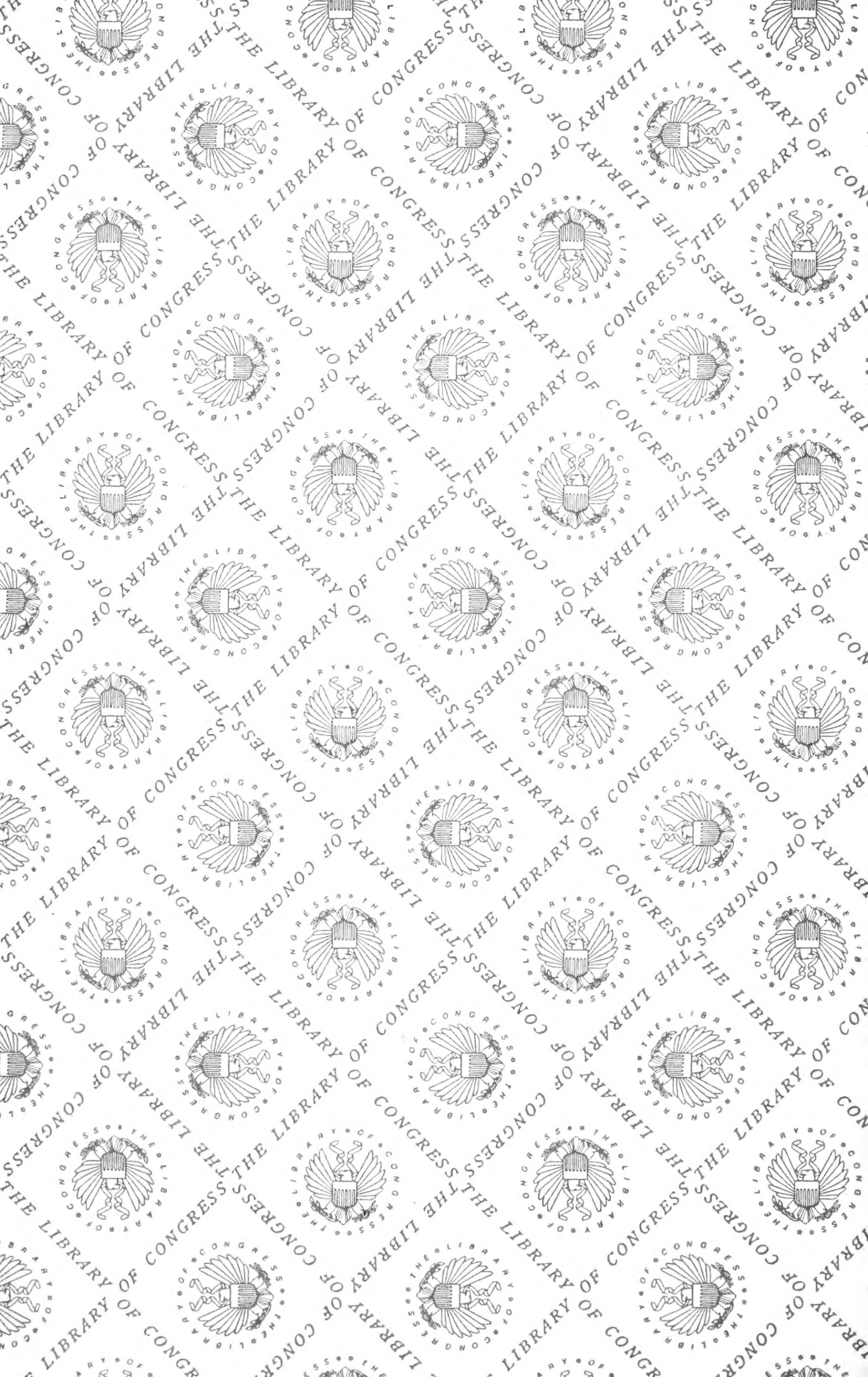
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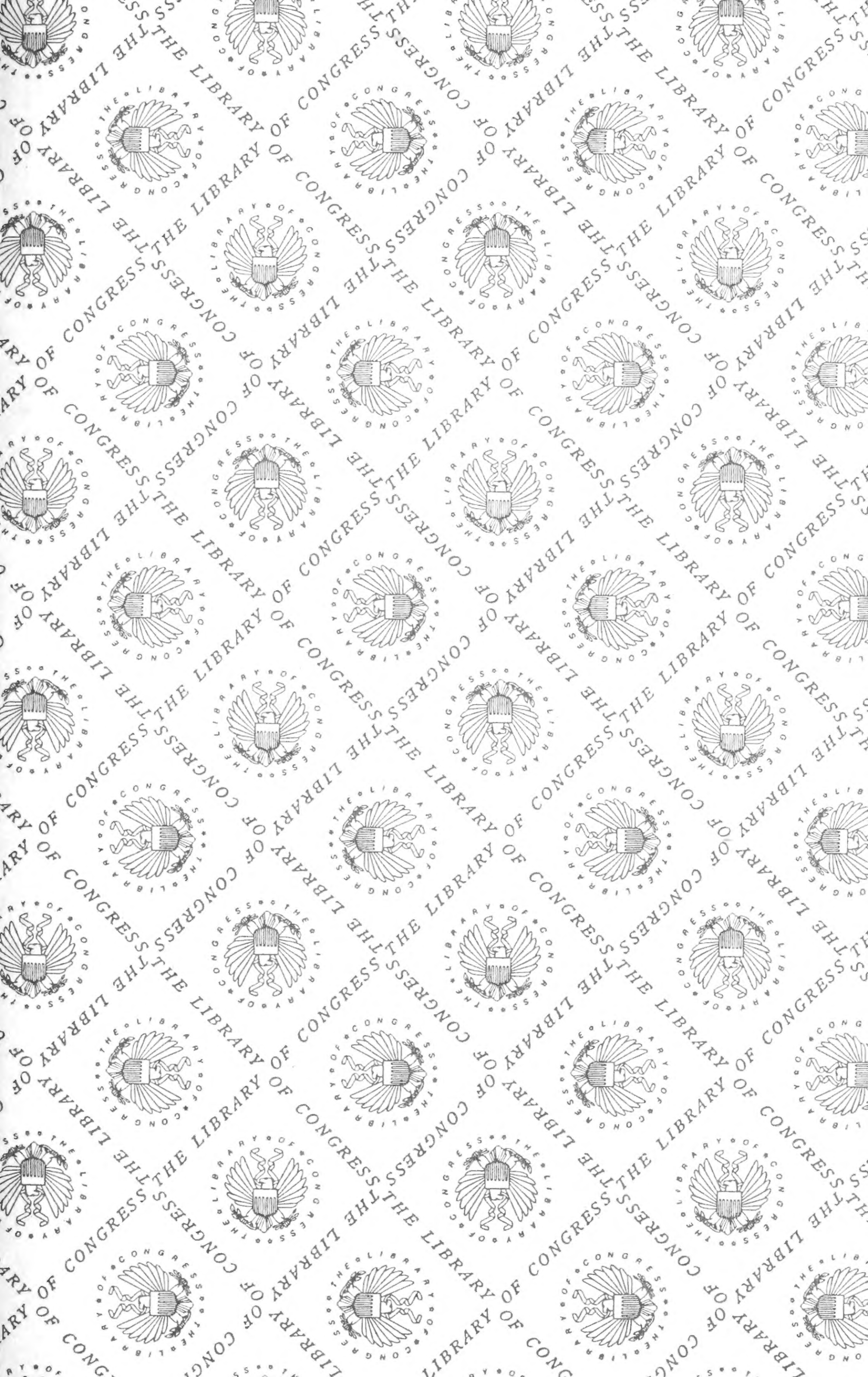
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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 148, NUMBER 3

**Charles D. and Mary Vaux Walcott
Research Fund**

UPPER CAMBRIAN TRILOBITE FAUNAS OF NORTHEASTERN TENNESSEE

(WITH 21 PLATES)

BY
FRANCO RASETTI

The Johns Hopkins University
Baltimore, Md.

(PUBLICATION 4598)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
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CONNECTICUT PRINTERS, INC.
HARTFORD, CONN., U.S.A.

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Charles D. and Mary Vaux Walcott Research Fund

UPPER CAMBRIAN TRILOBITE FAUNAS OF NORTHEASTERN TENNESSEE

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PART I. STRATIGRAPHY AND FAUNAS

The purpose of this paper is both to describe the fossils and to present them in their proper stratigraphic setting. In the study of the Cambrian of the southern Appalachians, there has been in the past little collaboration between geologists and paleontologists. Stratigraphic work was done by geologists who had only a secondary interest in fossil collecting; on the other hand, almost all the species described by Walcott and by Resser were derived from old collections that bear more or less precise locality labels but no accurate indication of the stratigraphic position. In his paper on the Cambrian of the southern Appalachians, Resser (1938a) tried to refer the Upper Cambrian fossils to several zones. This assignment was essentially based on the occurrence of the genera in question in better-understood areas of the United States, chiefly the Upper Mississippi valley, and in a broad sense succeeded in providing an approximately correct time order for the fossils of the southern Appalachians. However, none of the finer details of the time succession could be determined.

The obvious procedure was therefore to locate well-exposed, relatively undisturbed, fossiliferous sections, to collect fossils from carefully measured horizons, and to rely on these alone, and not on the old collections, in establishing the faunal succession. Many of the previously known Upper Cambrian trilobites from Tennessee were thus collected again from known strata; those that could not be found seldom represent more than slightly variant forms related to the ones of ascertained age. A number of new forms were discovered. In general, the collections are much larger than the ones previously in existence, and provide indications on intraspecific variability in populations from a single bed and similar questions that cannot be discussed on the basis of a few scattered specimens from different localities.

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On the basis of published records, first a brief reconnaissance was made of various areas of Cambrian outcrop in northeastern Tennessee and some adjacent areas of Virginia in search for sections that might yield the desired biostratigraphic information. Several belts of Cambrian outcrop did not appear promising for either one of two reasons. For example, those north of Clinch Mountain yield a few well-exposed sections, such as the ones at Thorn Hill, described by Hall and Amick (1934), and at Lee Valley, described by Rodgers and Kent (1948). However, most of these sections, with the notable exception of the one near Washburn, hold few fossiliferous beds of the *Crepicephalus* and *Aphelaspis* zones, and the preservation leaves much to be desired. On the other hand, other Cambrian belts, such as those in the vicinity of Greeneville and Morristown, yielded good fossils to the early collectors, but the sections are fragmentary and poorly exposed. Several localities were found that offered undisturbed, well-exposed, and highly fossiliferous sections.

Upper Cambrian fossils occur in northeastern Tennessee chiefly in the upper portion of the Maryville limestone and in the Nolichucky formation (including the Maynardville limestone). The overlying Copper Ridge dolomite, which seems to represent most of the Franconian and Trempealeauian stages, is almost totally barren. The few trilobites collected from this formation are mentioned by Rodgers (1953) and Bridge (1956). No search was made in the Copper Ridge dolomite.

Since the purpose of this paper is essentially paleontologic, no attempt was made to discuss the stratigraphy and nomenclature of the formations in question. This problem has been dealt with by Hall and Amick (1934), Rodgers and Kent (1948), Rodgers (1953), and Bridge (1956). The main points under discussion are whether the Maynardville limestone should be recognized as a separate formation or considered as the uppermost portion of the Nolichucky shale, and where the Maynardville–Copper Ridge contact should be placed. Several sections were measured and are described herein only in order to precisely locate the fossiliferous beds and establish the succession of the faunules. Questions of stratigraphic nomenclature are of secondary importance for these purposes.

Rodgers' geologic map of northeast Tennessee at the scale of 1:125,000 and the geologic map of the Mascot–Jefferson City zinc district by Bridge were found exceedingly useful in searching for possible sections and fossil localities. Dr. Charles R. L. Oder, Chief Geologist of the American Zinc Company of Tennessee, who has been studying the Maynardville limestone for years, showed the writer several interesting sections.

The area under consideration is covered by recent U.S. Geological

Survey 7½-minute quadrangles at the scale of 1:24,000. Localities are always indicated herein by coordinates (x = abscissa, y = ordinate) in millimeters, measured from the southeast corner of the map.

The present study has been limited to trilobites. In the Dresbachian formations of Tennessee the brachiopods are, as usual, the next invertebrate group in order of abundance. The phylum is represented mostly by inarticulates. Recent studies, such as those by Palmer (1954) and Bell and Ellinwood (1962) in Texas, have shown that adequate investigation of these fossils requires extensive etching of limestone with acetic or formic acid, since mechanical preparation generally yields only the exterior of the shell, of scarce taxonomic significance. It is possible that etching of large amounts of limestone of the *Aphelaspis* zone—the only portion of the Upper Cambrian in the area where brachiopods are relatively abundant—might yield interesting results. For a number of reasons such a program was not undertaken.

The other invertebrates observed are indeterminable echinoderm plates, fairly common in certain beds but poorly preserved; a small gastropod of the *"Helcionella"* type, and a few dendroid graptolites in shale beds. The description of these groups of fossils would not bring any significant contribution to paleontology.

ACKNOWLEDGMENTS

The present work was started as part of a research project under a grant from the Penrose Bequest of The Geological Society of America. This grant had already produced two papers (Rasetti, 1959, 1961) on the Cambrian of the central Appalachians. When funds from this source were no longer available, the work was continued and completed with grant No. 2829-P from the Penrose Fund of the American Philosophical Society. The author is greatly indebted to both institutions for their support.

Thanks are also due to Dr. Allison R. Palmer for valuable discussions on problems of taxonomy and biostratigraphy and for communicating unpublished results of his investigations in the Upper Cambrian of the western United States; to Dr. Robert B. Neuman for stratigraphic information; and to Dr. Charles R. L. Oder for communicating his unpublished measurements of sections and for accompanying the author in some field excursions.

DESCRIPTIONS OF LOCALITIES AND SECTIONS

GENERAL STATEMENT

This part of the paper presents the stratigraphic evidence that was used in arranging the Upper Cambrian faunules in their proper time order. Sections were measured, and are described in some detail, whenever they yielded several faunules in unquestionable stratigraphic succession. Descriptions of lithology are generally limited to those indications that may be useful to a geologist in order to identify in the field the units from which the fossils were collected. In several cases, when the topography was not favorable to an accurate measurement of the thickness, the section was described qualitatively, by giving the succession of the various lithic units and an estimate of their thicknesses. Even in these cases the time order of the fossils collected is certain. Sections where any kind of structural complication might bring doubt about the sequence of the strata were never used.

The localities are indicated in the text only approximately with respect to towns, roads, etc., since a complete list of the fossil localities defined by coordinates on the U.S. Geological Survey topographic maps follows.

Faunal lists given in the descriptions of the sections usually assign to each species an indication of relative abundance (cc = very common, c = common, r = rare, rr = very rare). These indications are missing when the collection was too small to supply significant data. For brevity, author's names are omitted, since all the species listed are discussed elsewhere in this paper. An asterisk preceding the name indicates the type locality for the species.

Fossil collections are all labeled with the letters cn (for Cambrian, Nolichucky) followed by a third letter designating the horizon and a number indicating the locality. At least for the later collections, the same number is applied to all the collections from a given section. As far as possible it was attempted to designate by the same letters correlative beds in the different sections; a few discrepancies are inevitable since precise correlation was not always apparent at the time when the fossils were labeled. Collections designated by cna to cne belong to the *Cedaria* zone, cnk to cnn to the *Crepicephalus* zone, and cno to cnx to the *Aphelaspis* zone.

HAWKINS COUNTY

Big Creek section, near Rogersville.—The most complete and satisfactory section of the entire fossiliferous portion of the Upper Cambrian was found along Big Creek, just south of U.S. Route 11-W, a few miles east of Rogersville, Hawkins County (Burem quadrangle). The U.S. National Museum collections contain numerous fossils from unspecified horizons in this section; several species were described by Walcott (1916a, 1916b) and Resser (1938a).

A section of the upper portion of the Maryville formation and the entire Nolichucky formation were measured chiefly on the hill slopes on the east bank of Big Creek; the rest of the Maryville formation was added from complete sections exposed a short distance east along the strike. This section with its numerous fossil-bearing beds represents a standard with which partial sections studied in other areas will be correlated. The upper boundary of the Nolichucky formation is here set at the first appearance of dolomite beds, which at Big Creek coincides with the disappearance of limestone. However, Rodgers (1953) assigned some of the lower, noncherty dolomite beds to the upper portion of the Nolichucky (Maynardville limestone member) rather than to the overlying Copper Ridge dolomite. The author, without questioning the reasons that prompted this assignment, has provisionally placed all the dolomite in the Copper Ridge formation because this boundary was more readily recognized in the field. In other sections there is an interval where limestone and dolomite beds alternate, making the definition of the formational boundary more uncertain than at Big Creek.

Big Creek section, measured 3 miles northeast of Rogersville, Hawkins County, Tenn.:

Nolichucky formation		Thickness Feet
8. Limestone and shale; aphanitic, dark-gray, gray-weathering limestone in thin, often nodular beds, ribboned with tan-weathering shale or dolomite. Some crystalline lenses are fossiliferous		67
Collection 66 feet above base (cnx/1):		
Cheilocephalus brachyops	r	
Dytremacephalus angulatus	c	
Dytremacephalus sulcifrons	rr	
Collection 42 feet above base (cnw/1):		
Aphelaspis tarda	r	
Dytremacephalus angulatus	c	
Collection 3–4 feet above base (cnv/1):		
Aphelaspis tarda	c	
7. Limestone and shale: similar to preceding unit, with lesser percentage of limestone in more distinctly nodular layers		6
Collection 0–1 feet above base (cnu/1):		
Aphelaspis tarda	c	
6. Shale, lacking limestone beds		16
5. Shale, with several limestone lenses and nodules		10
Collection 1 foot below top (cnt/1):		
Aphelaspis arsoides	r	
Aphelaspis tumifrons	c	
Pseudagnostus communis	r	
Collection 4 feet below top of interval (cns/1):		
Aphelaspis arsoides	c	
Aphelaspis tumifrons	c	
4. Limestone: one bed, massive, crystalline and conglomeratic, well exposed across stream bed		1

The above portion of the section was measured on the slopes SE of a dry creek bed at x = 182, y = 297 mm, Burem quadrangle.

3. Shale: finely fissile, with a few siltstone beds near the top		40
2. Limestone: mostly very thick-bedded, light-gray, aphanitic, in part crystalline or oolitic, with some intervals of intraformational		

Thickness
Feet

pebble conglomerate. At the base some thin beds alternating with shale. Very sharp contact with overlying shale 156

Collection in top few inches (cnn/1):

Blountia arcuosa	r
Blountia montanensis	r
Coosia alethes	c
Coosia robusta	r
Coosia, sp. undet.	r
Crepicephalus cf. *convergens*	r
Kingstonia inflata	c
Maryvillia arion	c
Meteoraspis mutica	r
Terranovella dorsalis	r
Tricrepicephalus thoosa	c

Collection from loose blocks in lower third of interval (cnk/3):

Blountia alexas	r
Dresbachia amata	r
Kingstonia inflata	c

1. Shale: finely fissile, green or tan, with a few siltstone beds in uppermost portion. In the lower 15 feet a few lenses of silty or crystalline limestone 337

Collections in lower 15 feet both in shale and limestone lenses (cne/1, cne/2):

Genevievella, sp. undet.	r
Kormagnostus simplex	c
Norwoodella saffordi	c

Total thickness of Nolichucky formation 633

Maryville formation

3. Dolomite and limestone: massive, gray, gray-weathering dolomite in lower part, grading upward to massive, gray, more coarsely crystalline or oolitic limestone. Fossile not rare in top 30 feet, more common in top 10 feet 185

Collections made at various places (cnc/2 to cnc/5):

Hyolithes, sp. undet.	c
Bonneterrina appalachia	c
Coenaspis spectabilis	rr
Coosella andreas	r
Genevievella, sp. undet.	r
Holcacephalus praecursor	r
Kormagnostus simplex	c
Menomonia tuberculata	r
Menomonia, sp. undet.	r
Modocia crassimarginata	c
Modocia dubia	c
Modocia ? agatho	r
Norwoodia, sp. undet.	r
Tricrepicephalus, sp. undet.	c

2. Dolomite: very light gray, weathering almost white 67
1. Dolomite: gray, weathering tan or dark gray 740

Total thickness of Maryville formation 992

The following comments may be made about this section and the contained fossils:

The Maryville formation here consists mostly of dolomite, except in the uppermost portion which is rather pure, crystalline or oolitic limestone. The contact of the formation with the underlying Rogersville shale is very sharp. Presumably the Middle-Upper Cambrian boundary lies somewhere within the Maryville, since the uppermost portion holds a faunule of the *Cedaria* zone, of very early Dresbachian age. The author was unable to find fossils in the lower parts of the formation in the Rogersville area. However, a collection in the U.S. National Museum (loc. 107x, 11 miles NW. of Knoxville) mentioned by Walcott (1916b, p. 394) yielded the types of *Asaphiscus glaber* Walcott and a species of *Olenoides*. These are undoubted Middle Cambrian fossils and were certainly collected from limestone of the Maryville formation, or at least its equivalent in the Conasauga group.

The Nolichucky formation at Big Creek and in other sections studied in the Rogersville outcrop belt, as well as at many other localities, consists in ascending order of four members: a shale, a limestone, another shale, and the uppermost limestone. The lower limestone member, although very thick and conspicuous in the present section, is quite variable in thickness. It is essentially absent from some of the sections north of Clinch Mountain, such as the Thorn Hill and Purchase Ridge sections, and even from the section on Price School road which is not far from Rogersville and in the same outcrop belt. At several localities this limestone is in part of algal origin (Oder and Bumgarner, 1961). Geologists who discussed the stratigraphy of northeastern Tennessee generally recognized a Maynardville limestone, either as a member of the Nolichucky or as a separate formation. In the typical area, in the Maynardville quadrangle, there is essentially one limestone succession above the shale of the lower Nolichucky, and this was named the Maynardville limestone. It includes at least portions of *Crepicephalus* and *Aphelaspis* faunizones (see discussion of the Hurricane Hollow section). The question arises whether in areas where the upper Nolichucky consists of two limestone units separated by a shale, the name Maynardville should apply to this entire complex, or to the upper limestone alone, the characteristic thin-bedded limestone ribboned with shale and dolomite. Since the author's purpose is not to discuss stratigraphic nomenclature, the more noncommittal attitude of assigning all the strata in question to the Nolichucky is adopted, without implying any judgment on the validity and boundaries of the Maynardville limestone.

The faunules listed in the section show that the basal Nolichucky shale holds essentially the same fossils as the uppermost Maryville limestone, indicating no considerable time interval between the deposition of the two units. In this section, younger faunules of the *Cedaria* zone such as those found at several localities north of Clinch Mountain seem to be absent, probably owing to the lack of limestone beds or nodules in the shale. The next higher faunules occur in the lower limestone unit, and these belong to the *Crepicephalus* zone. The upper, unfossiliferous 40-foot shale unit separates the uppermost *Crepicephalus* zone faunule from the lowest *Aphelaspis* zone faunule. As shown in the later discussion of other sections, the faunules of the lower portion of the *Aphelaspis* zone are here missing, while the faunules of the upper *Aphelaspis* zone are well represented.

Forgey Creek.—A partial section of the Maryville and Nolichucky formations is exposed along Forgey Creek, between Zion Hill and Carter Valley road, in the NE. corner of the Burem quadrangle. The uppermost beds of the Maryville hold the usual *Cedaria* zone fauna. This was the easternmost locality examined.

U.S. Route 11-W, 6½ miles NE. of Rogersville.—Although the section is poorly exposed here, the locality is important for the presence of unusual, highly fossiliferous red beds at the base of the Nolichucky shale. The best collecting locality (now deteriorated) was the road cut on the S. side of U.S. Route 11-W at the foot of the hill located at x = 326, y = 434, Burem quadrangle (U.S.N.M. locality 27d, author's locality cnd/1). Good collections were also made here in the underlying Maryville limestone, about 30 feet below the top of the formation (cnc/1).

Yellow and pink layers, absent in other areas, begin to appear here in the upper portion of the Maryville. The overlying Nolichucky formation consists, for the lower 50 feet, of alternating red shale and thick, irregular, partly lenticular beds of limestone. Each limestone bed often presents an irregular alternation of aphanitic, brick-red or pink limestone and coarse, yellow to light-brown calcarenite. Both types of limestone are highly fossiliferous in places. The calcarenite is sometimes a coquina of extremely fragmentary trilobite tests, among which only the strong, compact pygidia of *Ankoura triangularis* have escaped destruction. The red, aphanitic limestone supplies better-preserved fossils, including numerous larval stages of trilobites. A list of the species is given in the discussion of the faunas.

A search was made to ascertain how far along the strike these peculiar beds extend. The red beds can be traced eastward, north of the highway, to the south flank of the westernmost hill of Miller Ridge, about half a mile E. of locality cnd/1. On the next hill, where the Maryville–Nolichucky contact is well exposed, the red shale and limestone have disappeared. West of locality cnd/1, the first exposure of the formational contact occurs at a distance of about half a mile, and no trace of red beds is present. In conclusion, the red beds probably extend for less than 1 mile along the strike. They were observed at no other locality.

The lower limestone member of the Nolichucky is sharply defined near this locality and has an approximate thickness of 180 feet.

One mile E. of Rogersville.—A good section of the lower limestone member of the Nolichucky was measured in a cut on the E. side of the road leading to Bell Cemetery. The limestone is 175 feet thick; however, the lower 50 feet here alternate with shale. Good fossils were collected about 40 feet above the lowest limestone bed (cnk/1).

Highly fossiliferous beds about 45 feet below the top of the lower limestone member of the Nolichucky occur about 0.2 miles SW. of the preceding locality, on the hill S. of a dirt road (loc. cnm/2). Loose blocks on the hill slope (cnm/3) were partly derived from these beds, partly seemingly from a higher horizon, as some hold a faunule more similar to that found in the uppermost beds of the lower limestone.

Guntown Road.—The lower limestone member of the Nolichucky is fairly well exposed on the E. side of the Guntown Road, about ½ mile S. of Rogersville. Good collections were made from the top beds of the lower limestone member of the Nolichucky (loc. cnn/2).

Crockett Creek.—Partial sections of the Nolichucky are exposed on the hills S. of Crockett Creek (Pressmen's Home quadrangle). A good section of the lower limestone member was found near the end of a dirt road branching off from U.S. Route 11-W near Bench Mark SN-113. The limestone is approximately 145 feet thick. Numerous fossils were collected from the top beds (loc. cnn/3).

Price School Road.—A partial section of the Nolichucky formation is exposed on the east side of Price School Road ($x = 99$–102 mm., $y = 475$–485 mm., Bulls Gap quadrangle). Shale beds a few feet above the top of the Maryville limestone yield *Kormagnostus simplex* and *Norwoodella saffordi* as do the strata at the same level in the Big Creek section. The lower limestone member of the Nolichucky, however, is here reduced to a small fraction of the thickness of 150 feet observed in all the sections near Rogersville. It consists of about 30 feet of limestone alternating with shale. This limestone is overlain by a thick succession of shale beds with a few, thin limestone lenses. A lens 90 feet above the top of the limestone yielded *Amiaspis?* sp.; one 140 feet above contained *Coosina* sp. and *Crepicephalus* sp.; and one 170 feet above, *Aphelaspis* sp. and *Glaphyraspis* sp. Even though the fossils are scarce and fragmentary, it is clear that the *Crepicephalus–Aphelaspis* zone boundary is somewhere between 140 and 170 feet above the top of the limestone. This is in contrast with the relationships at Big Creek and Lost Creek, where the faunizone boundary approximately coincides with the limestone-shale contact, and on Shields Ridge (Piedmont Road, Russell Gap), where the boundary lies within the limestone unit. These observations indicate that, in accordance with its erratically varying thickness, the lower limestone member of the Nolichucky does not occupy the same time span in different sections. Limestone units in the Nolichucky shale are developed erratically at different levels, the only persistent one being the characteristic "ribbon rock" at the top.

HAMBLEN COUNTY

Three Springs.—A section of the upper Nolichucky formation is well exposed in a recent road cut on the E. shore of the Three Springs embayment of Cherokee Reservoir (Russellville quadrangle). This locality is in the same outcrop belt as the Big Creek section and is 14 miles distant along the strike. Unfortunately, some of the upper (Maynardville) limestone and its contact with the Copper Ridge dolomite are obscured by incomplete exposures and structural complications. The section was measured in descending order (northward), starting near an old stone bridge, where good exposures in the road cut on the E. side of the road begin. An undetermined portion of the upper limestone unit is therefore missing.

		Thickness	
		Feet	Inches
32. Limestone, in thin beds ribboned with shale or dolomite, somewhat more shaly in lower portion		Not measured	
Collection cnv/15, 0–5 feet above base:			
Aphelaspis tarda	c		
Dytremacephalus angulatus	r		
31. Shale		3	6
30. Shale and limestone, the latter in nodular beds		4	
Collection cnu/15:			
Aphelaspis tarda	c		
29. Shale, partly slumped and poorly exposed. A prominent lens of knobbly limestone 4 feet below top is exposed along road		10-30	
28. Shale, with nodular limestone beds		14	
Collection cnt/15 at top:			
Aphelaspis arsoides	c		
Aphelaspis tumifrons	c		
Pseudagnostus communis	r		
Collection cnt′/15 at base:			
Aphelaspis arsoides	r		
Aphelaspis tumifrons	cc		
27. Shale		1	
26. Limestone: massive, granular, with tan-weathering stringers		2	

		Thickness	
		Feet	Inches
25. Siltstone, with thin limestone beds and lenses		2	
Collection cnt″/15:			
Aphelaspis arsoides	c		
Aphelaspis tumifrons	cc		
Pseudagnostus communis	r		
24. Shale		3	
23. Limestone: massive, one bed		1	
22. Shale		6	
21. Shale, with thin limestone beds		4	
Collection cns″/15, 2 feet above base:			
Aphelaspidella macropyge			
Aphelaspis rotundata			
Paraphelaspis vigilans			
20. Limestone: massive, one bed		2	
19. Shale, with thin-bedded limestone		5	
Collection cns′/15, from limestone lenses at middle and top of interval:			
Aphelaspis arses	r		
Aphelaspis rotundata	c		
Paraphelaspis vigilans	c		
18. Limestone: granular, one bed		1	2
17. Siltstone		2	5
16. Limestone: massive, granular		1	
15. Shale, with some thin siltstone and limestone beds		9	
Collection cns/15, 5 feet below top:			
Aphelaspis camiro	c		
Aphelaspis laxa	r		
Aphelaspis quadrata	c		
Aphelaspis washburnensis	r		
Aphelaspis, sp. undet.	r		
14. Limestone conglomerate: one bed			5
13. Shale, with a few thin limestone beds and lenses		10	
Collection cnr′/15, 2 feet below top:			
Aphelaspis laxa	c		
12. Limestone: one bed, partly conglomerate			5
11. Shale, with a few, thin limestone beds		1	6
Collection cnr/15, 8 inches below top:			
Aphelaspis walcotti	cc		
Glaphyraspis declivis	c		
Glaphyraspis oderi	c		
10. Limestone: one bed of irregular thickness			2–4
9. Shale		2	
8. Limestone: one bed of irregular thickness, partly conglomerate		1	
7. Shale, finely fissile		2	8
6. Limestone: silty, granular, one bed			6–7
5. Shale with thin siltstone and limestone beds, partly lenticular		4	8
Collection cnq/15, 6 inches below top:			
Aphelaspis minor	cc		
Glaphyraspis ornata	r		

		Thickness	
		Feet	Inches
Collection cnp′/15, 1 foot below top:			
Aphelaspis lata	c		
Aphelaspis walcotti	c		
Collection cnp/15, 2 feet below top:			
Aphelaspis lata	cc		
Collection cno/15, 3–4 feet below top:			
Aphelaspis buttsi	cc		
Coosella perplexa	r		
Glaphyraspis parva	cc		
4. Limestone: 4 beds several inches thick, separated by shale and siltstone		3	4
3. Shale, siltstone, and limestone: one 3-inch limestone bed in middles of unit.		5	4
Collection cnn/15 from loose pieces at foot of cliff, presumably derived from this or preceding unit:			
Amiaspis, sp. undet.			
Coosia alethes			
Crepicephalus, sp. undet.			
Terranovella dorsalis			
2. Limestone conglomerate: one bed, well exposed near road			5–7
1. Shale, siltstone, and limestone in part conglomerate, alternating as in preceding units, underlain by massive limestone. This part of the section was not measured as it yielded no fossils, and change in dip affects its lower portion.			

As it can be seen from the faunal lists, this section offers one of the most complete successions of *Aphelaspis* zone faunules observed anywhere. Noteworthy is the collection cno/14 at the base of the *Aphelaspis* zone, yielding *Coosella,* a genus more characteristic of the *Crepicephalus* zone, associated with *Aphelaspis buttsi,* so far known only from this locality in Tennessee, where it is believed to be the oldest species of the genus. Equivalent beds will be described from the Russell Gap section.

GRAINGER COUNTY

Smith Hollow.—A continuous section of the upper portion of the Nolichucky formation is exposed in a road cut at Smith Hollow, Luttrell quadrangle. The writer is indebted to Dr. Oder for leading him to this locality and supplying measurements of the section. Collections at various levels were made by Dr. Oder and the author. A brief description of the section in descending order follows.

The uppermost part of the Nolichucky is the usual limestone in thin beds, ribboned with shale or dolomite, alternating with minor shale intervals. This suit is approximately 150 feet thick.

Oder's collection No. 14A, about 80 feet below top of unit:
Aphelaspis tarda

Oder's collection No. 14, a short distance below the preceding:
Aphelaspis arsoides
Aphelaspis tumifrons

The above unit is underlain by a thick shale interval with minor siltstone, limestone, and limestone conglomerate layers. Some of the limestone beds are lenticular. The base of this shale rests on massive limestone as in the sections of the Rogersville area. The thickness of the limestone cannot be accurately measured but seems to be much less than in the vicinity of Rogersville.

The following collections were all made from thin limestone beds in the shale unit.

Collection cns/16 (= Oder's collection No. 13), about 100 feet below top of shale:	
Aphelaspis camiro	c
Aphelaspis laxa	r
Aphelaspis quadrata	c
Collection cnq/16, about 2 feet below the preceding:	
Aphelaspis walcotti	
Glaphyraspis ornata	
Glaphyraspis declivis	
Collection cnr/16, about 2 feet below the preceding:	
Aphelaspis walcotti	cc
Glaphyraspis ornata	r
Collection cnn/16, about 145 feet below top of shale:	
Amiaspis erratica	
Amiaspis obsolescens	
Coosia alethes	
Crepicephalus buttsi	

This section affords a good sequence of *Aphelaspis* faunules and confirms the order of the species of this genus observed in other sections. The lowest faunule belongs to the *Crepicephalus* zone. It is notable for the presence of the genus *Amiaspis*.

Thorn Hill.—The Nolichucky formation exposed in the Thorn Hill section, measured by Hall and Amick, is not particularly fossiliferous. The author collected from limestone beds interstratified with shale in the lower portion of the formation (*Cedaria* zone, loc. cnd/13) the following species:

Cedaria tennesseensis
Kormagnostus simplex
Menomonia, sp. undet.
Norwoodella walcotti

Washburn.—A richly fossiliferous and excellently exposed section of the beds of the *Aphelaspis* zone was measured in a cut of the Southern Railway about a mile north of Washburn. The locality is in the Dutch Valley quadrangle, in the same outcrop belt as the Thorn Hill section studied by Hall and Amick, at a distance of 10 miles along the strike. The beds dip 42°–45° S. The Nolichucky–Copper Ridge contact is exposed in a ravine on the E. side of the railroad and seems to be rather gradational, the dolomite content increasing upward. Only the basal part of the upper (Maynardville) limestone member of the Nolichucky is exposed in the railroad cut, the best exposures being on the E. side. Below the limestone, every bed to the base of the *Aphelaspis* zone is visible.

		Thickness Feet
16. Limestone, ribboned with shale and dolomite, rather poorly exposed in ravine; only lowest 6 feet exposed in railroad cut		70
Collection cnx/20, 2–6 feet above base:		
Aphelaspis tarda	cc	
15. Shale		5
14. Limestone, ribboned with shale and dolomite		21
Collection cnw/20, 4–7 feet below top:		
Aphelaspis punctata	c	
**Aphelaspis tarda*	cc	
Cheilocephalus brachyops	r	
Dunderbergia tennesseensis	r	
13. Shale, finely fissile		12
12. Shale, with thin limestone beds and lenses		16
Collection cnt′/20, 8 feet above base:		
Aphelaspis arsoides	c	
Aphelaspis tumifrons	cc	
Pseudagnostus communis	c	
Collection cnt/20, 2 feet above base:		
Aphelaspis tumifrons	c	
Pseudagnostus communis	r	
11. Shale: finely fissile, lacking limestone beds		14
10. Shale, with thin limestone beds and lenses; one thick limestone bed at base		10
Collection cns/20, 0–4 feet below top:		
Aphelaspidella macropyge	c	
Aphelaspis arses	c	
**Aphelaspis rotundata*	c	
**Paraphelaspis vigilans*	c	
9. Shale: finely fissile, lacking limestone beds		9
8. Shale, with thin limestone lenses		2
Collection cnr′/20:		
Aphelaspis camiro	c	
Aphelaspis laxa	c	
Aphelaspis quadrata	c	
Glaphyraspis oderi	r	
7. Shale: finely fissile, lacking limestone beds		5
6. Shale, with thin limestone beds and lenses; a few limestone beds up to 4–5 inches thick, one at top		22

Thickness
Feet

Collection cnr/20 in thin lenses in top 1 foot:
Aphelaspis camiro c
Aphelaspis laxa r
Aphelaspis quadrata c
Collection cnq′/20 in thin bed 2½ feet below top:
**Aphelaspis washburnensis*
Aphelaspis, sp. undet.
Aphelaspidella macropyge
Glaphyraspis declivis
Collection cnq/20 in thin beds and lenses, 10–14 feet above base:
Aphelaspis walcotti cc
Glaphyraspis oderi c
Collection cnp′/20, in thin beds and lenses 6–8 feet above base:
Aphelaspis minor c
Glaphyraspis oderi r
Collection cnp/20 in lenses and nodules 1–4 feet above base:
Aphelaspis lata cc
Cheilocephalus brevilobus r

5. Limestone: in rather thick beds, with some shale intervals 7
4. Shale and thin-bedded limestone 5

Collection cnn/20, 1 foot above base:
Crepicephalus, sp. undet.
Terranovella dorsalis

3. Limestone: in rather thick beds, with some shale intervals 6
2. Shale, siltstone, and thin-bedded limestone. Unit extends almost to northern end of railroad cut 27

Collection cnm′/20, 3½ feet below top:
**Amiaspis obsolescens*
Coosia alethes
Collection cnm/20, 11 feet below top:
Kingstonia inflata

The Washburn section supplies one of the most complete successions of *Aphelaspis* faunules observed in Tennessee, and is probably unequaled in the number of fossils of the *Aphelaspis* zone. The trilobites are mostly well preserved, including the extremely numerous larval stages of *Aphelaspis* present in collection cnw/20 (pl. 20, fig. 1).

JEFFERSON COUNTY

The Nolichucky formation is partly exposed near the crest of Shields Ridge, in the New Market and Jefferson City quadrangles. Three localities yielded important fossils and information about the faunal succession.

New Market–Piedmont Road.—The Nolichucky formation is incompletely exposed along the road on the N. and S. slopes of Shields Ridge. The top of the lower limestone unit crops out where the road crosses the summit. This locality yielded numerous trilobites to early collectors, and several of the fossils in the U.S. National Museum collections were used as types by Walcott and Resser (U.S.N.M. locality 120). In these early collections fossils from the *Crepicephalus* and *Aphelaspis* zones were indiscriminately mixed. Bridge (1956) gave a description of the section in which, however, many intervals were stated to be covered. His collection No. 2804, from which the new species *Aphelaspis bridgei* is described herein, was made at this locality.

The general lithology of the Nolichucky is very similar to that described for the Rogersville Big Creek section. Thicknesses were not measured because of the unfavorable topography and incomplete exposures. The lower Nolichucky shale is followed by a massive limestone unit that bears fossils at least in its upper portion. Fossils of the *Crepicephalus* zone occur (loc. cnn/5) 30–40 feet below the top of the limestone (*Tricrepicephalus thoosa, Meteoraspis* sp.). However, the top of the massive limestone belongs in the *Aphelaspis* zone. Crystalline lenses in aphanitic limestone in the uppermost 1 foot of the unit, as well as limestone lenses in the lower few feet of the overlying shale, yielded collection cns/2. The species observed are:

**Aphelaspis arsoides*	c
**Aphelaspis inermis*	r
Aphelaspis tumifrons	cc
Cheilocephalus, sp. undet.	r
Pseudagnostus communis	r

Comparison with the faunules of the Big Creek, Three Springs, and Washburn sections indicates that the above faunule is fairly high in the middle portion of the *Aphelaspis* zone. The U.S. National Museum collection 120 includes the types of *Aphelaspis camiro, A. laxa,* and *A. quadrata* which, as it appears from other evidence, are somewhat older than the species listed above. Collection 2804 of the U.S. Geological Survey yielded the types of *Aphelaspis bridgei,* unknown from other localities. Its association with *Blountia bristolensis* and *Glaphyraspis ornata,* species that were found only in the basal beds of the *Aphelaspis* zone at other localities, shows that this collection was made from beds still lower than those yielding *Aphelaspis camiro, A. laxa,* and *A. quadrata.* Unfortunately, the portion of the massive limestone with interbedded shale intervals, from which all these fossils are presumed to come, is now poorly exposed and shows only aphanitic, unfossiliferous beds.

The massive limestone is overlain by 40 to 50 feet of shale, the lower portion of which contains the rare limestone lenses mentioned above. The shale is in turn overlain by the usual limestone ribboned with shale and dolomite. Its exposures are not extensive, and no fossils were observed. The contact with the Copper Ridge dolomite is exposed in a road cut on the S. slope of the ridge.

Russell Gap.—The lower limestone unit of the Nolichucky is more favorably exposed where a dirt road crosses Shields Ridge at Russell Gap, in the SW. corner of the New Market quadrangle. The overlying shale is poorly exposed in a dip slope in the woods E. of the road. The uppermost limestone is partly exposed only in a ravine E. of the road. The best exposures of the fossiliferous upper portion of the lower limestone unit are located near the crest of the ridge in the woods NE. of the gap. Fossils were collected from the following beds in descending order.

Collection cnw/14.—Crystalline beds in lower portion (probably lower 10 feet) of upper limestone unit of the Nolichucky. These lower beds are predominantly calcareous, with little shale or dolomite:

Aphelaspis tarda	r
**Dunderbergia tennesseensis*	r
**Dytremacephalus angulatus*	c
**Dytremacephalus sulcifrons*	rr
Cheilocephalus brachyops	r

Collection cnq/14.—Top 1–2 feet of lower limestone unit, underlying the upper shale unit, about 40–50 feet below the preceding collection. This and the underlying beds are massive, aphanitic limestone with crystalline lenses:

Aphelaspis minor	c
Blountia bristolensis	c
Cheilocephalus brevilobus	cc
Glaphyraspis ornata	r

Collection cnp/14.—Massive limestone, about 3 feet below the preceding, hence 4–5 feet below top of lower limestone unit:

**Aphelaspis lata*	c
Blountia bristolensis	cc
Cheilocephalus brevilobus	c
Glaphyraspis ornata	r

Collection cno/14.—Massive limestone, 11 feet below top:

Aphelaspis cf. *lata* (or *buttsi*)	r
Blountia bristolensis	c
Cheilocephalus brevilobus	c
Coosella perplexa	c
Glaphyraspis parva	r
Tricrepicephalus, sp. undet.	r

Collection cnn/14.—Massive limestone, 14 feet below top:

Blountia, sp. undet.	r
Blountiella, sp. undet.	r
Coosia alethes	r
Coosina, sp. undet.	r

Kingstonia inflata	r
Metearaspis, sp. undet.	r
Terranovella dorsalis	r
Tricrepicephalus thoosa	c

Collection cnw/14 belongs to the uppermost *Aphelaspis* zone of Tennessee, yielding an assemblage known from a number of sections. The middle portion of the faunizone may be represented in the poorly exposed shale unit. The underlying, massive limestone offers a remarkable transition from the *Crepicephalus* to the *Aphelaspis* zone within a few feet of beds. Collection cnn/14 contains a typical upper *Crepicephalus* zone assemblage. Collection cno/14, only 3 feet higher, still includes the typical *Crepicephalus* zone genera *Coosella* and *Tricrepicephalus,* associated with *Aphelaspis* and *Cheilocephalus.* The specimens of *Tricrepicephalus* are too fragmentary to be specifically identifiable, but the generic characters of the pygidium are unmistakable. An equivalent faunule was collected from the Three Springs section, where, however, *Tricrepicephalus* was not found.

Lost Creek.—A partial section of the upper Nolichucky was studied in a recent road cut near the headwaters of Lost Creek, 0.2 mile W. of Tennessee Route 92, about 2 miles S. of Jefferson City. The lower, massive limestone unit is partly exposed and is overlain by alternating beds of shale, limestone, and limestone conglomerate. The exposed section barely reaches the base of the uppermost limestone unit of the Nolichucky. Notwithstanding the limited exposure, this locality yielded a number of faunules in clear relative stratigraphic order. The section is described below.

		Thickness	
		Feet	Inches
13. Limestone: massive, crystalline, banded with dolomite		2	4
12. Shale, with small scattered limestone lenses		12	0
Collection cnt/4, 0–2 feet above base:			
Aphelaspis arsoides	c		
Aphelaspis tumifrons	cc		
Dytremacephalus angulatus	rr		
Pseudagnostus communis	r		
11. Limestone: crystalline, one bed		1	0
10. Shale, with scattered limestone lenses		8	0
Collection cns/4, 3–4 feet above base:			
Aphelaspis inermis	c		
Aphelaspis arses	c		
Aphelaspis camiro	r		
Aphelaspis laxa	r		
Cheilocephalus, sp. undet.	r		
Pseudagnostus communis	r		
9. Limestone: coarsely granular, with insoluble stringers; one bed		1	0

		Thickness	
		Feet	Inches
8. Shale		5	0
7. Limestone: massive, coarsely granular, with siliceous stringers		3	6
6. Shale, with thin limestone beds		2	6
Collection cnr′/4 in limestone bed at top:			
Aphelaspidella macropyge			
Collection cnr/4 in limestone bed at base:			
Aphelaspis arses	r		
Aphelaspis cf. *lata*	r		
**Aphelaspidella macropyge*	c		
Cheilocephalus, sp. undet.	r		
Paraphelaspis vigilans	r		
5. Limestone: coarsely granular, one bed		2	0
4. Shale		2	0
3. Limestone pebble conglomerate: one bed			10
2. Shale, with limestone lenses and thin beds, especially in upper portion		18	0
Collection cnq″/4 at top:			
Aphelaspis cf. *rotundata*			
Collection cnq′/4, 13 feet above base:			
Aphelaspis cf. *laxa*			
Collection cnq/4 in a limestone bed 8 feet above base:			
Aphelaspis walcotti			
Collection cnn/4 in 1-inch limestone bed, 6 inches above base:			
Coosia alethes	c		
Crepicephalus, sp. undet. No. 1	r		
Maryvillia arion	c		
Tricrepicephalus thoosa	c		
1. Limestone: massive, granular, aphanitic, or oolitic, poorly bedded, with tan-weathering siliceous stringers; incompletely exposed			60+

Although this section is in the same outcrop belt as the Piedmont Road and Russell Gap sections, it shows several differences. Here the *Crepicephalus* zone includes all the lower, massive limestone unit and extends a few feet above it. The overlying shale has much more interbedded limestone. The earliest *Aphelaspis* zone faunule with *Aphelaspis walcotti* is younger than the earliest faunules observed in the Russell Gap, Three Springs, Washburn, and Hurricane Hollow sections.

UNION COUNTY

Hurricane Hollow.—A section of the upper portion of the Nolichucky is exposed along the Hurricane Hollow embayment of Norris Reservoir (Maynardville quadrangle) and was measured by Dr. C. R. L. Oder, who showed it to the writer. The strata are exposed both in the road cut and along the shores on both sides of the embayment.

Dr. Oder measured his section in the road cut, whereas the more interesting fossils were found on the E. shore of the embayment, where the writer measured a partial section. Difficulty was experienced in correlating the road-cut section with the shore section, since the strata could not be accurately traced through the intervening area. However, all the fossils discussed herein were collected by Dr. Oder and the author from the shore beds in unquestionable stratigraphic order. The beds dip 25°–30° S. The section in descending order follows, beginning with the highest limestone beds below the dolomite.

		Thickness	
		Feet	Inches
12. Limestone: weathering blue-gray, mostly very massive, at top and bottom thin-bedded, in part dolomitic		20	
11. Limestone: very massive, mottled with dolomite, weathering to rough surfaces		14	
10. Limestone: thin-bedded, aphanitic, with tan-weathering partings, weathering to smooth, blue-gray surfaces		6	
9. Limestone: crystalline, massive, with insoluble stringers weathering in relief		18	
8. Shale and thin-bedded limestone		2	
Collection cnr′/17 (= Oder's coll. No. 2):			
Aphelaspis walcotti			
Blountia mimula			
**Glaphyraspis declivis*	c		
**Glaphyraspis oderi*	c		
7. Limestone: crystalline, massive, weathering blue-gray; basal part weathering to spongy residue		2	6
6. Limestone: massive, mottled with dolomite, weathering to rough surfaces; in lower part with regular, insoluble stringers		10	
5. Shale, with limestone nodules		1	4
4. Limestone: massive, mottled with dolomite, weathering to rough surfaces		6	
3. Shale, with limestone lenses and nodules		8	
Collection cnr/17, 2 feet below top:			
Aphelaspis, sp. undet.			
2. Limestone and shale: limestone in thin, partly lenticular beds; interval grades eastward to almost pure limestone		7	
Collections cnq/17, 2½ feet above base:			
**Aphelaspis minor*	c		
Glaphyraspis ornata	r		
1. Limestone: mostly crystalline, massive, with a few thin-bedded intervals. Base of unit forms bottom of ravine on lake shore		18	
Collection cnp/17 in thin limestone bed at top:			
**Aphelaspis transversa*	c		
Blountia bristolensis	c		
Cheilocephalus brevilobus	r		

Collection cnn/17, in massive limestone beds 5–8 feet below top:
Coosia, sp. undet.
Crepicephalus, sp. undet.
Tricrepicephalus, sp. undet.

The section extends into lower beds of similar lithology, with alternating massive and thin-bedded limestones and shale, the latter becoming more prevalent downward. Occasional very fragmentary fossils of the *Crepicephalus* zone were seen in this lower, unmeasured portion of the section.

This section, like the ones at Three Springs and Russell Gap, is interesting for offering an *Aphelaspis* faunule a few feet above a typical *Crepicephalus* zone faunule. The earliest *Aphelaspis* here is a new species, *A. transversa,* closely related to *A. buttsi* and *A. lata* which are the first to appear in the two above-mentioned sections.

CLAIBORNE COUNTY

Comby Ridge.—An interesting fossil locality occurs where U.S. Route 25-E crosses Comby Ridge (Howard Quarter quadrangle). On the E. side of the road and creek, the lower part of the Nolichucky formation consists of shale with numerous limestone beds and lenses. One such lens collected by Dr. Gunnar Henningsmoen and Dr. Robert B. Neuman yielded fossils of the *Cedaria* zone, some of which are illustrated herein. The author found further fossiliferous beds, in addition to collecting from the above-mentioned lens. Unfortunately, the exposures are poor and some of the fossiliferous lenses are weathered out of the shale, hence their stratigraphic order is not always certain. Lenses or beds believed to occur in ascending order were labeled cnb/10, cnd/10, and cne/10. There is a considerable thickness of shale underlying these fossiliferous beds but overlying the Maryville limestone.

The fossils are for the most part extremely fragmentary in a coarse-grained calcarenite. The following faunules were observed.

Collection cne/10:	
Cedaria tennesseensis	c
Kormagnostus simplex	r
Menomonia, sp. undet.	r
Norwoodella walcotti	cc
Collection cnd/10:	
Ankoura triangularis	r
Kormagnostus simplex	c
Norwoodella halli	c
Norwoodella walcotti	r

Collection cnb/10:	
Ankoura triangularis	c
Kormagnostus simplex	r
Olenoides, sp. undet.	r

River Ridge.—A section of the uppermost part of the Nolichucky formation (Maynardville limestone member) was measured in a deep cut on the W. side of U.S. Route 25-E where it crosses River Ridge, a short distance N. of the bridge on the Clinch River (Howard Quarter quadrangle). At the top of the measured section are readily recognizable, massive beds of dolomite that may be considered the base of the Copper Ridge dolomite.

		Thickness Feet
14. Dolomite: mottled, weathering to rough surface. This bed is almost at top of exposures on west side of road; higher beds exposed on east side		3
13. Dolomite: thick-bedded, weathering to smooth surface. This and the overlying unit may be referred to the Copper Ridge dolomite		6
12. Shale		2
11. Dolomite, one bed		2
10. Shale: dark gray, hard, not fissile, with some interbedded dolomite but very little limestone		73
9. Shale: dark gray, fissile		5
8. Shale: as unit 10, but containing thin limestone beds and lenses		18
Collection cnv/21, 10 feet above base:		
Aphelaspis tarda	c	
Collection cnu/21, 4 feet above base:		
Aphelaspis tarda	c	
7. Shale: dark gray, fissile, with one limestone bed in middle of interval		3
6. Shale, alternating with thin-bedded limestone; more shaly in upper 5 feet		22
Collection cnu′/21, in limestone bed at top:		
Aphelaspis tarda		
5. Shale: finely fissile		3
4. Limestone, ribboned with shale or dolomite		5
3. Shale, finely fissile. Thickness approximate		20
2. Limestone, ribboned with shale or dolomite		3½
1. Shale: finely fissile, only the uppermost portion exposed. Thin limestone lenses present 20–25 feet below top		not measured
Collection cnt/21 in limestone lenses:		
Aphelaspis arsoides	c	
Aphelaspis tumifrons	c	
Pseudagnostus communis	c	

KNOX COUNTY

Copper Ridge.—Numerous Upper Cambrian fossils in the U.S. National Museum collections were recovered from beds of the *Cedaria, Crepicephalus,* and *Aphelaspis* zones on the NW. slope of Copper Ridge near Bull Run, south of Heiskell (Powell quadrangle).

This area appears to offer now neither the opportunity for measuring good sections, nor plentiful fossils. A partial section of the Nolichucky is exposed in the cut of the Southern Railway, and some of the material of *Norwoodella walcotti* illustrated herein was collected at this locality (cnd/12). The fossils occurred in thin limestone beds in shale, and their stratigraphic position could not be referred to readily recognizable lithic units.

Mascot.—A partial section of the Nolichucky formation is exposed in a road cut on the E. side of the road leading N. from Mascot to U.S. Route 11-W. The lower limestone unit of the Nolichucky and some of the overlying shale with thin-bedded, partly conglomeratic limestone beds are exposed. Fossils of the *Crepicephalus* zone were collected from limestone beds in shale about 5 feet above the top of the massive limestone (loc. cnn/19).

MONROE COUNTY

Owing to flat topography, exposures are generally scarce in the southwestern portion of the area investigated. A partial section of the Nolichucky formation was studied by A. R. Palmer and R. H. Raymond in the bluffs on the E. bank of the Little Tennessee River, near the E. end of the bridge on U.S. Route 411. Two trilobite collections were made. Collection U.S.G.S. 2970 is from a single bed at the top of a 38-foot unit of thin-bedded, knobbly limestone; collection 2969 is from weathered siltstone about 45 feet higher. The author was able to find only fossils of the upper *Aphelaspis* zone in the higher beds.

The U.S. Geological Survey collections are interesting because they include 3 species not observed elsewhere. The list of species follows.

Collection 2969:
  Dytremacephalus angulatus (complete specimens)
Collection 2970:
  Aphelaspidella macropyge
  Aphelaspis arses
  **Aphelaspis palmeri*
  Cheilocephalus, sp. undet.
  **Dunderbergia longifrons*
  **Dytremacephalus strictus*
  Paraphelaspis vigilans

Collection 2970 may be correlated with collection cnr/4 from the Lost Creek section and collection cns/20 from the Washburn section, having in common with both *Aphelaspidella macropyge, Aphelaspis arses, Cheilocephalus* sp. undet., and *Paraphelaspis vigilans.* Thus the stratigraphic position of the three new species, *Aphelaspis palmeri, Dunderbergia longifrons,* and *Dytremacephalus strictus,* is at least approximately determined in the middle *Aphelaspis* zone.

PURCHASE RIDGE, SCOTT COUNTY, VIRGINIA

Although the section here discussed is outside of Tennessee, it was deemed worth mentioning because it is close to the State line, and occurs in the northernmost Cambrian outcrop belt in this portion of the Appalachians.

Most of the Maryville and Nolichucky formations are exposed in cuts on the road from Pattonsville to Clinchport, Scott County (Duffield quadrangle). The Nolichucky formation is mostly shale excepting the upper (Maynardville) limestone unit. The contact with the Copper Ridge dolomite is not well exposed. A partial section of the strata of the *Aphelaspis* zone in descending order follows.

		Thickness	
		Feet	Inches
11. Limestone: in thin, often nodular beds, mostly aphanitic, ribboned with shale or dolomite		75+	
10. Limestone: similar to unit 11, but more readily weathering to separate layers		13	
Collection cnv'/7, one foot below top:			
Aphelaspis tarda	c		
9. Shale, with some limestone lenses		3	
Collection cnv/7, 1 foot above base:			
Aphelaspis tarda	c		
8. Limestone: thin-bedded, alternating with shale		10	
7. Shale		1	4
6. Limestone: crystalline, one bed filled with trilobite fragments			5
Collection cnu/7:			
Aphelaspis tarda	cc		
Dunderbergia tennesseensis	r		
5. Shale, with a few, thin limestone beds		6	
4. Limestone: thick-bedded		2	
3. Shale, with thin limestone beds		5	
2. Limestone: one bed		1	6
1. Shale, with some siltstone and limestone beds. Seemingly several hundred feet thick and extending to limestones of basal Nolichucky		not measured	
Collection cnt/7 from thin limestone lens 10 feet below top:			
Aphelaspis tumifrons	cc		
Pseudagnostus communis	c		

The upper (Maynardville) limestone unit of the Nolichucky shows the same lithology and faunal succession of the upper *Aphelaspis* zone as in the Big Creek section. Fossils of the lower *Aphelaspis* zone could not be found because of the unfavorable shaly lithology of the interval. The massive lower limestone of the Nolichucky present in many other sections is here lacking or greatly reduced. In most respects the lithology of the Nolichucky is very similar to that described by Hall and Amick (1934) for the Thorn Hill section.

INDEX OF LOCALITIES

CEDARIA ZONE

Collection	Quadrangle	x	y	County	Name of locality
cnc/1	Burem	325	435	Hawkins	U.S. Route 11-W
cnc/2	“	179	318	“	Big Creek
cnc/3	“	172	312	“	Big Creek
cnc/4	“	168	306	“	Big Creek
cnc/5	“	161	299	“	Big Creek
cnc/6	“	61	181	“	Rogersville
cnc/7	“	437	497	“	Forgey Creek
cnd/1	“	327	436	“	U.S. Route 11-W
cnd/2	“	343	442	“	Miller Ridge
cne/1	“	179	318	“	Big Creek
cne/2	“	168	306	“	Big Creek
cnb/10 cnd/10 cne/10	Howard Quarter	16	151	Claiborne	Comby Ridge
cne/12	Powell	249	248	Knox	Copper Ridge
cne/13	Avondale	227	560	Grainger	Thorn Hill
U.S.G.S. 2407	Howard Quarter	= cnd/10		Claiborne	Comby Ridge
U.S.G.S. 2406	“ “	= cnb/10		“	Comby Ridge

CREPICEPHALUS ZONE

Collection	Quadrangle	x	y	County	Name of locality
cnk/1	Burem	68	171	Hawkins	Rogersville
cnk/3	“	172	295	“	Big Creek
cnm/2 cnm/3	“	58	165	“	Rogersville
cnn/1	“	68–73	171–174	“	Big Creek
cnn/2	“	13	127	“	Rogersville
cnn/3	Pressmens Home	367	52	“	Crockett Creek
cnn/4	Jefferson City	91	408	Jefferson	Lost Creek
cnn/ 5	New Market	295	237	“	Piedmont Road
cnn/14	“ “	140	191	“	Russell Gap
cnm/15 cnn/15	Russellville	305	260	Hamblen	Three Springs
cnn/16	Luttrell	353	270	Grainger	Smith Hollow
cnn/17	Maynardville	50	129	Union	Hurricane Hollow
cnn/19	Mascot	14	403	Knox	Mascot
cnm/20 cnm′/20 cnn/20	Dutch Valley	98	266	Grainger	Washburn

APHELASPIS ZONE

Collection	Quadrangle	x	y	County	Name of locality
cns/1–cnx/1	Burem	180–183	290–296	Hawkins	Big Creek
cns/2	New Market	292	235	Jefferson	Piedmont Road
cnq/4–cnt/4	Jefferson City	91–94	411	“	Lost Creek
cnt/7–cnv/7	Duffield, Va.	194	277	Scott	Purchase Ridge

cno/14–cnq/14	New Market	138–141	190–193	Jefferson	Russell Gap
cnw/14	" "	142	188	"	Russell Gap
cno/15–cnv/15	Russellville	305–312	260–257	Hamblen	Three Springs
cnq/16–cns/16	Luttrell	354	271	Grainger	Smith Hollow
cnp/17–cnr/17	Maynardville	50	129	Union	Hurricane Hollow
cnp/20–cnx/20	Dutch Valley	98	266–263	Grainger	Washburn
cnt/21–cnv/21	Howard Quarter	137	141–139	Claiborne	River Ridge
U.S.G.S. 2969–70	Vonore	144	481	Monroe	Little Tennessee River

FAUNA OF THE _CEDARIA_ ZONE

Fossils of the _Cedaria_ zone occur in the uppermost portion of the Maryville limestone (only in the Rogersville area) and in the basal part of the Nolichucky formation. At all the localities studied, an unfossiliferous interval in the Nolichucky shale separates the uppermost beds carrying a _Cedaria_ fauna from the lowermost beds holding a _Crepicephalus_ zone fauna. Hence assemblages transitional between the two faunizones, as reported by Lochman and Duncan (1944) from Montana and Palmer (1954) from Texas, have not been observed.

The oldest Upper Cambrian faunule seems to be the one occurring in the uppermost 10–30 feet of the Maryville limestone in the Rogersville outcrop belt. The corresponding interval was examined at several other localities but yielded no fossils. Collections were made at several localities in the vicinity of Rogersville (author's collections cnc/1 to cnc/7; U.S.N.M. localities 102a, 123a). The species known from these beds are listed below. An asterisk preceding the name indicates that the types were collected from this area and horizon.

*_Bonneterrina appalachia_
*_Coenaspis spectabilis_
*_Coosella andreas_
Genevievella, sp. undet.
*_Hawkinsia minuta_
*_Holcacephalus praecursor_
Ithycephalus typicalis
Kormagnostus simplex
*_Menomonia tuberculata_
Menomonia, sp. undet.
*_Modocia crassimarginata_
Modocia dubia
*_Modocia ? agatho_
Norwoodella, sp. undet.
Norwoodia, sp. undet.
Tricrepicephalus, sp. undet.

The next higher faunule is especially well represented in the red limestone beds at the base of the Nolichucky, of very limited extent in the Rogersville area as previously discussed (author's localities cnd/1, cnd/2; U.S.N.M. locality 27d). The faunule from these beds, excluding a few unrecognizable forms named by Resser, includes:

Ankoura triangularis
Bonneterrina appalachia
Cedarina, sp. undet.
Coosella resseri
Genevievella, sp. undet.
Holcacephalus granulatus
Ithycephalus typicalis
Kormagnostus simplex
Loxoparia obliqua
Menomonia prominens
Modocia bidentata
Modocia crassimarginata
Modocia dubia
Norwoodella saffordi
Norwoodella rotundicollis
Norwoodia rogersvillensis
Tricrepicephalus, sp. undet.

In the equivalent stratigraphic position in other parts of the Rogersville outcrop belt, the basal beds of the Nolichucky consist of the usual gray-green shale with rare lenses of crystalline limestone (author's localities cne/1, cne/2; U.S.N.M. localities 103, 124). The species collected from these beds include:

Genevievella, sp. undet.
Kormagnostus simplex
Menomonia prominens
Norwoodella saffordi

Outside of the immediate vicinity of Rogersville, fossils of the *Cedaria* zone occur in Tennessee chiefly in the northwestern portion of the Cambrian outcrop area, in the belts N. of Clinch Mountain from Forked Deer Creek (Thorn Hill section) to Heiskell W. of Knoxville. Trilobites occur at scattered localities, usually either in shale or in a coarse, glauconitic calcarenite where most of the tests have been ground to unrecognizable fragments. Very little information about the faunal succession can be determined from these occurrences. Species collected from several localities are listed below.

