were relatively narrow (at least 1.5 mm wide but less than 2.2 mm wide) throughout their length. The thecae are strongly mucronate and relatively short, so that they overlap only about half their length. On the elongated (left) stipe, the thecae are spaced 11 per centimeter; on the thickened (right) stipe, they number 16 per centimeter. Presumably, the actual number falls between these extremes.

Discussion.—This form resembles *Didymograptus* cf. *hemicyclus* Harris (Cooper, 1979, fig. 43) but is much larger and has the symmetrical arrangement of sicula and first theca characteristic of *Isograptus*. It also resembles *I. victoriae lunatus* Harris in size and shape but appears to have shorter, less overlapping thecae. Also, *I. v. lunatus* is an older species (early Castlemainian), possibly a forerunner of this one.

Horizon and locality.—Ledbetter Slate, collection D354-CO, *Oncograptus* Zone.

Family GLOSSOGRAPTIDAE Lapworth, 1873, emended by Cooper and Ni, 1986
Subfamily GLOSSOGRAPTINAE Lapworth, 1873
Genus *Glossograptus* Emmons, 1855
Glossograptus ciliatus Emmons

Figures 6*L*, *M*, 8*F*

Glossograptus ciliatus Emmons, 1855, p. 103, pl. 1, fig. 25. Ruedemann, 1908, p. 379–383, pl. 26, figs. 1–5, pl. 27, figs. 1-4, text figs. 324-335. Ruedemann, 1947, p. 449-450, pl. 77, figs. 27-40. Harris and Thomas, 1955, p. 40-41, figs. 40-44.

Glossograptus hincksii hincksii (Hopkinson). Carter and Churkin, 1977, p. 21, pl. 3, fig. 4.

Diagnosis.—Rhabdosome 25 mm or more in length, 2.5 to 3.0 mm in width (excluding spines), with parallel margins and rounded proximal end. Thecae 11 per centimeter, with paired apertural spines.

Discussion.—Most of the Washington specimens are narrow (2.5 mm wide) and have thecal spines 1.0 to 1.5 mm long. They have 6 thecae in 5 mm proximally and 11 thecae per centimeter distally. One specimen (fig. 6*L*) has a pair of unusually long (5.4 mm) proximal spines; in this respect, it resembles *G. horridus* as described by Ross and Berry (1963) but differs from that form mainly in its shorter thecal spines. In scalariform view, the rhabdosome of *G. ciliatus* is about 2 mm (rarely 3.0 mm) wide and has septal spines 2 to 4 mm long or more. Figure 8*F* is an obliquely compressed specimen showing the very long septal spines and the paired thecal spines that give the appearance of twice as many thecae per centimeter as are actually present.

G. ciliatus is probably conspecific with *G. hincksii* (John Riva, oral communication, 1977), but revision of the species is beyond the scope of this work. *Ciliatus* is distinguished from other glossograptids by the size and shape of its rhabdosome and thecal spines.

Horizon and locality.—Ledbetter Slate, collections B-458b (*D.*? *decoratus* Zone); B-87 (36-P-22) (*D.*? *decoratus-N. gracilis* Subzones); B-459, 65WCn 91, and 66Y-200 (*N. gracilis* Subzone); and B-456?, D543-CO (*C. bicornis* Zone). Zones of *G. hincksii* and *Climacograptus bicornis* (Phi Kappa Formation) at Trail Creek, Idaho (Carter and Churkin, 1977); New York State (Normanskill Shale), Alabama (Athens Shale), Arkansas, and British Columbia (Glenogle Formation) (Ruedemann, 1908, 1947); and Wellington River area (Gisbornian), Victoria, Australia (Harris and Thomas, 1955; A.H.M. VandenBerg, unpublished report, 1981).

Genus *Apiograptus* Cooper and McLaurin, 1974
?*Apiograptus* cf. *A. crudus* (Harris and Thomas)

Figure 3*C*

cf. *Glossograptus*? *crudus* Harris and Thomas, 1935, p. 303-304, fig. 1, no. 13; fig. 2, nos. 15-17.

cf. *Apiograptus crudus* (Harris and Thomas). Cooper and McLaurin, 1974, p. 81-84, text figs. 2a-h.

Description.—The single poorly preserved specimen is 6.5 mm long and 5.5 mm wide and has 6½ thecae in the space of 5 mm. A stout virgula extends from the dorsal margin, and the thecae have long apertural denticles.

Discussion.—The specimen has the size and shape of *A. crudus*, but the proximal thecae are not preserved, so it cannot be identified with certainty.

Horizon and locality.—Ledbetter Slate, collection B-458a, *Oncograptus* Zone. *A. crudus* is found in the *Oncograptus* Zone in New Zealand (Cooper, 1979) and in the upper Yapeenian (Ya2) in Australia (Cooper and McLaurin, 1974).

Genus *Cryptograptus* Lapworth, 1880
Cryptograptus insectiformis Ruedemann

Figure 10*C*

Cryptograptus tricornis mut. *insectiformis* Ruedemann, 1908, p. 448-449, pl. 28, fig. 5, text figs. 419-422. Ruedemann, 1947, p. 446-447, pl. 76, figs. 34-41.

Cryptograptus insectiformis Ruedemann. Ruedemann and Decker, 1934, p. 324, pl. 43, figs. 13-17.

Diagnosis.—Rhabdosome short (8-9 mm long), widest at proximal end (1.6 mm), tapering distally to 1.2 mm. Thecae 16 per centimeter. Proximal end in scalariform view exhibits two curved lateral spines.

Discussion.—*C. insectiformis* resembles *C. tricornis* (Carruthers) but has a smaller rhabdosome and more thecae per centimeter. It is distinguished from other cryptograptids by its short rhabdosome. The Ledbetter specimens are severely tectonically distorted, but their small size and distinctive proximal portions serve to identify them as *C. insectiformis.*

Horizon and locality.—Ledbetter Slate, collection 65WCn 102, *Climacograptus spiniferus* Zone. Viola Limestone of Oklahoma (Ruedemann and Decker, 1934), Zones of *D. multidens* through *C. manitoulinensis* in eastern North America (Riva, 1974).

Genus *Kalpinograptus* Jiao, 1977
Kalpinograptus ovatus (T.S. Hall)

Figures 6*D*, *E*

Didymograptus ovatus T.S. Hall, 1902, p. 33, fig. 1.

Isograptus ovatus (T.S. Hall), Harris, 1933, p. 105-106, text figs. 45, 46. Beavis and Beavis, 1974, p. 202-203, figs. 11a, b.

Dicellograptus perspinosus Ruedemann, 1947, p. 386, pl. 64, figs. 20-22.

Diagnosis.—Rhabdosome with two curved, reclined stipes that often converge distally, giving the rhabdosome an ovate outline. Stipes 12 to 18 mm long, 1.7 to 2.7 mm wide (including apertural processes). Sicula 3.1 to 4.0 mm long (including virgella), extending very little above dorsal margin of rhabdosome but with conspicuous nema up to 2 mm long or more. Thecae 10 to 13 (averaging 12) per centimeter, curved, with apertural margins drawn out into long, slender processes about 1 mm long that appear quite spinelike.

Discussion.—*Kalpinograptus* superficially resembles *Isograptus*, especially in flattened material, but has been shown to have a pericalycal, monopleural arrangement of the proximal end (Jiao, 1977; Finney, 1978, p. 489). *K. lyra* (Ruedemann) is very similar in appearance to *K. ovatus* but apparently has a longer sicula (5-6 mm long) and wider stipes (about 3 mm including apertural processes). *K. spiroptenus* Jiao has shorter, narrower stipes (5 mm long, 1 mm wide distally), and the thecae are more closely spaced (eight in 5 mm). In flattened material, *K. ovatus* may be distinguished from *Isograptus* by its spinelike apertural processes and a pointed proximal end that has almost no pendent thecae.

Horizon and locality.—Ledbetter Slate, collection B-458b, *D.*? *decoratus* Zone. Upper Darriwillian in Victoria, Australia (Beavis and Beavis, 1974; VandenBerg, 1981).

Subfamily PSEUDISOGRAPTINAE Cooper and Ni, 1986

Genus *Pseudisograptus* Beavis, 1972

Pseudisograptus? aff. *P. manubriatus koi* Cooper and Ni

Figures 4*L*, *M*

aff. *Pseudisograptus manubriatus koi* Cooper and Ni, 1986, p. 332-339, pl. 24, figs. 1-6, 9-12.

Pseudisograptus? aff. *P. manubriatus koi* Cooper and Ni. Carter, this volume, p. A13, fig. 7*K*.

Diagnosis.—Sicula 2.0 to 2.6 mm long, forming manubrium(?) with first three or four thecae; supradorsal height 1.0 to 1.2 mm. Manubrium(?) about 1 mm wide at base. Stipes diverging at about 230°, gently dorsally curved initially to nearly straight distally; up to 3.5 mm long, 1.0 to 1.3 mm wide. Thecae isograptid, eight to seven in 5 mm.

Discussion.—This species has a longer sicula and wider stipes than *Isograptus tenuis* Harris. It has a shorter sicula, a shorter and narrower "manubrium," shorter thecae, and a smaller angle of divergence than *P. manubriatus koi* does.

Horizon and locality.—Metaline Limestone, collection D913-CO, *P. tentaculatus* Zone.

Family THAMNOGRAPTIDAE Hopkinson and Lapworth, 1875, emended by Finney, 1980

Genus *Thamnograptus* Hall, 1859

Thamnograptus capillaris (Emmons)

Figure 8*C*

Nemagrapsus capillaris Emmons, 1855, p. 109-110, pl. 1, fig. 7.

Thamnograptus capillaris Hall, 1859, p. 520, fig. 3.

Thamnograptus capillaris (Emmons). Ruedemann, 1908, p. 206-210, text figs. 108-112, pl. 10, figs. 4-8, pl. 12, figs. 9-16. Ruedemann, 1947, p. 274-275, pl. 43, figs. 4-7. Finney, 1980, p. 1189-1197, pl. 1, figs. 1, 3-7, pl. 2, fig. 8, text figs. 3, 4C-D, F-G, 5-7.

Thamnograptus typus Hall, 1859, p. 519-520, figs. 1, 2.

Diagnosis.—Main stipes as much as 1.6 mm wide, giving rise to alternating second-order branches at 3- to 5-mm intervals. Second-order branches bear thamnograptid thecae proximally and dichograptid thecae distally; thamnograptid thecae are tubular, slender, with little overlap, numbering 8 to 10 per centimeter. Proximal end development unknown.

Discussion.—The main stipes of the Ledbetter specimens are 0.3 to 0.6 mm wide, and the secondary stipes on either side are 3.5 to 5.0 mm apart. No dichograptid thecae have been observed, but numerous thamnograptid thecae can be detected.

Horizon and locality.—Ledbetter Slate, collection B-459, *N. gracilis* Subzone. *Glyptograptus teretiusculus* and *N. gracilis* Zones (Athens Shale) in Alabama (Finney, 1980). *N. gracilis* Zone (Normanskill Shale) in New York and British Columbia (Ruedemann, 1947).

Family DICRANOGRAPTIDAE Lapworth, 1873

Genus *Dicranograptus* Hall, 1865

Dicranograptus hians hians T.S. Hall

Figures 9*A*, *C*, *L*

Dicranograptus hians T.S. Hall, 1905, p. 24, pl. 6, fig. 6. Harris and Thomas, 1955, p. 41-42, figs. 16-18.

Dicranograptus hians hians T.S. Hall. VandenBerg and Stewart, 1983, p. 41, fig. 20.

Diagnosis.—Biserial portion short (about 3 mm long), parallel sided, about 1 mm wide, three to four thecae on each side. Uniserial stipes straight or slightly curved, untwisted, about 6 cm long and 1 mm wide, enclosing an axillary angle of 60° to 110° or more. Thecae with slightly curved ventral margins, numbering 12 in 10 mm.

Discussion.—The Ledbetter specimens are all tectonically distorted to varying degrees but seem to compare well with the dimensions and characters of *D. h. hians* (short, parallel-sided biserial portion, three to four thecae per side; untwisted uniserial stipes). *D. hians kirki* Ruedemann is distinguished from this subspecies by its more curved and twisted uniserial stipes.

The pyritized specimens from northeastern Washington (figs. 9*A*, *C*) reveal details of morphology, some of which were not previously known for this species. The sicula is about 1 mm long, and the first theca arises

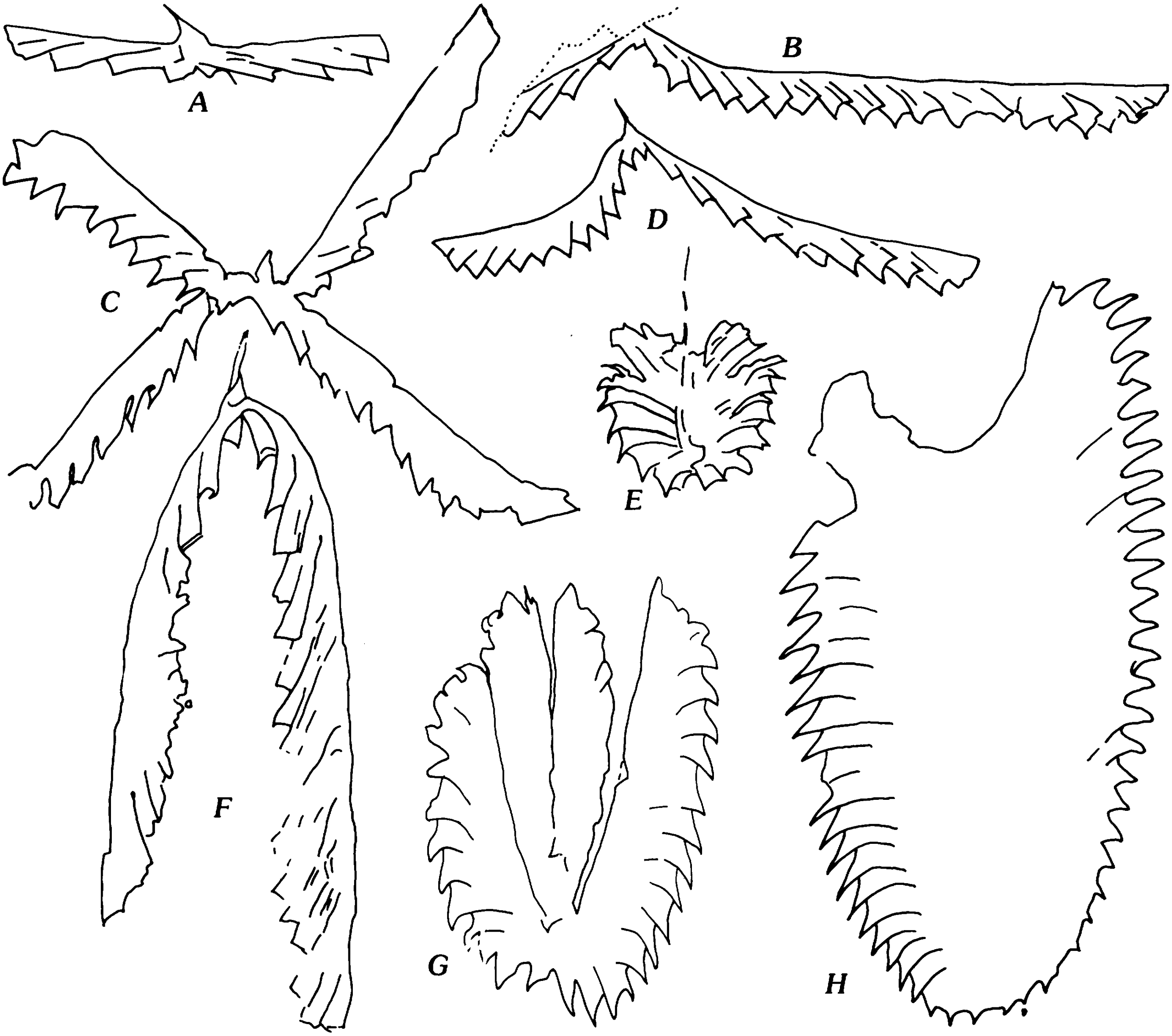


Figure 2. Graptolites from the *Oncograptus* Zone. *A*, *Xiphograptus* sp., USNM 413729, collection D354-CO, ×8. *B*, *Didymograptus* cf. *D. v-deflexus* Harris, USNM 413719, collection B-458a, ×5. *C*, *Tetragraptus amii* Elles and Wood, USNM 413720, collection B-458a, ×5. *D*, *D. v-deflexus* Harris, USNM 413730, collection D354-CO, ×5. *E*, *Phyllograptus*? sp., USNM 413722, collection B-458a, ×5. *F*, *Didymograptus* (*Didymograptellus*) sp., USNM 413723, collection B-458a, ×10. *G*, *Tetragraptus* (*Tetragraptus*) cf. *T.* (*T.*) *bigsbyi* (Hall), USNM 413731, collection D354-CO, ×5. *H*, *Cardiograptus morsus* Harris and Keble, USNM 413733, collection D354-CO, ×5.

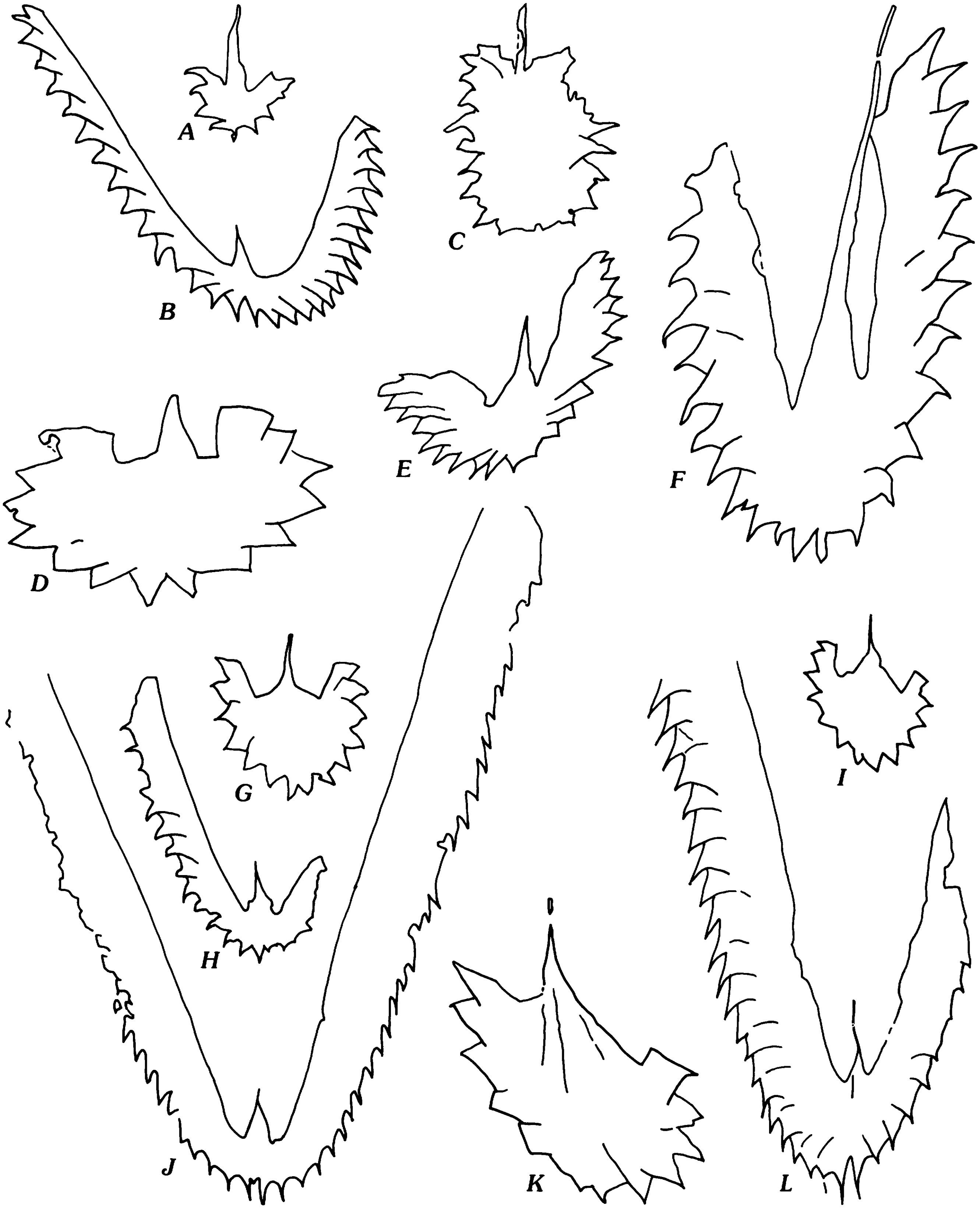


Figure 3. Graptolites from the *Oncograptus* Zone. *A, Pseudisograptus manubriatus koi* Cooper and Ni, USNM 413724, collection B-458a, immature specimen, ×5. *B, Isograptus* sp., USNM 413735, collection D354-CO, tectonically distorted, ×5. *C, ?Apiograptus* cf. *A. crudus* (Harris and Thomas), USNM 413725, collection B-458a, ×5. *D, P. dumosus* form B (Harris), USNM 413734, collection D354-CO, tectonically distorted, ×10. *E, P. manubriatus harrisi* Cooper and Ni, USNM 413732, collection D354-CO, tectonically distorted, ×5. *F, P. m. harrisi* Cooper and Ni, USNM 413736, collection D354-CO, tectonically distorted, ×10. *G, P. dumosus* form B (Harris), USNM 413726, collection B-458a, ×5. *H, P. m. koi* Cooper and Ni, USNM 413727, collection B-458a, ×5. *I, P. dumosus* form B (Harris), USNM 413721, collection B-458a, ×5. *J, Isograptus victoriae divergens* Harris, USNM 413728, collection B-458a, ×5. *K, P. dumosus* form B (Harris), USNM 413737, collection D354-CO, tectonically distorted, ×10. *L, I. v. divergens* Harris, USNM 413738, collection D354-CO, tectonically distorted, ×5.

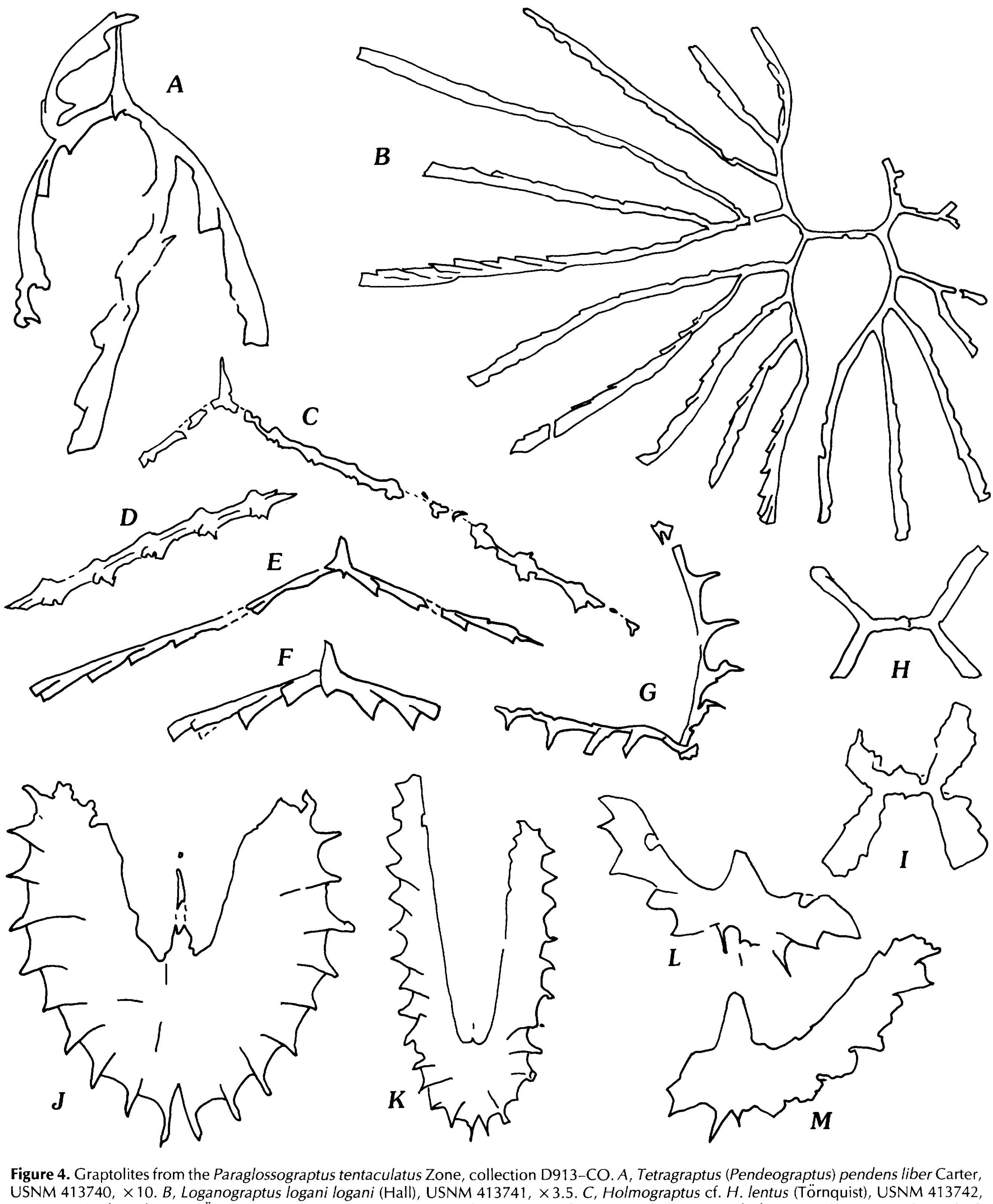


Figure 4. Graptolites from the *Paraglossograptus tentaculatus* Zone, collection D913–CO. *A*, *Tetragraptus* (*Pendeograptus*) *pendens liber* Carter, USNM 413740, ×10. *B*, *Loganograptus logani logani* (Hall), USNM 413741, ×3.5. *C*, *Holmograptus* cf. *H. lentus* (Törnquist), USNM 413742, ×10. *D*, *H.* cf. *H. lentus* (Törnquist), USNM 413744, ×10. *E*, *Didymograptus* cf. *D. cognatus* Harris and Thomas, USNM 413748, ×10. *F*, *Didymograptus* sp., USNM 413746, ×10. *G*, *Kinnegraptus*? sp., USNM 413749, ×10. *H*, *T. quadribrachiatus* (Hall), USNM 413747, ×5. *I*, *T.* cf. *T. amii* Elles and Wood, USNM 413751, ×5. *J*, *Isograptus caduceus australis* Cooper, USNM 413752, ×10. *K*, *I. c. australis* Cooper, USNM 413753, ×5. *L*, *Pseudisograptus*? aff. *P. manubriatus koi* Cooper and Ni, USNM 413750, ×10. *M*, *P.*? aff. *P. m. koi* Cooper and Ni, USNM 413755, ×10.

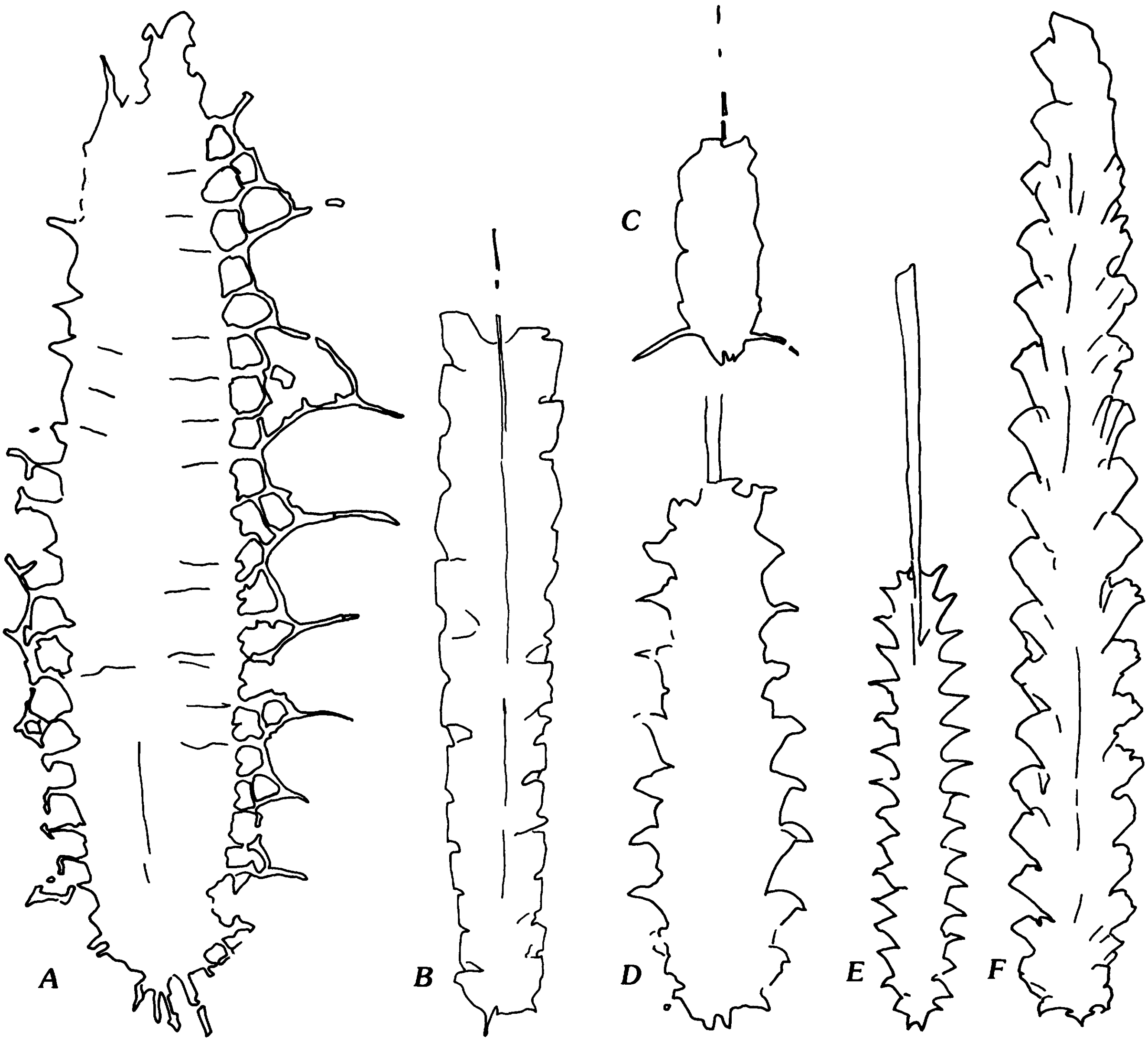
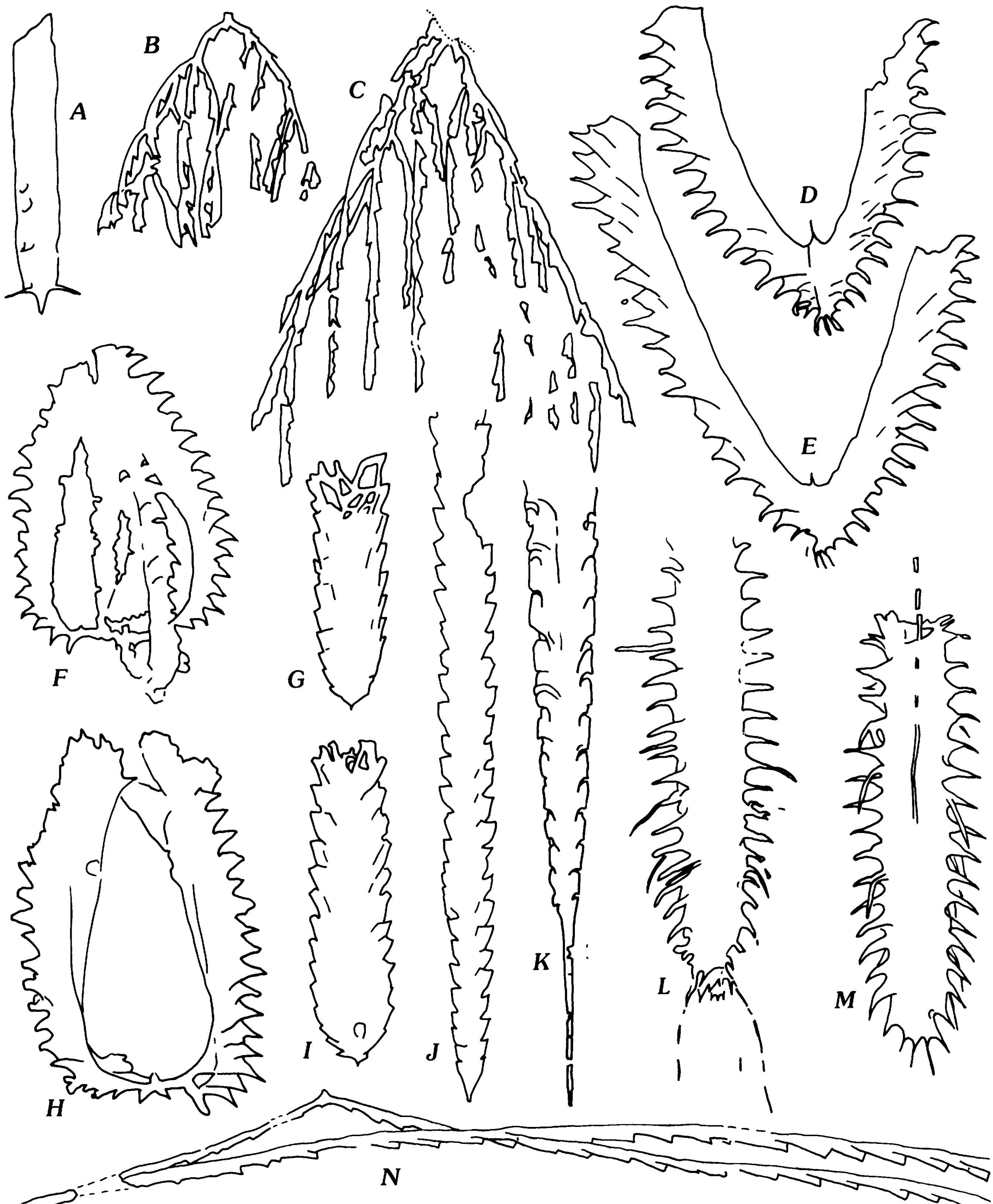


Figure 5. Graptolites from the *Paraglossograptus tentaculatus* Zone, collection D913-CO. *A*, *P. tentaculatus* (Hall), USNM 413756, ×8. *B*, *Undulograptus*? cf. *U*.? *intersitus* (Harris and Thomas), USNM 413745, semiscalariform view, ×10. *C*, *Cryptograptus* sp., USNM 413757, ×10. *D*, *Cryptograptus*? *inutilus* (Hall), USNM 413739, ×10. *E*, *C*.? *inutilus* (Hall), USNM 413754, ×5. *F*, Genus and species indeterminate, USNM 413743, ×10.