Seemingly the oldest Upper Cambrian fossils occur in U.S.G.S. collection 2406 (= author's collection cnb/10), where the following species were identified:

Ankoura triangularis
Kormagnostus simplex
Olenoides, sp. undet.

The most striking fossil is the *Olenoides,* unfortunately known only from fragmentary pygidia. Notwithstanding the presence of this predominantly Middle Cambrian genus, the abundance of *Ankoura* and *Kormagnostus* suggests about the same age as the red beds at the base of the Nolichucky in the Rogersville area.

Faunules collected from the Comby Ridge localities (cnd/10 = U.S.G.S. collection 2407, cne/10), Thorn Hill (cne/13), and Copper Ridge (cne/12) yielded:

Ankoura triangularis
Cedaria tennesseensis
Kormagnostus simplex
Menomonia, sp. undet.
Norwoodella halli
Norwoodella walcotti

This faunule is presumably somewhat younger than any of those of the *Cedaria* zone collected from the vicinity of Rogersville.

FAUNA OF THE *CREPICEPHALUS* ZONE

In all the sections studied, an unfossiliferous interval separates the youngest observed faunule of the *Cedaria* zone from the oldest fossils of the *Crepicephalus* zone. The lower and middle portions of the Nolichucky formation are in general sparingly fossiliferous, being represented either by shales with siltstone beds, or in part by the massive lower limestone member. Only when either the shales contain fairly pure, crystalline limestone layers, or the massive limestone is partly replaced by a thin-bedded limestone, may well-preserved fossils be expected. These conditions occur erratically at different localities, hence a single section seldom supplies a succession of several faunules, and it is difficult to place those collected in different areas in proper stratigraphic order. In general, the beds of the *Crepicephalus* zone become more fossiliferous upward, the richest in most sections being those that just underlie the *Aphelaspis* zone.

Probably the earliest fossils of the *Crepicephalus* zone collected in the area are those from near the base of the lower limestone member occurring in the vicinity of Rogersville (collections cnk/1, cnk/3). The species include:

**Blountia alexas*
Blountia montanensis
**Coosella planicauda*
Coosella, sp. undet.
**Crepicephalus convergens*
Dresbachia amata
**Kingstonia inflata*
Maryvillia arion

Meteoraspis brevispinosa
Tricrepicephalus thoosa
Undetermined cranidium No. 2

Most of these species are represented in higher beds except *Blountia alexas* and *Meteoraspis brevispinosa,* which were not found in the highly fossiliferous, higher portions of the same limestone unit. *Maryvillia arion* is very rare in the above faunule, whereas it becomes abundant in higher beds.

A rather large faunule was collected near Rogersville, a short distance from locality cnk/1, in beds approximately 45 feet below the top of the lower limestone unit of the Nolichucky, hence about 90 feet above the beds cnk/1. At other localities no fossils were observed at this horizon. The faunule (collection cnm/2) includes:

Blountia arcuosa
Blountia montanensis
Coosella planicauda
Coosia alethes
Coosina amage
Coosina ariston
Dresbachia amata
Kingstonia inflata
Llanoaspis walcotti
Madarocephalus laetus
Maryvillia arion
Meteoraspis mutica
Tricrepicephalus thoosa

Finally, the youngest faunule of the *Crepicephalus* zone is well represented at numerous localities. It occurs either near the top of the massive lower limestone unit of the Nolichucky, or in thin limestone beds near the base of the overlying shale. The transition between the *Crepicephalus* and *Aphelaspis* zones may occur either within the upper portion of the limestone unit, or within the lower part of the overlying shale. In some sections, such as at Big Creek, it is possible that the faunizone boundary coincides with the lithologic contact. The species observed at localities cnn/1, cnn/2, cnn/3, cnn/4, cnn/5, cnn/14, cnn/15, cnn/16, cnn/17, cnn/19, and cnm′/20 are listed below. These collections are lumped together, since age differences between them appear insignificant.

Amiaspis erratica
**Amiaspis obsolescens*
**Blountia arcuosa*
Blountia lata
Blountia montanensis
Blountiella, sp. undet.
Coosella, sp. undet.

**Coosia alethes*
Coosia robusta
Coosia, sp. undet.
Coosina ariston
Coosina, sp. undet.
Crepicephalus buttsi
Crepicephalus cf. *convergens*
Crepicephalus cf. *scissilis*
Crepicephalus, sp. undet. No. 1
Crepicephalus, sp. undet. No. 2
Kingstonia inflata
Llanoaspis walcotti
**Maryvillia arion*
Meteoraspis mutica
Meteoraspis, sp. undet.
Pemphigaspis, sp. undet.
Terranovella dorsalis
**Tricrepicephalus thoosa*
Undet. cranidium No. 1

Fossils from the U.S.N.M. localities 24m, 104, 121a, 123b, 125 and 125a were certainly all collected in the Rogersville area from the lower limestone member of the Nolichucky formation, hence from the horizons here designated cnk, cnm, and cnn.

FAUNA OF THE *APHELASPIS* ZONE

The faunal succession in the *Aphelaspis* zone is particularly well developed in Tennessee and was studied in great detail in several sections.

At some of the localities there is no gap in fossiliferous beds between the *Crepicephalus* and *Aphelaspis* zones, hence the change from one fauna to the other could be thoroughly investigated. It was shown in the preceding section that the latest *Crepicephalus* zone faunule is characterized by species of *Coosia, Crepicephalus, Tricrepicephalus, Blountia,* and *Kingstonia,* in addition to *Maryvillia arion* and *Terranovella dorsalis*. Other genera, such as *Amiaspis* and *Llanoaspis,* are occasionally present. At Russell Gap, a faunule that is considered to belong in the *Aphelaspis* zone appears about 3 feet above the typical *Crepicephalus* fauna, in a succession of massive limestone beds of uniform lithology. This basal *Aphelaspis* zone faunule (loc. cno/14) yielded several species of trilobites representing a holdover of *Crepicephalus* zone forms with the addition of new elements, which had certainly evolved elsewhere since no possible immediate ancestors occur in the local *Crepicephalus* fauna. The *Crepicephalus* zone genera *Tricrepicephalus,* represented by an undetermined species, and *Coosella,* represented by *Coosella perplexa,* are associated with the typical *Aphelaspis* zone forms *Aphelaspis* cf. *A. lata* and *Cheilocephalus* *brevilobus.* Further members of the faunule are *Blountia bristolensis* and *Glaphyraspis parva. Blountia bristolensis* was not found in the *Crepicephalus* zone but is there represented by the very similar *Blountia montanensis. Glaphyraspis* was not found in Tennessee below the *Aphelaspis* zone. However, the author collected cranidia attributed to *G. parva* in a late *Crepicephalus* zone faunule from northeastern Virginia (Rasetti, 1961).

In the Hurricane Hollow section, also, an interval of a few feet separates the uppermost *Crepicephalus* zone faunule from the earliest *Aphelaspis* zone faunule in a uniform succession of massive limestone beds. Here, however, the only remnant of the *Crepicephalus* fauna is the genus *Blountia,* represented again by *B. bristolensis.* It is associated with *Aphelaspis transversa* and *Cheilocephalus brevilobus.*

The transition between the two faunizones is excellently shown in the Three Springs section. Here the rock at this level is mostly shale with thin fossiliferous limestone beds and lenses. The earliest *Aphelaspis* zone faunule (loc. cno/15) is essentially the same as at Russell Gap, holding in great abundance *Aphelaspis buttsi* and *Glaphyraspis parva,* with rare specimens of *Coosella perplexa.*

At all these localities, *Coosella* is absent from higher beds, while *Blountia* and *Glaphyraspis* continue in association with different species of *Aphelaspis.* In this portion of the section faunal changes may occur within a few feet of beds, and very accurate determinations of the relative positions of beds and lenses are required to avoid mixing forms that do not occur together. In the field every single lens was labeled separately and its stratigraphic position carefully recorded. In the Russell Gap and Three Springs sections, a characteristic faunule (locs. cnp/14, cnp/15) including innumerable remains of *Aphelaspis lata,* a close relative of *A. buttsi,* occurs a few feet above the faunule described above. Associated species are *Blountia bristolensis, Cheilocephalus brevilobus,* and *Glaphyraspis ornata.* This faunule is well represented also in the Washburn section (loc. cnp/20).

In the Three Springs section, in a thin bed 1 foot higher, *Aphelaspis walcotti* appears in association with *A. lata.* This is an unusually early occurrence of that species which is more common in higher strata. Still 6 inches higher, another species of *Aphelaspsis, A. minor,* makes its appearance in the Three Springs section and is also common in the equivalent position in the Russell Gap and Hurricane Hollow sections (locs. cnq/15, cnq/14, cnq/17). Associated forms, as in the underlying faunule, are *Blountia bristolensis, Cheilocephalus brevilobus,* and *Glaphyraspis ornata.*

The next higher faunule, known from a number of sections, is characterized by *Aphelaspis walcotti,* the type species of the genus. The stratigraphic position of the type collection from Saltville, Va., is unknown, but in Tennessee the species was found to occur always in the same relative position to other forms of *Aphelaspis,* excepting the unusually early occurrence mentioned above. It was collected at Three Springs (cnr/15), Smith Hollow (cnq/16, cnr/16), Lost Creek (cnq/4), Hurricane Hollow (cnr/17 = Oder's coll. No. 2), and Washburn (cnq/20). Associated species are *Glaphyraspis declivis, G. oderi,* and *Blountia mimula,* the last found only at Hurricane Hollow.

This is the latest known occurrence of *Blountia* in Tennessee. In view of this fact and other faunal changes, it seems proper to designate the strata so far discussed as the lower portion of the *Aphelaspis* zone.

The overlying beds, here assigned to the middle *Aphelaspis* zone, hold various faunules characterized by several species of *Aphelaspis* and related genera. These assemblages do not appear exactly in the same order in the different sections, hence we may assume that they are essentially of the same age. In the Washburn section, the earliest of these faunules (collection cnq'/20) consists of *Aphelaspis washburnensis* and *Glaphyraspis declivis.* This is followed by an assemblage of *Aphelaspis camiro, A. laxa,* and *A. quadrata,* recognized at several localities (U.S.N.M. locality 120, Shields Ridge; cns/15, cns'/15, Three Springs; cns/16 (= Oder's collection No. 13), Smith Hollow; cnr/20, cnr'/20, Washburn). The Washburn section yields from somewhat higher beds (cns/20) a very characteristic assemblage of *Aphelaspidella macropyge, Aphelaspis arses, A. rotundata,* and *Paraphelaspis vigilans.*

However, at Lost Creek we encounter in ascending order a bed with rare *Aphelaspis* cf. *laxa* (cnq'/4), followed by one with *A. rotundata* (cnq''/4). Above the latter are limestone beds (cnr/4, cnr'/4) with an abundance of *Aphelaspidella macropyge,* accompanied by *Aphelaspis arses, Aphelaspis* cf. *lata, Cheilocephalus* sp., and *Paraphelaspis vigilans.* The still higher beds cns/4 yielded rare *Aphelaspis camiro* and *A. laxa,* in addition to other species to be mentioned later. In the Three Springs section, above a bed (cnr'/15) with *Aphelaspis laxa,* collection cns/15 yielded *Aphelaspis camiro, A. laxa, A. quadrata, A. washburnensis,* and *Aphelaspis,* sp. undet. (the last two not associated in the same stratum with the other three). The still higher beds cns'/15 and cns''/15 yielded *Aphelaspidella macropyge, Aphelaspis arses, A. rotundata,* and *Paraphelaspis vigilans.* These findings indicate that although the *Aphelaspis camiro–laxa–quadrata* and the *Aphelaspidella macropyge–Aphelaspis rotundata–Paraphelaspis vigilans* assemblages were never observed in the same bed, each may occur either below or above the other.

An approximate equivalent of the last-mentioned assemblage is the one collected from Monroe County (U.S.G.S. collection 2970) with *Aphelaspidella macropyge, Aphelaspis arses, A. palmeri, Cheilocephalus,* sp., *Dunderbergia longifrons, Dytremacephalus strictus,* and *Paraphelaspis vigilans.*

In Jefferson County, lenses at the previously mentioned locality cns/4 also yield *Aphelaspis arses* and *A. inermis,* both also present in collection cns/2, accompanied by *Cheilocephalus* sp. and *Pseudagnostus communis.*

Above these faunules appears a widespread assemblage characterized in all sections where it is known by innumerable examples of *Aphelaspis tumifrons.* It was collected from Big Creek (cns/1, cnt/1), Lost Creek (cnt/4), Shields Ridge (cns/2), Three Springs (cnt/15, cnt′/15), Smith Hollow (Oder's coll. No. 14), Washburn (cnt/20, cnt′/20), River Ridge (cnt/21), and Purchase Ridge, Va. (cnt/7). Here should be mentioned the exceptional occurrence at Lost Creek in the collection cnt/4 of very rare specimens of *Dytremacephalus angulatus,* a species that becomes common in strata of the upper *Aphelaspis* zone. Normal associates of *Aphelaspis tumifrons* are instead *Aphelaspis arsoides, Cheilocephalus* sp., and *Pseudagnostus communis.*

The beds above the *Aphelaspis tumifrons* faunule and up to the top of the fossiliferous sequence, i.e., to the top of the Nolichucky formation (or Maynardville limestone), shall be assigned to the upper *Aphelaspis* zone. One faunule seems to occupy this interval, covering in the Big Creek section about 70 feet of strata, and the characteristic species are *Aphelaspis tarda* and *Dytremacephalus angulatus.* Less frequent and widespread are *Aphelaspis punctata, Cheilocephalus brachyops, Dunderbergia tennesseensis,* and the rare *Dytremacephalus sulcifrons.* This *Aphelaspis tarda* faunule was collected at Big Creek (cnu/1, cnv/1, cnw/1, cnx/1), Purchase Ridge (cnu/7, cnv/7, cnv′/7), Russell Gap (cnw/14), Three Springs (cnu/15, cnv/15), Smith Hollow (Oder's coll. No. 14A), Washburn (cnw/20, cnx/20), and River Ridge (cnu/21, cnv/21).

In Tennessee all the higher fossiliferous beds of the Nolichucky, up to the top of the formation, have been assigned to the *Aphelaspis* zone, since the faunules are very homogeneous, being dominated by species of *Aphelaspis.* However, the younger of these faunules may be equivalent to faunules attributed by Palmer to post-*Aphelaspis* zones in the western sections (see later discussion).

It seems likely that the vertical distribution of genera and species described above does not mean that each species only lived for the short time span indicated by the thickness of beds through which it was collected. Two examples, the presence of *Aphelaspis* cf. *lata* at an unusually high horizon in collection cnr/4, and the early occurrence of *Dytremacephalus angulatus* in collection cnt/4, probably indicate that while at a given locality each species was abundant for only a very limited time, it may have lived at different times at other places. The inversion of the order of the *Aphelaspis camiro* and *Aphelaspis rotundata* assemblages, observed in two sections, even though it does not involve a considerable thickness of strata, is another indication that the presence or absence of a species at a certain level may have little time significance, being determined rather by some ecologic factor, or simply a historical accident.

Even considering these restrictions to its validity, it is clear that the above-discussed succession of *Aphelaspis* faunules is the best documented in the entire Cambrian of the Appalachians and may allow the stratigrapher to correlate new sections with great precision. As it will be pointed out in the discussion of *Aphelaspis,* a species of that genus may not be identifiable from a single individual, even if perfectly preserved, much less from weathered or flattened material. Fortunately, however, the strata of the *Aphelaspis* zone, and especially thin, crystalline limestone lenses in shale, may be so fossiliferous that a small sample of rock in many cases supplies sufficient information for the clear recognition of one of the faunules described herein.

In view of the relatively meager knowledge of the biostratigraphy of the *Aphelaspis* zone in North America and of the observed transition between the *Crepicephalus* and *Aphelaspis* faunas, a comparison with recent findings in other areas is of interest. A detailed study of the distribution of genera and species of trilobites near and above the *Crepicephalus–Aphelaspis* zone boundary was made by Palmer (1954, 1962b) in Alabama, central Texas, and Nevada. His main conclusions, derived from the study of the faunal succession in the Conasauga formation at Woodstock and Cedar Bluff, Ala., and in the uppermost part of the Hamburg limestone and the overlying Dunderberg shale at several localities in Nevada, may be thus summarized: (1) There is a sudden change, often occurring in a few feet of strata, from a faunule containing trilobite genera of the *Crepicephalus* zone ("Crepicephalid biofacies") to a faunule with *Aphelaspis* and other trilobites of the *Aphelaspis* zone ("Pterocephaliid biofacies"). (2) This change in Nevada coincides with the contact between the relatively pure, massive Hamburg limestone and the interstratified siltstone and silty limestone beds of the overlying Dunderberg formation. (3) Notwithstanding the great faunal change, no appreciable hiatus is believed to be involved. (4) The replacement of the Crepicephalid biofacies with the Pterocephaliid biofacies is believed not to have been synchronous everywhere, but to have taken place earlier in the geosynclinal areas and to have spread later toward the interior of the continental shelf. Hence the use of the term "biofacies" rather than faunizones. (5) The uppermost faunule attributed to the Crepicephalid biofacies at McGill, Nev., and a similar faunule collected at Woodstock, Ala., include *Cedaria prolifica,* the type species, or related forms of *Cedaria.* If the interpretation is correct, the type species of *Cedaria* would be a trilobite of the *Crepicephalus* rather than the *Cedaria* zone.

In a second, more extensive paper on the Upper Cambrian faunas of Nevada, Palmer (1965)[1] recognizes in ascending order the *Aphelaspis, Dicanthopyge, Prehousia, Dunderbergia,* and *Elvinia* zones, all belonging to a Pterocephaliid "biomere." The validity of some of these zones may be limited to the Great Basin.

The observations in Tennessee show several features in common with the faunal development in Nevada. The change from the *Crepicephalus* to the *Aphelaspis* fauna is equally sudden, and the writer has already expressed agreement with Palmer's conclusion that most of the trilobites of the *Aphelaspis* fauna have no immediate ancestors in the *Crepicephalus* fauna; hence the change occurred by immigration of a new fauna that had been evolving elsewhere, presumably in geosynclinal areas. In Tennessee the faunal change may occur either within the lower, massive limestone member of the Nolichucky formation, or coincide with the contact between this limestone unit and the overlying shale with interbedded, thin limestone beds and lenses; or it may occur within the latter lithologic unit. In any case there is no evidence whatever that the faunal change is associated with a hiatus.

The earliest *Aphelaspis* faunule observed in Tennessee has species identical with or closely related to some of the earliest species of the Pterocephaliid biofacies found by Palmer in Nevada. In particular, *Aphelaspis buttsi* is the earliest species of the genus appearing both at McGill, Nev., and in the Three Springs section in Tennessee. Instead, no very close relationship appears between the youngest faunules of the Crepicephalid biofacies observed in Nevada and Tennessee; only the genus *Coosia* seems common to both. This fact might be indicative of the presence of a hiatus in the Nevada sections.

It becomes more difficult to correlate younger faunules from Tennessee with those of the Nevada sections. Several *Aphelaspis* species described from Nevada, *A. brachyphasis, haguei, subditus,* and *longispina,* all closely resemble species from Tennessee, but in view of the fact that in either region species of *Aphelaspis* of rather different ages

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[1] The writer is indebted to Dr. Palmer for reading the manuscript before publication.

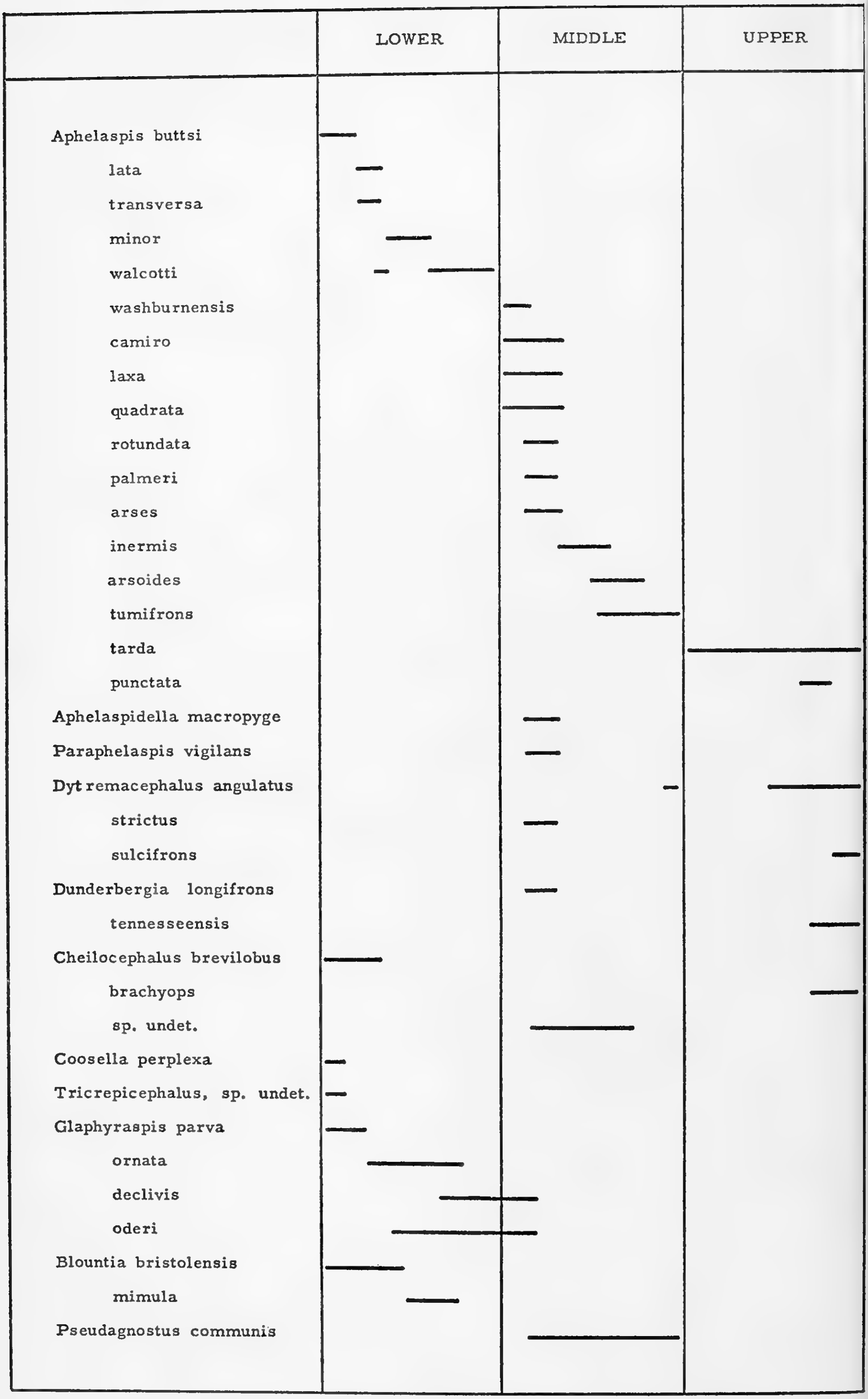

FIG. 1.—Range of trilobite species in the *Aphelaspis* zone of Tennessee.

may be extremely similar (e.g., in Tennessee the early species *A. walcotti* resembles the late species *A. tarda*), not much time significance can be attributed to such similarities. In Nevada, Palmer finds *Tumicephalus* (based on a species almost identical with *Aphelaspis tumifrons*) in the post-*Aphelaspis, Dicanthopyge* zone, species of *Dytremacephalus* in the still younger *Prehousia* and *Dunderbergia* zones, *Cheilocephalus brachyops* and various species of *Dunderbergia* in the *Dunderbergia* zone. These findings might be taken to indicate that part of the middle *Aphelaspis* zone and all of the upper *Aphelaspis* zone of this paper are equivalent to portions of Palmer's post-*Aphelaspis* zones in Nevada. On the other hand, these latter zones are characterized by a large number of genera of Pterocephaliid trilobites never observed in Tennessee. Hence it is difficult to decide what fauna in Nevada is the equivalent of the youngest *Aphelaspis* faunule from Tennessee, the *Aphelaspis tarda* faunule, which occurs in the uppermost beds of the Nolichucky formation. Perhaps the evidence favors equivalence to part of the *Prehousia* or *Dunderbergia* zones in Nevada.

Even in the lower part of the *Aphelaspis* zone several genera present in the early *Aphelaspis* fauna in Alabama and Nevada were not found in Tennessee. Conspicuous among these are *Glyptagnostus* and other agnostid genera, and the Pterocephaliid genus *Olenaspella,* indistinguishable from *Aphelaspis* in the cranidial features but characterized by the development of one or more pairs of marginal pygidial spines. Apparently these trilobites are more characteristic of the geosynclinal facies and never migrated far enough within the continental shelf to reach northeastern Tennessee. Absence of trilobites of the geosynclinal facies is a feature of both the *Crepicephalus* and *Aphelaspis* faunas.

The observations in Tennessee bear no evidence on the question whether the replacement of the *Crepicephalus* fauna with the *Aphelaspis* fauna was simultaneous or not in different areas, since the localities studied are all within a narrow belt parallel to the margin of the geosyncline.

In Tennessee no occurrence of *Cedaria* or other genera of the *Cedaria* zone close to the base of the *Aphelaspis* zone, or even a few hundred feet below this level, was ever observed. This fact may again be related to the "cratonic" rather than geosynclinal environment prevailing through the entire Upper Cambrian in Tennessee.

PART II. SYSTEMATIC PALEONTOLOGY

GENERAL STATEMENT

Not all the species of trilobites described from the Upper Cambrian of Tennessee are treated in this paper. With few exceptions, only those collected by the author from measured sections and hence contributing to the knowledge of the faunal succession are discussed herein.

Type catalog numbers and type localities for previously described species are given only when the types are from the southern Appalachians.

Unless otherwise stated, all the described and illustrated specimens are preserved in limestone, and show the outer surface of the test, on which the description is based.

The author's localities are often given only by their numbers in this descriptive part; their topographic position may be readily identified from the locality list, the stratigraphic position from the descriptions of the sections.

All the types and other figured specimens collected by the writer were deposited in the U.S. National Museum collections. All the Museum numbers beyond 144000 are listed in Paleozoic catalog No. 30.

DESCRIPTIONS OF TRILOBITE GENERA AND SPECIES

Order AGNOSTIDA

Family AGNOSTIDAE McCoy, 1849

Genus KORMAGNOSTUS Resser, 1938

Type species.—*Kormagnostus simplex* Resser.

KORMAGNOSTUS SIMPLEX Resser

Plate 1, figures 8, 9

Kormagnostus simplex Resser, 1938a, p. 49, pl. 9, figs. 11–13.
Kormagnostus harlanensis Resser, 1938a, p. 49, pl. 10, figs. 11, 12.
Kormagnostus simplex Resser, Palmer, 1954, p. 718, pl. 76, figs. 8–12 (includes complete synonymy).
Kormagnostus simplex Resser, Lochman and Hu, 1960, p. 822, pl. 99, figs. 5–31.

Common almost everywhere in the fossiliferous beds at the top of the Maryville limestone and the overlying basal Nolichucky shale (*Cedaria* zone).

Occurrence.—Type locality for *K. simplex* is U.S.N.M. 27d (= author's locality cnd/1); red beds at the base of the Nolichucky E. of Rogersville. Type locality for *K. harlanensis* is U.S.N.M. locality

124, presumably near the top of the Maryville limestone and identical with one of the author's localities, cnc/2 to cnc/5. Collected by the author at localities cnc/5, cnc/6, cnd/1, cnd/2, cne/1, cne/2, cnb/10, cnd/10, cne/10, cne/13.

Types.—Cotypes of *K. simplex:* U.S.N.M. 94842. Cotypes of *K. harlanensis:* U.S.N.M. 94863. Plesiotypes figured herein: U.S.N.M. 144546.

Genus PSEUDAGNOSTUS Jaekel, 1909

Type species.—*Agnostus cyclopyge* Tullberg.

PSEUDAGNOSTUS COMMUNIS (Hall & Whitfield)

Plate 10, figures 23–25

Agnostus communis HALL and WHITFIELD, 1877, p. 228, pl. 1, figs. 28, 29.
Agnostus neon HALL and WHITFIELD, 1877, p. 229, pl. 1, figs. 26, 27.
Pseudagnostus communis (Hall and Whitfield) PALMER, 1955, p. 94, pl. 19, figs. 16, 19–21; pl. 20, figs. 4–11, 14; 1960, p. 61, pl. 4, figs. 3, 4.
Pseudagnostus communis (Hall and Whitfield) RASETTI, 1961, p. 109, pl. 23, figs. 13–17.

A *Pseudagnostus* that occurs at several localities in beds of the *Aphelaspis* zone does not differ in any observable features from topotype material illustrated by Palmer. The latter is from the *Dunderbergia* zone of Nevada. The author (Rasetti, 1961) figured specimens from the *Dunderbergia* zone of Maryland.

Occurrence.—Collected at localities cnt/1, cns/2, cns/4, cnt/4, cnt/7, cns/15, cnt/15. All these collections are from the middle portion of the *Aphelaspis* zone.

Types.—Plesiotypes: U.S.N.M. 144547.

Order CORYNEXOCHIDA

Family DORYPYGIDAE Kobayashi, 1935

Genus OLENOIDES Meek, 1877

Type species.—*Paradoxides nevadensis* Meek.

OLENOIDES, species undetermined

Plate 5, figures 12, 13

Available material.—Two fragmentary pygidia.

Description.—Pygidium fully typical of the genus, of the four-spined group. Axis not preserved except for the terminal portion, almost reaching the posterior margin. Pleural regions of low convexity. Three pairs of pleural furrows and as many of interpleural grooves about equally impressed, regularly curved, all becoming somewhat deeper in the indefinite border furrow; each interpleural groove approximately parallel to the preceding furrow but diverging from the following furrow. Spines progressively closer to each other; those of the first two pairs strong, the last two progressively more slender. Spines of last pair directed straight backward, their distance greater than between the third and fourth pairs. Surface of test smooth.

Discussion.—This form, as far as can be ascertained from the fragmentary material, does not greatly differ from several Middle Cambrian species of the genus, such as *O. curticei* Walcott, and *O. convexus* Rasetti, but is readily distinguished by the course of the pleural furrows and the spacing of the marginal spines. The writer (Rasetti, 1946) described a Dresbachian species of the genus which, however, has only 3 pairs of marginal spines.

Occurrence.—U.S.G.S. collection 2406 (= author's collection cnb/10), Comby Ridge. The species occurs in the same piece of rock with abundant *Ankoura triangularis*.

Disposition of material.—Figured specimens: U.S.N.M. 144548.

Order PTYCHOPARIIDA

Family LONCHOCEPHALIDAE Hupé, 1953

Genus TERRANOVELLA Lochman, 1938

Type species.—*Terranovella obscura* Lochman.

TERRANOVELLA DORSALIS (Hall)

Plate 6, figure 7

Conocephalites? (Arionellus?) dorsalis Hall, 1863, p. 222.
Ptychoparia dorsalis (Hall) Vogdes, 1890, p. 141.
Lonchocephalus sospita Walcott, 1916a, p. 195, pl. 36, figs. 1, 1a.
Terranovella buttsi Resser, 1938a, p. 100, pl. 15, figs. 22–26.
Terranovella dorsalis (Hall) Raasch and Lochman, 1943, p. 234, pl. 35, figs. 3–10, 17.
Terranovella dorsalis (Hall) Rasetti, 1961, p. 118, pl. 22, figs. 7–13.

Occurrence.—Type locality for *T. buttsi* is U.S.N.M. 35s, near Abingdon, Va. Collected by the author in the uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at localities cnn/1, cnn/14, cnn/15, cnn/19, and cnn/20.

Types.—Holotype of *T. buttsi:* U.S.N.M. 94984. Plesiotype: U.S.N.M. 144549.

Genus GLAPHYRASPIS Resser, 1937

Type species.—*Liostracus parvus* Walcott.

GLAPHYRASPIS PARVA (Walcott)

Plate 10, figures 9–17

Liostracus parvus Walcott, 1899, p. 463, pl. 65, fig. 6.
Glaphyraspis parva (Walcott) Resser, 1937, p. 12.
Raaschella occidentalis Lochman, in Lochman and Duncan, 1944, pl. 43, pl. 4, figs. 1–5.

Glaphyraspis parva (Walcott) RASETTI, 1961, p. 112, pl. 22, figs. 14–17.
Glaphyraspis parva (Walcott) LOCHMAN and HU, 1962b, p. 438, pl. 68, figs. 7–52.

A form that occurs in the transition beds between the *Crepicephalus* and *Aphelaspis* zones is referred to the species. The cranidia are somewhat variable both in shape and ornamentation. The glabella is typically parallel-sided, but in some individuals it is slightly tapered and proportionately shorter and wider. The depth of the glabellar furrows is also variable. The ornamentation of the type material from Yellowstone National Park consists of a dense, extremely fine granulation plus scattered, larger granules. Some of the individuals from Tennessee match this type of ornamentation; others show granules of one size, while some are almost smooth. All these features may be found in specimens from a single piece of rock, hence they must be ascribed to intraspecific variability.

Occurrence.—The illustrated material is from locality cno/15, Three Springs. Also collected at locality cno/14, Russell Gap. At both localities it occurs below the beds yielding other species of *Glaphyraspis.*

Types.—Plesiotypes: U.S.N.M. 144550.

GLAPHYRASPIS ORNATA (Lochman)

Plate 10, figure 8; plate 11, figures 13, 14

Raaschella ornata LOCHMAN, 1938, p. 82, pl. 18, figs. 6–10.
Raaschella ornata Lochman, PALMER, 1954, p. 767, pl. 98, figs. 7–9.
Glaphyraspis ornata (Lochman) RASETTI, 1961, p. 112.

The species is not rare in the basal beds of the *Aphelaspis* zone. Complete specimens in shale collected by Dr. Oder, one of which is illustrated herein, show that the thorax has 8 segments. The axial rings have no nodes or spines. The pleurae are flat, straight, and uniformly furrowed for most of their course. Near the distal end they bend backward and downward and possess the peculiar ridges previously observed in the pygidium.

Occurrence.—Author's localities cnp/14, cnq/14, cnq/15, cnq/16, cnr/16, cnq/17. Also in Oder's collection No. 3 at Hurricane Hollow and U.S.G.S. collection 2804 on Shields Ridge.

Types.—Plesiotypes: U.S.N.M. 144551–2.

GLAPHYRASPIS ODERI Rasetti, new species

Plate 10, figures 18–22

Available material.—Numerous cranidia, free cheeks, and pygidia well preserved in limestone.

Description.—Glabella of same shape as in *G. ornata;* glabellar furrows of usual pattern but exceedingly shallow on outer surface.

Occipital furrow well impressed; occipital ring expanded medially, rounded. Fixed cheeks convex, rising somewhat above axial furrow, then downsloping. Frontal area short, about one-fifth the glabellar length; border narrow and poorly defined by a shallow border furrow. Ocular ridges faint, transverse in direction; palpebral lobes narrow and short, in advance of glabellar midpoint. Posterior area as in type species, steeply downsloping, well furrowed. Free check with border well defined anteriorly, poorly marked posteriorly; genal angle rounded.

Pygidium with long axis, showing about 4 distinct rings, reaching the posterior margin. Pleural platforms flat; border downsloping. Pleural and interpleural furrows both well marked. Each segment has the characteristic distal ridge as in other species.

Surface of cranidium in most of the specimens from the type locality with scattered tubercles only in certain areas, more apparent on the posterior portion of the fixed cheeks, almost lacking on the glabella. Some of the cranidia appear entirely smooth, particularly among those from collection cnq/20, and especially from the higher collection cnr′/20. However, smooth and granulated cranidia occur on the same piece of rock, and there are all intermediate forms.

Length of largest cranidium 3.0 mm.; length of largest pygidium 1.8 mm.

Discussion.—This species resembles both *G. parva,* from which it differs in the somewhat wider and shorter glabella, and *G. ornata,* from which it can be separated by the much weaker ornamentation.

Occurrence.—The types are from Oder's collection No. 2 at Hurricane Hollow, in beds immediately overlying those with *G. ornata.* Also present in collections cnr/15, cnp′/20, cnq/20, and cnr′/20. The species ranges through an appreciable thickness of beds, appearing in the *Aphelaspis minor, A. walcotti,* and the *A. camiro, A. laxa,* and *A. quadrata* assemblages.

Types.—Holotype: U.S.N.M. 144553. Paratypes: U.S.N.M. 144554.

GLAPHYRASPIS DECLIVIS Rasetti, new species

Plate 14, figures 20–24

Available material.—Numerous cranidia and free cheeks well preserved in limestone.

Description.—Glabella subovate, slightly tapered, rounded in front, rising well above the cheeks. Posterior glabellar furrows of same shape as in *G. ornata,* very shallow; other pairs indistinct. Occipital furrow moderately impressed; occipital ring widely subtriangular, bearing an indistinct node. Cheeks sloping down steeply from axial furrow; frontal area about one-fourth the glabellar length, slightly convex, barely divided by a trace of a border furrow; anterior outline somewhat pointed medially. Ocular ridges faint; palpebral area about one-fourth the glabellar width; palpebral lobes very small, at level of anterior third of glabella. Anterior section of facial suture convergent immediately in front of palpebral lobes; posterior section slightly convex outward, gradually curving backward and inward to produce broad, well-rounded posterior area. Furrow on posterior area broad and shallow. Free cheek rounded at genal angle; border narrow but fairly distinct anteriorly, becoming indistinct posteriorly. Surface of test smooth. Length of largest cranidium 2.4 mm.

Discussion.—The pygidium has not been identified. The cranidium of *G. declivis* differs from other species of the genus in the steeply downsloping palpebral area and the tendency to obsolescence of all the furrows; however, its close relationship to the more typical forms is unmistakable.

Occurrence.—The type is from Oder's collection No. 2, Hurricane Hollow. Also present in collections cnr/15, Three Springs, and cnr/16, Smith Hollow. In all these occurrences it is associated with *Aphelaspis walcotti*. Rare specimens were collected at locality cnq′/20, Washburn, in somewhat higher beds.

Types.—Holotype: U.S.N.M. 144556. Paratypes: U.S.N.M. 144557.

Genus AMIASPIS Lochman, 1944

Type species.—*Amiaspis erratica* Lochman.

AMIASPIS ERRATICA Lochman

Plate 5, figure 20

Amiaspis erratica Lochman, in Lochman and Duncan, 1944, p. 68, pl. 8, figs. 41-46.

A few cranidia do not appear to differ appreciably from topotype material from Montana.

Occurrence.—Locality cnn/16, Smith Hollow.

Type.—Plesiotype: U.S.N.M. 144558.

AMIASPIS OBSOLESCENS Rasetti, new species

Plate 5, figures 21-24

Available material.—The holotype, a good cranidium, is the only specimen from the type locality. Several fragmentary cranidia from another locality are also available.

Description.—Glabella large, somewhat tapered, widely rounded in front, unfurrowed, barely defined on the outer surface by a very shallow axial furrow, almost merging with the general convexity of the cephalon. Occipital furrow very shallow; occipital ring extended into a long, slender, almost horizontal spine. Fixed cheeks convex and downsloping; frontal area short (sag.), not differentiated into preglabellar field and border. Ocular ridges barely indicated; palpebral lobes almost indistinct, at level of the anterior fourth of glabella. Posterior area broad, strongly downsloping, rounded distally, deeply furrowed in contrast to the shallowness of all other furrows. Margin of posterior border showing a geniculation close to the axial furrow. Surface of test completely smooth. Length of largest cranidium, exclusive of spine, 2.2 mm.

Discussion.—The species differs from the type, with which it is associated, in the obsolescence of the axial furrow and the proportionately larger and unfurrowed glabella.

Occurrence.—The type locality is cnm′/20, Washburn. Also in collection cnn/16, Smith Hollow. The stratigraphic position is in the upper *Crepicephalus* zone.

Types.—Holotype: U.S.N.M. 144559. Paratypes: U.S.N.M. 144-560.

Family CATILLICEPHALIDAE Raymond, 1938

Genus PEMPHIGASPIS Hall, 1863

Type species.—*Pemphigaspis bullata* Hall.

PEMPHIGASPIS, species undetermined

Plate 7, figures 23–25

A few cranidia and pygidia of *Pemphigaspis,* the latter fragmentary, may be identical with the type species but are not sufficient for a satisfactory identification.

Occurrence.—Uppermost beds of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnn/3.

Disposition of material.—Figured specimens: U.S.N.M. 144562.

Genus MADAROCEPHALUS Resser, 1938

Type species.—*Madarocephalus laetus* Resser.

MADAROCEPHALUS LAETUS Resser

Plate 8, figure 20

Madarocephalus laetus Resser, 1938a, p. 87, pl. 10, figs. 51–53.

A single cranidium agrees with the types, and proves that the species belongs to the *Crepicephalus* zone.

Occurrence.—Type locality is U.S.N.M. 56v, near McCalla, Ala. The author collected the specimen in the upper part of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnm/2.

Types.—Cotypes: U.S.N.M. 94885. Plesiotype: U.S.N.M. 144563.

Family CREPICEPHALIDAE Kobayashi, 1935

Genus CREPICEPHALUS Owen, 1852

Type species.—*Dikelocephalus ? iowensis* Owen.

CREPICEPHALUS cf. C. SCISSILIS Resser

Plate 8, figure 30

Crepicephalus scissilis Resser, 1938a, p. 72, pl. 11, figs. 34, 35.
Crepicephalus greendalensis Resser, 1938a, p. 73, pl. 11, figs. 46, 47.

A few, exfoliated pygidia resemble this species in the general shape, differing in the following minor features. The outline between the spines is slightly concave rather than straight; the median profile of the pleural region behind the axis is somewhat concave, instead of convex as it appears in Resser's specimens. Possibly these differences should be attributed specific value when better-preserved and more complete material can be found.

Occurrence.—Type locality for *C. scissilis* is U.S.N.M. 124a, 4 miles NE. of Rogersville. Type locality for *C. greendalensis* is U.S.N.M. 36u, near Greendale, Va. The author's material was collected from the uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnn/3.

Disposition of material.—Figured specimen: U.S.N.M. 144564.

CREPICEPHALUS BUTTSI Resser

Plate 6, figures 5, 6

Crepicephalus buttsi Resser, 1938a, p. 72, pl. 11, figs. 28, 29, 49, 50.
Crepicephalus expansus Resser, 1938a, p. 73, pl. 11, fig. 36.

Crepicephalus buttsi is represented by cranidia and pygidia poorly preserved and somewhat flattened in shale, while *C. expansus* is based on a limestone pygidium. No observable differences separate the pygidia bearing the two names. A form collected by the author and represented only by pygidia is identified with this species. The individual specimens vary to some extent in possessing straight or somewhat inward curved spines. Since both types occur in the same bed, these slight differences are not attributed specific significance.

Occurrence.—The type locality of *C. buttsi* is U.S.N.M. 26s, near Cleveland, Va. The type locality of *C. expansus* is U.S.N.M. 105, near Sneedville, Hancock County, Tenn. The specimens figured herein are from locality cnn/19.

Types.—Holotype of *C. buttsi* (pygidium): U.S.N.M. 94907. Paratypes: U.S.N.M. 94908. Holotype of *C. expansus:* U.S.N.M. 94910. Plesiotypes: U.S.N.M. 144565.

CREPICEPHALUS CONVERGENS Rasetti, new species

Plate 8, figures 5–8

Available material.—Several pygidia and cranidia, the former of small size, mostly preserving the test.

Description.—Cranidium fully typical of the genus. Glabella tapered, rounded in front, showing 2 pairs of shallow furrows even on the outer surface; occipital furrow straight, occipital ring rounded. Frontal area divided into preglabellar field and border of about equal widths (sag.); border slightly convex. Palpebral area and lobes as in other species of the genus; posterior area not preserved.

Pygidium represented by better specimens than the cranidium. Axis occupying two-thirds of the length, somewhat tapered, extended into a short postaxial ridge which reaches the wide, indistinct border furrow. About 2 rings distinct, 1 or 2 more barely indicated. Pleural lobes with rounded anterior angles, fairly straight sides converging toward the rear, and concave posterior margin between the spines. Pleural platforms relatively small, with 3 short, well-marked furrows, no interpleural grooves; slope dropping rather steeply to border furrow and wide, flat border. Spines rapidly tapered, flat, relatively short. Surface finely granulate. Length of largest pygidium 6.5 mm., width 10.5 mm.

Discussion.—This form is chiefly characterized by the pygidium, which differs in outline, form of the spines, and relative length of axis from described species.

Occurrence.—Lower portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnk/1.

Types.—Holotype (pygidium): U.S.N.M. 144566. Paratypes: U.S.N.M. 144567.

CREPICEPHALUS cf. C. CONVERGENS Rasetti

Plate 8, figures 9–11

Several pygidia collected in strata higher than those yielding the types of the species differ consistently in several features aside from the different manner of preservation (these pygidia are exfoliated). The sides are even more strongly convergent than in *C. convergens,* thus bringing the spines closer together; these are also shorter and more obtuse in shape, and the margin between them more definitely notched.

Occurrence.—Uppermost beds of the lower limestone member (*Crepicephalus* zone) of the Nolichucky (loc. cnn/1, cnn/3).

Dispostion of material.—Figured specimens: U.S.N.M. 144568-9.

CREPICEPHALUS, species undetermined No. 1

Plate 8, figures 17, 18

Available material.—Represented by incomplete, exfoliated pygidia and one poorly preserved cranidium that may belong to the same species.

Description.—Pygidium twice as wide as long. Axis occupying about five-sixths of the length, somewhat tapered, showing 3 rings and a terminal section. Pleural lobes extended into a pair of broad-based, strongly outward-directed, and presumably very long spines. Pleural platforms relatively short, with 3 pairs of pleural furrows. Border furrow indistinct.

Discussion.—This form cannot be identified with any described species on account of the character of the pleural spines.

Occurrence.—Uppermost beds of the lower limestone member (*Crepicephalus* zone) of the Nolichucky (loc. cnn/4).

Disposition of material.—Figured specimens: U.S.N.M. 144570.

CREPICEPHALUS? species undetermined No. 2

Plate 8, figures 12, 13

Available material.—A few cranidia and pygidia tentatively assigned to one species, preserved in limestone as internal impressions.

Description.—Glabella rather strongly convex in both directions, straight-sided, tapered, rounded in front, unfurrowed. Occipital furrow well impressed, straight; occipital ring lacking node or spine. Preglabellar field very short; border sharply elevated, convex, somewhat arched transversely; border furrow lacking depressions. Palpebral area slightly upsloping, about 0.25 times glabellar width; palpebral lobes small, curved, opposite glabellar midpoint; ocular ridges faintly indicated. Anterior facial sutures slightly divergent; anterior angles of cranidium narrowly rounded. Posterior area not preserved.

Associated pygidium of the *Crepicephalus* type, twice as wide as the midlength. Axis long, showing 3 rings and a terminal section, extended into a short postaxial ridge that reaches the margin. Pleural platforms convex and downsloping, with 3 pairs of deep, wide furrows, ending at wide, shallow border furrow. Spines continue the straight, slightly convergent outline of pygidial sides and are sharply pointed without attaining great length; margin between spines forming a broad curve. Length of largest cranidium 16 mm.; of pygidium 7 mm., width 14 mm.

Discussion.—The pygidium seems definitely to belong in the genus; the cranidium, however, is unusual in the strongly elevated anterior border and slightly upsloping palpebral area. The first of these characters would rather suggest *Meteoraspis,* but in that genus the palpebral area rises above the axial furrow and then slopes downward in characteristic fashion.

Occurrence.—Uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone); locality cnn/3.

Disposition of material.—Figured specimens: U.S.N.M. 144571.

Genus COOSELLA Lochman, 1936

Type species.—*Coosella prolifica* Lochman.

COOSELLA ANDREAS (Walcott)

Plate 1, figures 1–4

Blountia andreas Walcott, 1916b, p. 398, pl. 64, fig. 2.
Coosella andreas (Walcott) Resser, 1938a, p. 70, pl. 13, fig. 11.

Available material.—The holotype is a cranidium. Two cranidia and two associated pygidia collected by the author allow a more complete description. The cranidia differ from the holotype in the slightly less downsloping attitude of the anterior border, but such differences are common in obviously conspecific populations.

Description.—The pygidium has a very prominent, tapered, rounded axis reaching more than two-thirds of the pygidial midlength; it shows 3 rings and a terminal section extended into a low, broad postaxial ridge. Pleural lobes with unusually strong convexity, sloping down steeply to a narrow, poorly defined, concave border. Pleural platforms furrowed for a short distance, with 2 pairs of furrows and 1 pair of interpleural grooves indicated, all ending on the line that marks the inner edge of the doublure. Posterior margin in dorsal view showing a narrow notch between rounded lobes, in posterior view strongly raised medially. Surface of test smooth. The strong convexity of the pygidium distinguishes the species from all others attributed to the genus.

Occurrence.—Uppermost beds of Maryville limestone (*Cedaria* zone). Type locality is U.S.N.M. 102a, east of Rogersville. Collected by the author at locality cnc/2.

Types.—Holotype: U.S.N.M. 62823. Plesiotypes: U.S.N.M. 144572.

COOSELLA RESSERI Rasetti, new name

Plate 1, figures 5–7

Uncaspis tennesseensis Resser (part), 1938a, p. 105, pl. 9, fig. 20 (only).

Available material.—The pygidium, holotype of *Uncaspis tennesseensis*, and 2 additional pygidia, all preserved in limestone but exfoliated.

Description.—Pygidial axis slightly tapered, very prominent, showing 3 rings plus a terminal section, extended into a low postaxial ridge. Pleural platforms convex and strongly downsloping, showing several pairs of shallow furrows and interpleural grooves, all curving backward. Pleural region extended into a pair of slightly concave, horizontal, somewhat falcate lobes separated by a wide, rounded notch. Midlength of pygidium 5 mm., width 10 mm.

Discussion.—The cranidium referred by Resser to *Uncaspis tennesseensis* is an example of *Modocia dubia,* as mentioned in the synonymy of that species. The holotype pygidium is certainly not an *Uncaspis,* whatever the characters of this poorly understood genus may be, and seems definitely referable to *Coosella.* This assignment requires a change in the trivial name, because the binomial combination *Coosella tennesseensis* was used by Resser for another species. The pygidium has fundamentally the same structure as *Coosella andreas,* but is more strongly bilobate, and the notch between the lobes is much wider.

Occurrence.—Red beds at the base of the Nolichucky (*Cedaria* zone) at U.S.N.M. locality 27d, where it was also collected by the author (loc. cnd/1).

Types.—Holotype: U.S.N.M. 94846. Plesiotype: U.S.N.M. 144573.

COOSELLA PLANICAUDA Rasetti, new species

Plate 7, figures 1–5

Available material.—A few cranidia and numerous pygidia.

Description.—Glabella of usual shape, with traces of lateral furrows; occipital furrow deep and straight, occipital ring bearing a low node. Preglabellar field and border of about equal width (sag.); border strongly convex, with terrace lines. Palpebral lobes narrow, half the glabellar length; width of palpebral area about 0.3 times the glabellar width. Midpoint of palpebral lobes somewhat in advance of glabellar midpoint.

Pygidium with very little overall relief. Axis moderately convex, little more than half the pygidial length, moderately tapered, showing 2 or 3 rings and an unfurrowed terminal section, extended into a brief postaxial ridge. Pleural lobes almost flat, showing faint furrows in the narrow triangular portions anterior to the inner margin of the wide doublure, smooth in the remainder of the broad, slightly concave area; posterior outline well rounded except for a shallow median notch between the pair of wide lobes. Surface of test smooth. Length of largest pygidium 7.5 mm., width 11 mm.

Discussion.—This species possibly resembles *Coosia* more than *Coosella* in the shape of the pygidium, but the cranidial features rather indicate the present generic assignment.

Occurrence.—Lower and middle portions of the lower limestone member of the Nolichucky (*Crepicephalus* zone). Localities cnk/2, cnm/2.

Types.—Holotype: U.S.N.M. 144574. Paratypes: U.S.N.M. 144575–6.

COOSELLA PERPLEXA (Palmer)

Plate 15, figures 19–26

Crepicephalus? perplexus PALMER, 1954, p. 733, pl. 77, figs. 1, 2, 4.

Represented in the collections by numerous cranidia and pygidia and a few free cheeks. Careful comparison with topotype specimens and further material from Nevada identified by Palmer (private communication) failed to disclose any significant difference, hence the identification seems highly reliable.

Palmer tentatively referred the species to *Crepicephalus* rather than *Coosella* because of the stratigraphic position rather than morphology. The cranidia of the two genera are indistinguishable, and it has been customary to refer to *Crepicephalus* the forms with pygidia extended into a pair of lateral spines, to *Coosella* those with a pair of rounded lobes more or less separated by a median notch. Hence the reference to *Coosella* seems indicated in the present case. Other species of *Coosella, e.g., C. planicauda,* occur in the upper *Crepicephalus* zone, hence there is no stratigraphic discontinuity in the distribution of the genus.

Occurrence.—Basal beds of the *Aphelaspis* zone in collections cno/14, Russell Gap, and cno/15, Three Springs.

Types.—Plesiotypes: U.S.N.M. 144577–8.

COOSELLA, species undetermined

Plate 6, figure 19

A single pygidium was collected. It has a short axis and wide, flat pleural lobes with a slight median notch in the posterior margin. The axis is extended into a long, narrow postaxial ridge. This specimen resembles a pygidium of an unnamed species of *Coosella* figured by Palmer (1954, p. 730, pl. 79, fig. 1) but the sides are straighter and the posterior angles not so widely rounded.

Occurrence.—Lower portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnk/1.

Disposition of material.—Figured specimen: U.S.N.M. 144579.

Genus COOSINA Rasetti, 1956

Type species.—*Maryvillia ariston* Walcott (part).

COOSINA AMAGE (Walcott)

Plate 7, figures 14–22

Blountia amage WALCOTT, 1916b, p. 398, pl. 64, figs. 3, 3a.
Blountia alethes WALCOTT (part), 1916b, p. 397, pl. 64, figs. 1b, 1c (only).
Coosella amage (Walcott) RESSER, 1938a, p. 70, pl. 13, figs. 12, 13.

Available material.—*Blountia amage* was based on a proper combination of cranidium and pygidium, both represented by specimens preserving the test. *Blountia alethes* was described on a cranidium of *Coosia* illegitimately combined with an exfoliated pygidium of the preceding species. Since Walcott designated the cranidium as the holotype, the name *alethes* belongs to the species of *Coosia,* as used by Resser. The present generic assignment seems the proper one for *Blountia amage.* This species was found to be exceedingly common at one locality, and the numerous and better preserved material allows a more complete description.

Description.—Glabella defined by a fairly deep axial furrow, strongly tapered, rounded in front; glabellar furrows obsolete on outer surface, faint on impression of interior. Occipital furrow wide, occipital ring simple. Frontal area as in type species except for the greater distinctness of the border furrow and border. Palpebral area approximately horizontal, about 0.4 times the glabellar width; palpebral lobes about 0.4 times the glabellar length. Posterior area somewhat more slender and more deeply furrowed than in type species.

Pygidium 1.4 times as wide as long. Axis elevated, slightly tapered, occupying 0.8 of the pygidial length, extended into a brief postaxial ridge, with about 5 distinct rings and a terminal section. Pleural lobes convex, downsloping to moderately wide concave border. Anterior marginal furrow deep and wide, three other pairs of furrows shallow even on interior casts, traces of interpleural furrows also visible; all furrows end sharply at a line that corresponds to the inner edge of the doublure on the ventral side. The lateral and posterior margin with almost even curvature, except for a slight indication of flattening medially. Surface of test smooth. Length of largest cranidium 14 mm., of largest pygidium 10 mm.

Occurrence.—The type locality is U.S.N.M. 107, 11 miles NW. of Knoxville. Type locality for *Blountia alethes,* U.S.N.M. 123b, near Rogersville. Illustrated plesiotypes from the middle portion of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnm/2.

Types.—Holotype: U.S.N.M. 62824. Paratype: U.S.N.M. 62825. Paratype pygidium of *Blountia alethes* assigned to the species: U.S.N.M. 62822. Plesiotypes: U.S.N.M. 144580, 144561.

COOSINA ARISTON (Walcott)

Plate 7, figure 27

Maryvillia ariston WALCOTT (part), 1916b, p. 401, pl. 64, figs. 5, 5′ (not fig. 5a).
Coosina ariston (Walcott) RASETTI, 1956, p. 1267 (includes complete synonymy); 1961, p. 111, pl. 21, figs. 12, 13.

Several pygidia seem identical with this species. The cranidium was not identified; it would be difficult to distinguish from that of the far more common associated species *C. amage.*

Occurrence.—Type locality is U.S.N.M. 120, on Shields Ridge, New Market quadrangle. Collected by the writer in the middle portion of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnm/2.

Types.—Holotype: U.S.N.M. 62829. Plesiotype: U.S.N.M. 144581.

Genus COOSIA Walcott, 1911

Type species.—*Coosia superba* Walcott.

COOSIA ALETHES (Walcott)

Plate 6, figures 15–18; plate 7, figures 6–13

Blountia alethes Walcott (part), 1916b, p. 397, pl. 64, figs. 1, 1a (only).
Coosia alethes (Walcott) Resser, 1938a, p. 71.

Available material.—Abundant new specimens show that Walcott's type cranidium is an immature individual of a species of *Coosia* that attains large dimensions and is common everywhere in the upper *Crepicephalus* zone of the Nolichucky.

Description.—Glabella well defined by the axial furrow, unfurrowed, not changing much in shape in cranidia from 2.3 to 18 mm. in length, except for a gradual decrease of the convexity. Occipital furrow straight, well impressed, occipital ring simple. Frontal area increasing in length relative to the entire cranidium from 0.30 to 0.37 in the above-mentioned size range. Border furrow becoming gradually wider and shallower; midlength of preglabellar field about equal to border width (sag.) in small cranidia, decreasing to about half of border in adults. Palpebral area decreasing in relative width with size; palpebral lobes regularly curved in early stages, becoming somewhat angular later. Entire thorax preserved in an immature specimen that may represent a holaspid and has 12 segments. The pygidium in this individual has a long axis and the pleural lobes show 3 or 4 distinct pairs of furrows. In larger pygidia the axis becomes shorter, equaling only half or less of the pygidial length, and extends into a postaxial ridge. It is composed of 3 rings and a terminal section distinct even on the outer surface. The pleural lobes are slightly downsloping and furrowed in a limited area near the axis, then flatten out into a wide, smooth, somewhat concave area that corresponds to the extent of the doublure. The anterior marginal furrow is the only one that extends almost to the lateral margin. The largest fairly complete cranidium is 18 mm. long, but fragments indicate larger individuals. A large, incomplete pygidium has a length of 22 mm. and a width of 44 mm. Surface of test smooth except for wavy terrace lines on cranidial and pygidial borders.

Discussion.—It may be questioned whether forms of *Coosia* described under various names from other areas, such as *C. dakotensis* Resser, *C. albertensis* Resser, *C. modesta* Lochman, *C. grandis* Lochman are distinct from the present species. In any case, the trivial name *alethes* would be the proper one for the species from Tennessee since it has priority.

Occurrence.—Type locality is U.S.N.M. 123b, near Rogersville. Common in the uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone). Localities cnn/1 to cnn/4, cnn/19, and cnn/16; rare in somewhat lower beds (loc. cnm/2).

Types.—Holotype: U.S.N.M. 62821. Plesiotypes: U.S.N.M. 144582–6.

COOSIA ROBUSTA Walcott

Plate 7, figure 26

Coosia robusta Walcott, 1911, p. 97, pl. 16, figs. 2, 2a.
Coosia robusta Walcott, Resser, 1938a, p. 70, pl. 11, figs. 12, 13.

Several pygidia associated with the preceding species seem identical with the types; however, no cranidia could be identified. The pygidium differs from that of *C. alethes* in the longer axis and almost entirely convex surface. The largest pygidium found is 25 mm. long and 40 mm. wide.

Occurrence.—Type locality is U.S.N.M. 107, NW. of Knoxville. Collected from the uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at localities cnn/1, cnn/2.

Types.—Cotypes: U.S.N.M. 57590, 57591. Plesiotype: U.S.N.M. 144587.

COOSIA, species undetermined

Plate 5, figure 19

Known from a single pygidium. Axis stout, prominent, slightly tapered, rounded posteriorly, somewhat over half the pygidial length, extended into a short postaxial ridge. Pleural regions flat, with straight anterior and posterior outlines that give the entire pygidium a rectangular appearance. Pleural furrows, except the first pair, almost indistinct, curving backward. Surface of posterior portion of pleural regions with transverse wrinkles. Length 3.0 mm., width 8.0 mm.

This pygidium differs from the associated species of *Coosia* in its subquadrate shape.

Occurrence.—Upper portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnn/1.

Disposition of material.—Figured specimen: U.S.N.M. 144588.

Family TRICREPICEPHALIDAE Palmer, 1954

Genus TRICREPICEPHALUS Kobayashi, 1935

Type species.—*Arionellus (Bathyurus) texanus* Shumard.

TRICREPICEPHALUS THOOSA (Walcott)

Plate 6, figures 1–4

Crepicephalus thoosa Walcott, 1916a, p. 214, pl. 31, figs. 1, 1a–k.
Paracrepicephalus walcotti Lochman, 1936, p. 39, pl. 9, figs. 29, 31, 33.
Tricrepicephalus walcotti (Lochman) Resser, 1938a, p. 102, pl. 11, fig. 54.
Tricrepicephalus thoosa (Walcott) Resser, 1938a, p. 101, pl. 14, fig. 8.
Tricrepicephalus coria (Walcott) Palmer (part), 1954, p. 755 (includes synonymy).

Palmer placed a number of described forms of *Tricrepicephalus* in the synonymy of *Tricrepicephalus coria* (Walcott), the type of which is from the House Range, Utah. He pointed out that the species construed in this broad sense includes a considerable amount of variation.

Since the material from the type locality for *T. coria* is rather poorly preserved, the writer prefers to adopt for the southern Appalachians form a name based on specimens from that area, and as new material was collected from the type locality for *T. thoosa,* this is the name here used. The differences between the type specimens of *T. thoosa* and *T. walcotti* fall well within the range of variation in cranidial and pygidial features observed in individuals from a single bed, hence Lochman's name is placed in synonymy. It was also included by Palmer in the list of synonyms of *T. coria.*

Occurrence.—Type locality for *T. thoosa* is U.S.N.M. 125a, 4 miles NE. of Rogersville (presumably identical with author's locality cnn/1). Type locality for *T. walcotti* is U.S.N.M. 119, S. of Morristown. Collected by the author at localities cnk/1, cnm/2, cnn/1 to cnn/5. The species ranges throughout the lower limestone member (*Crepicephalus* zone) of the Nolichucky formation.

Types.—Holotype of *T. thoosa:* U.S.N.M. 61654. Holotype and paratype of *T. walcotti:* U.S.N.M. 61655, 61658. Plesiotypes: U.S.N.M. 144589–91.

Genus METEORASPIS Resser, 1935

Type species.—*Ptychoparia metra* Walcott.

METEORASPIS MUTICA Rasetti

Plate 6, figures 13, 14

Meteoraspis mutica Rasetti, 1961, p. 116, pl. 21, figs. 25–29.

The assignment of cranidium and pygidium to the same species is made certain by the frequent association in the same bed observed in Tennessee. The largest cranidium observed has a length of 11 mm., the largest pygidium a length of 5 mm. and a width of 9 mm.

Occurrence.—The types are from the Conococheague formation near Winchester, Va. Plesiotypes from localities cnm/2 and cnn/1, in the upper portion of the lower limestone member of the Nolichucky (*Crepicephalus* zone).

Types.—Plesiotypes: U.S.N.M. 144592–3.

METEORASPIS BREVISPINOSA Rasetti, new species

Plate 6, figures 9–12

Available material.—Several cranidia and pygidia preserved in limestone, the larger ones lacking the test.

Description.—Glabella of usual shape and convexity, unfurrowed, defined by a deep axial furrow all around. Occipital furrow deep, occipital ring rounded, bearing a low node. Preglabellar field and palpebral area narrow, convex, downsloping; border elevated, convex, defined by a deep border furrow; the latter with a pair of shallow depressions. Posterior area deeply furrowed.

Pygidium subrectangular, about as wide as long. Axis very prominent, large, somewhat tapered, rounded posteriorly, almost reaching posterior margin; 3 rings and a terminal section defined by deep furrows. Pleural lobes steeply downsloping, with fairly straight sides slightly convergent backward, extended into a pair of blunt spines; margin between spines straight for a considerable length. A few broad and shallow pleural furrows indicated on internal impression; border furrow and border indistinct. On the outer surface the pleural lobes would probably appear almost entirely smooth, except for the anterior marginal furrow. Length of largest cranidium 11 mm., of largest pygidium 11 mm.

Discussion.—The cranidium differs little from *M. metra* and other described species, but the pygidium is characteristic, lacking the long spines of other species. The pygidium of *M. mutica* lacks spines but is quite different in other respects.

Occurrence.—Lower portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnk/1.

Types.—Holotype (pygidium): U.S.N.M. 144594. Paratypes: U.S.N.M. 144595.

Family ASAPHISCIDAE Raymond, 1924

Genus BLOUNTIA Walcott, 1916

Type species.—*Blountia mimula* Walcott.

BLOUNTIA ARCUOSA Resser

Plate 9, figures 1–8

Blountia arcuosa Resser, 1938a, p. 64, pl. 12, fig. 25.

Available material.—The hypodigm contains only cranidia. Excellent additional material allows a more complete description of the species.

Description.—Glabella very slightly expanding forward in the posterior half, well rounded anteriorly, exceedingly convex in the anterior portion, overhanging the frontal area; occipital furrow exceedingly faint on outer surface, occipital ring very short (sag.); glabellar furrows lacking. Preglabellar field vertical; border about as wide (sag.) as the preglabellar field, convex, with terrace lines. Anterior sections of facial sutures parallel; posterior section with gentle curvature, defining slender, sharply pointed, faintly furrowed posterior area. Palpebral lobes small and faintly elevated; palpebral area about 0.2 times the glabellar width.

Pygidium almost twice as wide as long. Axis long, not rising above the general convexity; axial furrow shallow. Pleural lobes with convexity increasing toward the margin, lacking distinct border furrow and border, sharply downrolled especially in the posterior portion. Furrows obsolete on outer surface; on interior cast, 6 or 7 rings are distinguishable on the axis and 3 faint pairs of furrows on the pleural lobes. Surface smooth.

Occurrence.—Type locality is U.S.N.M. 121a, 4 miles NE. of Rogersville. The species is not rare in the upper part of the lower limestone member of the Nolichucky formation (*Crepicephalus* zone) in the Rogersville area (localities cnm/1, cnm/2, cnn/2, cnn/3).

Types.—Holotype: U.S.N.M. 94960. Plesiotypes: U.S.N.M. 144555.

BLOUNTIA ALEXAS Walcott

Plate 9, figures 9–12

Blountia alexas Walcott, 1916b, p. 398, pl. 61, figs. 5, 5a.
Blountia alexas Walcott, Resser, 1938a, p. 65, pl. 12, fig. 27.

Available material.—The hypodigm consists of the holotype cranidium. Additional cranidia and pygidia allow a more complete description.

Description.—Glabella of moderate convexity, straight-sided, slightly tapered, rounded in front, unfurrowed. Occipital furrow almost indistinct on outer surface, occipital ring very short (sag.). Preglabellar field on the average somewhat shorter (sag.) than border, the ratio varying somewhat in different individuals; border slightly convex, wide (sag.), set off from preglabellar field by its upturned position. Palpebral area about 0.3 times the width of glabella at same level. Anterior facial sutures divergent, anterior angles of cranidium well rounded; posterior section of facial suture with gentle curvature; posterior area falcate, extending farther backward than occipital ring, with faint furrow in proximal portion only.

Pygidium with little convexity. Length 0.6 times width. Axis tapered, occupying two-thirds of length; axial furrow shallow laterally, almost obsolete posteriorly. Pleural lobes with faint border furrow and wide border. Only traces of segmentation on outer surface. Surface smooth.

Occurrence.—Type locality is U.S.N.M. 125, 4 miles NE. of Rogersville. Plesiotypes from the lower portion of the lower limestone member (*Crepicephalus* zone) of the Nolichucky formation (loc. cnk/1, cnk/3, the latter presumably identical with type locality).

Types.—Holotype: U.S.N.M. 62785. Plesiotypes: U.S.N.M. 144596, 144701.

BLOUNTIA LATA (Resser)

Plate 9, figure 21

Blountiella lata Resser, 1938a, p. 65, pl. 12, fig. 37.
Blountia rogersvillensis Resser, 1938a, p. 64, pl. 12, figs. 29, 30.

The species was described under the two names on the basis of cranidia preserving the test or not, respectively, as recognized by Lochman and Duncan (1944). This trilobite was found as a rare member of the faunule of the upper portion of the lower limestone member of the Nolichucky. The previous descriptions and the illustrations supply the available information about the species.

Occurrence.—The type locality for *Blountiella lata* is U.S.N.M. 125 and that for *Blountia rogersvillensis* is U.S.N.M. 121a, both 4 miles NE. of Rogersville. The author collected the species from the uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnn/3.

Types.—Holotype: U.S.N.M. 94961. Holotype of *Blountia rogersvillensis:* U.S.N.M. 94959. Plesiotype: U.S.N.M. 144597.

BLOUNTIA MONTANENSIS Duncan

Plate 9, figures 13–20

Blountia montanensis Duncan, in Lochman and Duncan, 1944, p. 53, pl. 8, figs. 29–34.

This species, described from Montana, is common in the *Crepicephalus* zone in Tennessee. There is some variation in the length of the preglabellar field, elevation of the anterior border and depth of the axial furrow on the cranidium, but since all intermediate forms occur in the same beds, these features should be interpreted as intraspecific variability.

Occurrence.—Localities cnk/1, cnm/2, cnn/1, cnn/3. The species is more common in the lower portion of the lower limestone member of the Nolichucky (*Crepicephalus* zone) but ranges throughout this limestone.

Types.—Plesiotypes: U.S.N.M. 144598–9.

BLOUNTIA BRISTOLENSIS Resser

Plate 10, figures 1, 2; plate 11, figures 9–12

Blountia bristolensis RESSER, 1938a, p. 65, pl. 12, fig. 24.
Maryvillia bristolensis RESSER, 1938a, p. 87, pl. 12, fig. 38.
Blountia nixonensis Lochman, in LOCHMAN and DUNCAN, 1944, p. 43, pl. 4, figs. 7–12.

Available material.—The hypodigm of *B. bristolensis* includes the holotype pygidium. *Maryvillia bristolensis* is based on a cranidium from the same collection. *Blountia nixonensis* was described from numerous cranidia and pygidia. The author's collections include numerous fragments and one articulated shield. The latter allows a description of the thorax.

Description.—Entire exoskeleton ovate; pygidium as large as cephalon. Thorax of 7 segments, not tapered, as wide as cephalon and pygidium. In the specimen, evidently an exuvia as it lacks the free cheeks, the cranidium was pushed over the thorax, concealing the entire first and part of the second thoracic segment. The entire thorax was exposed during preparation when the cranidium broke off. In the illustration the cranidium is shown restored. Thoracic axis slightly tapered, at much lesser rate than pygidial axis. Axial furrows on thorax rather deep. Pleurae unfurrowed, flat and horizontal in proximal two-thirds, presenting sharp geniculation and showing anterior facet that allowed enrollment of the animal. Termination of pleurae narrowly rounded, sharper in anterior pleurae. Length of exoskeleton, allowing for displacement of cranidium, 17.4 mm., of which 7.0 belong to the cephalon, 4.4 to the thorax, and 6.0 to the pygidium. The individual corresponds almost to the largest size of cranidia and pygidia in the author's collections.

Discussion.—A species of *Blountia* common in the basal beds of the *Aphelaspis* zone in Tennessee is identified with *B. bristolensis.* This and *Maryvillia bristolensis,* from the same collection, obviously are conspecific. Careful comparison of the author's material with *B. nixonensis* from Montana failed to reveal any differences.

The species, like *B. mimula,* has 7 thoracic segments. In the present case one may be certain that the individual is a holaspid. However, it should not be inferred that all species of *Blountia* have 7 segments. An undescribed *Blountia* from the Murphy's Creek formation of the Gaspé Peninsula of Quebec, collected by the author, has 9 thoracic segments. This *Blountia* occurs in association with *Cedaria* and *Crepicephalus* and is therefore considerably older.

Occurrence.—Type locality for *Blountia bristolensis* and *Maryvillia* *bristolensis* is U.S.N.M. 36v, near Bristol, Va. Collected by the author at localities cnp/17 (complete specimen), cnp/14, and cnq/14.

Types.—Holotype of *Blountia bristolensis:* U.S.N.M. 94942. Holotype of *Maryvillia bristolensis:* U.S.N.M. 94963. Plesiotypes: U.S.N.M. 144600–1.

BLOUNTIA MIMULA Walcott

Plate 10, figures 3–7

Blountia mimula WALCOTT, 1916b, p. 399, pl. 61, figs. 4, 4a–c.
Blountia mimula Walcott, RESSER, 1938a, p. 63, pl. 12, figs. 18, 19.

As far as can be determined, a species of *Blountia* collected from the lower *Aphelaspis* zone seems identifiable with the species. The holotype is an articulated exoskeleton of very small size and is the only specimen in the hypodigm that comes from the type locality. The paratypes are from a different locality and appear conspecific with the holotype as far as one can compare immature individuals. The cranidia and pygidia illustrated herein are larger than any of the types and differ only in the shallower axial furrow around the glabella, a modification gradually acquired during the growth of these trilobites.

Occurrence.—The holotype is from U.S.N.M. locality 120 on Shields Ridge. Under this label trilobites from both the *Crepicephalus* and *Aphelaspis* zones are mixed. The paratypes are from U.S.N.M. locality 107c, NW. of Knoxville. The specimens illustrated herein are from Oder's collection No. 2 in the Hurricane Hollow section, in association with *Aphelaspis walcotti,* in beds higher than those holding *Blountia bristolensis.*

Types.—Holotype: U.S.N.M. 62781. Paratypes: U.S.N.M. 62782–4. Plesiotypes: U.S.N.M. 144602.

Genus MARYVILLIA Walcott, 1916

Type species.—Maryvillia arion Walcott.

MARYVILLIA ARION Walcott

Plate 9, figures 22–26

Maryvillia arion WALCOTT, 1916b, p. 400, pl. 64, figs. 4–4c.
Maryvillia arion Walcott, RASETTI, 1956, p. 1267 (includes complete synonymy); 1961, p. 116, pl. 21, figs. 14, 15.

Occurrence.—Type locality is U.S.N.M. 123b, ½ mile E. of Rogersville (probably identical with author's locality cnn/2). A common and diagnostic fossil of the upper part of the *Crepicephalus* zone. Collected at localities cnk/1 (very rare), cnm/2, cnn/1, cnn/2, cnn/3, cnn/4, cnn/14.

Types.—Holotype: U.S.N.M. 62826. Plesiotypes: U.S.N.M. 144603–4.

Family KINGSTONIIDAE Kobayashi, 1933

Genus KINGSTONIA Walcott, 1924

Type species.—*Kingstonia apion* Walcott.

KINGSTONIA INFLATA Resser

Plate 8, figures 21–28

Kingstonia inflata Resser, 1938a, p. 84, pl. 12, figs. 5, 6.
Kingstonia rotundata Resser, 1938a, p. 83, pl. 12, figs. 9–10.

Available material.—The two names represent the same species, described from the appearance of the outer surface and from internal impressions respectively. Abundant material of this exceedingly common form allows a more complete description.

Description.—Cranidium very convex in both directions, barely showing a trace of the axial furrow on outer surface. Glabella defined on internal impressions, straight-sided, slightly tapered, very wide in proportion to cranidial width. Anterior border indicated only by its terraced surface, without change in slope from glabella and preglabellar field. Palpebral lobes almost indistinct; facial suture showing little change of direction before and after palpebral lobes in dorsal view; anterior sections strongly convergent; posterior section gently convex outward, defining a stout posterior area; posterior angles of cranidium obtuse. Posterior outline rounded in axial portion, with indentations corresponding to the axial furrow; convex along the margin of the posterior area.

Pygidium with axis occupying less than one-third of the maximum width, well defined anteriorly but merging with the pleural region posteriorly, not tapered. Pleural lobes increasingly convex toward the margin. Facet at anterior angles very distinct. Five axial rings and 3 or 4 broad, shallow pleural furrows visible on interior impressions. Length of largest cranidia 4.5 mm.

Several cranidia, one of which is figured, show through the dark surface of the test a regular pattern of yellow stains that presumably represent muscle attachments on the inner surface.

Occurrence.—Type localities for *K. inflata* are U.S.N.M. 121a, 125, 4 miles NE. of Rogersville. Type locality for *K. rotundata* is U.S.N.M. 123b, near Rogersville. Found by the writer throughout the lower limestone member of the Nolichucky (*Crepicephalus* zone) in the Rogersville area (locs. cnk/1, cnk/3, cnm/2, cnm/3, cnn/1, cnn/3).

Types.—Cotypes of *K. inflata:* U.S.N.M. 94934, 94953. Cotypes *K. rotundata:* U.S.N.M. 94935. Plesiotypes: U.S.N.M. 144605–7.

Genus ANKOURA Resser, 1938

Type species.—*Ankoura triangularis* Resser.

ANKOURA TRIANGULARIS Resser

Plate 3, figures 15–21

Ankoura triangularis Resser, 1938a, p. 58, pl. 9, fig. 33.

Available material.—Although the pygidia are quite common at the type locality, the much more fragile cranidia are difficult to obtain. Resser figured a fragmentary cranidium, from which the precise characters were not clearly understood. Lochman (1940) attributed to the species good limestone material from the Bonneterre dolomite; however, her form belongs to a different species. Hence a brief description of the cranidium of *Ankoura triangularis* is in order. This description is based on exfoliated topotype material, plus specimens preserving the test from another locality.

Description.—Glabella parallel-sided, rounded in front, well defined on internal impressions but barely indicated on the outer surface. Occipital furrow almost obsolete on outer surface; occipital ring very short, lacking a spine. Frontal area convex and downsloping; border barely represented on outer surface by a narrow striated band as in many species of *Kingstonia*. On internal impressions there is a shallow border furrow. Furrow on posterior area almost obsolete on outer surface.

Discussion.—The species differs from the material identified by Lochman in two important characters: the simple occipital ring and the absence of a flat border.

Occurrence.—The type locality is U.S.N.M. 27d; red beds at the base of the Nolichucky (*Cedaria* zone) E. of Rogersville. The specimens figured herein are partly from the type locality, partly from a limestone lens at an unspecified level near the base of the Nolichucky on Comby Ridge, Howard Quarter quadrangle (author's locality cnb/10).

Types.—Cotypes: U.S.N.M. 94851. Plesiotypes: U.S.N.M. 144608–9, 144702.

Family MENOMONIIDAE Walcott, 1916

Genus DRESBACHIA Walcott, 1916

Type species.—*Dresbachia amata* Walcott.

DRESBACHIA AMATA Walcott

Plate 8, figures 1–4

Dresbachia amata Walcott, 1916a, p. 167, pl. 26, figs. 5, 5a–c.
Dresbachia appalachia Resser, 1938, p. 74, pl. 10, figs. 32–34.
Dresbachia amata Walcott, Lochman, 1950, p. 338, pl. 48, figs. 11–14.

A few cranidia and more numerous free cheeks were collected from the lower limestone member of the Nolichucky (*Crepicephalus* zone) at localities cnk/1, cnk/3, cnm/2.

Types.—Holotype of *D. appalachia* (from loc. U.S.N.M. 22z, near Greendale, Va.): U.S.N.M. 94875. Plesiotypes: U.S.N.M. 144694.

Genus MENOMONIA Walcott, 1916

Type species.—*Conocephalites calymenoides* Whitfield.

MENOMONIA PROMINENS Resser

Plate 5, figures 14–17

Menomonia prominens Resser, 1938a, p. 88, pl. 9, figs. 42, 43.
Dresbachia speciosa Resser, 1938a, p. 75, pl. 9, figs. 28, 29.

Available material.—Resser's two names were based on the cranidia and free cheeks of the same species. Additional material allows a more complete description.

Description.—Glabella straight-sided, tapered, rounded in front, with 2 pairs of short lateral furrows; occipital furrow well impressed, occipital ring rounded. Preglabellar field slightly arched transversely, fairly long (sag.); border upturned, arched transversely. Palpebral lobes with their midpoint at the level of the anterior end of the glabella, strongly upsloping, rising higher than glabella. Posterior area tapered, large, strongly downsloping and hence giving strong relief to the cranidium, deeply furrowed; posterior cranidial margin curving backward. Free cheek with border well defined only anteriorly, almost parallel-sided, well rounded at the genal angle. The surface characters are described as they appear on internal impressions, as none of the specimens preserve the test. Large tubercles on the glabella are arranged more or less regularly in 4–5 pairs. Tubercles of the same size are irregularly scattered on the fixed cheeks, decreasing in number toward the distal end of the posterior area. The tubercles are more crowded on the anterior border. The free cheeks have larger granules near the eye and finer granules distally. The largest cranidium has a length of 4.8 mm.

Occurrence.—Type locality is U.S.N.M. 27d; red beds at the base of the Nolichucky E. of Rogersville (*Cedaria* zone). Collected by the author at the same locality (cnd/1).

Types.—Holotype and paratypes: U.S.N.M. 94857. Plesiotypes: U.S.N.M. 144695.

MENOMONIA TUBERCULATA Rasetti, new species

Plate 2, figures 19–24

Available material.—Several cranidia and free cheeks in limestone.

Description.—Glabella and occipital ring similar to preceding species. Preglabellar field about as long (sag.) as border width (sag.); border elevated, arched transversely. Palpebral area almost as wide as anterior portion of glabella, less upsloping than in *M. prominens;* palpebral lobe moderately upsloping, not extending much farther forward than the anterior end of the glabella. Posterior area much less tapered than in *M. prominens,* more rounded distally, bearing a deep, wide furrow. Posterior outline of cranidium transverse; posterolateral angles not extending farther backward than occipital ring.

Free cheek almost subtriangular. Border distinct for more than half the length of the margin. Anterior section of facial suture much longer than in *M. prominens,* corresponding to the more posterior position of the eye. Posterior section with slight sigmoidal curvature, cutting posterior margin closer to genal angle than in preceding species. Elevated portions of surface covered with coarse tubercles, possibly representing the base of broken spines, those on the glabella being arranged more or less regularly in several rows. Length of largest cranidium 5 mm.

Discussion.—The present species resembles *M. calymenoides* rather than *M. prominens,* the differences from the latter having been already pointed out in the description. An accurate comparison with topotypes of *M. calymenoides* is not very significant because of the poor preservation of these small trilobites as internal casts in the Eau Claire sandstone. One definite difference seems to be that in *M. calymenoides* the anterior border has almost even width, whereas in the present species it tapers at the sides. The palpebral area seems to be proportionately wider.

Occurrence.—Uppermost beds of the Maryville limestone (*Cedaria* zone) at localities cnc/1 to cnc/6.

Types.—Holotype: U.S.N.M. 144696. Paratypes: U.S.N.M. 144697–8.

MENOMONIA, species undetermined

Plate 2, figures 25–27

A few incomplete cranidia and several free cheeks apparently represent a form of *Menomonia* different from the two previously discussed species.

Most of the cranidial features agree with *M. tuberculata,* except in the somewhat more anterior position of the eyes, narrower palpebral area, and lack of tubercles on the posterior area, where the surface is finely wrinkled. The free cheek resembles more closely that of *M. prominens* in general shape and also shows a wrinkled surface with, in addition, a few tubercles on the anterior part of the border.

Occurrence.—Uppermost beds of the Maryville limestone (*Cedaria* zone) at localities cnc/4, cnc/6.

Disposition of material.—Figured specimens: U.S.N.M. 144699-700.

Family NORWOODIIDAE Walcott, 1916

Genus NORWOODIA Walcott, 1916

Type species.—*Norwoodia gracilis* Walcott.

NORWOODIA ROGERSVILLENSIS Resser

Plate 4, figures 25, 26

Norwoodia rogersvillensis RESSER, 1938a, p. 91, pl. 9, figs. 25, 26.
Norwoodia harlanensis RESSER, 1938a, p. 91, pl. 9, fig. 31.

Available material.—The hypodigms consist of cranidia from the same locality. In addition to further cranidia, pygidia occur in the author's collection.

Description.—Glabella tapered, rounded in front, rather convex, defined by a well-impressed axial furrow. Glabellar furrows probably obsolete on outer surface. Occipital furrow shallow; occipital ring extended into a large, horizontal spine longer than the glabella. Frontal area as long as glabella, mostly consisting of downsloping preglabellar field; border wide (sag.), upturned. Palpebral area about half the glabellar width; ocular ridges distinct. Anterior sections of facial sutures very slightly divergent; posterior section directed outward and somewhat forward, reaching the margin well in advance of genal angle. Posterior area slightly expanding distally, well furrowed, extended into a slender and moderately long genal spine.

The pygidia are attributed to the species because of the close similarity to *N. gracilis* and other closely related species. Pygidium twice as wide as long, convex. Axis defined laterally, merging with the pleural region posteriorly, of 3 distinct rings. Pleural lobes convex, with 3 pairs of shallow furrows; border narrow but distinct. All the described cranidial and pygidial features refer to the impression of the interior since none of the specimens preserves the test.

Discussion.—Among the species of the southern Appalachians, the present one resembles *N. gracilis* Walcott, differing mainly in the proportionately wider and shorter glabella, shorter occipital spine, and different shape of the posterior area and genal spine.

Occurrence.—Found only in the red beds (*Cedaria* zone) at the base of the Nolichucky. Type locality is U.S.N.M. 27d, the same as the author's locality cnd/1.

Types.—Holotype: U.S.N.M. 94847. Holotype of *N. harlanensis:* U.S.N.M. 94850. Plesiotypes: U.S.N.M. 144610.

NORWOODIA, species undetermined

Plate 4, figure 24

Cranidia of *Norwoodia,* too incomplete for specific identification but certainly very close to the preceding species, are present in the uppermost beds of the Maryville limestone in the Rogersville area.

Occurrence.—Maryville limestone (*Cedaria* zone); localities cnc/2, cnc/4, cnc/6.

Disposition of material.—Figured specimen: U.S.N.M. 144611.

Genus NORWOODELLA Resser, 1938

Type species.—Norwoodia saffordi Walcott.

NORWOODELLA SAFFORDI (Walcott)

Plate 3, figures 1–6

Norwoodia saffordi WALCOTT, 1916a, p. 171, pl. 27, figs. 1–1f.
Norwoodella saffordi (Walcott) RESSER, 1938a, p. 89, pl. 10, figs. 40, 41, 49, 50.

This species is readily distinguished from all others of the genus by the depth of the axial furrow and the fixed cheeks which rise above the furrow itself instead of sloping down from it. Limestone specimens are figured, in addition to the complete holotype exoskeleton flattened in shale. The thorax of this individual seemingly has 9 segments, not 8 as stated by Walcott. The material from Missouri attributed to this species by Lochman (1940) was incorrectly identified.

Occurrence.—Type locality is U.S.N.M. 103, near Rogersville. The species is common in the basal beds of the Nolichucky shale and interstratified limestone lenses (*Cedaria* zone). Collected at localities cnd/1, cne/1, cne/2.

Types.—Lectotype (herein designated): U.S.N.M. 61595. Paratypes: U.S.N.M. 61596–600. Plesiotypes: U.S.N.M. 144612–3.

NORWOODELLA ROTUNDICOLLIS Rasetti, new species

Plate 4, figures 1–7

Available material.—Numerous cranidia and a few free cheeks and pygidia, preserved in limestone but mostly lacking the test.

Description.—Glabella tapered, straight-sided, rounded in front, fairly convex, rising above the cheeks, unfurrowed on outer surface. Axial furrow on outer surface impressed laterally but obsolete in front; on interior impressions well defined all around. Occipital furrow impressed throughout; occipital ring subtriangular but rounded, lacking a spine. Frontal area convex and downsloping, somewhat over one-third the glabellar length, undivided by a border furrow even on internal impressions. Palpebral area downsloping, about 0.3 times the glabellar width; ocular ridges faint. Posterior area wide (exsag.), parallel-sided, with a distinct furrow even on outer surface. Genal spine slightly curved, of moderate length. Free cheek as in other species of the genus. Surface of test perfectly smooth; internal impressions show fine anastomosing lines on frontal area and free cheeks. Length of largest cranidium 8 mm.

The pygidia attributed to the species are so similar to *N. saffordi,* which occurs in the same beds, that some doubt remains concerning their assignment. Pygidium somewhat fan-shaped, with regularly curved pleurae and anterior margin. Axis prominent, long, tapered, showing 3 rings plus a terminal section. Pleurae poorly fused, with 3 pairs of wide furrows and as many narrow interpleural grooves, all furrows and grooves extending to the margin, where the separate endings of the pleurae form a wavy outline. Border furrow and border lacking.

Discussion.—The cranidium resembles *N. declivis* Resser, which also appears to lack an occipital spine. However, this condition in the type material in shale may be due to imperfect preservation, and therefore it was deemed preferable not to attempt identification with that species. The pygidium resembles, besides *N. saffordi,* pygidia associated with the type cranidia of *N. kingstonensis* Resser. All these pygidia strongly differ from those of other species of the genus, such as *N. walcotti* and *N. halli* illustrated herein, which have well-fused pleural regions, a smooth posterior margin, and a border furrow, much like pygidia of *Norwoodia.*

Occurrence.—Red beds at the base of the Nolichucky (*Cedaria* zone) at locality cnd/1 (= U.S.N.M. loc. 27d).

Types.—Holotype: U.S.N.M. 144614. Paratypes: U.S.N.M. 144615.

NORWOODELLA WALCOTTI Resser

Plate 4, figures 16–23

Norwoodella walcotti Resser, 1938a, p. 89, pl. 10, figs. 42, 54.

Available material.—The hypodigm consists of cranidia flattened in shale. Good cranidia, free checks, and pygidia in limestone occur in the U.S.G.S. and author's collections.

Description.—Glabella entirely undefined on upper surface, except for a faint indication of its anterior boundary. Occipital furrow obsolete; occipital ring extended into a slender, horizontal spine. Frontal area undifferentiated, somewhat downsloping. Palpebral area, as determinable on exfoliated specimens, very narrow. Palpebral lobes small, somewhat elevated. Anterior sections of facial suture convergent, making the frontal portion of the cranidium very narrow, well rounded. Posterior section directed almost straight outward from palpebral lobe, almost parallel to posterior cranidial margin, sharply curving backward, cutting margin near base of genal spine. Genal spine slender, of moderate length. Furrow on posterior area obsolete on outer surface, impressed on interior cast. Free cheek completely lacking border furrow on outer surface, entirely convex, extended into a short, slender strip that simulates a genal spine, but actually contributes to the cephalic margin in a region in advance of the base of the genal spine borne by the cranidium. Visual surface of eye convex, bean-shaped; facets indistinguishable.

Pygidium approximately semicircular, twice as wide as long. Facets well developed. Posterior outline with uniform curvature. Axis well defined anteriorly but merging with the pleural lobes posteriorly, showing 2 rings plus a terminal indistinctly segmented section. Pleural lobes entirely convex, lacking any furrows, showing barely a trace of differentiated border. Surface of cranidium and free cheeks perfectly smooth. Pleural lobes of pygidium with very fine, transverse terrace lines only visible under conditions of perfect preservation.

Discussion.—This species is quite distinctive in the lack of all furrows on the outer surface, and especially the narrowing of the cranidium in front of the eyes. The pygidium is much like *Norwoodia gracilis* and *N. rogersvillensis* and unlike *Norwoodella saffordi, N. kingstonensis,* and *N. rotundicollis.* This fact would perhaps justify redistributing the species hitherto referred to *Norwoodia* and *Norwoodella* on the basis of the pygidia, rather than the questionable character of the structure of the frontal area. This revision should only be undertaken when the pygidia of most species of this group are known with certainty. For the present species the assignment is certain, since only one species of the Norwoodiidae occurred in the beds yielding the material illustrated herein.

Occurrence.—Basal portion of the Nolichucky (*Cedaria* zone). The type locality is U.S.N.M. 107a, NW. of Knoxville. The specimens illustrated are from the collections cne/10, Comby Ridge (= U.S.G.S. collection 2407), and cne/12 near Heiskell (the latter presumably close to or identical with the type locality).

Types.—Holotype and paratypes: U.S.N.M. 94880. Plesiotypes: U.S.N.M. 144616–8.

NORWOODELLA HALLI Resser

Plate 4, figures 8–15

Norwoodella halli Resser, 1938a, p. 90, pl. 10, figs. 45, 46.
Norwoodella halli Resser, Lochman, 1940, p. 47, pl. 5, figs. 31–36.

The types are cranidia preserved in shale. Lochman gave a detailed description of the species and figured unflattened limestone material from Missouri, including the pygidium. The assignment of the two parts of the shield is confirmed by the specimens illustrated herein.

Occurrence.—The type locality is U.S.N.M. 22t in the Thorn Hill section, in the interval 45–133 feet above the base of the formation. Also in author's collection cnd/10, Comby Ridge.

Types.—Holotype and paratypes: U.S.N.M. 94883. Plesiotypes: U.S.N.M. 144619.

Genus HOLCACEPHALUS Resser, 1939

Type species.—*Holcacephalus granulatus* Resser.

HOLCACEPHALUS GRANULATUS Resser

Plate 3, figures 12–14

Holcacephalus granulatus Resser, 1938a, p. 81, pl. 9, figs. 15–17.

Available material.—The species, quite common at the type locality, was not found elsewhere. All the available specimens lack the test.

Description.—Glabella definitely tapered, defined by a deep axial furrow, with two pairs of short, but deep lateral furrows, and another pair less distinct. Occipital furrow deep, occipital ring long (sag.), bearing a short, very slender spine. Preglabellar field downsloping, border narrow, well defined by the border furrow. Ocular ridges transverse; palpebral lobes at level of anterior third of glabella; palpebral area almost as wide as anterior portion of glabella. Posterior area slender, slightly expanded distally, bearing a genal spine that is broken off in almost all available specimens. Surface covered with relatively large granules.

Pygidium twice as wide as long, subelliptical; with posterior outline slightly indented medially. Axis occupying almost entire length, with 4 prominent rings. Pleural lobes slightly convex, lacking border furrow or border. Three pairs of pleurae are clearly separated by interpleural grooves; each pleura is furrowed and the posterior band bears a row of tubercles like those on the cranidium.

Discussion.—This species differs considerably from all others hitherto attributed to the genus in the tapered, deeply furrowed glabella.

Occurrence.—Red limestone beds at the base of the Nolichucky (*Cedaria* zone) at U.S.N.M. locality 27d (= author's locality cnd/1).

Types.—Cotypes: U.S.N.M. 94844. Plesiotypes: U.S.N.M. 144620.

HOLCACEPHALUS PRAECURSOR Rasetti, new species

Plate 3, figures 10, 11

Available material.—Several cranidia and pygidia.

Description.—Owing to the similarity to the preceding species, it is sufficient to point out the differences. The anterior border is somewhat wider and flat instead of convex; the ocular ridges are more prominent;

the cranidial surface has fewer and smaller granules than *H. granulatus;* these are barely apparent on the glabella and frontal area, being more conspicuous on the palpebral and posterior areas. The pygidium has the same structure as in *H. granulatus,* but here again the granules are indistinct. The species attains a larger size, with cranidia 3–4 mm. in length. This form may be ancestral to *H. granulatus.*

Occurrence.—Uppermost beds of Maryville limestone (*Cedaria* zone) at locality cnc/1.

Types.—Holotype: U.S.N.M. 144621. Paratypes: U.S.N.M. 144622.

Family CEDARIIDAE Raymond, 1937

Genus CEDARIA Walcott, 1924

Type species.—*Cedaria prolifica* Walcott.

CEDARIA TENNESSEENSIS Walcott

Plate 5, figures 4–8

Cedaria tennesseensis WALCOTT, 1925, p. 79, pl. 17, figs. 22–25.
Cedaria tennesseensis Walcott, RESSER, 1938a, p. 68, pl. 11, figs. 3–5.

Available material.—The types are cranidia, free cheeks, and pygidia flattened in shale. Fragmentary material in limestone was collected by the writer.

Description.—Cranidium of moderate convexity. Glabella as in other species of the genus. Frontal area sharply divided into preglabellar field and border by a narrow border furrow; border flat, its sagittal length more than half the length of the preglabellar field. Palpebral area and lobe without specific features. Posterior area broad (exsag.), the posterior section of the facial suture running outward and slightly forward; border furrow on posterior area turning forward for a considerable distance. Anterior sections of facial suture less divergent than in most other species of the genus. Free cheek with ocular platform and border of about equal widths, separated by sharp border furrow. Genal spine long and strong as in other species of *Cedaria.*

Pygidium 1.6 times as wide as long, almost elliptical, with anterior angles widely rounded. Axis short, in larger individuals not exceeding half of the pygidial length, showing about 3 rings plus a terminal section. Pleural regions almost flat, wide, with 3 pairs of broad, shallow furrows and a trace of a fourth, and indistinct interpleural grooves. The furrows run straight through the pleural platform, change to a more backward direction in passing onto the wide, slightly concave border, and almost reach the pygidial margin. Pygidial doublure very wide, its anterior margin well visible as an impression on the dorsal side. Pygidial border with very fine, wavy lines.

Discussion.—This species differs considerably from the type species, *C. prolifica,* in the lesser divergence of the anterior section of the facial suture, wider cephalic border, broader (exsag.) posterior area, pygidium more transverse, with shorter axis, fewer pleural segments, and much wider border and doublure.

Occurrence.—The type locality is U.S.N.M. 107a, Copper Ridge, NW. of Knoxville (very close to author's locality cne/12). Collected by the writer at localities cne/10, cne/12, cne/13. All the limestone material is fragmentary, especially the cranidia.

Types.—Lectotype (designated herein): U.S.N.M. 70270. Paratypes: U.S.N.M. 70271–3. Plesiotypes: U.S.N.M. 144623.

Genus CEDARINA Lochman, 1940

Type species.—*Cedarina vale* Lochman.

CEDARINA, species undetermined

Plate 5, figure 18

Available material.—A few pygidia, all lacking the test.

Description.—Pygidium almost 3 times as wide as long. Axis elevated, tapered, composed of 3 rings plus a terminal section, almost reaching the posterior pygidial margin. Anterior outline of pleural lobes slightly curved, anterior angles sharp, posterior margin with shallow, rounded median notch. Three pairs of pleural furrows well impressed, shallow interpleural grooves distinct near border. Border furrow indistinct, border flat, narrow. Length of largest pygidium 3.3 mm., width 9.2 mm.

Discussion.—The pygidium closely resembles that of *Cedarina vale* Lochman from Missouri. The pygidia of other species of the genus described by Lochman from the West are all proportionately longer. No definite identification can be made without the cranidium.

Occurrence.—Rare in the red beds at the base of the Nolichucky (*Cedaria* zone) at locality cnd/1.

Disposition of material.—Figured specimen: U.S.N.M. 144624.

Genus LLANOASPIS Lochman, 1938

Type species.—*Llanoaspis modesta* Lochman.

LLANOASPIS WALCOTTI (Resser)

Plate 8, figures 14–16

Genevievella walcotti Resser, 1938a, p. 77, pl. 15, figs. 3–5.
Genevievella rogersvillensis Resser, 1938a, p. 78, pl. 15, figs. 16–18.
Rogersvillia rogersvillensis (Resser) Hupé, 1953, p. 182, fig. 159.

Palmer (1954) placed a number of described species of the genus, including *walcotti,* in the synonymy of the type species. While the writer agrees that not all the described forms are distinguishable, he believes that the one here discussed is readily separable by the shape of the pygidium, which completely lacks the lateral expansion of the posterior border clearly apparent in the specimens of *L. modesta* figured by Lochman (1938) and Palmer (1954).

The type specimens of *walcotti* are preserved in limestone, while those of *rogersvillensis* are flattened in shale, but there seems to be no specific difference between the two.

Occurrence.—Type locality for *L. rogersvillensis* is U.S.N.M. 24m, near Rogersville. Type locality for *L. walcotti* is U.S.N.M. 107, NW. of Knoxville. The figured specimens are from the uppermost beds of the lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnn/3.

Types.—Holotype and paratypes of *L. rogersvillensis:* U.S.N.M. 94974–5. Holotype and paratypes of *L. walcotti:* U.S.N.M. 94970–1. Plesiotypes: U.S.N.M. 144625.

Genus GENEVIEVELLA Lochman, 1936

Type species.—Genevievella neunia Lochman.

GENEVIEVELLA, species undetermined

Plate 5, figures 9–11

Known from several cranidia. The shape and convexity of glabella, frontal area and posterior area are about the same as in the type species. However, the present form lacks the strong elevation of the palpebral area and palpebral lobes present in *G. neunia.* As the material is scarce, imperfectly preserved, and from different localities, it does not warrant naming a new species.

Occurrence.—A large cranidium was collected from locality cnc/4, and another from locality cnc/2, both in the uppermost Maryville limestone. Further material was collected in limestone beds or lenses at the base of the Nolichucky (localities cnd/1, cne/2). All these beds belong in the *Cedaria* zone.

Disposition of material.—Figured specimens: U.S.N.M. 144626–7.

Family ELVINIIDAE Kobayashi, 1935

Genus DUNDERBERGIA Walcott, 1924

Type species.—Crepicephalus (Loganellus)nitidus Hall and Whitfield.

DUNDERBERGIA TENNESSEENSIS Rasetti, new species

Plate 15, figures 1–12

Available material.—Several cranidia and free cheeks, two pygidia, and one tentatively assigned hypostome.

Description.—Glabella of fairly strong convexity, straight-sided, tapered, somewhat truncate in front, defined by deep axial furrows laterally, shallower furrow in front. Three pairs of lateral furrows;

posterior pair very oblique, moderately deep; third pair shorter and shallower, directed slightly backward; second pair very short and shallow, directed slightly forward. Occipital furrow deep, occipital ring bearing a node. Preglabellar field slightly convex longitudinally and more or less downsloping in different individuals. Border furrow well impressed, in some cranidia showing an indication of the median angle more marked in several other species of the genus. Border somewhat convex, not greatly tapered laterally; midlength (sag.) of border about half the length of preglabellar field. In anterior view the border appears fairly arched transversely in some cranidia, especially the larger ones, rather flat in smaller individuals. It was considered whether this might be a specific distinction; however, since the two kinds are mixed in the collections from both localities where the species was found, it was thought more likely that the differences are due either to growth stages, to intraspecific variability, or both. Palpebral area somewhat convex, on average horizontal, half as wide as glabella. Ocular ridges straight, slanted backward, more strongly so in the larger cranidia. Palpebral lobe defined by deep furrow even on upper surface, narrow, strongly curved, somewhat convex transversely, 0.20 to 0.25 times as long as glabella; distance from posterior margin greater than length of lobe. Anterior section of facial suture as divergent as in an average *Aphelaspis.* Posterior area slender, somewhat narrower (tr.) than occipital ring. Ocular platform moderately convex. Border on free cheek of uniform width, almost flat, defined by shallow furrow; genal spine strong, of moderate length.

All portions of the cranidial surface except in the furrows covered with granules, usually of two sizes, although in some of the cranidia only the larger granules are distinct. The border of the free cheek has, in addition to dense, fine granules, a few scattered, somewhat larger granules. Length of largest (holotype) cranidium 15 mm.

Pygidium twice as wide as long. Axis large, wider than the pleural lobe, elevated, subcylindrical, rounded at the extremity, extended into a short postaxial ridge reaching the posterior margin. First two axial rings well defined, the rest merging into a terminal section. Pleural platforms without much relief, with 2 pairs of broad, rather indefinite furrows. Border rather narrow, flat, poorly defined. In posterior view the posterior margin appears elevated medially. Surface finely granulate.

Discussion.—The cranidium seems definitely referable to *Dunderbergia* and shows most similarity to *D. bigranulosa* Palmer (1960) and *D. anytus* (Hall and Whitfield), both from Nevada. The pygidium also closely agrees with pygidia of *Dunderbergia* figured by Palmer. *D. bigranulosa* is from the *Dunderbergia* zone, while the stratigraphic position of *D. anytus* does not seem to be known with certainty.

Occurrence.—Uppermost *Aphelaspis* zone, in association with *Aphelaspis tarda.* The type locality is cnw/14, Shields Ridge. Also in collections cnw/20, Washburn, and cnu/7, Purchase Ridge, Scott County, Va.

Types.—Holotype: U.S.N.M. 144628. Paratypes: U.S.N.M. 144629–31.

DUNDERBERGIA LONGIFRONS Rasetti, new species

Plate 15, figures 13–18

Available material.—Several cranidia and one pygidium.

Description.—Glabella strongly convex transversely and fairly convex longitudinally, slightly tapered, rounded in front, with 2 pairs of shallow lateral furrows. Occipital furrow deep, occipital ring lacking a distinct node. Frontal area relatively short; preglabellar field steeply downsloping; border convex, elevated. Palpebral area convex transversely, on the average horizontal; ocular ridges low and broad; palpebral lobes well defined by furrow even on outer surface, slightly more anterior with respect to the glabella than in the preceding species. Anterior section of facial suture weakly divergent; posterior section and posterior area not entirely preserved.

Pygidial axis broad, elevated, showing two very distinct rings and a terminal section with a third shallow ring furrow; axis extended into a broad postaxial ridge. Pleural regions with 3 distinct pairs of broad furrows; interpleural grooves lacking. Border furrow broad, border narrow, poorly defined. The posterior outline shows a faint median notch in dorsal view and is elevated medially in posterior view.

Surface of both shields covered with moderately elevated granules. Length of largest (holotype) cranidium 6 mm. Length of pygidium 1.3 mm., width 2.4 mm.

Discussion.—The species differs from *D. tennesseensis* and most other forms of the genus in the proportionately longer glabella relative to the entire cranidium.

Occurrence.—U.S.G.S. collection 2970, Monroe County. The association of species at that locality indicates the middle *Aphelaspis* zone.

Types.—Holotype: U.S.N.M. 144632. Paratypes: U.S.N.M. 144633.

Family PTEROCEPHALIIDAE Kobayashi, 1935

Genus APHELASPIS Resser, 1935

Type species.—*Aphelaspis walcotti* Resser.

The study of the species of *Aphelaspis* from the southern Appalachians presents such taxonomic problems as may be expected when thousands of individuals from numerous localities and slightly different horizons are available. Each thin limestone bed or lens, where the well-preserved material occurs, shows a population with a certain range of variability, but often statistically distinguishable from those occurring in lower or higher beds. In certain cases the range of variation within a population is such that extreme individuals overlap in several features those of different populations. Nevertheless, as material from a larger number of localities was studied, 17 well-characterized species emerged. Most of these could be found at a number of different localities in the same stratigraphic order, hence are valuable for correlation.

A favorable factor in the study of this difficult genus was offered by the frequent occurrence in a single bed or lens of a coquina of fragments of a single species. Hence the various parts could be assigned unequivocally for all the species described herein. Less frequently 2 species occurred in the same bed, and only 1 association of 3 species (*A. camiro, laxa,* and *quadrata*) was observed.

Difficulties in identification resulted from the presence in some beds of only immature forms of species that occur in much larger sizes at other localities. Cranidia less than 4 or 5 mm. in length are often indeterminable. Exfoliated specimens are difficult to compare accurately with individuals preserving the test; the latter were chosen almost exclusively for the descriptions and illustrations. Material preserved in shale or siltstone can seldom be specifically identified.

Virtually all the specimens collected could be assigned to the species discussed herein. However, it is to be expected that future collections from new localities will yield further new species, owing to the fact that fossiliferous limestone beds in shale may occur at slightly different horizons at different places.

In agreement with Palmer (1962b), *Proaulacopleura* Kobayashi, 1936, *Clevelandella* Resser, 1938, and *Labiostria* Palmer, 1954, are here considered subjective synonyms of *Aphelaspis.*

The characters of the genus have been described in great detail by Palmer (1954, 1962b). Only one point concerning ornamentation will be mentioned here. The upper surface of the test in the southern Appalachian species is either perfectly smooth, or finely punctate, in some species only in the furrows (*A. inermis, A. arsoides, A. palmeri*). The inner surface is invariably very finely granulate, and the internal impression therefore finely and densely pitted. Lack of comment on ornamentation in the specific descriptions means that the outer surface is entirely smooth.

The characters most frequently used for specific discrimination are the following.

(1) The width of the palpebral area relative to the glabellar width at the same level.

(2) The sagittal length of the frontal area relative to the length of glabella, including the occipital ring.

(3) The relative sagittal lengths of preglabellar field and border. This ratio and the preceding one, although of undoubted statistical significance, were found variable within a population for some of the species (e.g., *A tarda, A. camiro*). Such variations appeared uncorrelated with either stratigraphic position or size of the cranidia.

(4) The (exsagittal) length of the palpebral lobes relative to the length of glabella inclusive of occipital ring.

(5) The (exsagittal) length of the palpebral lobe relative to the exsagittal distance between the posterior end of the palpebral lobe and the posterior cranidial margin.

(6) The (transverse) width of the posterior area relative to the width of the occipital ring.

(7) The angle of divergence of the anterior sections of the facial suture and the more or less sharp change of direction of the suture in crossing the anterior border furrow. The posterior section of the facial suture has the same course in all species.

(8) The slope of the palpebral area, also a somewhat variable feature within a population.

(9) The slope and convexity of the preglabellar field and the more or less sharp angle formed by the border with respect to the preglabellar field. These features show large intraspecific variability, e.g., in *A. laxa* and *A. tarda*.

(10) The free cheeks in some cases offered useful characteristics in the features of the border and genal spine.

(11) The pygidia may be virtually indistinguishable for several species. In other cases species whose cranidia are very similar may show quite different pygidia.

All the species previously described from Virginia and Tennessee by Walcott (1916a) and Resser (1938a) could be found again, represented by more abundant and better preserved material, and with three exceptions are discussed herein. *Saratogia aruno* Walcott and *Clevelandella nitida* Resser are specifically undetermined forms of *Aphelaspis* possessing an occipital spine, presumably identical with either *A. arses* or *A. arsoides*. *Aphelaspis hamblenensis* is based on a complete exoskeleton flattened and weathered in shale; since individuals so preserved do not preserve the specific features, the name should be restricted to the holotype. In these three cases the stratigraphic position of the type specimens is unknown.

APHELASPIS WALCOTTI Resser

Plate 18, figures 10–20

Aphelaspis walcotti RESSER, 1938a, p. 59, pl. 13, fig. 14.
Aphelaspis walcotti Resser, PALMER, 1962b, p. 33, pl. 4, figs. 24, 28, 33.
Aphelaspis simulans RESSER, 1938a, p. 59, pl. 13, figs. 19–21.

Available material.—The hypodigm of *A. walcotti* consists of several cranidia, free cheeks, and pygidia, moderately well preserved and exfoliated. The types of *A. simulans* also include cranidia, free cheeks, and pygidia. Abundant material from the author's collections at various localities is also available.

Description.—Cranidium with less relief than average in the genus. Glabella defined by a shallow axial furrow on outer surface, weakly convex. Preglabellar field moderately downsloping and somewhat convex. Border flat, forming sharp angle with preglabellar field. Frontal area on average 0.6 times the length of glabella plus occipital ring. Sagittal length of border averaging slightly less than the length of preglabellar field. Palpebral area of average width, from slightly upsloping to horizontal. Ocular ridges very faint, almost transverse to slightly slanted backward. Palpebral lobe averaging somewhat more than one-third the length of glabella plus occipital ring; distance from posterior end of palpebral lobe to posterior margin greater than length of palpebral lobe. Anterior section of facial suture with average divergence; anterior angles of cranidium more widely rounded than in most species. Width (tr.) of posterior area less than width of occipital ring.

Free cheek with ocular platform of low convexity. Border slightly concave, upturned, not defined by furrow or sharp change in slope. Genal spine flat on upper side, of less than average length, rather rapidly tapered.

Pygidium 3 times as wide as long. Anterior margin almost straight; anterior angles sharp. Axis short, showing 2 or 3 rings plus a terminal section. Pleural lobes flat, with furrows and interpleural grooves, almost indistinct on outer surface, well marked on internal impression. Border flat, very narrow medially.

Length of largest cranidium collected 15 mm.

Discussion.—Careful examination of the types of *Aphelaspis simulans* and additional topotype material preserved in the U.S. National Museum indicates that the species may be definitely synonymized with *A. walcotti*. *Aphelaspis simulans* is based on a population showing a slightly greater relief of the cranidial parts than the average in *A. walcotti,* in particular, definitely upsloping palpebral area; however, the differences are not consistent among individual cranidia and fall within the range of variability observed within a single population. The pygidium also fully agrees with that of typical *A. walcotti.*

The species is closest to *A. bridgei, A. quadrata,* and *A. tarda.* The differences will be discussed in describing these species.

Palmer (1954) assigned to *Aphelaspis walcotti* material from Texas which seems to include excessive variation to represent a single species. The Texas pygidia differ considerably from the Tennessee forms, hence it appears doubtful that the species exists in Texas. Cranidia from Wyoming illustrated by Shaw (1956) certainly do not belong to the species.

Occurrence.—The type locality is U.S.N.M. 10u, near Saltville, Va. The type locality for *A. simulans* is U.S.N.M. 117d, near Washburn, Grainger County. Collected by the author at localities cnq/4, cnr/15, cnr/16, cnq/16, cnr′/17, and cnq/20.

Types.—Holotype and paratypes: U.S.N.M. 94923. Holotype and paratypes of *Aphelaspis simulans:* U.S.N.M. 94925–6. Plesiotypes: U.S.N.M. 144632–4.

APHELASPIS BRIDGEI Rasetti, new species

Plate 13, figures 1–7

Available material.—Large numbers of cranidia and less numerous free cheeks and pygidia well preserved in limestone.

Description.—Glabella defined by a shallow axial furrow, of usual shape. Occipital furrow shallow, occipital ring bearing a small node. Frontal area about 0.55 times as long as glabella. Preglabellar field somewhat convex longitudinally; border sharply defined by border furrow and change in slope, slightly convex, approximately horizontal; sagittal length of border almost equaling preglabellar field. Palpebral area slightly downsloping, 0.4 times as wide as glabella. Average exsagittal length of palpebral lobe 0.34 times length of glabella plus occipital ring and 0.84 times distance from posterior end of palpebral lobe to posterior cranidial margin. Ocular ridges faint, somewhat slanted backward. Width (tr.) of posterior area 0.8 times the width of the occipital ring.

Free cheek with flat border defined by shallow border furrow; genal spine flat on upper side, of moderate length.

Pygidium about 2.8 times as wide as long. Axis tapered, showing 2 or 3 well-defined rings and a terminal section. Anterior outline of pleural region almost straight, without apparent geniculation. Anterior angles rounded, posterior margin regularly curved. Three pairs of pleural furrows very distinct; interpleural grooves faint. Furrows and grooves not extending to narrow, flat border.

Surface of all parts of test smooth. Length of large cranidium 10 mm. Length of largest pygidium 4.3 mm., width 12 mm.

Discussion.—This species is very close to *A. walcotti,* from which it may be distinguished, at least statistically, by the slightly downsloping palpebral area, flat rather than concave border of the free cheeks, and more deeply furrowed pygidium. In some respects the species is transitional between *A. lata* and *A. walcotti.*

Occurrence.—U.S.G.S. collection 2804, from N. slope of Shields Ridge on New Market–Piedmont road, in upper part of lower limestone unit of the Nolichucky. The association with *Blountia bristolensis* and *Glaphyraspis ornata* shows that the species belongs to the lower portion of the *Aphelaspis* zone. The author was unable to collect fossils from this portion of the zone at the locality. The nearby locality at Russell Gap yielded fossils of the basal *Aphelaspis* zone, including, in ascending order, *Aphelaspis lata* and *A. minor.* The present species presumably occurs in higher beds, but lower than those which yielded *Aphelaspis camiro, A. laxa,* and *A. quadrata* at their type locality, U.S.N.M. 120, which is also on the New Market–Piedmont road.

Types.—Holotype: U.S.N.M. 144635. Paratypes: U.S.N.M. 144636.

APHELASPIS QUADRATA Resser

Plate 18, figures 1–9

Aphelaspis quadrata Resser, 1938a, p. 59, pl. 13, figs. 16–17.

Available material.—The holotype is a large, somewhat incomplete cranidium. The collection from the type locality includes several cranidia and pygidia, from which a clear picture of the specific characters can be gathered. The species was collected by Dr. Oder and the writer from the Three Springs, Washburn, and Smith Hollow sections. Free cheek and pygidium were unequivocally identified.

Description.—Glabella of average shape and convexity, defined by a well-impressed axial furrow. Preglabellar field downsloping, of moderate and fairly uniform convexity. Border averaging two-thirds of the sagittal length of preglabellar field, upturned and hence forming a sharp angle with the preglabellar field, almost flat; border furrow uniformly curved. Frontal area on average 0.50 times as long as glabella inclusive of occipital ring. Palpebral area slightly convex, horizontal to slightly upsloping. Ocular ridges definitely slanted backward. Length of palpebral lobe 0.25 times length of glabella plus occipital ring, and 0.7 times distance from posterior end of palpebral lobe to posterior margin. Anterior section of facial suture with average divergence. Width (tr.) of posterior area equals width of occipital ring.

Free cheek with fairly convex ocular platform. Border flat, upturned. Genal spine relatively short, rapidly tapered.

Pygidium 2.3 times as wide as long. Anterior margin definitely curving backward. Axis elevated, tapered, showing 3 rings plus a terminal section. Pleural lobes with distinct furrows and shallower interpleural grooves even on outer surface. Border flat, narrower medially; margin with slight median inbend.

Length of largest cranidium about 15 mm.

Discussion.—This species may be compared with *A. laxa* and *A. walcotti.* From *laxa* it differs consistently in the somewhat more convex glabella, less bulging preglabellar field, more posterior position of the eyes, and shorter (tr.) posterior area. The pygidium is proportionately narrower and more strongly furrowed. Compared with *A. walcotti, A. quadrata* has a cranidium with greater relief, lesser relative sagittal length of border relative to preglabellar field, and the pygidium has a more curved anterior margin.

Occurrence.—The type locality is U.S.N.M. 120, Shields Ridge. Although material under this label includes collections from different horizons, the association of the species with *A. camiro* and *A. laxa* is proved by the occurrence of the three species on the same piece of rock. Also collected by the author at localities cns/15, cns/16, cnr/20 and cnr′/20, in association with the equally common *A. camiro* and rare specimens of *A. laxa.*

Types.—Holotype and paratypes: U.S.N.M. 94924. Plesiotypes: U.S.N.M. 144637–8.

APHELASPIS TARDA Rasetti, new species

Plate 20, figures 1–18

Available material.—Large numbers of cranidia, free cheeks, and pygidia from several localities, both preserving the test and exfoliated.

Description.—Glabella of average shape and convexity; occipital ring bearing a median node. Frontal area averaging 0.65 times the glabellar length, but showing wide variation in this ratio, uncorrelated with size, locality, or horizon. Preglabellar field more or less convex longitudinally; border flat, forming sharp angle with preglabellar field. Sagittal length of border on average half of that of preglabellar field; this ratio is also highly variable. Palpebral area and lobe always more or less upsloping; palpebral area from 0.3 to 0.4 times as wide as glabella. Ocular ridges transverse to slightly slanted backward. Length of palpebral lobe about 0.4 times glabellar length and equal to distance to posterior margin. Width (tr.) of posterior area 0.8 times the width of occipital ring.

Free cheeks with border furrow distinct and border of variable width, flat to somewhat convex. Genal spine subcylindrical, rather flat on upper side, wide at the base, of moderate length.

Pygidium 2.5 times as wide as long. Axis showing 2 or 3 distinct rings on outer surface. Anterior outline of pleural lobes gradually curving backward without sharp geniculation, anterior angles more or less rounded. Pleural platforms with very faint furrows on outer surface; border furrow and border indefinite.

Length of largest cranidium 18 mm. Length of largest pygidium 4 mm., width 10 mm.

Discussion.—The numerous populations of this species observed show individual variability, especially in the relative proportions of border, preglabellar field, and glabellar length. Single cranidia with short preglabellar field and long border may be confused with *A. walcotti* and possibly other species. However, statistically the species is fairly well defined. The considerable length of the preglabellar field in most individuals, the upsloping palpebral area, definite flat border and border furrow on the free cheeks, and the characteristic pygidium with well-rounded anterior angles clearly distinguish a population of *A. tarda* from one of *A. walcotti*. The two species are rather widely separated stratigraphically, and no transition forms were observed in intermediate beds.

Occurrence.—Common at every locality where fossiliferous beds of the upper *Aphelaspis* zone are developed. The type locality is cnw/20, Washburn. Also present in collections cnu/1, cnv/1, cnw/1, cnw/14, cnu/15, cnv/15, cnx/20, cnu/21, cnv/21 and Oder's collection No. 14A. The species is also common in beds cnu/7, cnv/7 and cnv′/7 in the Purchase Ridge section, Scott County, Va.

Types.—Holotype: U.S.N.M. 144639. Paratypes: U.S.N.M. 144640–2.

APHELASPIS LAXA Resser

Plate 12, figures 18–21; plate 13, figures 8–15

Aphelaspis laxa Resser, 1938a, p. 60, pl. 13, fig. 18.

Available material.—The holotype is an exfoliated cranidium lacking the palpebral lobes and part of the anterior border. Several paratype cranidia are much better preserved, and further topotype material exists in the U.S. National Museum collections. The species also occurs in several of the author's collections, represented by cranidia, free cheeks, and pygidia.

Description.—Glabella of low convexity, rising little above the level of the cheeks, but defined at least laterally by a rather deep axial furrow. Frontal area about 0.6 times the glabellar length. Preglabellar field strongly convex longitudinally, hence sloping down steeply to border furrow. Border almost flat, horizontal; sagittal length of border more than half the length of preglabellar field. Palpebral area 0.4 times as wide as glabella, approximately horizontal; ocular ridges faint, with transverse course. Sagittal length of palpebral lobe 0.3 times the glabellar length, and about 0.6 times the distance from posterior end of palpebral lobe to posterior margin. Width (tr.) of posterior area 1.1 times the width of occipital ring.

Free cheek with relatively convex ocular platform, and wide, flat border upturned with respect to platform. Genal spine broad at base, rather rapidly tapered, flat on upper side, in most specimens somewhat curving upward. Depression at end of posterior border furrow deeper than in most species of the genus.

Pygidium definitely identified from collections where the species occurs alone. Pygidium about 3 times as wide as long; anterior margin fairly straight, anterior angles narrowly rounded. Axis tapered, showing 2 and sometimes 3 rings plus a terminal section. Two or three pairs of broad, shallow pleural furrows usually visible; some specimens also show a trace of interpleural grooves.

Length of largest cranidia 16 mm. Length of largest pygidium 5 mm., width 15 mm.

Discussion.—The species is well distinguished, at least statistically, by the low glabella, strongly convex preglabellar field, anterior position of the eyes, and considerable width (tr.) of the posterior area. However, single cranidia, especially if incompletely preserved, may be confused with such species as *A. walcotti, A. quadrata,* and *A. tarda.* The pygidium resembles those of *A. walcotti* and *A. bridgei.*

Occurrence.—The type locality is U.S.N.M. 120 on Shields Ridge; beds holding this species are not now exposed at that locality. The stratigraphic position of the species is well established by its occurrence in the author's collections cns/4, cns/15, cns/16, cns′/15, cnr/20, and cnr′/20.

Types.—Holotype and paratypes: U.S.N.M. 94929. Plesiotypes: U.S.N.M. 144643–5.

APHELASPIS PALMERI Rasetti, new species

Plate 14, figures 13–19

Available material.—Several cranidia, free cheeks, hypostomes, and pygidia.

Description.—Glabella of average shape and convexity; occipital ring bearing a small node. Preglabellar field convex longitudinally, steeply downsloping in anterior portion, forming sharp angle with horizontal, slightly convex border. Preglabellar field about one and one-half times as long (sag.) as border; entire frontal area about three-fourths the length of glabella plus occipital ring. Border furrow showing in most specimens a slight median inbend. Palpebral area half of the glabellar width, slightly upsloping; ocular ridge transverse. Palpebral lobe 0.4 times the length of glabella plus occipital ring; distance to posterior cranidial margin slightly greater than length of palpebral lobe. Anterior facial sutures slightly more divergent than the average in the genus; anterior angles of cranidium more widely rounded than in most species. Posterior area as wide (tr.) as occipital ring. Free cheek with wide border well defined anteriorly, the border furrow fading out posteriorly; genal spine convex on upper face, rather long, somewhat curving inward.

Pygidium somewhat more than twice as wide as long. Axis occupying somewhat less than a third of the width, tapered, showing at least on internal impression 3 rings plus a terminal section, extended into a broad, low postaxial ridge. Anterior outline of pleural lobes and furrows curving backward, producing well-rounded anterior angles. Doublure fairly wide laterally, reduced medially. Posterior margin rather straight in median portion, with suggestion of a slight median notch.

Surface of cranidium and free cheeks punctate in the furrows, especially in the anterior border furrow where the puncta are larger. Length of largest (holotype) cranidium 20 mm. Length of pygidium 2.6 mm., width 5.5 mm.

Discussion.—The cranidium is somewhat similar to *A. laxa* in the longitudinal profile of the frontal area, differing from that species in the proportionately longer (sag.) border, more widely rounded anterior angles, longer palpebral lobe, lesser distance from palpebral lobe to posterior margin, narrower (tr.) posterior area, and punctate surface. The pygidium is unlike *A. laxa* and much more like *A. tarda* in the lesser relative width and rounded sides. The rather strong divergence of the anterior facial sutures and median inbend of the border furrow give the cranidia of this species some resemblance to *Aphelaspidella macropyge,* but the pygidium is definitely of the *Aphelaspis* type.

Occurrence.—The type locality is U.S.G.S. 2970, Monroe County, where it occurs in association with *Aphelaspidella macropyge, Aphelaspis arses,* and *Paraphelaspis vigilans.* These species indicate the lower portion of the middle *Aphelaspis* zone. A few, imperfect cranidia in the collection cnq′/4 from the Lost Creek section may belong to this species, but, especially in the absence of the pygidia, cannot be distinguished with certainty from *A. laxa.* The stratigraphic position would confirm the assignment indicated above.

Types.—Holotype: U.S.N.M. 144646. Paratypes: U.S.N.M. 144647.

APHELASPIS CAMIRO (Walcott)

Plate 12, figures 1–17

Crepicephalus camiro Walcott (part), 1916a, p. 205, pl. 32, figs. 2, 2′.
Uncaspis camiro (Walcott) Kobayashi, 1935, p. 279.
Aphelaspis camiro (Walcott) Resser, 1938a, p. 60, pl. 13, fig. 27.

Available material.—Resser properly restricted the name to Walcott's holotype cranidium, excluding the pygidium which not only does not belong to the species, but probably is a trilobite of the *Crepicephalus* zone. The hypodigm includes a number of paratype cranidia well preserved in limestone. The species was collected at other localities by Dr. Oder and the author. From these collections the proper free cheek and pygidium could be identified unequivocally. Many of these pygidia were then discovered in the collection from the type locality in the U.S. National Museum.

Description.—Glabella somewhat smaller in proportion to the cranidium than in other species of the genus. Occipital ring bearing a small node near the posterior margin. Frontal area unusually long, averaging 0.8 times the glabellar length; as in other species, however, this ratio varies considerably among the individuals from one bed. Anterior sections of facial sutures diverging at average angle, making the cranidium very wide between the anterior angles. Border furrow better impressed than usual in the genus. Border slightly convex, its sagittal length averaging two-thirds the length of preglabellar field; border furrow showing in most, but not all, specimens a definite median inbend, and generally pitted on the outer surface. Preglabellar field as a whole rather flat, showing a low median boss. Palpebral area upsloping, about half the glabellar width. Ocular ridges transverse to slightly slanted backward. Palpebral lobe averaging 0.3 times the glabellar length, and about 0.5 times the distance from posterior end of palpebral lobe to posterior margin. Posterior area at least as wide (tr). as occipital ring. Length of largest observed cranidium 22 mm.

Free cheek with distinct, flat border set off by definite furrow, deeper in anterior portion, and long, slowly tapered genal spine, flat on the upper side.

Pygidium on average 1.75 times as wide as long, with a somewhat pointed shape. Axis relatively large, prominent, tapered, rounded posteriorly, showing 3 very distinct rings plus a terminal section. Anterior outline of pleural lobes after a short transverse course turning backward like the first pair of pleural furrows. Two other pairs of furrows may be faintly indicated. Border furrow and border poorly defined. Length of largest pygidium 3.8 mm., width 6.8 mm.