Figure 6. Graptolites from the *Diplograptus*? *decoratus* Zone, collection B-458b, all ×5. *A*, *Cryptograptus schaeferi* Lapworth, USNM 413758. *B*, *Pterograptus elegans* Holm, USNM 413759. *C*, *P. elegans* Holm, USNM 413760. *D*, *Kalpinograptus ovatus* (T.S. Hall), previously unfigured paratype of *Dicellograptus perspinosus* Ruedemann, USNM 413761. *E*, *K. ovatus* (T.S. Hall), previously unfigured paratype of *D. perspinosus* Ruedemann, USNM 413762. *F*, *Tetragraptus* n.sp., USNM 413763. *G*, *Orthograptus* n.sp., USNM 413765. *H*, *Tetragraptus* n.sp., USNM 413764. *I*, *Orthograptus* n.sp., USNM 413766. *J*, *Glyptograptus euglyphus* (Lapworth), USNM 413767. *K*, *Climacograptus riddellensis* Harris, having unusually long virgella, USNM 413768. *L*, *Glossograptus ciliatus* Emmons, USNM 413769. *M*, *G. ciliatus* Emmons. USNM 413770. *N*, *Didymograptus serratulus* (Hall), USNM 413771. ▶


A
B
C
D
E
F
G
H
I
J
K
L
M
N

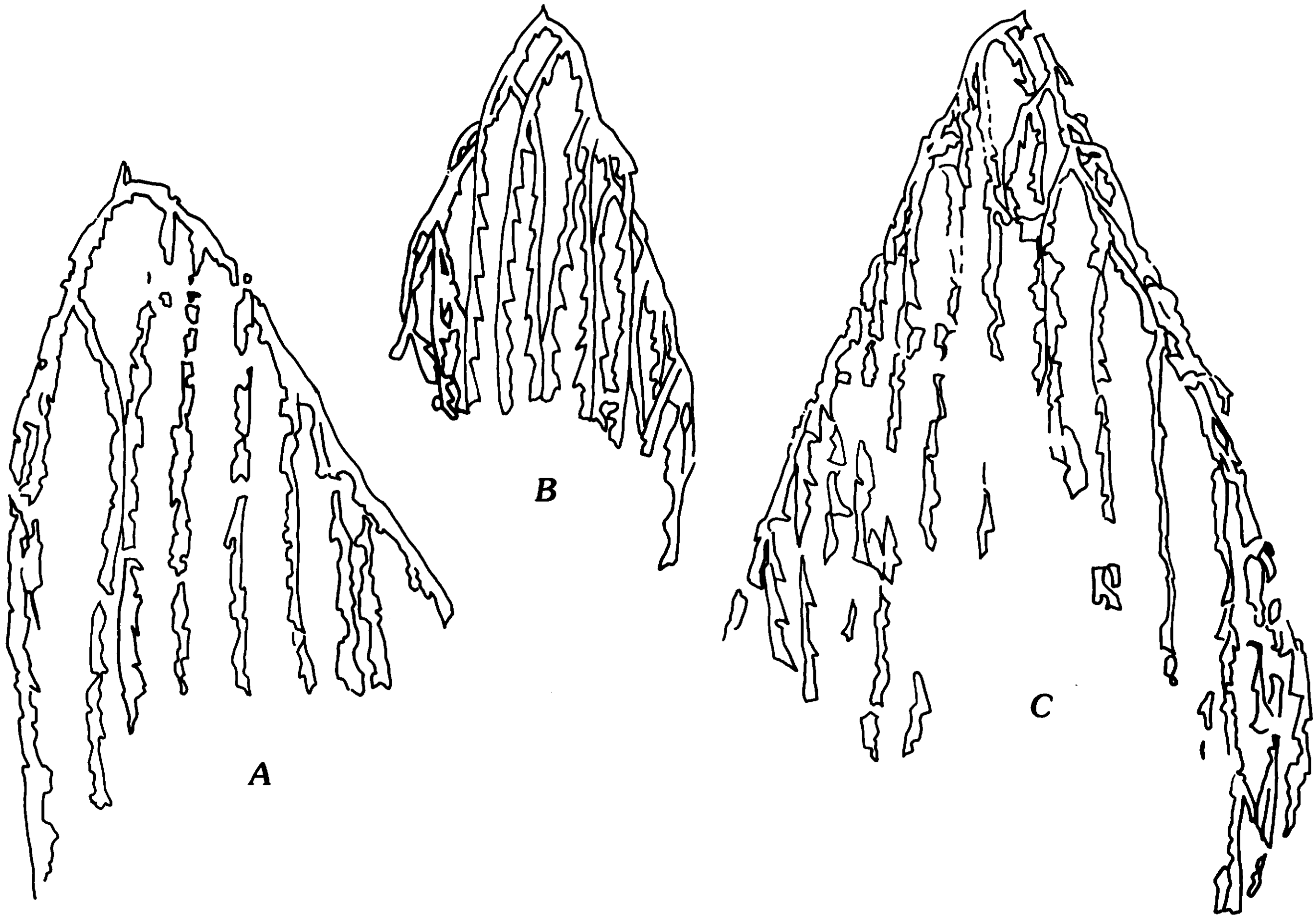


Figure 7. *Pterograptus elegans* Holm from the *Diplograptus*? *decoratus* Zone. Collection B-458b. *A*, Specimen on slab with USNM 127962e and USNM 127964a, ×8. *B*, USNM 127964c, ×5, illustrated by Ruedemann (1947, pl. 61, fig. 28) as a paratype of *Syndeograptus bridgei* Ruedemann. *C*, USNM 127963, ×5, holotype of *S. bridgei* Ruedemann, illustrated by Ruedemann (1947, pl. 61, figs. 24, 25).

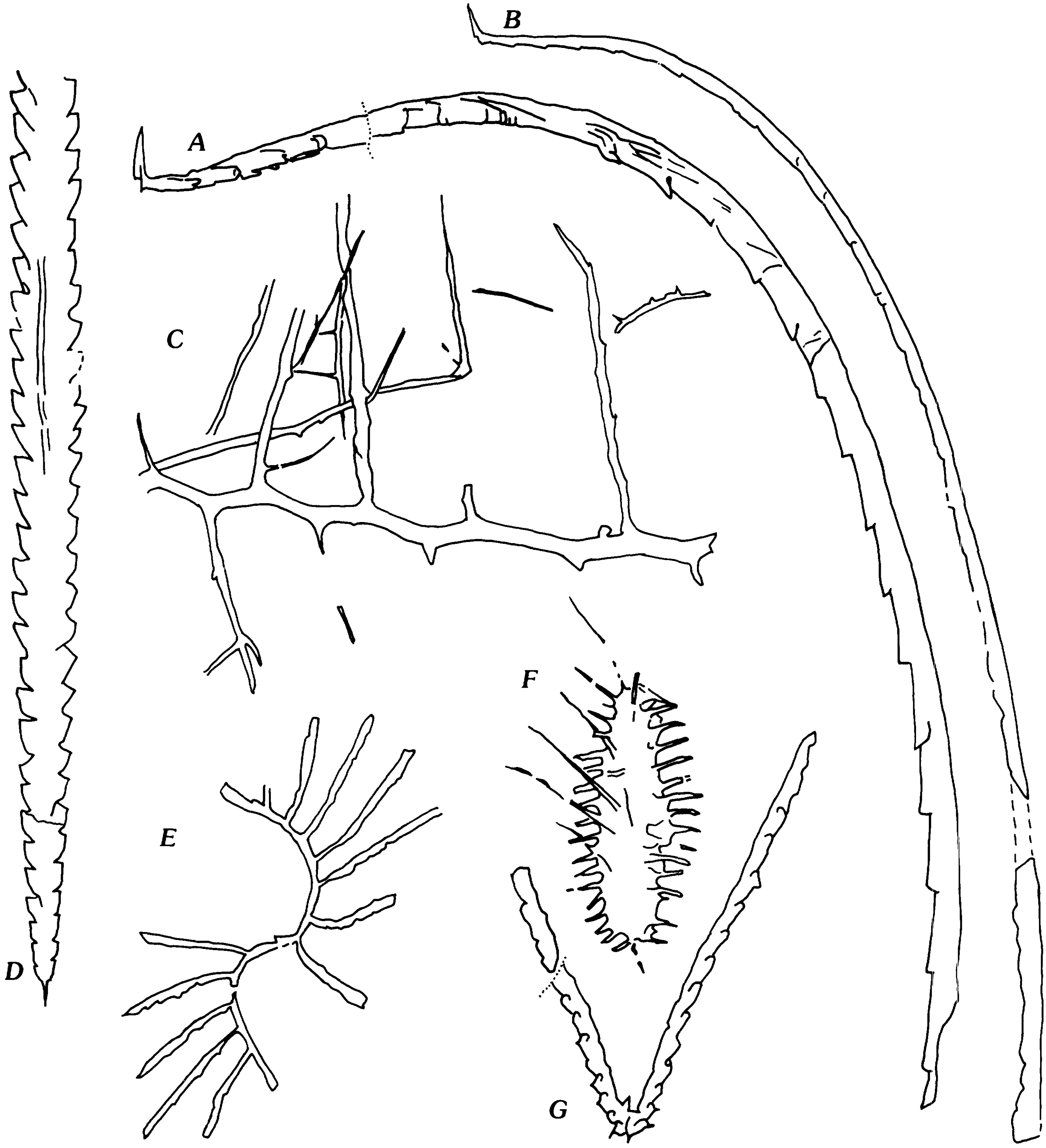


Figure 8. Graptolites from the *Nemagraptus gracilis* Subzone, collection B-459. *A*, *Azygograptus* cf. *A. canadensis* Ruedemann, USNM 413772, ×8. *B*, *A.* cf. *A. canadensis* Ruedemann, USNM 413773, ×5. *C*, *Thamnograptus capillaris* (Emmons), USNM 413775, ×5. *D*, *Glyptograptus euglyphus* (Lapworth), USNM 413776, ×5. Drawing is a composite of part and counterpart. *E*, *N. gracilis* (Hall), USNM 413777, ×5. *F*, *Glossograptus ciliatus* Emmons, USNM 413778, ×5, illustrated by Ruedemann (1947, pl. 77, fig. 38). *G*, *Dicellograptus sextans* (Hall), USNM 413774, ×5.

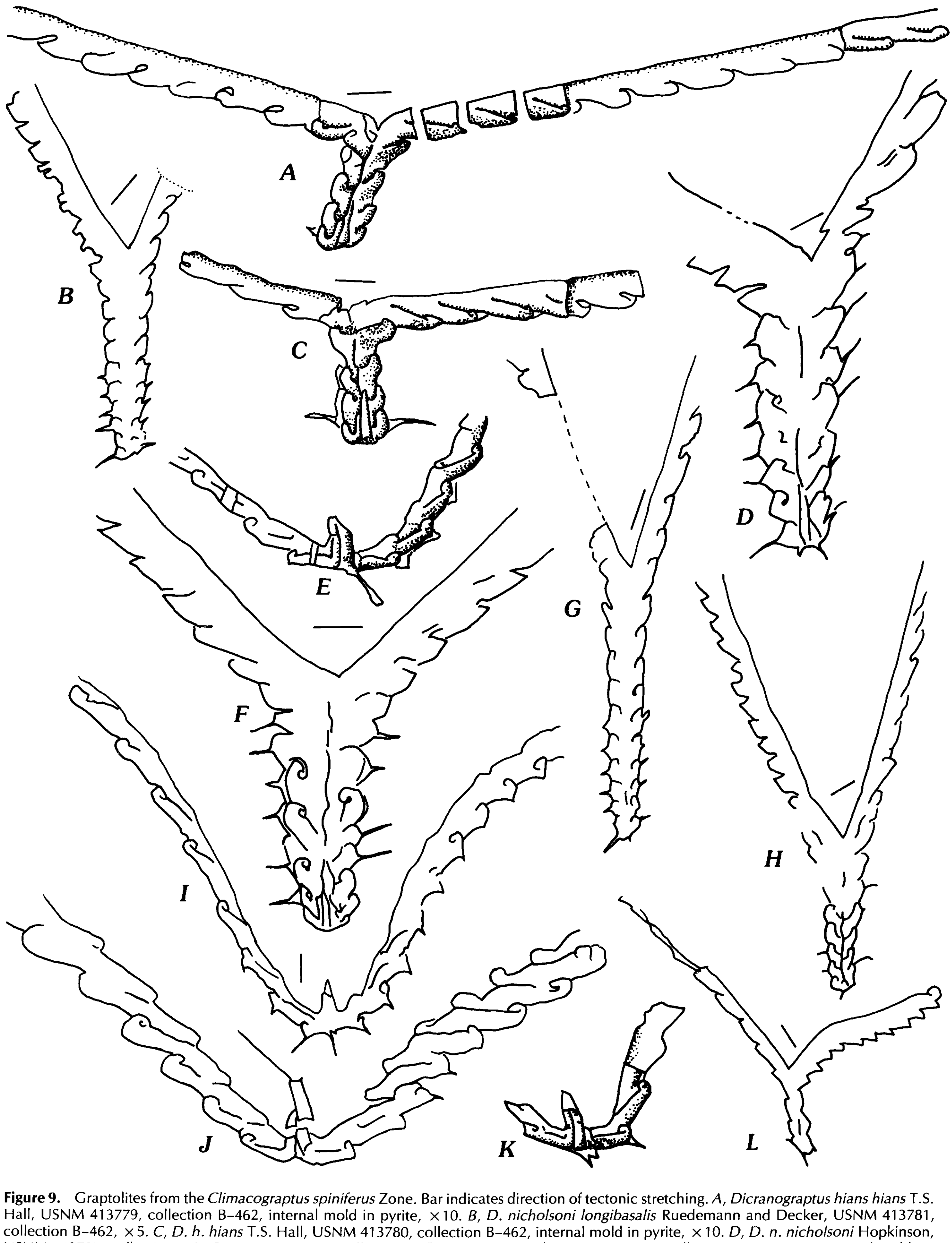


Figure 9. Graptolites from the *Climacograptus spiniferus* Zone. Bar indicates direction of tectonic stretching. *A*, *Dicranograptus hians hians* T.S. Hall, USNM 413779, collection B-462, internal mold in pyrite, ×10. *B*, *D. nicholsoni longibasalis* Ruedemann and Decker, USNM 413781, collection B-462, ×5. *C*, *D. h. hians* T.S. Hall, USNM 413780, collection B-462, internal mold in pyrite, ×10. *D*, *D. n. nicholsoni* Hopkinson, USNM 413787, collection 65WCn 102, ×10. *E*, *Dicellograptus flexuosus* Lapworth, USNM 413790, collection 65WCn 102, internal molds in pyrite, ×15. *F*, *Dicranograptus nicholsoni nicholsoni* Hopkinson, USNM 413788, collection 65WCn 102, ×10. *G*, *D. n. longibasalis* Ruedemann and Decker, USNM 413782, collection B-462, ×5. *H*, *D. n. nicholsoni* USNM 413789, collection 65WCn 102, ×5. *I*, *Dicellograptus flexuosus* Lapworth, USNM 413792, collection 65WCn 102, internal mold in pyrite, ×10. *J*, *D. flexuosus* Lapworth, USNM 413793, collection 65WCn 102, internal mold in pyrite, ×15. *K*, *D. flexuosus* Lapworth, USNM 413791, collection 65WCn 102, internal mold in pyrite, ×15. *L*, *Dicranograptus hians hians* T.S. Hall, USNM 413808, collection 65WCn 102, ×5.

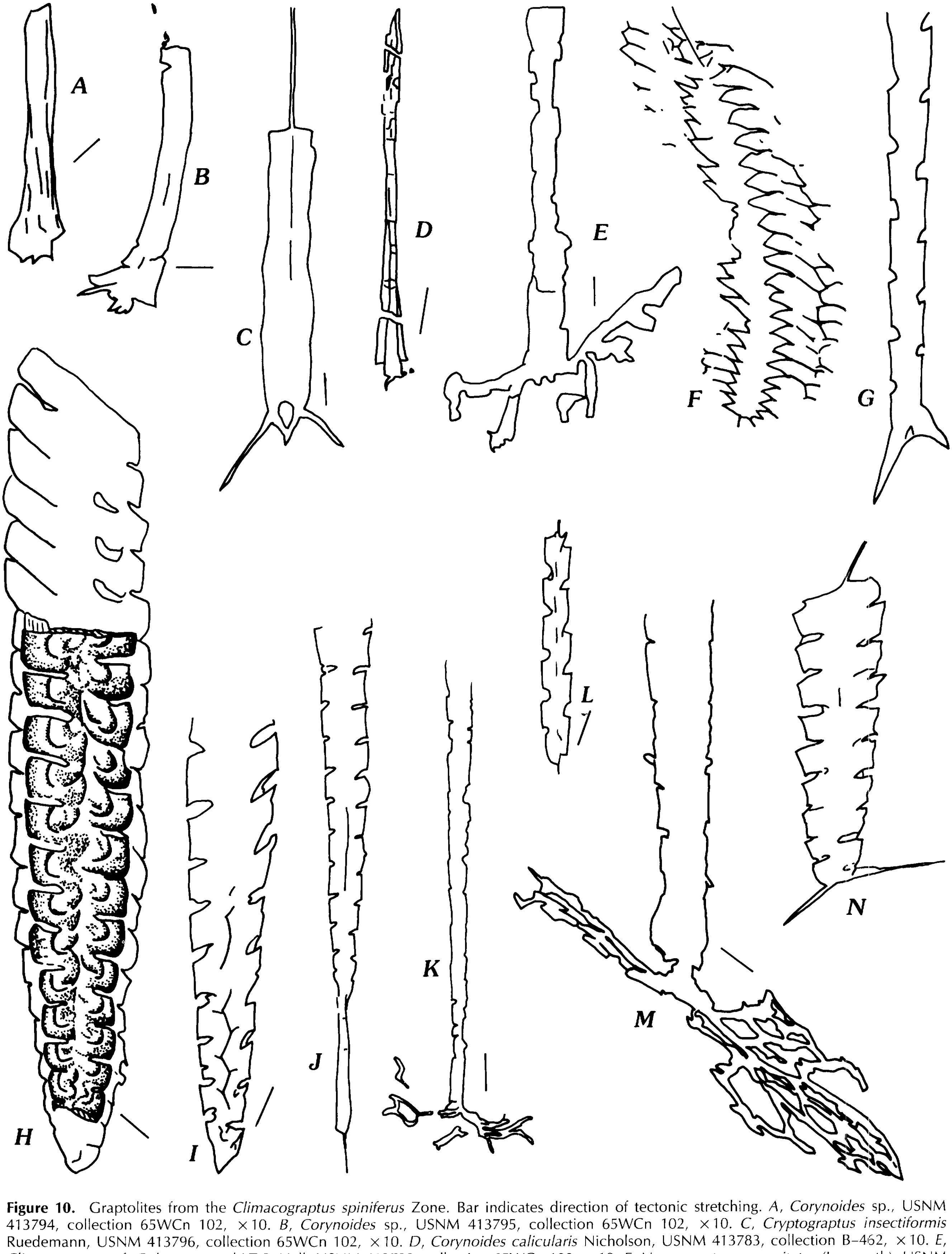


Figure 10. Graptolites from the *Climacograptus spiniferus* Zone. Bar indicates direction of tectonic stretching. *A, Corynoides* sp., USNM 413794, collection 65WCn 102, ×10. *B, Corynoides* sp., USNM 413795, collection 65WCn 102, ×10. *C, Cryptograptus insectiformis* Ruedemann, USNM 413796, collection 65WCn 102, ×10. *D, Corynoides calicularis* Nicholson, USNM 413783, collection B-462, ×10. *E, Climacograptus* cf. *C. baragwanathi* T.S. Hall, USNM 413798, collection 65WCn 102, ×10. *F, Neurograptus margaritatus* (Lapworth), USNM 413800, collection 65WCn 102, ×5. *G, C. spiniferus spiniferus* Ruedemann, USNM 413802, collection 65WCn 102, stretched approximately lengthwise, ×10. *H, Pseudoclimacograptus* sp., USNM 413784, collection B-462, internal mold in pyrite, outlined by obliquely deformed external mold, ×10. *I, Pseudoclimacograptus* sp., USNM 413804, collection 65WCn 102, ×10. *J, C. caudatus* Lapworth, USNM 413805, collection 65WCn 102, ×7. *K, C.* cf. *C. baragwanathi* T.S. Hall, USNM 413801, collection 65WCn 102, ×5. *L, Climacograptus* sp., USNM 413797, collection 65WCn 102, ×10. *M, C.* cf. *C. baragwanathi* T.S. Hall, USNM 413799, collection 65WCn 102, ×10. *N, C. s. spiniferus* Ruedemann, USNM 413803, collection 65WCn 102, stretched approximately widthwise, ×10.

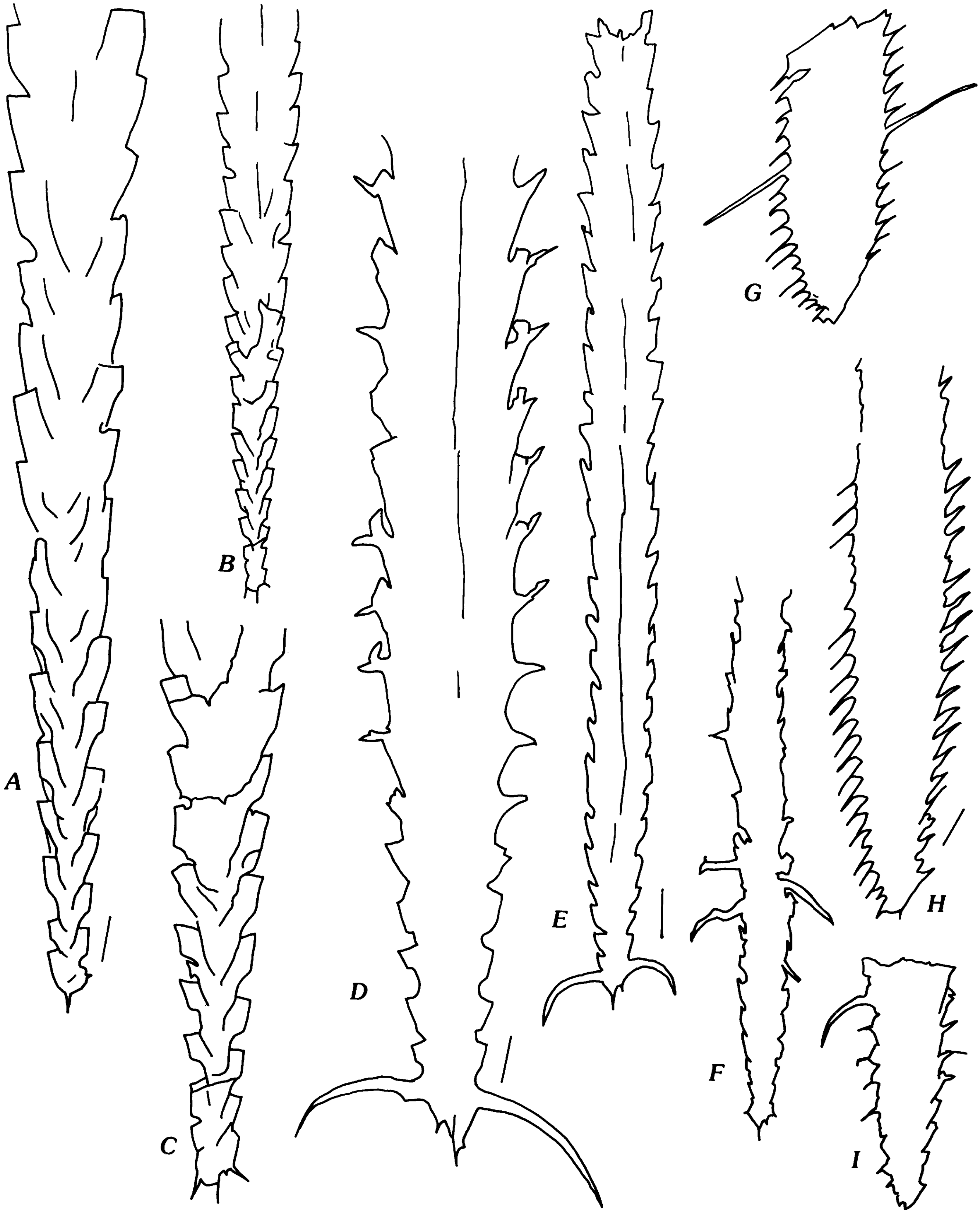


Figure 11. Graptolites from the *Climacograptus spiniferus* Zone. Bar indicates direction of tectonic stretching. *A*, *Amplexograptus* sp., USNM 413806, collection 65WCn 102, ×10. *B*, *Amplexograptus* sp., USNM 413807, collection 65WCn 102, ×5. *C*, Enlargement of proximal portion of USNM 413807 (*B*), ×10. *D*, *Orthograptus calcaratus tenuicornis* Elles and Wood, USNM 413809,collection 65WCn 102, ×10. *E*, *O. c. tenuicornis* Elles and Wood, USNM 413786, collection B-462, ×5. *F*, *O. quadrimucronatus spinigerus* (Lapworth), USNM 413810, collection 65WCn 102, ×5. *G*, *O. q. spinigerus* (Lapworth), USNM 413811, collection 65WCn 102, ×5. *H*, *O. quadrimucronatus* (Hall) sensu lato, USNM 413785, collection B-462, ×5. *I*, *O. q. spinigerus* (Lapworth), USNM 413812, collection 65WCn 102, ×5.