Discussion.—This is one of the most distinctive species of *Aphelaspis*. Larger cranidia may be distinguished by the long frontal area.

upsloping palpebral area, flat preglabellar field with a more or less distinct preglabellar boss, and anterior position of the eyes. The pygidium is unique in its relatively long and narrow shape and well-rounded sides. Immature cranidia, however, are not always easily distinguishable from those of associated species.

Occurrence.—The type locality is U.S.N.M. 120, Shields Ridge (see discussion of *A. quadrata* and *A. laxa*). Also collected by the author at localities cns/4, cns/15, cns/16, cnr/20, and cnr′/20.

Types.—Holotype and paratypes: U.S.N.M. 61672. Plesiotypes: U.S.N.M. 144648–51.

APHELASPIS ROTUNDATA Rasetti, new species

Plate 14, figures 1–12

Available material.—Numerous cranidia, free cheeks, and pygidia, and a few hypostomes. Most of the specimens lack the test.

Description.—Cranidium with low relief. Glabella and occipital ring without distinctive features. Preglabellar field slightly downsloping, with little convexity; border furrow better defined than in most species; border elevated, somewhat convex. Total length (sag.) of frontal area averaging 0.6 times the length of glabella plus occipital ring; midlength (sag.) of border about 0.3 times the midlength of preglabellar field. Palpebral area averaging somewhat less than half the glabellar width, upsloping; palpebral lobe also upsloping, defined by shallow furrow even on outer surface. Exsagittal length of palpebral lobe about 0.4 times the length of glabella plus occipital ring; exsagittal distance to posterior margin equal to length of palpebral lobe. Posterior area slender, about as wide (tr.) as occipital ring. Anterior sections of facial suture on the average more divergent than in most species, but there is considerable variability in this character among the population from a single thin bed. Free cheek with well-defined, flat border; genal spine flat dorsally at least in basal part, very long.

Pygidium twice as wide as long. Outline oval, lacking definite geniculation on anterior margin, widely rounded laterally, not notched but elevated medially. Axis stout, composed of 3 rings plus a terminal section, extended into a broad postaxial ridge that reaches the margin. Pleural platforms downsloping, giving pygidium considerable relief compared to other species. Pleural furrows and grooves shallow, the first furrow curving backward to follow the curvature of the margin. Border flat, poorly defined; doublure wide laterally, tapering medially.

Surface of test smooth, except for the genal coeca showing faintly on outer surface on preglabellar field and ocular platform, well marked on internal impression. Length of largest cranidium 21 mm.; length of largest pygidium 7 mm., width 14 mm.

Discussion.—This is a large species, whose cranidia somewhat resemble *A. camiro*. They differ in the narrower and more elevated anterior border, proportionately longer palpebral lobes, and lesser width (tr.) of the posterior area. The free cheek and genal spine are also very similar to that species. The pygidium is quite distinctive, with a proportionately narrower axis and regularly oval rather than subtrapezoidal outline.

Unless careful attention is paid to the divergence of the anterior sections of the facial suture, cranidia of *Aphelaspis rotundata* may be confused with those of the associated species *Aphelaspidella macropyge*. Even though there is some variability in the divergence of the sutures in either species, usually well-preserved cranidia can be classified on this character alone. The pygidia are immediately distinguishable, although the pygidium of *Aphelaspis rotundata,* with its doublure wider than in most species of the genus, approaches in shape the pygidium of *Aphelaspidella.*

Occurrence.—Medial portion of the *Aphelaspis* zone, in association with *Aphelaspis arses, Aphelaspidella macropyge,* and *Paraphelaspis vigilans.* The type locality is cns/20, Washburn. Also present in collections cns/20a, Washburn, cnq″/4, Lost Creek, and cns′/15, cns″/15, Three Springs.

Types.—Holotype: U.S.N.M. 144652. Paratypes: U.S.N.M. 144653–4.

APHELASPIS WASHBURNENSIS Rasetti, new species

Plate 17, figures 15–23

Available material.—Several cranidia, free cheeks, and pygidia.

Description.—Glabella relatively small in proportion to cranidium, of low convexity but defined by a fairly deep axial furrow. Frontal area averaging 0.75 times the length of glabella plus occipital ring. Preglabellar field tumid, strongly downsloping in anterior portion; border well defined by sharp change in slope, about half as long (sag.) as preglabellar field. Palpebral area somewhat upsloping, unusually wide (somewhat more than half the glabellar width); ocular ridges transverse; palpebral lobes about 0.3 times the length of glabella plus occipital ring; distance from posterior end of palpebral lobe to posterior margin about equaling length of palpebral lobe. Anterior section of facial suture diverging at average angle; anterior angles of cranidium fairly sharp. Posterior area slender, considerably wider (tr.) than occipital ring.

Free check with relatively narrow and well-defined border; border furrow becoming obsolete along posterior portion of lateral margin. Genal spine rather broad-based, flat on dorsal side, of average length.

Pygidium slightly more than twice as wide as long; axis prominent, showing 2 rings plus a terminal, indistinctly segmented section, occupying more than two-thirds of pygidial length. Pleural regions with 2 pairs of broad pleural furrows and traces of interpleural grooves; border flat, fairly wide.

Surface of test smooth except for more or less distinct puncta in the depressions, especially the anterior border furrow. Length of holotype cranidium 15 mm.

Discussion.—The combination of cranidium and pygidium forms a distinctive species. The cranidium differs from most of the known species of *Aphelaspis* in the relative width of the palpebral area; other species that have a wide palpebral area (*A. lata, A. buttsi*) are quite different in other cranidial features. The low glabella and tumid preglabellar field recall *A. laxa,* in which, however, the palpebral area is narrow and the palpebral lobes are more anteriorly situated. The pygidium resembles none of the above-mentioned species, being similar to *A. rotundata* and *A. palmeri.*

As far as can be ascertained from the scarce and mostly fragmentary material, the species is rather variable in most of its features. At both localities where it was collected, *A. washburnensis* occurs in association with another species of *Aphelaspis,* possibly the same in both cases. This second species seems somewhat intermediate between *A. walcotti* and *A. quadrata,* but the material was deemed insufficient to decide whether it should be identified with either of these two species or described as a new one. Therefore this form appears as *Aphelaspis* sp. undet. in the faunal lists.

Occurrence.—The type locality is cnq′/20, Washburn. In this section the species occurs in association with *Aphelaspidella macropyge* and *Glaphyraspis declivis,* above the strata holding *A. walcotti* and below those with *A. camiro, A. laxa,* and *A. quadrata.* In the Three Springs section, a limestone lens holding *Aphelaspis washburnensis* and possibly *Aphelaspidella macropyge* was collected at the same level (cns/15) as beds yielding *Aphelaspis camiro, A. laxa,* and *A. quadrata,* but the latter 3 species were not associated with *A. washburnensis* in the same lens. From this evidence it is clear that *A. washburnensis* occurs near the base of the middle *Aphelaspis* zone.

Types.—Holotype: U.S.N.M. 144655. Paratypes: U.S.N.M. 144656–7.

APHELASPIS BUTTSI (Kobayashi)

Plate 16, figures 1–7

Olenus cf. *truncatus* (Brünnich) Butts, 1926, pl. 9, figs. 6, 7.
Proaulacopleura buttsi Kobayashi, 1936, p. 93, pl. 15, fig. 6.
Proaulacopleura buttsi Kobayashi, Resser, 1938a, p. 95, pl. 16, fig. 18.
Aphelaspis buttsi (Kobayashi) Palmer, 1962b, p. 35, pl. 4, figs. 23, 26, 31, 32; pl. 6, fig. 15.

Large numbers of specimens, many of them complete exoskeletons like the holotype, are available from the type locality in Alabama. This material is all flattened in shale, hence identification with limestone specimens inevitably leaves some uncertainty. However, all the features of cranidium, free cheek, and pygidium, excepting the convexity that cannot be compared, match so perfectly that reference of the Tennessee material to the species seems justified. Palmer (1962b) referred to *A. buttsi,* his excellent limestone specimens from Nevada, which are identical in all respects with those from the writer's collections.

Occurrence.—The species is very abundant in collection cno/15, Three Springs, from beds containing a mixture of genera of the *Crepicephalus* and *Aphelaspis* zones. Cranidia of an *Aphelaspis* collected from the essentially equivalent beds cno/14 at Russell Gap may belong to the species, but they cannot be distinguished with certainty from *A. lata* in the absence of associated pygidia. This is the oldest *Aphelaspis* species found in Tennessee. The type locality is U.S.N.M. 91o, near Center, Ala.

Types.—Holotype: U.S.N.M. 93048. Plesiotypes: U.S.N.M. 144658.

APHELASPIS LATA Rasetti, new species

Plate 16, figures 8–20

Available material.—Large numbers of cranidia and several free cheeks and pygidia, both preserving the test and exfoliated.

Description.—Cranidium proportionately wide and short, its sagittal length equaling the width between the palpebral lobes, which is slightly greater than the width between the anterior angles. Glabella somewhat wider and shorter than in most species, of moderate convexity. Fixed cheeks not rising above the level of the axial furrow. Preglabellar field of moderate, uniform longitudinal convexity; border somewhat convex, defined by change in slope and shallow border furrow. Length of frontal area 0.6 times the length of glabella; sagittal length of border slightly less than half the length of preglabellar field. Border furrow somewhat angular on midline. Palpebral area horizontal to slightly downsloping, wider than in most species, half as wide as glabella. Ocular ridges transverse or even slightly slanted forward. Palpebral lobe averaging 0.4 times the glabellar length. Distance from posterior end of palpebral lobe to posterior margin equal to length of palpebral lobe. Anterior section of facial suture of average divergence. Posterior area as wide (tr.) as occipital ring.

Free cheek with slightly convex border like the cranidium; genal spine flat, of average length.

Pygidium somewhat less than 3 times as wide as long, transversely subelliptical. Axis relatively long, showing 2 or 3 rings plus a terminal section, well defined on outer surface. Pleural lobes with well-impressed furrows and very shallow interpleural grooves visible on outer surface. Posterior margin slightly indented medially.

Length of largest cranidium collected 8 mm. Length of largest pygidium 3.6 mm., width 10 mm.

Discussion.—The cranidium of this species is almost indistinguishable from *A. buttsi* except for the shallower glabellar and axial furrows. Even this difference can be determined statistically only when numerous well-preserved specimens in limestone are available. The pygidium, however, is markedly distinct in possessing one less segment both in the axis and pleural lobes, and in its posterior outline which is slightly notched medially, like *A. walcotti* and several other species, rather than somewhat pointed as in *A. buttsi*. The interpleural grooves are less distinct than in that species.

Occurrence.—The type locality is cnp/14, Shields Ridge. Also collected at localities cnp/15, Three Springs, and cnp/20, Washburn. A few, small cranidia apparently identical with topotypes of the same size were recovered from considerably higher beds at locality cnr/4, Lost Creek. Since several species of *Aphelaspis* are distinguishable only from the pygidia, the identification must be considered tentative.

Types.—Holotype: U.S.N.M. 144659. Paratypes: U.S.N.M. 144660–2, 144734.

APHELASPIS TRANSVERSA Rasetti, new species

Plate 16, figures 21–27

Description.—Cranidium wide and short, of the same general proportions as in *A. lata*. Glabella of considerable transverse convexity, defined by a rather deep axial furrow at the sides, a shallower furrow in front, truncate. Occipital furrow deeper than usual in the genus; occipital ring bearing a small node. Preglabellar field with considerable convexity on midline; border furrow straight at the sides, forming a rounded, obtuse angle medially. Border sharply upturned from preglabellar field, almost flat; sagittal border length two-thirds of length of preglabellar field. Frontal area averaging slightly over 0.6 times the glabellar length. Palpebral area rising above the axial furrow, somewhat convex, on average somewhat upsloping, half as wide as glabella. Ocular ridges stronger than in most species, transverse to slightly slanted forward. Palpebral lobes 0.4 times the glabellar length; distance from posterior end of palpebral lobe to posterior margin equal to length of palpebral lobe. Posterior area as wide (tr.) as occipital ring. Free cheek with flat genal spine of average rate of tapering.

Pygidium about 3 times as wide as long. Axis with 2 rings plus a terminal section. Pleural lobes showing only 1 distinct pair of pleural furrows.

Length of largest cranidium observed 7 mm.

Discussion.—This species resembles *A. lata* but is clearly distinguished by the depth of the axial furrow, convexity of the palpebral area, wider anterior border, and smoother pygidium.

Occurrence.—Locality cnp/17, Hurricane Hollow, in the basal bed of the *Aphelaspis* zone, a few feet above strata with typical *Crepicephalus* fauna.

Types.—Holotype: U.S.N.M. 144663. Paratypes: U.S.N.M. 144664.

APHELASPIS MINOR Rasetti, new species

Plate 19, figures 18–25

Available material.—Large numbers of cranidia and free cheeks, and a few pygidia.

Description.—Glabella of average shape and convexity; occipital furrow fairly well impressed, occipital ring bearing a low node. Preglabellar field moderately convex longitudinally; border furrow well impressed, slightly angular on midline; border convex, its midlength (sag.) less than the length of preglabellar field. Length of frontal area averaging 0.50 times length of glabella plus occipital ring. Palpebral area upsloping; palpebral lobes slightly elevated above palpebral area, set off by shallow furrow, half the length of glabella plus occipital ring. Distance from posterior end of palpebral lobe to posterior cranidial margin less than length of palpebral lobe. Ocular ridges transverse. Anterior sections of facial suture with average divergence. Posterior area about as wide (tr.) as occipital ring. Free cheek with rather flat border defined by sharp change in slope. Genal spine relatively long, rather flat on dorsal side.

Pygidium exactly 3 times as wide as long. Axis well tapered, rounded posteriorly, showing 2 rings plus a terminal section, reaching the border furrow. Pleural platforms rather convex, faintly furrowed.

Anterior outline without definite geniculation. Border and doublure very narrow throughout.

Length of largest of hundreds of cranidia observed, 7 mm. Length of largest pygidium 2.5 mm., width 7.5 mm.

Discussion.—The cranidia may not be easy to distinguish from immature examples of some of the larger species, but the combination of cranidium and pygidium characterizes the species as definitely distinct from all others. The cranidium is extremely similar to that of *A. inermis,* the distinguishing features being pointed out in the description of that species. The pygidium instead is very much like *A. walcotti* and *A. bridgei.*

Occurrence.—Lower part of the *Aphelaspis* zone, above the beds with *A. lata* and below those carrying *A. walcotti.* Type locality is cnq/17, Hurricane Hollow. Also in collections cnq/14, Shields Ridge, cnq/15, Three Springs, and cnp′/20, Washburn.

Types.—Holotype: U.S.N.M. 144665. Paratypes: U.S.N.M. 144666–8.

APHELASPIS INERMIS Rasetti, new species

Plate 19, figures 8–17

Available material.—Numerous cranidia and free cheeks, and a few tentatively assigned pygidia.

Description.—Glabella of average shape and convexity; occipital furrow shallow; occipital ring bearing a node, lacking spine. Frontal area averaging slightly less than half the glabellar length. Preglabellar field somewhat convex longitudinally especially on midline. Border defined by shallow furrow and change in slope, slightly convex, rather narrow for the genus. Anterior section of facial suture moderately divergent, straight to border furrow. Palpebral area slightly upsloping, about 0.3 times the glabellar width. Palpebral lobes set off by very shallow furrow, somewhat elevated, averaging 0.3 times the glabellar length and somewhat less than distance from posterior margin. Width (tr.) of posterior area equal to width of occipital ring. Free cheek with slightly convex border defined by shallow furrow. Genal spine oval in cross section, rather thick and long.

Pygidia associated with the cranidia in more than one collection are transversely subelliptical, about 2.5 times as wide as long. Axis very prominent, equally long and wide, rounded posteriorly, with 1 distinct ring. Pleural lobes with 2 pairs of furrows and indistinct interpleural grooves, all ending in flat border which is wider laterally than medially.

Surface of test pitted in furrows of cranidium and free cheek, but not as coarsely as in *A. arsoides.* Length of unusually large cranidium 9 mm. Most of the specimens do not exceed 6 mm.

Discussion.—This species is very similar to *A. arsoides* in all proportions. Apart from lack of an occipital spine, it may be distinguished at least statistically by the lesser divergence of the anterior section of the facial suture, greater convexity of the preglabellar field, slightly upsloping palpebral area, and convex instead of flat genal spine. It is also very similar to *A. minor,* with which it had been confused before large collections were made. It may be distinguished from that species by the usually slanted instead of transverse course of the ocular ridge, sharper anterior angles of the cranidium, slightly smaller palpebral lobe, and lesser average slope of the palpebral area. The pygidia are quite different, the one of *A. minor* being proportionately shorter and wider, with narrower border and furrows extending almost to the margin. The pygidium of *A. inermis* is more like that of *A. arses.* The present species and *A. minor* occupy different stratigraphic positions, and no transition forms are known from intermediate beds.

Occurrence.—The type locality is cns/2, Shields Ridge. Also present in collections cnr/4, cns/4 and cnt/4. It occurs in association with *A. tumifrons* or *A. arsoides.*

Types.—Holotype: U.S.N.M. 144669. Paratypes: U.S.N.M. 144670–1.

APHELASPIS TUMIFRONS Resser

Plate 19, figures 1–7

Aphelaspis tumifrons RESSER, 1938a, p. 60, pl. 13, fig. 15.

Available material.—The hypodigm includes the holotype and several other cranidia in fair state of preservation. Abundant and well-preserved new specimens from various localities allow a more complete description.

Description.—Glabella poorly defined on upper surface by a very shallow axial furrow. Occipital furrow shallow; occipital ring bearing a node. Frontal area averaging 0.45 times the glabellar length. Preglabellar field with definite median boss. Border defined by somewhat gradual change in slope, of average width medially, almost vanishing at the sides. Anterior cranidial margin slightly pointed medially. Palpebral area approximately horizontal, about 0.3 times the glabellar width; palpebral lobe more or less upsloping, not defined by palpebral furrow on outer surface. Average exsagittal length of palpebral lobe 0.4 times the glabellar length and 0.8 times the distance to posterior margin. Ocular ridges wide, almost undefined on outer surface, somewhat slanted backward. Transverse width of posterior area 0.8 times width of occipital ring. Free cheek with somewhat convex ocular platform, broad and vaguely defined border furrow, and fairly long, cylindrical genal spine.

Pygidium more than twice as wide as long. Axis strongly tapered, usually showing 1 distinct ring plus a terminal unsegmented section, almost reaching posterior margin. Anterior outline of pleural lobe with sharp geniculation situated about midway from axial furrow to anterior angle. Two pairs of broad pleural furrows and somewhat indistinct pleural grooves are visible on upper surface. Border narrow all along posterior margin, poorly defined by shallow border furrow.

In some specimens fine puncta are present in the furrows on cranidium and free cheeks. Length of largest cranidium observed among several hundred specimens 10 mm. The overwhelming majority of the cranidia do not exceed 7 mm. Length of largest pygidium 1.6 mm., width 4.0 mm.

Discussion.—This is a distinctive species, that can seldom be confused with other forms of *Aphelaspis* even if only a small sample is available. The main characteristics are the shallowness of the axial furrow, the tumid preglabellar field, the poorly defined anterior border, and the relatively anterior position of the eyes.

Occurrence.—The species is usually extremely abundant when present, and represents an excellent index fossil for the upper portion of the middle *Aphelaspis* zone. The type locality is U.S.N.M. 119, S. of Morristown, Hamblen County. Present in the author's collections cns/1, cnt/1, cns/2, cnt/4, cnt/7, cns/15, cnt/15, cnt'/15, cnt/20, cnt/21, and in Oder's collection No. 14.

Types.—Holotype: U.S.N.M. 94927. Plesiotypes: U.S.N.M. 144672.

APHELASPIS PUNCTATA Rasetti, new species

Plate 18, figures 21–29

Available material.—Numerous cranidia and free cheeks and a few pygidia.

Description.—Glabella of usual shape and convexity; axial furrow with deep pits at anterior corners of glabella. Frontal area markedly convex in front of glabella; border furrow well impressed, forming rounded angle on midline; border convex, averaging in midlength (sag.) one-third of length of preglabellar field. Entire frontal area over half the length of glabella plus occipital ring. Palpebral area somewhat upsloping; palpebral lobes elevated above palpebral area, half the glabellar length, defined by distinct furrow. Distance from posterior end of palpebral lobe to posterior cranidial margin less than length of palpebral lobe. Anterior sections of facial suture with average divergence; anterior angles of cranidium very sharp. Posterior area equal in width (tr.) to occipital ring. Free cheek with narrow, convex border. Genal spine rapidly tapered, fairly flat on dorsal side;

posterior border furrow with shallow extension on proximal portion of genal spine.

Associated pygidium with large axis, wider than pleural lobes, elevated, rounded at the extremity, showing 3 poorly defined rings plus a terminal section. Anterior outline of pleural lobes showing geniculation not far from axial furrow, then bending backward rather sharply; posterior margin with maximum curvature on midline. One pair of pleural furrows well impressed, two other pairs shallow and rather indistinct. Border narrow, poorly defined by border furrow.

Surface of cranidium and free cheeks almost entirely covered with fine, dense puncta. Surface of pygidium also punctate. Length of largest cranidium 8 mm. Length of pygidium 2.1 mm., width 3.7 mm.

Discussion.—The cranidium of this species would be distinctive even without the unique feature of the punctate surface because of the deep pits in the axial furrow, the roll in front of the glabella, and the elevated palpebral lobes. All these features tend to give the species an aspect approaching *Dytremacephalus angulatus.* The pygidium is also distinctive in shape, having a proportionately larger axis than other species of *Aphelaspis.*

Occurrence.—Uppermost beds of the *Aphelaspis* zone, in association with *Aphelaspis tarda.* The type locality is cnw/14, Shields Ridge, but the species is less rare at locality cnw/20, Washburn.

Types.—Holotype: U.S.N.M. 144673. Paratypes: U.S.N.M. 144674–5.

APHELASPIS ARSES (Walcott)

Plate 13, figures 16–23

Saratogia arses Walcott, 1916a, p. 196, pl. 35, figs. 4–4b.
Clevelandella arses (Walcott) Resser, 1938a, p. 69, pl. 13, fig. 22.

Available material.—The hypodigm consists exclusively of the holotype, a good cranidium in limestone. Collections by the author supplied numerous cranidia and free cheeks and a few pygidia.

Description.—Glabella of average shape and convexity. Occipital furrow well defined throughout, deeper than in most species of the genus. Occipital ring bearing a small node and, in addition, a long, slender, somewhat upturned spine. Frontal area averaging half the length of glabella (exclusive of spine). Preglabellar field slightly convex longitudinally. Border narrow, defined by shallow furrow and change in slope, in most specimens definitely convex. Anterior sections of facial suture quite straight from palpebral lobe to border furrow. Palpebral area slightly convex, horizontal to slightly upsloping, averaging 0.3 times the glabellar width. Ocular ridges broad but distinct, slanted backward. Palpebral lobes set off by distinct furrow on upper surface, relatively narrow, about 0.3 times the glabellar length and equaling the distance to posterior cranidial margin. Posterior area about as wide (tr.) as occipital ring. Free cheek with slightly convex border defined by shallow furrow; genal spine oval in cross section, fairly long, tapering to sharp point.

Pygidium associated with the cranidia transversely subelliptical, twice as wide as long. Axis prominent, showing 2 rings plus a terminal section, almost reaching margin. Pleural lobes with 2 more or less distinct pairs of broad furrows and very weak interpleural grooves. Anterior outline regularly curved, anterior angles rounded. Border furrow and border undefined.

Surface of test smooth. Length of largest cranidium (exclusive of spine) 7 mm. Length of pygidium 2 mm., width 4 mm.

Discussion.—The assignment of the species to *Aphelaspis* was justified in the discussion of the genus. *Aphelaspis arses* may be distinguished from most species of the genus, apart from the occipital spine, by the better than average definition of the occipital ring and palpebral lobe. The closest relatives are two species described herein, *A. arsoides* and *A. inermis;* the differences are mentioned in their discussion.

Occurrence.—The type locality is U.S.N.M. 173, near Maryville. The exposures in that area were very poor and may now be concealed in built-up areas. The author's material was collected from localities cnr/4 and cns/4, Lost Creek, cns/20, Washburn, and cns′/15, Three Springs.

Types.—Holotype: U.S.N.M. 61617. Plesiotypes: U.S.N.M. 144676, 144733.

APHELASPIS ARSOIDES Rasetti, new species

Plate 11, figures 15–21; plate 12, figure 22

Available material.—Large numbers of cranidia and free cheeks from several localities, and a few pygidia.

Description.—Glabella rather flat, defined by shallow axial furrow. Occipital furrow shallow; occipital ring extended into long, slender, almost horizontal spine, not bearing a node. Frontal area from 0.5 to 0.7 times the glabellar length. Preglabellar field with very slight longitudinal convexity; border of average width, defined by furrow and change in slope, more or less convex. Anterior sections of facial suture straight to border furrow, diverging at somewhat greater angle than in most species, including *A. arses.* Palpebral area horizontal to slightly downsloping, about 0.3 times the glabellar width. Ocular ridges distinct, slanted backward. Palpebral lobe almost undefined by furrow on upper surface, about 0.3 times the glabellar length, and equaling the distance to posterior margin. Posterior area somewhat narrower (tr.) than occipital ring. Free cheek with flat border well defined by lateral border furrow, which, however, becomes indistinct before meeting posterior border furrow, as in all species of *Aphelaspis.* Genal spine flat, of average length. Facial suture cutting posterior margin somewhat farther from genal angle than in *A. arses.*

Surface distinctly pitted in furrows on cranidium and free cheeks, especially in border furrow. Length of unusually large cranidium exclusive of spine, 13 mm.; the majority do not exceed 8 mm.

Pygidium transversely ovate, two and one-half times as wide as long. Axis stout, showing 2 rings and a terminal section, almost reaching the margin. Pleural lobes almost flat and horizontal. Anterior and posterior outlines slightly and regularly curved, lateral angles well rounded. Anterior pleural furrow distinct, distally curving backward to parallel the margin; another pair of furrows indistinct. The surface in the depressions in some specimens is pitted as in the cranidium and free cheeks. Length of largest pygidium 3.5 mm., width 8.5 mm.

Discussion.—This species can be distinguished from the closely related *A. arses* by the shallower axial furrow, almost horizontal palpebral area, indistinct palpebral furrow, the characteristic pitted surface in the depressions of the test, and somewhat different shape and flat border of the free cheek.

Occurrence.—This species occupies a somewhat higher stratigraphic position than *A. arses* and is frequently associated with *A. tumifrons.* The type locality is cns/2. Also present in collections cns/1, cnt/1, cnt/4, cns/15, cnt/15, cnt′/15, cnt/20, cnt′/20, cnt/21, and Oder's collection No. 14.

Types.—Holotype: U.S.N.M. 144677. Paratypes: U.S.N.M. 144678–80.

Genus APHELASPIDELLA Rasetti, new genus

Description.—Cranidium similar to *Aphelaspis,* except in the very strong divergence of the anterior sections of the facial suture. Free cheek as in *Aphelaspis,* with long genal spine. Pygidium proportionately much larger than in *Aphelaspis.* Axis occupying less than half the length, extended into a postaxial ridge. Pleural lobes wide, with little relief, with shallow furrows and grooves and a wide, concave border; doublure very wide.

Discussion.—The very close relationship to *Aphelaspis* is obvious. However, the different course of the anterior section of the facial suture and the pygidial characters are important enough to deserve generic recognition.

Type species.—*Aphelaspidella macropyge* Rasetti, n. sp.

Occurrence.—*Aphelaspis* zone of the southern Appalachians.

APHELASPIDELLA MACROPYGE Rasetti, new species

Plate 11, figures 1–8

Available material.—Numerous cranidia, free cheeks, and pygidia excellently preserved in limestone.

Description.—Cranidium of low general convexity. Glabella straight-sided, subtruncate in front, of low convexity, defined by a shallow axial furrow. Glabellar furrows barely indicated on outer surface; occipital furrow shallow, occipital ring short (sag.) and simple. Frontal area 0.8 times the glabellar length; preglabellar field convex, slightly downsloping; border furrow deep, with a median inbend; border somewhat convex, wide medially, tapering in width at the sides. Palpebral area half as wide as the glabella, slightly upsloping. Ocular ridges faint, transverse. Palpebral lobes 0.3 times the length of glabella plus occipital ring, defined by a very shallow palpebral furrow. Anterior sections of facial suture forming an angle of almost 60° with the median line; anterior angles of cranidium more widely rounded than in any species of *Aphelaspis;* marginal portion of suture about one-third the length of anterior cranidial margin, as in most *Aphelaspis* species. Posterior section of facial suture first directed backward, curving outward, then again somewhat backward, defining slender posterior area identical with that of most *Aphelaspis* species. Free cheek with well-defined lateral border.

Pygidium twice as wide as long, subelliptical. Axis rapidly tapered, showing 3 rings and a terminal section, less than half the pygidial length, extended into a long postaxial ridge. Three pairs of increasingly shallow pleural furrows and less distinct interpleural grooves are visible; the furrows extend, very broad and shallow, even across the wide, concave border. The inner edge of the doublure is clearly apparent on the upper surface.

Surface of test smooth, except for a dense row of puncta in the anterior border furrow. Length of largest cranidium 18 mm. Length of largest pygidium 9 mm., width 18 mm.

Occurrence.—The type locality is author's locality cnr/4, Lost Creek. Also common in collections cns/20, cns/20a, Washburn, and present in collections cns''/15, Three Springs, and U.S.G.S. 2970. In the U.S. National Museum there is a collection of cranidia and pygidia of the species from locality 173, marked "Maryville, Tenn." which is also the type locality for *Aphelaspis arses.*

Types.—Holotype: U.S.N.M. 144681. Paratypes: U.S.N.M. 144682.

Genus PARAPHELASPIS Rasetti, new genus

Description.—Cranidium with considerable relief. Glabella well tapered, truncate in front, fairly convex transversely, defined by a deep axial furrow laterally. Occipital furrow and ring as in *Aphelaspis.* Frontal area less than half the glabellar length, downsloping. Preglabellar field slightly convex; border narrow, elevated. Palpebral area narrow, upsloping; palpebral lobe elevated, opposite anterior third of glabella. Posterior area narrower (tr.) than occipital ring, broadly triangular, rather strongly downsloping. Anterior section of facial suture as in *Aphelaspis.* Free cheek wide, steeply downsloping; ocular platform somewhat convex; border narrow. Facial suture cutting posterior margin rather far from genal angle; genal spine short and slender. Size small. Surface smooth except for puncta in the depressions.

Discussion.—The close affinity with *Aphelaspis* is obvious. Nevertheless the genus appears to deserve recognition because of the greater relief of the cranidial parts, in particular the elevation of the palpebral area and lobe and the downsloping attitude of the free cheek and posterior area. Another distinguishing feature is the anterior position of the eyes. The cranidia of *Paraphelaspis* resemble immature cranidia of *Aphelaspis* rather than adult individuals of that genus. Possibly we have a case of paedogenesis, *Paraphelaspis* representing an offshoot of the *Aphelaspis* stock preserving immature features in sexually mature individuals.

One should also mention the resemblance of the genus to *Kujandaspis* Ivshin (type species: *Kujandaspis kujandensis* Ivshin, 1956), which seems also to represent another close relative of *Aphelaspis.* In *Kujandaspis* the glabella is relatively smaller and the eyes do not have such an anterior position as in *Paraphelaspis.*

Type species.—Paraphelaspis vigilans Rasetti, n. sp.

Occurrence.—Aphelaspis zone of the southern Appalachians.

PARAPHELASPIS VIGILANS Rasetti, new species

Plate 21, figures 14–28

Available material.—Numerous cranidia and free cheeks.

Description.—Glabella strongly tapered, truncate in front, defined by a deep axial furrow at the sides, a shallower furrow in front. One or two shallow pairs of lateral furrows visible even on outer surface, of the same pattern as in *Aphelaspis.* Occipital furrow well marked; occipital ring bearing a node. Frontal area 0.4 to 0.5 times as long as glabella plus occipital ring, proportionately longer in larger cranidia. Preglabellar field with a more or less pronounced convexity in front of the glabella; border furrow regularly curved; border length (sag.) less than half the preglabellar field; border convex, elevated. Palpebral area very narrow, proportionately wider in larger cranidia, more or less strongly upsloping; ocular ridges distinct, very short, directed somewhat forward. Palpebral lobe somewhat less than 0.3

times as long as glabella plus occipital ring, set off by shallow but distinct furrow even on outer surface; its anterior end almost at the level of the front of the glabella, its posterior end slightly anterior to level of glabellar midpoint. Distance to posterior margin about twice length of palpebral lobe. Anterior section of facial suture straight to border furrow, divergent as the average in *Aphelaspis;* posterior section directed straight outward and backward, curving rather sharply backward before cutting posterior margin at right angle, defining much longer (exsag.) and narrower (tr.) posterior area than in *Aphelaspis* species; width of posterior area less than width of occipital ring.

Free cheek proportionately wide, evidently steeply sloping. Ocular platform convex near the eye. Border furrow shallow and broad; border narrow, convex as in cranidium. Facial suture cutting margin at considerable distance from short, slender genal spine. The pygidium has not been identified.

Length of largest among hundreds of cranidia observed 5.5 mm.

Discussion.—It was mentioned in the generic description that *Paraphelaspis* resembles immature individuals of *Aphelaspis* in several respects. This also agrees with the fact, apparent from the description and the illustrations, that the similarity to *Aphelaspis* increases with increasing size of the cranidia of *Paraphelaspis,* especially in the features of greater relative length of the frontal area and width of the palpebral area. Nevertheless, there are still considerable differences between the largest cranidia of *Paraphelaspis vigilans* and individuals of the same size of all the known species of *Aphelaspis.* In particular, immature cranidia of the two species of *Aphelaspis* that occur in association with *Paraphelaspis* are known and are quite different from *Paraphelaspis.* Of all species of *Aphelaspis, A. inermis* is possibly closest to *Paraphelaspis.*

Occurrence.—The type locality is cns/20, Washburn. Also present in collections cns/20a, Washburn, cnr/4, Lost Creek, cns′/15, cns″/15, Three Springs, and U.S.G.S. 2970. The species has been found only in association with *Aphelaspidella macropyge.*

Types.—Holotype: U.S.N.M. 144683. Paratypes: U.S.N.M. 144684–5.

Genus DYTREMACEPHALUS Palmer, 1954

Type species.—*Dytremacephalus granulosus* Palmer.

DYTREMACEPHALUS ANGULATUS Rasetti, new species

Plate 21, figures 1–9

Available material.—Large numbers of cranidia, a few free cheeks and pygidia in excellent state of preservation.

Description.—Glabella tapered, straight-sided, truncate in front, of moderate convexity, defined by deep axial furrows at the sides, a shallow furrow in front. A pair of deep pits in furrow at anterior corners of glabella. Three shallow pairs of lateral furrows visible on upper surface. Occipital furrow deep at the sides, shallow medially; occipital ring long (sag.), bearing a node. Preglabellar field swollen in posterior portion, rising above the frontal portion of the axial furrow, downsloping in anterior portion; border furrow wide with strong curvature on midline, giving it an angular aspect. Border about half as long (sag.) as preglabellar field, upturned, convex, tapering at the sides. Entire frontal area half as long as glabella inclusive of occipital ring. Palpebral area slightly more than half as wide as glabella, slightly convex and upsloping from the axial furrow. Ocular ridges distinct, moderately slanted backward. Palpebral lobes defined by furrow even on outer surface, fairly wide, not rising above palpebral area, 0.4 times as long as glabella. Distance from palpebral lobe to posterior cranidial margin considerably shorter than palpebral lobe. Anterior sections of facial suture moderately divergent as in *Aphelaspis,* straight to border furrow. Posterior area as in *Aphelaspis,* narrower (tr.) than occipital ring. Free cheek with well-defined, convex border and border furrow; ocular platform more convex than in species of *Aphelaspis;* genal spine short, rapidly tapered, flat on upper side.

Thorax preserved in complete exoskeletons in shale. One small individual appears to have 12 segments; however, the larger thorax illustrated herein, attached to the pygidium but lacking the cephalon, shows 13 segments, and this seems to be the number in the holaspid, as in the species of *Aphelaspis* where the thorax is known. The pleurae are straight proximally, curving backward to short falcate extension distally, and are furrowed through all their length, much as in *Aphelaspis.*

Pygidium with considerable convexity. Axis occupying one-third of the width, almost reaching margin, strongly elevated, showing 3 to 5 distinct rings plus terminal section, rounded posteriorly. Pleural platforms steeply downsloping, with strong furrows and distinct interpleural grooves. Border flat, wide at the sides, almost vanishing medially, as the axis almost attains the margin. Anterior margin curving backward, almost attaining longitudinal course; angles fairly sharp; posterior margin straight laterally, forming fairly sharp angle medially.

Surface of cranidium finely and densely granulate except in the furrows. Border of cranidium and free cheek with terrace lines. Ocular platform granulate like the cranidium. Ornamentation of pygidium indistinct. Length of largest cranidium 6.5 mm. Fragments indicate that the species attains a somewhat larger size. Length of largest pygidium 2.4 mm., width 6 mm.

Discussion.—This trilobite, obviously a very close relative of *Aphe-*

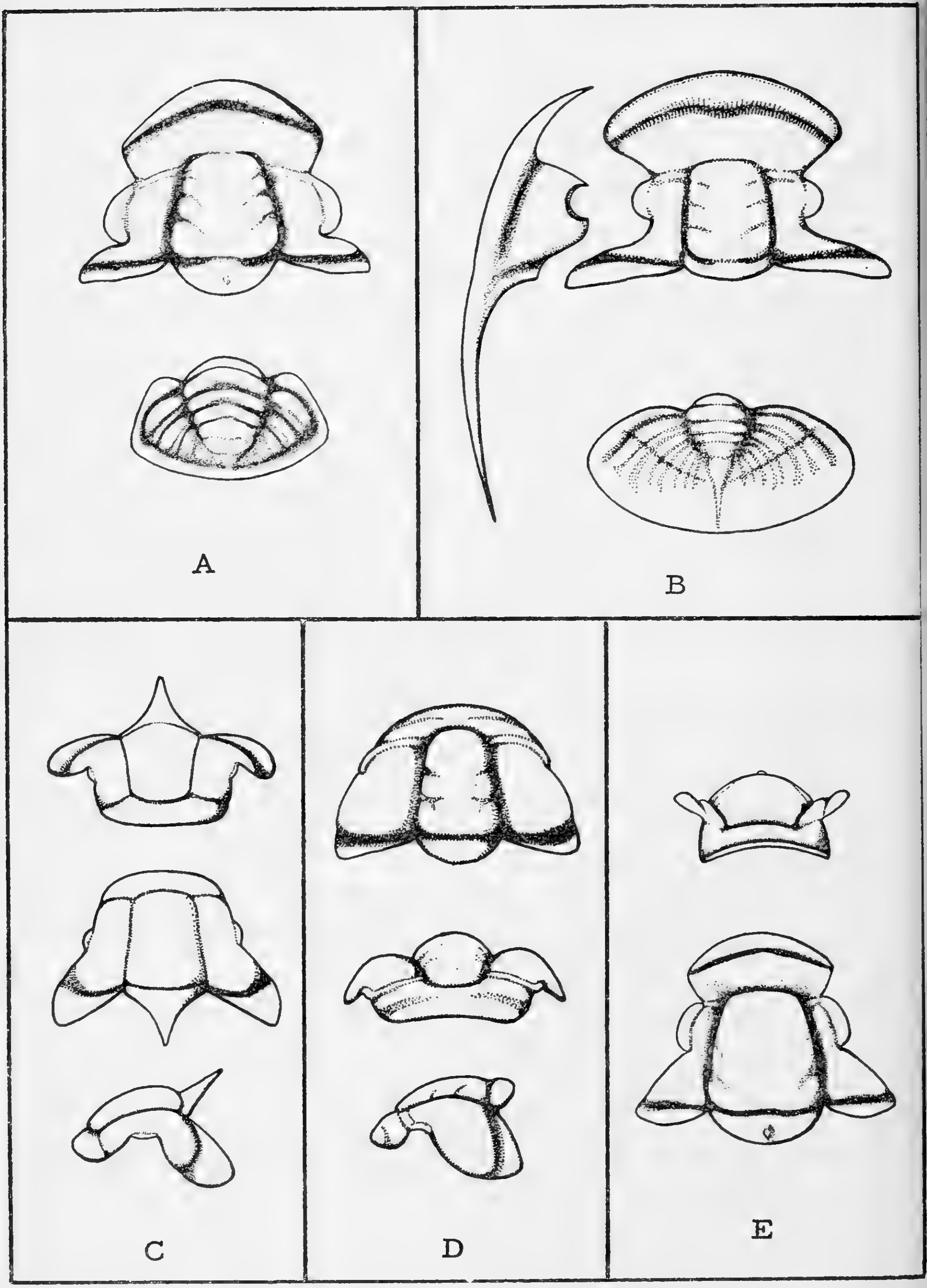

FIG. 2.—A, *Dytremacephalus angulatus* Rasetti, n. sp. Cranidium, pygidium. B, *Aphelaspidella macropyge* Rasetti, n. gen., n. sp. Cranidium, free cheek, pygidium. C, *Loxoparia obliqua* Rasetti, n. gen., n. sp. Frontal, dorsal, and lateral views of cranidium. D, *Hawkinsia minuta* Rasetti, n. gen., n. sp. Dorsal, frontal, and lateral views of cranidium. E, *Paraphelaspis vigilans* Rasetti, n. gen., n. sp. Frontal and dorsal views of cranidium.

laspis, seems best referred to *Dytremacephalus,* although the palpebral area is wider than in *D. granulosus* and the palpebral lobe larger and more posterior in position. The frontal and palpebral areas are more like *D. laevis* Palmer (1954). In Nevada, Palmer (1965) finds two species of *Dytremacephalus* in the lower part of the *Dunderbergia* zone. In view of the somewhat questionable assignment of the present species to the genus, this fact should not be attributed much significance for correlation. *Dytremacephalus angulatus* differs from all species of *Aphelaspis* in the deep axial furrows, more posterior position of the eyes, granulate surface, and shortness of the genal spine.

One should also note the considerable similarity of the cranidia of this trilobite to *Acrocephalaspis fidus* Ivshin (1956) from Kazakhstan, where it occurs in association with *Aphelaspis,* and hence may be taken to be approximately of the same age as the present species. Unfortunately Ivshin's material includes only cranidia. Ivshin compared *Acrocephalaspis* with *Acrocephalites,* but, judging from the illustrations, his new genus seems very close to *Aphelaspis.* It is also possible that *Aphelaspis* and *Acrocephalites* are closely related.

Occurrence.—Mainly characteristic of the uppermost portion of the *Aphelaspis* zone in Tennessee, usually associated with *Aphelaspis tarda.* The type locality is cnw/14, Shields Ridge. Also present in collections cnw/1, cnx/1, cnv/15, and U.S.G.S. 2969. A single specimen was found in the collection cnt/4, from somewhat lower beds here assigned to the upper portion of the middle *Aphelaspis* zone.

Types.—Holotype: U.S.N.M. 144686. Paratypes: U.S.N.M. 144687–9.

DYTREMACEPHALUS SULCIFRONS Rasetti, new species

Plate 12, figures 23–25

Available material.—Two cranidia from different localities.

Description.—Cranidium as a whole and glabella with greater longitudinal convexity than in preceding species. Glabella with 2 fairly deep pairs of lateral furrows, a third pair very short and shallow, more rounded anteriorly than in *D. angulatus.* Shallow portion of axial furrow shorter than in preceding species. Palpebral area, palpebral lobes, and course of facial sutures as in *D. angulatus.* Surface ornamentation of the same type. Length of cranidium 6 mm.

Discussion.—The differences from *D. angulatus* were pointed out in the description. This may be an extreme case of variation within that species; however, in the absence of intermediate forms, it is described as a representative of an associated, rare species. It resembles the type species of the genus.

Occurrence.—The holotype is from collection cnw/14, Shields Ridge; the paratype from collection cnx/1, Big Creek.

Types.—Holotype: U.S.N.M. 144690. Paratype: U.S.N.M. 144691.

DYTREMACEPHALUS STRICTUS Rasetti, new species

Plate 21, figures 10–13

Available material.—Several cranidia and one tentatively assigned pygidium.

Description.—Glabella as in *D. angulatus,* defined by a deeper furrow in front. Occipital ring unusually short (sag.), set off by a deep occipital furrow, bearing a small node. Pits at anterior corners of glabella marked in some individuals. Preglabellar field convex longitudinally, somewhat shorter than in *D. angulatus;* border furrow not distinctly angulate as in that species; border somewhat less elevated. Palpebral area somewhat convex, upsloping, from one-third to one-half the glabellar width; ocular ridges slightly slanted backward. Palpebral lobe, posterior area, and facial sutures as in *D. angulatus.* Granulation of surface rather indistinct.

The pygidium tentatively assigned to the species is proportionately shorter and wider than *D. angulatus* and has fewer segments both in the axis and the pleural lobes.

Discussion.—The species was compared in the description with *D. angulatus,* from which the cranidium differs essentially in the proportionately larger glabella. As it appears from the illustrations, considerable variation occurs among the specimens, all from one small piece of rock.

Occurrence.—Locality U.S.G.S. 2970, Vonore quadrangle, Monroe County, in association with *Aphelaspidella macropyge, Aphelaspis palmeri,* and other species.

Types.—Holotype: U.S.N.M. 144692. Paratypes: U.S.N.M. 144693.

PTYCHOPARIIDA OF UNCERTAIN AFFINITIES

Genus BONNETERRINA Lochman, 1936

Type species.—*Bonneterrina prima* Lochman.

BONNETERRINA APPALACHIA (Walcott)

Plate 2, figures 10–18

Lonchocephalus appalachia Walcott, part, 1916a, p. 190, pl. 35, figs. 6, 6a, 6c.
Lonchocephalus appalachia Walcott, Resser, 1938a, p. 86, pl. 10, fig. 30.
Bonneterrina appalachia (Walcott) Palmer, 1954, p. 726, pl. 80, fig. 9.

The species is one of the most common and readily recognizable fossils of the uppermost beds of the Maryville formation in the Rogersville area. A considerable amount of variability is present in the cranidia; since the various forms intergrade and occur in the same bed, it would be improper to split the species, even though the extremes in the range of variation might suggest such action.

The main variable features are the convexity of the glabella and the entire cranidium; the depth of the axial furrow; the direction of the occipital spine, varying from almost horizontal to upturned at 45 degrees; the distinctness of the occipital furrow; the relative width and convexity of the anterior border. The figured cranidia show some of these features. The largest cranidium has a length of 15 mm. exclusive of the spine.

The pygidium, although less common than the cranidium, can be assigned with virtual certainty. It is about twice as wide as long, regularly rounded posteriorly. Axis occupying almost entire length, tapered, with 3 prominent rings and a terminal section, bearing a large upright spine on the first ring. Pleural lobes convex and downsloping, with 3 pairs of broad pleural furrows and 2 pairs of narrower interpleural grooves, all reaching almost to the margin; border furrow shallow, border narrow, poorly defined. Length of largest pygidium 9 mm., width 18 mm.

The pygidium closely resembles that of *Shickshockia cristata* (Rasetti, 1946), and the cranidium also has similar features. It is questionable whether *Shickshockia* should be maintained as a distinct genus.

Occurrence.—Uppermost beds of Maryville and basal beds of Nolichucky formation (*Cedaria* zone). Type locality is U.S.N.M. 123a, 4 miles NE. of Rogersville. Collected by the author at localities cnc/1 to cnc/6 in the Maryville limestone and localities cnd/1, cnd/2 in the red beds of the Nolichucky.

Types.—Holotype: U.S.N.M. 61719. Paratypes: U.S.N.M. 61721, 61722. Plesiotypes: U.S.N.M. 144703–6.

Genus CHEILOCEPHALUS Berkey, 1898

Type species.—*Cheilocephalus stcroixensis* Berkey.

CHEILOCEPHALUS BREVILOBUS (Walcott)

Plate 17, figures 1–5

Lisania? breviloba Walcott, 1916b, p. 404, pl. 66, figs. 3–3c.
Pseudolisania breviloba (Walcott) Kobayashi, 1935, p. 162.
Pseudolisania breviloba (Walcott) Resser, 1938a, p. 96, pl. 16, fig. 17.
Cheilocephalus breviloba (Walcott) Palmer, 1954, p. 759, pl. 88, figs. 1–4 (includes complete synonymy up to 1954).
Cheilocephalus brevilobus (Walcott) Lochman and Hu, 1962b, p. 436, pl. 69, figs. 1–24.

The species is common in the basal beds of the *Aphelaspis* zone in Tennessee. The largest cranidium observed has a length of 20 mm. and a width between the tips of the posterior area of 40 mm. The largest pygidium has a length of 21 mm. and a width of 34 mm.

The free cheek has never been described. Fragments are common in association with other parts of the exoskeleton, but it is difficult to prepare good specimens. The free cheek has a concave border not differentiated from the ocular platform by a furrow. The facial suture cuts the posterior margin very close to the genal angle. This is extended into a short, flat, triangular genal spine. Hence the suture does not have a proparian course, as some authors have conjectured.

Occurrence.—The types are from an unspecified horizon in the Nolichucky formation at U.S.N.M. locality 118a, near Greeneville, Greene County. Collected by the author at localities cno/14, cnp/14, cnq/14, cnp/17.

Types.—Holotype: U.S.N.M. 62852. Paratypes: U.S.N.M. 62853–4. Plesiotypes: U.S.N.M. 144707–8.

CHEILOCEPHALUS BRACHYOPS Palmer

Plate 17, figures 6–11

Cheilocephalus brachyops Palmer, 1965, p. 105, pl. 1, figs. 12–15, 17.

A species of *Cheilocephalus* that occurs in the upper *Aphelaspis* zone fully agrees in all characters of cranidium and pygidium with the species, described from the *Dunderbergia* zone in Nevada.

Occurrence.—Collections cnx/1, Big Creek, and cnw/14, Shields Ridge.

Types.—Plesiotypes: U.S.N.M. 144709–10.

CHEILOCEPHALUS, species undetermined

Plate 17, figures 12–14

Rare specimens of *Cheilocephalus* that occur in the middle portion of the *Aphelaspis* zone possess a frontal area short as in *C. brachyops,* but flat and lacking the raised border of that species. The surface shows indistinct ornamentation. The pygidium is like both *C. brevilobus* and *C. brachyops.* A close comparison is made uncertain by the fact that all the specimens in question are small and obviously immature. Hence it will be left undecided whether this form should be assigned to a new species.

Occurrence.—The figured specimens are from locality cnr/4, Lost Creek. Also present in collections cns/4, cns/2, and U.S.G.S. 2970.

Disposition of material.—Figured specimens: U.S.N.M. 144711.

Genus COENASPIS Resser, 1938

Type species.—Coenaspis spectabilis Resser.

COENASPIS SPECTABILIS Resser

Plate 5, figures 1–3

Coenaspis spectabilis Resser, 1938a, p. 69, pl. 16, fig. 9.

The only new information about this rare trilobite is its stratigraphic position.

Occurrence.—Beds of the lower *Cedaria* zone at the top of the Maryville formation. The type locality is U.S.N.M. 123a, near Rogersville. One cranidium was collected by the writer at locality cnc/3, close to or identical with the preceding.

Types.—Holotype: U.S.N.M. 94978.

Genus HAWKINSIA Rasetti, new genus

Description.—Very small trilobites. Cranidium subtrapezoidal, rather convex. Glabella moderately convex, defined by deep axial furrow, tapered, with short, shallow lateral furrows. Occipital furrow deep, occipital ring simple. Frontal area short (sag.), convex and downsloping, barely differentiated into preglabellar field and border. Ocular ridges well marked, subtransverse, curved. Palpebral area convex, as wide as glabella; palpebral lobes small and inconspicuous, situated far in advance of glabellar midpoint. Posterior area large, deeply furrowed. Facial sutures showing little change of direction between anterior and posterior section in dorsal view; in lateral view there is a marked angle. Anterior sections convergent, curving inward, rounding off the anterior cranidial outline. Posterior section first running outward and backward, gradually curving backward and finally slightly inward, giving the cranidium a sharp posterolateral angle.

Type species.—Hawkinsia minuta Rasetti, n. sp.

Discussion.—Although the known specimens of the type species are quite small, the fact that they are all about the same size suggests that they are not immature. In any case, *Hawkinsia* could not be the immature form of any of the larger trilobites known from the same beds. No plausible affinities of the genus can be suggested. The name is derived from Hawkins County, where the type species occurs.

Occurrence.—Upper Cambrian (*Cedaria* zone) of the southern Appalachians.

HAWKINSIA MINUTA Rasetti, new species

Plate 3, figures 22–25

Available material.—Several cranidia preserved in limestone.

Description.—The generic description includes most of the known characters of the species. The glabella shows 2 pairs of short, rather shallow lateral furrows; those of the posterior pair show a tendency to bifurcate. The occipital ring is rounded, lacking spine or node. The frontal area is divided about equally into preglabellar field and border by an excessively shallow furrow, which becomes obsolete medially. The surface of the test is very finely granulate. Length of holotype cranidium 2.2 mm., width at posterior end 3.3 mm.

Occurrence.—Uppermost beds of the Maryville limestone (*Cedaria* zone) at locality cnc/1.

Types.—Holotype: U.S.N.M. 144712. Paratypes: U.S.N.M. 144713.

Genus ITHYCEPHALUS Resser, 1939

Type species.—Ithycephalus typicalis Resser.

ITHYCEPHALUS TYPICALIS Resser

Plate 1, figures 10–12

Ithycephalus typicalis RESSER, 1938a, p. 82, pl. 9, fig. 10.

A perfect cranidium of this rare species is figured.

Occurrence.—Type locality U.S.N.M. 27d; red beds at the base of the Nolichucky (*Cedaria* zone) east of Rogersville. The figured specimen is from the same beds and locality (author's locality cnd/1). One specimen was also collected from the underlying uppermost beds of the Maryville limestone (loc. cnc/1).

Types.—Holotype: U.S.N.M. 94841. Plesiotype: U.S.N.M. 144714.

Genus MODOCIA Walcott, 1924

Type species.—Arionellus (Crepicephalus) oweni Meek and Hayden.

Three genera have been considered synonyms of *Modocia: Armonia* Walcott, 1924 (type species, *Armonia pelops* Walcott); *Metisia* Resser, 1937 (type species, *Ptychoparia metisensis* Walcott); and *Semnocephalus* Resser, 1942 (type species, *Solenopleura? weedi* Walcott (part)).

A question arises concerning the status of the genus *Syspacheilus* Resser, 1938 (type species, *Syspacheilus typicalis* Resser). Palmer (1954) discussed the problem of assigning a pygidium to *Syspacheilus.* He attributed to cranidia identified as *Syspacheilus camurus* Lochman pygidia indistinguishable from *Coosella.* Lochman and Hu (1961) attributed to *S. dunoirensis* (Miller) and a new species, *Syspacheilus praecedens,* short pygidia of the generalized ptychoparioid type.

The latter assignment seems unquestionable, in view of the abundance of the material and of the almost identical association of cranidia and pygidia observed by the author in other areas. Then, if Palmer's pygidium is correctly attributed, we must conclude that there are two genera of trilobites with indistinguishable cranidia and very different pygidia, not an unusual situation. In that case it would be impossible at present to decide which one is *Syspacheilus,* since there is no reliable assignment of a pygidium to the type species.

Whatever the solution of this problem may be, the author sees no reason to maintain the use of *Syspacheilus* for the species with a short pygidium, typified by *Syspacheilus praecedens,* which are almost identical with *Metisia metisensis* (Rasetti, 1963). If these forms are sufficiently distinct from *Modocia oweni* to warrant generic recognition, then they should be referred to *Metisia* accepted as a valid genus. Possibly the same arguments apply to *Talbotina* (at least as represented by *T. juweli* Lochman, in Lochman and Duncan, 1944) and *Ithyektyphus* Shaw (1956), (Lochman and Hu, 1960).

In conclusion, it seems best at present to restrict the use of *Syspacheilus* to the type species until the characters of the genus are clarified.

MODOCIA DUBIA (Resser)

Plate 1, figures 22–26

Asaphiscus? agatho Walcott (part), 1916b, p. 391, pl. 63, fig. 9a (only).
Ehmania dubia Resser, 1938a, p. 75, pl. 9, figs. 18, 19.
Uncaspis tennesseensis Resser, 1938a (part), p. 105, pl. 9, fig. 21 (only).

Three species of *Modocia* are common in the red beds at the base of the Nolichucky, and two of them were also collected at various localities in the underlying beds of the Maryville formation. Through association in several instances it was possible to obtain an unambiguous assignment of the pygidia to the respective cranidia.

Description.—Entire cranidium of moderate convexity. Glabella moderately convex, proportionately wide and short, strongly tapered, rounded in front, bearing a trace of furrows on outer surface. Preglabellar field flat; border not greatly elevated or convex, about as wide (sag.) medially as the preglabellar field. Palpebral area slightly convex and downsloping; ocular ridges faint; palpebral lobes one-third the glabellar length, placed about parallel to the axial furrow, defined by a sharp palpebral furrow, situated well in advance of glabellar midpoint. Posterior area long (exsag.), deeply furrowed. The anterior sections of the facial sutures are barely divergent. The surface of the test is densely and finely granulate. Length of larger cranidia 12 mm.

Pygidium twice as wide as long. Axis stout and prominent, showing two distinct rings, and in some specimens a less distinct third ring, plus a terminal section, almost reaching posterior margin. Pleural regions of low convexity, with almost equally deep pleural furrows and interpleural grooves, curving back distally and almost reaching the margin. Border furrow and border almost indistinct. Length of a large pygidium 6.5 mm., width 13 mm.

Discussion.—This form differs from the type species in many details of the cranidium, such as the lesser prominence of the glabella, lesser divergence of the anterior sections of the facial suture, and more anterior position of the eyes.

Occurrence.—The type locality is U.S.N.M. 27d; red beds at the base of the Nolichucky (*Cedaria* zone) near Rogersville. Collected by the author at the same locality (cnd/1) and also in the uppermost beds of the underlying Maryville limestone (localities cnc/1 to cnc/6).

Types.—Holotype and paratypes: U.S.N.M. 94845. Paratype of *Asaphiscus ? agatho:* U.S.N.M. 62820. Paratype of *Uncaspis tennesseensis:* U.S.N.M. 94846. Plesiotypes figured herein: U.S.N.M. 144715–6.

MODOCIA BIDENTATA Rasetti, new species

Plate 1, figures 13–21

Available material.—Numerous cranidia and pygidia in limestone.

Description.—Glabella rather convex, rising above the cheeks, relatively narrow and long, unfurrowed. Occipital furrow well marked; occipital ring short, simple. Frontal and palpebral areas downsloping; preglabellar field longer (sag.) than border width; border well defined, slightly convex, tapered in width at the sides. Palpebral area about half the glabellar width; ocular ridges faint; palpebral lobes located somewhat in advance of glabellar midpoint. Anterior sections of facial suture somewhat divergent; posterior section curving backward, producing blunt posterior area.

Pygidium of same general proportions as in preceding species, not greatly convex transversely. Axis as in preceding species. Pleural regions with pleural furrows and interpleural grooves of progressively decreasing strength. First pleural segment extended into a pair of short, backward-directed marginal spines.

Surface of test smooth. Length of largest cranidium 17 mm. Length of largest pygidium 8.5 mm., width 17 mm.

Discussion.—The cranidial proportions are fully typical of *Modocia.* The chief distinguishing feature is the pair of short pygidial spines. This character is not uncommon in several genera of late Medial Cambrian and Dresbachian ptychoparioid trilobites, e.g., in species of *Ehmaniella.*

Occurrence.—Red beds at the base of the Nolichucky (*Cedaria* zone) E. of Rogersville (locality cnd/1).

Types.—Holotype (pygidium): U.S.N.M. 144717. Paratypes: 144718.

MODOCIA CRASSIMARGINATA Rasetti, new species

Plate 2, figures 1–9

Available material.—Numerous cranidia and pygidia well preserved in limestone.

Description.—Glabella rather plump, defined by a deep axial furrow, rounded in front, unfurrowed; occipital furrow well impressed, occipital ring simple. Preglabellar field downsloping, short (sag.), on the average shorter than the border width (sag.), although there is variability in this character. Border convex, wide (sag.). Ocular ridges faintly indicated; palpebral lobes narrow, defined by a shallow palpebral furrow, about 0.3 times the glabellar length, somewhat in advance of level of glabellar midpoint. Palpebral area convex, on average downsloping, 0.4 times the glabellar width. Anterior sections of facial suture somewhat divergent, curving inward after crossing the border furrow, rounding off the anterior cranidial angles. Posterior section first directed outward, curving backward, rounding off the extremity of the posterior area which is deeply furrowed.

Pygidium with a stout, barely tapered, well-rounded axis showing 3 rings and a terminal section, not reaching the margin. Pleural regions transversely downsloping and convex longitudinally, showing 3 pairs of well-impressed furrows and 2 pairs of slightly shallower interpleural grooves, all fading out toward the margin without the presence of any defined border furrow or border.

Surface of test with inconspicuous ornamentation. Some of the cranidia show a punctate surface, the puncta being small and so dense as to produce the effect of a fine granulation; other cranidia appear almost smooth. Pygidia where the test is preserved show a very fine granulation.

Length of the largest cranidia 17mm. Length of largest pygidium 6.5 mm., width 14 mm.

Discussion.—Species of this type were assigned to *Syspacheilus* (see discussion of *Modocia*); for example, the present form does not seem to differ greatly from *Syspacheilus camurus* Lochman (1940), *S. dunoirensis* (Miller), as figured by Lochman and Hu (1961), and *S. praecedens* Lochman and Hu (1961). From the latter two forms, where the pygidium is known, the present species differs in the more deeply furrowed pleural lobes. *Armonia pelops* Walcott is also close to the present species, but an accurate comparison is difficult since all the type material is more or less flattened. It would seem that *Armonia pelops* has a proportionately narrower glabella and a more nearly triangular pygidium. *Metisia metisensis* (Walcott) is almost identical in the proportions and convexity of all the cranidial parts, but the surface ornamentation is coarser, and the pygidium has a definite border and is not turned down marginally as in the present form.

Occurrence.—Uppermost beds of Maryville limestone (*Cedaria* zone). Type locality cnc/2; also common at localities cnc/1, cnc/3 to cnc/6. Also occurring in the red beds at the base of the Nolichucky at locality cnd/1.

Types.—Holotype: U.S.N.M. 144719. Paratypes: U.S.N.M. 144-720–23.

MODOCIA ? AGATHO (Walcott)

Plate 1, figures 27–30

Asaphiscus? agatho Walcott (part), 1916b, p. 391, pl. 63, fig. 9 (only).
Ehmania? agatho (Walcott) Resser, 1938b, p. 29.

Available material.—Walcott based the species on the holotype cranidium and assigned to it a pygidium on the same piece of limestone. The author's collections, however, indicate that the pygidium belongs to the more common, associated species *Modocia dubia.* A pygidium believed to belong to the species is present in the collection from the type locality. The author collected several cranidia and one pygidium.

Description.—Glabella of moderate convexity, fairly straight-sided, moderately tapered, rounded in front, with a bare trace of lateral furrows on outer surface. Occipital furrow well marked; occipital ring subtriangular, rounded. Frontal area downsloping, rather flat, divided into preglabellar field and border by a shallow furrow, not accompanied by much change in slope. Ocular ridges present; palpebral area convex, on average horizontal, one-third the glabellar width. Palpebral lobes 0.3 times the glabellar length, narrow, defined by shallow palpebral furrow, situated at the level of glabellar midpoint and hence more posterior in position than in the 3 preceding species. Anterior sections of facial suture definitely divergent; posterior section directed outward from palpebral lobe, curving backward distally; posterior area almost parallel-sided, rounded distally, deeply furrowed; surface smooth.

Pygidium tentatively assigned to the species 2.2 times as wide as long. Anterior margin fairly straight. Axis stout, not greatly tapered, showing 2 rings plus a terminal section. Pleural regions with little convexity, almost horizontal, showing several pairs of furrows and interpleural grooves; only the first pair of furrows fairly deep. All furrows and grooves extend to a shallow border furrow that sets off a slightly elevated border. Surface very finely granulate.

Length of largest cranidium 6 mm. Length of pygidium 3.5 mm., width 7.5 mm.

Discussion.—This species cannot be given a satisfactory generic assignment. The cranidium differs from typical *Modocia* in the lack of a convex anterior border, horizontal rather than downsloping palpebral area, more posterior position of the eyes, and parallel-sided rather than tapered posterior area. In all these features it closely resembles cranidia of *Marjumia typa*. However, if the pygidium is correctly assigned, it is rather indicative of *Modocia;* spinose pygidia of the *Marjumia* type were not recovered from the Maryville formation.