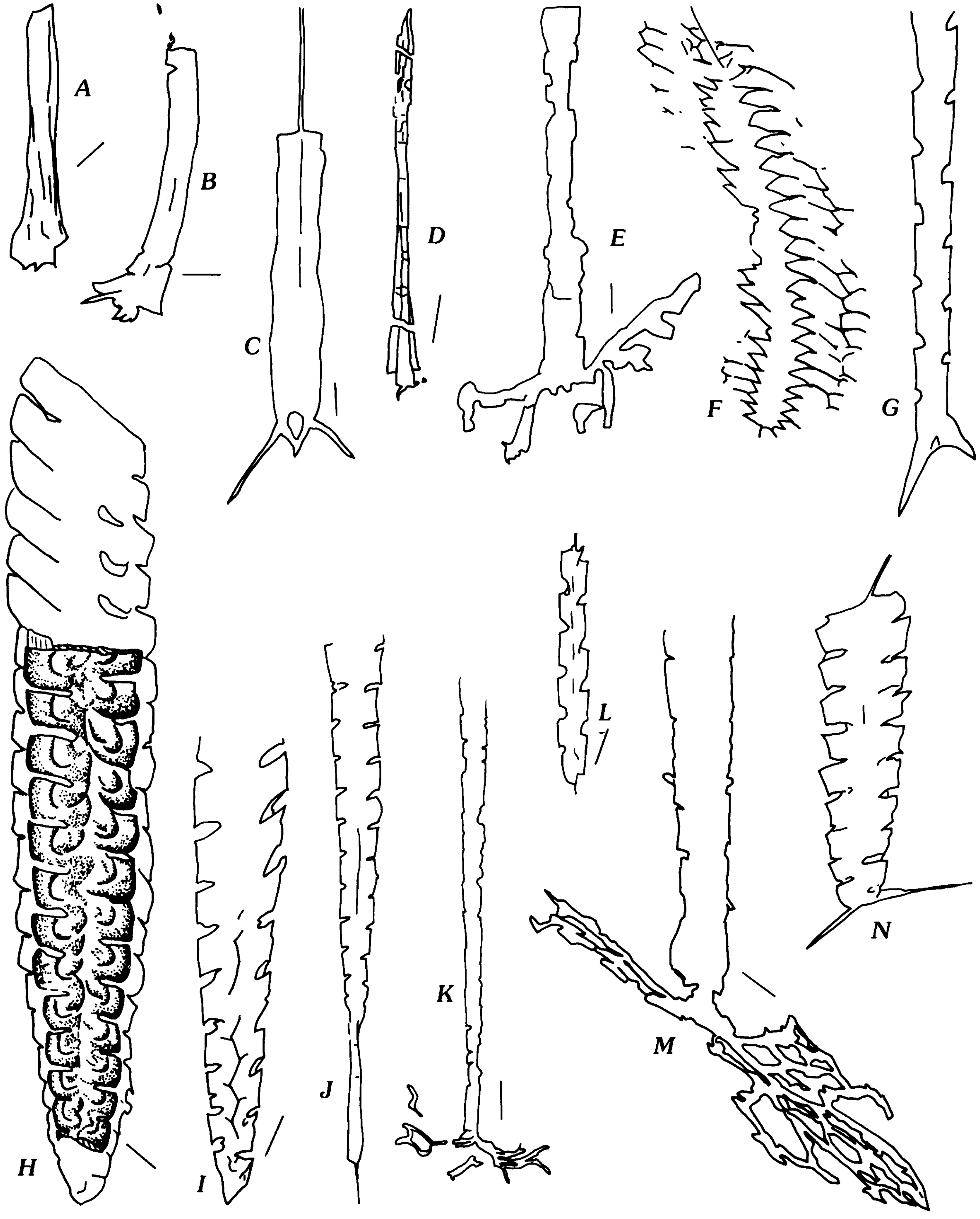


Figure 10. Graptolites from the *Climacograptus spiniferus* Zone. Bar indicates direction of tectonic stretching. *A*, *Corynoides* sp., USNM 413794, collection 65WCn 102, ×10. *B*, *Corynoides* sp., USNM 413795, collection 65WCn 102, ×10. *C*, *Cryptograptus insectiformis* Ruedemann, USNM 413796, collection 65WCn 102, ×10. *D*, *Corynoides calicularis* Nicholson, USNM 413783, collection B-462, ×10. *E*, *Climacograptus* cf. *C. baragwanathi* T.S. Hall, USNM 413798, collection 65WCn 102, ×10. *F*, *Neurograptus margaritatus* (Lapworth), USNM 413800, collection 65WCn 102, ×5. *G*, *C. spiniferus spiniferus* Ruedemann, USNM 413802, collection 65WCn 102, stretched approximately lengthwise, ×10. *H*, *Pseudoclimacograptus* sp., USNM 413784, collection B-462, internal mold in pyrite, outlined by obliquely deformed external mold, ×10. *I*, *Pseudoclimacograptus* sp., USNM 413804, collection 65WCn 102, ×10. *J*, *C. caudatus* Lapworth, USNM 413805, collection 65WCn 102, ×7. *K*, *C.* cf. *C. baragwanathi* T.S. Hall, USNM 413801, collection 65WCn 102, ×5. *L*, *Climacograptus* sp., USNM 413797, collection 65WCn 102, ×10. *M*, *C.* cf. *C. baragwanathi* T.S. Hall, USNM 413799, collection 65WCn 102, ×10. *N*, *C. s. spiniferus* Ruedemann, USNM 413803, collection 65WCn 102, stretched approximately widthwise, ×10.

Genus *Dicellograptus* Hopkinson, 1871
Dicellograptus flexuosus Lapworth

Figures 9*E, I, J, K*

Dicellograpsus forchhammeri (Geinitz). Hopkinson, 1871, p. 23-24, pl. 1, figs. 1a-d.

Dicellograptus forchammeri (Geinitz) var. *flexuosus* Lapworth, 1876, pl. 4, fig. 90. Elles and Wood, 1901-18, p. 152-153, pl. 22, figs. 2a-d, text figs. 95a-d. Ruedemann and Decker, 1934, p. 307-308, pl. 40, figs. 10, 10a, 11, pl. 41, figs. 1, 2. Ruedemann, 1947, p. 382, pl. 63, figs. 13-20.

Dicellograptus forchammeri (Geinitz). Lapworth, 1876, pl. 4, fig. 88. Elles and Wood, 1901-18, p. 150-152, pl. 22, figs. 1a-d, text figs. 94a-d. Ruedemann and Decker, 1934, p. 307, pl. 40, figs. 9, 9a. Ruedemann, 1947, p. 381-382, pl. 63, figs. 9-12.

Dicellograptus flexuosus Lapworth. Williams, 1982, p. 243, figs. 9a-e. VandenBerg and Stewart, 1983, p. 41, fig. 19. Bergström and Mitchell, 1986, figs. 7G, H, I. Finney, 1986, p. 452, figs. 8L, 9B, F.

Diagnosis.—Stipes long (10 cm or more), straight or gently flexed, increasing gradually from 0.4 mm wide proximally to a maximum width of 0.9 mm about 2 cm from sicula. Axial angle variable from 45° to 120°. Sicula 1.0 to 1.5 mm long, with small but conspicuous virgella. Thecae simple, 12 to 9 per centimeter, with straight, inclined ventral walls and slightly introverted apertures.

Discussion.—The Ledbetter specimens are commonly preserved as pyritized internal molds, and all exhibit significant tectonic distortion. However, they have the characteristic thin stipes and simple thecae of *D. flexuosus*, and their first two thecae grow nearly horizontally, as they do in *flexuosus*. In some of the more distorted specimens (fig. 9*J*), the prothecal folds have been accentuated by compression. *D. alector* Carter is similar to *D. flexuosus* but has a longer sicula (2 mm), a "squarer" axil, and longer $th1^1$ and $th1^2$.

Horizon and locality.—Ledbetter Slate, collection 65WCn 102, *C. spiniferus* Zone. Viola Springs Formation in Oklahoma (Ruedemann and Decker, 1934; Finney, 1986; Bergström and Mitchell, 1986). Polk Creek Shale in Arkansas (Ruedemann, 1947). The *C. baragwanathi* Zone in Victoria, Australia (VandenBerg and Stewart, 1983). Hartfell Shale (*Dicranograptus clingani* and *Pleurograptus linearis* Zones) in the British Isles (Elles and Wood, 1901-18; Williams, 1982).

Family DIPLOGRAPTIDAE Lapworth, 1873
Genus *Diplograptus* M'Coy, 1850
Diplograptus cf. *D. ingens wellingtonensis* Harris and Thomas

Figures 12*A-G*

cf. *Diplograptus* (*Mesograptus*) *ingens* T.S. Hall, var. *wellingtonensis* Harris and Thomas, 1955, p. 38, figs. 31, 32.

cf. *Diplograptus ingens wellingtonensis* Harris and Thomas. Moors, 1970, p. 270-271, figs. 5e, f.

Description.—The rhabdosome is as much as 3 cm long and distinctly tapers from a narrow proximal end (0.8-0.9 mm at first pair of thecae) to a maximum width of 3.2 to 4.2 mm at about 1 cm above the sicula. Distally, the rhabdosome width may diminish slightly or be maintained. The sicula is about 1.0 mm long, and its apex is at or slightly above the level of the aperture of $th2^1$. It bears a short virgella and at least one antivirgellar spine, although they are not always preserved. $th1^1$ bears a short, mesial spine. The rhabdosome is aseptate. The thecae are moderately geniculate, with horizontal apertural margins, but their apparent shape depends on preservation. In some specimens (fig. 12*G*), they appear amplexograptid; in others (fig. 12*A*), they appear to be orthograptid. The thecae are spaced 6½ to 8 in 5 mm proximally and 10 to 13 per centimeter distally.

Discussion.—Most specimens are preserved as pyritized internal molds, and all have undergone some degree of tectonic distortion; the given dimensions reflect that distortion.

The Ledbetter specimens resemble *D. ingens wellingtonensis* in general size and shape, especially in their narrow proximal ends and relatively wide "midsections." *D. ingens ingens* T.S. Hall is a much wider form (6-7 mm).

Horizon and locality.—Ledbetter Slate, collection 65WCn 102, *C. spiniferus* Zone. *D. i. wellingtonensis* is found with *D. i. ingens* in the Lower Eastonian of Victoria, Australia (Harris and Thomas, 1955), and in the Mallongulli Formation of New South Wales, Australia (Moors, 1970).

Genus *Amplexograptus* Elles and Wood, 1907
Amplexograptus sp.

Figures 11*A-C*

Description.—The rhabdosome is as much as 5 cm long and increases gradually in width from 0.7 mm at the aperture of $th1^1$ to about 1.2 mm wide at the aperture of $th5^1$ and to a maximum distal width of 2.5 to 3.8 mm. The maximum width is attained at about 2.3 cm above the proximal end and is thereafter maintained or decreases slightly. The sicula has not been observed, but it bears a short virgella and at least one antivirgellar spine; $th1^1$ has a short mesial spine. The thecae are gently sigmoidal proximally, becoming straighter distally; their apertural margins are generally straight and perpendicular to the axis of the rhabdosome. They number five to six in 5 mm proximally and eight per centimeter distally.

Discussion.—The above description is of specimens that have been stretched longitudinally. They are assigned to the genus *Amplexograptus* because they have aseptate rhabdosomes and amplexograptid proximal ends having a virgella, antivirgellar spine(s), and a mesial spine on $th1^1$. The amplexograptid nature of their thecae has been obscured by tectonic distortion.

Horizon and locality.—Ledbetter Slate, collection 65WCn 102, *C. spiniferus* Zone.

Genus *Climacograptus* Hall, 1865
Climacograptus cf. *C. baragwanathi* T.S. Hall

Figures 10*E*, *K*, *M*

cf. *Climacograptus baragwanathi* T.S. Hall, 1902, p. 277, pl. 34, fig. 6. Harris and Thomas, 1955, p. 38, figs. 1–3. Thomas, 1960, pl. 9, figs. 122a, b. VandenBerg and Stewart, 1983, p. 41, fig. 24.

Description.—The rhabdosome is long and slender, as much as 4 cm long, 0.5 mm wide proximally, and 1.5 mm wide distally in specimens that have undergone lengthwise tectonic stretching. Thecae are difficult to distinguish but appear to have very small apertural excavations and relatively long supragenicular walls; they number about eight per centimeter in lengthwise-stretched specimens. The proximal end is adorned with a conspicuous network of anastomosing fibers that, in one specimen (fig. 10*M*), branches off from a short virgella but, in most of the others (figs. 10*E*, *K*), appears to arise directly from the rhabdosome itself.

Discussion.—The Washington specimens are very poorly preserved and tectonically stretched. Clearly, they are allied with, if not identical to, *C. baragwanathi* because of their peculiar proximal networks. The difference between their dimensions and those of *C. baragwanathi* (about 3 cm long, about 2 mm wide distally, 12–9½ thecae per centimeter) is probably caused by tectonic distortion. However, according to Harris and Thomas (1955, p. 38), the proximal network of *baragwanathi* always arises from the end of the virgella.

Horizon and locality.—Ledbetter Slate, collection 65WCn 102, *C. spiniferus* Zone. *C. baragwanathi* is restricted to the zone of the same name (Eastonian Ea2) in Victoria, Australia (VandenBerg, 1981; VandenBerg and Stewart, 1983), and possibly has been found in Nevada (Riva, 1970, p. 2712).

Climacograptus sp.

Figure 10*L*

Description.—The illustrated specimen is 4.5 mm long and 0.4 to 0.5 mm wide. It has been tectonically stretched lengthwise and consequently is longer and narrower than an undeformed specimen would be. It has four thecae in 3 mm (about 13 per centimeter).

Discussion.—The specimen shown (fig. 10*L*) closely resembles a specimen of *C. brevis strictus* (Ruedemann) illustrated by Ruedemann (1908, p. 420, fig. 381) and Riva (1974, text fig. 5h) and said to be badly deformed by lateral compression. In the absence of undeformed specimens, it is difficult to determine the identity of this form.

Horizon and locality.—Ledbetter Slate, collection 65WCn 102, *C. spiniferus* Zone.

Genus *Orthograptus* Lapworth, 1873
Orthograptus quadrimucronatus (Hall) sensu lato

Figure 11*H*

Graptolithus quadrimucronatus Hall, 1865, p. 144–146, pl. 13, figs. 1–10.

Diplograptus (*Orthograptus*) *quadrimucronatus* (Hall). Elles and Wood, 1901–18, p. 223–224, pl. 28, figs. 1a–d, text figs. 145a–f. Harris and Thomas, 1955, p. 37, fig. 37.

Glossograptus quadrimucronatus (Hall). Ruedemann, 1947, p. 452–454, pl. 78, figs. 1–5, pl. 81, figs. 29–32.

Orthograptus quadrimucronatus (Hall). Berry, 1960, p. 91, pl. 18, fig. 1. Toghill, 1970, p. 23, pl. 13, figs. 10, 11. Williams, 1982, p. 247–248, figs. 12a–d. Koren' and others, 1983, p. 152–153, pl. 45, figs. 1, 2, text figs. 58a–d. Lenz and Chen, 1985, pl. 3, figs. 19–21. Finney, 1986, p. 453, figs. 8B, C, 12E.

Diagnosis.—Rhabdosome up to 7 cm long, 1.0 to 1.2 mm wide proximally, and up to 3.0 mm wide distally. Thecae 14 to 8 per centimeter, with paired apertural spines, except for first two thecae, which have a single apertural spine each.

Discussion.—All of the Ledbetter specimens are tectonically distorted, but they exhibit the same general size and characteristically spinose thecae that *O. quadrimucronatus* does. They are generally much longer than *O. pageanus pageanus* Lapworth, a similarly spinose form that is shorter and wider than *O. quadrimucronatus* and has more thecae per centimeter.

Horizon and locality.—Ledbetter Slate, collections 65WCn 102 and B-462, *C. spiniferus* Zone. *O. quadrimucronatus* has been reported from the *quadrimucronatus* Zone in the northern Canadian Cordillera (Lenz and Chen, 1985) and in the northeastern U.S.S.R. (Koren' and others, 1983); from the *C. tubuliferus* Zone and passage beds at Trail Creek, Idaho (Carter and Churkin, 1977); from the *quadrimucronatus* Zone in Texas (Berry, 1960); from the Eastonian of Victoria, Australia (Harris and Thomas, 1955; VandenBerg, 1981; VandenBerg and Stewart, 1983); from eastern Canada

(Hall, 1865); from New York State (Ruedemann, 1947); from the zones of *O. amplexicaulis* and *C. tubuliferus* in Arkansas and Oklahoma (Finney, 1986); and from the Zones of *Dicranograptus clingani* and *P. linearis* (Hartfell Shales) in Scotland (Elles and Wood, 1901-18; Toghill, 1970; Williams, 1982).

Orthograptus quadrimucronatus spinigerus (Lapworth)

Figures 11*F, G, I*

Diplograptus quadrimucronatus var. *spinigerus* Lapworth, 1876, pl. 2, fig. 43.

Diplograptus (*Orthograptus*) *quadrimucronatus* var. *spinigerus* Lapworth. Elles and Wood, 1901-18, p. 225, pl. 28, figs. 2a-d.

Glossograptus quadrimucronatus (Hall) var. *spinigerus* (Lapworth). Ruedemann and Decker, 1934, p. 318-319, pl. 42, figs. 9-10a. Ruedemann, 1947, p. 457, pl. 79, figs. 14-15.

Orthograptus quadrimucronatus spinigerus (Lapworth). Williams, 1982, p. 248, fig. 12e.

Diagnosis.—Rhabdosome same as that of *O. quadrimucronatus* s.s. except for abnormally long (about 5 mm or more) apertural spines on the ninth or tenth (occasionally the fourteenth) pair of thecae.

Discussion.—*O. q. inequispinosus* (Ruedemann) has longer spines on the fifth, sixth, or seventh pair of thecae; *O. q. spinifer* T.S. Hall has longer spines on two, three, or four thecae at varying distances (3-7 mm) from the proximal end. The Ledbetter specimens have their extra-long spines on the eight, ninth, or tenth (occasionally the twelfth) pair of thecae, and, in some cases (fig. 11*F*), two pairs of thecae have longer spines.

Horizon and locality.—Ledbetter Slate, collections 65WCn 102 and B-88(?), *C. spiniferus* Zone; the *P. linearis* Zone (Hartfell Shales) in Scotland (Elles and Wood, 1901-18; Williams, 1982); the Utica Shale in New York (Ruedemann, 1947); the Viola Springs Formation in Oklahoma (Ruedemann and Decker, 1934).

Orthograptus n.sp.

Figures 6*G, I*

Description.—The rhabdosome is only about 10 mm long (9.0-14.5 mm) and relatively broad. It widens extremely rapidly from about 1.4 mm at the first pair of thecae to a maximum width of 2.6 to 3.0 mm at the fifth or sixth pair of thecae; the width is thereafter maintained or decreases slightly towards the distal end (fig. 6*I*). The thecae are spaced 6 to 6½ in 5 mm proximally and 10 to 11 per centimeter distally. They appear to be of the orthograptid type, with nearly horizontal apertures that do not project much from the ventral margins of the rhabdosome. In one specimen (fig. 6*G*), the periderm thins distally, so that the thickened apertural margins and lists appear almost retiolitid. The sicula has not been observed, but a very short virgella is present.

Discussion.—This form is distinguished by its broad and blunt proximal end. It resembles *O. calcaratus priscus* Elles and Wood in this respect but is not nearly as long or as wide, and it lacks apertural spines on $th1^1$ and $th1^2$. It has not been named, because only three specimens are present in the collection.

Horizon and locality.—Ledbetter Slate, collection B-458b, *D.? decoratus* Zone.

Graptoloid of unknown affinity
Genus and species indeterminate

Figure 5*F*

Description.—The biserial rhabdosome is 15.6 mm long and widens rapidly from an initial width of 1.1 mm to a maximum of 2.0 mm at about the third pair of thecae. This width is maintained until about the eleventh pair of thecae, after which the rhabdosome begins to narrow slightly. The thecae are spaced 12 to 11 per centimeter. They appear, in this flattened specimen, to have straight or slightly concave free ventral walls that are inclined to the rhabdosome axis at about 45° to 50° in the proximal portion of the rhabdosome and at about 35° distally. The apertural margin is everted and convex in outline. The sicula has not been observed.

Discussion.—This enigmatic form somewhat resembles Cooper's (1979) Graptoloid Genus 1 sp. 3 but is much narrower than that form, and its thecae are less inclined to the rhabdosome axis. It also resembles the genus *Exigraptus* Mu and some species of *Cryptograptus*, but its thecal apertures are not nearly as denticulate. More and better preserved specimens are needed before the true nature and affinity of this form can be determined.

Horizon and locality.—Metaline Limestone, collection D913-CO, *P. tentaculatus* Zone.

REFERENCES CITED

Beavis, F.C., and Beavis, S., 1974, The Victorian isograptids and isograptid-like graptoloids: Proceedings of the Royal Society of Victoria, v. 86, pt. 2, p. 175-213.

Benson, W.N., Keble, R.A., King, L.C., and McKee, J.T., 1936, The Ordovician graptolites of north-west Nelson, N.Z., second paper, *with notes on* Other Ordovician fossils: Transactions of the Royal Society of New Zealand, v. 65, pt. 4, p. 357-382.

Bergström, S.M., and Mitchell, C.E., 1986, The graptolite correlation of the North American Upper Ordovician standard: Lethaia, v. 19, p. 247-266.

Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Bureau of Economic Geology Publication 6005, 179 p., 20 pls.
——— 1964, The Middle Ordovician of the Oslo region, Norway; graptolites of the Ogygiocaris series: Norsk Geologisk Tidsskrift, v. 44, no. 1, p. 61–170, pls. 1–16.
Bulman, O.M.B., 1970, Treatise on invertebrate paleontology, pt. V, Graptolithina (2d ed.): Boulder, Colo., Geological Society of America, 163 p.
Bulman, O.M.B., and Cowie, C.M., 1962, On the occurrence of *Kinnegraptus* Skoglund in Norway: Norsk Geologisk Tidsskrift, v. 42, no. 3, p. 253–260, 1 pl.
Carter, C., and Churkin, M., Jr., 1977, Ordovician and Silurian graptolite succession in the Trail Creek area, central Idaho—A graptolite zone reference section: U.S. Geological Survey Professional Paper 1020, 37 p., 7 pls.
Carter, C., and Tailleur, I.L., 1984, Ordovician graptolites from the Baird Mountains, western Brooks Range, Alaska: Journal of Paleontology, v. 58, no. 1, p. 40–57.
Cooper, R.A., 1973, Taxonomy and evolution of *Isograptus* Moberg in Australasia: Palaeontology, v. 16, pt. 1, p. 45–115.
——— 1979, Ordovician geology and graptolite faunas of the Aorangi Mine area, north-west Nelson, New Zealand: New Zealand Geological Survey Paleontological Bulletin 47, 127 p., 19 pls.
Cooper, R.A., and Fortey, R.A., 1982, The Ordovician graptolites of Spitzbergen: Bulletin of the British Museum (Natural History), Geology, v. 36, no. 3, p. 157–302, pls. 1–6.
Cooper, R.A., and McLaurin, A.N., 1974, *Apiograptus* gen. nov. and the origin of the biserial graptoloid rhabdosome, *in* Rickards, R.B., Jackson, D.E., and Hughes, C.P., eds., Graptolite studies in honour of O.M.B. Bulman: Special Papers in Palaeontology, no. 13, p. 75–85.
Cooper, R.A., and Ni Yunan, 1986, Taxonomy, phylogeny, and variability of *Pseudisograptus* Beavis: Palaeontology, v. 29, pt. 2, p. 313–363, pls. 24–27.
Dings, M.G., and Whitebread, D.H., 1965, Geology and ore deposits of the Metaline zinc-lead district, Pend Oreille County, Washington: U.S. Geological Survey Professional Paper 489, 109 p., 6 pls.
Elles, G.L., and Wood, E.M.R., 1901–18, A monograph of British graptolites: London, Palaeontographical Society of London, 526 p., 52 pls.
Emmons, E., 1855, American geology, v. 1, pt. 2: Albany, N.Y., p. 1–251.
Finney, S.C., 1978, The affinities of *Isograptus*, *Glossograptus*, *Cryptograptus*, *Corynoides*, and allied graptolites: Acta Palaeontologica Polonica, v. 23, no. 4, p. 481–495.
——— 1980, Thamnograptid, dichograptid and abrograptid graptolites from the Middle Ordovican Athens Shale of Alabama: Journal of Paleontology, v. 54, no. 6, p. 1184–1208.
——— 1986, Graptolite biofacies and correlation of eustatic, subsidence, and tectonic events in the Middle to Upper Ordovician of North America: Palaios, v. 1, p. 435–461.
Finney, S.C., and Bergström, S.M., 1986, Biostratigraphy of the Ordovician *Nemagraptus gracilis* Zone, *in* Hughes, C.P., and Rickards, R.B., eds., Palaeoecology and biostratigraphy of graptolites: Geological Society [London] Special Publication 20, p. 47–59.
Greenman, C., Chatterton, B.D.E., Boucot, A.J., and Berry, W.B.N., 1977, Coarse Silurian(?) and Devonian detrital rocks in northeastern Washington: Evidence of Silurian(?) and Devonian tectonic activity, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States; Pacific Coast Paleogeography Symposium 1, Bakersfield, CA: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 467–479.
Hall, J., 1847, Paleontology of New York, v. 1 (containing descriptions of the organic remains of the lower division of the New York System): Albany, N.Y., 338 p., 33 pls.
——— 1859, Natural history of New York, v. 3, Paleontology (containing descriptions and figures of the organic remains of the lower Helderberg Group and the Oriskany Sandstone): Albany, N.Y., Geological Survey of New York, 532 p.
——— 1865, Graptolites of the Quebec Group, *in* Figures and descriptions of Canadian organic remains, Decade II: Ottawa, Ont., Geological Survey of Canada, p. 1–151, pls. A, B, 1–21.
Hall, T.S., 1902, Report on graptolites: Geological Survey of Victoria Records, v. 1, pt. 1, p. 266–278, pl. 34.
——— 1905, Victorian graptolites, pt. III, From near Mount Wellington: Proceedings of the Royal Society of Victoria, v. 18 (new series), pt. 1, p. 20–24, pl. 6.
Harris, W.J., 1916, The palaeontological sequence in the Castlemaine district: Proceedings of the Royal Society of Victoria, v. 29, p. 50–74.
——— 1924, Victorian graptolites (new series), pt. I: Proceedings of the Royal Society of Victoria, v. 36 (new series), pt. II, p. 92–106, pls. 7, 8.
——— 1933, *Isograptus caduceus* and its allies in Victoria: Proceedings of the Royal Society of Victoria, v. 46 (new series), pt. 1, p. 79–114.
Harris, W.J., and Thomas D.E., 1935, Victorian graptolites (new series), pt. III: Proceedings of the Royal Society of Victoria, v. 47 (new series), pt. II, p. 288–313.
——— 1955, Victorian graptolites, pt. XIII, Graptolites from the Wellington River, pt. 1: Mining and Geological Journal of Victoria, v. 5, no. 6, p. 35–45, pls. 1, 2.
Holm, G., 1881, Bidrag till Kännedomen om Skandinaviens Graptoliter, I, *Pterograptus*, ett nytt graptolitslägte: Öfversight af Svenska Vetenskaps-Akademiens Förhandlingar 1881, v. 38, no. 4 (1882), p. 71–83.
Hopkinson, J., 1871, On *Dicellograpsus*, a new genus of graptolites: Geological Magazine, v. 8, p. 20–26, pl. 1.
Jiao Xindong, 1977, *Kalpinograptus*, a new graptolite from the Saergan Formation in Kalpin of Xinjiang: Acta Palaeontologica Sinica, v. 16, no. 2, p. 287–292.
Koren', T.N., Oradovskaya, M.M., Pylma, L.J., Sobolevskaya, R.F., and Chugaeva, M.N., 1983, The Ordovician and Silurian boundary in the northeast of the USSR: Leningrad, Nauka, 205 p. [in Russian].
Lapworth, C., 1876, The Silurian System in the south of Scotland, *in* Armstrong, J., Young, J., and Robertson,

D., eds., Catalogue of the western Scottish fossils: Glasgow, Blackie, 164 p., 4 pls.

Lenz, A.C., 1979, Llandoverian graptolite zonation in the northern Canadian Cordillera: Acta Palaeontologica Polonica, v. 24, no. 1, p. 137–154.

Lenz, A.C., and Chen Xu, 1985, Middle to Upper Ordovician graptolite biostratigraphy of Peel River and other areas of the northern Canadian Cordillera: Canadian Journal of Earth Sciences, v. 22, no. 2, p. 227–239.

Lenz, A.C., and Jackson, D.E., 1986, Arenig and Llanvirn graptolite biostratigraphy, Canadian Cordillera, *in* Hughes, C.P., and Rickards, R.B., eds., Palaeoecology and biostratigraphy of graptolites: Geological Society (London) Special Publication 20, p. 27–45.

Moors, H.T., 1970, Ordovician graptolites from the Cliefden Caves area, Mandurama, N.S.W., with a re-appraisal of their stratigraphic significance: Proceedings of the Royal Society of Victoria, v. 83, pt. 2, p. 253–287.

Mu Enzhi, Ge Meiyu, Chen Xu, Ni Yunan, and Lin Yaokun, 1979, Lower Ordovician graptolites of southwest China: Palaeontologia Sinica, no. 156 (new series B, no. 13), 192 p., 48 pls.

Park, C.F., Jr., and Cannon, R.S., Jr., 1943, Geology and ore deposits of the Metaline quadrangle, Washington: U.S. Geological Survey Professional Paper 202, 81 p., 34 pls.

Rigby, J., 1986, A critique of graptolite classification, and a revision of the suborders Diplograptina and Monograptina, *in* Hughes, C.P., and Rickards, R.B., eds, Palaeoecology and biostratigraphy of graptolites: Geological Society (London) Special Publication 20, p. 1–12.

Riva, J., 1970, Thrusted Paleozoic rocks in the northern and central HD Range, northeastern Nevada: Geological Society of America Bulletin, v. 81, p. 2689–2716.

——— 1974, A revision of some Ordovician graptolites of eastern North America: Palaeontology, v. 17, pt. 1, p. 1–40, pls. 1–2.

Ross, R.J., Jr., and Berry, W.B.N., 1963, Ordovician graptolites of the Basin Ranges in California, Nevada, Utah, and Idaho: U.S. Geological Survey Bulletin 1134, 177 p., 13 pls.

Ruedemann, R., 1908, Graptolites of New York, pt. 2: New York State Museum Memoir 11, 583 p., 31 pls.

——— 1947, Graptolites of North America: Geological Society of America Memoir 19, 652 p., 92 pls.

Ruedemann, R., and Decker, C.E., 1934, The graptolites of the Viola Limestone: Journal of Paleontology, v. 8, no. 3, p. 303–327, pls. 40–43.

Skevington, D., 1965, Graptolites from the Ontikan Limestones (Ordovician) of Öland, Sweden, pt. II, Graptoloidea and Graptovermida: Bulletin of the Geological Institute of the University of Uppsala, v. 43, p. 1–74.

Skoglund, R., 1961, *Kinnegraptus*, a new graptolite genus from the Lower *Didymograptus* Shale of Västergötland, central Sweden: Bulletin of the Geologic Institute of the University of Uppsala, v. 40, p. 389–400, pl. 1.

Skwarko, S.K., 1962, Graptolites of Cobb River–Mount Arthur area, north-west Nelson, New Zealand: Transactions of the Royal Society of New Zealand, v. 1, no. 15, p. 216–247.

Snook, J.R., Lucas, H.E., and Abrams, M.J., 1981, A cross section of a Nevada-style thrust in northeast Washington: Washington Division of Geology and Earth Resources Report of Investigations 25, 9 p.

Thomas, D.E., 1960, The zonal distribution of Australian graptolites: Journal and Proceedings of the Royal Society of New South Wales, v. 94, p. 1–58.

Toghill, P., 1970, Highest Ordovician (Hartfell Shales) graptolite faunas from the Moffat area, south Scotland: Bulletin of the British Museum (Natural History), Geology, v. 19, no. 1, p. 1–26, 16 pls.

VandenBerg, A.H.M., 1981, Victorian stages and graptolite zones, *in* Webby, B.D., ed., The Ordovician System in Australia, New Zealand, and Antarctica: Correlation chart and explanatory notes: International Union of Geological Sciences Publishing Co., p. 2–7, fig. 2.

VandenBerg, A.H.M., and Stewart, I.R., 1983, Excursion to Devilbend Quarry and Enoch's Point: Nomen Nudum, vol. 12, p. 35–52.

Wang Xiao-feng, and Jin Yu-qin, eds., 1977, Handbook of paleontology of central-south China, pt. 1, Early Paleozoic: Beijing, Geologic Press, 470 p., 116 pls. [in Chinese].

Williams, S.H., 1982, Upper Ordovician graptolites from the top lower Hartfell Shale Formation (*D. clingani* and *P. linearis* Zones) near Moffat, southern Scotland: Philosophical Transactions of the Royal Society of Edinburgh, v. 72, p. 229–255.