Occurrence.—The type locality is U.S.N.M. 123a, near Rogersville. Also collected by the author in the same area at localities cnc/2 to cnc/5. The species belongs to the lower *Cedaria* zone faunule of the uppermost Maryville limestone.

Types.—Holotype: U.S.N.M. 62819. Plesiotypes: U.S.N.M. 144-724–6.

Genus LOXOPARIA Rasetti, new genus

Description.—Cranidium subtrapezoidal, moderately convex. Glabella moderately convex, unfurrowed, rising above the cheeks, with slightly concave side outline, subtruncate in front, reaching the border. Occipital furrow well marked; occipital ring extended into spine. Frontal area flat, consisting only of border; border furrow present at the sides, merging with axial furrow medially. Palpebral area somewhat over half the glabellar width, convex, downsloping; ocular ridges barely distinct, strongly slanted; palpebral lobes short and narrow, inconspicuous, situated in advance of glabellar midpoint. Anterior sections of facial sutures directed forward from palpebral lobes, curving inward; anterior angles of cranidium widely rounded. Posterior section of facial suture directed outward and backward, fairly straight for half its course, then curving backward and finally somewhat inward. Posterior area of fixed cheeks large, downsloping, extending backward much farther than glabella, sharply pointed. Furrow on posterior area deep, first directed outward and then curving forward; posterior margin of posterior area straight, strongly slanted outward and backward.

Type species.—*Loxoparia obliqua* Rasetti, n. sp.

Discussion.—The shape of the glabella and frontal area are suggestive of *Llanoaspis* and related forms; however, the characters of the palpebral area, palpebral lobes, and course of the posterior section of the facial sutures are radically different. The affinities of this trilobite are obscure.

Occurrence.—Upper Cambrian (*Cedaria* zone) of the southern Appalachians.

LOXOPARIA OBLIQUA Rasetti, new species

Plate 3, figures 7–9

Available material.—Three cranidia preserved in limestone.

Description.—The generic description and the illustrations present all the observable characters of the species. The axial and border furrows are shallow on the outer surface. The occipital ring has a subtriangular shape, extending into a broad-based, short spine. Surface of test perfectly smooth. Length of largest cranidium 7 mm.

Occurrence.—Red beds at the base of the Nolichucky (*Cedaria* zone) at locality cnd/1.

Types.—Holotype: U.S.N.M. 144727. Paratypes: U.S.N.M. 144728.

UNDETERMINED TRILOBITES

Undetermined Cranidium No. 1

Plate 8, figure 29

Known from a single, incomplete specimen. Glabella large, rising well above the cheeks, almost straight-sided, strongly tapered, rounded in front. Occipital furrow deep and straight; occipital ring short (sag.), extended into an uptilted spine of unknown length. Posterior glabellar furrows fairly deep, bifurcated, with the shorter anterior branch transverse, the longer posterior branch turning backward. Two other pairs of lateral furrows short, the anteriormost one very shallow. Preglabellar field almost vanishing medially; border slightly convex, not greatly arched transversely. Palpebral area and lobe not preserved. Incomplete posterior area deeply furrowed, the furrow turning forward in the distal part. Surface covered with medium-sized granules. Length of cranidium, exclusive of occipital spine, 4 mm.

Although this trilobite cannot be referred to any described genus, the incomplete material does not warrant a new name. Possibly the nearest known forms are certain species of *Genevievella*.

Occurrence.—Uppermost beds of the lower limestone member of Nolichucky (*Crepicephalus* zone) at locality cnn/3.

Disposition of material.—Figured specimen: U.S.N.M. 144729.

Undetermined Cranidium No. 2

Plate 8, figure 19

Known from a single, incomplete specimen. Glabella very convex, defined by a deep axial furrow, strongly tapered to a pointed anterior end which is somewhat truncate. Surface of glabella mostly broken off; lateral furrows, if present, must have been very shallow. Occipital furrow broad and deep; occipital ring short (sag.), but extended into a very long, uptilted spine. Frontal area consisting of convex, downsloping, preglabellar field and elevated, convex, transversely arched border. Ocular ridges wide and fairly prominent, directed slightly forward from the glabella, curving slightly to assume a transverse direction. Palpebral area somewhat wider than glabella, rising above the axial furrow and strongly convex transversely. Palpebral lobes and posterior area not preserved. Surface of glabella and fixed cheeks covered with granules of different sizes. Length of cranidium 4.2 mm. exclusive of occipital spine.

This cranidium, remarkable for the pointed glabella, wide palpebral area, and forward-directed ocular ridges, cannot be assigned to any described genus. No affinities can be suggested, beyond its inclusion in the great ptychoparioid group.

Occurrence.—Lower portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnk/1.

Disposition of material.—Figured specimen: U.S.N.M. 144730.

UNDETERMINED PYGIDIUM NO. 1

Plate 6, figure 8

Known from a single example. Pygidium 2.5 times as wide as long. Axis prominent, tapered, showing 3 rings plus a terminal section, reaching the border furrow. Pleural region with a straight anterior outline, rounded anterior angles, and posterior margin fairly straight on either side, slightly pointed medially. Three pairs of rather deep pleural furrows and shallow interpleural grooves are present. Border furrow shallow, border very narrow.

This pygidium somewhat resembles the pygidia of *Llanoaspis,* differing in its shortness and small number of pleural furrows. No cranidium to which it may be assigned was collected from the same beds.

Occurrence.—Lower portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnk/1.

Disposition of material.—Figured specimen: U.S.N.M. 144731.

UNDETERMINED PYGIDIUM NO. 2

Plate 6, figures 20, 21

Known from several examples. Pygidium of low convexity, 1.75 times as wide as long. Axis long, tapered, straight-sided, extended into a sharp postaxial ridge that reaches the posterior margin. Seven or eight axial rings separated by shallow furrows are distinguishable. Pleural regions with straight anterior outline, well-rounded anterior angles, and regularly semicircular posterior margin except for a shallow median notch. Five pairs of shallow, broad pleural furrows end very sharply on the line corresponding to the margin of the doublure. The remaining portion of the pleural regions is smooth and flat or slightly concave. Surface of test smooth. Length of largest pygidium 6 mm., width 10.7 mm.

This pygidium may belong to *Coosia* or a related trilobite. It differs from the usual pygidia of *Coosia* in the great relative length of the axis. No corresponding cranidium was collected.

Occurrence.—Upper portion of lower limestone member of the Nolichucky (*Crepicephalus* zone) at locality cnm/2. One specimen was collected from the lower portion of the same limestone at locality cnk/1.

Disposition of material.—Figured specimens: U.S.N.M. 144732.

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EXPLANATION OF PLATES

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Figs. 1–4. *Coosella andreas* (Walcott) 48

1, Cranidium, ×4. 2–4, Dorsal, lateral, and posterior views of pygidium, ×4 (coll. cnc/2); U.S.N.M. 144572, plesiotypes.

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Figs. 10–12. *Ithycephalus typicalis* Resser 106

10–12, Dorsal, lateral, and anterior views of cranidium, ×5 (coll. cnd/1); U.S.N.M. 144714, plesiotype.

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1, 2, Dorsal and lateral views of exfoliated cranidium, ×3 (coll. cnd/1); U.S.N.M. 144614, holotype. 3, Exfoliated cranidia, ×3. 4, Free check, ×5. 5, Cranidium, ×5. 6, Exfoliated pygidium, ×10. 7, Exfoliated pygidium, ×8 (coll. cnd/1); U.S.N.M. 144615, paratypes.

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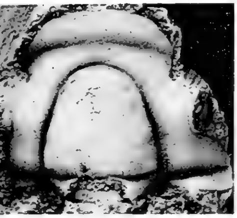
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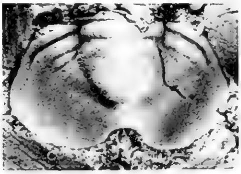
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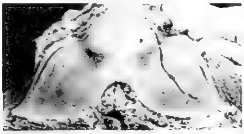
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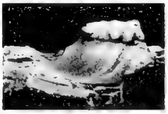
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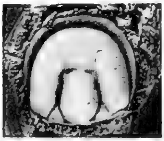
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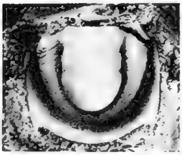
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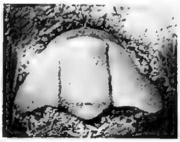
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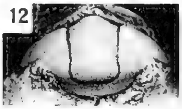
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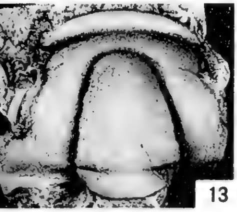
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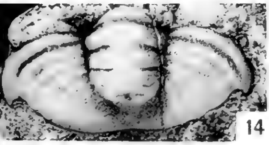
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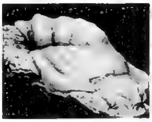
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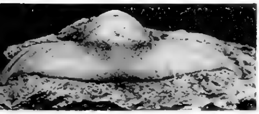
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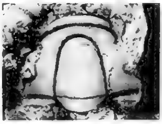
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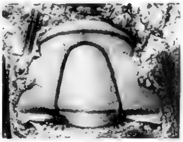
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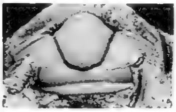
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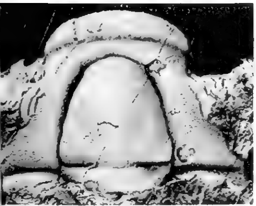
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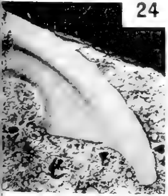
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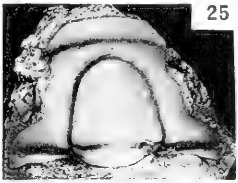
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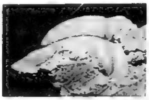
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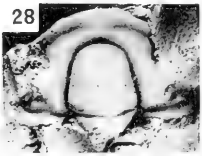
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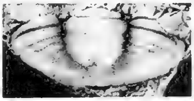
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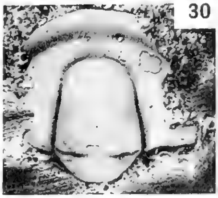
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TRILOBITES OF THE CEDARIA ZONE.

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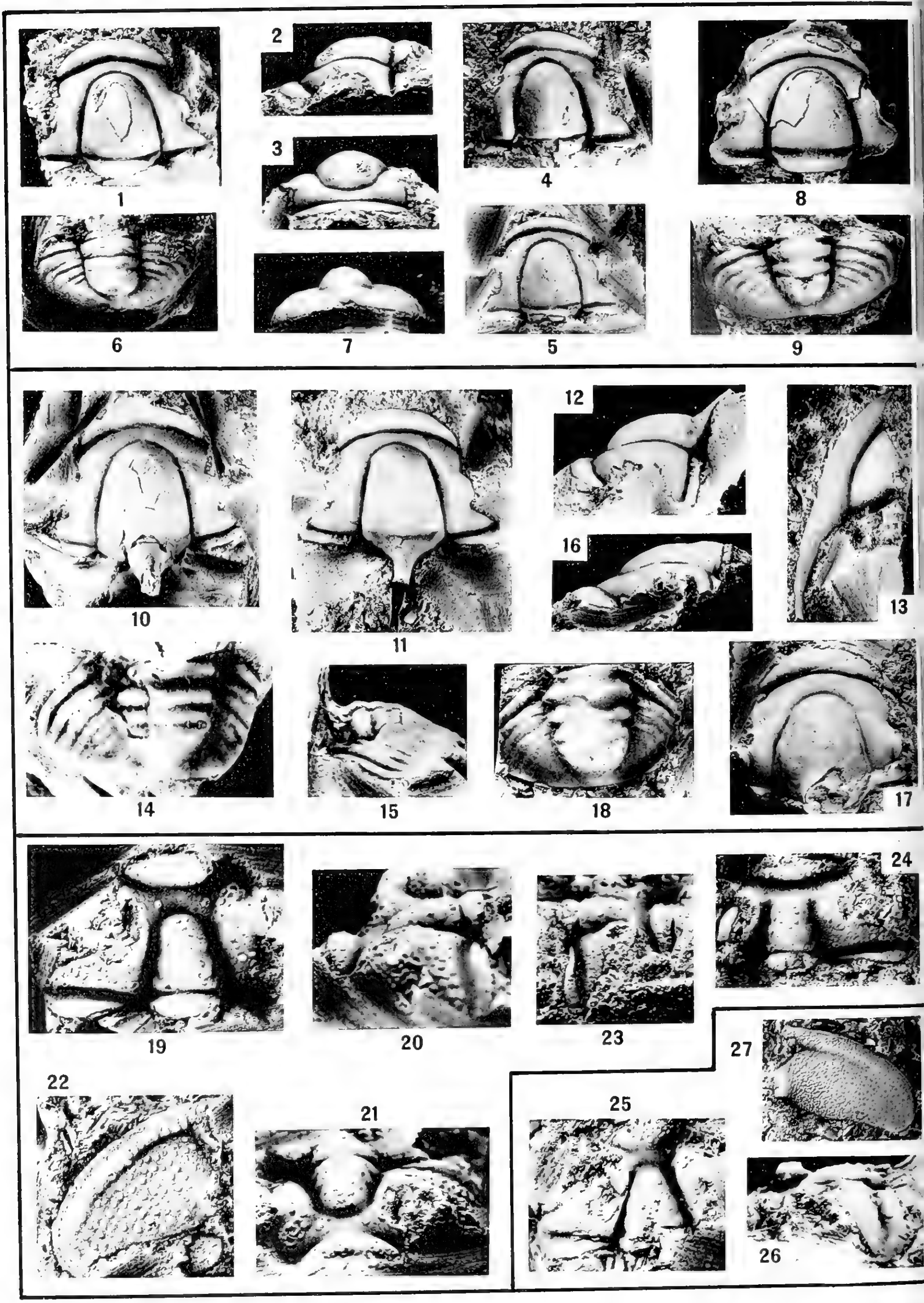

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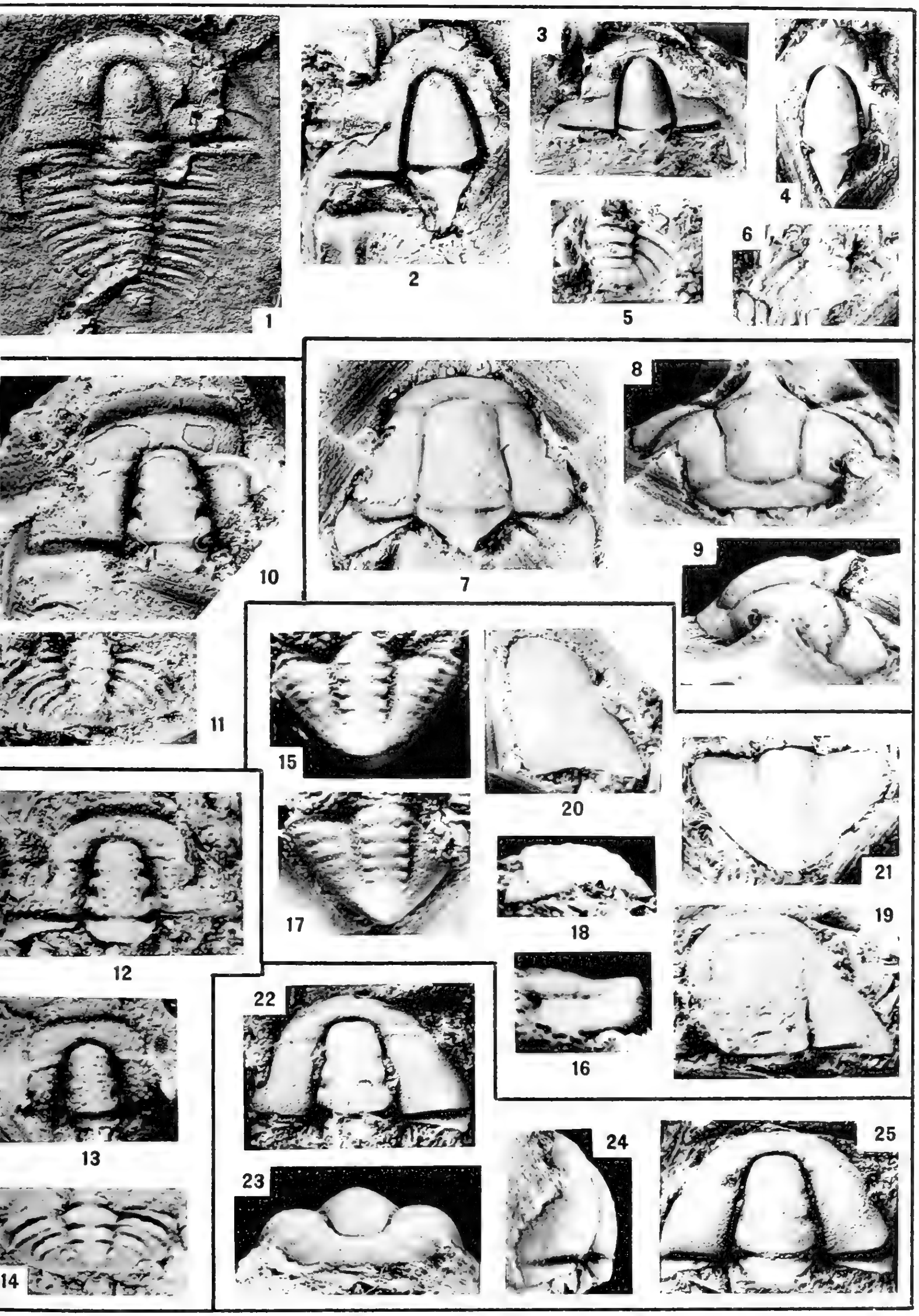

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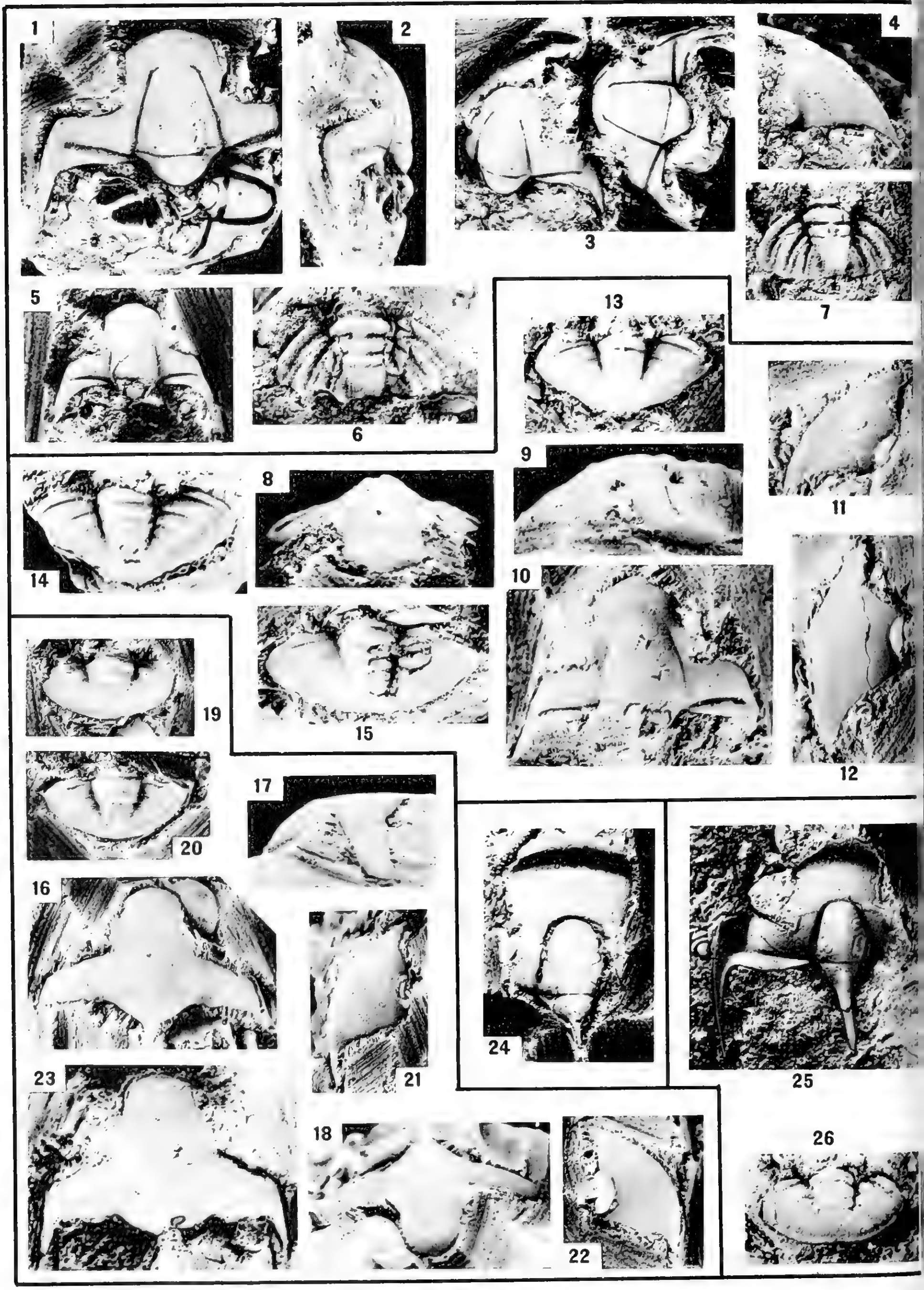

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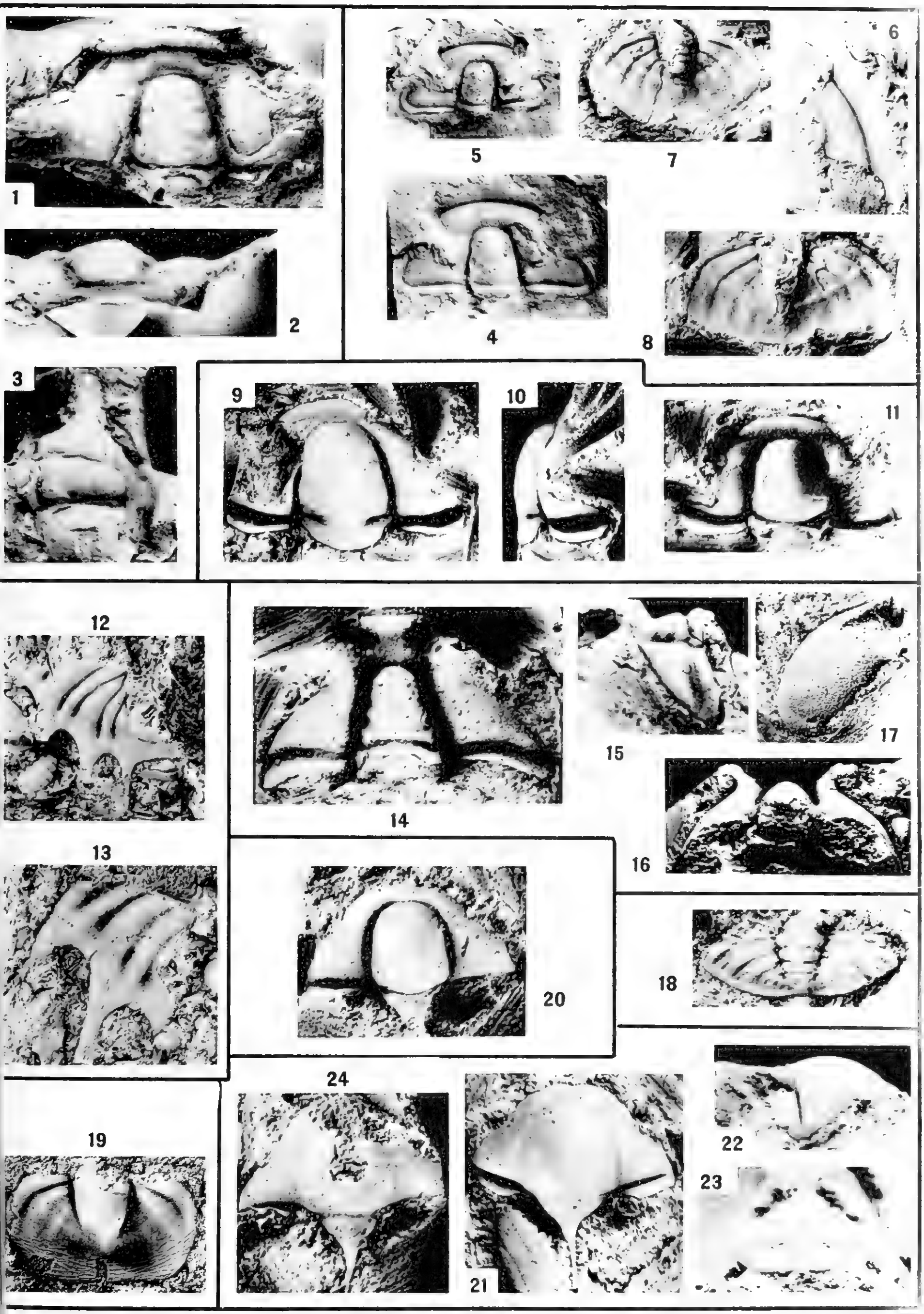

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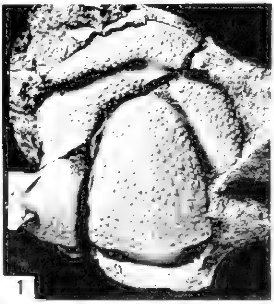
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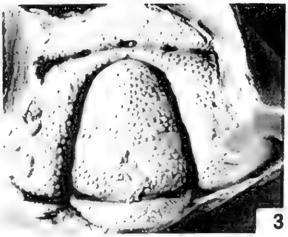
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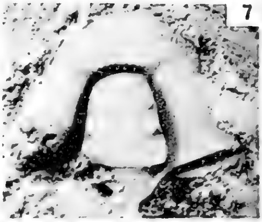
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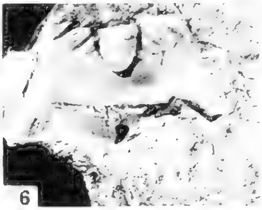
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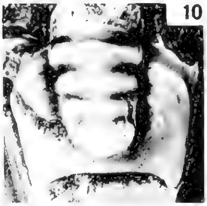
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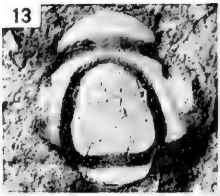
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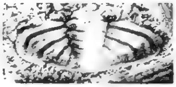
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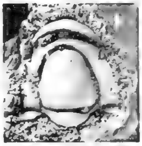
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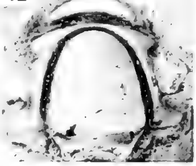
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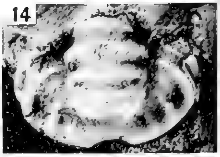
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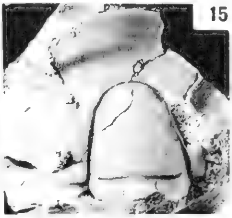
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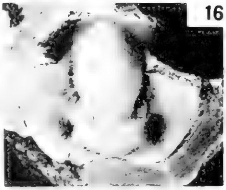
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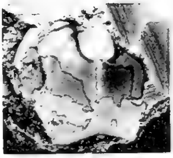
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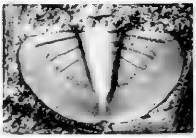
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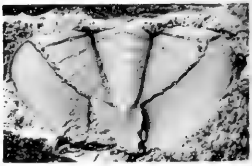
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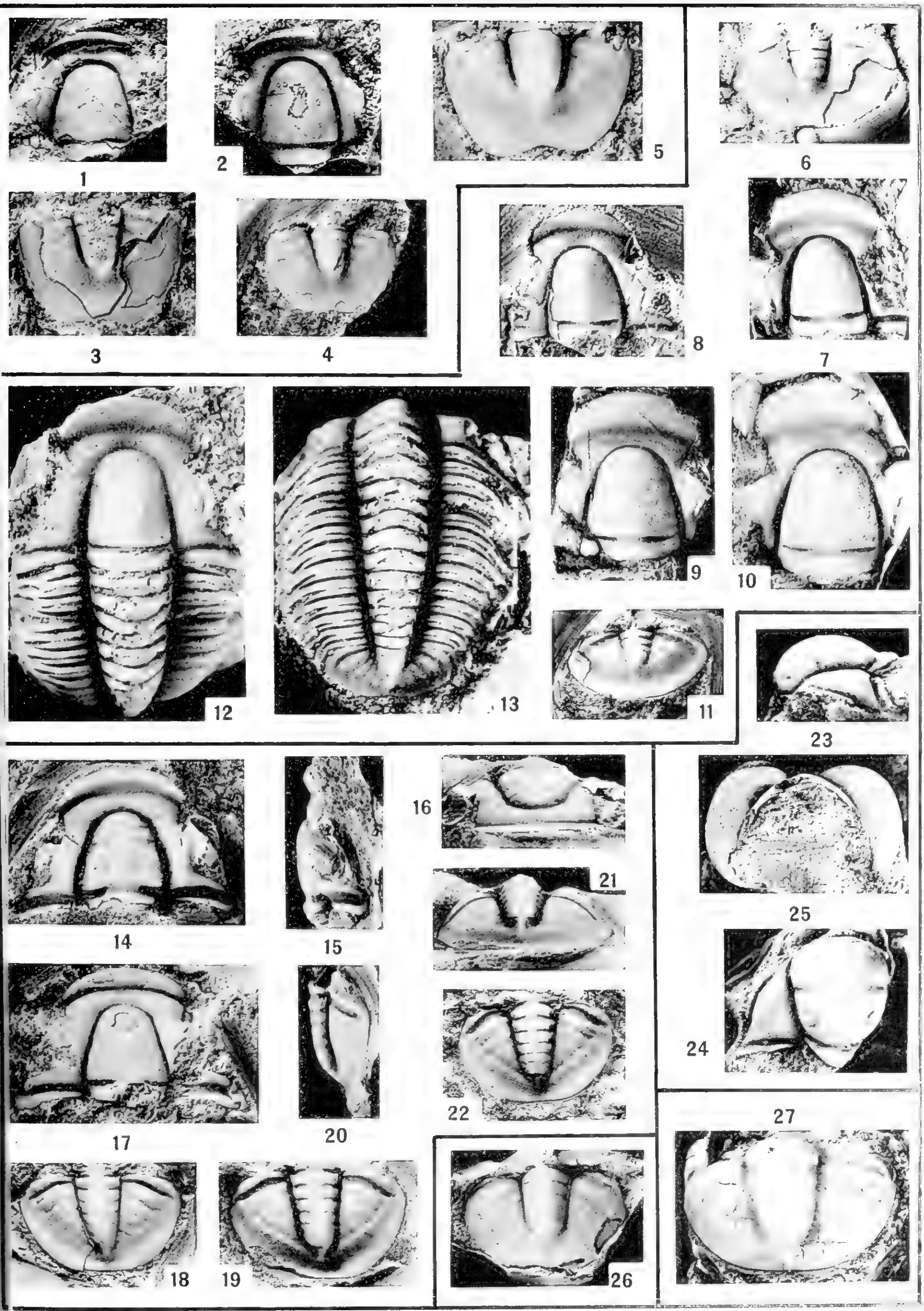

Trilobites of the Crepicephalus Zone.

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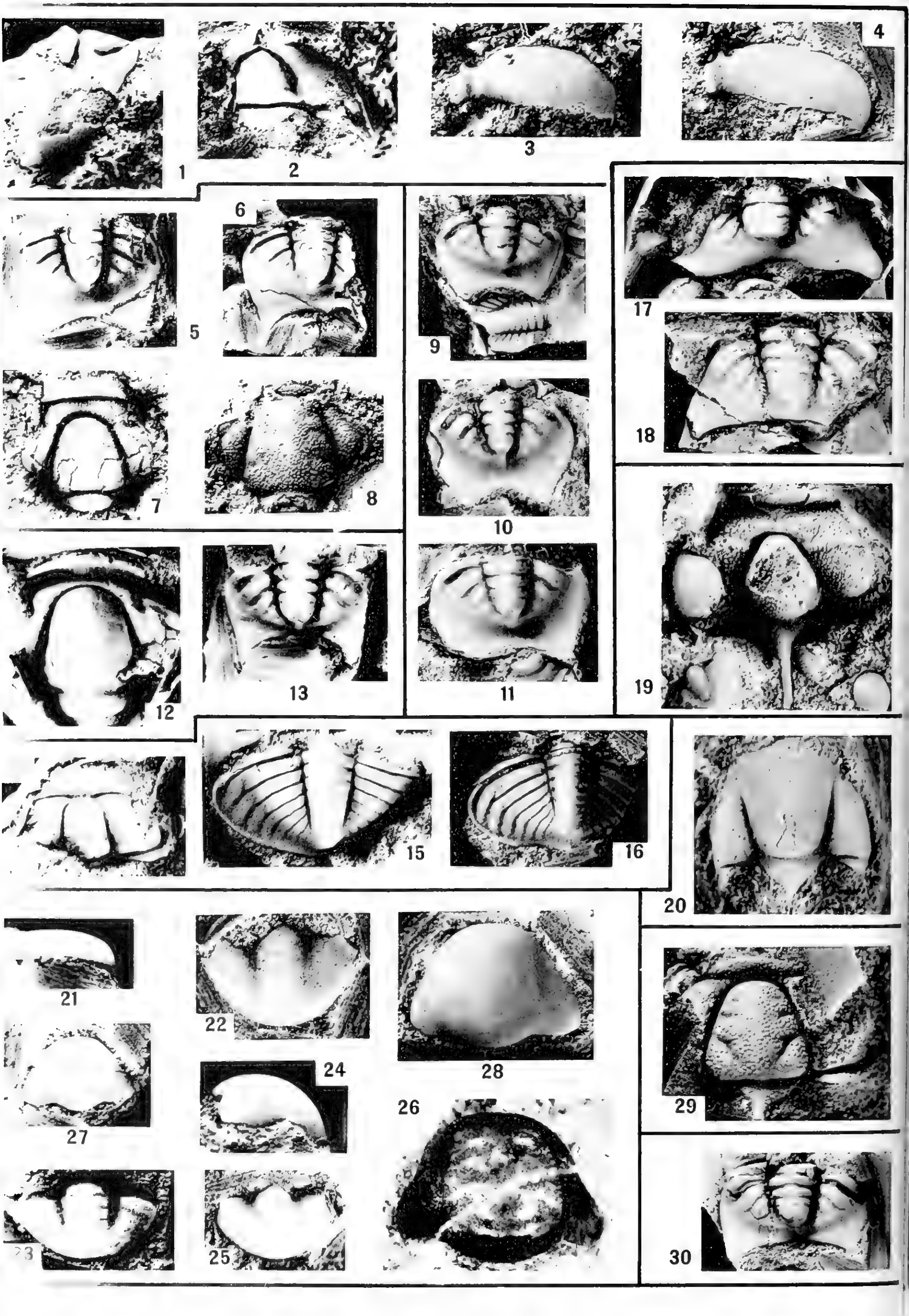

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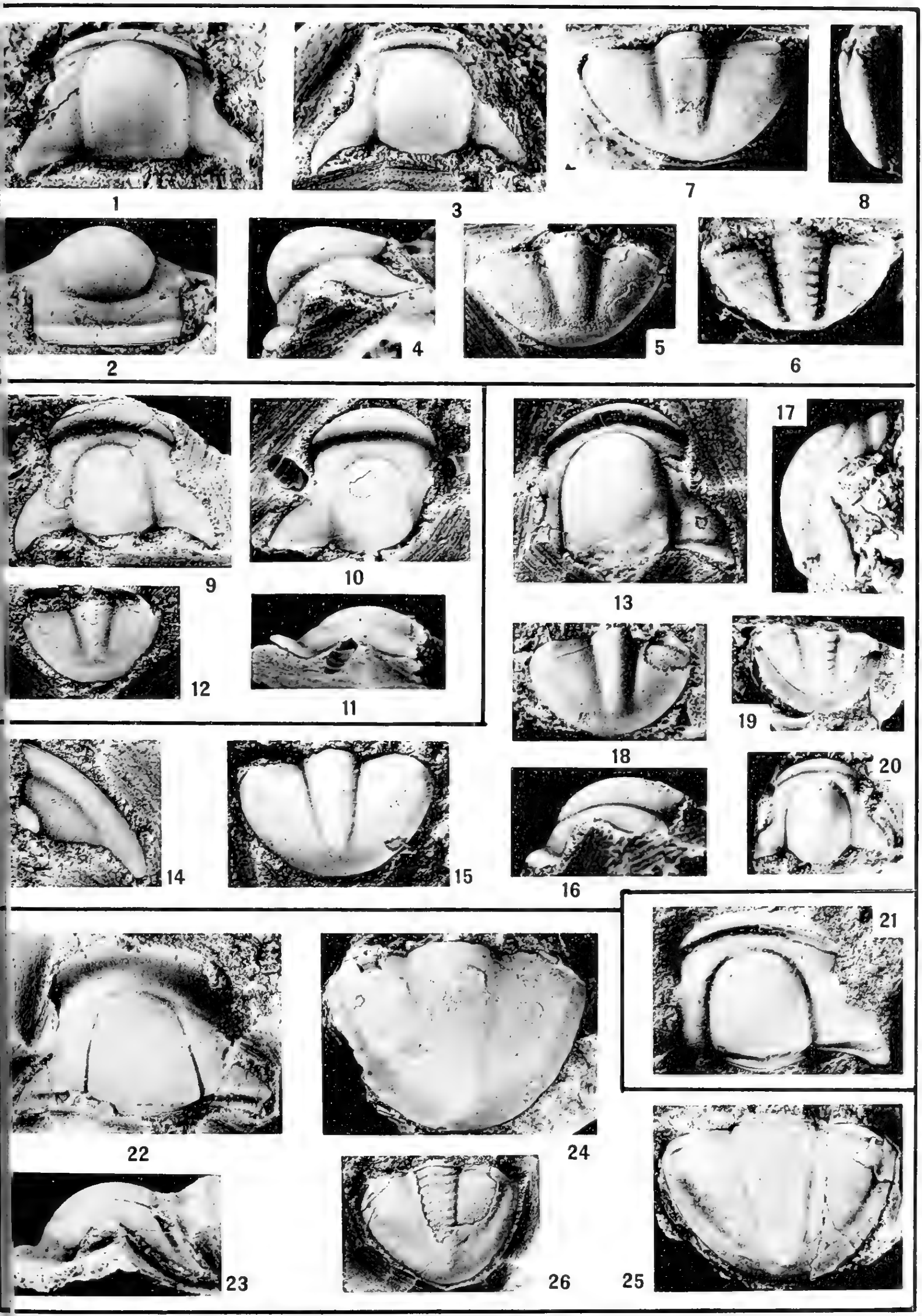

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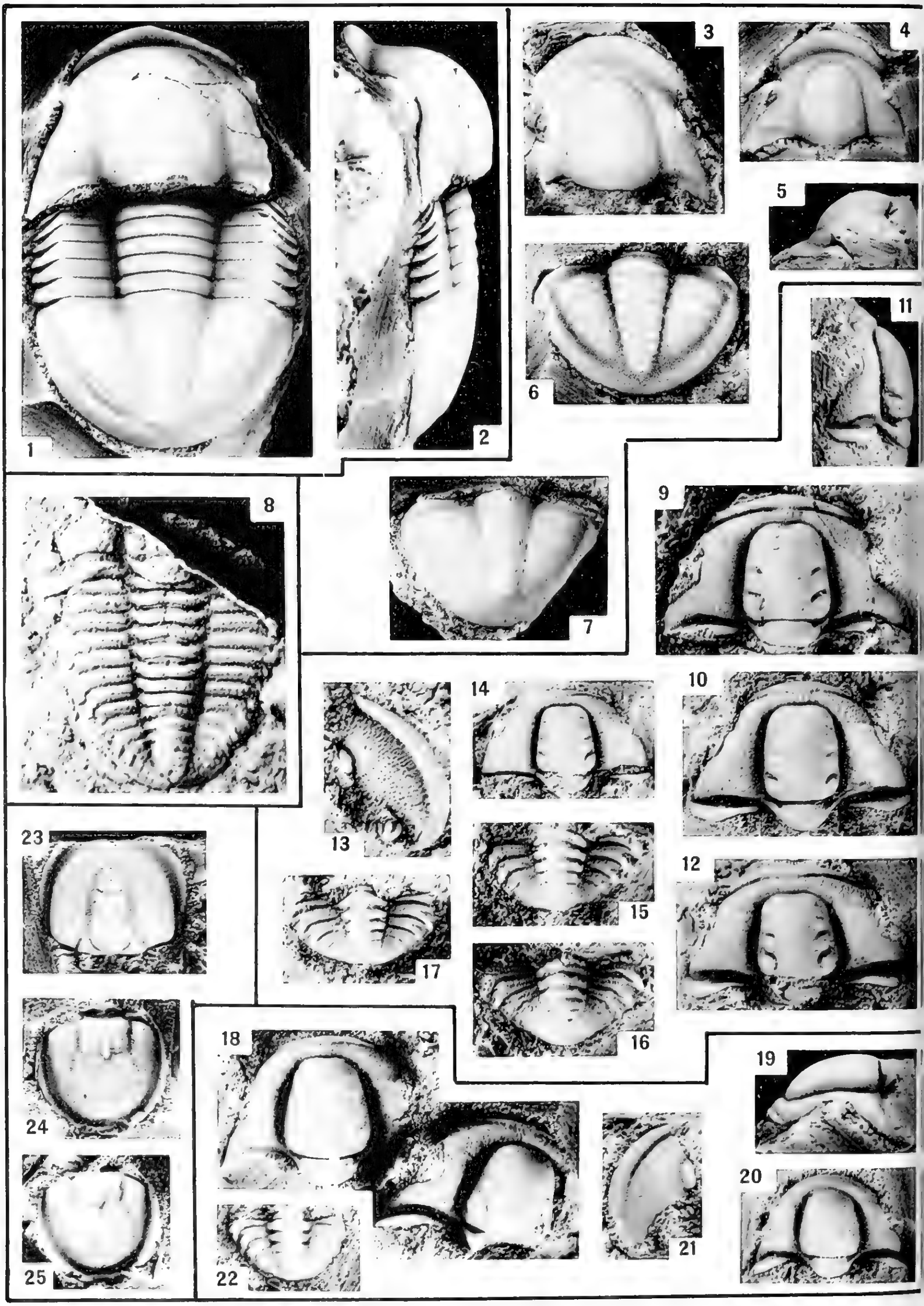

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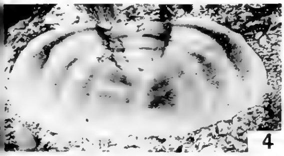
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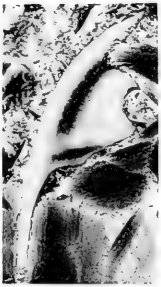
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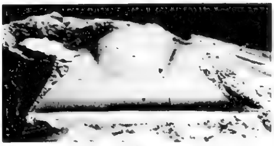
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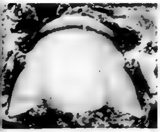
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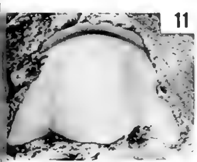
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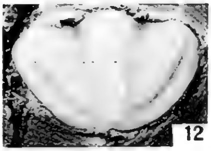
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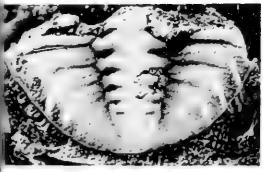
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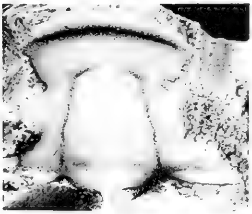
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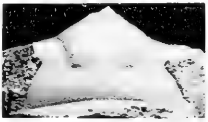
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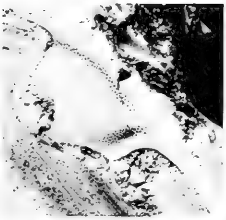
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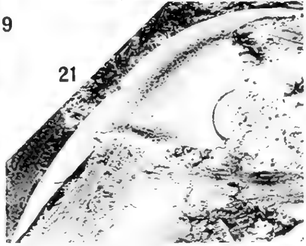
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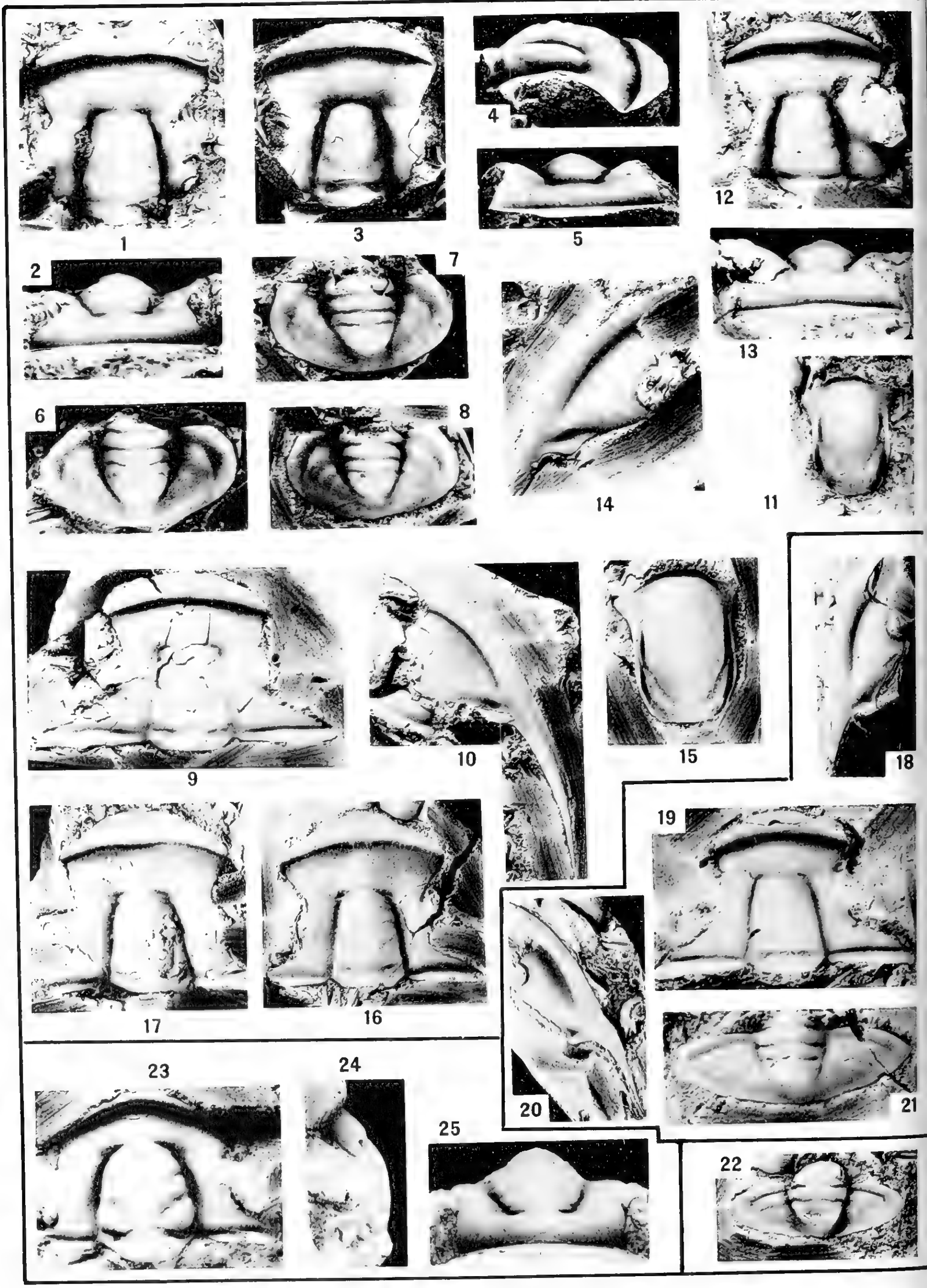
TRILOBITES OF THE APHELASPIS ZONE.

(SEE EXPLANATION OF PLATES AT END OF TEXT.)



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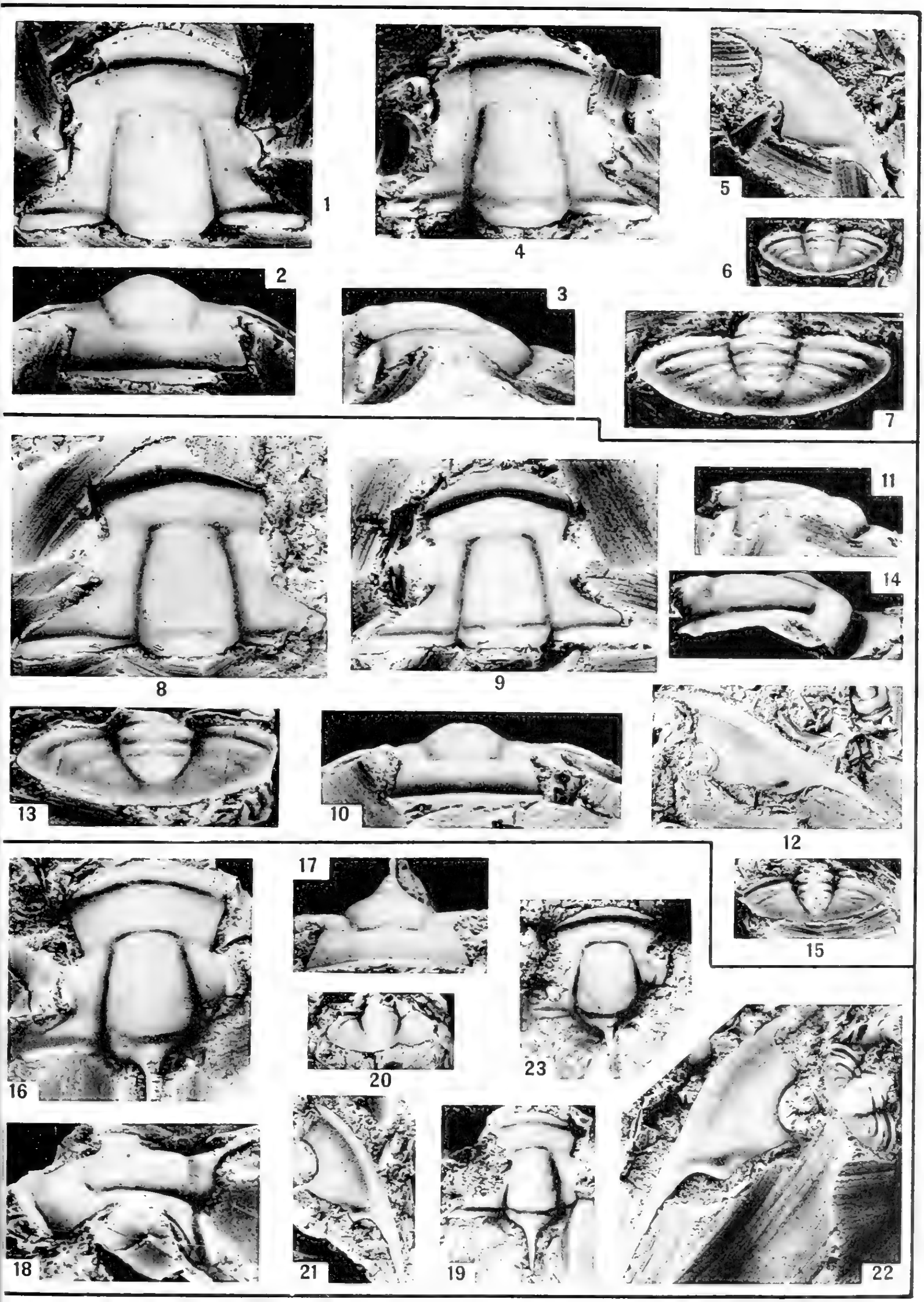

Trilobites of the Aphelaspis Zone.

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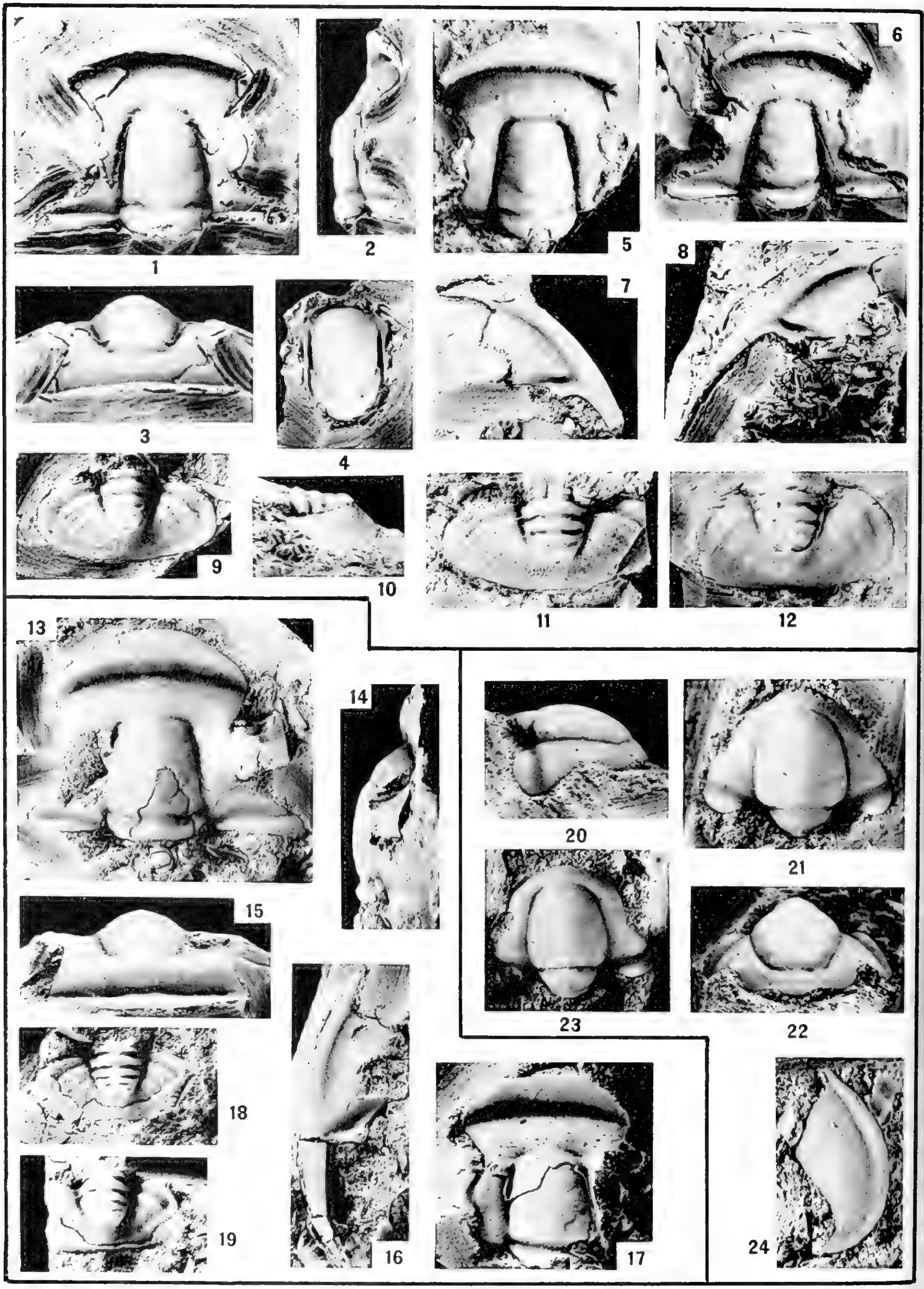

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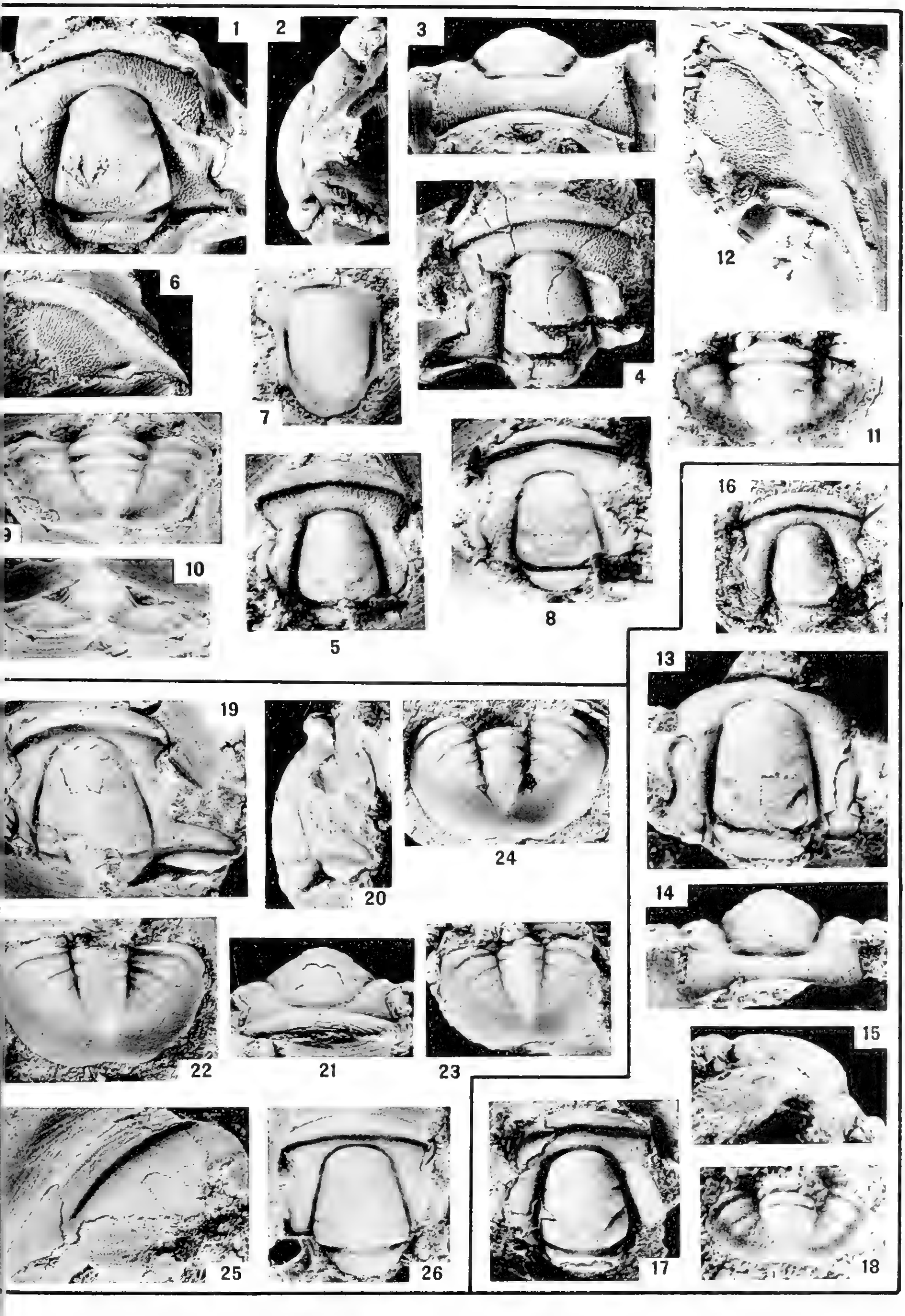

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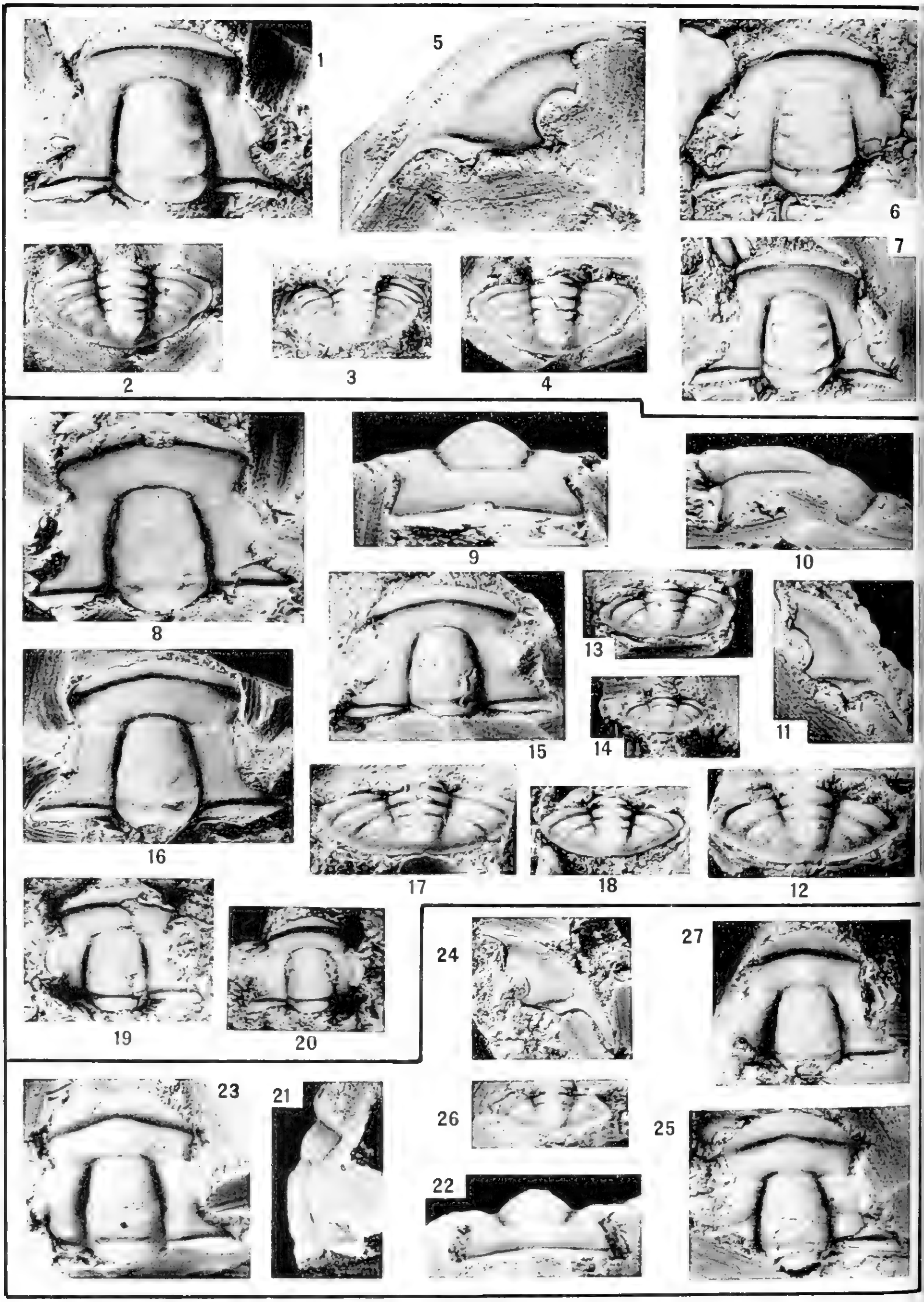

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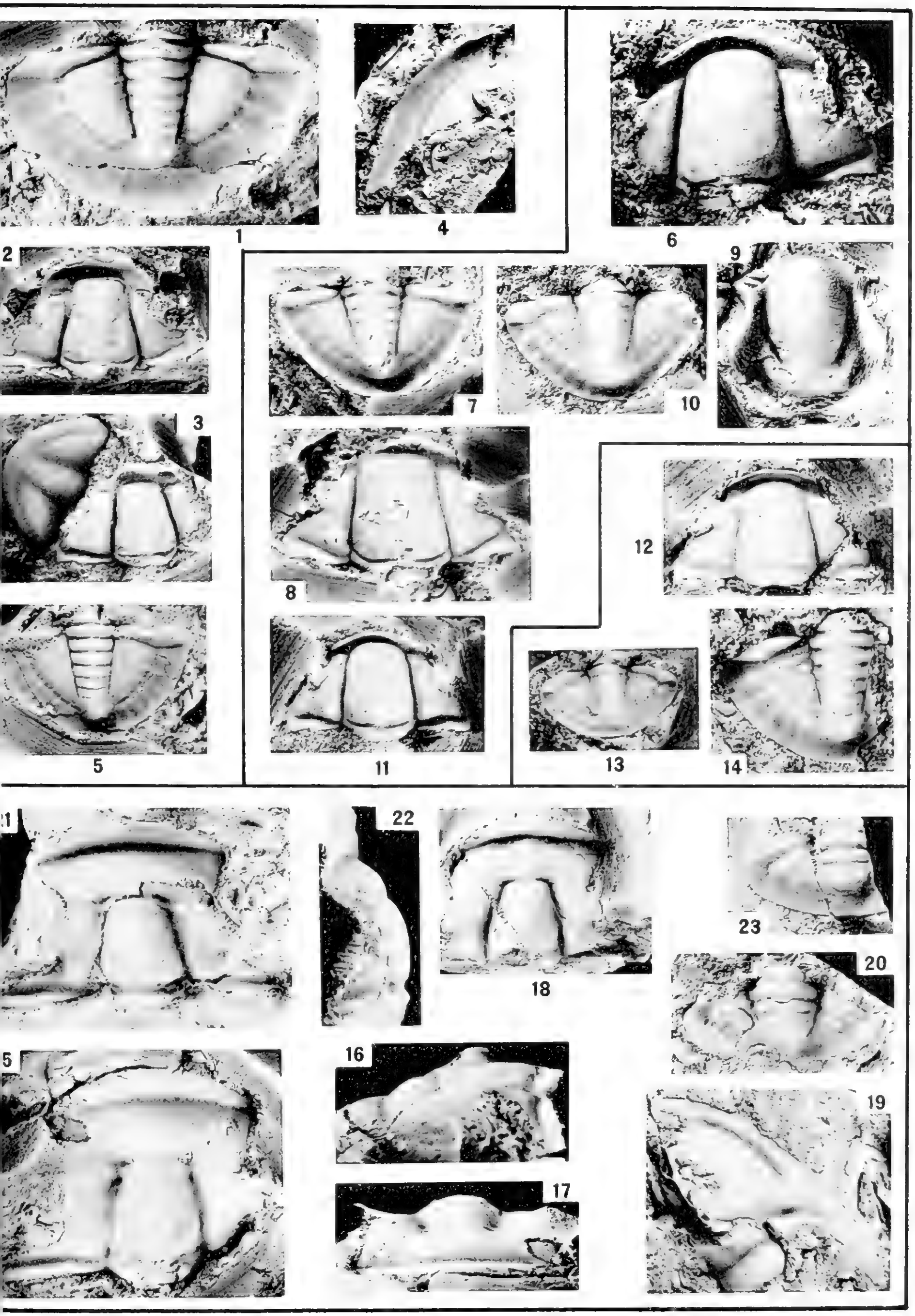

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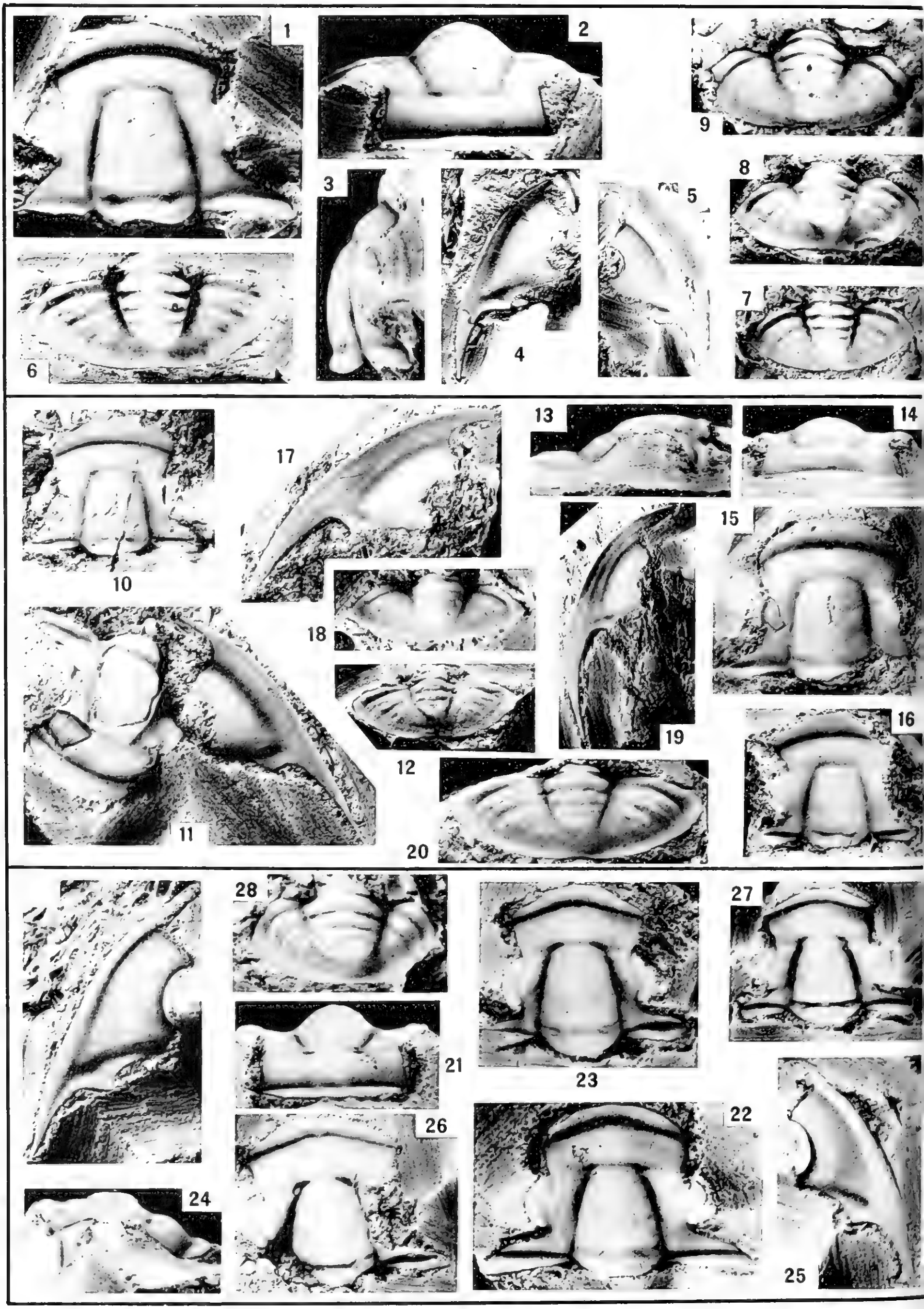

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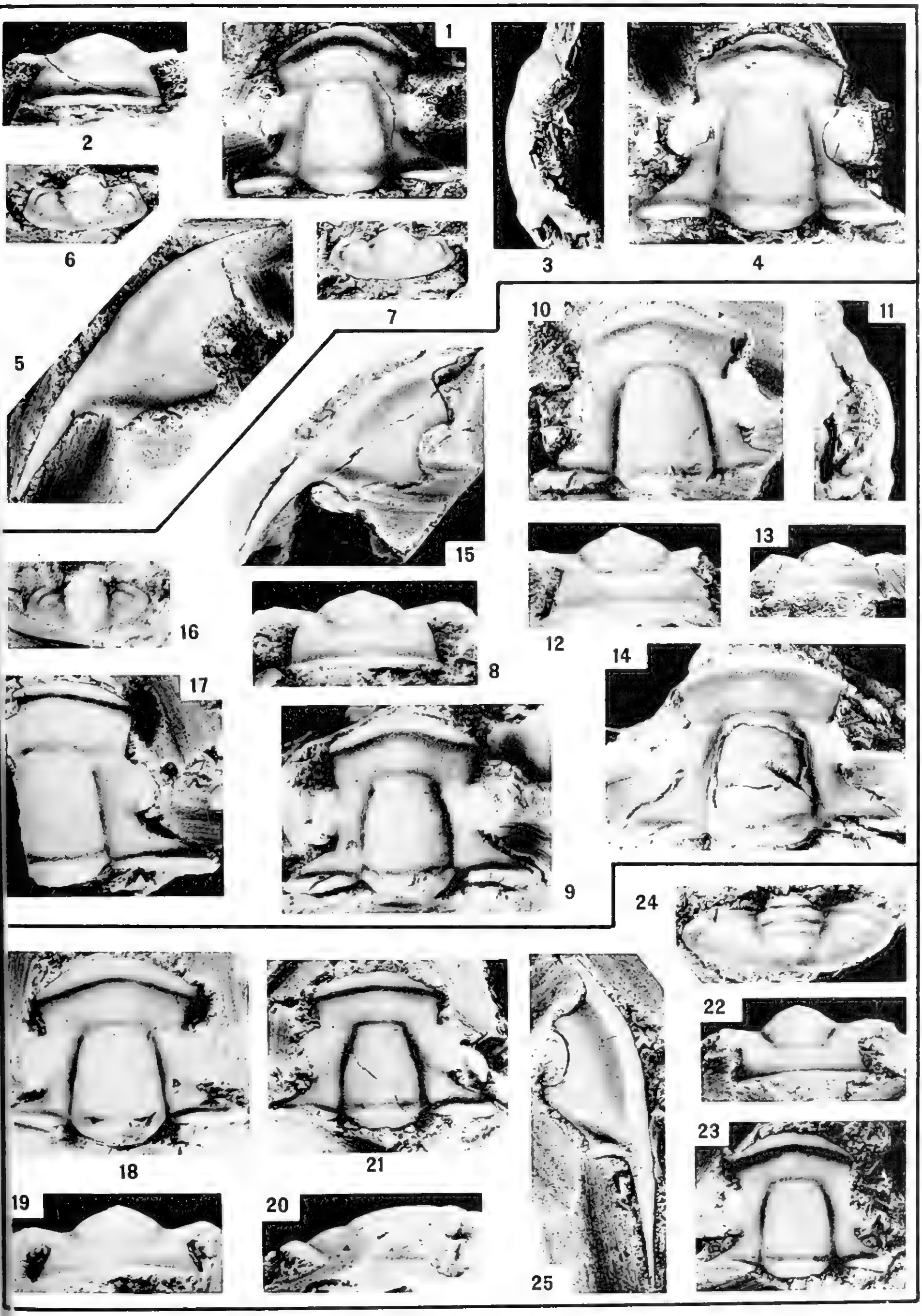

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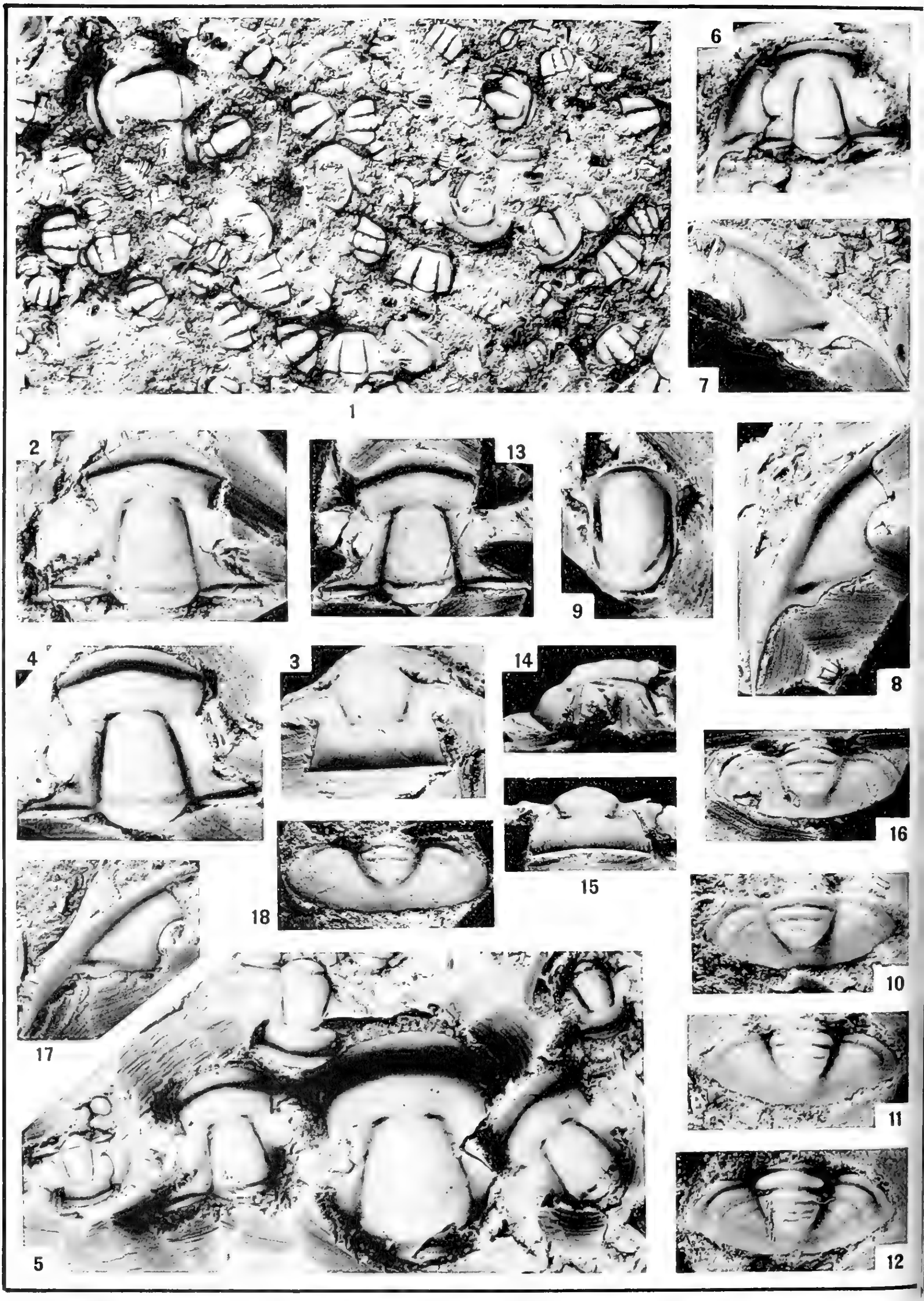

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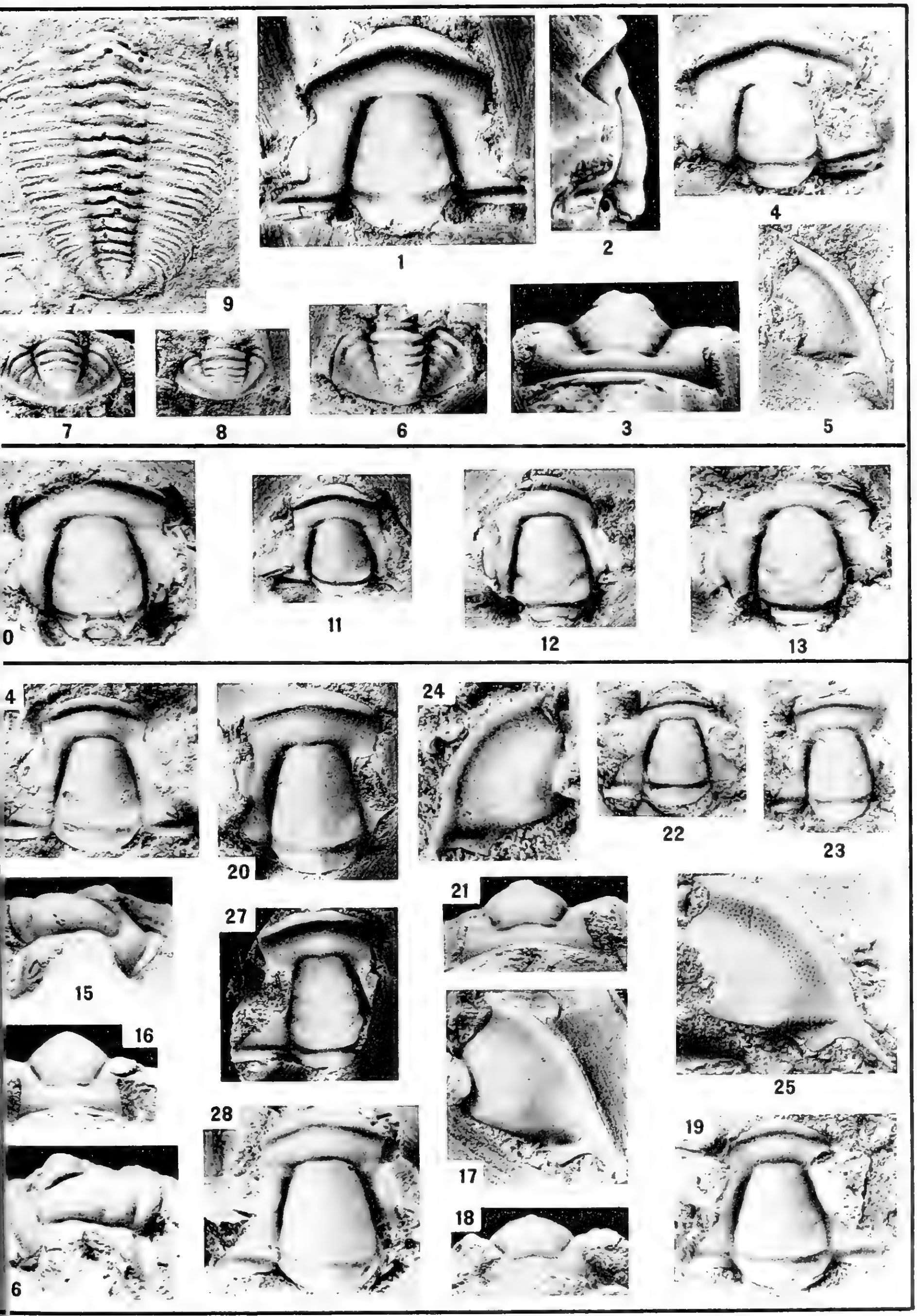

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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 148, NUMBER 4

Charles D. and Mary Vaux Walcott Research Fund

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(WITH NINE PLATES)

BY
RICHARD CIFELLI
U. S. National Museum
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(PUBLICATION 4599)

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INTRODUCTION

The present paper describes and records the distribution of Foraminifera collected in plankton tows from four seasonal traverses between Cape Cod and Bermuda. Plankton stations were occupied in the shelf waters, slope waters, Gulf Stream and Sargasso Sea (see Appendix for details). The Gulf Stream stations, except for the fall traverse, were determined by bathythermograph at the times of collection and were encountered at approximately longitude 69° W. In this part of the North Atlantic the Gulf Stream is an important hydrographic boundary, separating the temperate slope waters from the subtropical Sargasso Sea. The chief purpose of this study was to determine the influence of this boundary on the distribution of planktonic Foraminifera.

The four seasonal cruises were made in 1960 and 1961 aboard the Woods Hole Oceanographic Institution vessels *Chain* and *Crawford;* the position of the stations are shown in figure 1. The summer and winter stations are the ones that have been regularly occupied by the Woods Hole Oceanographic Institution over a period of years in a continuing program to study the biology and chemistry of the western North Atlantic. The distribution of epizooplankton from those stations has been reported on by Grice and Hart (1962).

The collections were obtained in oblique tows with a No. 10 plankton net having a $\frac{3}{4}$-meter open-mouth diameter. At shallow stations the net was lowered as close as possible to the bottom, and beyond the shelf it was lowered to 200 meters. The ship's speed during

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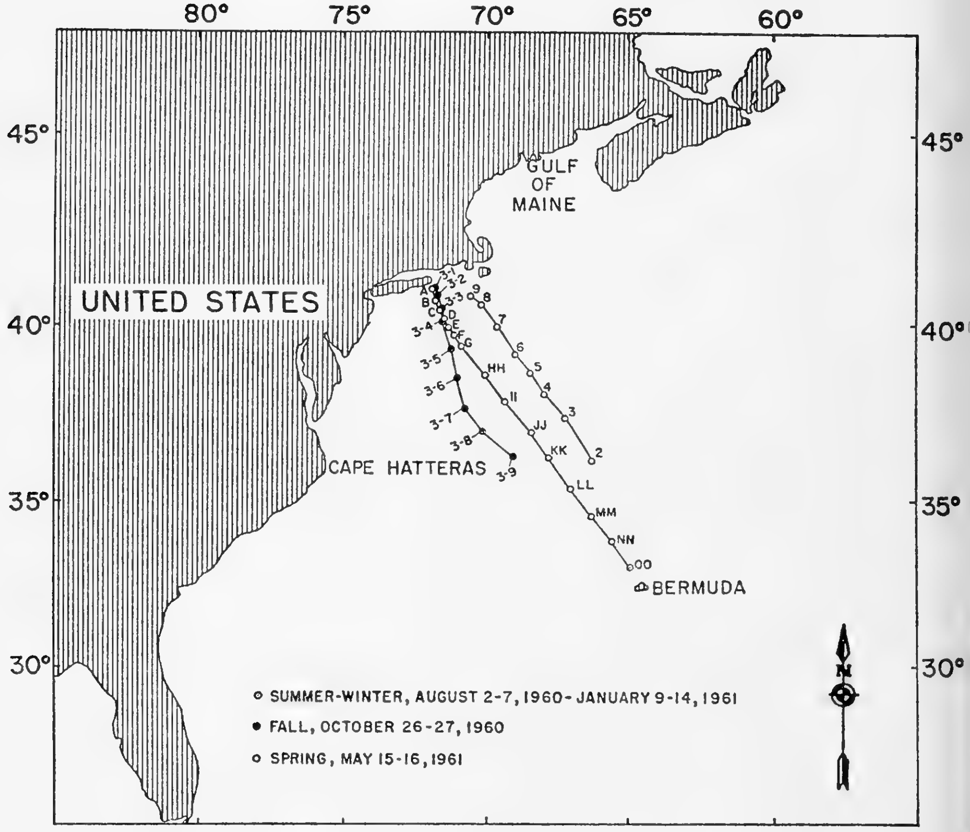

FIG. 1.—Location of stations.

towing was approximately 2 knots. The samples were preserved in 5-percent formalin, buffered with hexamethylenamine.

Acknowledgments.—Travel, ship-time, and facilities for this work were provided by the Woods Hole Oceanographic Institution, supported variously by the Office of Naval Research under contract Nonr-2196 and the Atomic Energy Commission under grant AT (30-1)-1918. I am grateful to the Woods Hole Oceanographic Institution staff for making this study possible, for their assistance aboard ship, and for the collateral data that they made available. This is Woods Hole Oceanographic Institution Contributions No. 1498.

HYDROGRAPHIC SETTING

Between Cape Cod and Bermuda the subtropical waters of the Sargasso Sea are in close proximity to the temperate shelf and slope waters of the North Atlantic. Separating these water bodies is the Gulf Stream, a well-defined band of currents originating in the straits of Florida that moves clockwise and can be traced as far north and east as the Grand Banks. Significant short- and long-period variations occur in the velocity and position of the Gulf Stream, but throughout the year it forms a sharp pressure gradient between the slope waters and the Sargasso Sea (Iselin, 1936). Because of this pressure gradient the slope waters and the Sargasso Sea maintain their more or less unique hydrographic properties.

The waters in the Sargasso Sea are warm, and surface temperatures remain relatively uniform throughout the year, ranging from about 19° C. to 27° C. In contrast, the surface temperatures of the shelf and slope waters range from about 12° C. in March, the coldest month, to about 26° C. in September, the warmest month (Stommel, 1958, fig. 5). During the warmer months there is a pronounced stratified surficial layer in the Sargasso Sea with a summer thermocline developing between 40 and 70 meters (Cifelli, 1962, figs. 3, 6). In the slope and shelf waters the summer thermocline develops between 10 and 40 meters, but there is relatively little surficial stratification. The summer warming affects mostly the upper 100 meters; below that depth there is little change, and at 200 meters the temperature remains relatively constant throughout the year, which is generally between 9° and 12° C. in the slope waters and between 19° and 21° C. in the Sargasso Sea. Lateral variations in temperature are more common in the slope waters than in the Sargasso Sea and, moreover, subsurface temperature inversions occur in the former (Grice and Hart, 1962, p. 289).

The Sargasso Sea is more saline than the shelf and slope waters. In the Sargasso Sea salinities are between 36-37 o/oo, while those in the slope waters normally range between 34-36 o/oo. The shelf waters tend to be even less saline, with salinities as low as 25-31 o/oo having been recorded at the location of the inshore shelf stations (Grice and Hart, 1962, p. 289).

The hydrographic differences between the shelf slope waters and the Sargasso Sea are reflected in the composition of their planktonic foraminiferal faunas. In the vicinity of the Gulf Stream is located the boundary between the temperate and the subtropical faunas.

DISTRIBUTION

Tables 1-4 show the percentage of total population at the stations sampled expressed in number of specimens per half-hour tow.

The principal features of the distribution and the faunal changes observed in the traverses studied as ascertained from these tables have been discussed in a previous paper (Cifelli, 1962). Briefly, these features may be summarized as follows:

Abundance.—Considerable areal variation in numerical abundance of specimens was observed, even between nearby stations. Some of this variation is probably more apparent than real, since, in the absence of a current meter, the actual amount of water filtered at the towing stations is unknown, and the length of towing time is an inexact and variable expression of this quantity. For the most part, however, the differences in abundances between stations in the same water body reflect the patchiness of distribution, a phenomenon that has long been known to be characteristic of planktonic organisms. Patchiness of distribution among planktonic Foraminifera has been recognized in the Pacific by Bradshaw (1959) and Smith (1963). In general, of the waters sampled the Sargasso Sea was the most uniform in the abundance of specimens.

The slope waters yielded the richest concentrations of specimens, whereas the Sargasso Sea was generally impoverished. The shelf waters were the most variable, and planktonic Foraminifera appear to be rare and sparsely distributed at the inner part of the shelf. Seasonally, the highest concentrations of specimens were obtained in the fall and in the spring. The poorest concentrations were obtained in the summer.

Faunal composition.—That the Gulf Stream is a boundary of major biogeographic importance can be seen in the changes in faunal composition of planktonic Foraminifera along the traverses studied. On the shelf and inner slope the fauna is distinctly temperate in character, being composed throughout the year almost exclusively of species of *Globigerina.* The dominant species are *Globigerina bulloides* and *G. pachyderma incompta,* but relative frequencies were found to be variable and *G. inflata* and *G.* aff. *quinqueloba* are also common. To the south *Globigerina* is replaced by a diverse subtropical group of species that characterize the Sargasso Sea. The dominant subtropical species are *Globigerinoides ruber, G. trilobus trilobus, Globigerinella aequilateralis, Globorotalia truncatulinoides,* and *Pulleniatina obliquiloculata.* The relative frequencies of these species, however, were inconstant along the traverses and varied considerably throughout the year. The position of the boundary between the temperate and subtropical faunas also changed throughout the year but was always observed on the north side of the Gulf Stream. It was closest inshore in the fall and farthest offshore between winter and spring. Insofar as could be observed, the Gulf Stream contained no endemic elements,

TABLE 1.—*Relative frequencies, in percentage, of planktonic Foraminifera, summer traverse, August 1960.*

Number of specimens per half-hour tow...	0	608	0	0	1530	5484	4988	4943	6874	3188	1287	372	1398	533	310
Station (summer traverse)...	A	B	C	D	E	F	G	HH	HH′	HH″	II	JJ	KK	LL	MM
Candeina nitida													<1		
Globigerina bulloides		38			50	46	51	2	4	12					
dutertrei							1	2	5	1		1	<1	1	
inflata						10	4	8	7	18	1		1		
pachyderma incompta		50			50	29	40	7	8	26			<1		
aff. quinqueloba						4	2			2					
sp.								1	1		1				2
Globigerinella aequilateralis						1		11	6	8	26	18	26	28	20
Globigerinita glutinata		12				9		2	3	4	2		2	4	12
Globigerinoides conglobatus								1	2		1	4	15	1	3
elongatus	BARREN		BARREN	BARREN							<1		<1		
ruber						1		43	40	17	20	45	9	11	20
trilobus trilobus						<1		15	8	3	28	12	12	21	11
Globorotalia hirsuta											1		1	1	1
menardii								1	1		4		7	2	4
punctulata								1	<1	2	1	3	3	2	4
truncatulinoides									<1			1	1	1	1
Hastigerina pelagica						1		2	6	3	5	10	4	24	18
Orbulina universa							<1	4	8	3	10	6	17	3	4
Pulleniatina obliquiloculata												<1		1	
Total specimens examined...	0	32	0	0	80	245	204	324	228	244	306	122	283	140	166

Table 2.—*Relative frequencies, in percentage, of planktonic Foraminifera, fall traverse, October 1960.*

Number of specimens per half-hour tow...	375	424	1963	100,000	8470	30,259	12,000	6771	8265
Station (fall traverse)	1	2	3	4	5	6	7	8	9
Globigerina bulloides	40	3	44	18	3		2		
dutertrei				2	<1	9	4	1	1
inflata		15	14	38	35	25	21	2	
pachyderma incompta	60	63	36	32	21	5	23	2	1
aff. quinqueloba		19	5	4	3		<1		
sp.				2					
Globigerinella aequilateralis				1	3	4	1	6	9
Globigerinita glutinata					2		1	6	9
Globigerinoides conglobatus					<1	3	<1	1	3
elongatus									2
ruber			1	2	5	11	23	18	30
trilobus trilobus					1	8	9	45	28
Globorotalia hirsuta						<1		<1	
menardii				<1	11	4	2	2	7
punctulata						1	2	<1	
truncatulinoides				<1	3	1	2	<1	
Hastigerina pelagica					<1	<1		3	3
Orbulina universa					4	15	1	6	7
Pulleniatina obliquiloculata					8	14	9	6	1
Total specimens examined	30	32	143	258	263	277	221	215	226

TABLE 3.—*Relative frequencies, in percentage, of planktonic Foraminifera, winter traverse, January 1961.*

Number of specimens per half-hour tow	0	912	10,394	14,025	1980	1340	24,956	1422	5116	2805	1411	2795	5152	6334	4881
Station (winter traverse)	A	B	C	D	E	F	G	HH	II	JJ	KK	LL	MM	NN	OO
Globigerina bulloides		67	70	35	40	22	40	34	12	4	2	4		1	
inflata				1	3	16	9	11	6	1	2	2	2	2	2
pachyderma incompta		5	6	7	6	24	36	18	6	8	2				
aff. quinqueloba		27	21	57	50	20	7	21		1					
sp.						1									
Globigerinella aequilateralis									10	10	6	9	17	16	22
Globigerinita glutinata			3			16	5	13	5	5	7	2	1	4	5
Globigerinoides conglobatus									<1					1	
elongatus														2	1
ruber									8		<1			2	4
trilobus trilobus	BARREN								7	3	4	<1	1	1	1
Globorotalia hirsuta											2	<1	3	2	4
menardii									2				2	1	1
punctulata													3	4	1
truncatulinoides							1	3	4	55	38	51	39	43	46
Hastigerina pelagica									5	4	13	3	2	<1	1
Orbulina universa									1		2	<1	1	<1	1
Pulleniatina obliquiloculata					1	1	2		34	9	18	27	29	21	11
Total specimens examined	0	92	71	136	80	86	253	104	172	100	100	122	236	183	125

TABLE 4.—*Relative frequencies, in **percentage**, of planktonic Foraminifera, spring traverse, May 1961.*

Number of specimens per half-hour tow	0	2925	1320	11,990	34,797	57,520	22,775	4328
Station (spring traverse)	9	8	7	6	5	4	3	2
Candeina nitida							<1	
Globigerina bulloides		43	30	37	28	49		1
dutertrei					<1		2	
inflata		28	15	19	26	10	<1	1
pachyderma incompta		14	30	26	34	22	1	1
aff. quinqueloba		14	25	6	3	3		
sp.							1	1
Globigerinella aequilateralis				3	<1	2	30	60
Globigerinita glutinata				2	4	5	6	
Globigerinoides conglobatus							<1	
elongatus							<1	
ruber	BARREN			3	4	3	38	22
trilobus trilobus					<1	2	10	6
Globorotalia hirsuta						<1		<1
menardii							<1	<1
punctulata				1		<1		<1
truncatulinoides						2		2
Hastigerina pelagica				<1			1	1
Orbulina universa				<1		<1	3	3
Pulleniatina obliquiloculata				2		<1	6	1
Total specimens examined	0	56	48	218	329	251	249	196

and its fauna was identical with that of the Sargasso Sea. The boundary is transitional in faunal character and contains a mixture of *Globigerina* and subtropical species. The mixed character of the assemblage strongly suggests that mixing of surficial waters occurs across the Gulf Stream and that the subtropical species occurring with *Globigerina* in the slope waters are expatriates.

Seasonal changes in faunal composition.—Clearly, seasonal cycles cannot be described, nor, even, can the fact be established that such cycles exist on the basis of only four seasonal traverses. However, some marked changes were observed in composition of the subtropical fauna from traverse to traverse and there can be no doubt that some species of that fauna undergo considerable changes in relative frequencies throughout the year. The most remarkable change noted was the sharp increase of *Globorotalia truncatulinoides* in the winter. Mostly rare or absent in the spring and summer stations, that species showed some increase in the fall and was dominant in the winter when, at one station (II), it occurred at a frequency of 55 percent. This winter increase in *Globorotalia truncatulinoides* was mainly at the expense of *Globigerinoides* species (mostly *G. ruber* and *G. trilobus trilobus*), which were relatively rare then but were dominant or important elements of the subtropical fauna at the other seasons. *Pulleniatina obliquiloculata* also showed a considerable increase in the winter. *Globigerinella aequilateralis* attained its highest frequency in the spring (60 percent at station 2) but remained fairly common through all the seasons.

It is more difficult to determine whether changes in frequencies of species occur throughout the year within the temperate *Globigerina* fauna because of the considerable lateral changes in frequencies that occur from station to station and also, possibly, because of the morphologic variation of the *Globigerina* species, which are sometimes difficult to separate. The indications are that the relative frequencies of the *Globigerina* species are fairly stable throughout the year except for *Globigerina* aff. *quinqueloba,* which appears to increase appreciably in the winter.

SYSTEMATICS

Since the primary purpose of this work was to determine the distribution of planktonic Foraminifera in a limited sector of the North Atlantic, no attempt is made to treat the species monographically. Only the original and a few pertinent references are given in the synonymies. Extensive synonymies can be found in the works of Cushman, Todd, Parker, and others.

In a group as highly variable as the planktonic Foraminifera it is perhaps inevitable that opinions will vary as to the morphologic limits of species. Some workers will tend to split more finely than others, and in the absence of quantitative treatments of population structures and the lack of data on the biology of the animal, judgments on the limits of species are bound to be subjective. The policy here has been to group together in a single species those forms that occur together with intermediaries among which no line of demarcation could be perceived. Admittedly, further taxonomic refinements are possible, but it is believed that with the morphologic limits recognized here, an internal consistency in identification has for the most part been maintained and further refinements would not significantly change the distributional patterns presented. The specimens used for illustration were chosen to show the range of forms included in the species, and the descriptive remarks under the species refer to the specimens actually examined, with the emphasis on those characters that were found particularly useful for identification.

Generic as well as specific characters are variable in the planktonic Foraminifera, and some species include end forms showing close affinities to species placed in other genera. In fact, *Globigerina inflata* shows a transition from *Globigerina* to *Globorotalia*. Such continuous variability across established generic boundaries suggests that the Recent planktonic Foraminifera comprise a closely related group. Therefore, they are included here in a single family, the Globigerinidae. The species are grouped into eight commonly recognized genera, though, admittedly, the genera serve in some cases, owing to a lack of exclusive characters, more as conveniences than as representations of genetic affinities.

In the use of specific names an attempt has been made to conform with the present Code of Zoological Nomenclature (1961). As pointed out by Todd (1961, 1963) this code now limits the application of priority in the naming of species. However, it is not clear from the provision of conservation (article 23b) what these limitations are, and, in fact, there is some question as to whether that provision can actually be interpreted. Therefore, it would appear that the code serves as a guide rather than a "cook book," and the individual is not relieved of the responsibility of exercising individual judgment in serving the interests of nomenclatural stability. As a result, some arbitrary decisions were found necessary in the choice of names, and these are discussed under the species concerned.

Family GLOBIGERINIDAE Carpenter, Parker, and Jones, 1862

Genus GLOBIGERINA d'Orbigny, 1826

Globigerina bulloides d'Orbigny

Plate 1; figures 1-3, 5

Globigerina bulloides D'ORBIGNY, 1826, Ann. Sci. Nat., vol. 7, p. 777, Nos. 76, 17.—BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 33, pl. 6, figs. 1-4.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 15-17.—BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Res., vol. 11, pt. 1, p. 3, figs. 1, 4.—PARKER, 1962, Micropaleontol., vol. 8, No. 2, p. 221, pl. 1, figs. 1-8.

Most of the specimens have bulbous chambers and broad, rounded apertures that join in the center of the ventral side to form a large, open umbilicus. The species, however, shows continuous gradation to small compact forms with restricted apertures and reduced umbilical areas (pl. 1, fig. 2b). These latter forms are relatively scarce but are included in *G. bulloides* because of the continuous gradation.

The final chamber in *Globigerina bulloides* and other species of Globigerinidae shows considerable variation and, as noted by Parker (1962, p. 246), sometimes covers the umbilicus and is reduced in size. I agree with Parker that a bulla is often nothing more than a much-reduced final chamber covering the umbilicus. A specimen of *G. bulloides* with a well-defined bulla is figured here (pl. 1, fig. 5b). Other specimens with the final chamber covering the umbilicus and grading from bulla size to normal size were also observed. An effect of the final chamber covering the umbilicus is that the aperture is reduced to a narrow slit or is completely absent.

Distribution.—Overall, *Globigerina bulloides* was observed to be the dominant species in the shelf and slope waters. The highest frequency was 70 percent at winter shelf station C. Along with other species of *Globigerina* it diminishes in importance in the vicinity of the Gulf Stream and was found to be rare or absent in most of the Gulf Stream and Sargasso Sea stations.

GLOBIGERINA PACHYDERMA INCOMPTA Cifelli

Plate 1, figures 4, 6

Globigerina incompta CIFELLI, 1961, Contr. Cushman Found. Foram. Res., vol. 12, pt. 3, p. 84, pl. 4, figs. 1-7.

This problematic form, which is characterized mainly by its simplicity and paucity of distinctive characters, varies in the amount of inflation of the test and in nature of the final chamber. As in *G. bulloides,* the test is sometimes compact, and the final chamber occasionally deviates from the axis of coiling and partially covers the umbilicus. Also, the last chamber is often reduced in size. Specimens with a compact test and a reduced final chamber covering the umbilicus are identical with *G. pachyderma.* Several such specimens have been observed in a few of the samples studied, and two are figured here. These specimens show that *G. incompta* grades into *G. pachyderma.* However, they are of rare occurrence in the region studied, and it is useful to retain *G. incompta* as a subspecies. Parker (1962, p. 224) has shown that in Recent Pacific bottom sediments *G. incompta* grades into *G. pachyderma,* with *G. pachyderma* dominating in the high latitudes. The transition is further shown by Smith (1963) from northeastern Pacific plankton tows. The form that Smith figures (pl. 1, figs. 12-14) as a *Globigerina pachyderma-eggeri* intergrade is identical with *G. pachyderma incompta.* The relationships, however, with *G. eggeri* (=*G. dutertrei*) are not yet completely clear.

Distribution.—*Globigerina pachyderma incompta* is next in dominance to *G. bulloides* in the shelf and slope waters. The highest frequencies were observed in the summer (50 percent at stations B and E) and the fall (63 percent at station 2).

GLOBIGERINA DUTERTREI d'Orbigny

Plate 2, figures 1, 2

Globigerina eggeri RHUMBLER, 1900, Nordische Plankton, pt. 14, Foraminiferen, p. 19, text figs. 20a-c.

Globigerina eggeri BRADSHAW, 1959 (part), Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 35, figs. 5, 10 only.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, figs. 1-3.

Globigerina dutertrei D'ORBIGNY, 1839.—BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Res., vol. 11, pt. 1, p. 11, pl. 2, fig. 1.

This species closely resembles both *Globigerina pachyderma incompta* and the early stages of *Pulleniatina obliquiloculata. G. dutertrei* is distinguishable from *G. pachyderma incompta* by its relatively high trochoid spire and its broad, open umbilicus. The differences are slight, however (Cifelli, 1961), and future studies of additional material, particularly from the warmer waters, may show that *G. dutertrei* belongs to the *G. pachyderma* species group.

The coiling in *G. dutertrei* is trochoid throughout except, occasionally, for the last chamber, which, like other *Globigerina* species, tends to deviate toward the umbilicus. Thus, in the last whorl the chambers tend to wrap around the umbilicus, rather than overlap it as they do in *Pulleniatina obliquiloculata.*

In view of the close morphologic affinities of *G. dutertrei* to *G. pachyderma incompta* and *Pulleniatina obliquiloculata,* I disagree with Parker (1962, pp. 221, 242) in removing *G. dutertrei* from the genus *Globigerina* and placing it in the genus *Globoquadrina,* family Globorotaliidae. At least, I can find no consistent difference in wall surface between *G. dutertrei* and other species of *Globigerina.* Nor can a separation be made by the presence or absence of spines, since, as Parker points out (Parker, 1962, p. 224), *Globigerina pachyderma* only sometimes has spines. The fact that spines may be present or absent in a single species weakens considerably the argument that spines are a character of sufficient importance to separate otherwise similar species into different families.

Distribution.—Globigerina dutertrei appears to be relatively rare among the *Globigerina* in the northwestern part of the Atlantic. In the summer, the maximum frequency was 5 percent (station HH′) and in the fall, 9 percent (station 6). It was not recorded in the winter, and in the spring the maximum frequency was only 2 percent (station 3).

GLOBIGERINA aff. G. QUINQUELOBA Natland

Plate 2, figures 3, 4

Globigerina cf. *quinqueloba* Todd and Bronniman, 1957, Cushman Found. Foram. Res. Spec. Publ. No. 3, p. 40, pl. 12, fig. 2.

Globigerina aff. *quinqueloba* Bé, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 21, 22.

The test is small, and there are 4 to 6 chambers visible on the ventral side. The periphery is lobulate, and the final chamber deviates slightly from the trochoid spiral, projecting over the umbilicus. The wall is thin and translucent. The aperture is a rounded umbilical opening that is sometimes partially obscured by a thin, weakly developed chamber. The coiling is both sinistral and dextral, but the sinistral mode is dominant.

The specimens included here and those in the figures cited closely resemble *G. quinqueloba* but differ in having a thinner wall and a less developed lip.

The present specimens also resemble in general form and outline *Globigerina concinna* Reuss and *G. diplostoma* Reuss (which appears to be identical with *G. concinna*) as originally figured. Those figures, however, are lacking in diagnostic detail, and *G. concinna* and *G.*

diplostoma have been interpreted in so many different ways that they include a mixed bag of specimens ranging in age from Lower Tertiary to Recent. Clarification of these species is needed before the form designated here as *Globigerina* aff. *G. quinqueloba* can be definitely assigned taxonomically.

Distribution.—This species appears to be relatively scarce in the summer (a maximum of 4 percent at station G) but common or abundant at other times of the year. A maximum frequency of 57 percent was recorded at winter station D.

GLOBIGERINA INFLATA d'Orbigny

Plate 4, figures 1-3

Globigerina inflata D'ORBIGNY, 1839, *in* Barker-Webb and Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 134, pl. 2, figs. 7-9.—BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 36, pl. 6, figs. 16-18.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 12-14.

Globorotalia inflata (d'Orbigny) PARKER, 1962, Micropaleontol., vol. 8, No. 2, p. 236, pl. 5, figs. 6-9.

This is an interesting species as it bridges the morphologic gap between *Globigerina* and *Globorotalia.* Suites of specimens range from a globigerine form with highly inflated chambers, a rounded periphery and a large umbilical aperture to a globorotalid form with compressed chambers, an angular periphery and a relatively low, elongate, extra-umbilical aperture. The surface of the wall is also variable, ranging from smooth to rough, with blunt spines. Radiating spines, however, are absent.

Since this species is transitional between *Globigerina* and *Globorotalia,* the generic assignment becomes somewhat arbitrary. The species has been referred to both genera, but most commonly to *Globigerina.* In the samples studied the globigerine form appears to be dominant, and the species has a distribution like that of the *Globigerina* species.

The angular, globorotalid form of *Globigerina inflata* closely approaches *Globorotalia punctulata,* which is distinguishable by its lower, slitlike aperture and its sharper, more angular periphery. These characters, however, are variable and end forms are sometimes difficult to distinguish.

Distribution.—*Globigerina inflata* is common in the shelf and slope waters but apparently is not one of the dominant temperate species. The highest frequency recorded was 38 percent, at fall station 4. In the winter it was recorded in the Sargasso Sea as far south as station OO with a frequency of 2 percent.

GLOBIGERINA sp.

Plate 2, figures 5, 6

The test is small and relatively high trochospirally. In the last whorl the final 1 or 2 chambers tend to bend over the umbilicus. In some specimens the umbilicus is covered with a small bubblelike chamber with a narrow aperture at the margin. The surface of the test is spinose.

In general form this species resembles *Globigerinita glutinata*, but the surface is spinose and the chambers are more inflated.

Distribution.—This form was recorded in frequencies of less than 1 percent at summer stations HH″, MM; fall stations 4, 9; spring station 2.

Genus PULLENIATINA Cushman, 1927

PULLENIATINA OBLIQUILOCULATA (Parker and Jones)

Plate 3, figures 1, 3; text figure 2

Pullenia sphaeroides (d'Orbigny) var. *obliquiloculata* PARKER and JONES, 1865, Philos. Trans. Roy. Soc. London, vol. 155, pp. 365, 368, pl. 19, figs. 4a-b.

Pulleniatina obliquiloculata (Parker and Jones) BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 49, pl. 8, figs. 19, 20.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, figs. 4-6.

Pullenia sphaeroides (d'Orbigny) var. *obliquiloculata* BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Res., vol. 11, pt. 1, p. 25, pl. 7, figs. 4a-c.

In this species the coiling changes during growth from trochospiral to streptospiral (Bolli, Loeblich, and Tappan, 1957, p. 39). The change in the axis of coiling becomes apparent at about the end of the second whorl, and the last 2 or 3 chambers overlap the umbilical area. Some of the stages in development are shown in figure 2. Stages 1-4 comprise the majority of forms, and stages 5-7, which are like the typical form, make up only about 20 percent of the present total populations in this species. Stages 5-7 appear to represent variations in the degree of overlap of the final chamber over the umbilicus rather than successive periods of development. In stage 7, the umbilicus is completely covered and the aperture is an extra-umbilical, crescent-shaped arch. The highly polished surface occurs only in the final 1 or 2 chambers, in stages 6-7. In the earlier stages the surface is hispid, but no spines were observed.

In its early stages this species closely resembles *Globigerina dutertrei* in having a broad, open umbilicus and a large umbilical aperture. However, at about the end of the second whorl the streptospiral coiling of *Pulleniatina obliquiloculata* becomes apparent and the chambers in the final whorl can be seen to deviate from the axis of coiling of the earlier chambers when the test is viewed from the dorsal side. Also, the later chambers of *P. obliquiloculata* tend to be elongate in their axis of coiling.

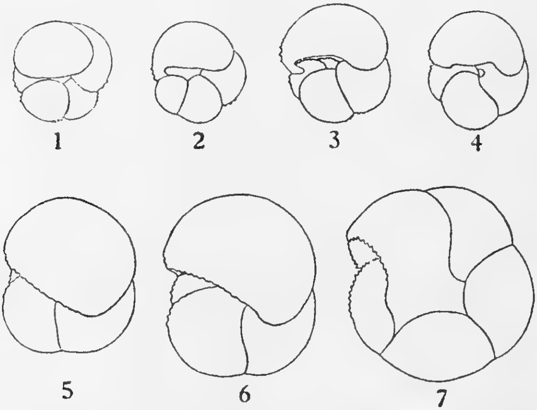

FIG. 2.—Some developmental stages in *Pulleniatina obliquiloculata.*

Distribution.—This species was recorded mostly from the southern stations and was most common in the winter, when it reached a maximum frequency of 34 percent at station II. It was extremely scarce in the summer and was recorded at only two stations (LL and JJ) with frequencies of 1 and less than 1 percent respectively.

Genus GLOBIGERINITA Bronnimann, 1951

GLOBIGERINITA GLUTINATA (Egger)

Plate 3, figures 2, 4, 5

Globigerina glutinata EGGER, 1893, Abhandl. K. Wiss. München, Cl. II, vol. 18, p. 371, pl. 13, figs. 19-21.

Globigerinita glutinata BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 40, pl. 7, figs. 7, 8.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 25-26.—PARKER, 1962, Micropaleontol., vol. 8, No. 2, p. 246, pl. 9, figs. 1-16.

Globigerinita glutinata is distinguishable mainly by its smoothly polished surface and low umbilical aperture. The bulla and dorsal aperture, characters diagnostic of the genus *Globigerinita,* are poorly developed in the studied assemblages of this species, and neither character appeared on more than about 1 percent of the specimens. No single specimen was observed that combined both bulla and dorsal aperture.

To me, the relationship of *Globigerinita* with the Globigerinidae seems clear enough, and I see no need in placing that genus in Incertae Familiae (Parker, 1962, p. 244). The test of *Globigerinita* is distinctly globigerine in form, and there is not a known character in its species that is not found in the Globigerinidae. The bulla, or modified last chamber, occurs in variants of both *Globigerina* and *Globigerinoides* species, and the dorsal aperture is a diagnostic feature of *Globigerinoides.* Nor is the nonspinose, smooth, finely perforate wall hard to come by in the Globigerinidae, as *Pulleniatina obliquiloculata* lacks spines and, in its final stage, has a smooth wall, comparable to that of *Globigerinita glutinata.*

Distribution.—Globigerinita glutinata appears to be a euryopic species. In the traverses studied, this species ranged from the shelf waters to the Sargasso Sea in about equal abundances. Frequencies were low to moderate, the highest being 16 percent at the winter shelf station F. In the summer a maximum frequency of 12 percent was recorded at both shelf station B and Sargasso Sea station MM.

Genus **ORBULINA** d'Orbigny, 1839

ORBULINA UNIVERSA d'Orbigny

Plate 3, figures 6, 7

Orbulina universa d'Orbigny, 1839, *in* De la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 3, pl. 1, fig. 1.—Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 49, pl. 8, figs. 17, 18.—Bé, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, fig. 18.

The test is highly porous, with the pores being of two sizes evenly scattered throughout the surface. The wall of the inner globigerine stage is highly fragile and was seldom found preserved in the material studied. Mostly all that was visible of this early stage was protoplasm roughly retaining the shape of the chambers and some spiny remnants of the wall. The globigerine stage is highly spinose, and the spines radiate out into the outer chamber, sometimes penetrating through the wall.

The wall of the outer chamber is variable in thickness and almost always single layered. However, on a few specimens the wall was observed to be double layered, with the layers loosely attached like the concentric rings of an onion. On these specimens the outer layer could easily be separated from the inner one with a dissecting needle.

The bichambered form, *Biorbulina bilobata* of some authors, is regarded here as a variant form of *Orbulina universa.* It is very rare and was observed at only one station (Sargasso Sea, summer station KK).

Distribution.—This species occurs mostly in the Sargasso Sea and Gulf Stream in low to moderately high frequencies. The lowest frequencies were recorded in the winter, with less than 2 percent at all stations. The summer traverse yielded the highest frequencies, reaching 18 percent at station KK.

Genus GLOBOROTALIA Cushman, 1927

GLOBOROTALIA PUNCTULATA (d'Orbigny)

Plate 4, figure 4; plate 5, figure 1

Globigerina punctulata D'ORBIGNY, 1826, Ann. Sci. Nat., vol. 7, p. 277, No. 8.—FORNASINI, 1898, Paleontol., Ital., vol. 4, p. 210, text fig. 5.

Globorotalia punctulata Phleger, PARKER and PEIRSON, 1953, Rep. Swedish Deep-Sea Exped., vol. 7, No. 1, p. 20, pl. 4, figs. 8-12.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 9-12.

Globorotalia crassaformis (Galloway and Wissler, 1927). PARKER, 1962, Micropaleontol., vol. 8, No. 2, p. 35, pl. 4, figs. 17-18, 20-21.

The test of this species is characterized by its flattened dorsal side and its relatively high spire. The periphery is angular and, occasionally, thinly keeled. The aperture is slitlike and extends from the umbilicus to the vicinity of the periphery. On some specimens there is a thin lip above the aperture.

The close morphologic affinities between *Globorotalia punctulata* and *Globigerina inflata* were mentioned under the latter. It is possible that somewhere in their geographic and stratigraphic ranges these forms intergrade, and they may eventually prove to be conspecific subspecies.

There has been considerable confusion concerning the rightful name of this species, but no attempt is made here to resolve this complicated legal problem which has been dealt with by Parker (1958, p. 281; 1962, p. 235) and Banner and Blow (1960, p. 15). Suffice it to say that the present specimens are identical with *G. punctulata* as figured by Fornasini. However, they are not identical with the single lectotype for both *G. puncticulata* and *G. punctulata* designated by Banner and Blow. That lectotype clearly is not the same specimen figured by

Fornasini as *G. punctulata* and in fact, as figured, appears referable to *G. inflata.* Therefore, the lectotype is a potential source of taxonomic confusion. With *G. punctuculata* as the senior synonym of *G. punctulata* and *G. inflata,* the past records of two commonly occurring, related species having different distributional patterns would become virtually uninterpretable.

Distribution.—This species occurred mostly in the southern stations. Frequencies were low throughout the year. A maximum frequency of 4 percent was recorded in the summer at station MM in the Sargasso Sea and in the winter at station NN, also in the Sargasso Sea. The fall maximum was 3 percent (station 5, slope waters), and the spring maximum was 1 percent (station 6, slope waters).

GLOBOROTALIA HIRSUTA (d'Orbigny)

Plate 5, figures 2, 3

Rotalina hirsuta d'Orbigny, 1939, *in* Barker-Webb and Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 131, pl. 1, figs. 37-39.

Globorotalia hirsuta Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 44, pl. 8, figs. 1, 2.

This species is convex on the dorsal side and flattened on the ventral side. The periphery is subacute and slightly keeled. The aperture is a narrow opening extending beyond the umbilicus and sometimes reaching the periphery. The surface of the test is coarsely, but irregularly, spinose and punctate, closely resembling the surface of *G. truncatulinoides, G. punctulata,* and some representatives of *Globigerina inflata.*

The spire of *Globorotalia hirsuta* is much compressed, and the test has the appearance of a *G. punctulata* that has been flattened on the ventral side and expanded somewhat on the dorsal side.

Distribution.—This species was observed to occur rarely and was found only in the stations south of the Gulf Stream. It was most abundant in the winter at station OO, where the frequency was 4 percent.

GLOBOROTALIA MENARDII (d'Orbigny)

Plate 6, figures 3, 4

Rotalia menardii d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 273, No. 26; Modèles, No. 10.

Globorotalia menardii Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 44, pl. 8, figs. 3, 4.—Bé, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 1-3.

Globorotalia cultrata (d'Orbigny, 1839) Parker, 1962, Micropaleontol., vol. 8, No. 2, p. 235, pl. 5, figs. 3-5.

The present specimens were compared with representatives of this species from plankton tows collected in the Lesser Antilles region of the Caribbean. Although the present Central Atlantic forms are clearly identical with Caribbean forms, some small general differences were noted, as follows:

1, The Central Atlantic form, on the average, appears to be of smaller size.

2, In the Central Atlantic form the test is smooth with few or no pustules on the surface. In the Caribbean form the test ranges from smooth to rough, with many pustules or, occasionally, an additional coating of calcite on the surface.

3, The keel of the Central Atlantic form is thin and smooth with little or no denticulation. In the Caribbean form the keel is more variable and includes forms with thickened and crenulate keels.

In general, the Central Atlantic form is simpler and shows less variation than the Caribbean form.

Distribution.—This species was observed mostly in the Sargasso Sea stations. The highest frequency was recorded in the summer at station KK (7 percent). However, most of the records were 1 percent or less, suggesting that the stations occupied are beyond the optimum range of *G. menardii.* It was particularly scarce in the stations from the winter and spring traverses.

GLOBOROTALIA TRUNCATULINOIDES (d'Orbigny)

Plate 6, figures 1, 2; text figure 3

Rotalina truncatulinoides d'Orbigny, 1939, *in* Barker-Webb and Berthelot, Hist. Nat. Îles Canaries, vol. 2, pt. 2, Foraminifères, p. 132, pl. 2, figs. 25-27.

Globorotalia truncatulinoides Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 44, pl. 8, figs. 7, 8.—Bé, 1959, Micropaleontol., vol. 5, No. 1, pl. 1, figs. 5-7.

Globorotalia truncatulinoides is a distinctive and easily recognizable species. In the adult form the test is high spired and has the shape of a truncated cone, flattened on the dorsal side and with 5 chambers visible on the ventral side. The periphery is subrounded in side view, slightly keeled and denticulate. The aperture is a narrow, basal slit that extends to a deep, narrow umbilicus; above the aperture there is a well-defined lip. The projections of the lips of apertures on the chambers surrounding the umbilicus form weak umbilical teeth.

Pustules or blunt spines are distributed over the entire surface but are concentrated mostly beneath the aperture of the final chamber.

The young form of this species does not have an umbilicus, and the ventral cone is much lower than in the adult form. The truncated conical shape of the test with an umbilicus is achieved during the ontogeny, at about the end of the second whorl, where there is a sudden relative increase in size of the lateral dimensions of the chamber. The lateral slope at this stage is less acute than in the early stage and tends to flare out with respect to the axial dimension of the chamber (fig. 3).

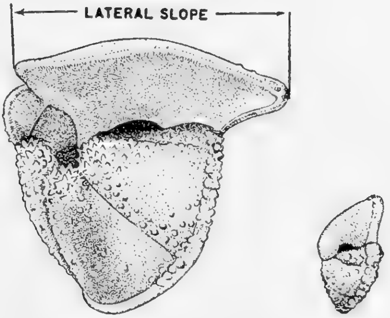

FIG. 3.—Relative increase in lateral slope of *Globorotalia truncatulinoides*. Left, mature form. Right, immature form.

In the material studied, this species showed a decided preference for sinistral coiling. However, specimens were not available in sufficient numbers from the summer and fall traverses to determine possible seasonal differences in coiling ratios.

Distribution.—*Globorotalia truncatulinoides* was the dominant species in the southern stations (JJ through OO) in the winter. The highest frequency was 55 percent at station JJ. At other seasons this species was rare or absent at most stations, the highest frequency being 3 percent in the fall at station 5.

Genus CANDEINA d'Orbigny, 1839

CANDEINA NITIDA d'Orbigny

Plate 5, figure 4

Candeina nitida D'ORBIGNY, 1839, *in* De la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 108, pl. 2, figs. 27-28.—BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 32, pl. 7, fig. 19.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, figs. 19, 20.

Candeina nitida is a very distinctive species, having 3 large, highly inflated final chambers that envelop most of the previous part of the test. Pores are distributed along the sutures of the last 3 chambers.

Distribution.—This species is very rare in the northwestern part of the Atlantic and was recorded only in the Sargasso Sea, at summer station KK and spring station 3. At both stations the frequencies were less than 1 percent.

Genus GLOBIGERINELLA Cushman, 1927

GLOBIGERINELLA AEQUILATERALIS (Brady)

Plate 7, figures 3-5

Globigerina aequilateralis Brady, 1884, Rep. Voy. *Challenger,* Zool., vol. 9, p. 605, pl. 80, figs. 18-21.

Globigerinella aequilateralis Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 38, pl. 7, figs. 1, 2.—Bé, 1959. Micropaleontol., vol. 5, No. 1, pl. 1, figs. 19, 20, 27.

Globigerinella siphonifera (d'Orbigny, 1839) Parker, 1962, Micropaleontol., vol. 8, No. 2, p. 228, pl. 2, figs. 22-28.

In its early stages this species is distinctly trochospiral and evolute. As growth proceeds the coiling becomes planispiral and the test partially involute with the later chambers overlapping and sometimes obscuring the trochospiral portion of the test. The large, inflated forms, however, are variable in coil and some tend to uncoil and grow erratically, with the final 1 or 2 chambers sometimes being added on either the dorsal or ventral side.

The wall is lacking in the axial region of the chambers so that the sides of the chambers in the later stages do not touch the previous whorl. As a result the aperture is usually a basal slit but is variable in size and extends entirely around the final chamber. It is often visible around the margins of the previous 1 or 2 chambers. In the larger forms that are partially uncoiled, the axial regions of the last few chambers are entirely exposed.

Banner and Blow (1960, p. 22) have resurrected the name *H. siphonifera* (d'Orbigny) for this species. However, this unnecessary name change is based on an uncertain type specimen (Todd, 1963, p. 110) and is contrary to the present principle of conservation of the International Code of Zoological Nomenclature.

Distribution.—Globigerinella aequilateralis is one of the dominant species of the subtropical assemblages. In the spring it reached a maximum frequency of 60 percent in the Sargasso Sea at station 2. In the summer the maximum frequency was 28 percent at station

LL. The percentages dropped in the fall, when the maximum was only 9 percent (station 9, in the Sargasso Sea) but increased in the winter, when the maximum was 17 percent (Sargasso Sea station MM).

Genus HASTIGERINA Thompson, 1876

HASTIGERINA PELAGICA (d'Orbigny)

Plate 7, figures 1, 2

Nonionina pelagica D'ORBIGNY, 1838, Foram. Amér. Mérid., p. 27, pl. 3, figs. 13, 14.

Hastigerina murrayi Thompson, 1876, BOLLI, LOEBLICH, and TAPPAN, 1957, U. S. Nat. Mus. Bull. 215, p. 29, pl. 3, figs. 1-3b.

Hastigerina pelagica BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 47, pl. 8, figs. 14, 15.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, figs. 21-22.—BANNER and BLOW, 1960, Micropaleontol., vol. 6, p. 20, text fig. 1.

The test consists of a highly involute, biumbilicate planispiral coil of inflated chambers that is sometimes compressed laterally. A trochoid stage was not observed. The aperture is an equatorial opening at the base of the last chamber that varies in size from a slit to a broad arch. Above the aperture is a thin lip. The wall of the test is very thin and extremely fragile, and specimens are often in a poor state of preservation, even from plankton tows. The spines are few in number but are coarse and triradiate (Banner and Blow, 1960, p. 21). The spines extend into, and even through, the walls of the chambers from the previous whorl.

Hastigerina pelagica is one of the most distinctive and easily recognizable Recent planktonic species. It is most readily comparable with *Globigerinella aequilaterlalis,* but I agree with Parker (1962, p. 228) in retaining these two species in separate genera. As Parker states, a much better case can be made for combining *H. pelagica* with *Hastigerinella digitata,* as these two latter species are unique in their spinosity.

Distribution.—This species reached a maximum frequency of 24 percent in the summer at Sargasso Sea station (LL) but otherwise occurred mostly in low percentages. The winter maximum was 13 percent (Sargasso Sea station KK), but the fall maximum was only 3 percent and the spring maximum only 1 percent.

Genus GLOBIGERINOIDES Cushman, 1927

The genus *Globigerinoides* includes a distinctive group of species with peculiar chamber arrangements that tend to deviate considerably from the trochospiral coil as seen in *Globigerina.* The chamber arrangements, though sometimes difficult to express geometrically, are useful in distinguishing the species of *Globigerinoides.* Illustrations of chamber arrangements in Recent species of *Globigerinoides* are shown in figure 4.

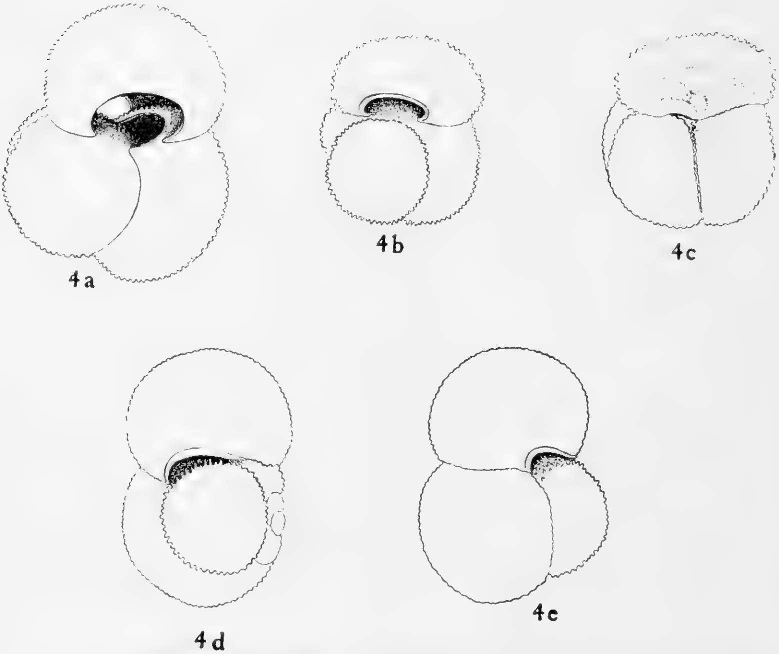

Fig. 4.—Chamber arrangements and positions of primary apertures in some species of *Globigerinoides.* 4a, *G. ruber,* ventral view. 4b, *G. conglobatus,* immature form, ventral view. 4c, *G. conglobatus,* mature form, ventral view. 4d, *G. trilobus trilobus,* edge view. 4e, *G. trilobus trilobus,* ventral view.