Yates, R.G., 1970, Geologic background of the Metaline and Northport mining districts, Washington, *in* Weissenborn, A.E., Lead-zinc deposits in the Kootenay Arc, northeastern Washington and adjacent British Columbia: Washington Division of Mines and Geology Bulletin 61, p. 17–39.

APPENDIX

Listed below, in biostratigraphic order from oldest to youngest, are the fossil localities that are included in this study and their corresponding faunal lists. All are from the Ledbetter Slate except as noted. Almost all are shown in plate 1.

Collection: 2178-CO (56WDu 3)
Location: Leadpoint 7.5-minute quadrangle, NE¼, NE¼, NE¼, sec. 30, T. 40 N., R. 42 E.; Iroquois Mine and along road loading to adit
Collected by: J.T. Dutro and A.R. Palmer, 1956
Fossils: Masses of uniserial scraps—possibly didymograptids and (or) multibranched anisograptids
Age: Early Ordovician

Collection: 2179-CO (56WDu 4)
Location: Leadpoint 7.5-minute quadrangle, NE¼, NW¼, sec. 20, T. 40 N., R. 42 E.; along Terry Trail about 70 ft north of the Metaline-Ledbetter contact, eastern site
Collected by: J.T. Dutro, A.R. Palmer, and R.G. Yates, 1956
Fossils: *Caryocaris*? sp.
Multibranched graptolites of indeterminate genus
Age: Early Ordovician

Collection: 2180–CO (56WDu 5)
Location: Leadpoint 7.5-minute quadrangle, NE¼, NW¼, sec. 20, T. 40 N., R. 42 E.; on Terry Trail, about 520 ft north of the Metaline-Ledbetter contact, eastern site
Collected by: J.T. Dutro and A.R. Palmer, 1956
Fossils: Anisograptid? fragments of indeterminate genera
Age: Early Ordovician

Collection: D508–CO
Location: Leadpoint 7.5-minute quadrangle, northeastern corner of sec. 30, T. 40 N., R. 42 E.; from talus at portal of Iroquois Mine and from adit of same, 300 ft in from portal; probable that all specimens come from same 100 ft of beds
Collected by: R.G. Yates, date unknown
Fossils: Masses of uniserial scraps—possibly didymograptids and (or) multibranched anisograptids
Age: Early Ordovician

Collection: D1450–CO (PC–64–1D)
Location: Inchelium 15-minute quadrangle, center, SE¼, sec. 18, T. 33 N., R. 38 E.; on western side of ridge crest, altitude 3,800 ft
Collected by: A.B. Campbell, 1964
Fossils: *Tetragraptus* cf. *T. acclinans* Keble
T. cf. *T. serra* (Brongniart)
Phyllograptus? sp.
Age and comments: Possibly the Zones of *Tetragraptus approximatus* and *T. fruticosus* (early Arenigian). Specimens very badly stretched, poorly preserved.

Collection: 1071 (MD–51–5)
Locations: Leadpoint 7.5-minute quadrangle, sec. 30, T. 40 N., R. 42 E.; at Iroquois Mine, along main adit, approximately 120 ft southeast of portal
Collected by: M. Klepper, A.E. Weissenborn, and W. Puffet, 1951
Fossils: Large dendroid rhabdosome
Large anisograptid(?) rhabdosome
Age: Early Ordovician

Collection: B–458a (37–P–176)
Location: Boundary Dam 7.5-minute quadrangle, sec. 16, T. 39 N., R. 43 E.; river bank, western side of Pend Oreille River, northeast of (old) Pend Oreille Mine
Collected by: C.F. Park, 1937
Fossils: *Isograptus victoriae divergens* Harris (fig. 3*J*)
Pseudisograptus dumosus (Harris) form B of Cooper (1973) (figs. 3*G*, *I*)
P. manubriatus koi Cooper and Ni (figs. 3*A*, *H*)
Didymograptus cf. *D. v-deflexus* Harris (fig. 2*B*)
D. (*Didymograptellus*) sp. (fig. 2*F*)
D. sp. (extensiform)
Tetragraptus amii Elles and Wood (fig. 2*C*)
?*Apiograptus* cf. *A. crudus* (Harris and Thomas) (fig. 3*C*)
Phyllograptus? sp. (fig. 2*E*)
Age and comments: *Oncograptus* Zone (Yapeenian; late Arenigian). Reported by Park and Cannon (1943, p. 20). Collection B–458 was "picked up at several horizons in a series of vertical strata several hundred feet across." The exposure is accessible at extreme low-water stages only. Josiah Bridge recognized two distinct faunas and designated them B–458a (Deepkill fauna) and B–458b (Normanskill fauna). Actually, B–458a is from the *Oncograptus* Zone, B–458b is from the *D.*? *decoratus* Zone, and a single slab of B–458b, renumbered herein as B–458c, is from the *C. spiniferus* Zone.

Collection: D354–CO
Location: Boundary 7.5-minute quadrangle, NE¼, sec. 23, T. 39 N., R. 40 E.; from adit level of Scandia Mine within 30 ft of contact with Metaline Limestone
Collected by: R.G. Yates, 1956
Fossils: *Isograptus victoriae divergens* Harris (fig. 3*L*)
Isograptus sp. (fig. 3*B*)
Pseudisograptus dumosus (Harris) (figs. 3*D*, *K*)
P. manubriatus harrisi Cooper and Ni (figs. 3*E*, *F*)
Cardiograptus morsus Harris and Keble (fig. 2*H*)
Didymograptus v-deflexus Harris (fig. 2*D*)
Didymograptus sp. (declined form)
Xiphograptus sp. (fig. 2*A*)
Tetragraptus cf. *T. bigsbyi* (Hall) (fig. 2*G*)
Phyllograptus noblis Harris and Keble
Pseudotrigonograptus sp.
Caryocaris sp.
Age: *Oncograptus* Zone

Collection: D1450a
Location: Inchelium 15-minute quadrangle, NW¼, SE¼, sec. 18, T. 33 N., R. 38 E.
Collected by: J.R. Snook (Eastern Washington University), early 1970's(?)
Fossils: *Isograptus victoriae* cf. subsp. *divergens* Harris
Pseudisograptus manubriatus (T.S. Hall)
Didymograptus cf. *D. v-deflexus* Harris
Didymograptus? sp.
Cardiograptus cf. *C. morsus* Harris and Keble
Pseudotrigonograptus sp.
Age and comments: *Oncograptus* Zone. Reported by Snook and others (1981, p. 6).

Collection: 913–CO
Location: Boundary Dam 7.5-minute quadrangle, sec. 15, T. 39 N., R. 43 E.; at 1,700-ft level of Pend Oreille Mine (eastern side)
Collected by: A.E. Weissenborn, 1961
Unit: From a shale lens in Metaline Limestone about 40 ft below the Ledbetter-Metaline contact
Fossils: *Isograptus caduceus australis* Cooper (figs. 4*J*, *K*)

Pseudisograptus? aff. *P. manubriatus koi* Cooper and Ni (figs. 4*L*, *M*)
Loganograptus logani logani (Hall) (fig. 4*B*)
Tetragraptus pendens liber Carter (fig. 4*A*)
T. quadribrachiatus (Hall) (fig. 4*H*)
T. cf. *T. amii* Elles and Wood (fig. 4*I*)
Holmograptus cf. *H. lentus* (Törnquist) (figs. 4*C*, *D*)
Didymograptus cf. *D. cognatus* Harris and Thomas (fig. 4*E*)
Didymograptus sp. (fig. 4*F*)
Paraglossograptus tentaculatus (Hall) (fig. 5*A*)
Cryptograptus sp. (fig. 5*C*)
C.? *inutilus* (Hall) (figs. 5*D*, *E*)
Pseudotrigonograptus ensiformis (Hall)
Undulograptus? cf. *U.*? *intersitus* (Harris and Thomas) (fig. 5*B*)
Kinnegraptus? sp. (fig. 4*G*)
Biserial genus and species indet. (fig. 5*F*)
Caryocaris sp.

Age: *P. tentaculatus* Zone (early Darriwillian; Llanvirnian)

Collection: B-458b
Location: See B-458a (p. B25)
Fossils: *Didymograptus serratulus* (Hall) (fig. 6*N*)
Tetragraptus n.sp. (figs. 6*F*, *H*)
Pterograptus elegans Holm (= *Syndeograptus bridgei* Ruedemann) (figs. 6*B*, *C*, 7*A*–*C*)
Kalpinograptus ovatus (T.S. Hall) (= *Dicellograptus perspinosus* Ruedemann) (figs. 6*D*, *E*)
Glossograptus ciliatus Emmons (figs. 6*L*, *M*)
Cryptograptus schaeferi Lapworth (fig. 6*A*)
Glyptograptus euglyphus (Lapworth) (fig. 6*J*)
Orthograptus n.sp. (figs. 6*G*, *I*)
Climacograptus riddellensis Harris (fig. 6*K*)
Caryocaris sp.

Age and comments: *D.*? *decoratus* Zone (late Darriwillian; late Llanvirnian). Reported by Park and Cannon (1943, p. 21).

Collection: B-87 (36-P-22)
Location: Boundary Dam 7.5-minute quadrangle, sec. 16, T. 39 N., R. 43 E.; right side of entrance of main (Cascade) tunnel, 500-ft level of Pend Oreille Mine (western side)
Collected by: C.F. Park, 1936
Fossils: *Didymograptus* cf. *D. serratulus* (Hall)
Glossograptus ciliatus Emmons
Glyptograptus cf. *G. euglyphus* (Lapworth)
Retiolitid, possibly *Reteograptus* sp.
Caryocaris sp.

Age: *D.*? *decoratus* and *N. gracilis* Zones

Collection: B-459
Location: Boundary Dam 7.5-minute quadrangle, sec. 15, T. 39 N., R. 43 E.; eastern bank of Pend Oreille River north of Morning and Mammoth shaft
Collected by: C.F. Park, 1937
Fossils: *Nemagraptus gracilis* (Hall) (fig. 8*E*)
Azygograptus cf. *A. canadensis* Ruedemann (= *Didymograptus* n.sp. aff. *D. fasciculatus* Nicholson) of Park and Cannon (1943) (figs. 8*A*, *B*)
Thamnograptus capillaris (Emmons) (fig. 8*C*)
Dicellograptus sextans (Hall) (fig. 8*G*)
Glossograptus ciliatus Emmons (fig. 8*F*)
Cryptograptus cf. *C. tricornis* (Carruthers)
Glyptograptus euglyphus (Lapworth) (fig 8*D*)
Pseudoclimacograptus scharenbergi (Lapworth) (= *Climacograptus parvus* Hall of Park and Cannon (1943))
Reteograptus sp.
Caryocaris sp.

Age and comments: *N. gracilis* Subzone (early Caradocian). Reported by Park and Cannon (1943, p. 21).

Collection: 65WCn 91
Location: Boundary 7.5-minute quadrangle, NW¼, sec. 18, T. 39 N., R. 41 E.; southern side of Black Canyon
Collected by: M. Churkin, 1965
Fossils: *Nemagraptus gracilis* (Hall)
Nemagraptus sp.
Leptograptus sp.
Dicellograptus cf. *D. intortus* Lapworth
Dicellograptus spp.
Dicranograptus sp.
Glossograptus ciliatus Emmons
Cryptograptus sp.
Glyptograptus cf. *G. euglyphus* (Lapworth)
Orthograptus? cf. *O. calcaratus* subsp. indet.

Age and comments: *N. gracilis* Subzone. Specimens tectonically stretched.

Collection: 66Y-200
Location: Echo Valley 7.5-minute quadrangle, center of sec. 3, T. 37 N., R. 39 E.; near Leadville Mine, at sheared contact between the Metaline Limestone and the Ledbetter Slate, in lower 30 ft of slate
Collected by: R.G. Yates, 1966
Fossils: *Azygograptus* sp.
Didymograptus? sp.
Dicellograptus vagus Hadding
D. intortus Lapworth
Glossograptus ciliatus Emmons
Cryptograptus schaeferi Lapworth
Glyptograptus euglyphus (Lapworth)
Pseudoclimacograptus? sp.
Reteograptus geinitzianus Hall
Pseudotrigonograptus sp. (higher than usual for this genus)

Age: *N. gracilis* Subzone

Collection: B-90 (36-P-230)
Location: Boundary Dam 7.5-minute quadrangle, sec. 35, T. 40 N., R. 43 E.; mouth of Slate Creek
Collected by: C.F. Park, 1936
Fossils: *Dicellograptus* cf. *D. divaricatus salopiensis* Elles and Wood
Didymograptus sp.
Glossograptus sp.
Cryptograptus tricornis (Carruthers)

Orthograptus calcaratus cf. subsp. *acutus* Elles and Wood
Glyptograptus sp.

Age and comments: *N. gracilis* Subzone? Reported by Park and Cannon (1943, p. 21). Specimens tectonically stretched.

Collection: B–456

Location: Boundary Dam 7.5-minute quadrangle, SW¼, sec. 30, T. 40 N., R. 44 E.; mine prospect. (Label with fossils gives locality as "Halliday Trail Prospect dump, NW¼, sec. 31, T. 39 N., R. 43 E.," but the published locality is more than likely the correct one.)

Collected by: C.F. Park, 1937

Fossils: *Dicellograptus divaricatus divaricatus* (Hall)
D. cf. *D. divaricatus salopiensis* Elles and Wood
Dicranograptus cf. *D. contortus* Ruedemann
Dicranograptus sp.
Glossograptus cf. *G. ciliatus* Emmons
Cryptograptus tricornis (Carruthers)
Climacograptus bicornis bicornis (Hall)
Glyptograptus sp.
Orthograptus? cf. *O. calcaratus* sensu lato

Age and comments: *C. bicornis* Subzone (Caradocian). Reported by Park and Cannon (1943, p. 21). Specimens tectonically stretched.

Collection: D511–CO

Location: Leadpoint 7.5-minute quadrangle, sec. 3, T. 39 N., R. 41 E.; elevation 3,880 ft; S. 17° E., 2,600 ft from northwestern corner of section; about 150 ft above top of what is believed to be upper part of the Metaline Limestone

Collected by: R.G. Yates

Fossils: *Dicellograptus* aff. *D. intortus* Lapworth
Dicranograptus? sp. or *Dicellograptus*? sp. with crossing stipes
Climacograptus cf. *C. bicornis bicornis* (Hall)
Orthograptus? sp.

Age and comments: *C. bicornis* Subzone. Specimens stretched, very poorly preserved.

Collection: D543–CO

Location: Inchelium 15-minute quadrangle, NW¼, NE¼, sec. 24, T. 34 N., R. 37 E.; southern side of road, 2,800-ft attitude.

Collected by: A. Campbell, 1958

Fossils: *Dicranograptus* sp.
Dicellograptus sp.
Glossograptus ciliatus Emmons
Cryptograptus tricornis (Carruthers)
Climacograptus bicornis bicornis (Hall)
Orthograptus sp.

Age and comments: *C. bicornis* Subzone. Reported by Snook and others (1981, p. 6). Some of these fossils appear to be giant forms, apparently not affected by any tectonic distortion.

Collection: 65WCn 92

Location: Boundary 7.5-minute quadrangle, NE¼, sec. 13, T. 39 N., R. 40 E.; southern side of Black Canyon

Collected by: M. Churkin, 1965

Fossils: *Dicellograptus divaricatus salopiensis* Elles and Wood
Dicranograptus cf. *D. contortus* Ruedemann
D. cf. *D. nicholsoni nicholsoni* Hopkinson
Glossograptus sp.
Cryptograptus sp.
Nemagraptus gracilis (Hall)
Climacograptus bicornis bicornis (Hall)
C. bicornis tridentatus Lapworth
Orthograptus calcaratus subsp. indet.
Glyptograptus sp.
Hallograptus? sp.

Age and comments: *C. bicornis* Subzone. Specimens badly stretched.

Collection: 65WCn 102

Location: Boundary Dam 7.5-minute quadrangle, NW¼, sec. 3, T. 39 N., R. 43 E.; west of road south of Ledbetter Lake

Collected by: M. Churkin, 1965

Fossils: *Dicranograptus hians hians* T.S. Hall (fig. 9*L*)
D. nicholsoni nicholsoni Hopkinson (figs. 9*D*, *F*, *H*)
Dicellograptus flexuosus Lapworth (figs. 9*E*, *I*, *J*, *K*)
Cryptograptus insectiformis Ruedemann (fig. 10*C*)
Corynoides sp. (figs. 10*A*, *B*)
Climacograptus spiniferus spiniferus Ruedemann (figs. 10*G*, *N*)
C. caudatus Lapworth (fig. 10*J*)
C. cf. *C. baragwanathi* T.S. Hall (figs. 10*E*, *K*, *M*)
Climacograptus sp. (fig. 10*L*)
Orthograptus quadrimucronatus (Hall) sensu lato
O. quadrimucronatus spinigerus (Lapworth) (figs. 11*F*, *G*, *I*)
O. calcaratus tenuicornis Elles and Wood (fig. 11*D*)
Orthograptus? sp.
Pseudoclimacograptus sp. (fig. 10*I*)
Diplograptus cf. *D. ingens wellingtonensis* Harris and Thomas (figs. 12*A*–*G*)
Amplexograptus sp. (figs. 11*A*–*C*)
Neurograptus margaritatus (Lapworth) (fig. 10*F*)

Age and comments: *C. spiniferus* Zone. Specimens tetonically stretched; some pyritized.

Collection: B–86 (36–P–125)

Location: Boundary Dam 7.5-minute quadrangle, sec. 3, T. 39 N., R. 43 E.; on highway southwest of Ledbetter Lake

Collected by: C.F. Park, 1936

Fossils: *Dicranograptus* sp.
Climacograptus spiniferus spiniferus Ruedemann
Orthograptus calcaratus cf. subsp. *incisus* Lapworth
Orthograptus? sp.

Age and comments: *C. spiniferus* Zone. Reported by Park and Cannon (1943, p. 21).

Collection: B–88 (36–P–239)

Location: Metaline 7.5-minute quadrangle, sec. 32, T. 39 N.,

R. 43 E.; prospect dump 1 mi south of Bella May Mine
Collected by: C.F. Park, 1936
Fossils: *Dicranograptus* cf. *D. hians hians* T.S. Hall
Dicellograptus sp.
Leptograptus? sp.
Orthograptus calcaratus subsp. indet.
O.? cf. *O. amplexicaulis* (Hall)
?*O. quadrimucronatus spinigerus* (Lapworth)
Diplograptid with thickened virgula
Age and comments: *C. spiniferus* Zone. Reported by Park and Cannon (1943, p. 21). Specimens extremely distorted.

Collection: B-89 (36-P-229)
Location: Boundary Dam 7.5-minute quadrangle, west center, sec. 2, T. 39 N., R. 43 E.
Collected by: C.F. Park, 1936
Fossils: *Dicranograptus hians hians* T.S. Hall
Climacograptus spiniferus spiniferus Ruedemann
Orthograptus cf. *O. amplexicaulis* (Hall)
Glyptograptus? sp.
Age and comments: *C. spiniferus* Zone. Reported by Park and Cannon (1943, p. 21). Specimens tectonically stretched.

Collection: B-458C
Location See B-458a (p. B25)
Fossils: *Dicranograptus hians hians* T.S. Hall
Orthograptus calcaratus sensu lato and (or) *O. quadrimucronatus* (Hall)
Age and comments: *C. spiniferus* Zone. Specimens tectonically stretched.

Collection: B-462
Location: Boundary Dam 7.5-minute quadrangle, NW¼, sec. 10, T. 39 N., R. 43 E.; roadcut southwest of Ledbetter Lake
Collected by: R.S. Cannon, 1937
Fossils: *Dicranograptus hians hians* T.S. Hall (figs. 9*A*, *C*)
D. nicholsoni longibasalis Ruedemann and Decker (figs. 9*B*, *G*)
D. cf. *D. ramosus* (Hall)
Cryptograptus sp.
Corynoides calicularis Nicholson (fig. 10*D*)
Orthograptus calcaratus tenuicornis Elles and Wood (fig. 11*E*)
O. quadrimucronatus (Hall) sensu lato (fig. 11*H*)
O. cf. *O. amplexicaulis* (Hall)
Pseudoclimacograptus sp. (fig. 10*H*)
Glyptograptus sp.
Age and comments: *C. spiniferus* Zone. Reported by Park and Cannon (1943, p. 21)

Collection: D770-CO
Location: Hunters 15-minute quadrangle, W½, sec. 11, T. 30 N., R. 37 E.; 2,400- to 2,600-ft altitude, northern nose of hill 3197
Collected by: A.B. Campbell, 1960
Fossils: *Dicranograptus* sp.
Climacograptus spiniferus spiniferus Ruedemann
Orthograptus cf. *O. amplexicaulis* (Hall)
O. calcaratus subsp. indet.
O. cf. *O. quadrimucronatus* (Hall)
Age: *C. spiniferus* Zone

Collection: D1502-CO
Location: Boundary Dam 7.5-minute quadrangle, NW¼, sec. 3, T. 39 N., R. 43 E.; roadcut 0.25 mi southwest of Ledbetter Lake
Collected by: F.K. Miller and L.D. Clark, 1964
Fossils: *Dicranograptus hians hians* T.S. Hall
Orthograptus calcaratus tenuicornis Elles and Wood
O. cf. *O. quadrimucronatus* (Hall)
Indeterminate diplograptids
Age: *C. spiniferus* Zone

Collection: B-91 (36-P-231)
Location: Gypsy Peak 7.5-minute quadrangle, west center, sec. 12, T. 40 N., R. 44 E.; last trail fork to Bailey Hanson prospect
Collected by: C.F. Park, 1936
Fossils: *Glossograptus*? sp.
Some unidentifiable scraps
Age and comments: Approximately Middle Ordovician. Reported by Park and Cannon (1943, p. 21).

Collection: B-92 (36-P-232)
Location: Gypsy Peak 7.5-minute quadrangle, NE¼, sec. 22, T. 40 N., R. 44 E.; above switchback on road to Lead Hill Mine
Collected by: C.F. Park, 1936
Fossil: *Glyptograptus euglyphus* (Lapworth)
Age and comments: Approximately Middle Ordovician. Reported by Park and Cannon (1943, p. 21).

Collection: B-94
Location: Metaline Falls 7.5-minute quadrangle; Metaline Falls
Collected by: H. Mills, 1934
Fossils: *Orthograptus calcaratus* subsp. indet.
Climacograptus? sp.
Cryptograptus? sp.
Age and comments: Approximately Middle Ordovician. Specimens pyritized.

Collection: D510-CO
Location: Leadpoint 7.5-minute quadrangle, sec. 3, T. 39 N., R. 41 E.; elevation 3,440 ft, 2,600 ft S. 73° W. from northeastern corner of section. Within 100 ft of top of what is believed to be upper part of the Metaline Limestone.
Collected by: R.G. Yates, date unknown
Fossils: *Didymograptus*? sp.
Dicellograptus sp.
Orthograptus? sp.

Chapter C

An Early Middle Devonian Coral Faunule from the Needmore Shale in South-Central Pennsylvania and Adjacent Areas of West Virginia and Virginia

By WILLIAM A. OLIVER, JR.

U.S. GEOLOGICAL SURVEY BULLETIN 1860

Shorter Contributions to Paleontology and Stratigraphy

CONTENTS

PLATES

[Plates follow References cited]

FIGURES

TABLES

An Early Middle Devonian Coral Faunule from the Needmore Shale in South-Central Pennsylvania and Adjacent Areas of West Virginia and Virginia

By William A. Oliver, Jr.

Abstract

A small faunule of solitary rugose corals from the Needmore Shale (Onesquethaw age; probably early Eifelian) includes four species, three of which are described as new. Similarities between the Needmore corals and the corals of the Bois Blanc Formation and the Edgecliff Member of the Onondaga Limestone in New York and Ontario and the Río Cachirí Group of Venezuela are analyzed, but the ages of these stratigraphic units within the Emsian and Eifelian stages are still not precisely known.

INTRODUCTION

The problem of the position of the Lower-Middle Devonian boundary (Emsian-Eifelian stage boundary) in New York and the central Appalachians was recently reviewed by Kirchgasser and others (1985, p. 235–242). Briefly, the Eastern Americas Realm was isolated in Early and early Middle Devonian times, and the key fossils for recognition of the Lower-Middle boundary are lacking. In New York, the boundary is at or above the top of the Schoharie–Bois Blanc Formations and below the middle part of the Nedrow Member of the Onondaga Limestone (text fig. 1). The Edgecliff Member of the Onandaga Limestone and the lower part of the Nedrow Member can be either Emsian or Eifelian, although it seems most likely that the boundary is at the base of, or within, the Edgecliff Member.

Similar uncertainty pertains with respect to the ages of the Needmore Shale and of the rugose coral-bearing parts of the Río Cachirí Group in Venezuela. These questions are discussed in the following sections.

NEEDMORE SHALE

The Needmore Shale was originally named by Willard (1939, p. 149–150) for the calcareous shale between the Selinsgrove Limestone (above) and the Oriskany Group (below) in south-central Pennsylvania. Willard clearly understood it to be a facies of the Selinsgrove ("Beneath the Selinsgrove limestone and supplanting it southward . . .") and assigned both formations to the "Onondaga Group." Woodward (1943) extended the name Needmore to Maryland, Virginia, and West Virginia, including the area of this report. On the 1960 Geologic Map of Pennsylvania (Gray and others, 1960), the two units were mapped together as members of the Onondaga Formation. The most detailed lithostratigraphic studies of the Needmore Shale and related units in the area of present concern are by Dennison (1961, p. 19–25) and de Witt and Colton (1964, p. 40–42). Most of the corals described in this paper are from the area mapped by de Witt (1974). Recent correlation charts show the Needmore Shale as a member of the Onondaga Formation (Berg and others, 1983) and as a formation of the Onondaga Group (Patchen, 1985).

All of the above workers recognized the Needmore as, at least partly, a facies of the Selinsgrove Limestone and of the Huntersville Chert and considered this complex of rock units equivalent to the Schoharie–Bois Blanc Formations and the Onondaga Limestone of New York, which embrace most of the Onesquethaw Stage (see text fig. 1). These general correlations have long been accepted and are based on close overall faunal similarities, principally among the brachiopods. Willard (1939, p. 131–160) reviewed the history of work on the "Onondaga Group" and summarized arguments for the correlations with New York.

Significant new information on both age and correlation of the Needmore Shale resulted from goniatite studies by House (1978, p. 4–7, 25–26). He found two goniatite faunas in the Needmore: a lower *Agoniatites oliveri* assemblage and an upper *Foordites buttsi* assemblage. The latter occurs also in the upper half of

Manuscript approved for publication May 16, 1988.

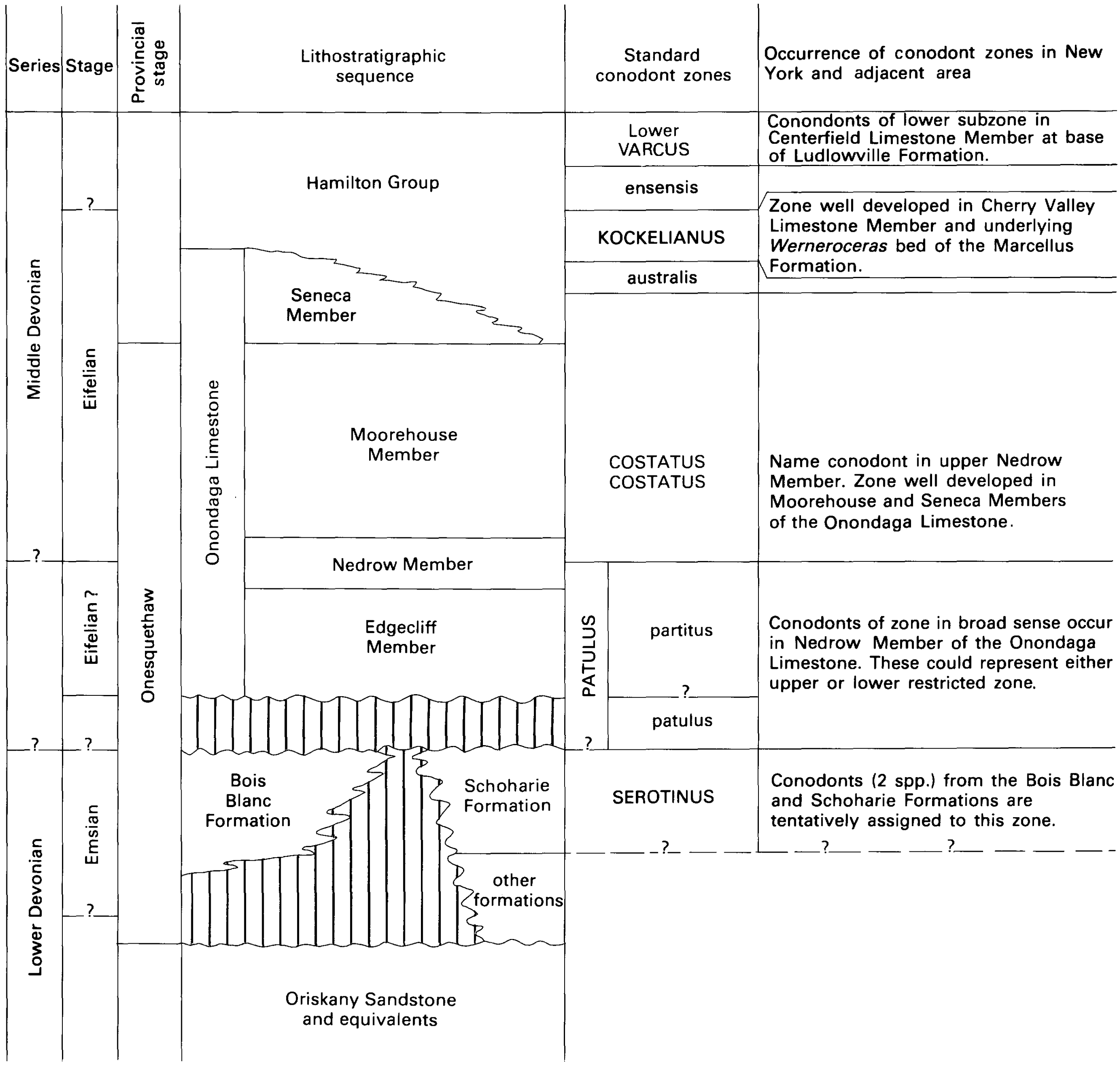


Figure 1. Emsian-Eifelian stratigraphy in New York. Only those terms necessary for understanding the text discussion are included. Conodont zones and annotations are extracted from Kirchgasser and others (1985, table 2). Zones set in capital letters have been recognized in New York; other standard zones (in lower case) are inserted in their proper sequence. By international agreement, the base of the Eifelian Stage and of the Middle Devonian Series is at the base of the *partitus* Zone (see Kirchgasser and others, 1985, p. 235, for discussion).

the Nedrow Member of the Onondaga Limestone in New York (House, 1978, p. 8) and provides a strong basis for correlating these units. The position of *Foordites* and the recognition of the *Polygnathus costatus costatus* conodont Zone in the upper Nedrow and younger parts of the Onondaga indicate that the base of the Eifelian Stage (the Lower-Middle Devonian boundary) is below this position (Kirchgasser and others, 1985, p. 237, 242). The lower (*Agoniatites*) assemblage has not been found in New York and could be either Emsian or Eifelian in age, although House (1978, p. 61–62) clearly considered an Eifelian age more likely.