In *Globigerinoides conglobatus* the chambers are coiled in a fashion similar to that in *Pulleniatina obliquiloculata,* with the early chambers added in a trochoid spiral and the final chambers added streptospirally, overlapping the umbilicus. In the final stage of development the last chamber completely covers the umbilicus.

In *Globigerinoides ruber* there is a pronounced shift in the axis of the chambers as they are added; in fact, it is somewhat difficult to think of the chambers actually forming a coil. Each chamber is added directly above the aperture of the earlier chamber. The aperture of the new chamber is 90 degrees apart from the aperture of the previous chamber. This arrangement of chambers might possibly be thought of as an extreme streptospiral coil, with the coil changing 90 degrees in direction with the addition of each chamber. The test is nonumbilicate, as in the mature *G. conglobatus.* The chamber arrangement of *G. elongatus* is identical with that of *G. ruber.*

The chamber arrangement in *Globigerinoides trilobus* is more obscure. In edge view the test is rather flattened and the chambers appear to adhere to the trochospiral coil as in *Globigerina.* At the same time, however, portions of the new chambers overlap the ventral side of the test considerably, so that the umbilicus is almost obscured and the aperture is low and elongate. In overall appearance *G. trilobus* is similar to *G. ruber* when viewed from the ventral side, where 3 chambers are visible with 1 larger chamber set above 2 smaller, earlier chambers. However, in *G. ruber* the primary aperture is symmetrical above the 2 earlier chambers, while in *G. trilobus* it is asymmetrical (Bolli, 1957, p. 112).

GLOBIGERINOIDES ELONGATUS (d'Orbigny)

Plate 8, figures 1, 4

Globigerina rubra D'ORBIGNY, 1839, *in* De la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 82, pl. 4, figs. 12-14.—BANNER and BLOW, 1960, Contr. Cushman Foram. Res., vol. 11, pt. 1, p. 19, pl. 3, figs. 8a, b.

Globigerinoides rubra BRADSHAW, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 42, pl. 7, figs. 12, 13.—BÉ, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, figs. 16, 17.

This species is nonumbilicate, and each new chamber is added above the primary aperture of the earlier chamber. The final chamber is sometimes reduced in size, appearing like a small bubble on the previous part of the test. The primary aperture is a broad arched opening at the base of the last chamber, which is symmetrically located above the 2 earlier chambers. There are 2 supplementary apertures on the side of the chamber opposite to the primary aperture. The supplementary apertures vary from low slits to broad, rounded openings; on some of the smaller specimens they are barely perceptible. When well developed, the supplementary apertures can be seen on the last 2 or 3 chambers.

The color in *Globigerinoides ruber* ranges from white through various shades of pink to bright red. Most often, the red or pink color is confined, appearing only in part, particularly the early part, of the test. In the summer traverse over 75 percent of the specimens were red or pink in color, and most of these were bright red. In the winter traverse the white forms predominated, accounting for over 50 percent of this species. The winter-colored specimens included only shades of pink, and bright red forms were lacking. In the fall and spring traverses the colors were intermediate between summer and winter.

Distribution.—Overall, *Globigerinoides ruber* is the most abundant species of *Globigerinoides* in the traverses studied. It was also one of the dominant species of the subtropical assemblages. The highest frequency recorded was 43 percent at the summer slope station HH. Along with other species of *Globigerinoides,* the frequency dropped considerably in the winter, reaching a maximum of only 8 percent (station II).

GLOBIGERINOIDES ELONGATUS (d'Orbigny)

Plate 9, figure 5

Globigerina elongata d'Orbigny, 1826, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, pt. 1, p. 12, pl. 3, figs. 10a-c.

This species closely resembles and may turn out to be a variant form of *Globigerinoides ruber.* However, the test is more compact than in *G. ruber,* and the final chambers are compressed, almost flattened, as in *G. conglobatus.*

The primary aperture is symmetrically located above the two earlier chambers in *G. elongatus* but is less broad than in *G. ruber.* The present specimens agree with the lectotype of *G. elongatus* as figured by Banner and Blow.

Distribution.—This species is rare and was recorded only from Sargasso Sea stations. In all cases the frequencies were less than 1 percent.

GLOBIGERINOIDES TRILOBUS TRILOBUS (Reuss)

Plate 9, figures 1-3

Globigerina triloba Reuss, 1850, Denkr. K. Akad. Wiss. Wien, vol. 1, p. 374, pl. 47, fig. 11.

Globigerinoides sacculifer (Brady, 1877), Bé, 1959, Micropaleontol., vol. 5, pl. 2, figs. 13-15.

In this species the final chamber is set above the two preceding ones, as in *Globigerinoides ruber.* However, the coiling of *G. trilobus trilobus* is essentially trochospiral, and the final chamber does not completely cover the umbilicus, so that the primary aperture is a narrow slit at the base of the chamber. On the dorsal side of the chamber there is a single supplementary aperture, in contrast to *G. ruber* in which there are two supplementary apertures on the chamber.

This species shows variation in the size of the supplementary aperture and in the development of the final saclike chamber. The following forms which are completely transitional were recognized in the material studied.

1, Supplementary aperture small, saclike final chamber lacking.
2, Supplementary aperture large, saclike final chamber lacking.
3, Supplementary aperture small, saclike final chamber present.
4, Supplementary aperture large, saclike final chamber present.

Form 1 occurs most commonly, but form 2 is also present in appreciable numbers. Form 3 and particularly form 4 are relatively scarce. The specimens agree very well and are identical with Miocene topotypes of *Globigerina trilobus* Reuss in the U. S. National Museum collections, which include both forms 1 and 2, with dominance of form 1. They differ from *G. sacculifer* Brady in having smaller supplementary apertures and less-developed saclike final chambers. Specimens of *G. sacculifer* from Recent Pacific bottom sediments studied for comparison included the same range of forms as *G. trilobus* but showed a dominance of forms 3 and 4. Moreover, the Pacific *sacculifer* includes a form with an elongate saclike final chamber (Brady, 1884, pl. 80, fig. 4) that was not observed in the North Atlantic material.

Thus, *G. trilobus* and *G. sacculifer* represent overlapping parts of a gradational series, a fact noted by several earlier workers, and as such are distinguishable only at the subspecific level. Although called subspecies, however, *trilobus* and *sacculifer* are not subspecies in the geographic sense of the neontologist, since *G. trilobus* sensu lato has a long, complex fossil record. Additional difficulties in applying the neontological subspecies concept are introduced by the fact that the species has a pelagic habitat. The isolating mechanisms in the open ocean are much less understood than those on land or even on the ocean bottom.

It would be convenient if the gradational series between *trilobus* and *sacculifer* also represented an evolutionary series, as then it would be an easy matter to divide the series into vertical subspecies, in the sense of the paleontologist. Unfortunately, such a simple phyletic trend does not characterize this lineage. The present North Atlantic assemblages show a closer morphologic affinity to the Miocene assemblages of *trilobus* than to Recent assemblages of *sacculifer*. Thus, *G. trilobus* will not yield gracefully to a vertical division of subspecies.

Vertical subspecies could not be identified without knowing the age of the assemblage.

There are, in the fossil record, several additional forms that can be linked to the *trilobus–sacculifer* gradational series, such as *G. altiapertura* and *G. immatura.* These forms have been treated in different ways by various authors, but the treatment thus far has been dominantly typological. As a result, the range of forms in *G. trilobus* sensu lato is reasonably well known, but there is still a poor understanding of the nature of population structures at the various stratigraphic levels. Parker (1962, p. 219) pointed out the necessity of treating assemblages as populations, and it could be added that this particular problem lends itself to a quantitative analysis, since the distinctions between the subspecies involve gradational characters. In order to determine the actual changes that have occurred in *G. trilobus* sensu lato since the Miocene, it will be necessary to analyze statistically the character of many assemblages from widely separated localities ranging from Miocene to Recent; a formidable task, but only in this way can a complete and realistic alignment of subspecies be attained.

Thus, any present arrangement of subspecies must be considered tentative and incomplete. It seems unnecessarily pretentious to force subspecies into horizontal or vertical straitjackets, and it is much more compatible with the evidence at hand to recognize subspecies as dynamic populations in which the range of variation fluctuates through time and space.

Distribution.—Although *Globigerinoides trilobus trilobus* was not as common, overall, as *G. ruber,* the ratio between the two species varied considerably from station to station, and at a few stations *G. trilobus trilobus* was the dominant species of *Globigerinoides.* Its highest frequency was 45 percent, which was recorded in the fall at station 8, in the Sargasso Sea.

GLOBIGERINOIDES CONGLOBATUS (Brady)

Plate 8, figures 2, 3

Globigerina conglobata Brady, 1884, Rep. Voy. *Challenger,* Zool., vol. 9, p. 603, pl. 80, figs. 1-5, pl. 82, fig. 5.

Globigerinoides conglobata Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, p. 40, pl. 7, figs. 5, 6.—Bé, 1959, Micropaleontol., vol. 5, No. 1, pl. 2, figs. 7-12.

Globigerinoides sp. Bradshaw, 1959, Contr. Cushman Found. Foram. Res., vol. 10, pt. 2, pl. 7, figs. 16, 17.

Throughout most of the test the coiling is trochospiral, but in the last whorl the final 2 chambers overlap the umbilicus. In many specimens the last chamber completely covers the umbilicus, and the primary aperture is a small, rounded opening symmetrically located above 2 earlier chambers. The last chamber is compressed and flattened in appearance. In the early stages this species has an open umbilicus and in coiling closely resembles species of *Globigerina*. The specimen that Bradshaw (1959, pl. 7, figs. 16, 17) figured as *Globigerinoides* sp. is considered here to be an early stage of *G. conglobatus*. The wall of this species is relatively thick for a *Globigerinoides* and the surface is coarsely spinose.

Distribution.—This is a characteristic species in the subtropical assemblages but was found mostly at frequencies of less than 5 percent. However, at Sargasso Sea summer station KK it was recorded at a frequency of 15 percent and was the dominant species of *Globigerinoides*.

APPENDIX

TABLE 5.—*Positions of plankton-collecting stations, summer traverse, August 1960. Water depths are given for the shelf stations only.*

Water body	*Station*	*Depth in meters*	*Latitude N.* ° ′	*Longitude W.* ° ′
Shelf waters	A	36	40 58	71 49
“	B	64	40 44	71 41
“	C	67	40 31	71 35
“	D	77	40 18	71 28
“	E	314	40 00	71 19
Slope waters	F		39 48	71 12
“	G		39 36	71 06
“	HH		38 46	70 12
“	HH′		38 39	69 33
“	HH″		38 12	69 18
Gulf Stream	II		38 00	69 32
Sargasso Sea	JJ		37 12	68 48
“	KK		36 23	68 04
“	LL		35 35	67 20
“	MM		34 47	66 29

TABLE 6.—*Positions of plankton-collecting stations, fall traverse, October 1960. Water depths are given for the shelf stations only.*

Water body	*Station*	*Depth in meters*	*Latitude N.* ° ′	*Longitude W.* ° ′
Shelf waters	1	36	41 03	71 29
“	2	65	40 48	71 25
“	3	68	40 28	71 21
“	4	122	40 06	71 15
Slope waters	5		39 17	71 03
“	6		38 27	70 53
Gulf Stream *	7		37 38	70 41
Sargasso Sea	8		36 58	70 08
“	9		36 14	69 18

* A bathythermograph was not available on this cruise and the position of Gulf Stream was estimated by the set of the ship.

TABLE 7.—*Positions of plankton-collecting stations, winter traverse, January 1961. Water depths are given for the shelf stations only.*

Water body	*Station*	*Depth in meters*	*Latitude N.* ° ′	*Longitude W.* ° ′
Shelf waters	A	36	40 59	71 51
"	B	65	40 44	71 41
"	C	70	40 31	71 36
"	D	77	40 18	71 28
"	E	342	39 56	71 18
Slope waters	F		39 48	71 12
"	G		39 37	71 06
"	HH		38 46	70 19
Gulf Stream	II		37 46	69 20
Sargasso Sea	JJ		37 10	68 38
"	KK		36 23	68 05
"	LL		35 35	67 21
"	MM		34 43	66 22
"	NN		33 56	65 51
"	OO		33 06	65 03

TABLE 8.—*Positions of plankton-collecting stations, spring traverse, May 1961. Water depths are given for the shelf stations only.*

Water body	*Station*	*Depth in meters*	*Latitude N.* ° ′	*Longitude W.* ° ′
Shelf waters	9	52	40 45	70 30
"	8	58	40 31	70 20
Slope waters	7		39 51	69 47
"	6		39 07	69 14
"	5		38 35	68 50
"	4		38 00	68 26
Gulf Stream	3		37 20	67 51
Sargasso Sea	2		36 06	67 06

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EXPLANATION OF PLATES

PLATE 1

Fig. 1. *Globigerina bulloides* d'Orbigny. Summer slope station HH″. U.S.N.M. 641307. a, Dorsal view. b, Ventral view. ×93.

Fig. 2. *Globigerina bulloides* d'Orbigny. Fall shelf station 3. U.S.N.M. 641308. a, Dorsal view. b, Ventral view. ×93.

Fig. 3. *Globigerina bulloides* d'Orbigny. Spring slope station 4. U.S.N.M. 641309. a, Ventral view. b, Dorsal view. ×93.

Fig. 4. *Globigerina pachyderma incompta* Cifelli. Fall slope station 5. U.S.N.M. 641310. a, Ventral view. b, Dorsal view. ×148.

Fig. 5. *Globigerina bulloides* d'Orbigny. Summer slope station F. U.S.N.M. 641311. a, Dorsal view. b, Ventral view. ×93.

Fig. 6. *Globigerina pachyderma incompta* Cifelli. Fall slope station 6. U.S.N.M. 641312. a, Dorsal view. b, Ventral view. ×148.

PLATE 2

Fig. 1. *Globigerina dutertrei* d'Orbigny. Summer slope station HH′. U.S.N.M. 641313. a, Dorsal view. b, Ventral view. ×65.

Fig. 2. *Globigerina dutertrei* d'Orbigny. Fall slope station 6. U.S.N.M. 641314. a, Ventral view. b, Dorsal view. ×65.

Fig. 3. *Globigerina* aff. G. *quinqueloba* Natland. Winter shelf station B. U.S.N.M. 641315. a, Ventral side. b, Dorsal side. ×214.

Fig. 4. *Globigerina* aff. G. *quinqueloba* Natland. Winter shelf station B. U.S.N.M. 641316. a, Ventral side. b, Dorsal side. ×214.

Fig. 5. *Globigerina* sp. Winter shelf station D. U.S.N.M. 641317. a, Ventral side. b, Dorsal side. ×148.

Fig. 6. *Globigerina* sp. Winter shelf station D. U.S.N.M. 641318. a, Dorsal side. b, Ventral side. ×148.

PLATE 3

Fig. 1. *Pulleniatina obliquiloculata* (Parker and Jones). Winter slope station HH. U.S.N.M. 641319. a, Dorsal view, b, Ventral view. ×93.

Fig. 2. *Globigerinita glutinata* (Egger). Spring Gulf Stream station 3. U.S.N.M. 641320. a, Ventral view. b, Dorsal view. ×148.

Fig. 3. *Pulleniatina obliquiloculata* (Parker and Jones). Winter slope station HH. U.S.N.M. 641321. a, Dorsal view. b, Ventral view. ×93.

Fig. 4. *Globigerinita glutinata* (Egger). Spring slope station 4. U.S.N.M. 641322. a, Ventral view. b, Dorsal view. ×148.

Fig. 5. *Globigerinita glutinata* (Egger). Spring slope station 4. U.S.N.M. 641323. a, Ventral view. b, Dorsal view. ×148.

Fig. 6. *Orbulina universa* d'Orbigny. Summer Sargasso Sea station KK. U.S.N.M. 641324. Bichambered form. ×46.

Fig. 7. *Orbulina universa* d'Orbigny. Fall Sargasso Sea station 9. U.S.N.M. 641325. ×46.

Plate 4

Fig. 1. *Globigerina inflata* d'Orbigny. Spring slope station 5. U.S.N.M. 641326. a, Ventral view. b, Edge view. c, Dorsal view. ×93.

Fig. 2. *Globigerina inflata* d'Orbigny. Fall slope station 5. U.S.N.M. 641327. a, Ventral view. b, Edge view. c, Dorsal view. ×93.

Fig. 3. *Globigerina inflata* d'Orbigny. Fall slope station 6. U.S.N.M. 641328. a, Ventral view. b, Dorsal view. ×93.

Fig. 4. *Globorotalia punctulata* (d'Orbigny). Summer Sargasso Sea station KK. U.S.N.M. 641329. a, Ventral view. b, Edge view. c, Dorsal view. ×93.

Plate 5

Fig. 1. *Globorotalia punctulata* (d'Orbigny). Summer Sargasso Sea station KK. U.S.N.M. 641330. a, Ventral view. b, Edge view. c, Dorsal view. ×93.

Fig. 2. *Globorotalia hirsuta* (d'Orbigny). Winter Sargasso Sea station OO. U.S.N.M. 641331. a, Dorsal view. b, Ventral view. ×65.

Fig. 3. *Globorotalia hirsuta* (d'Orbigny). Spring Sargasso Sea station 2. U.S.N.M. 641332. a, Dorsal view. b, Edge view. c, Ventral view. ×65.

Fig. 4. *Candeina nitida* d'Orbigny. Summer Sargasso Sea station KK. U.S.N.M. 641333. a, Ventral view. b, Dorsal view. ×93.

Plate 6

Fig. 1. *Globorotalia truncalulinoides* (d'Orbigny). Winter Sargasso Sea station NN. U.S.N.M. 641334. a, Ventral view. b, Dorsal view. ×93.

Fig. 2. *Globorotalia truncatulinoides* (d'Orbigny). Fall slope station 5. U.S.N.M. 641335. a, Dorsal view. b, Ventral view. ×93.

Fig. 3. *Globorotalia menardii* (d'Orbigny). Summer Sargasso Sea station LL. U.S.N.M. 641336. a, Ventral view. b, Dorsal view. ×93.

Fig. 4. *Globorotalia menardii* (d'Orbigny). Fall Sargasso Sea station 9. U.S.N.M. 641337. a, Ventral view. b, Dorsal view. ×93.

Plate 7

Fig. 1. *Hastigerina pelagica* (d'Orbigny). Winter Sargasso Sea station MM. U.S.N.M. 641338. a, Side view. b, Edge view. ×65.

Fig. 2. *Hastigerina pelagica* (d'Orbigny). Summer Sargasso Sea station LL. U.S.N.M. 641339. a, Edge view. b, Side view. ×65.

Fig. 3. *Globigerinella aequilateralis* (Brady). Winter Sargasso Sea station NN. U.S.N.M. 641340. a, Ventral view. b, Dorsal view. ×65.

Fig. 4. *Globigerinella aequilateralis* (Brady). Spring Gulf Stream station 3. U.S.N.M. 641341. a, Dorsal view. b, Ventral view. ×65.

Fig. 5. *Globigerinella aequilateralis* (Brady). Spring Gulf Stream station 3. U.S.N.M. 641342. a, Dorsal view. b, Ventral view. ×65.

Plate 8

Fig. 1. *Globigerinoides ruber* (d'Orbigny). Spring Gulf Stream station 3. U.S.N.M. 641343. a, Ventral view. b, Dorsal view. ×93

Fig. 2. *Globigerinoides conglobatus* (Brady). Fall slope station 6. U.S.N.M. 641344. a, Ventral view. b, Dorsal view. ×65.

Fig. 3. *Globigerinoides conglobatus* (Brady). Summer Sargasso Sea station LL. U.S.N.M. 641345. a, Dorsal view. b, Ventral view. ×93.

Fig. 4. *Globigerinoides ruber* (d'Orbigny). Spring Gulf Stream station 3. U.S.N.M. 641346. a, Dorsal view. b, Ventral view. ×93.

Plate 9

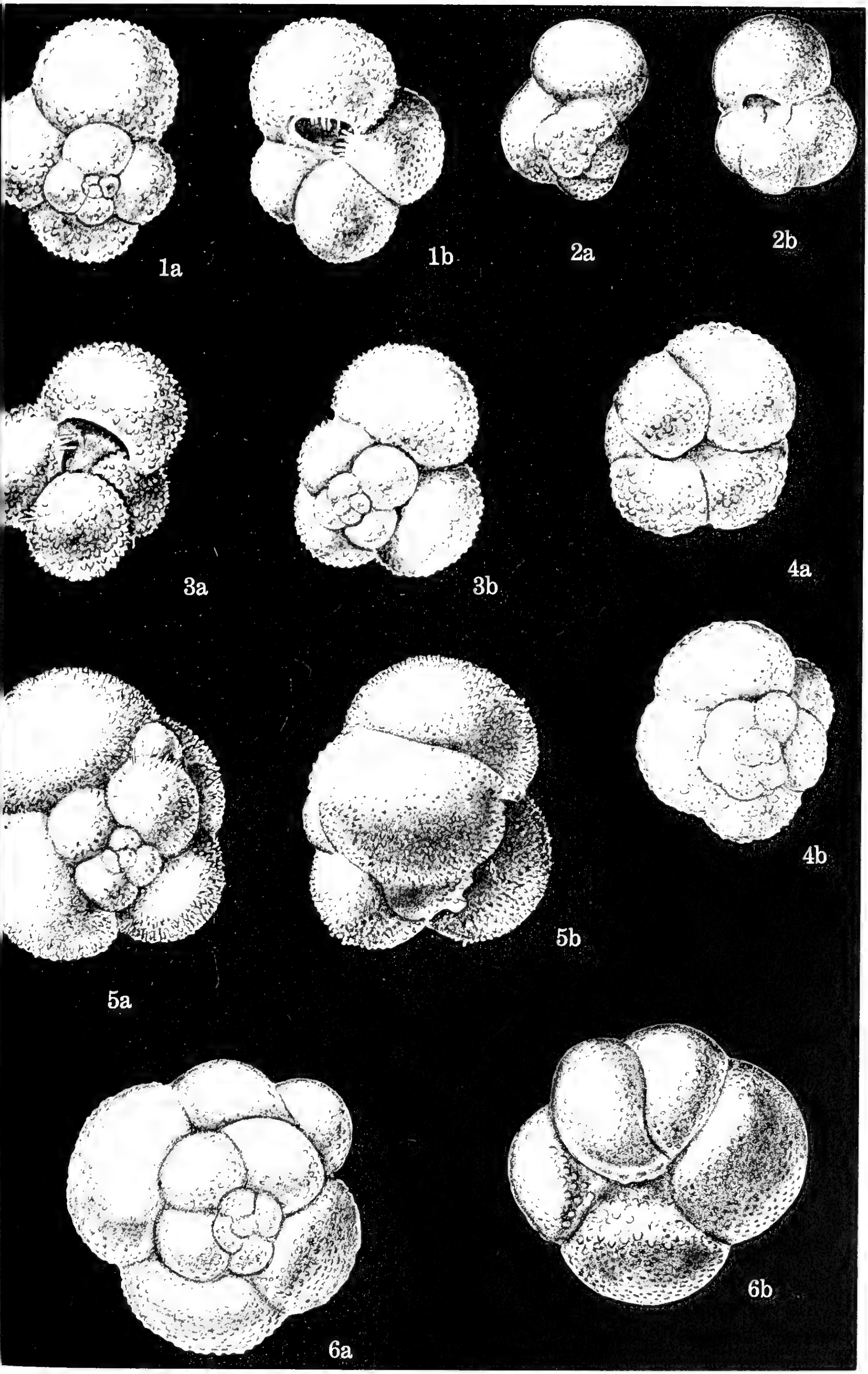
Fig. 1. *Globigerinoides trilobus trilobus* (Reus). Fall slope station 6. U.S.N.M. 641347. a, Ventral view. b, Dorsal view. ×65.

Fig. 2. *Globigerinoides trilobus trilobus* (Reus). Summer Sargasso Sea station KK. U.S.N.M. 641348. a, Ventral view. b, Dorsal view. ×65.

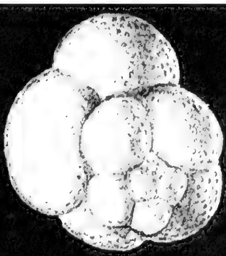
Fig. 3. *Globigerinoides trilobus trilobus* (Reus). Summer Sargasso Sea station KK. U.S.N.M. 641349. a, Ventral view. b, Dorsal view. ×65.

Fig. 4. *Globigerinoides trilobus trilobus* (Reus). Summer slope station HH′. U.S.N.M. 641350. a, Ventral view. b, Dorsal view. ×65.

Fig. 5. *Globigerinoides elongatus* (d'Orbigny). Winter Sargasso Sea station NN. U.S.N.M. 641351. a, Ventral view. b, Dorsal view. ×148.



GLOBIGERINA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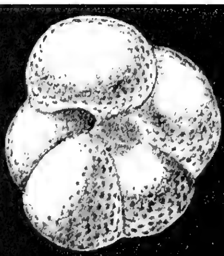
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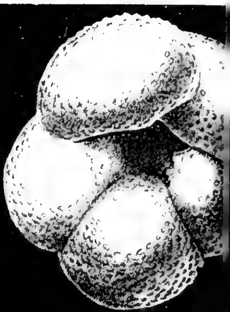

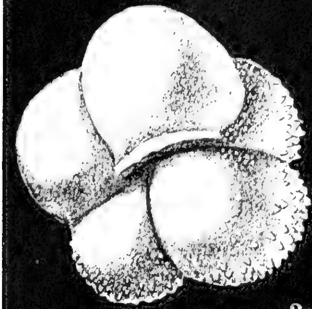
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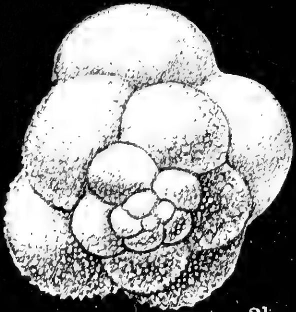
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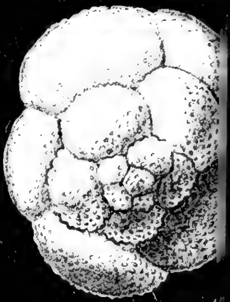

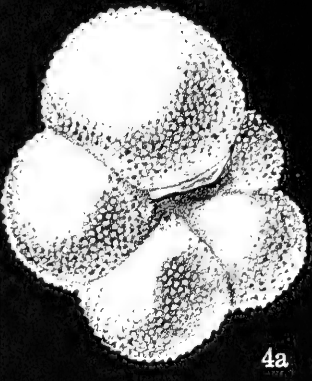
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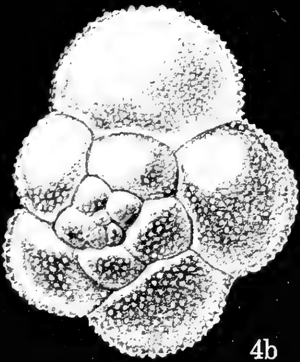
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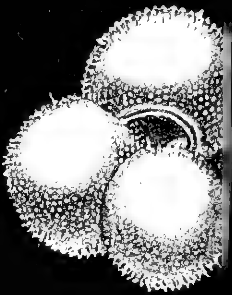
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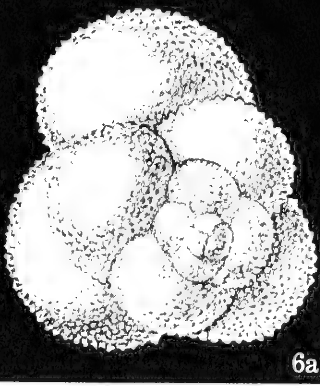
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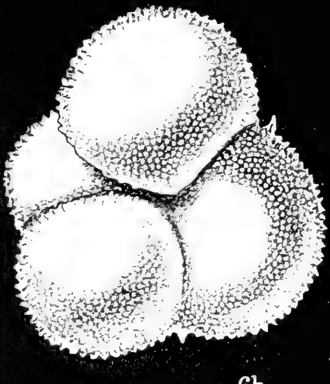
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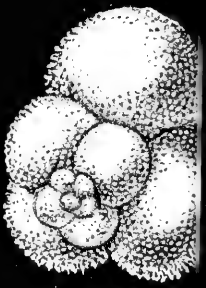
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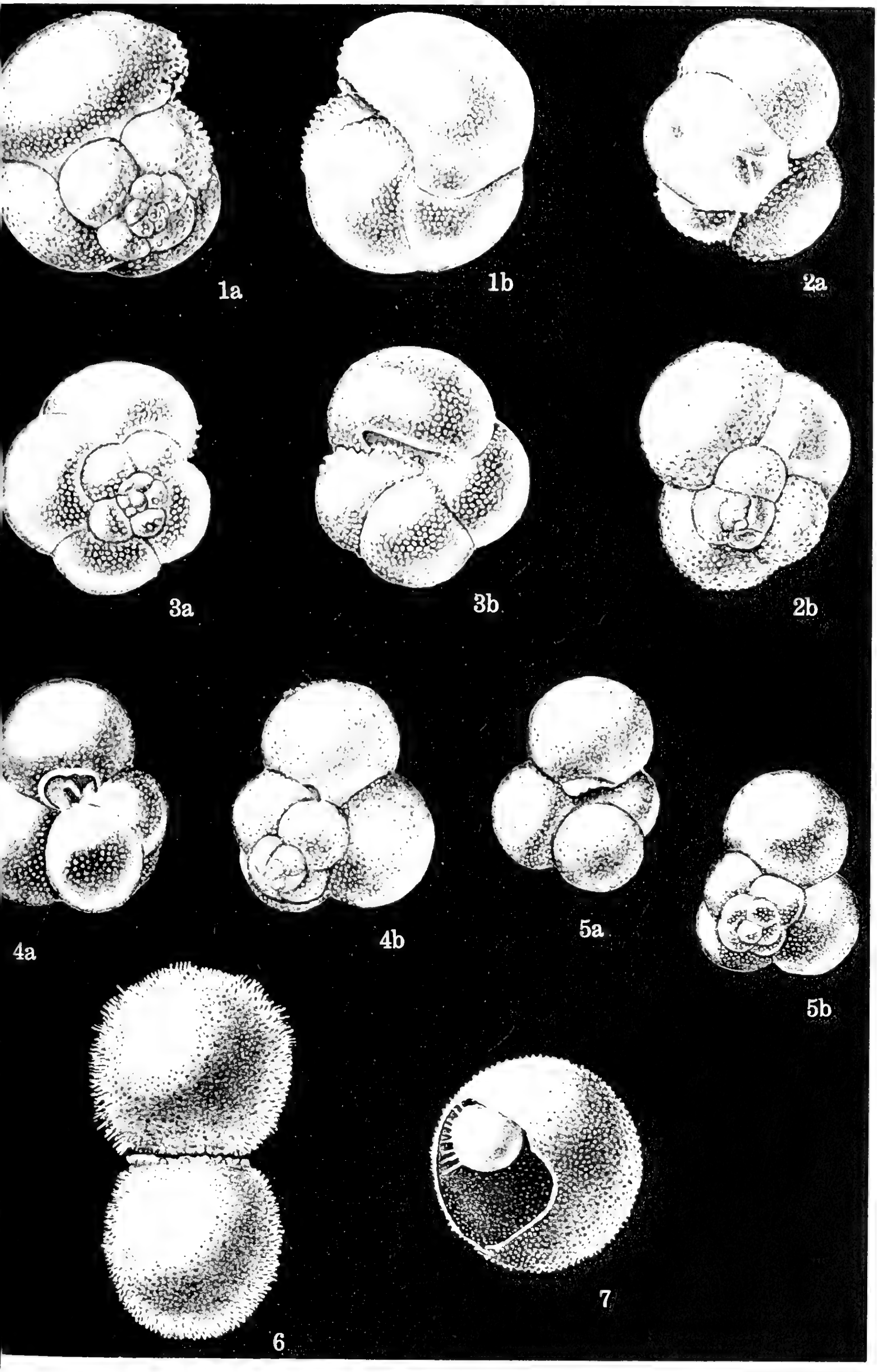
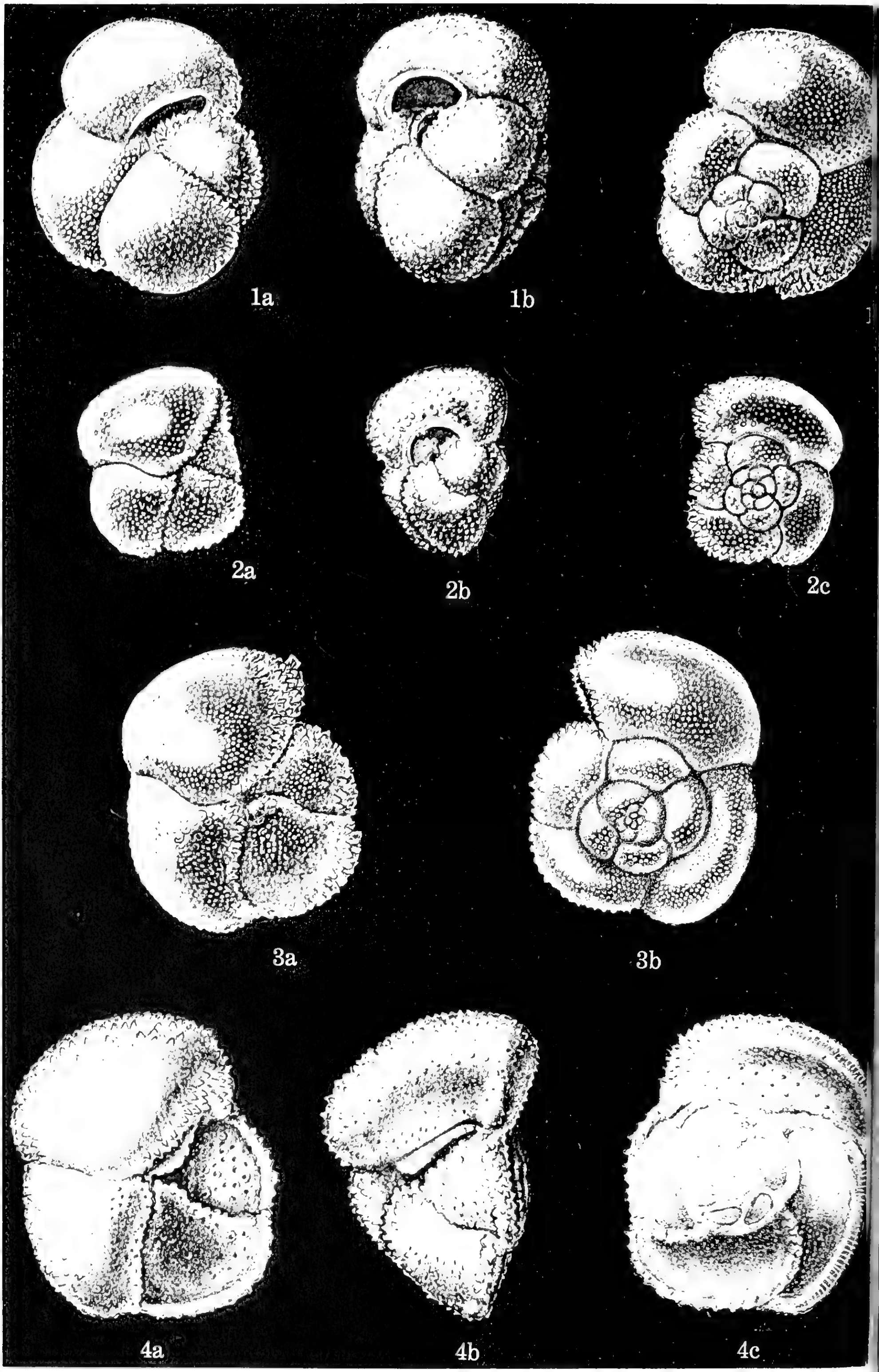
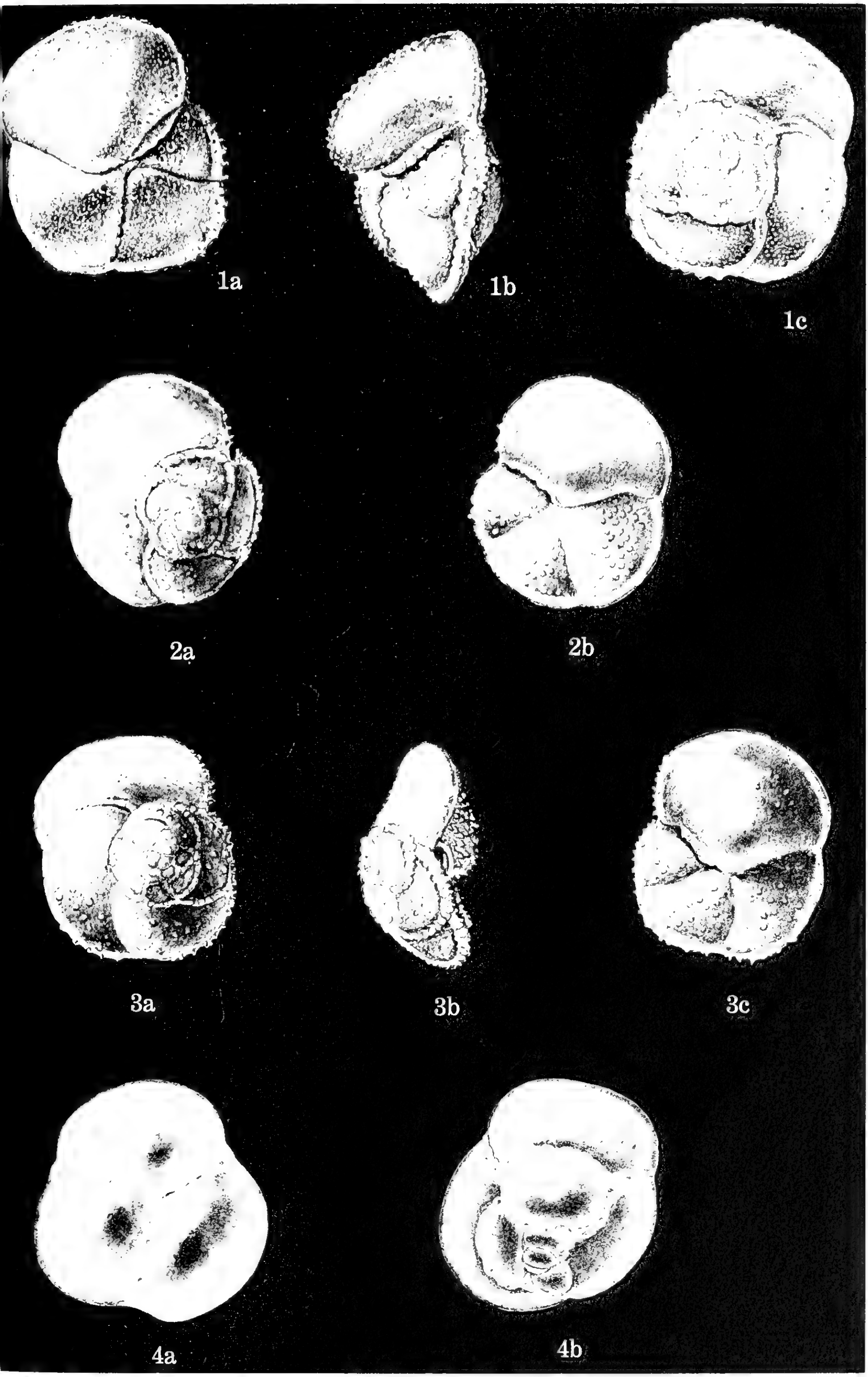
GLOBIGERINA



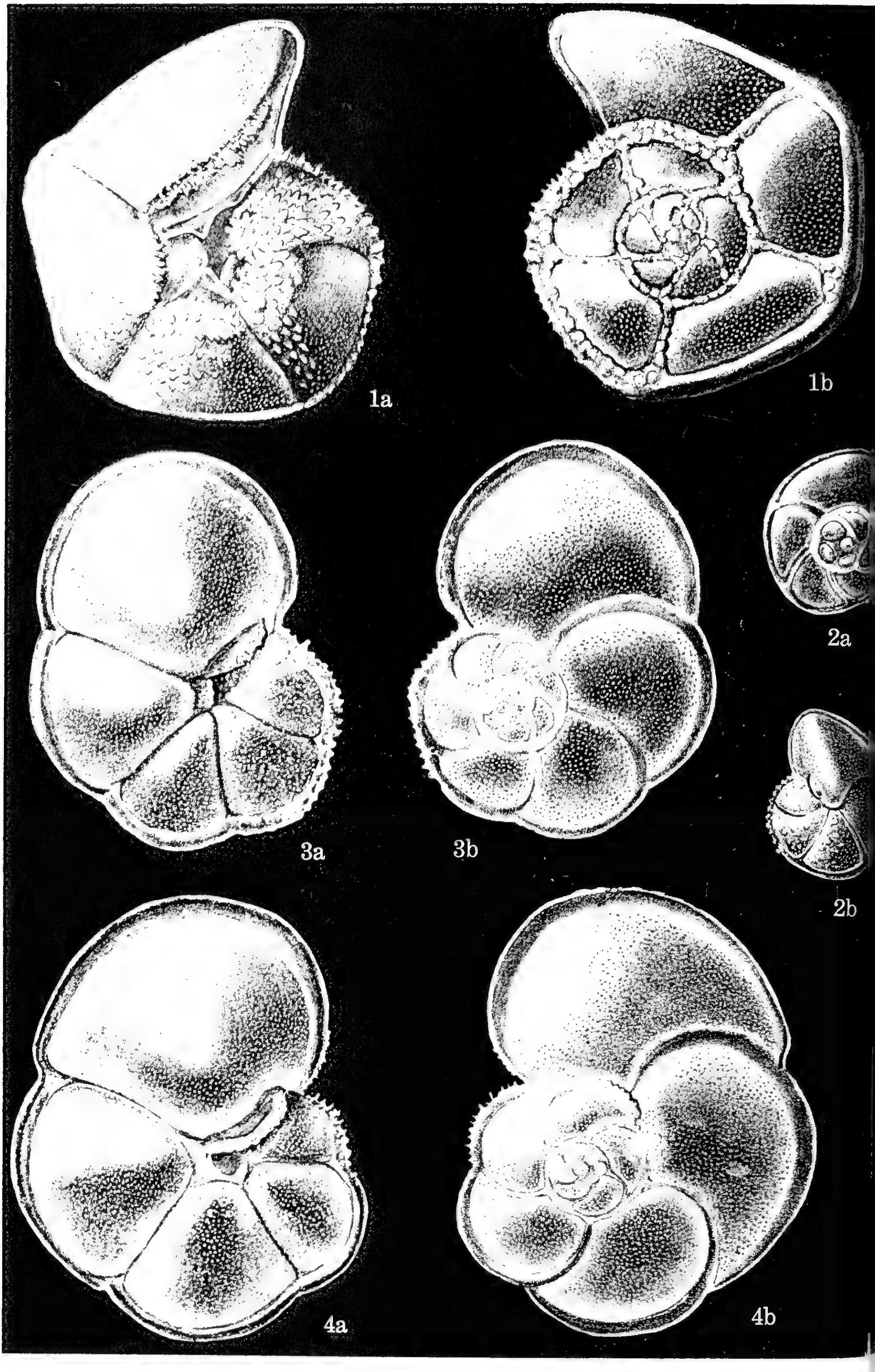
PULLENIATINA, GLOBIGERINITA, ORBULINA



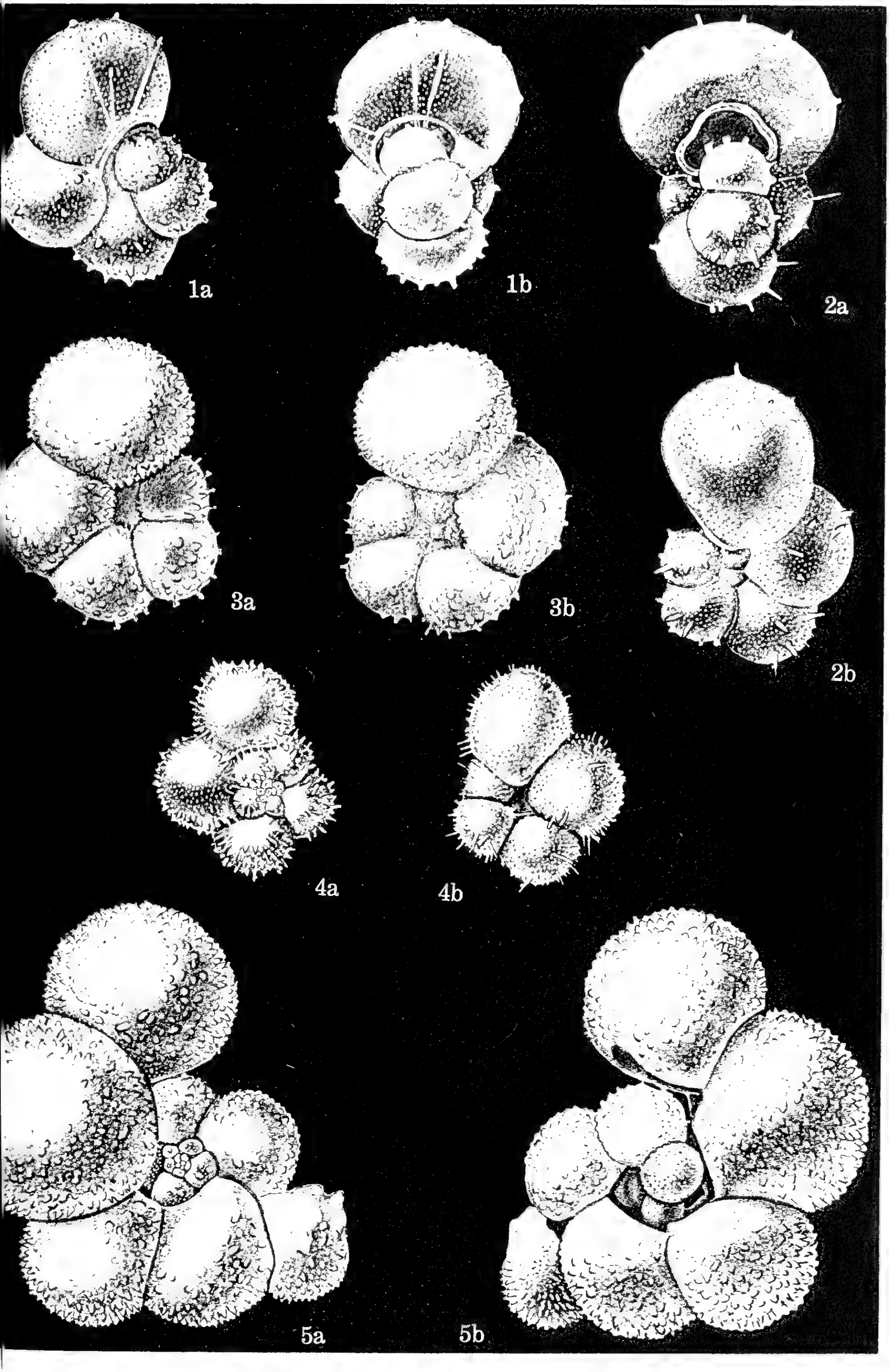
GLOBIGERINA, GLOBOROTALIA



GLOBOROTALIA, CANDEINA



Globorotalia



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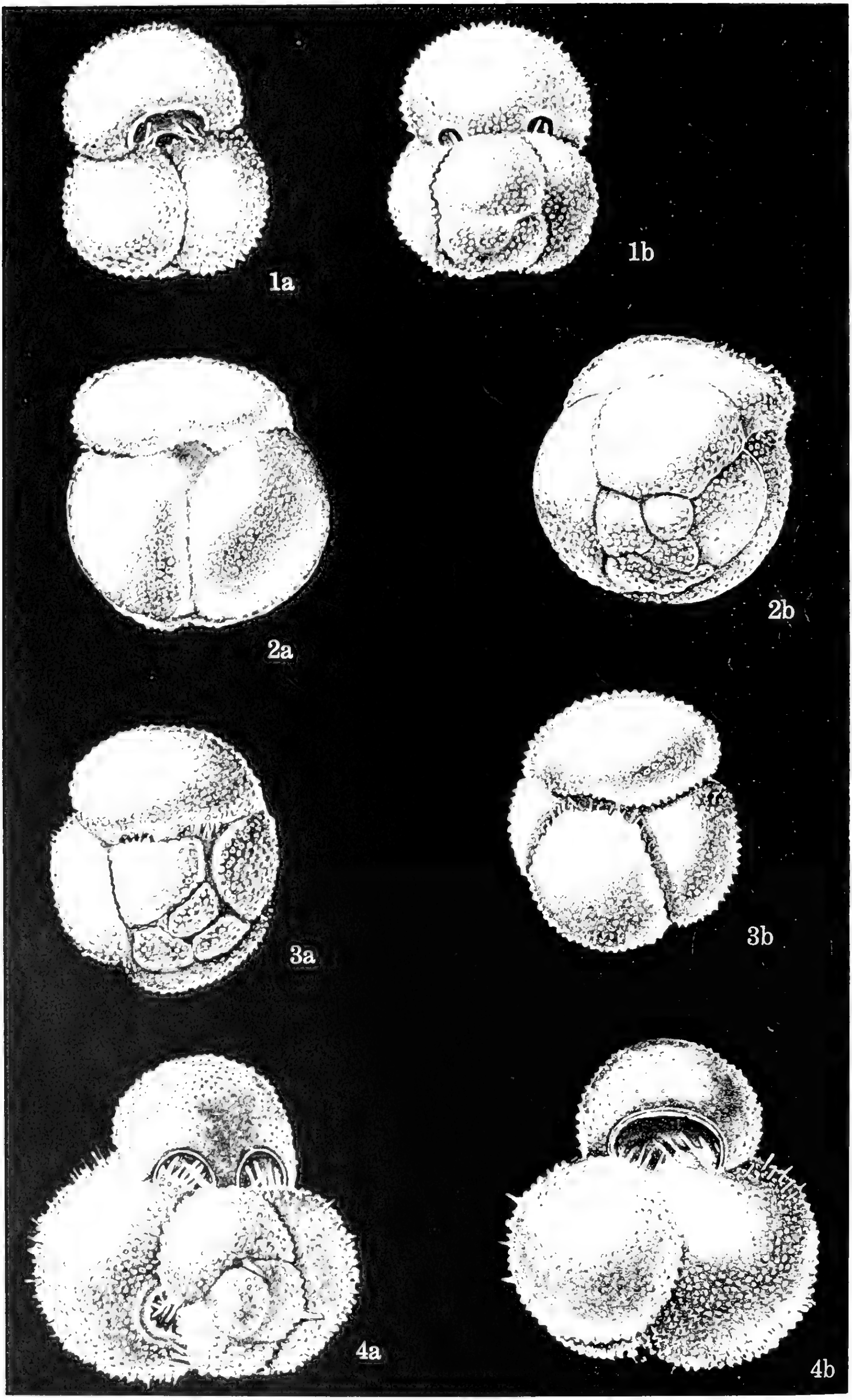

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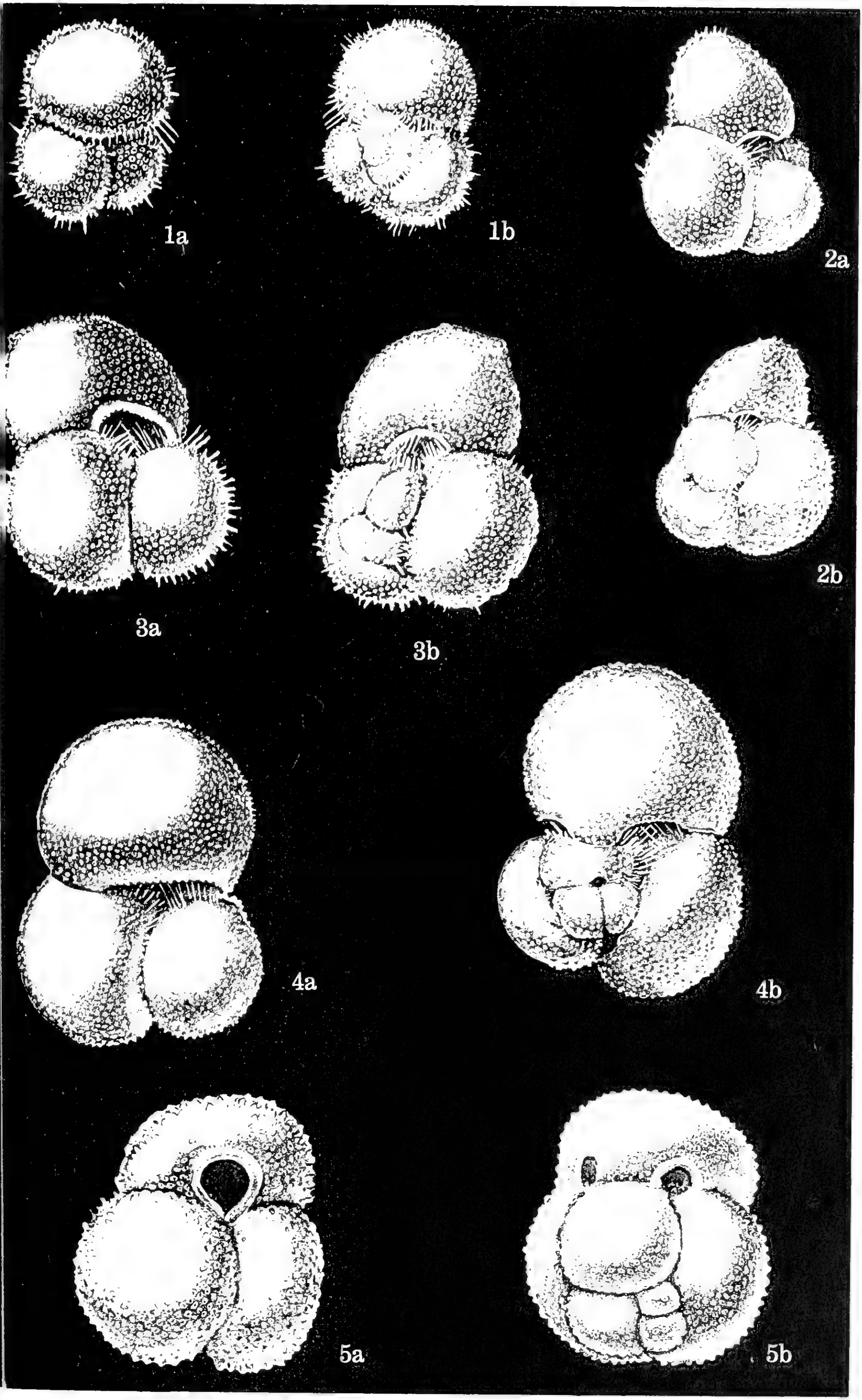

Globigerinoides

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 148, NUMBER 5

Charles D. and Mary Vaux Walcott Research Fund

HEXAHEDRITES

(WITH FOUR PLATES)

BY
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INTRODUCTION

Hexahedrites are the simplest of the iron meteorites and a comparatively easy type to recognize, yet many have been incorrectly classified. In several places these irons were found distributed in such a manner that they seem to have fallen as a shower. This investigation of the worldwide distribution of hexahedrites was made to determine how general these local concentrations are. In assembling the geographic data, certain characteristics were noted which could have a bearing on the scatter of these irons.

Acknowledgments.—Because these topics were discussed with many investigators in diverse disciplines over the years, it is difficult to credit specific points to the proper source. The author realizes that some names probably have been overlooked and to them he offers apologies. The following persons have made substantial contributions to this study: H. J. Axon, University of Manchester, Manchester, England; Harrison Brown, California Institution of Technology, Pasadena, Calif.; V. Buchwald, Technical University, Copenhagen, Denmark; Walter Corvello, National Museum, Rio de Janeiro, Brazil; Roy S. Clarke, Jr., U. S. National Museum, Washington, D. C.; M. E. Lipschultz, Goddard Space Flight Center, National Aeronautics and Space Administration, Washington, D. C.; Brian Mason, American Museum of Natural History, New York City; Charles Olivier, formerly of Flower Observatory, University of Pennsylvania, Philadelphia, Pa.; Sharat Roy (deceased), Chicago Museum of Natural History, Chicago, Ill.; Harold Urey, University of California, La Jolla, Calif.; H. Wänke, Max Planck Institute, Mainz, Germany.

HEXAHEDRITES AND THE NICKEL–IRON SYSTEM

The three types of iron meteorites, hexahedrites, octahedrites, and ataxites, are accounted for by the nickel–iron phase diagram, fig. 1; however, there are no clearly defined separations between the different types. The hexahedrite group is located to the left of the line AB in figure 1. These should consist of a single phase, alpha iron or kamacite. The octahedrites fall in the area between AB and AC and consist of two phases of nickel–iron alloys, kamacite (alpha iron) and taenite (gamma iron). The third group, ataxites, should

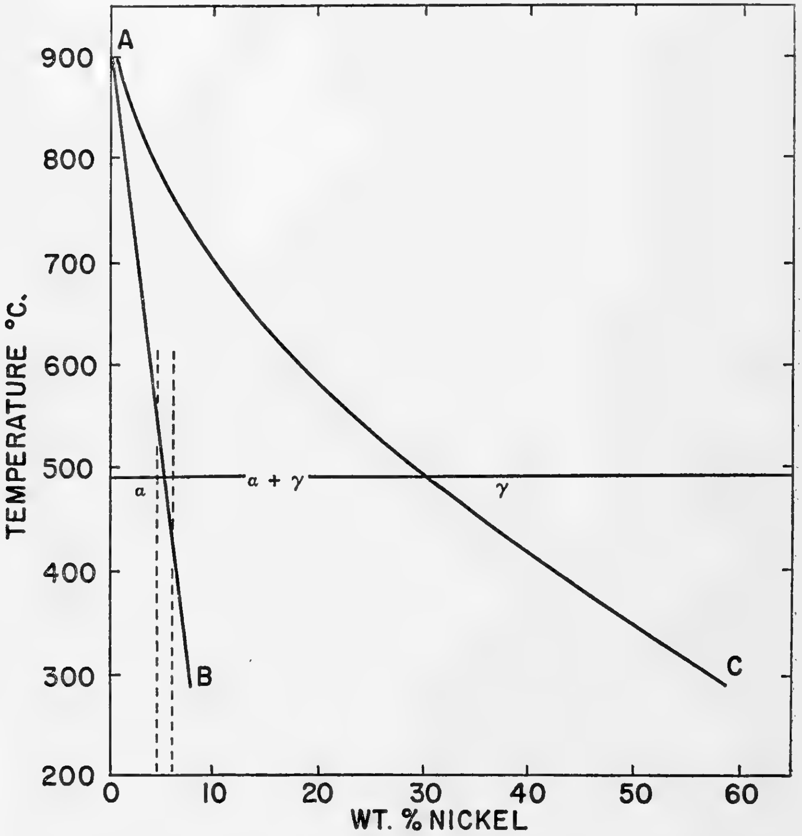

Fig. 1.—Nickel-iron phase diagram. The hexahedrites and nickel-poor ataxites fall into the same area, i.e., left of the line AB and usually within the area defined by the two dotted lines. A hexahedrite should consist of one nickel-iron alloy, kamacite or alpha iron.

occupy the area to the right of AC and chiefly consist of taenite, but usually also contain an appreciable quantity of alpha iron, kamacite.

Meteorites lying along the borderlines of groups are difficult to classify. Thus, any list of hexahedrites compiled by one investigator will contain irons that another compiler might regard as coarse octahedrites.

The Ni–Fe diagram (fig. 1) shows the conditions under which kamacite (alpha iron), the sole constituent of a hexahedrite, forms. The two dotted vertical lines at 5.5 and 6.0 percent Ni define the range within which hexahedrites grade into coarse octahedrites. Thus, no hexahedrite has a nickel value to the right of these dotted lines, and most hexahedrites lie either on or slightly to the left of the 5.5 line.

The different classes of meteorites—hexahedrites, nickel-poor ataxites, octahedrites, and nickel-rich ataxites—do not correspond to the diagram for 1 atmosphere of pressure, as stated by Uhlig (1954) and by Henderson and Perry (1954). According to Uhlig, this is due to the fact that meteorites form under pressures greater than 1 atmosphere.

If a horizontal line is drawn in figure 1 at 490°C., and if it is assumed that no changes take place below this temperature, the modified diagram more faithfully depicts the structures in iron meteorites. Following a 490° line from left to right, the hexahedrites, which consist of one component, lie to the left of the line AB while the octahedrites and nickel-rich ataxites lie between AB and AC.

The chemical composition reported for the hexahedrites and nickel-poor ataxites only represents an average composition of the area selected for analysis and not the entire meteorite. Since the Ni values of hexahedrites range from about 4 to 6 percent, there is no valid chemical reason for continuing the use of the term nickel-poor ataxite. This term should be dropped.

The available analyses of the nickel-rich ataxites, hereafter referred to as ataxites, show nickel values which can be located on the 490° line to the left of where it crosses the AC line. Actually most of the Ni percentages lie nearer to the AB than the AC line. Thus, kamacite should be a common constituent in ataxites, and indeed, kamacite spindles are recognizable in these meteorites. The structures of ataxites are more confused than the structures in the octahedrites and hexahedrites.

An interesting relationship was noted in the range of Ni percentages of the three groups of meteorites. The difference between the lowest and highest nickel value in the hexahedrites is about 2 percent, in octahedrites the range is about 6 percent, while in ataxites it is nearer 18 percent.

DESCRIBED HEXAHEDRITES

Table 1 lists all known hexahedrites as of July 1962, together with their weights and dates of fall or find. Synonyms are not numbered.

Table 1.—*List of described hexahedrites.*

	Name	Weight, *kilograms*	Date of discovery	Date of fall
	Angela (see La Primitiva)			
	Aragon, Ga. (see Cedartown)			
1.	Aswan, Egypt	?	1953	
2.	Auburn, Ala.	3.6	1867	
3.	Avče, Italy	1.23		Mar. 31, 1908
4.	Barraba, Australia (Bingara)	1.36	unknown	
5.	Bellsbank, S. Africa	38	1950 (?)	
6.	Bennet Co., S. Dak.	89	1934	
7.	Bingara, N. S. Wales	1.1 & 6.4	1880	
8.	Boguslavka, Siberia	199 & 57		Oct. 18, 1916
9.	Braunau, Czechoslovakia	22 & 17		July 14, 1847
10.	Bruno, Canada	13	1913	
11.	Cedartown, Ga.	11.3	before 1898	
12.	Central Missouri [1]	25	1885	
13.	Chesterville, S. C.	16.5	1848	
14.	Chico Mountain, Tex.	2,000 [2]	before 1915	
15.	Chinguetti, French W. Africa	— [3]	1920	
16.	Cincinnati, Ohio	unknown	1870	
17.	Coahuila, Mexico	1,000	1837	
18.	Corrego do Areado, Brazil	32	1925	
19.	Coya Norte, Chile	17.9	1927	
20.	Edmonton, Canada	7.34	1939	
	El Mocovi (see Otumpa)			
21.	Filomena, Chile	21.1	1941	
	Fort Duncan (see Coahuila)			
22.	Forsyth County, N. C.	17	1891	
	Gressk, Russia (see Hressk)			
23.	Hex River, Africa	60	1882	
24.	Holland's Store, Ga.	12.27	1887	
25.	Hressk, Russia	11.9	1954	
26.	Indian Valley, Va.	14	1887	
27.	Iredell, Tex.	1.5	1898	

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[1] Usually this iron is listed as a coarse octahedrite, but Perry (1944) considered it a granulated hexahedrite. See plate 4.

[2] Sample lost, weight unconfirmed.

[3] Reported as 100 meters long, 45 meters high. These figures probably were intended to be centimeters, not meters.

TABLE 1.—*Continued*

28. Keen Mt., Va.	6.7	1950	
29. Kendall County, Tex.	21	1887	
30. La Primitiva, Chile	3.1, 4, 1.5, 4.3, 9	1888	
31. Lick Creek, N. C.	1.24	1879	
32. Locust Grove, Ga.	10	1857	
33. Lombard, Mont.	unknown	?	
34. Mayodan, N. C.	16	1950	
35. Mejillones, Chile	—[4]	1875	
Mejillones, Chile	14.5	1905	
36. Murphy, N. C.	8	1889	
37. Mt. Joy, Pa.	385	1887	
38. Navajo, Ariz.	1499 680	1921-1926	
39. Nedagolla, India[5]	4.5		Jan. 23, 1870
40. Negrillos, Chile	28.5	before 1936	
41. Nenntmannsdorf, Saxony	12.5	1872	
42. Okano, Japan	4.74		Apr. 7, 1904
43. Opavo, Czechoslovakia	7.4, 5.8, 1.0, 0.1	1925	
44. Otumpa, Argentina	(15 tons, est.)	1576	
45. Pima County, Ariz.	0.21	before 1947	
46. Pirapora, Brazil[6]	2.56		
47. Puripica, Chile	19	1929	

[4] "A cart would be required for its carriage," G. A. Daubree, Compt. Rend., Acad. Sci. Paris, vol. 81, p. 597, 1875.