The Needmore corals that are the subject of this paper (table 1) are not directly tied into the goniatite stratigraphy. In general, however, they come from the upper half of the formation. At the Hayfield, Va., locality (loc. 5, text fig. 2), they are associated with or are no more than a few meters below the *Foordites*

Table 1. Distribution and number of specimens of rugose corals at each of the five Needmore Shale localities mentioned in the text (see text fig. 2 and locality list)

[Locality 1, Hyndman, Pa.; locality 2, Lake Koon, Pa.; locality 3, Berkeley Springs, W.Va.; locality 4, Gainsboro, Va.; locality 5, Hayfield, Va.]

Genus	Number of specimens				
	Loc. 1	Loc. 2	Loc. 3	Loc. 4	Loc. 5
Briantelasma moorense n.sp.	40	1			1
Stereolasma fereplena n.sp.	4	5			6
Neaxon sp. A	1	1			
Enterolasma dutroi n.sp.			1	1	1

assemblage. At Gainsboro, Va. (loc. 4, text fig. 2), the single described coral seems to have been collected from between the two goniatite assemblages. At Berkeley Springs, W. Va. (loc. 3, text fig. 2), the single coral was collected from the uppermost part of the formation, well above known *Agoniatites*.

The positions of the goniatites are not known at either of the Pennsylvania localities (locs. 1, 2, text fig. 2). However, the Hyndman, Pa., corals are from the upper 12 m of the Needmore and are associated with *Ambocoelia umbonata* (Conrad) and *Longispina mucronata* (Hall), identified by J.T. Dutro, Jr. (personal communication, 1970), who considered them to be "most likely Onondaga" in age. The tabulate coral *Procteria*, at this locality, is also suggestive of Edgecliff or younger age. The Lake Koon, Pa., corals are from the uppermost part of the formation.

In summary, most of the corals seem to have been closely associated with the *Foordites* assemblage in the upper part of the Needmore and to be Eifelian in age. However, it is possible that the coral assemblage ranges through much of the Needmore and is Edgecliff (early Eifelian?) or even older, as well as younger Onondaga (Eifelian) in age.

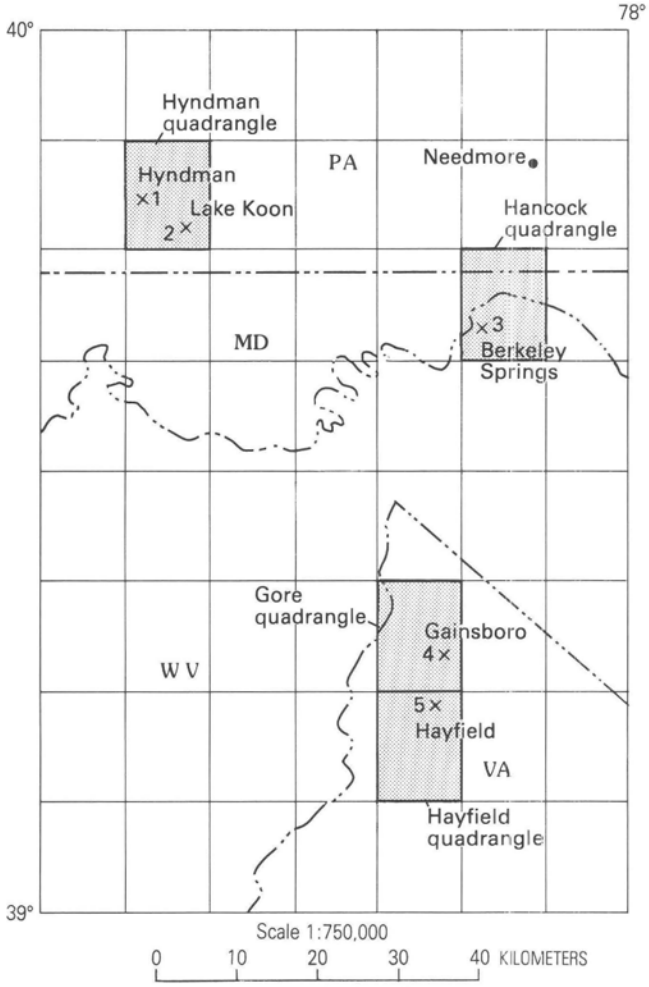


Figure 2. Localities of corals from the Needmore Shale. The grid lines mark the boundaries of standard 7½-minute topographic maps; quadrangles that include localities are outlined and named. Localities are numbered from north to south in table 1 and in the list of localities.

RÍO CACHIRÍ GROUP, VENEZUELA

Devonian corals from the Sierra de Perijá in northwestern Venezuela have been described by Weisbord (1926), Wells (1943), Scrutton (1973), and Oliver (1976). Scrutton's comprehensive work is the principal basis for my analyses of this fauna (Oliver, 1977, p. 118–119; this paper). Weisbord recognized that the corals showed the closest relationships to upper Lower and lower Middle Devonian species from the Eastern United States (Weisbord, 1926, p. 32), and all subsequent studies have strengthened this conclusion. Every genus known from the Venezuelan assemblage is also known from Eastern North America, and species-level similarities are impressive.

Table 2 lists the Río Cachirí genera of rugose corals, shows their known stratigraphic range in Eastern North America, and gives the stratigraphic position of the "most similar" Eastern North American species. The latter is a combination of Scrutton's (1973) comparisons and my own analysis. Table 2 and this discussion are a revision of an earlier work (Oliver, 1977, p. 118–119, table 11) and are based on the present study of the Needmore corals and additional knowledge of other Eastern North American corals (principally from New York).

Two conclusions can be drawn from table 2. First, *Hadrophyllum* sp. and *Stewartophyllum*? sp. should be separated from the rest of the corals. They are the only corals from the Caño del Oeste Formation (Scrutton, 1973, p. 230, table 1), which is thought to be the

Table 2. Genera from formations of the Río Cachirí Group, Venezuela, with age range in Eastern North America and age of most similar Eastern North American species

Formation[1]	Genus	Range in Eastern North America[2]	Age of most similar Eastern North American species
1	*Stereolasma*	2–6	Needmore
1	*Syringaxon*	2–6	–
1–2	*Heliophyllum*	3–6	Edgecliff to Hamilton.
1–2	*Heterophrentis*	1–6	Edgecliff
2	*Acinophyllum*	3–5	Edgecliff
2	*Bowenelasma*	3–4	Edgecliff
2	*Breviphrentis*	1–6	Edgecliff?
2	*Briantelasma*	1–4	Needmore
2?	*Cylindrophyllum*	3–5	Edgecliff
2	*Cystiphylloides*	3–6	Edgecliff to Hamilton.
3	*Hadrophyllum*	5	Upper Onondaga
3	*Stewartophyllum*?	5–6	Hamilton?

[1]Río Cachirí Group: 3, Caño del Oeste Formation; 2, Caño Grande Formation; 1, Caño Los Guineos Formation.

[2]6, Givetian; 5, Eifelian; 4, Edgecliff (Eifelian?); 3, Emsian; 2, Pragian; 1, Lochkovian.

youngest of the coral-bearing units in the Río Cachirí Group (Scrutton, 1973, p. 226–229). The two genera are the only ones whose known range in Eastern North America is wholly post-Edgecliff (table 2).

The remaining 10 genera from the Caño Grande and Caño Los Guineos Formations have various Eastern North American ranges, but all overlap in the Emsian (Schoharie–Bois Blanc) and Edgecliff interval. Species-level similarities favor the Edgecliff by a large margin (table 2). Two species are closest to Needmore species, and one has no known close analogue.

The second conclusion, then, is that the Venezuelan corals, except for the two youngest, are most similar to Edgecliff-age corals in Eastern North America. The most probable age of the Caño Grande corals is Edgecliff, probably early Eifelian (because of the Needmore relationships) but possibly late Emsian. Although the small Caño Los Guineos assemblage can be slightly older, as Scrutton (1973, fig. 3 and discussion) suggested, it falls into essentially the same age range.

LOCALITIES

The described corals are from five localities in south-central Pennsylvania, eastern West Virginia, and northern Virginia (text fig. 2). In this relatively small area, the maximum distance between any two of the sites is 75 km. The total thickness of the Needmore varies from some 40 m at the Virginia localities (Dennison, 1961, p. 18) to as much as 60 m in the Hyndman, Pa., area (de Witt, 1974). Table 1 shows the distribution of the corals at the five localities.

Locality 1. USGS 9005/9016–SD. 2.9 km south of Hyndman, Pa., on Route 96; Hyndman 7½-minute quadrangle. Collected from approximately 12 m below top of Needmore (estimated 60 m thick in this area). Initial collection by Wallace de Witt, Jr., U.S. Geological Survey (USGS).

Locality 2. USGS 9011/9015–SD. Lake Koon, north of Koon Dam; Hyndman 7½-minute quadrangle. Collected from near top of Needmore. Initial collection by Wallace de Witt, Jr., USGS.

Locality 3. USGS 11462–SD. Blair Ss. Quarry, north of Berkeley Springs, W. Va. Hancock 7½-minute quadrangle. Single specimen from upper 3 m of Needmore. Collected by J.T. Dutro, Jr., USGS.

Locality 4. USGS 6062–SD. Quarry 1 km northwest of Gainsboro, Va. Gore 7½-minute quadrangle. Single specimen from middle part of Needmore. Collected by W.A. Oliver, Jr., USGS.

Locality 5. American Museum of Natural History (AMNH) locality. Hayfield, Va., at intersection of U.S. 50 and Va. 600, collected on northern side of intersection on both eastern and western corners. Hayfield 7½-minute quadrangle. Collected by Niles Eldredge, AMNH. The *Foordites* goniatite assemblage is found on the eastern corner (M.R. House, personal communication, approximately 1970), so the corals are from the goniatite level to no more than 10 m lower.

Acknowledgments

Thin sections were prepared by William C. Pinckney, Jr., with his usual skill; photographs are by Haruo E. Mochizuki, Pinckney, and myself. Needmore corals were first called to my attention by Wallace de Witt, Jr., who also provided stratigraphic information for localities 1 and 2. Niles Eldredge of the American Museum of Natural History arranged the loan of specimens from locality 5 in 1974 and provided the field data; Melvin Hinkley, also of the American Museum, precipitated the final draft of the paper by requesting that the loaned specimens be returned in 1987. Other specimens were collected by J.T. Dutro, Jr., and myself. The manuscript was critically reviewed by de Witt and Dutro, to whom I give thanks for many improvements.

SYSTEMATIC PALEONTOLOGY

Family HETEROPHRENTIDAE Kullmann, 1965

Heterophrentinae Kullmann, 1965, p. 140.
Siphonophrentinae Birenheide, 1974, p. 253.
Heterophrentinae Kullmann. Birenheide, 1978, p. 68

Diagnosis.—Trochoid to cylindrical solitary corals with moderately deep to very deep calice and a distinct cardinal fossula, commonly on the convex side of curved coralla. Major septa long or short, commonly with a clear pinnate arrangement in the cardinal quadrants. Arrangement is radial in the counter quadrants and becomes radial in cardinal quadrants of larger forms. Amplexoid septa characteristic of those genera in which septa withdraw from the axis. Tabulae tend to be complete, arched with an axial depression; this M shape in longitudinal section may be strongly marked or only gently developed. No dissepiments.

In early ontogenetic stages, septa are commonly dilated and may fill the lumen. Such dilation persists to maturity in some forms. Attenuation takes place with growth in most family members and tends to be symmetrical (that is, equal in cardinal and counter quadrants).

Septal microstructure is characteristic. In transverse thin section, septa appear to be composed of two parts: a core zone is clearly separated from an outer zone by dark lines. The core zone may terminate axially in a rounded end or fade into the sterome of the outer zone of the septa or of the axis where present. Peripherally, the core zone thins and passes into the marginarium or wall. The fine structure of the core zone is unclear. In longitudinal sections of what is thought to be core zone, growth laminae can be seen (these incline toward the axis, as would be expected) that presumably mark the shape of the upper edge of the septa at earlier stages. The laminae are composed of fine fibers, and there is no indication of trabeculae. The sterome of the outer zone and axis appears featureless; no structure has been discerned.

Discussion.—Kullmann (1965, p. 140) and Birenheide (1974, p. 253) independently recognized the basic similarity of *Heterophrentis*, *Breviphrentis*, and *Siphonophrentis*, but both erected subfamilies, implying relationships that I consider unlikely. I consider them to represent a distinct family and have no suggestions at this time as to their relationships to other families. I think them quite unrelated to the Halliidae (Birenheide, 1974, 1978) or to the Streptelasmatidae (Kullmann, 1965). They seem to be a characteristic Eastern Americas Realm development, although some of the genera became more widespread in the Middle Devonian (especially Givetian).

To the basic three genera I add *Briantelasma* (see below) and *Pseudoblothrophyllum*, the earliest known family members. *Briantelasma* would make a good ancestor for the others. Progressive attenuation in later ontogenetic stages would give *Pseudoblothrophyllum* and *Heterophrentis* (of which *Compressiphyllum* is a compressed version), and withdrawal of septa from the axis would give *Breviphrentis* and, in its extreme development, *Siphonophrentis*.

Birenheide's (1978, p. 68) suggestion that *Homalophyllum* belongs to this family group warrants further study, but, at this time, I think of it as a streptelasmatid. Birenheide also included the genera *Aknisophyllum* Oliver and *Zmeinogorskia* Spassky in the group, both with queries. I reject *Aknisophyllum*, as it has a quite different gross structure and microstructure. I doubt the assignment of *Zmeinogorskia* (synonymized with *Altaiophyllum* Ivaniya by Hill (1981, p. F150)), but, as the early ontogenetic stages and microstructure of this form are unknown, family assignment is uncertain in any case.

Included genera.—*Breviphrentis* Stumm, *Briantelasma* Oliver, *Compressiphyllum* Stumm, *Heterophrentis* Billings, *Pseudoblothrophyllum* Oliver, and *Siphonophrentis* O'Connell.

Genus *Briantelasma* Oliver, 1960

1960a. *Briantelasma* Oliver, p. 89.
1960b. *Briantelasma* Oliver. Oliver, p. 6–7.
not 1963. *Briantelasma* Oliver. Oliver, p. 26–27.
1973. *Briantelasma* Oliver. Scrutton, p. 247–248.
1981. *Briantelasma* Oliver. Hill, p. F154.

Type species.—*Briantelasma americanum* Oliver, 1960a, p. 89–91, pl. 14, figs. 1–14. Lochkovian (Helderbergian), New York.

Diagnosis.—Simple, trochoid to cylindrical corals, with major septa extending to or nearly to the axis; minor septa one-half or less this length and limited to the marginarium. Dilated septa and additional deposits of stereoplasm fill the marginarium and may fill the tabularium, especially in the early growth stages. Tabulae strongly domed with axial depression, complete or incomplete, variably thickened with sterome. No dissepiments. Cardinal fossula present.

Discussion.—Study of small, solitary corals that are filled with stereoplasm is difficult because morphological details are hidden, and all specimens tend to look alike. I interpret *Briantelasma* as small, *Heterophrentis*-like, and filled with stereoplasm. Because of its geographic and stratigraphic position, it may well be the precursor of *Heterophrentis* and other members of the family (see family discussion).

Included species.—*B. americanum* Oliver, 1960a and *B. knoxboroense* Oliver, 1960a, Helderberg Group, Lochkovian, New York; "*B. mainense*" Oliver, 1960b (most paratypes but excluding the holotype, which is a ptenophyllid as noted by Pedder, 1983, p. 342), Beck Pond Limestone, Lochkovian, Maine; *B. oliveri* Scrutton, 1973, Caño Grande Formation, early Eifelian(?), Venezuela; *B. moorense* n.sp. Needmore Shale, early Eifelian(?), Pennsylvania and Virginia.

I now exclude from the genus *B.* sp. Oliver, 1963, from the Sayabec Formation, Wenlockian, Quebec. Weyer (1974, p. 161) suggested that it is a *Rhegmaphyllum*, and, while I am not certain of the generic assignment, I agree that it is not *Briantelasma*.

Distribution.—As presently known, *Briantelasma* is limited to the Eastern Americas Realm in rocks of Early Devonian and early Eifelian(?) age.

Briantelasma moorense n.sp.

Plates 1–4

Holotype.—USNM 421250, Needmore Shale, early Eifelian(?), 2.9 km south of Hyndman, Pa.

Diagnosis.—*Briantelasma* with stereoplasmic filling varying from partial to complete. Cardinal and counter septa thick and long below the calice; cardinal septum shortens and thins just below and in the calice to form a prominent fossula. Major septa tend to be pinnately arranged in the cardinal quadrants, radial in the counter quadrants. Minor septa very short.

External features.—Over 40 known coralla are trochoid to ceratoid and medium in size, up to 5 cm long and 2 cm or more in diameter. Most coralla are smoothly curved, with the cardinal septum on the convex side. Exteriors are worn but marked by shallow septal grooves and gentle rugae. Calices, as judged from sections, are moderately deep with a marked cardinal fossula and a small axial pit. The best-exposed calice shows the cardinal fossula to be formed by downbending of the tabulae and a cardinal septum that extends to the axis at the base of the fossula but does not rise as high as the other septa except at the wall. In this same calice, the counter septum is long and thick and rises higher above the calice floor than do the other septa.

Internal features.—Major septa number 18 to 32 in transverse sections 6 to 20 mm in diameter (text fig. 3). Major septa extend 0.8 to 0.9 times the distance to the axis, where they either merge into featureless stereoplasm or leave a free space. The counter septum tends to be longest and thickest, but the cardinal septum is similar below the calice; in higher sections, the cardinal septum is thinner and somewhat shorter, so that open spaces appear on either side of the cardinal septum before developing in adjacent interseptal spaces. There is a tendency for the other major septa to be pinnately arranged in the cardinal quadrants and radially so in the counter quadrants.

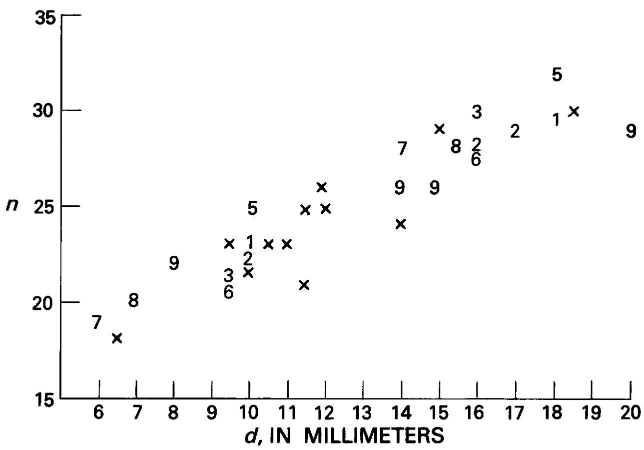


Figure 3. Number of major septa (*n*) plotted against diameter (*d*) in millimeters in *Briantelasma moorense* n.sp. Measurements and counts are from 30 thin sections in a sample of 19 sectioned specimens. Sequential plots from one coral are marked by a specimen number (for example, data from four sections of specimen 9 are plotted).

Minor septa are very short. In lower sections, they are triangular in shape, and their length is approximately equal to their width at base. In higher sections, they are parallel sided and tend to merge with the adjacent major septum in the direction away from the cardinal and toward the counter septum.

Stereoplasmic infilling varies. At diameters of 10 mm or less, nearly all specimens are completely filled. In some individuals, infilling with only occasional openings persists to diameters of 17 mm or more. In others, open interseptal spaces appear and are marked at 13 mm or less. Septal attenuation may be uniform in all quadrants, but there is a tendency for greater or earlier attenuation in the counter quadrants. However, the appearance of this attenuation in some sections is a result of the imperfect orientation of the sections in the curved coralla.

In longitudinal sections, the lumen may be filled with septa and stereoplasm in which faint traces of growth laminae and fibers can be discerned (for example, pl. 1, fig. 5) or relatively open (pl. 4, figs. 4, 5). In open spaces, tabulae are developed that are strongly arched with a depressed center. Tabulae are complete and incomplete. There are no dissepiments.

Variation.—Size and septal number variation is normal, as the scatter diagram (text fig. 3) shows. Most interesting is variation in the amount of stereoplasm, as the illustrations show. This variation is so extreme that end members of the spectrum would not be recognized as belonging to the same species or even the same genus if it were not for the large sample.

Discussion.—*B. moorense* differs from other species of the genus in its very short minor septa and in the variable stereoplasmic filling. Completely filled specimens are closest to *B. oliveri* Scrutton, but they differ in having shorter minor septa and longer major septa.

Distribution.—Needmore Shale, early Eifelian(?), south-central Pennsylvania and northern Virginia.

Material.—Locality USGS 9005/9016-SD, 2.9 km south of Hyndman, Pa.: 19 sectioned specimens, holotype USNM 421250, illustrated paratypes 421251 to 421259; other measured paratypes 421261 to 421269; 22 unsectioned paratypes, USNM 421270 and 421271. Locality USGS 9015-SD, shore of Lake Koon, Pa.: one specimen, illustrated paratype USNM 421260. AMNH locality, Hayfield, Va.: one specimen, AMNH 43519.

Family LINDSTROEMIIDAE Pocta, 1902

part 1902. Lindströmidae Pocta, p. 181-182.
part 1953. Stereolasmidae Fomichev, p. 96.
part 1971. Lindstroemiidae Pocta. Scrutton, p. 192.
1981. Lindstroemiidae Pocta. Hill, p. F201.
part 1981. Stereolasmatidae Fomichev. Hill, p. F308.

Diagnosis.—Small, nondissepimented horn corals with a solid axial column, at least in early stages. Major septa long; extend to and help form the column; may be withdrawn from axis in later stages; slightly pinnate in cardinal quadrants with a small but distinct cardinal fossula. Cardinal and counter septa tend to be long; minor septa commonly contratingent with counter minors (Kms) longer than others. Tabulae strongly arched. No dissepiments.

Discussion.—My concept of the family is based on a group of four Eastern American Realm genera whose type species are all from the upper half of the Hamilton Group (Tioughnioga; Givetian) in western New York. The most detailed morphologic descriptions and illustrations of these forms were given by Busch (1941) and Stumm and Watkins (1961). I tentatively accept the Stumm and Watkins synonymy of the nine Busch species into three species in three genera—*Amplexiphyllum*, *Stereolasma*, and *Stewartophyllum*. Curiously, neither of these papers included descriptions of the closely allied and associated fourth species (of *Lindstroemia* = *Lopholasma*).

The family may be more widespread and inclusive than my diagnosis and list of included genera would indicate, but these four genera are the core on which the family must be based. Hill's (1981) Stereolasmatidae comes close to my limits but includes a Carboniferous genus that I question. An analysis of other authors' family concepts is beyond the scope of this discussion. Detailed studies of ontogeny and microstructure in numerous well-preserved individuals are needed to understand the relationships of the large number of small, nondissepimented, columellate genera. The above family synonymy includes only first descriptions of the family and its junior synonym and later descriptions that are useful, close to, or included within my concept.

Distribution.—As here used, the family is known from rocks of Pragian to Givetian age in the Eastern Americas Realm.

Included genera.—*Amplexiphyllum* Stumm, *Lindstroemia* Nicholson and Thompson (= *Lopholasma* Simpson), *Stereolasma* Simpson, and ?*Stewartophyllum* Busch.

Genus *Stereolasma* Simpson, 1900

1900. *Stereolasma* Simpson, p. 205.
1941. *Stereolasma* Simpson. Busch, p. 395.
1949. *Stereoelasma* (sic) Simpson. Stumm, p. 7.
1961. *Stereolasma* Stumm and Watkins, p. 445.
1973. *Stereolasma* Simpson. Scrutton, p. 233.
1980. *Stereolasma* Oliver, p. 19, 26.
1981. *Stereolasma* Simpson. Hill, p. F308.

Type species.—*Strombodes*? *rectus* Hall, 1843, p. 210, text fig. 87-5; Hall, 1877, pl. 19, figs. 1-19 (part); Hamilton Group, western New York.

Diagnosis.—Lindstroemiids with column extending to the bottom of the calice without forming prominent boss. Cardinal septum long, extending to the axis of the column with or without the fossula indenting the column. Fossula formed by thinner and vertically shorter cardinal septum. Minor septa contratingent; Kms extra long. No flanges on septa. Tabulae strongly domed.

Discussion.—The holotype of Hall (1843) is apparently lost, although it may be one of the specimens that he illustrated in 1877 (not 1876, as commonly stated) (see Stumm, 1948; Oliver, 1987, p. 100). Most of the 1877 specimens are preserved in the New York State Museum in Albany or the American Museum of Natural History in New York City. A neotype should be selected from these specimens, but it must be done with care, because some of the specimens are *Lindstroemia columnaris* (= *Lopholasma carinatum*), as Simpson (1900, p. 206) noted.

Distribution.—Emsian to Givetian, Eastern Americas Realm.

Stereolasma fereplena n.sp.

Plate 5

?1973. *Stereolasma* sp. Scrutton, p. 233-234, pl. 1, figs. 6-7.
?1980. *Stereolasma* n.sp. A Oliver, p. 26, pl. 1, figs. 1-4 (?not *S*? sp. cf. *S*. n.sp. A, pl. 1, fig. 5).

Holotype.—AMNH 43520, Needmore Shale, early Eifelian(?), Hayfield, Va.

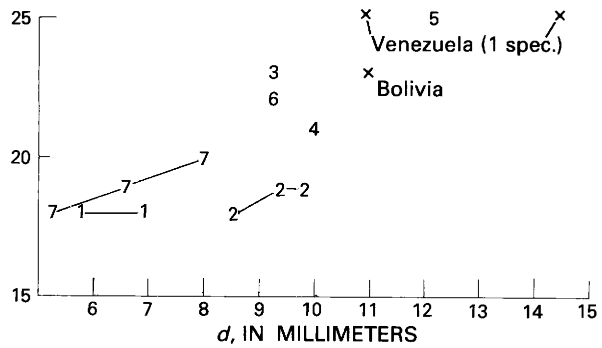


Figure 4. Number of major septa (*n*) plotted against diameter (*d*) in millimeters in *Stereolasma fereplena* n.sp. Measurements and counts are from 12 thin sections in a sample of 7 corals. Plots are marked by specimen number, and sequential plots from a single specimen are connected by lines. *Stereolasma* sp. Scrutton (Venezuela) and *S.* sp. A Oliver (Bolivia) are marked for comparison. See text discussion.

Diagnosis.—*Stereolasma* with a broad column and thick septa. The cardinal septum projects into the column, but the fossula does not; minor septa long and contratingent; Kms extend to the column.

External features.—Fifteen specimens are small, solitary, and trochoid to ceratoid in shape; specimens are up to 20 mm in length and 12 mm in diameter. Septal grooves and broad, rounded interseptal ridges are present. Calice depth is approximately 0.8 times the diameter. Fossula apparently is not conspicuous.

Internal features.—Major septa number 18 to 25 in transverse sections 5 to 12 mm in diameter (text fig. 4). Transverse sections are dominated by the broad, solid column formed by the thickened axial ends of the major septa and additional stereoplasm. Column diameter is approximately one-half the corallite diameter in mature parts and greater in lower parts of coralla. Major septa are thick and slightly pinnate near the cardinal septum but generally radial. Cardinal and counter septa are long and project well into the column; cardinal septum somewhat thinner than other majors. Minor septa are strongly contratingent, almost merging with adjacent major septa on the side away from the cardinal position, so that there is commonly no open space between minor and major septa on that side. Counterlateral minors extend to the column before fusing with counter septum, so that there are sizable intervening open spaces.

Longitudinal sections are largely filled with stereoplasm, and it is difficult to differentiate between septal and additional tissue. Apparent septa show growth lines sloping toward the axis; growth laminae seem to be composed of fine fibers normal to the laminae (pl. 5, fig. 7). Open spaces between column and wall contain a few outward sloping tabulae.

Variation.—Size and septal number variation is limited in the available sample (text fig. 4), and most specimens are remarkably uniform in appearance. One small specimen (pl. 5, figs. 1, 2) has a relatively narrower column and lacks obvious minor septa below the calice except for the prominent Kms. A calice section show very short minors, essentially limited to the wall (pl. 5, fig. 1).

Discussion.—*S. fereplena* differs from other *Stereolasma*, especially *S. rectum*, in the robustness of its septa and column. It is similar to *S.* sp. Scrutton, 1973 and *S.* n.sp. A Oliver, 1980 from Venezuela and Bolivia, respectively. Size and septal number of these forms plot at the upper end of the range of *S. fereplena* (text fig. 4), and the gross morphologies of both fit the description given here. Neither is as well preserved, and the descriptions of both were based on single specimens, so their assignment to this species is tentative.

Distribution.— Needmore Shale, early Eifelian(?), south-central Pennsylvania and northern Virginia. Possible additional occurrences are noted in Venezuela and Bolivia.

Material.—AMNH locality, Hayfield, Va.: four sectioned specimens, holotype AMNH 43520, paratypes AMNH 43521, 43522, and 43523; two unsectioned paratypes, AMNH 43524 and 43525. Locality USGS 9011/9015-SD, Lake Koon, Pa.: two sectioned and two unsectioned paratypes, USNM 421272, 421273, 421277, and 421278. Locality USGS 9016-SD, 2.9 km south of Hyndman, Pa.: two sectioned and two unsectioned paratypes, USNM 421274, 421275, 421276a, and 421276b.

Family LACCOPHYLLIDAE Grabau, 1928
Genus *Neaxon* Kullmann, 1965

1965. *Neaxon* Kullmann, p. 81.
1971. *Neaxon* Kullmann. Weyer, p. 294-295.
1981. *Neaxon* Kullman. Hill, p. F197.

Type species.—*Neaxon regularis* Kullmann, 1965, p. 83-86, text fig. 6, pl. 2, figs. 1-4. Upper Emsian, Spain.

Diagnosis.—Small, solitary corals with major septa meeting near axis to form aulos (or solid axial column in earliest stages). Septa not flanged, minor septa short and not contratingent. Tabulae tend to be horizontal within aulos, inclined downward from aulos to wall. See synonymy references for fuller discussion of genus.

Neaxon sp. A

Plate 6

Two specimens appear to be conspecific and belong to this genus. Both are small, trochoid to ceratoid, and incomplete at the apex; one is partially crushed. Exteriors are not known, although septal grooves are present. Size and numbers of major septa are:

USNM	*n*	*d* (mm)	*ad* (mm)	Maximum *d* (mm)	Estimated length (mm)
421279.....	22	11.8	2.4	13	20
421280.....	21	10	1.8	10	20

where *n* is the number of major septa in a transverse thin section of diameter *d*, *ad* is the inside diameter of the aulos in the same section, maximum *d* is the outside diameter in the upper part of the calice, and estimated length is a best guess.

In transverse section, the aulos and outer wall are formed by slightly dilated inner and outer parts of the septa. The inside diameter of the aulos is approximately 0.2 times the total diameter in each specimen. Most minor septa are limited to the outer wall, but a few project inward for 0.2 to 0.4 mm. In each specimen, one major septum is slightly longer than the others and is flanked by the longest of the minor septa; the long septa are probably the cardinal or counter septa and are taken to be the latter because long counterlateral minor septa characterize many laccophyllids. However, the identity of these septa has not been confirmed.

In longitudinal sections, tabulae within the aulos are mostly complete, nearly horizontal, and thickened with stereoplasm. Tabulae outside of the aulos are few in the available sections but are inclined toward the outer wall and seem to be thin.

Distribution.—Needmore Shale, early Eifelian(?), south-central Pennsylvania.

Material.—Illustrated specimen, USNM 421279, locality USGS 9015-SD, shore of Lake Koon, Pa. Unillustrated specimen, USNM 421280, locality USGS 9016-SD, 2.9 km south of Hyndman, Pa.

Family STREPTELASMATIDAE Nicholson, 1889

Streptelasmatidae of authors. Used in a very loose, inclusive sense.

Subfamily ENTEROLASMATINAE Hill, 1981

1981. Enterolasmatinae Hill, p. F165.

Diagnosis.—"Solitary, with spongy axial structure of corrugated and variably fused axial ends of major septa, of vermiform axial lobes or lamellae"; major septa may be flanged or waved parallel to distal edges; minor septa short; fossula indistinct; tabulae highly arched; no dissepiments (modified from Hill, 1981, p. F165).

Discussion.—The genera *Palaeocyathus* Foerste, *Enterolasma* Simpson, and *Orthopaterophyllum* Nikolaeva are similar and may be synonyms. All three have the subfamily axial structure, but it is weakly developed in *Palaeocyathus* (type species *P. australe* (Foerste)) (see Hill, 1981, p. F165, figs. 94-1a-c). The vermiform axial structure is well developed in *Enterolasma* (type species *E. strictum* (Hall)) (Simpson, 1900, p. 204, figs. 11, 12) (see also *E. waynense* (Safford) as beautifully illustrated by Sutherland (1965, pl. 30)). It is variably developed in "*Orthopaterophyllum*" as interpreted in the literature (compare illustrations of Bulvanker (1952, pl. 5, fig. 2, pl. 6, figs. 5-7) and Bulvanker and others (1960, p. 223-224, figs. 27-29, pls. 44, 45)). Hill (1981, p. F165-F166) tentatively recognized *Enterolasma* and *Palaeocyathus* and synonymized "*Orthopaterophyllum*" with the latter, but this synonomy may well depend on which species is the type. *O. conicum* Bulvanker, 1952 is an *Enterolasma* (if two genera are recognized) and is, in my opinion, the type species (but see Hill, 1981, p. F165).

In any case, the subfamily is based on a complex of species ranging in age from Llandoverian to Eifelian(?) (see below). Several additional genera may be related, but most are not well enough known for meaningful analysis. Hill (1981, p. F165), Weyer (1974), and Kullmann (1965, p. 143-144) have all discussed possible *Enterolasma* relationships. My discussion of the subfamily is to provide background for a new species of *Enterolasma*.

Included genera.—i.a. *Enterolasma* Simpson and *Palaeocyathus* Foerste.

Genus *Enterolasma* Simpson, 1900

1900. *Enterolasma* Simpson, p. 203.
1949. *Enterelasma* (sic) Simpson. Stumm, p. 8.
1952. *Orthopaterophyllum* Nikolaieva *in* Bulvanker, p. 7 (with type species *O. conicum* Bulvanker, 1952).
?1960. *Orthopaterophyllum* Nikolaieva. Bulvanker and others, p. 221-222.
1960. *Orthopaterophyllum* Nikolaeva. Spassky, p. 23.
part 1965. *Enterolasma* Simpson. Kullmann, p. 143-145.
1965. *Enterolasma* Simpson. Sutherland, p. 22.
part 1977. *Enterolasma* Simpson. Spassky, p. 76-77.
1981. *Enterolasma* Simpson. Hill, p. F165.

Type species.— *Streptelasma* (*Petraia*) *stricta* Hall, 1874, p. 114-115. Hall and Simpson, 1887, p. 1-2, pl. 1, figs. 1-10 (part?). Lochkovian (Helderbergian), New York.

Diagnosis.—Simple, commonly straight, trochoid to ceratoid corals with major septa extending nearly to the axis and forming a spongy axial column by the irregular interdigitation of vermiform axial extensions. Major septa radially arranged with little or no modification of protosepta. Minor septa short and straight. Wall a septotheca formed by dilated outer ends of septa. Major septa flanged or wrinkled, forming low ridges parallel to the growth lines and upper edges of the septa. Tabulae complete or incomplete, strongly arched.

Discussion.—*Enterolasma* seems very distinct because of its combination of characters, but this combination makes it difficult to interpret relationships. The spongy axial structure is not unique, as it occurs in other groups of presumably unrelated corals, but it is the principal character that unites the species here assigned to the genus. The flanges or wrinkles on the septa and the weakness of the fossula and of bilaterality in general are additional unifying characters that suggest a relationship to the "streptelasmatids," but this catchall is not very helpful.

Distribution.—Llandoverian(?) to Eifelian(?), Eurasia; Wenlockian to Eifelian(?), Eastern North America.

Enterolasma dutroi n.sp.

Plate 7

Holotype.—AMNH 43526, Needmore Shale, Emsian or early Eifelian(?), Hayfield, Va.

Diagnosis.—*Enterolasma* with thickened septa and septal lobes, a wide septotheca, and a prominent axial boss in the calice.

External features.—Simple, small- to medium-sized, straight, trochoid to ceratoid corals. The maximum diameter of three known specimens is 25 cm; the maximum length is estimated at 3 to 4 cm. The outside is marked by septal grooves and interseptal ridges and by a few gentle rugae. Calice has a marked boss, and depth is one-half diameter or less.

Internal features.—Major septa number 24, 30, and 30 in transverse sections with diameters of 10, 20, and 21 mm, respectively. Major septa are radially arranged and extend to the near axis, where vermiform extensions of the septa form a spongy axial structure. Cardinal and counter septa may be somewhat longer than other septa but are not easily recognized in sections. The column diameter is approximately one-fourth the corallite diameter.

The wall is a septotheca formed by the dilated peripheral ends of the septa; thickness is approximately 0.25 times the radius. Minor septa are essentially limited to the wall.

In longitudinal sections, the column area may be densely or loosely occupied by the irregular septal lobes (pl. 7.). There are faint suggestions of growth laminae and low horizontal flanges on the septa. Tabulae are incomplete and strongly domed.

Variation.—The two larger specimens are remarkably similar, although they are from different localities. The third and smaller specimen differs mainly in size and in having more open space in the lumen (pl. 7, fig. 5). All three specimens are illustrated.

Discussion.—*E. dutroi* differs from other species of the genus in having a well-developed calicinal boss, thicker walls and septa, and a somewhat less complex axial column. The small specimen is similar to *E. ibericum* Kullmann (1965, p. 145, pl. 7, figs. 2–6), but the other specimens are much larger and more robust.

Distribution.—*E. dutroi* is known only from the Needmore Shale in north-central Virginia and adjacent West Virginia.

Material.—Holotype, AMNH 43526, Hayfield, Va.; illustratated paratypes, USNM 421281 and 421282, from Berkeley Springs, W. Va., and Gainsboro, Va.

REFERENCES CITED

Berg, T.M., McInerney, M.K., Way, J.H., and MacLachlan, D.B., 1983, Stratigraphic correlation chart of Pennsylvania: Harrisburg, Pennsylvania Geological Survey, 1 sheet.

Birenheide, R., 1974, *Papiliophyllum lissingenense* n.sp. (Rugosa) aus dem Lissinger Schurfgraben (Emsium; Eifel): Senckenbergiana Lethaea, v. 55, p. 251–257.

——— 1978, Rugose Korallen: Leitfossilien, no. 2, 265 p.

Bulvanker, E.Z., 1952, [Rugose corals from the Silurian of Podolia]: Moscow, Trudy VSEGEI, 47 p. (in Russian).

Bulvanker, E.Z., and others, 1960, [Subclass Tetracoralla (Rugosa), *in* Markovskii, B.P., ed., New species of ancient plants and invertebrates of the USSR, part 1]: Moscow, VSEGEI, p. 220–254, pls. 44–61. p. (in Russian).

Busch, D.A., 1941, An ontogenetic study of some rugose corals from the Hamilton of western New York: Journal of Paleontology, v. 15, p. 392–411.

Dennison, J.M., 1961, Stratigraphy of Onesquethaw Stage of Devonian in West Virginia and bordering states: West Virginia Geological Survey Bulletin 22, 87 p.

de Witt, W., Jr., 1974, Geologic map of the Beans Cove and Hyndman Quadrangles and part of the Fairhope Quadrangle, Bedford County, Pennsylvania: U.S. Geological Survey Miscellaneous Investigations Map I-801, 1 sheet, scale 1:24,000, 6-p. text.

de Witt, W., Jr., and Colton, G.W., 1964, Bedrock geology of the Evitts Creek and Patterson's Creek Quadrangles, Maryland, Pennsylvania, and West Virginia: U.S. Geological Survey Bulletin 1173, 90 p.

Fomichev, V.D., 1953, [Rugose corals and stratigraphy of the Middle and Upper Carboniferous and Permian deposits of the Donets Basin]: Leningrad, Trudy VSEGEI, Leningrad, 622 p. (in Russian).

Gray, C., and others, 1960, Geologic map of Pennsylvania: Harrisburg, Pennsylvania Geological Survey, 2 sheets, scale 1:250,000.

Hall, J., 1843, Geology of New York, part IV, Comprising the survey of the Fourth Geological District: Albany, 683 p.

——— 1874, Descriptions of Bryozoa and corals of the Lower Helderberg Group: New York State Museum of Natural History annual report 23, p. 93–116.

——— 1877, Illustrations of Devonian fossils: Gasteropoda, Pteropoda, Cephalopoda, Crustacea and corals of the Upper Helderberg, Hamilton and Chemung Groups: Albany, New York State Geological Survey, 7 p., 133 pls. and explanations. (Title page bears 1876 date.)

Hall, J., and Simpson, G.B., 1887, Palaeontology, v. VI, Corals and Bryozoa: Containing descriptions and figures of species from the Lower Helderberg, Upper Helderberg and Hamilton Groups: Albany, New York State Geological Survey, 298 p., pls. 1–66.

Hill, D., 1981, Part F, Coelenterata, supp. 1, Rugosa and Tabulata, *in* Treatise on invertebrate paleontology: Boulder, Colo., and Lawrence, Kans., Geological Society of America and University of Kansas, 762 p.

House, M.R., 1978, Devonian ammonoids from the Appalachians and their bearing on international zonation and correlation: Palaeontological Association Special Papers in Palaeontology 21, 70 p.

Kirchgasser, W.T., Oliver, W.A., Jr., and Rickard, L.V., 1985, Devonian series boundaries in the eastern United States: Courier Forschungs-institut Senckenberg, v. 75, p. 233–260.

Kullmann, J., 1965, Rugose Korallen der Cephalopodenfazies und ihre Verbreitung im Devon des südöstlichen Kantabrischen Gebirges (Nordspanien): Akademie der Wissenschaften und der Literatur, Abhandlungen der Mathematisch-Naturwissenschaftlichen Klasse, 1965, no. 2, p. 33–168.

Nicholson, H.A., 1889, Palaeozoology, invertebrata, *in* Nicholson, H.A., and Lydekker, R., A manual of palaeontology for the use of students, v. 1: Edinburgh and London, Blackwood, p. 107–885.

Oliver, W.A., Jr., 1960a, Rugose corals from reef limestones in the Lower Devonian of New York: Journal of Paleontology, v. 34, p. 59–100.

——— 1960b, Devonian rugose corals from northern Maine: U.S. Geological Survey Bulletin 1111-A, 23 p.

——— 1963, A new *Kodonophyllum* and associated rugose corals from the Lake Matapedia area, Quebec: U.S. Geological Survey Professional Paper 430-C, p. 17–31.

——— 1976, Noncystimorph colonial rugose corals of the Onesquethaw and lower Cazenovia Stages (Lower and Middle Devonian) in New York and adjacent areas: U.S. Geological Survey Professional Paper 869, 156 p., 108 pls.

——— 1977, Biogeography of Late Silurian and Devonian rugose corals: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 22, p. 85–135.

——— 1980, Corals in the Malvinokaffric Realm: Münster Forschungen zur Geologie und Paläontologie, v. 52, p. 13–27.

——— 1987, James Hall and fossil corals: Earth Sciences History, v. 6, no. 1, p. 99–105.

Patchen, D.G., coord., 1985, Northern Appalachian Region, Correlation of Stratigraphic Units of North America (COSUNA) project: Tulsa, Okla., American Association of Petroleum Geologists, 1 sheet.

Pedder, A.E.H., 1983, Systematic paleontology, *in* Pedder, A.E.H., and Goodbody, O.H., New Devonian rugose corals of probable late Dalejan age from the Bird Fiord Formation of southwestern Ellesmere Island, Northwest Territories: Geological Survey of Canada Paper 83-1B, p. 335–352.

Pocta, P., 1902, Anthozoaires et Alcyonaires, *in* Barrande, J., Systeme Silurien du centre de la Boheme: Prague, Musee Boheme, v. 8, t. 2, 347 p.

Scrutton, C.T., 1971, Palaeozoic coral faunas from Venezuela, I, Silurian and Permo-Carboniferous corals from the Merida Andes: Bulletin of the British Museum (Natural History), Geology, v. 20, p. 183–227.

——— 1973, Palaeozoic coral faunas from Venezuela, II, Devonian and Carboniferous corals from the Sierra de Perigá: Bulletin of the British Museum (Natural History), Geology, v. 23, p. 221–281.

Simpson, G.B., 1900, Preliminary descriptions of new genera of Paleozoic rugose corals: New York State Museum Bulletin 39, p. 199–222.

Spassky, N.Ya., 1960, [Devonian tetraradiate corals of the Rudny Altay]: Paleontological basis of the Paleozoic stratigraphy of the Rudny Altay, part 3, 70 p. (in Russian).

——— 1977, [Devonian rugose corals of the USSR]: Leningrad, Leningrad University Publishing House, 344 p. (in Russian).

Stumm, E.C., 1948, The priority of Dana, 1846–48, versus Hall, 1847, and of Rominger, 1876, versus Hall, 1876 (?1877): University of Michigan, Contributions from the Museum of Paleontology, v. 7, no. 1, p. 1–6.

——— 1949, Revision of the families and genera of the Devonian tetracorals: Geological Society of America Memoir 40, 92 p.

Stumm, E.C., and Watkins, J.L., 1961, The metriophylloid coral genera *Stereolasma*, *Amplexiphyllum*, and *Stewartophyllum* from the Devonian Hamilton Group of New York: Journal of Paleontology, v. 35, p. 445–447.

Sutherland, P.K., 1965, Rugose corals of the Henryhouse Formation (Silurian) in Oklahoma: Oklahoma Geological Survey Bulletin 109, 92 p.

Weisbord, N.E., 1926, Venezuelan Devonian fossils: Bulletins of American Paleontology, v. 11, p. 223–268.

Wells, J.W., 1943, Anthozoa, *in* Liddle, R.A., The Río Cachirí Section in the Sierra de Perijá, Venezuela: Bulletins of American Paleontology, v. 27, p. 95–100.

Weyer, D., 1971, *Neaxon regulus* (Rh. Richter, 1848), ein Leitfossil der Mitteleuropäischen *Wocklumeria*-Stufe (Anthozoa, Rugosa; Oberdevon): Geologie, v. 20, no. 3, p. 292–315.

——— 1974, Zur Kenntnis von *Rhegmaphyllum* Wedekind, 1927 (Anthozoa, Rugosa; baltoskandisches Silur): Geologische Wissenschaften (Berlin), v. 2, p. 157–183.

Willard, B., 1939, Middle and Upper Devonian, *in* The Devonian of Pennsylvania: Pennsylvania Geological Survey Bulletin G-19, 481 p.

Woodward, H.P., 1943, Devonian System of West Virginia: West Virginia Geological Survey, v. 15, 655 p.

PLATES 1–7

All photographs are of thin sections at ×3 or ×10. Transverse sections are oriented with the cardinal position (or what I interpret to be the cardinal position) toward the top of the plate. On plates 1 through 4 (*Briantelasma moorense* n.sp.), several of the transverse sections are reversed; that is, they were photographed as though from the apical end of the coral rather than from above the calicinal end. These sections are marked "reversed" in the explanations. Specimens are reposited in the U.S. National Museum of Natural History (USNM) and the American Museum of Natural History (AMNH). Most collections are listed in the U.S. Geological Survey (USGS) Silurian-Devonian locality catalog.

PLATE 1

Briantelasma moorense n.sp.

Figures 1–5. Holotype, USNM 421250, collection USGS 9005-SD.

1, 2. Upper transverse (reversed), ×3; detail, ×10.

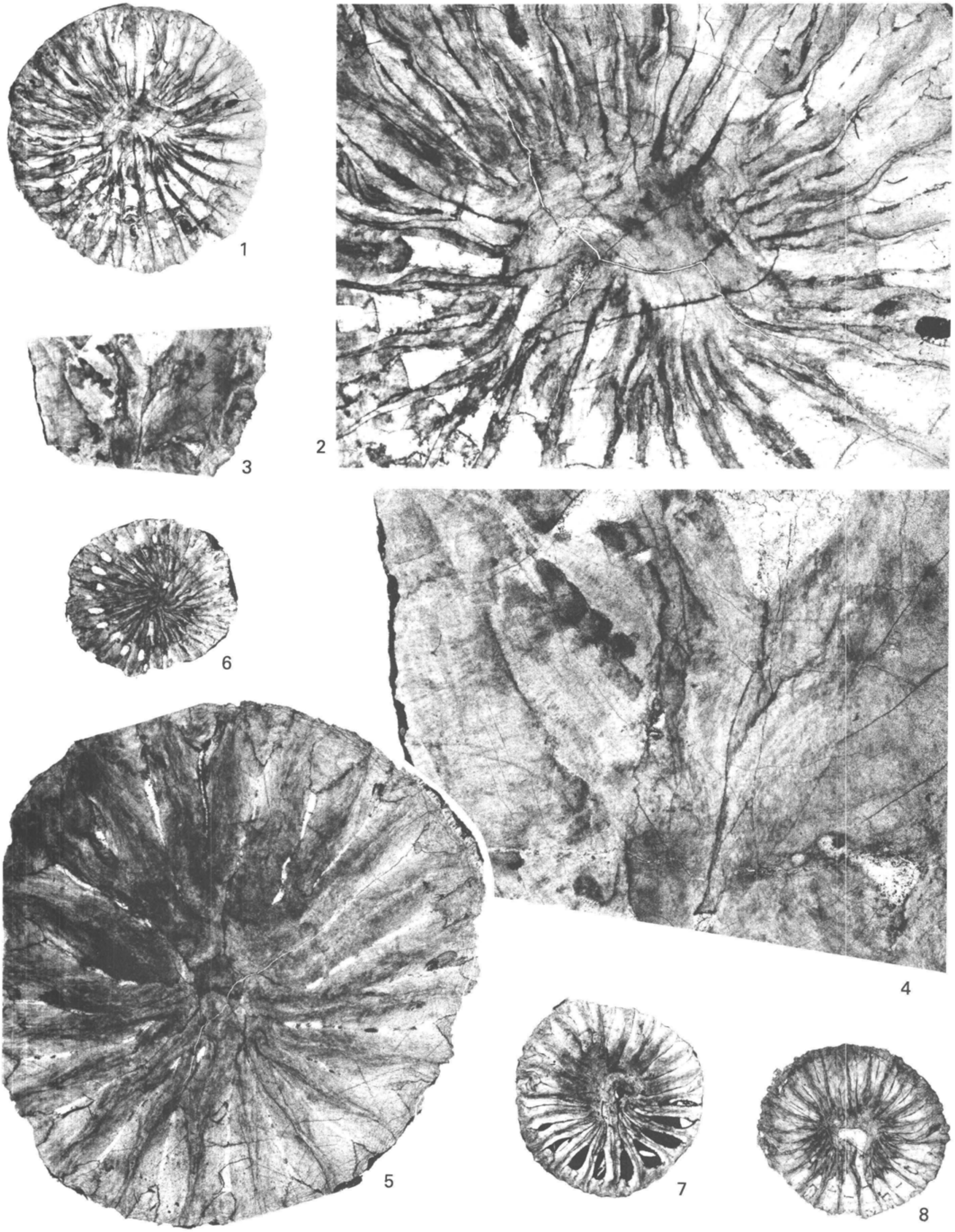
3, 4. Longitudinal from between upper and lower transverse, ×3; detail, ×10.

5. Lower transverse (reversed), approximately 13 mm below upper section, ×10.

6. Paratype, USNM 421253, collection USGS 9016-SD (reversed), ×3.

7. Paratype, USNM 421254, collection USGS 9016-SD (reversed), ×3.

8. Paratype, USNM 421252, collection USGS 9016-SD (reversed), ×3.



BRIANTELASMA

PLATE 2

Briantelasma moorense n.sp.

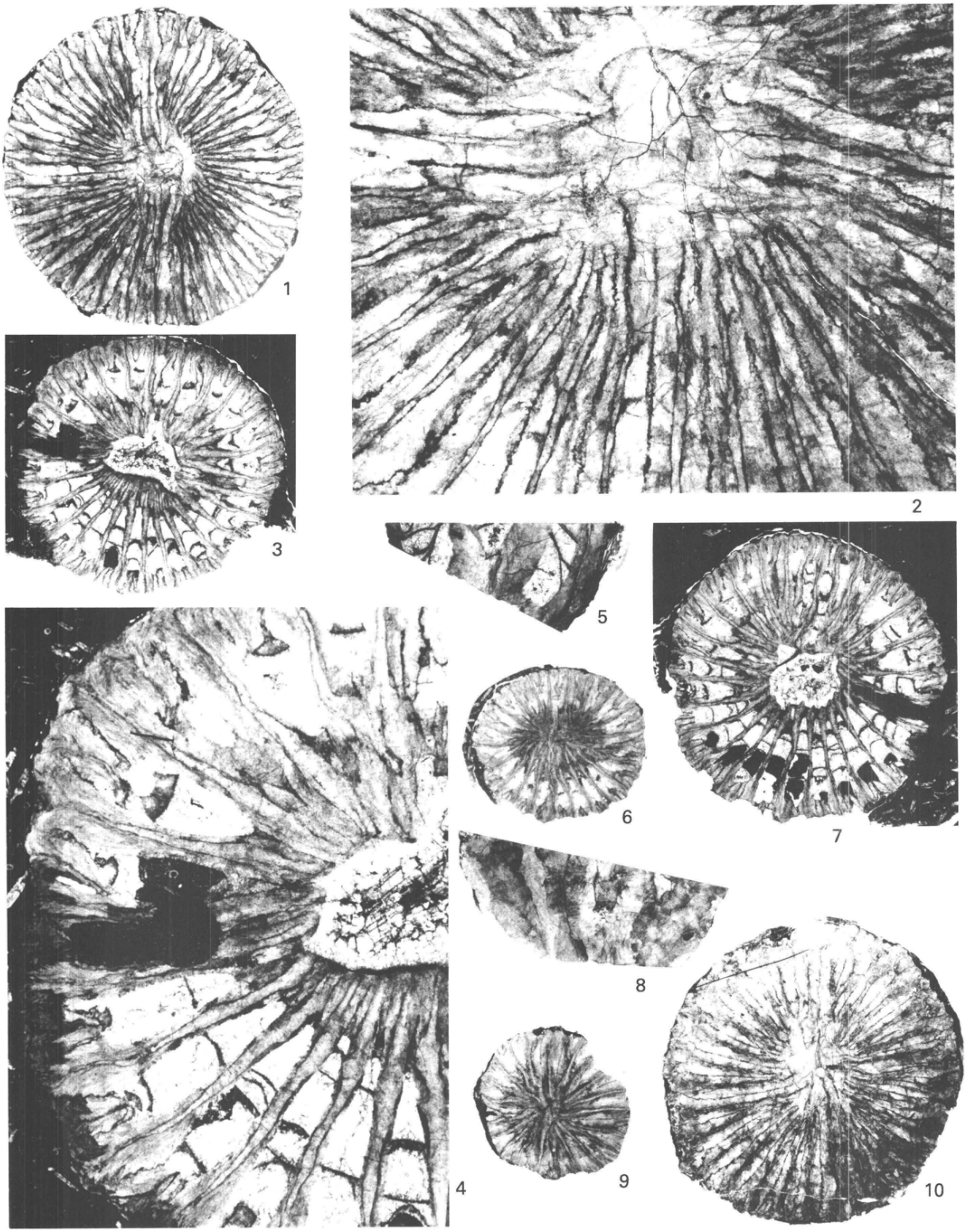
Figures 1, 2. Paratype, USNM 421256, collection USGS 9016-SD; transverse, ×3; detail (turned 90°), ×10.

3-7. Paratype, USNM 421260, collection USGS 9015-SD.

- 3, 4. Transverse (reversed) from above longitudinal, ×3; detail, ×10.
- 5. Longitudinal, ×3.
- 6. Transverse (reversed) below longitudinal, approximately 9 mm below figure 3, ×3.
- 7. Transverse through lowest part of calice, approximately 2 mm above figure 3 and 11 mm above figure 6, ×3.

8-10. Paratype, USNM 421255, collection USGS 9016-SD.

- 8. Longitudinal, ×3.
- 9, 10. Transverse sections below and above longitudinal, ×3; lower approximately 11 mm below upper.



BRIANTELASMA

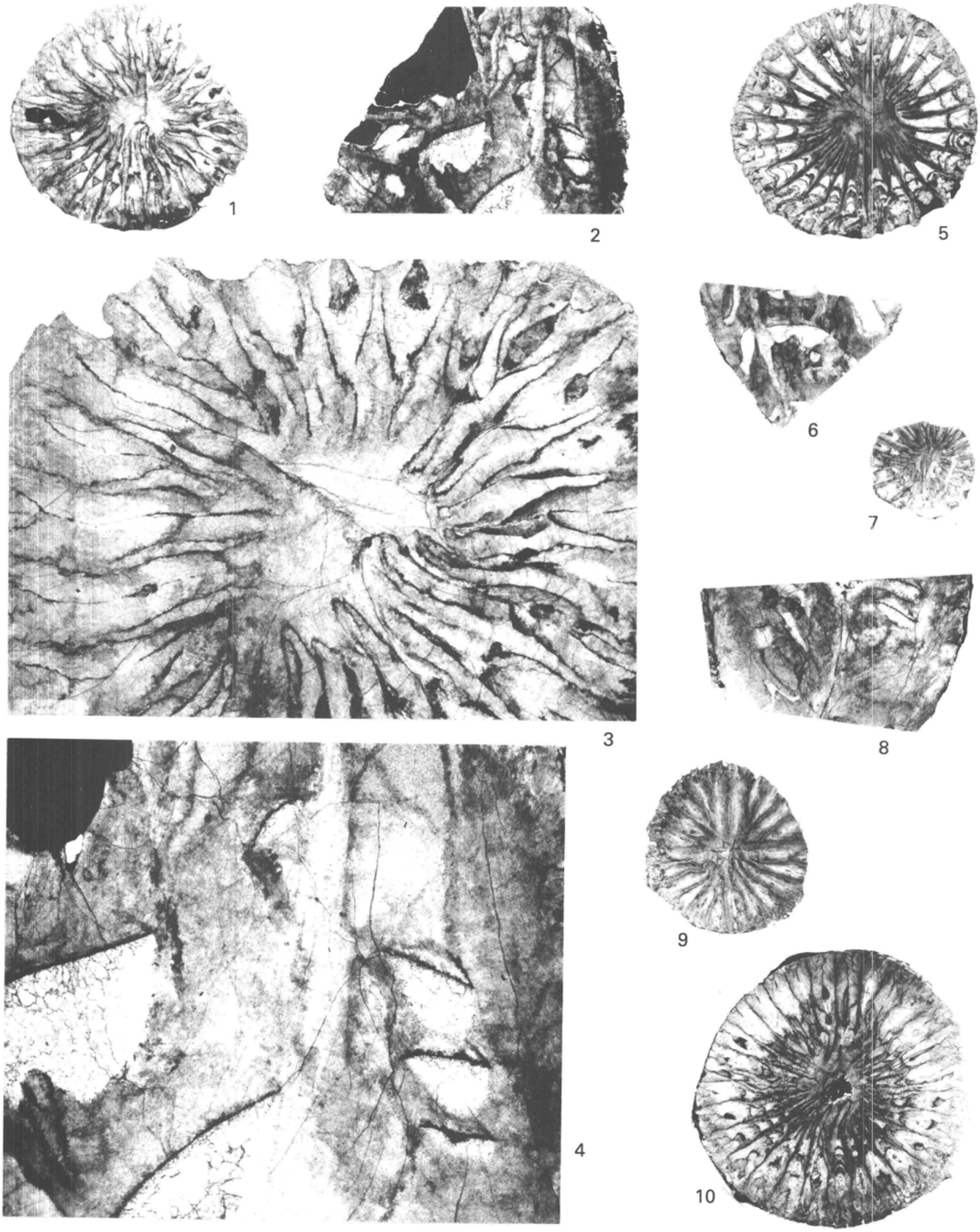
PLATE 3

Briantelasma moorense n.sp.

Figures 1–4. Paratype, USNM 421258, USGS collection 9016–SD. Transverse (reversed) from below longitudinal, each ×3; detail of each, ×10; note that figure 3 is rotated some 60° counterclockwise.

5–7. Paratype, USNM 421259, collection USGS 9016–SD. Upper and lower transverse (both reversed) and intervening longitudinal, all ×3; upper section approximately 10 mm above lower section.

8–10. Paratype, USNM 421257, collection USGS 9016–SD. Upper and lower transverse (lower reversed) and intervening longitudinal, all ×3; upper section approximately 12 mm above lower.

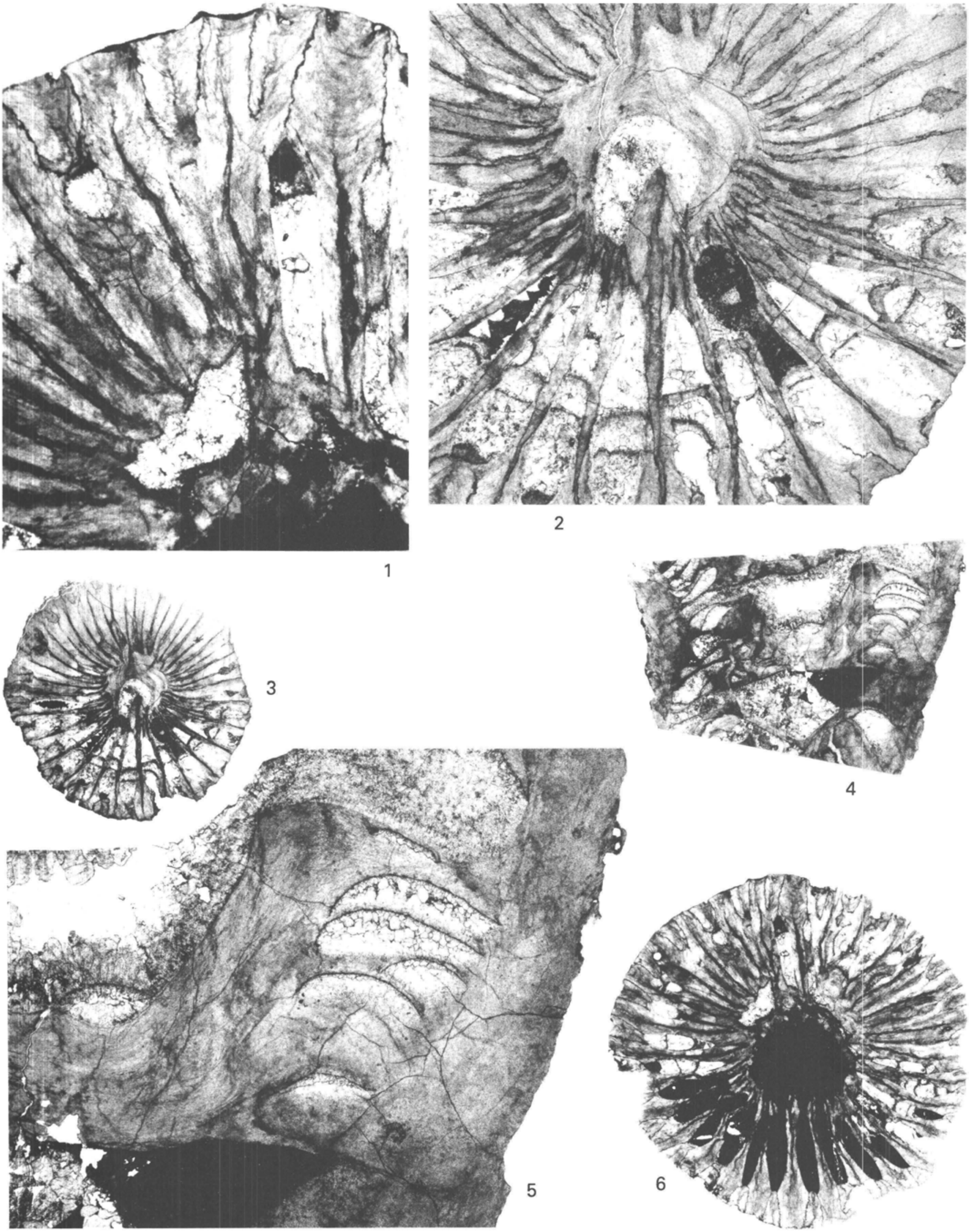


BRIANTELASMA

PLATE 4

Briantelasma moorense n.sp.

Figures 1–6. Paratype, USNM 421251, collection USGS 9005–SD.
- 1, 6. Section through base of calice (reversed), ×3; detail ×10.
- 2, 3. Transverse some 17 mm lower (reversed), ×3, detail ×10.
- 4, 5. Intervening longitudinal, ×3, detail ×10.



BRIANTELASMA

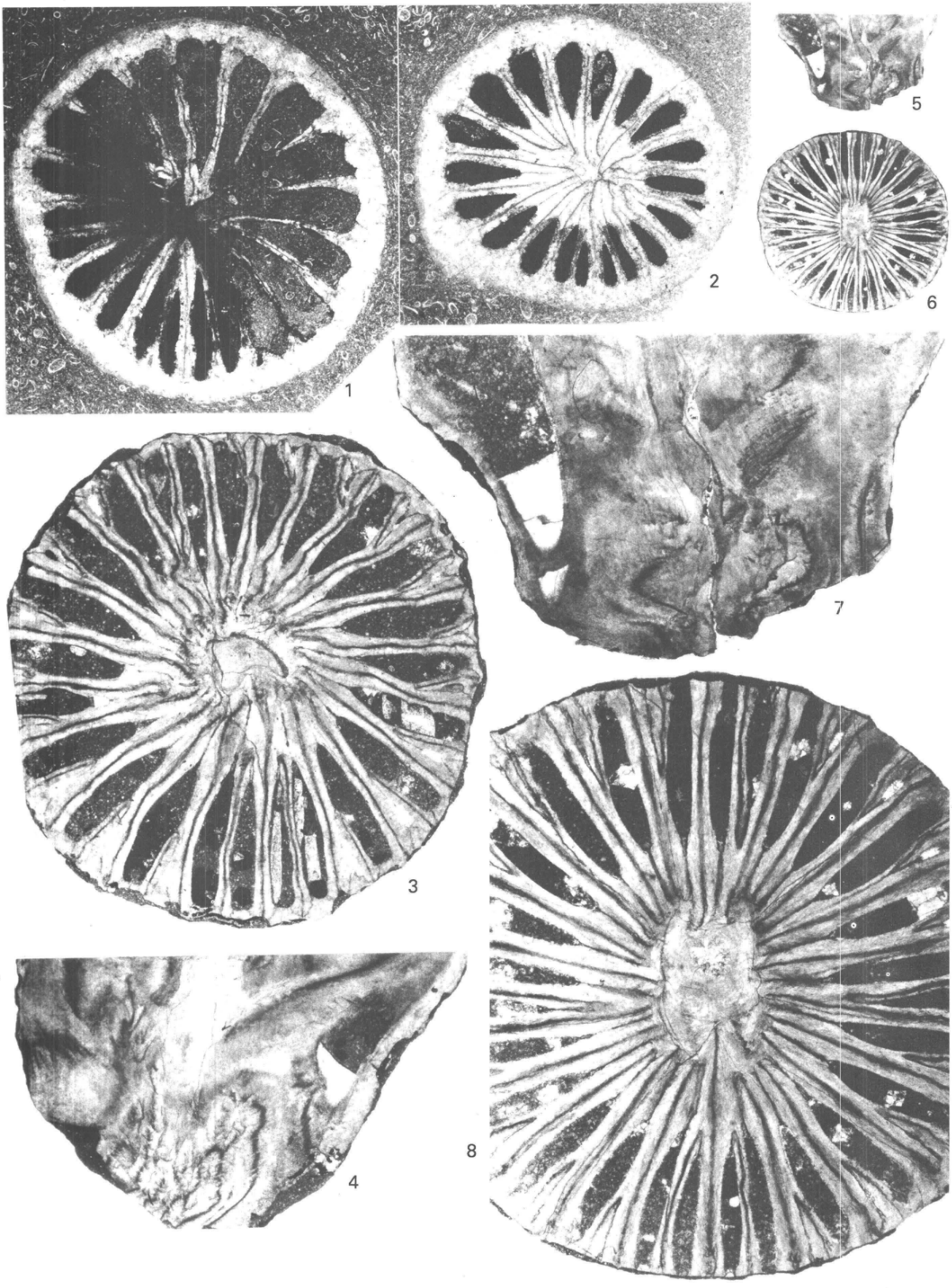
PLATE 5

Stereolasma fereplena n.sp.

Figures 1, 2. Paratype, USNM 421272, collection USGS 9015–SD. Transverse above and below base of calice, ×10; approximately 2 mm apart.

3, 4. Paratype, AMNH 43521, collection AMNH, Hayfield, Va. Transverse and lower longitudinal, ×10.

5–8. Holotype, AMNH 43520, collection AMNH, Hayfield Va. Transverse and lower longitudinal, each ×3 and ×10.

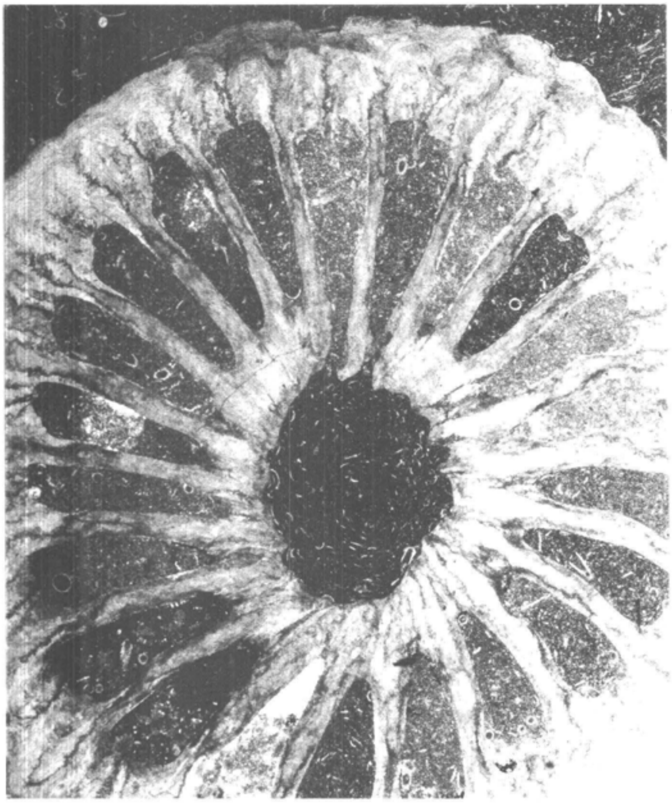


STEREOLASMA

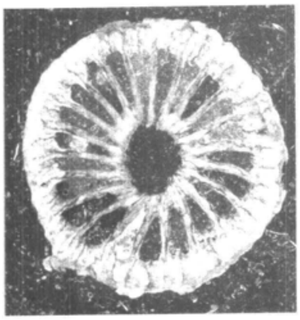
PLATE 6

Neaxon sp. A

Figures 1–3. USNM 421279, collection USGS 9015-SD. Transverse, ×10 and ×3; lower longitudinal, ×3.



1



2

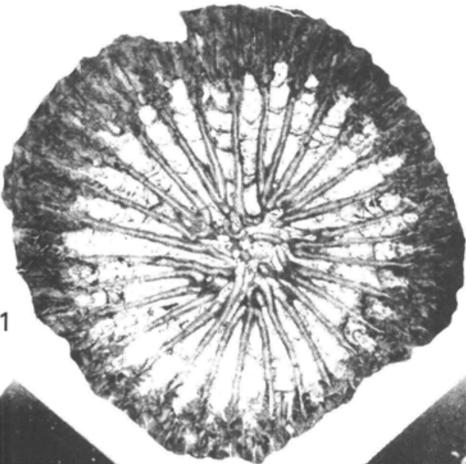
3

NEAXON

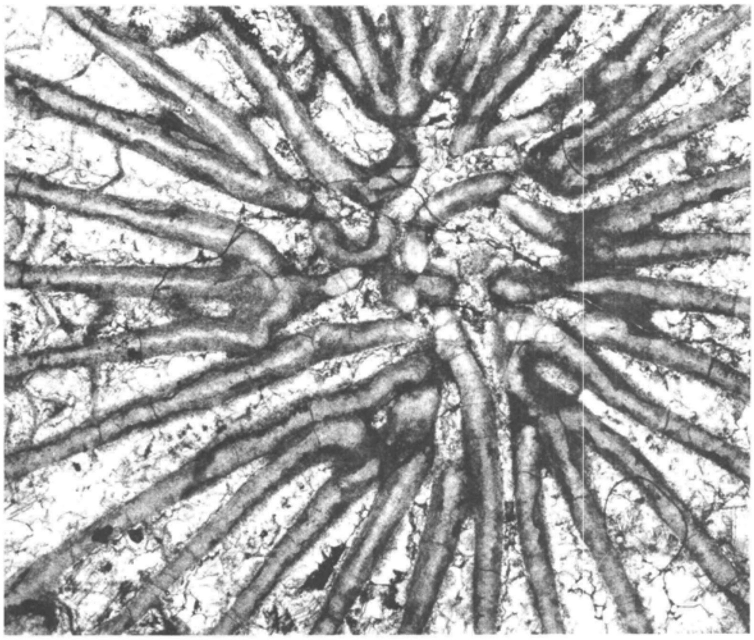
PLATE 7

Enterolasma dutroi n.sp.

Figures 1–4. Holotype, AMNH 43526, collection AMNH, Hayfield, Va.
1, 3, 4. Transverse, ×3; detail ×10.
2. Higher longitudinal, ×3, showing calice and boss.
5. Paratype, USNM 421282, collection USGS 6062–SD. Longitudinal of small specimen.
6–8. Paratype, USNM 421281, collection USGS 11462–SD. Transverse and lower longitudinal, ×3; detail of longitudinal ×10.



1



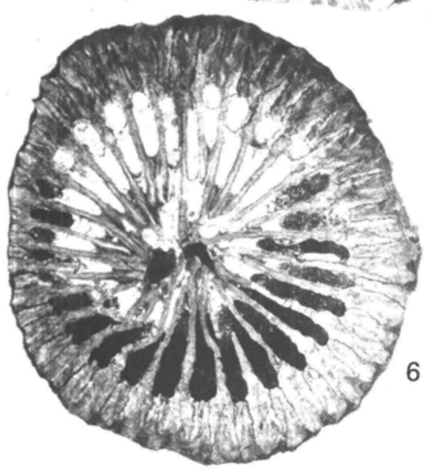
3

2

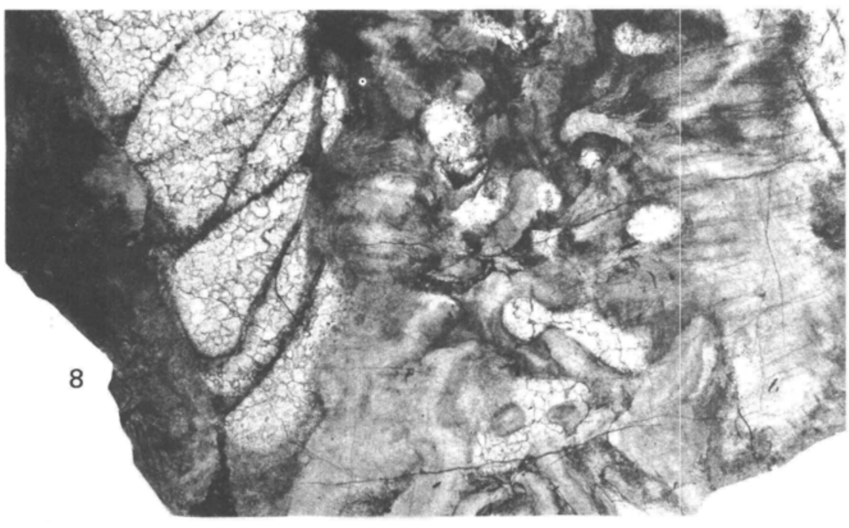
5

4

7



6



8

ENTEROLASMA

Chapter D

Bowenelasma (Rugose Coral) from the Emsian and Early Eifelian(?) (Devonian) of New York

By WILLIAM A. OLIVER, JR.

U.S. GEOLOGICAL SURVEY BULLETIN 1860

Shorter Contributions to Paleontology and Stratigraphy

CONTENTS

PLATES

[Plates follow References cited]

FIGURES

Bowenelasma (Rugose Coral) from the Emsian and Early Eifelian(?) (Devonian) of New York

By William A. Oliver, Jr.

Abstract

The rugose coral *Bowenelasma* Scrutton was originally described from early Eifelian(?) specimens in northwestern Venezuela. It is here described from New York on the basis of specimens from the Bois Blanc Formation (early? Emsian) and the Edgecliff Member of the Onondaga Limestone (early Eifelian?). The Bois Blanc *Bowenelasma* are beautifully silicified, so that morphologic details of both exterior and interior can be described.

Bowenelasma is limited to the Eastern Americas Realm and to rocks of late Early and early Middle Devonian age.

INTRODUCTION

The purpose of this paper is to describe and illustrate two species of *Bowenelasma* Scrutton that are of particular biogeographic importance and morphologic interest.

Bowenelasma was originally described from the Sierra de Perijá in northwestern Venezuela. The relationships of Venezuelan Devonian fossils to those from Eastern North America have long been recognized (see discussions by Oliver, 1977, p. 119; this volume), and Boucot (1975, p. 316) named an "Amazon-Colombian Subprovince" of the Eastern Americas Realm to include this area. With the recognition of *Bowenelasma* in New York (Oliver, 1977, p. 119), every Devonian rugose coral genus known from South America is also known from Eastern North America, and the definition of a northern South American province or subprovince, separate from the Appohimchi Province within the Eastern Americas Realm, has to be based on fossils other than the corals.

Bowenelasma is known only from Venezuela and New York. The Caño Grande Formation, from which *Bowenelasma* was originally described by Scrutton (1973), is of Emsian or Edgecliff (early Eifelian?) age (see Scrutton (1973, p. 229–232) and Oliver (this volume) for discussions). During Emsian-Edgecliff time, 75 percent of the Eastern Americas Realm rugose coral genera were endemic (Oliver, 1977; Oliver and Pedder, 1984, p. 451).

Specimens of *Bowenelasma* from the Bois Blanc Formation (Emsian) in New York are of unusual interest because of their preservation. In many specimens, a very thin outer layer of the coral is finely silicified, while interiors are calcitic and apparently little altered. The silicified layer provides a seal, which permits the specimens to be etched from the limestone with dilute HCl without damaging the interior. Thus, both external and internal morphologies of the same specimens can be illustrated and described in greater than normal detail.

STRATIGRAPHY OF *BOWENELASMA* IN NEW YORK

New species of *Bowenelasma* are described in the following section from the Bois Blanc Formation (early Emsian) in western New York and from the Edgecliff Member of the Onondaga Limestone (early Eifelian?) in both western and east-central New York (text fig. 1). The age of these units and the position of the Early-Middle Devonian (Emsian-Eifelian) boundary were recently discussed by Kirchgasser and others (1985, p. 237, 242) (see also summary by Oliver, this volume). The upper half of the Nedrow Member of the Onondaga Limestone (text fig. 1) is well dated as Eifelian (but not earliest Eifelian) by both conodonts and goniatites. The Bois Blanc Formation is somewhat less securely dated as Emsian (early?) by conodonts and brachiopods. The Edgecliff and lower Nedrow are in between, but analysis of the Needmore Shale fauna (House, 1978; Oliver, this volume) suggests that the Edgecliff is most likely Eifelian.

Acknowledgments

All thin sections were prepared by William C. Pinckney, Jr. Photographs of *B. scruttoni* exteriors are

---

Manuscript approved for publication May 16, 1988.

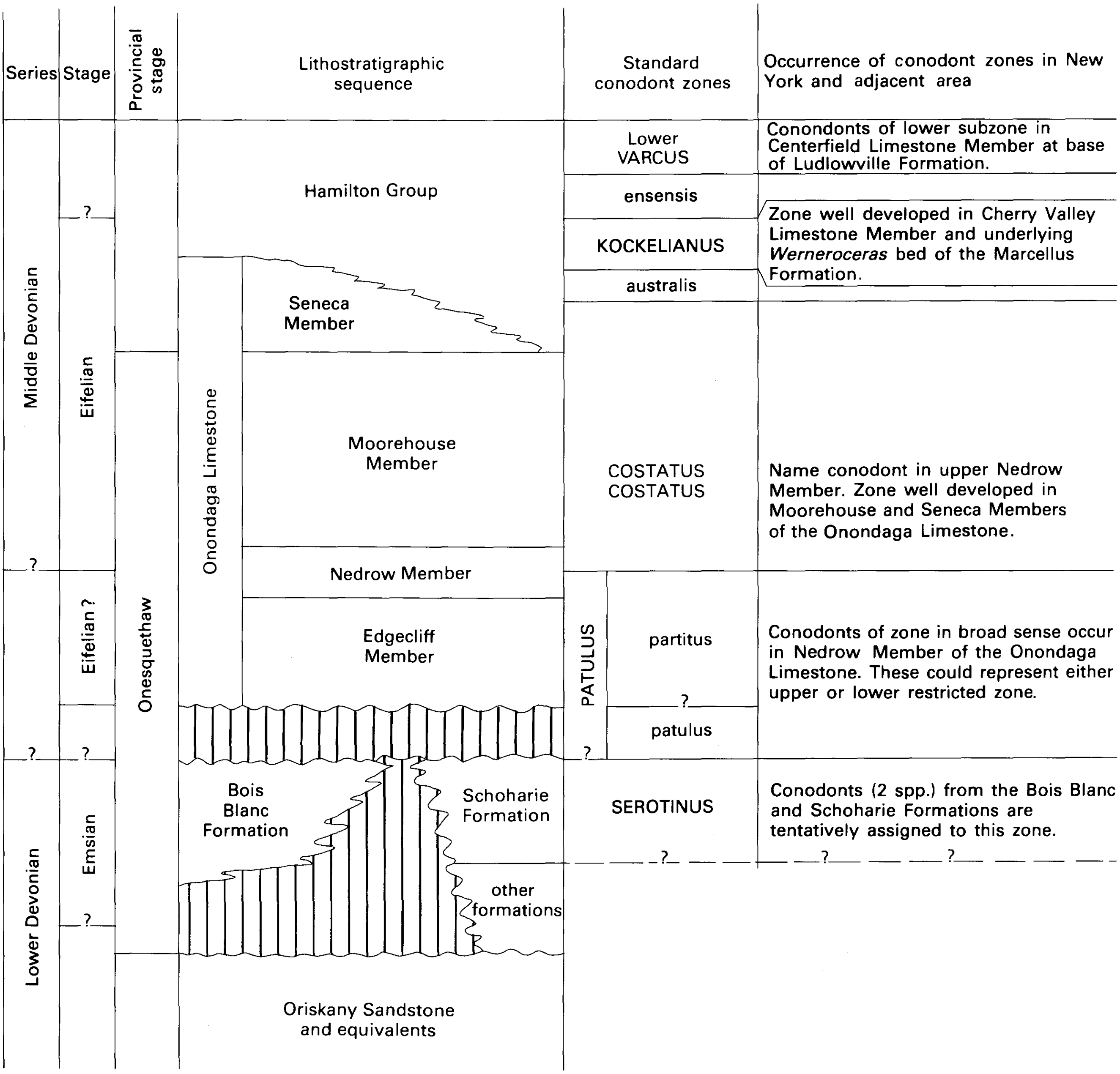


Figure 1. Emsian-Eifelian stratigraphy in New York. Only those terms necessary for understanding the text discussion are included. Conodont zones and annotations are extracted from Kirchgasser and others (1985, table 2). Zones set in capital letters have been recognized in New York; other standard zones (in lower case) are inserted in their proper sequence. The base of the Eifelian Stage and of the Middle Devonian Series is at the base of the *partitus* Zone, according to the decision of the International Subcommission on the Devonian System (see Kirchgasser and others, 1985, p. 235–237).

by N.W. Shupe and R.H. McKinney; I took the thin section photographs. The manuscript was critically reviewed by Jean M. Berdan and William J. Sando, whose suggestions were helpful. I am indebted to all of these individuals for their assistance.

SYSTEMATIC PALEONTOLOGY

All described specimens are preserved in the U.S. National Museum of Natural History (USNM) and are from collections that I made. Locality descriptions of all illustrated and measured specimens are cited on page D5.

Family STREPTELASMATIDAE Nicholson

part. Streptelasmatidae of authors.

1971. Streptelasmatidae Nicholson. Scrutton, p. 206–207.

1981. Streptelasmatinae Nicholson. Hill, p. F148.

Diagnosis.—Solitary corals with a narrow peripheral stereozone. Axial ends of major septa lobed, discontinuous or variously convoluted, commonly forming axial structure. Cardinal fossula present but may be weak or inconspicuous. Tabulae highly arched, complete or incomplete. No dissepiments.

Discussion.—No two specialists seem to agree on the definition or contents of this family, and, in its broadest usage at least, it certainly includes unrelated forms. The two descriptions cited in my synonymy come closest to my concept of the family, and my diagnosis is based on them. Hill (1981) used the family (as opposed to the subfamily) in a much broader sense, and some of her subfamilies seem to me to be quite unrelated to her Streptelasmatinae.

Bowenelasma Scrutton was placed in the family by Scrutton and in the subfamily by Hill. I have no better suggestion, but it is so different in its pronounced bilaterality, although it retains (or possesses) the basic family characters, that I consider it to be a separate subfamily. I have no comments on other aspects of streptelasmatid classification.

Subfamily BOWENELASMATINAE n.subfam.

Type genus.—*Bowenelasma* Scrutton, 1973, p. 242–243.

Diagnosis.—Solitary streptelasmatids with loose axial structure of vermiform axial lobes or convoluted lamellar extensions of major septa. Septa strongly dilated in early stages; dilation persisting to maturity in cardinal quadrants but septa becoming attenuate in counter quadrants. Cardinal fossula well developed and on convex side but inconspicuous in sections much below the calice floor.

Discussion.—The axial structure of *Bowenelasma* is strikingly similar to that of *Enterolasma* and other Enterolasmatinae but differs in the early-stage septal dilation and the pronounced bilaterality of its later stages. Enterolasmatinae are almost radial in transverse sections, the four primary septa are weakly marked except in the calice, and all major septa are approximately equal in thickness in all quadrants.

Hill (1981) established the Enterolasmatinae because of the peculiar axial structure of *Enterolasma* Simpson and its more obvious relatives. The Bowenelasmatinae have the same axial structure, although it is not as consistently well developed, but are very different in other respects. Both subfamilies are referable to the Streptelasmatidae as diagnosed above.

Genus *Bowenelasma* Scrutton, 1973

1973. *Bowenelasma* Scrutton, p. 242–243.

1981. *Bowenelasma* Scrutton. Hill, p. F154.

Type species.— *Bowenelasma typa* Scrutton, 1973. Caño Grande Formation, Emsian or early Eifelian(?), Venezuela.

Diagnosis.—Curved ceratoid corals with the cardinal septum [commonly] on the convex side of the corallum. Septa dilated to close [or nearly close] the lumen in early ontogeny; strongly dilated and more or less coated with sclerenchyme in the cardinal quadrants at the ephebic stage. Cardinal fossula [well developed on calice wall and at calice floor level; difficult to recognize in sections below calice.] Intertwined septal elements [, lobes, form a loose axial structure and] a low boss in the calice. Minor septa well developed. Tabulae [strongly domed]. No dissepiments. (Diagnosis mostly quoted from Scrutton, 1973, p. 242; I have added the words in brackets.)

Discussion.—*Bowenelasma* was first described from the Caño Grande Formation (early Eifelian(?)) in the Sierra de Perijá of Venezuela. Its recognition in rocks from New York adds another link connecting the Venezuela and Appohimchi coral assemblages. It also adds significantly to our knowledge of the genus, because etched specimens from New York show the features of the calice and exterior very nicely.

The genus combines the enterolasmatinid axial structure with a halliid septal arrangement; septal dilation persisting to a late stage in the cardinal quadrants gives a distinct bilteral appearance to transverse sections below the calice. However, I agree with Scrutton that the structure is basically streptelasmatid.

Distribution.—At present, *Bowenelasma* is known only from *B. typa* and *B. breviseptata* Scrutton from the Caño Grande Formation in Venezuela, *B. scruttoni* n.sp. from the Bois Blanc Formation (Emsian) in western New York, and *B. pinckneyi* n.sp. from the Edgecliff Member of the Onondaga Limestone in western and east-central New York.

Bowenelasma scruttoni n.sp.

Plates 1–4

Holotype.—USNM 421437, Bois Blanc Formation, Emsian, Goodrich Road, Town of Clarence, Erie County, New York.

Diagnosis.—Medium-sized *Bowenelasma* with well-developed fossula and a spongy column formed by the irregular interfingering of vermiform extensions of the septa.

External features.—Over 25 known coralla are irregularly curved, simple, ceratoid corals up to 6.5 cm long and 3 cm in diameter (pl. 1). Direction of curvature may change with growth, but the cardinal septum is commonly on the convex side at maturity. Exteriors are worn, but septal grooves and broad interseptal ridges are present, as are gentle rugae at intervals of 3 to 5 mm.

Calice depth is approximately 0.7 to 0.8 times the diameter. The cardinal fossula is well developed, formed by downbending of tabulae and by short cardinal septum. Major septa extend to the axial column and are irregularly involved in its formation; they are pinnately arranged on either side of the cardinal fossula, becoming radial in the counter quadrants. Major septa are deflected to the right at the column, so that an axial whorl contributes to the formation of the column. The column projects into the base of the calice and forms a low boss with short, irregular vermiform traces on its surface. Within the calice, major septa are thin and approximately equal; minor septa are significantly thinner and shorter than the majors.

Internal features.—Major septa number 19 to 35 in transverse sections 6.5 to 26 mm in diameter (text fig. 2). Major septa extend to the axial complex and are variously involved in it; minor septa are 0.3 to 0.65 times as long. Both cardinal and counter minors may be somewhat longer than the other minor septa. The cardinal septum is thin and short in sections in or just below the calice but is as thick as other major septa in lower sections.

Septal arrangement is bilateral in the cardinal quadrants and is emphasized in that septal dilation persists longer in these sectors. Septa are radial and attenuate at an earlier stage in the counter quadrants. In early ephebic and earlier stages, all septa are dilated, and the lumen can be completely filled.

The axial column is a complex network of twisted axial ends of septa, many with vermiform lobes. In mature parts of the corallum, the axial complex occupies the center third.

In longitudinal sections, the column area is very irregular (see illustrations). Outer areas are filled with septa, and there are faint indications of growth laminae that presumably marked the upper margins of septa at an earlier stage, but the microstructure is not well preserved. Tabulae are few but strongly arched, with a slight reversal at the outer wall.

Variation.—Individual variation in size and septal number is shown in text figure 2, but it is not practical to separate fully developed (ephebic) individuals or stages from earlier ones, because size and septal number increased throughout life. Extreme variation in the appearance of the column in both longitudinal and transverse sections and in the calice is owing to the erratic course followed by septa and septal lobes; this fact is best appreciated by reference to the illustrations (pls. 2–4).

Discussion.—*B. scruttoni* differs from *B. typa* and *B. breviseptata* in its very well developed enterolasmatinid axial complex and prominent fossula. It has fewer septa for a given diameter than *B. typa* and longer major septa than *B. breviseptata*. A comparison with *B. pinckneyi* is included in the discussion of that species.

Distribution.—*B. scruttoni* is known only from the Bois Blanc Formation (early? Emsian) in western New York.

Material.—The 25 specimens in the study lot were all etched from blocks of limestone by using dilute HCl. In these corals, silicification provided a very thin outer protective coating, and the internal structures are calcitic and moderately well preserved. The combination of external silicification and internal preservation with little modification permitted the illustration of the external form (pl. 1) and internal structures (pls. 2–4) of some of the same specimens.

Holotype, USNM 421437; illustrated paratypes, USNM 421438 to 421447; unillustrated paratypes, USNM 421448 to 421458. All specimens are from locality USGS 4672-SD.

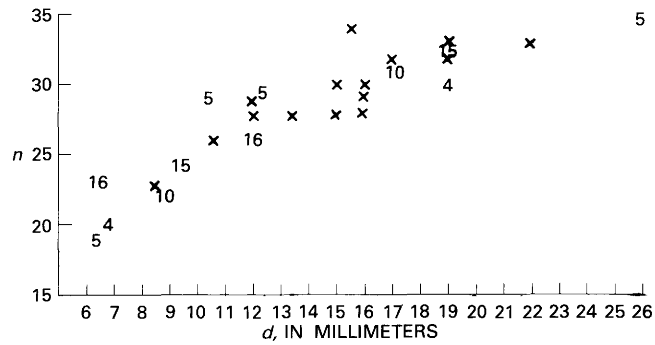


Figure 2. Number of major septa (*n*) plotted against diameter (*d*) in millimeters in *Bowenelasma scruttoni* n.sp. Measurements and counts are from 27 thin sections in a sample of 20 sectioned specimens. Sequential plots from one coral are marked by a specimen number (for example, figures from four sections of specimen 5 are plotted).

Bowenelasma pinckneyi n.sp.

Plates 5, 6

Holotype.—USNM 421459, Edgecliff Member of Onondaga Limestone (early Eifelian?), 2 km west of Leesville, in Otsego County, New York.

Diagnosis.—Medium to large *Bowenelasma* with weak or variable fossula, excessive and persistent dilation in cardinal quadrants, and a spongy column formed by irregular vermiform extensions of the septa.

External features.—Simple, curved, trochoid to ceratoid corals are up to 10 cm long and 4 cm in maximum diameter; the cardinal septum is commonly on convex side. Septal grooves, flat interseptal ridges, and numerous irregularly spaced rugae are present on the few exteriors that were seen. The calice is deep, and the fossula is present but shallow and formed by a short cardinal septum.

Internal features.—Major septa number 25 to 40 in transverse sections 10 to 25 mm in diameter (text fig. 3). Major septa extend to the axial complex and are variously involved in it; minor septa are 0.2 to 0.3 times as long. Minors may lean away from the cardinal toward the counter positions and rarely are contratingent. Both cardinal and counter minors may be somewhat longer than the other minor septa.

The cardinal septum is short in some sections, especially at or just below the floor of the calice; in many sections, neither cardinal nor counter septum is distinguishable. Bilateral septal arrangement is indicated by septal dilation. In early stages, septa are equally dilated, and the lumen may be completely filled; sections through these parts of the corallum cannot be independently oriented. In later stages, septa on the counter side are thin and become attenuate, while, on the cardinal side, dilation persists almost to the level of the calice. The dilation-attenuation pattern shows the bilaterality in thin sections through these stages, but the cardinal, counter, and alar septa are commonly not recognizable.

The axial complex is very irregular but is formed by the twisted axial ends of major septa, many of which have vermiform lobes. It is variable in density, since the septal elements may almost fill the column space or form a very loose and open network. The diameter of the column is approximately one-third that of the coral.

In longitudinal sections, the column area is irregular (see illustrations). Outer areas are occupied by septa, especially in the cardinal half; there are marked growth laminae. Tabulae are strongly arched with a slight reversal at the outer wall.

Variation.—Individual variation in size and septal number is shown in text figure 3, but it is not practical to separate ontogenetic variation from adult variation in these conical forms. Variation in axial structure and in dilation of septa is best appreciated by reference to the photographs (pls. 5, 6).

Discussion.—*B. pinckneyi* differs from *B. scruttoni* in its lack of marked C-K bilateral symmetry and late and weak fossula development, more persistent septal dilation in the cardinal side, and more variable column. *B. pinckneyi* tends to be larger and, at diameters greater than 15 mm, tends to have more septa for a given diameter.

B. pinckneyi differs from *B. typa* and *B. breviseptata* in its well-developed enterolasmatinid axial complex; it has longer major septa than *B. breviseptata*.

Distribution.—*B. pinckneyi* is known only from the Edgecliff Member of the Onondaga Limestone in New York.

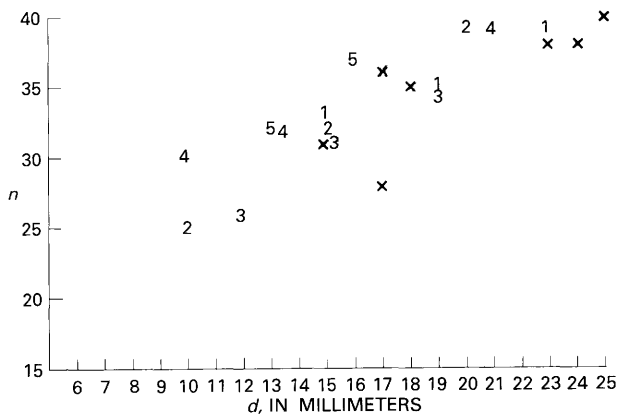


Figure 3. Number of major septa (*n*) plotted against diameter (*d*) in millimeters in *Bowenelasma pinckneyi* n.sp. from the Edgecliff Limestone Member. Data are from 21 thin sections in a sample of 13 specimens. Sequential plots from one coral are marked by a specimen number (for example, data from three sections of specimen 1 are plotted).

Material.—Holotype, USNM 421459; 18 paratypes, USNM 421460 to 421447. Locality information is given in the following section.

LOCALITIES

The described corals are from one Bois Blanc locality and several Edgecliff localities.

The Bois Blanc Formation in western New York was described and discussed by Oliver (1967). All specimens of *Bowenelasma scruttoni* n.sp. are from locality USGS 4672-SD (Oliver, 1967, p. 7). Most of the Bois Blanc brachiopods described by Boucot and Johnson (1968) were from the same locality (Boucot and Johnson, 1968, p. 4).

The general stratigraphy of the Onondaga Limestone was most recently reviewed by Oliver (1976). The specimens of *B. pinckneyi* n.sp. are from the biostrome facies of the Edgecliff Member (Oliver, 1976, p. 8–9). Localities from which specimens of the type assemblage were collected are listed here and described in the cited work (Oliver, 1976, p. 141), except for locality 228, which is described here.

Locality 154. Paratype, USNM 421469.
- 164. Holotype, USNM 421459; nine paratypes, USNM 421460 to 421468.
- 188. Paratype, USNM 421470.
- 206. Four paratypes, USNM 421471 to 421474.
- 215. Paratype, USNM 421475.
- 228. Paratypes, USNM 421476 and 421477. Jordanville quadrangle; southeastern part of map. Outcrop along Chyle Road, 0.7 km east of Warren Road, 3.5 km north of Warren, Herkimer County.

REFERENCES CITED

Boucot, A.J., 1975, Evolution and extinction rate controls: Amsterdam, Elsevier, 427 p.

Boucot, A.J., and Johnson, J.G., 1968, Brachiopods of the Bois Blanc Formation in New York: U.S. Geological Survey Professional Paper 584-B, 27 p.

Hill, D., 1981, Part F, Coelenterata, supp. 1, Rugosa and Tabulata, *in* Treatise on invertebrate paleontology: Boulder, Colo., and Lawrence, Kans., Geological Society of America and University of Kansas, 762 p.

House, M.R., 1978, Devonian ammonoids from the Appalachians and their bearing on international zonation and correlation: Palaeontological Association Special Papers in Palaeontology 21, 70 p.

Kirchgasser, W.T., Oliver, W.A., Jr., and Rickard, L.V., 1985, Devonian series boundaries in the eastern United States: Courier Forschungs-institut Senckenberg, v. 75, p. 233-260.

Oliver, W.A., Jr., 1967, Stratigraphy of the Bois Blanc Formation in New York: U.S. Geological Survey Professional Paper 584-A, 8 p.

——— 1976, Noncystimorph colonial rugose corals of the Onesquethaw and lower Cazenovia Stages (Lower and Middle Devonian) in New York and adjacent areas: U.S. Geological Survey Professional Paper 869, 156 p.

——— 1977, Biogeography of Late Silurian and Devonian rugose corals: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 22, p. 85-135.

Oliver, W.A., Jr., and Pedder, A.E.H., 1984, Devonian rugose coral biostratigraphy with special reference to the Lower-Middle Devonian boundary: Geological Survey of Canada Paper 84-1A, p. 449-452.

Scrutton, C.T., 1971, Palaeozoic coral faunas from Venezuela, pt. I, Silurian and Permo-Carboniferous corals from the Merida Andes: Bulletin of the British Museum (Natural History), Geology, v. 20, p. 183-227.

——— 1973, Palaeozoic coral faunas from Venezuela, pt. II, Devonian and Carboniferous corals from the Sierra de Perijá: Bulletin of the British Museum (Natural History), Geology, v. 23, p. 221-281.

PLATES 1–6

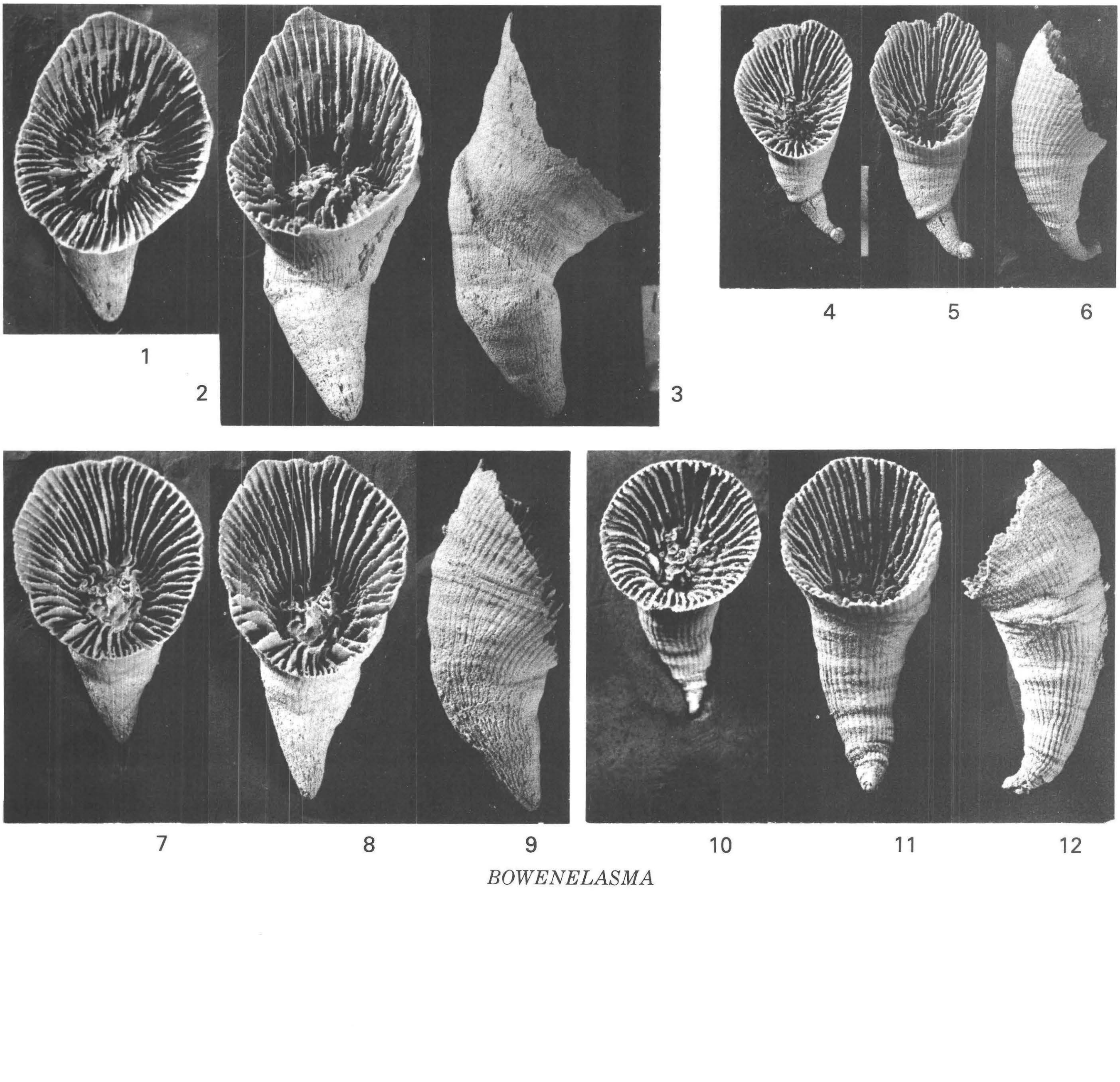
All photographs of thin sections are at ×3 or ×10. Transverse sections are oriented such that the cardinal position is toward the top of the plate; all are photographed as though looking down (that is, from the calice toward the apex). All specimens are reposited in the U.S. National Museum of Natural History (USNM), Washington, D.C.

PLATE 1

Bowenelasma scruttoni n.sp.

All figures ×1

Figures 1–3. Paratype, USNM 421437. Calice, front and side views. (See also pl. 4, figs. 7, 8.)
4–6. Paratype, USNM 421445. Calice, front and side views. (See also pl. 2, fig. 8.)
7–9. Paratype, USNM 421444. Calice, front and side views.
10–12. Paratype, USNM 421446. Calice, front and side views.



BOWENELASMA

PLATE 2

Bowenelasma scruttoni n.sp.

Figures 1–6. Holotype, USNM 421437.

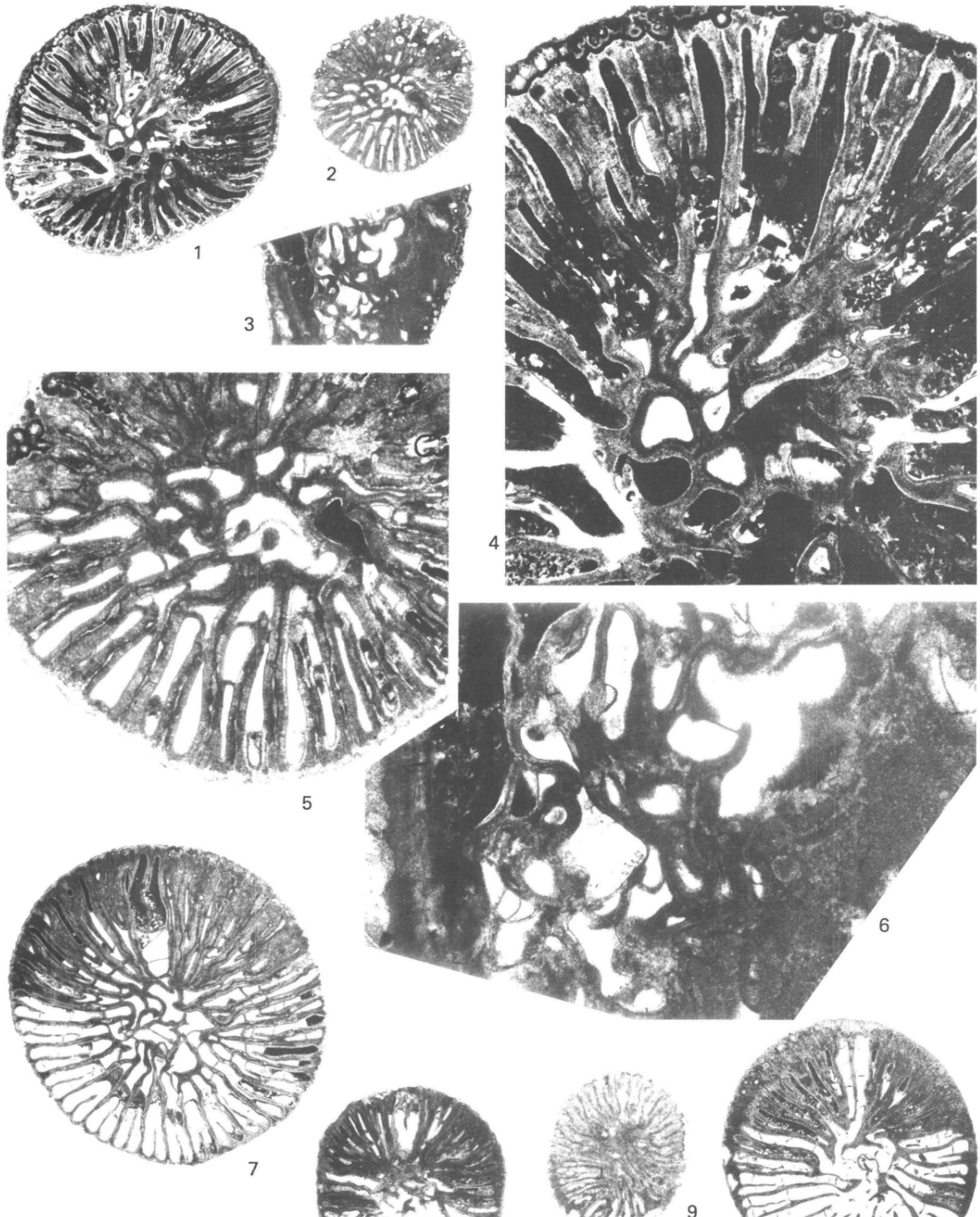
1–3. Upper transverse, middle longitudinal and lower transverse sections, ×3; upper and lower sections are separated by approximately 15 mm.

4–6. Details of three sections, ×10.

7. Paratype, USNM 421441. Transverse, ×3.

8. Paratype, USNM 421445. Transverse, ×3. (See also pl. 1, figs. 4–6.)

9–10. Paratype, USNM 421442. Lower and upper transverse sections originally approximately 15 mm apart, ×3.



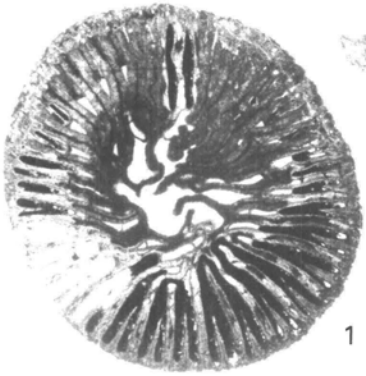
BOWENELASMA

PLATE 3

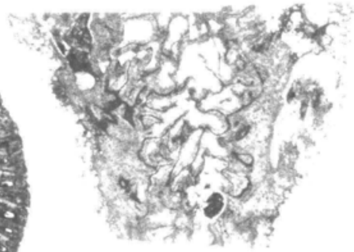
Bowenelasma scruttoni n.sp.

Figures 1–4. Paratype, USNM 421440. Transverse and longitudinal sections, ×3; details, ×10.

5–8. Paratype, USNM 421438. Upper and lower transverse sections, ×3; intervening longitudinal, ×3; detail, ×10. Upper and lower sections approximately 18 mm apart.

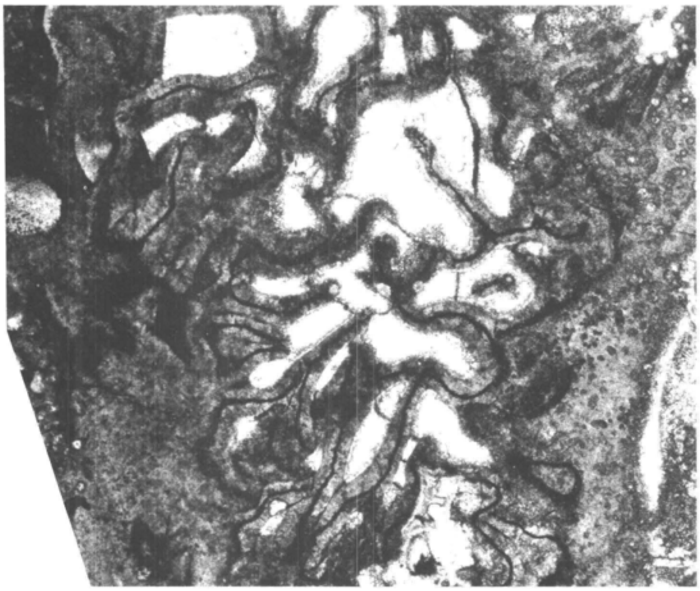


1

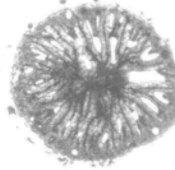


2

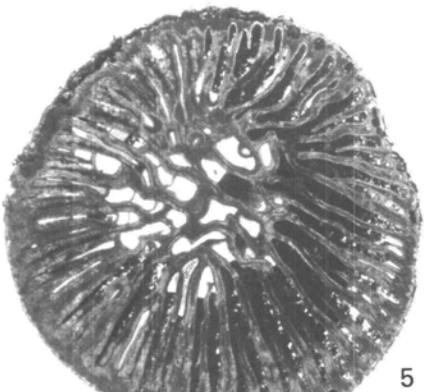
4



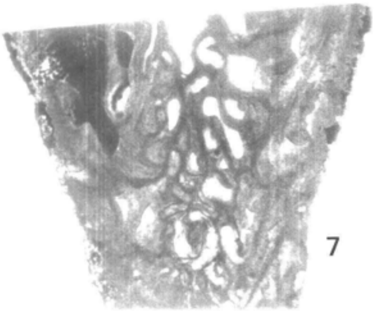
3



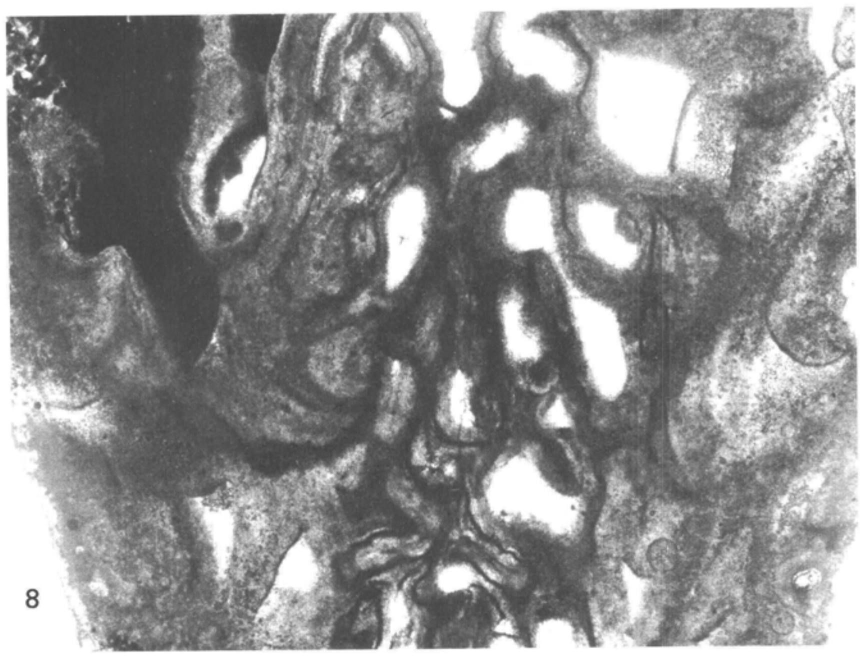
6



5



7



8

BOWENELASMA

PLATE 4

Bowenelasma scruttoni n.sp.

Figures 1–6. Paratype, USNM 421439.

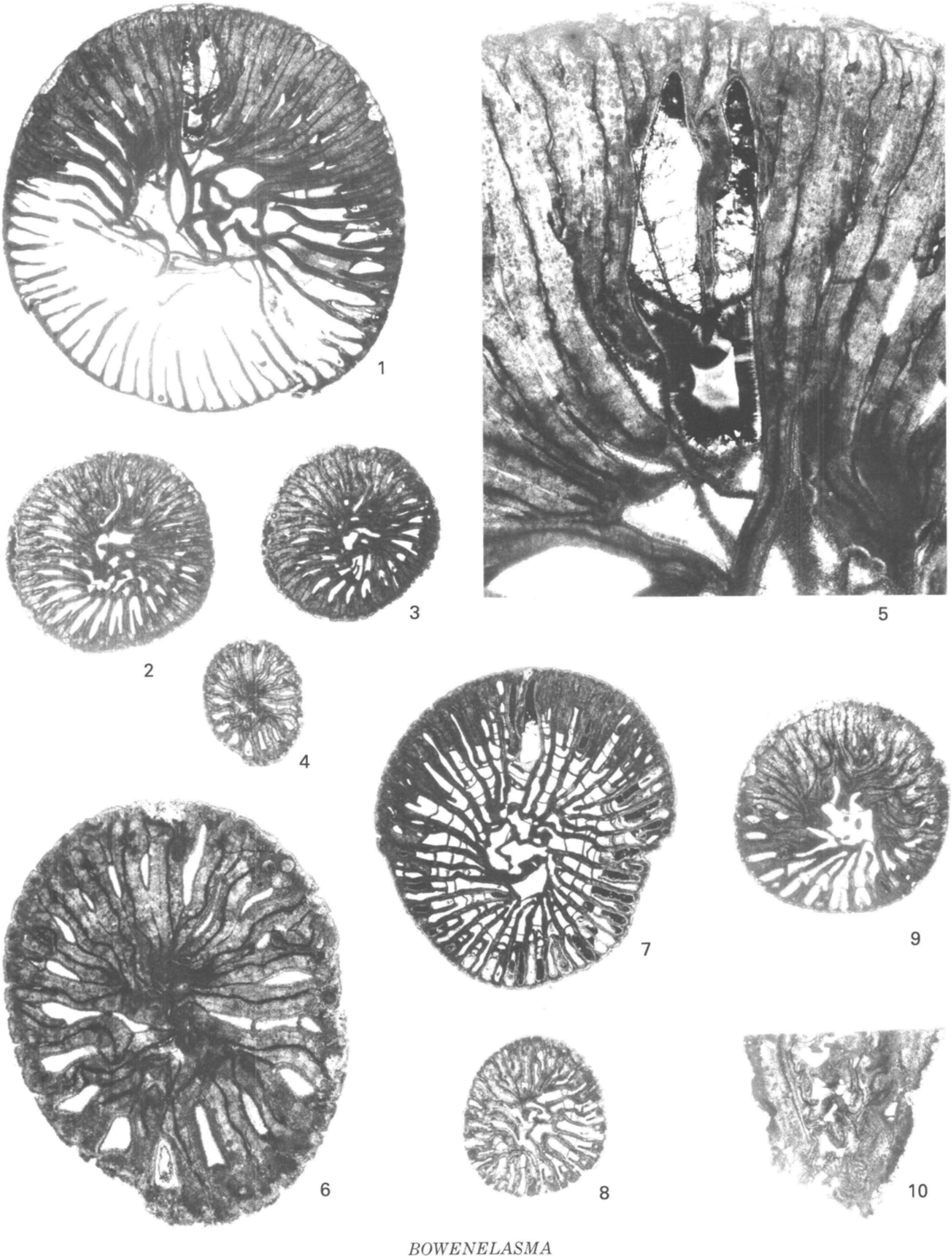
1–4. Serial transverse sections, ×3, from upper to lower, spaced approximately as follows: figures 1–2, 24 mm; figures 2–3, 2 mm; figures 3–4, 11 mm.

5. Detail of figure 1, ×10.

6. Original of figure 4, ×10.

7–8. Paratype, USNM 421443. Upper and lower transverse sections, ×3; originally separated by approximately 24 mm. (See also pl. 1, figs. 1–3.)

9, 10. Paratype, USNM 421447. Transverse and longitudinal sections, ×3.



BOWENELASMA

PLATE 5

Bowenelasma pinckneyi n.sp.

Figures 1–6. Holotype, USNM 421459.

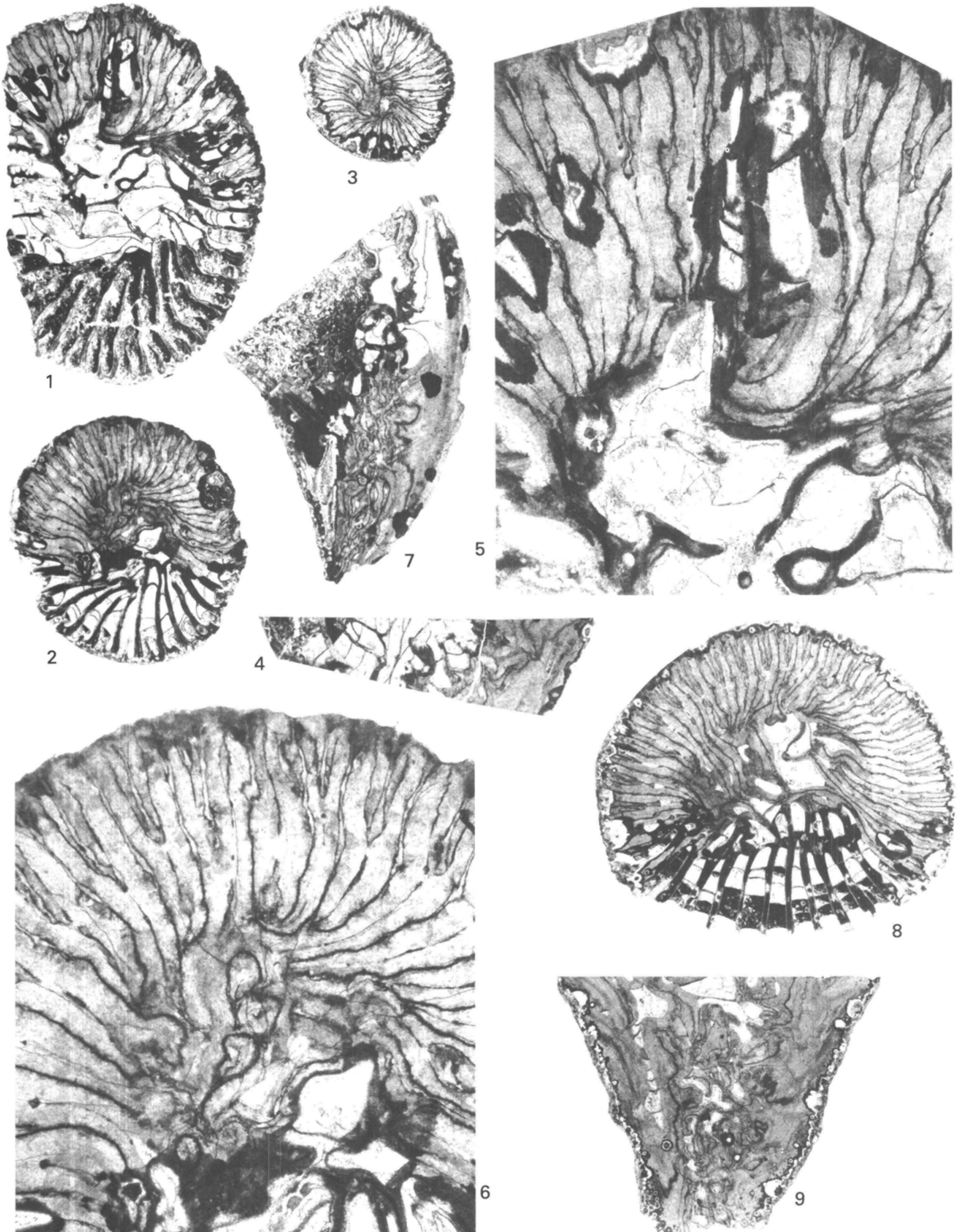
1–3. Serial transverse sections in descending order, ×3, spaced approximately as follows: figures 1–2, 10 mm; figures 2–3, 8 mm.

4. Longitudinal section, ×3, taken from between originals of figures 1 and 2.

5, 6. Details of originals of figures 1 and 2, ×10.

7. Paratype, USNM 421466. Longitudinal, ×3.

8–9. Paratype, USNM 421468. Transverse and longitudinal sections, ×3.



BOWENELASMA

PLATE 6

Bowenelasma pinckneyi n.sp.

Figures 1–3. Paratype, USNM 431477. Transverse, ×10 and ×3; lower longitudinal section, ×3.

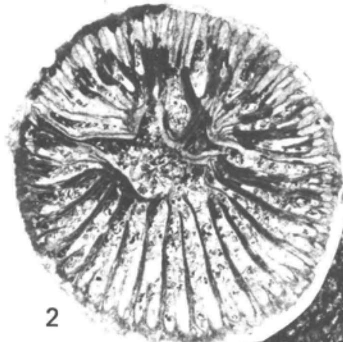
4–6. Paratype, USNM 431463.

- 4, 5. Upper and lower longitudinal sections separated by gap of approximately 2 mm, ×3.
- 6. Half of a transverse section taken from the other half of the coral at the level of the top of the lower longitudinal, ×3.

7–9. Paratype, USNM 431467.

- 8, 9. Longitudinal and transverse sections, ×3.
- 7. Detail of longitudinal, ×10.

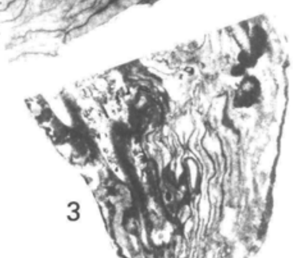
1



2

4

5



3

6

7

8

9

BOWENELASMA