[5] Although reported as a nickel-poor ataxite, the analyses show 6.2 and 6.1 percent of Ni. These values are above the Ni content of hexahedrites. This iron, which has exceptionally fine flight markings, obviously fell as an orientated individual. A cross section through its short dimension shows two well-defined heat-altered zones about 2.5-3.0 mm. wide. The metal between these thermally altered zones displays a pattern like that formed when metal is rapidly quenched (Axon, 1962). This structure is visible at low magnifications (6× to 10×); however, at higher magnifications a granular texture is noticeable. Both structures existed before this meteorite entered our atmosphere.

All witnessed falls of hexahedrites (table 2) occurred in the morning. Nedagolla fell at 7 p.m. Meteorites falling in the morning are oncoming ones, thus enter the atmosphere with higher velocities than those which fall in the afternoon hours. Hence, the Nedagolla differs from the witnessed hexahedrite falls not only in its metallography and chemistry, but also in the time of fall.

To combine two interpretations, one from its chemistry and the other from its metallography, to explain its past history, is difficult. The structure, noticeable at low magnifications, is that of a metal which solidified quickly, but the granular texture, visible at higher magnifications, is suggestive of later reheating to about 800°C. Where and when these events took place is unknown, but they happened prior to its fall in 1870. From its chemical composition this iron might represent a melted coarse octahedrite, and it is definitely unlike all other hexahedrites.

[6] The Pirapora, Brazil, iron was reported in private communications from Dr. Walter Curvello, Museum Nacional, Rio de Janeiro. No additional data are available.

TABLE 1.—*Continued*

48. Quillagua, Chile	78	1938	
49. Richland, Tex.	15.4	1951	
50. Rio Loa, Chile	4	1915	
51. Sakouchi, Japan[7]	4.18	1913	Apr. 13, 1913
52. San Francisco del Mezquital, Mexico	7.5	before 1868	
53. San Martin, Chile	29	before 1924	
54. Scottsville, Ky.	10	1867	
55. Sierra Gorda, Chile	22.0	1898	
56. Sikhote Alin, E. Siberia[8]	(many tons)		Feb. 12, 1947
57. Siratik, W. Africa	—[9]	1716	
58. Smithonia, Ga.[10]	70	1940	
59. Soper, Okla.	3.7	1938	
60. Summitt, Ala.	1	1890	
61. Tandil, Argentina	0.98		1916-1919
62. Tocopilla, Chile	75	1927	
63. Tombigbee, Ala.	43	1859-86	
64. Union, Chile	22	1930	
65. Uwet, Nigeria	54	1903	
66. Villanueva del Fresno, Spain	0.35[11]	not given	
67. Walker County, Ala.	75	1832	
68. Warialda, N. S. Wales (Bingera)	2.8	1919	
69. Wathena, Kans.	0.56	1939	
70. Yarroweyah, Victoria, Australia	9.5	1903	

[7] Since Kanda (1952) lists the Sakouchi as a hexahedrite, it is included in this list. The information about this meteorite is incomplete and conflicting.

[8] The composition lies along the border between the hexahedrites and the coarse octahedrites. Because there is an absence of a noticeable octahedral arrangement in these specimens, this iron is classified as a hexahedrite.

[9] This meteorite needs restudy. Although a large mass was found, only about 1.7 kg. is known today.

[10] When Roy and Wyant (1950) studied the Smithonia, Ga., iron, they found no Neumann lines, the nickel content below 6 percent, and hence classified it as a nickel-poor ataxite. In a later cut, which penetrated deeper into the meteorite, Henderson and Furcron (1957) observed Neumann lines which established this iron as a normal hexahedrite.

[11] Weight not reported, but was calculated from the dimensions.

METEORITES INCORRECTLY IDENTIFIED AND EXCLUDED FROM THE HEXAHEDRITES

Not included in the foregoing list of hexahedrites are seven specimens incorrectly listed as hexahedrites. These are:

1. Chihuahua City, Mexico. Although this iron was listed by Hey (1953) as a brecciated hexahedrite, Nininger (1931) reported it as having "a fine octahedral crystallization." Also Nininger

published an analysis by F. C. Hawley which reported 6.96 percent Ni. Again in 1950 Nininger classified this iron as a brecciated octahedrite. Goldberg and others (1951) published two nickel determinations, 6.97 and 6.85 percent. Thus, three analyses report values in excess of those for a hexahedrite.

2. Dorofeevka, U.S.S.R. Illustrations of this iron published by Zavaritsky (1954) show both narrow kamacite lamellae and plessite areas. In the text Zavaritsky mentions that this iron resembles a nickel-rich ataxite.

3. Granado, Ariz. Nininger and Nininger (1950) reported this 38-gram iron as a hexahedrite, but H. H. Nininger now regards it as a piece of Canyon Diablo (personal communications).

4. Lake Murray, Carter County, Okla. Classified as a coarse octahedrite. This specimen, weighing 272.7 kg., was found about 1932 but not excavated and recovered until 1952. La Paz considered it an intermediate member between the hexahedrites and octahedrites and proposed the term "hexaoctahedrite." Plate 1 shows a portion of a cut through the Lake Murray meteorite. In several areas wide kamacite bands are arranged in an octahedral pattern. The octahedral structure in other parts of this section is disrupted by the growth of large skeletons of schreibersite inclusions, some measuring more than 6 cm. in length and 4 cm. in width.

5. New Mexico. This 130-gram specimen was found in 1923 at approximately 34°31′ N. and 107° W. Nininger and Nininger (1950) listed it as a hexahedrite and said it had been fashioned into an ax. Obviously man had something to do with this iron. Since the Sandia Mountains, N. Mex., iron has kamacite grains of about this size and shape, H. H. Nininger now regards the New Mexico specimen as a man-worked fragment of the Sandia Mountains iron (personal communications).

6. Sulechow, Poland. Although typed as a hexahedrite by Pokrzywnicki (1959), the Ni value in analysis is within the range of the octahedrites.

7. Western Arkansas. Merrill (1927) reported an analysis with a nickel value within the range of the hexahedrites but did not classify the meteorite. Merrill's published analysis is inconsistent with the structure of this specimen. Also the analysis of the meteorite with which Merrill compared the analysis of the Western Arkansas was proved to be inaccurate. The Western Arkansas, therefore, is definitely not a hexahedrite.

PHENOMENA OF HEXAHEDRITE FALLS

WITNESSED FALLS OF HEXAHEDRITES

The first observed fall of a hexahedrite took place near Braunau, Czechoslovakia, in 1847. Since then, falls of five other hexahedrites have been witnessed. Six of the seven meteorites in table 2 fell north of the Equator in the Eastern Hemisphere, while one (Tandil) fell in the Western Hemisphere south of the Equator (table 2).

Since the two pieces of the Braunau iron, 22 and 17 kg., fell in 1847, two other hexahedrites have been recovered within 100 miles of Braunau (see fig. 7). Perhaps, therefore, the 1847 fall was a shower of hexahedrites.

TABLE 2.—*Witnessed falls of hexahedrites arranged chronologically.* (The Nedagolla iron, which is not a true hexahedrite, is included for comparison.)

Name	Country	Date of fall and hour	Coordinates	
Braunau	Czechoslovakia	July 14, 1847—3:45 a.m.	56.6° N.	16.3° E.
Nedagolla[1]	India	Jan. 23, 1870—7:00 p.m.	18°41′ N.	83°20′ E.
Okano	Japan	Apr. 7, 1904—6:35 a.m.	35°4′ N.	135°13′ E.
Avče	Italy	Mar. 31, 1908—8:45 a.m.	46° N.	13.5° E.
Boguslavka	Siberia	Oct. 18, 1916—11:47 a.m.	44°33′ N.	131°38′ E.
Tandil	Argentina	Between 1916-1919—?	37°17′ S.	59°6′ E.
Sikhote-Alin	Siberia	Feb. 12, 1947—10:38 a.m.	46°9.6′ N.	134°39.2′ E.

[1] See footnote 5 to table 1.

Another interesting fact about these witnessed falls is that five occurred in the morning, with the Boguslavka iron falling only 13 minutes before noon. The Nedagolla, which has structural features and a chemical composition unlike a hexahedrite, fell in the afternoon. The time of fall of the Tandil iron was not recorded. The fact that these irons, with the possible exception of the Tandil meteorite, fell in the morning may not be a coincidence.

CLUSTERING OF HEXAHEDRITES

The clustered occurrence of hexahedrites was once assumed to be due to transportation by man. Fletcher (1890) concluded that because iron meteorites were useful as anvils and for other purposes, man gathered them for use and later discarded them in places distant from where they fell. This point of view is no longer popular either with those who study meteorites or with archeologists.

In the late 19th century local concentrations of hexahedrites prompted the question, "Are these irons related?" Farrington (1915) said: "Early writers are inclined to group into one fall similar meteorites, even though separated by thousands of miles of distance, but later observations have failed to confirm this view."

Several widely scattered large hexahedrites are known from northern Mexico. Many of these have been sectioned and now are considered to be parts of the Coahuila meteorite. Thus, names given to individual masses, such as Sanchez Estate, Hacienda, Potosi, Fort Duncan, etc., are now relegated to synonomy, and all are collectively known as the Coahuila meteorite. Farrington (1915) accepted the Coahuila group as a shower and said, "In the State of Coahuila, Mexico, numbers of meteoritic irons of a rare class, hexahedrites, are found one or two hundred miles apart. It hardly seems likely that separate falls of these rare meteorites would occur within such a limited area."

Twenty-five hexahedrites have been found since Farrington wrote as he did in 1915. A number of these coincide with some of the geographic groupings noted by earlier writers. Of the new geographic groups found since Farrington's time, the most important is the Chilean group. In general, the places where hexahedrites were found suggest the probability that they fell as showers.

It is assumed that all the Coahuila meteorites come from latitude 28°40′ N. and longitude 102°50′ W., a midpoint in the scatter of those specimens in northern Coahuila. Earlier writers even suggested that some hexahedrites from Virginia, Georgia, and Kentucky were related to the Coahuila irons. Although it is possible that the hexahedrites from these eastern States are part of the Coahuila shower, this study lists them as hexahedrites from southeastern United States (see table 6).

If it is reasonable for Fletcher (1890) to regard the Coahuila irons as a shower, it would seem equally admissable to include some of the hexahedrites found slightly north and east of Coahuila in Texas and toward the Oklahoma border, as part of the same shower. Since the hexahedrites in this portion of Texas are as closely spaced as the hexahedrites in other geographic areas, they are grouped with the irons scattered around Coahuila (see table 5).

MECHANISM FOR SCATTERING METEORITES

The above distribution of hexahedrites would be accounted for if two or more large hexahedrites approached the earth on essentially parallel trajectories. Under these circumstances the second or third masses to enter our atmosphere and fall would scatter pieces in different places from those where the first or second one fell. Thus, the distance between the strewn fields would depend upon the interval that separated the arrival of the individual masses into the atmosphere and upon the trajectories along which they were traveling. For meteorites to approach the earth in such a manner probably would require the fragmentation of a larger object relatively close to the earth. Any mass fragmenting far out in space would scatter, and thus few pieces would have parallel orbits.

Many spectacular fireballs have been tracked across North America, and from some of them meteorites have fallen. Since the distance traversed by some fireballs exceeds the distance over which clustered hexahedrites have been found scattered, a few of these events will be briefly reviewed.

When Smith (1877) described the Rochester fireball of 1876, he may have considered a mechanism similar to that described above when he wrote:

> The Bolide made its appearance about 9 o'clock p.m., December 21, 1876, and was of extraordinary magnificence. It passed eastward over the States of Kansas, Missouri, Illinois, Indiana, Ohio, and parts of Pennsylvania and New York. Although no observations were made in the last two mentioned states, still Professor Kirwood is doubtless correct in defining this as its course. At Bloomington, its elevation was 15 degrees. According to the calculations, the length of its observed track was from 1000 to 1100 miles, one of the longest on record. Its height is supposed to have been 38 miles above the place where the small fragments fell from it.

The Canadian fireball of February 9, 1913, which was named Cyrillid by O'Keefe (1961), also made an unusually long streak across the country. Detonations were heard all the way from Toronto, Ontario, to Towanda, Pa., a distance of 200 miles. If more observations had been collected immediately after its passage, this distance possibly would have been extended. O'Keefe quotes observers as saying, "Before the astonishment aroused by the first meteor had subsided, other bodies were seen coming from the northwest, emerging from precisely the same place as the first one. Onward they moved, at the same deliberate pace, in twos or threes or fours, with trails streaming behind."

The Pasamonte meteorite, which fell March 24, 1933, also made a brilliant display over several states. Nininger (1934) interviewed observers in the area from near Wichita, Kan., to New Mexico, where the specimens were recovered. This fireball was seen for approximately 400 miles, but the objects known to have fallen from it are confined to a distance of about 4 miles.

The three foregoing events happened within 57 years, and in two cases the observed flights extended 1,000 to 1,100 miles and about 400 miles, respectively. Witnesses of the 1913 fireball reported that more than one object was seen moving through the sky. Meteorites are usually considered to be single objects when they enter our atmosphere, but it appears on the basis of the 1913 observation that several objects can enter the atmosphere at slightly different times and along the same trajectory. If more than one object was involved in the 1913 fireball, probably some were higher in the sky than others, although all appeared to be moving on the same or only slightly different trajectories.

Before leaving the subject of fireballs, some comments seem necessary on recurring meteor showers that appear from year to year. Elliott (1804) wrote about the November 12, 1799, display as follows:

> November 12, 1799, about three o'clock a.m., I was called up to see the shooting stars. The phenomenon was grand and awful, the whole heavens appeared as if illuminated by sky rockets, which disappeared only by the light of the sun after daybreak. The meteors which appeared at any one instant as numerous as stars, flew in all possible directions except from the earth towards which they are inclined more or less, and some of them descended perpendicularly over the vessel we were in. So that I was in constant expectation of their falling among us. We were in latitude 25° N. and SE. of Kay Largo near the edge of the Gulph Stream. I have since been informed that the phenomenon extended over a large proportion of the West India Islands and as far north of Mary's in latitude 30°42′, when it appeared as brilliant as with us off Cape Florida.[1]

Although it is frequently stated that meteorites do not fall from reappearing meteor showers, such as the Leonid showers in November, this may be incorrect, for the records show that from 1800 to the present time (January 1963), 43 meteorites have fallen in November. The greatest number of meteorites to fall on any day in November is 5, and this number fell on the 12th day of the month. Thus, until more information is available, we cannot be sure that these recurring meteor showers do not bring an occasional meteorite. However, one phenomenal shower like that observed in 1799 could have delivered most of these hexahedrites.

Between 1800 and mid-1962, 218 meteorites fell and were recovered in August, September, October, and November. The distribution of these falls is shown in figure 2 by listing the year and the day of the month on which the fall occurred.[2] The Bali, West

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[1] Humboldt, the German naturalist, who was in South America in 1799, also observed this meteor display.

[2] Seventeen falls were reported by year and month, but the day was not given.

DATE	AUGUST	SEPTEMBER
1	1835 1897 1898 1912	
2	1882 1946	1905 1955
3		1808 1935 1939
4	1835 1904	1886 1930 1952
5	1812 1855 1856 1898 1957	1812 1814 1854 1878
6		1911 1918 1925
7	1822 1823 1924 1942	1868 1924
8	1863 1897 1933 1933	1887
9	1921 1939	1829 1831 1961
10	1818 1932	1813 1930
11	1859 1862 1897 1956	
12	1865	
13	1920	1822 1902 1937
14	1846	1836
15	1829	1897 1910
16	1875 1885 1928	1843 1920
17	1936	1879 1937 1945 1945
18	1870 1942	
19		1869 1910 1949
20		1950
21		1865 1934 1949 1949
22	1902 1932	1887 1893
23	1900 1950	1873 1899 1936 1944
24	1880	1942
25	1865 1865	
26		1873
27	1931	1825
28	1925 1925	1891
29	1878 1892	1928 1938
30	1887 1919 1920	
31	1872 1961	

NO DATE : 1810,1826,1837,1858,1949,1950.

NO DATE: 1843,1875,1907,1930,1930,1933.

FIG. 2A.—Meteorite falls by day of month.

DATE	OCTOBER	NOVEMBER
1	1857 1868 1923	1862 1954
2	1933	
3	1815 1883	
4		1879 1906
5	1827 1866 1924 1950	1814 1841 1851 1932
6	1869	
7	1862	
8	1803 1954	
9		
10	1938	
11	1857 1950	1836
12		1843 1856 1902 1906 1928
13	1819 1838 1852 1914 1959	1949 1952
14	1824	
15	1928 1929	1898 1902 1957
16	1898 1919	
17	1910 1921 1951	
18	1897 1916	1924
19		1877 1881
20	1951 1951	1878
21	1844 1901	1916
22	1903	
23	1933 1933	1810 1811 1907
24	1899	1804 1910 1959
25		1930 1943
26	1886 1940	1874 1908 1934 1958
27		1868 1877 1885
28		
29	1904 1905	
30	1944	1822 1842 1850 1901
31	1849 1951	

NO DATE: 1918, 1930, 1951.

NO DATE: 1833, 1959.

FIG. 2B.—Meteorite falls by day of month (continued).

Africa, meteorite fell in the morning hours of either the 22d or 23d of November 1907, hence is shown midway between these dates.

An inspection of figure 2 shows the following:

1. The falls are not uniformly dispersed through these 122 days. Actually, on 32 days no meteorite falls were reported.
2. The longest gap without falls is the 6th to 10th of November, the interval which precedes the reappearance of the Leonid showers.
3. The greatest number of meteorites to fall on any date is 5, and this number fell on each of three days—August 5, October 13, and November 12 (see table 3B for detailed listing).

If the witnessed meteorite falls are grouped into 10-day intervals between August 1 and November 30 (table 3A), the maximum number of falls, 23, occurs between August 1 and 9; the minimum number is 8, between November 1 and 9.

GEOGRAPHICAL ANALYSIS OF HEXAHEDRITES

The next step is to examine the distribution of the hexahedrites listed in table 1 to determine whether their scatter suggests random falls or a shower. The hexahedrites from the different continents have been plotted on maps, and their groupings will be discussed by geographic areas.

NORTH AMERICA

The irons from this continent group themselves into two or possibly three areas, with two stragglers located outside the main geographic concentrations. The stragglers, which occur in western United States, are discussed at the end of the section on North America.

Western North America.—The four hexahedrites from the northwestern portion of the United States and from part of nearby Canada are shown in table 4. These irons can be enclosed within an ellipse 875 miles long. Four is an insufficient number of specimens from an ellipse of this size to suggest a shower. Yet if the groupings of hexahedrites in other areas of the world are significant, this may become a promising area for future hexahedrite discoveries.

Southern United States and northern Mexico.—Table 5 lists the specimens recovered in this part of the continent. Six were found in an area extending northeast from Coahuila, Mexico, across Texas to southern Oklahoma (fig. 3). This area can be enclosed by an ellipse with a long axis of about 500 miles. This distance, more than half the long axis of the group of four western hexahedrites

TABLE 3.—*Witnessed meteorite falls between 1800 and July 1962*

SECTION A

Grouped into arbitrary intervals.

	Falls between 1st and 9th	Falls between 10th and 19th	Falls between 20th and end of month
August	23	16	17
September	21	17	17
October	14	18	15
November	8	14	21

SECTION B

Meteorite falls of August 5, October 13, and November 12.

Year	Meteorite	Location	Coordinates		Hour of fall	Type	Percentage of Fe_2SiO_4 in olivine (X-ray)	Gamma index olivine .002±*	Prominent pyroxene present *
			August 5						
1812	Chantonnay	France	46°41′ N.	1°3′ W.	2	Chondrite	23	1.715	Hypersthene
1855	Petersburg	Tennessee	35°18′ N.	86°38′ W.	15.30	Eucrite	...	...	...
1856	Oviedo	Spain	43°24′ N.	5°52′ W.	17.45	Chondrite	...	1.717	Hypersthene
1898	Andover	Maine	44°37′ N.	70°45′ W.	7.30	Chondrite	25	1.720	Hypersthene
1957	Ufana	Tanganyika	4°16′ S.	35°21′ E.	18.20	Mesosid.	...	...	...
			October 13						
1819	Pohlitz	Germany	50°56′ N	12°8′ E.	8	Chondrite	...	1.717	Hypersthene
1838	Cold Bokkeveld	S. Africa	32°50′ S.	19°20′ E.	9	Carbon-ch.	...	...	...
1852	Borkut	Russia	48°9′ N.	24°17′ E.	15	Chondrite	26	1.715	Hypersthene
1914	Appley Bridge	England	53°35′ N.	2°43′ W.	20.45	Chondrite	30	1.732	Hypersthene
1959	Hamlet	Indiana	41°20′ N.	86°35′ W.	21.05	Chondrite	27	1.731	Hypersthene
			November 12						
1843	Verkhne Tschirskaia	Russia	48°25′ N.	43°12′ E.	12	Chondrite	...	1.702	Bronzite
1856	Trenzano	Italy	45°28′ N.	10°1′ E.	16	Chondrite	20	1.707	Bronzite
1902	Kamsagar	India	14°11′ N.	75°48′ E.	13	Chondrite	24	1.721	Hypersthene
1906	Kirbyville	Texas	30°45′ N.	95°57′ W.	15.30	Eucrite	...	...	...
1928	Isthilart	Argentina	31°6′ S.	58°4′ W.	19.30	Chondrite	18	1.707	Bronzite

* Personal communication from Brian H. Mason.

TABLE 4.—*Data on hexahedrites from northern and western areas of United States and Canada arranged by latitude.*

Meteorite	Date found	Latitude	Longitude
Bennett County, S. Dak.	1934	43° 28′ N.	101° 9′ W.
Lombard, Mont.	?	46° N.	111° 24′ W.
Bruno, Canada	1931	52° 16′ N.	105° 21′ W.
Edmonton, Canada	1939	53° 35′ N.	113° 30′ W.

(table 4), exceeds the scatter of stony meteorites from most of the witnessed falls by a factor between 50 and 100. The distance over which the hexahedrites are dispersed is a most difficult fact to account for in accepting the apparent clustering of these irons as evidence of a shower of meteorites.

Only the Chico Mountain, Tex., iron requires further mention here. Acquired by the U. S. National Museum in 1915 from E. M.

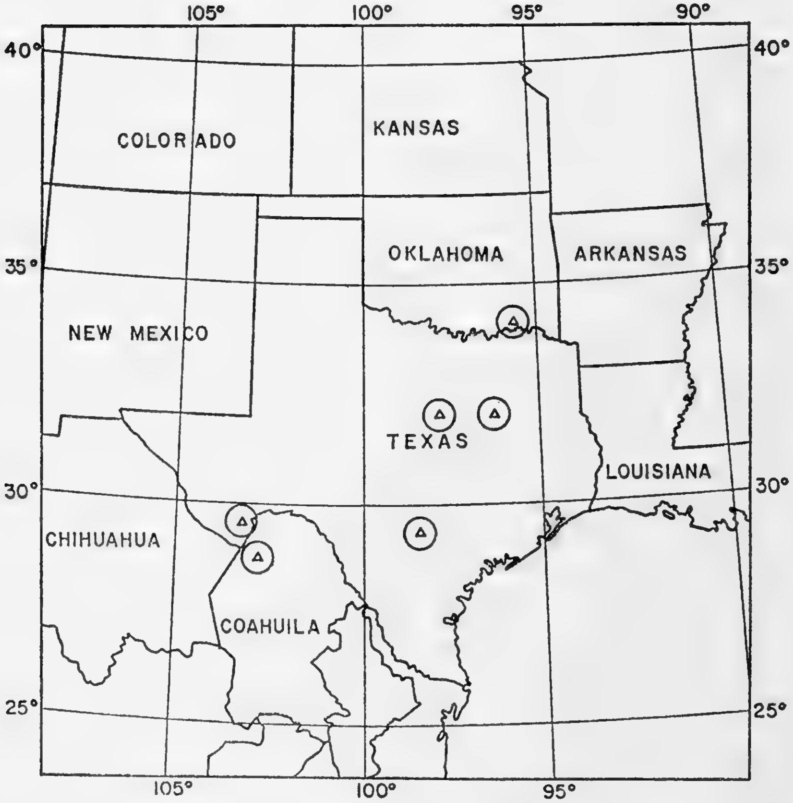

FIG. 3.—Geographic distribution of hexahedrites listed in table 5.

Flynn of Alpine, Tex., it was described by Merrill in 1922 as the Alpine, Brewster County, meteorite. Although it is reported that the original body weighed nearly 2 tons, the piece accessioned in the national collections weighs only 212 grams. Apparently the main mass has vanished.

Merrill's published picture shows that the specimen probably was reheated, but how and where this took place is not known. Actually, the entire surface of the small specimen is granulated, but the texture of the zone near the surface is finer grained than that of the central part. There is no indication of either cleavage or Neumann lines. The chemical analysis Merrill reports is consistent with that of other hexahedrites, and Merrill suggested the possibility that this specimen is related to the Coahuila meteorite.

TABLE 5.—*Data on hexahedrites from Coahuila, Mexico, and Texas–Oklahoma arranged by latitude.*

Meteorite	Date found	Latitude	Longitude
Coahuila, Mexico	1837	28°40′ N.	102°50′ W.
Kendall County, Tex.	1887	29°24′ N.	98°30′ W.
Chico Mountain, Tex.	1915	29° N.	103°15′W.
Richland, Tex.	1951	31°59′ N.	96°14′ W.
Iredell, Tex.	1898	31°58′ N.	97°52′ W.
Soper, Okla.	1938	34°5′ N.	95°37′ W.

Southeastern United States.—The hexahedrites from this area are arranged in table 6 according to the increasing latitudes of their points of discovery. Figure 4 shows the arrangement on a map of all of these finds with the exception of the Cincinnati iron, the omission of which is explained below. The distance from the southernmost one, Tombigbee River, Ala., to the northernmost, Mt. Joy, Pa., is approximately 850 miles. This distance exceeds the length of the strewn fields of stony meteorite falls by a factor of nearly 100.

Foote (1899) mentioned that six pieces of the Tombigbee River meteorite were found in nearly a straight line some 16 km. long, with the heaviest mass to the north. Similarly, the heaviest meteorite in table 6, the Mt. Joy iron, is located in the northeastern end of the 850-mile ellipse. It is easier to assume that the 6 irons along a line 16 km. long are related as a shower than that all 19 meteorites came as a shower. But if the north and south alignment of the Tombigbee River iron is important, all the 19 meteorites perhaps should be regrouped into smaller clusters, more or less in a north–south direction.

Both the Scottsville and Cincinnati irons lie to the north and west of the oval area enclosing the other hexahedrites found in the zone lying in a northeast–southwest direction. However, if the north–south alignment of the six Tombigbee River irons is important, and if the other hexahedrites are grouped into north and south clusters, then the Scottsville and Cincinnati irons fit better into the pattern with the other irons.

TABLE 6.—*Data on the hexahedrites from the southeastern area of the United States arranged by latitude.*

Meteorite	Weight, kilograms	Date found	Latitude	Longitude
Tombigbee River, Ala.	43.8	1858	32°13′ N.	88°10′ W.
Auburn, Ala.	3.5	1867	32°37′ N.	85°32′ W.
Locust Grove, Ga.	10.0	1857	33°20′ N.	84°8′ W.
Walker County, Ala.	75.0	1832	33°50′ N.	87°15′ W.
Cedartown, Ga.	11.3	1898	34°0′ N.	85°16′ W.
Smithonia, Ga.	69.8	1940	34°0′ N.	83°11′ W.
Aragon, Ga. (Cedartown) [1]	(5 gm.)	1898	34°1′ N.	85°3′ W.
Summit, Ala.	1	1890	34°15′ N.	86°25′ W.
Holland's Store, Ga.	12.5	1887	34°21′ N.	85°23′ W.
Chesterville, S. C.	16.3	1849	34°43′ N.	81°13′ W.
Lick Creek, N. C.	7.7	1899	35°5′ N.	84°2′ W.
Murphy, N. C.	1.2	1879	35°40′ N.	80°16′ W.
Forsyth County, N. C.	22.5	1891	36°1′ N.	80°2′ W.
Mayodan, N. C.	15.4	1920	36°23′ N.	79°52′ W.
Scottsville, Ky	10.0	1867	36°46′ N.	86°10′ W.
Indian Valley, Va.	14.2	1887	36°55′ N.	80°30′ W.
Keen Mountain, Va.	6.6	1950	37°13′ N.	82°0′ W.
Cincinnati, Ohio	(250 gm.)	1870	39°7′ N.	84°30′ W.
Mt. Joy, Pa.	385	1887	39°47′ N.	77°13′ W.

[1] Synonym.

Little is known about the Scottsville iron except that it was found in 1878, identified and described by Whitfield in 1887. There is no reason to suspect that it had been transported and abandoned by man.

The Cincinnati iron, which was found near a dwelling house in Cincinnati in 1870, was probably carried there by man from where it fell. The few specimens of this meteorite that are preserved suggest that it was small and easily transportable. Henderson and Perry (1958) found it to be a reheated specimen with a composition in the range of other hexahedrites. Because of its size and the fact that it is unlikely to have fallen in Cincinnati, this specimen is unimportant in this study.

The Keen Mountain, Va., specimen appears to be much younger than the others. Henderson and Perry (1958) assumed that this meteorite was a relatively recent fall because it had a fresh-looking black fusion crust with flight markings. Sections cut through one end showed numerous small open fractures extending into the interior only slightly farther than the thermally heated zone around its surface. Since these fractures contain little brown iron oxide and since this oxide is poorly consolidated, it was estimated by Gordon Davis (personal communication) and Henderson and Perry (1958) that the meteorite may have fallen between 1940 and 1950. Using Ar^{39} measurements, Vilcsek and Wänke (1962) reported the time of fall to be about 900 years ago.

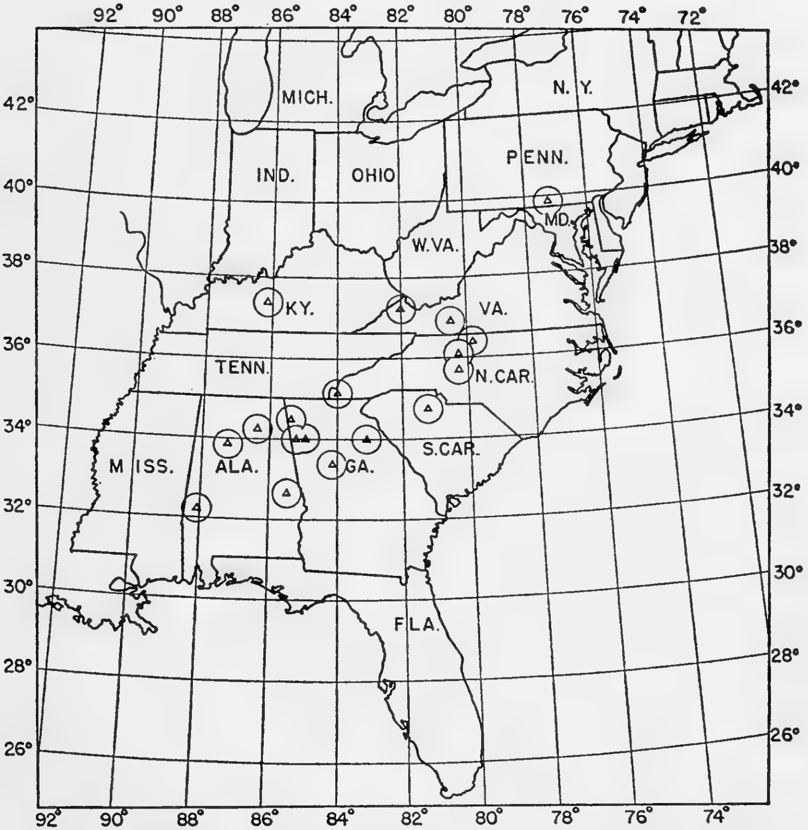

Fig. 4.—Geographic distribution of hexahedrites in table 6. The Cincinnati iron is omitted for reasons given on page 18.

H. Wänke commented as follows about the Keen Mountain iron in private communications: "The terrestrial age of this meteorite according to argon-39 and chlorine-36 measurements is 1100±200 years. I had a little problem with my standards, but this definitely would not change the value of the terrestrial age more than 200 years. The argon-39 content of this meteorite is so low that it must have been 3 half-lives of argon ($T\frac{1}{2}=325$ years) on the ground." A statement based on a measurement should be superior to an opinion about the time needed to alter a fresh flight crust from black to brown. However, 900 years seems a long time for fresh flight crust to survive in a climate as damp as that of Virginia. This iron may be an example of a hexahedrite falling into a cluster of an old hexahedrite fall.

The Walker County, Ala., iron was found in 1832, which makes it the first of this group to be discovered. The data on it came from Farrington's (1915) translation of Cohen's discussion in Meteoritenkunde (1903): "an iron mass of 75 kg. weight was found in 1832 in the northeast corner of Walker County, by a hunter living in Morgan County who preserved it in his house until 1843. . . . It was of an irregular oval form, with a smooth exterior covered with a thick coating of rust. . . ."

The alteration (rust) on the Walker County iron might mean a long terrestrial exposure. However, rust could have formed during the 10 years the specimen was stored in the cabin. Some irons exposed to high humidities corrode faster than ones remaining outdoors where the rain washes off the iron chlorides. Hence, the rust in this instance could represent corrosion products formed within a few years.

The New Baltimore and the Pittsburgh irons should be mentioned here even though they are not listed in table 6. These meteorites and the Mt. Joy iron were found in a straight line across Pennsylvania, and suggested to R. W. Stone (1932) that they were related. A subsequent investigation by Henderson and Perry (1958) indicates that these are unrelated meteorites.

The unique feature of the New Baltimore iron is the large inclusion, about 5 x 6 cm., with an octahedral pattern enclosed by large kamacite grains. The kamacite grains display well-developed, undisturbed Neumann lines, indicating that this kamacite was neither heated nor deformed since these lines formed.

It is difficult to explain the mechanism that produces a meteorite with two different types of Ni–Fe alloys in contact with each other. The possibility of the octahedrite colliding with and penetrating a hexahedrite must be considered. However, if a hexahedrite were struck in space by an oncoming octahedrite, both the target and the impacting object would probably show deformation resulting from their collision. In this meteorite, neither part is deformed. Although collisions between meteorites must have taken place in space, this specimen lacks the most important features one would expect if one iron meteorite penetrated another.

Hexahedrite stragglers in western North America.—Three isolated hexahedrites from the western part of the continent remain to be considered.

1. The Wathena, Doniphan County, Kans., iron. This 556-gram iron (Henderson and Perry, 1949) was found in 1939 near Wathena, Kans., in a locality about 400 miles northeast of the nearest grouping of hexahedrites. Since no other hexahedrites have been found in the intermediate area, the Wathena iron is assumed not to be associated with the foregoing groups.

2. The Pima County, Ariz., iron. This 210-gram mass is reported as having been found before 1947 near Tucson, Ariz. Nothing is known of its history except that it was at the University of Arizona for many years before it was accessioned into the national collections and described by Henderson and Perry (1949). It has exceptionally well developed flight surfaces. Although this strange-looking specimen is small enough to have been easily carried by man, it is thought probable that it fell where it was found, near Tucson.

3. Chico Mountain, Brewster County, Tex., iron. The 212-gram specimen in the National Museum apparently is all that remains of what was reported to be a 2-ton meteorite. So little is known about the history of this iron, and since it was found west of the area in which the meteorites listed in table 5 were found, the Chico Mountain iron is grouped with the stragglers.

SOUTH AMERICA

Chile

The hexahedrites from Chile are given in table 7, arranged by their increasing latitudes, and plotted on the map in figure 5. Henderson (1941) reported that these irons may represent a shower. On the other hand, the finding of these irons aligned along a railroad could be due to the fact that the exploration in this region followed the course of the railroad. Nitrates were hauled to the railroad for shipment, and the included irons could have been rejected from the ore before shipment. Also, the coordinates of the Chilean hexahedrites may be less accurately recorded than those of the American meteorites.

Thirteen hexahedrites are known from between latitudes 20° and 24° S., while twelve octahedrites were recovered between approximately the same northernmost latitude and 27° S. This is an unusually high proportion of hexahedrites to octahedrites. No hexahedrites are reported south of latitude 24° S., whereas four octahedrites were found there, one of which comes from a point as far south as 33°30′ S. No search has been made for meteorites in the area south of latitude 27°.

Table 7.—*Data on hexahedrites from Chile arranged by latitude.*

Name	Weight, kilograms	Latitude	Longitude
La Primitive (Angela)[1]	21.5	19°55′ S.	69°49′ W.
Negrillos	28.5	20°12′ S.	70°10′ W.
Rio Loa	4.0	21°26′ S.	70°5′ W.
Quillagua	78.0	21°36′ S.	69°32′ W.
San Martin	29.0	22°20′ S.	69°45′ W.
Coya Norte	17.0	22°20′ S.	69°40′ W.
Union	22.0	22°30′ S.	69°30′ W.
Tocopilla	75.0	22°40′ S.	69°50′ W.
Sierra Gorda	22.0	22°54′ S.	69°21′ W.
Filomena	20.7	23°0′ S.	69°24′ W.
Mejillones (1875)	(large)	23°7′ S.	70°29′ W.
Mejillones (1905)	14.5	23°7′ S.	70°29′ W.
Puripica	19.0	23°41′ S.	70°15′ W.

[1] Synonym.

Northern Chile is an arid region, while to the south the land is more suitable for agriculture. In northern Chile, owing to the extensive niter mining, more of the land surface has been scraped and sorted than elsewhere. Thus, large, heavy objects, such as iron meteorites, have a good chance of being recovered.

A comparison of statistics on meteorites from two widely separated geographic areas may be criticized because climate, topography, population density, and the uses made of the land have a bearing on the recovery of meteorites. Nevertheless, an area in the United States—Georgia and South Carolina—where a noticeable concentration of hexahedrites occurs, has been compared to northern Chile in table 8.

Georgia and South Carolina together make an area about 1.5 times that of northern Chile, yet more than 3 times as many hexahedrites are reported from Chile as from the larger area in the United States.

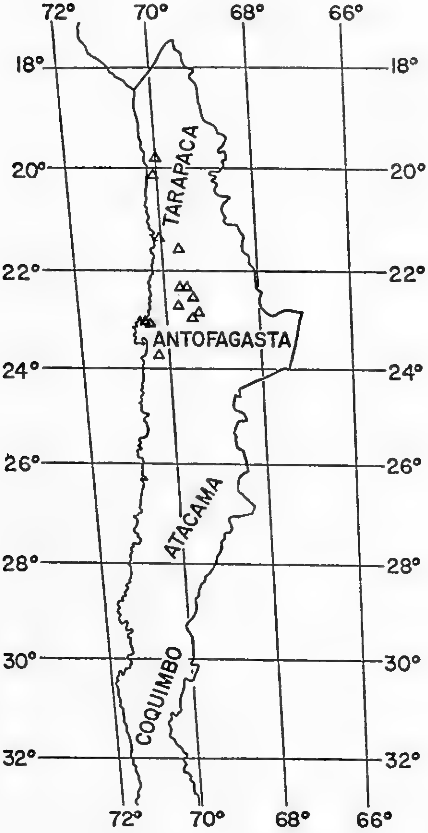

FIG. 5.—Geographic distribution of hexahedrites in table 7.

Ten octahedrites are known from northern Chile, but twelve came from Georgia and South Carolina. The conspicuous difference between the two areas is in the stony meteorites. All six of the stony meteorites from this part of the United States were observed falls, while the one stone from northern Chile was a find. This difference may be due to the fact that the population density of the Chilean area is far lower than in our two states, obviously making it easier for a

TABLE 8.—*Comparison of areas in which hexahedrites are abundant.*

	Area in square miles	Total meteorites	Hexahedrites	Octahedrites	Ataxites	Stones
Northern Chile....	60,000	26	13	10	2	1
Georgia	59,000	17	3	9	1	4
South Carolina....	31,000	6	1	3	0	2

meteorite to fall unnoticed in Chile. How these two localities would compare if both were as effectively prospected is problematic.

The arid climate of northern Chile favors preservation of meteorites. Stony meteorites from there should be less contaminated than those recovered from more humid areas because, without water, contamination is less likely to penetrate a meteorite. However, exposed meteorites in arid places can suffer from another type of weathering—wind ablation, which, in time, could be an effective way of obliterating a meteorite. Some irons from arid regions have sculptured surfaces that demonstrate how one constituent is ablated faster than another. Wind ablation is relatively rapid compared with chemical weathering in arid areas. The products of mechanical ablation might be confused with meteoritic dust, because undoubtedly some of the metallic iron is removed and accumulates in the windblown silt.

Many years ago the author called to C. A. Bauer's attention the possible identity of the northern Chilean hexahedrites and later furnished him with specimens for study. These specimens apparently were later turned over to Signer and Nier (1962), whose measurements are presented in tables 9 and 10, although in a somewhat different order so as to arrange the meteorites in their order of increasing latitude.

Signer and Nier (1962), in discussing the possibility of these Chilean irons being a common fall, said:

> Due to the low concentration of cosmogenic rare gases in these samples, the relative errors in these measurements may be somewhat higher than the 5% found for most other measurements; unfortunately, the samples available were so small that only a single analysis was possible and therefore, no check of reproducibility could be made. With this reservation, it seems possible that the Tocopilla, Coya Norte and Rio Loa belong to the same fall. Negrillos, however, appears to belong to a different fall. It should be mentioned that by nature of the interpretation two meteorites could by coincidence appear to belong to the same fall. The converse does not appear possible.

The overall scatter of the Chilean hexahedrites extends from about 20° to 24° S. latitude, while the three irons that Signer and Nier suspected of being related lie between 21°26′ and 22°40′ S. latitude. Thus, the Rio Loa, Coya Norte, and Tocopilla are confined within about 70 miles of the overall spread of about 240 miles for these Chilean hexahedrites.

TABLE 9.—*Concentrations and nuclide ratios for cosmogenic rare gases of 4 Chilean hexahedrites.* (*From Signer and Nier, 1962.*)

(Neon values are not corrected for slight amounts of atmospheric neon known to be present in some of the runs. Effect is negligible in case of Ne^{21}. Ar^{38} values are corrected for atmospheric argon assuming all the Ar^{40} is of atmospheric origin. Helium values do not require correction for atmospheric helium.)

Meteorite	Weight, milo-grams	He^3 $\times 10^3$	He^4 cc. STP/g.	Ne^{21}	Ar^{38}	$\frac{He^3}{He^4}$	$\frac{Ar^{36}}{Ar^{38}}$	$\frac{Ar^{40}}{Ar^{38}}$	$\frac{Ne^{20}}{Ne^{21}}$	$\frac{Ne^{22}}{Ne^{21}}$	$\frac{He^3}{Ne^{21}}$	$\frac{He^3}{Ar^{38}}$	$\frac{He^4}{Ne^{21}}$	$\frac{He^4}{Ar^{38}}$	$\frac{Ne^{21}}{Ar^{38}}$
Tocopilla	312	68.5	295	0.92	4.70	0.231	0.650	80	2.95	1.24	74.5	14.5	320	63.0	0.195
Coya Norte....	673	30.0	144	0.385	2.20	0.210	0.630	24	1.64	1.05	78.0	13.5	375	65.5	0.175
Rio Loa	708	31.5	140	0.360	2.10	0.226	0.625	46	2.10	1.14	87.5	15.0	390	66.5	0.170
Negrillos	672	9.6	40	0.14	0.69	0.24	0.650	45	2.15	1.16	69	14	285	58	0.20

TABLE 10.—*Conclusions based on the production model and the rare gas concentrations given in table 9.* (*From Signer and Nier, 1962.*)

		Preatmospheric				Production rates			
Meteorite	Recovered mass, weight in kilograms	Mass kg.	Radius cm.	$\frac{r}{R}$	Exposure age my.	He^3 $\times 10^{10}$	He^4 cc. STP/ g. my	Ne^{21}	Ar^{38}
Tocopilla	75	200000	182	0.8-0.9	250 ± 100	27	120	0.37	1.9
Coya Norte	17.9	200000	182	0.6-0.9	250 ± 200	12	58	0.15	0.88
Rio Loa	4	200000	182	0.8 0.9	150 ± 50	21	94	0.24	1.4
Negrillos	28.5	200000	182	0.8-0.9	30 ± 15	32	130	0.47	2.3

ARGENTINA

Only two hexahedrites, the Otumpa and the Tandil, are recorded from Argentina. A field investigation recently was made in the area of the Otumpa meteorite (Campo del Cielo) by the Lamont Geological Observatory under the leadership of Dr. William A. Cassidy. Dr. Daniel J. Milton of the U. S. Geological Survey, associated with Dr. Cassidy in the meteorite studies in Argentina, reports the following: Seven impact craters have been identified distributed along a single line about 18 km. long trending N. 60° E.,S. 60° W. Careful search in one area near the middle of this line indicates that a zone of abundant meteorites (many thousands per square kilometer) have the same ENE-WSW orientation and a width of about 3 kilometers. . . . In addition, a hexahedrite of 7 kg. has been found 65 kilometers N. 60° E. of the northeasternmost crater. The intervening distance has not yet been investigated. Locating this on a map, the middle of the crater line is about 27°35′ S. and 61°40′ W. with the westernmost crater in the Province of Santiago del Estero. The isolated iron comes from approximately 27°23′ S., 61°5′ W."

The Tandil iron is reported as a witnessed fall, although the details about this fall and its discovery are not satisfactorily documented. If this iron was seen to fall, its geographic relationship with the Otumpa specimens is accidental.

AUSTRALIA

Four of the five Australian hexahedrites listed in table 11 and plotted on the map in figure 6 show a narrow geographic grouping. These irons were found along a north and south line about 35 miles long—the direction in which the Tombigbee River (Alabama) and Chilean irons were aligned. However, in Chile, it would be impossible to align that many meteorites in any direction other than north and south.

Table 11.—*Data on Australian hexahedrites.*

Meteorite	Date found	Weight, kilograms	Coordinates	
Bingara 1[1]	1880	(240.7 gms.)	29°53′ S.	150°34′ E.
Bingara 2	1924	6.4	9 miles north of No. 1	
Bingara 3 (Barraba)	unknown	1.34	30°25′ S.	150°37′ E.
Bingara 4 (Warialda)	1919	2.5	29°34′ S.	150°35′ E.
Yarroweyah	1903	9.5	35°59′ S.	145°35′ E.

[1] The spelling of Bingara varies, in some places appearing as Bingera.

Although the Yarroweyah iron was found a long way from the other four Australian hexahedrites, all five can be enclosed within an ellipse approximately 450 miles long. There would be no reason to associate the Yarroweyah iron with the Bingara group were it not for the fact that the hexahedrite grouping in the other parts of the world extends a similar distance. Disregarding the Yarroweyah iron, the distribution of the four Bingara specimens shows that they must be related. However, the ellipse enclosing all the Australian hexahedrites exceeds the area in which fragments are scattered in observed falls of meteorites.

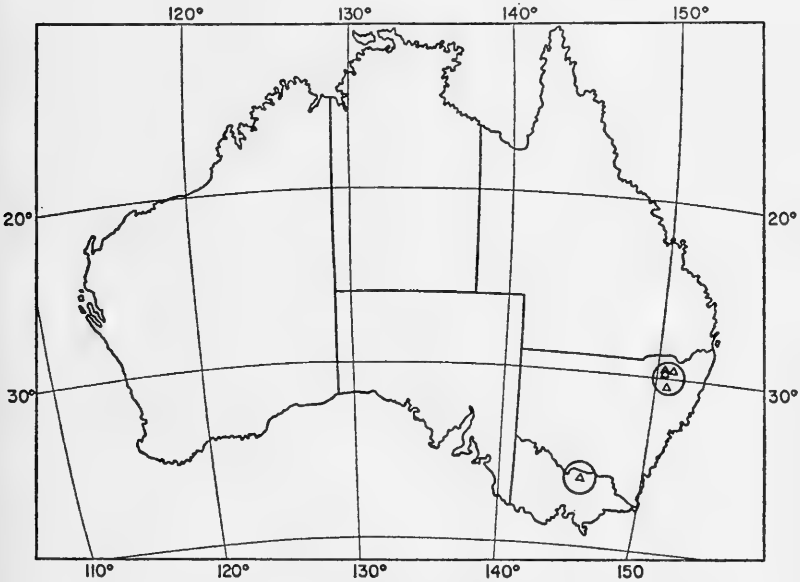

FIG. 6.—Geographic distribution of hexahedrites in table 11.

EUROPE

Since man used iron much earlier in Europe than in the Americas, Australia, or Africa, one might suspect that many of the European meteorites were transplanted or consumed by the early peoples. If this is true, the listing of the specimens in table 12 and the plotting of these on the map in figure 7 may not be reliable.

Two hexahedrites, Opava and Nenntmannsdorf, were found approximately 100 miles apart and close to where the Braunau meteorite fell in 1847. Since these three hexahedrites were found so close together, it seems likely that they fell as a shower.

Generally speaking, all the hexahedrites found in central Europe, Spain, and Russia follow a pattern of alignment which is also characteristic of those found from Mexico to Oklahoma and from Alabama to Pennsylvania and is also evident in those discoveries in Argentina and Australia. This agreement—alignment in a northeast–southwest direction—would not seem to be merely coincidence.

TABLE 12.—*Data on European hexahedrites.*

Meteorite	Date found	Weight, kilograms	Coordinates	
Opava, Czechoslovakia....	1925	14.3	49°58′ N.	17°54′ E.
Nenntmannsdorf, Saxony.	1872	12.5	50°58′ N.	15°57′ E.
Braunau, Czechoslovakia.	1847 (observed fall)	39.	50°36′ N.	16°18′ E.
Hressk, Russia[1]	1954	11.9	53°14′ N.	27°20.5′ E.
Villanueva del Fresno, Spain	Not given	(Not given)	38°24′ N.	3°26′ W.

[1] Also spelled Gressk.

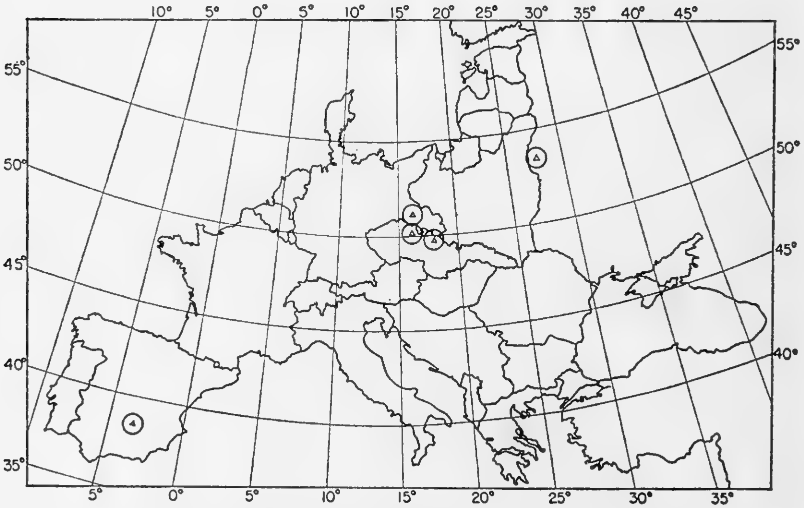

FIG. 7.—Geographic distribution of hexahedrites in table 12.

AFRICA

Although only six African hexahedrites are known (table 13; fig. 8), two pairs occur sufficiently close together to suggest that they fell as separate showers. These are the Bellsbank and Hex River irons in South Africa and the Chinguetti and Siratik in northwest Africa.

TABLE 13.—*Data on African hexahedrites.*

Meteorite	Date found	Weight, kilograms	Coordinates	
Aswan, Egypt	1955	12	23°59′ N.	32°37′ E.
Chinguetti, French West Africa	1920	?	20°15′ N.	12°41′ W.
Siratik, French West Africa	1716	1.7	14° N.	11° W.
Uwet, Nigeria	1903	54	5°17′ N.	8°15′ E.
Bellsbank, South Africa	1955	38	28°18′ S.	24°15′ E.
Hex River, South Africa	1882	60	33°19′ S.	19°37′ E.

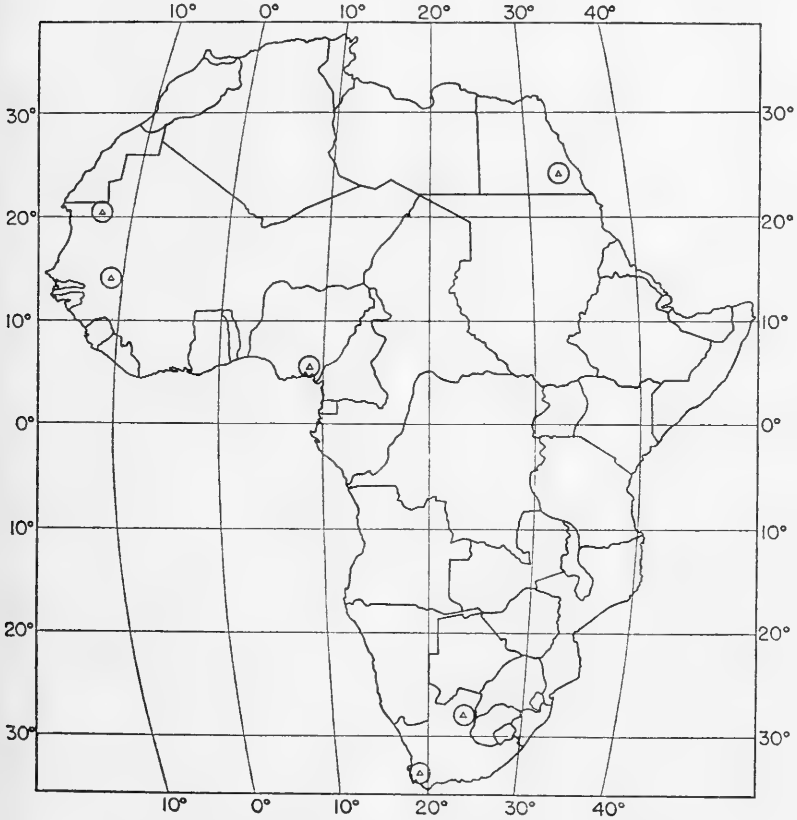

FIG. 8.—Geographic distribution of hexahedrites in table 13.

A YET UNEXPLAINED DISTRIBUTION PATTERN

If a line is drawn on a globe, extending northeasterly from where the Tandil, Argentina iron was found through the places listed in Table 14, it forms an arc which extends almost one quarter the distance of a great circle, and it passes through Braunau, Czechoslovakia, where a hexahedrite fell in 1847.

For what significance it may have, attention is called to two other pairs of hexahedrites, Uwet, Nigeria and Aswan, Egypt, and the Hex River and Bellsbank irons in South Africa, which if connected in this order form two lines which are essentially parallel to the one passing through the places in Table 14 where the 10 hexahedrites were found.

TABLE 14.—*A Yet Unexplained Distribution Pattern.*

Meteorite	Coordinates	
Tandil, Argentina	37°18′ S.	59°10′ W.
Otumpa, Argentina	27°28′ S.	60°35′ W.
Corrego de Arede, Brazil	18°35′ S.	46°30′ W.
Siratik, Mauretania, Africa	14° N.	11° W.
Chinguette, Mauretania, Africa	20°15′ N.	12°41′ W.
Villanueva del Fresne, Spain	38°24′ N.	3°26′ E.
Opava, Czechoslovakia	49°58′ N.	17°54′ E.
Braunau, Czechoslovakia	50°36′ N.	16°18′ E.
Nenntmannsdorf, Saxony	50°58′ N.	15°57′ E.
Hressk, U.S.S.R.	53°14′ N.	27°20.5′ E.

ROLE OF EARLY MAN IN THE DISTRIBUTION OF HEXAHEDRITES

Few iron meteorites other than witnessed falls are known from India and Spain. The reason may be that man found and used them. As stated previously, man used iron in Asia and Europe long before he did in America, Australia, and Africa, yet early North American man is known to have fashioned some things from iron meteorites and to have transported pieces of others from where they fell to his campsites. Previously it was mentioned that the distribution of the Coahuila meteorite is attributed to man. If some meteorites were scattered in this way, man may have effected the distribution of some of the other hexahedrites listed in table 5.

The fact that the hexahedrites ranging from Texas northeastward to Oklahoma are located in an oval provides good reason to believe that man had little to do with them. In this region, there are no natural barriers to prevent him from moving in a north–south or east–west direction any more than in the direction these hexahedrites are scattered. Furthermore, archeological studies in Texas (Shum and Krieger, 1954) show no relationship between the oval area enclosing the places where the hexahedrites were found and the culture pattern of early man in Texas.

Recent archeological work in northern Mexico has demonstrated that the cultural relationships of Chihuahua, Coahuila, eastern Texas, New Mexico, and Arizona are directly connected to influences out of the high culture area of the Valley of Mexico, and that relationships of Mexico and the southeastern part of the United States are along the Gulf Coast and up the Mississippi and its southern tributary, the Red River. From an archeological standpoint, the evidence suggests that man could not have distributed the hexahedrites in Texas over their oval pattern.[3]

American Indians chipped fragments from some large meteorites prior to the time modern man discovered the specimens. The Hopewell Mound Builders apparently transported small pieces of several different types of meteorites considerable distances. At some of the Ohio Mounds, several different types of meteorites have been identified, and at Havana, Ill., meteoritic iron was found fashioned into beads. The Casas Grandes, Mexico, iron, which was excavated from the ruins of a temple, was incased in wrappings similar to those surrounding the bodies found in neighboring graves.

To cite more meteorites which man obviously has transported seems unnecessary, as this study is limited to hexahedrites and only a small proportion of these irons seems to have been disturbed by man (see page 5). Furthermore, since many of the hexahedrites come from limited geographic areas, transportation by man would seem to have been negligible. If man was a factor, why would he concentrate these irons rather than disperse them? To argue that man moved these meteorites outward from a central spot strengthens the point that hexahedrites have a peculiar worldwide distribution.

THE PROBABLE GEOGRAPHIC ABUNDANCE OF HEXAHEDRITES

It can be argued that hexahedrites are equally abundant everywhere and that chance recovery is responsible for the pattern indicating fallout from showers. The best counterargument is the worldwide scatter of hexahedrites, which indicates that they frequently are concentrated into limited areas.

It can also be argued that possibly in certain localities we are dealing with a hexahedrite shower along with one or two single hexahedrite falls. Until the terrestrial ages of meteorites are better understood, it is impossible to assess the validity of such an assumption.

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[3] Personal communications from Dr. Clifford Evans, Jr., curator of the division of archeology, U. S. National Museum.

Six hexahedrites were seen to fall in the last 115 years. Relating this figure to an assumption that perhaps the known meteorites are those which fell in the past 10,000 years, by extrapolation, between 500 and 550 hexahedrites should have accumulated in this period. If this assumption is valid, less than 20 percent of all the hexahedrites have been found.

Although the area of the surface of the earth is slightly less than 200,000,000 square miles, only about 57,510,000 square miles of this is land. No consideration has been given to the hexahedrites which possibly fell into the water nor to the fact that only a small percentage of the land surface is effectively observed for meteorite showers. The above figures were obtained, assuming just 6 hexahedrites fell in the last 115 years, and surely there were more.

If 550 hexahedrites have fallen, and if these were equally scattered over the land surface, there would be one to about every 100,000 square miles of land surface. When the area of the places shown in table 8 is compared with this figure (100,000), or if the areas of the localities where hexahedrites seem to be concentrated are compared to this figure, the conclusion is that these particular meteorites are far from being in random distribution.

INTERFERENCE OF PHOSPHORUS WITH METEORITE STRUCTURES

Iron meteorites that contain considerable amounts of phosphorus often have strange structures. When the schreibersite develops a skeleton structure, such as that shown in the Lake Murray and other similar meteorites, the kamacite grains enclosing the phosphide body become large and equidimensional. Such kamacite grains interfere with the normal development of the structure in the meteorite. Four meteorites with large phosphide inclusions are shown in plates 1-4. Tombigbee River and Bellsbank are hexahedrites, and Santa Luzia, Sao Juliao de Moreira, and Lake Murray are coarse octahedrites.

Apparently no chemical analysis is available for the Lake Murray iron, and erratic nickel values will be obtained if the samples selected for study come from certain parts of the iron. In an area adjacent to the large schreibersite bodies, the nickel will be lower than in the kamacite some distance from these phosphide bodies.

The nickel values in the kamacite around the schreibersite in the Tombigbee River iron are lower than the kamacite more remote from the phosphide bodies (Henderson and Perry, 1958). Similar results were obtained in some unpublished work on other meteorites at the U. S. National Museum.

The Lake Murray, Okla., iron (pl. 1), shows an octahedral pattern with kamacite bands more than 1 cm. wide, but where the large skeletal growths of schreibersite form, the octahedral structure in the matrix is disrupted. The dark square areas are patches applied to protect troilite from being attacked by the etchant. Modern etching techniques have found this precaution unnecessary.

The Bellsbank, South Africa, iron (pl. 2), is a hexahedrite with large schreibersite inclusions. The thin lamellae at the left intersect each other at a variety of angles and are filled with an alteration product. The Neumann lines in the kamacite extend to the breaks, then continue on the other side of the lamellae without a change of direction. Along these lamellae the kamacite is clear, compared with the kamacite more remote from them.

The kamacite surrounding the schreibersite in the Bellsbank iron also is slightly lighter in color than the kamacite remote from the phosphide bodies. If iron is rejected from schreibersite as the temperature falls, of if nickel from the surrounding kamacite enters the phosphide in preference to iron, this may explain the clear kamacite.

The Santa Luzia, Brazil, meteorite (pl. 3), like the Lake Murray, Okla., iron, is a coarse octahedrite with wide kamacite bands, some about 1 cm. wide. However, when schreibersite forms a skeletal habit, the enclosing kamacite becomes equidimensional, and such kamacite bodies disrupt the octahedral pattern. Since the slice illustrated is 0.5 cm. thick, and this schreibersite body is about equally large on both sides of the slice, it probably continued into adjoining slices, thus some conception of its size can be made.

The dark triangular area in the central phosphide body is troilite. In places, the troilite makes a direct contact with the schreibersite; elsewhere, it is in direct contact with the kamacite. Schreibersite more commonly occurs surrounding the troilite.

The Central Missouri iron (pl. 4) was found between 1850 and 1860, but the chemical analysis given by Preston (1900) does not appear to be reliable. After Perry (1944) reexamined this iron, he considered it to be a granular hexahedrite and placed it in the transitional zone between coarse octahedrites and hexahedrites. The Central Missouri iron resembles very closely the Ainsworth, Nebr., meteorite. Both contain large skeletal schreibersites and some alteration products in the fractures separating the coarse kamacite grains. Howell (1908) reports that the 10.64-kg. Ainsworth iron was found beside a creek in Brown County, Nebr., about 6 miles northwest of Ainsworth. His analysis gave 6.49 percent Ni, which, although high for a hexahedrite, may be essentially correct because meteorites with these phosphide inclusions can give a wide range of nickel values depending upon the area selected for study.

PHYSICAL CHARACTERISTICS RELATIVE TO THE FALLS OF HEXAHEDRITES

CLEAVAGE IN HEXAHEDRITES

The cubical cleavage in hexahedrites may have an important bearing on their geographical distribution. Two pieces of the Boguslavka, Siberia, iron were found about 1,700 feet apart, yet they fitted together, Thus, this hexahedrite was split, near the end of its high-velocity flight, comparatively close to the earth while falling nearly vertically.

Any large piece produced by fragmentation of a larger hexahedrite mass will be covered with cleavage surfaces. Also, it will have large open cleavages and numerous small ones extending inward from its surface. While such an irregularly shaped body is in space, the poorly bonded pieces remain attached, but upon entry into our atmosphere, conditions change. When the mass meets appreciable atmospheric resistance, chunks cleave off. Small pieces will decelerate quickly and may fall unnoticed, while the large mass may blaze its way across the sky for hundreds of miles before falling to earth. Hence, many of the cleavages in a hexahedrite approaching the earth will part, causing fragments to separate. Because of this, more pieces may break off from a hexahedrite than from a stony meteorite or from other types of irons. It is said that an iron meteorite is more likely to survive its flight in the atmosphere than a stony meteorite, and conversely, that a stony meteorite is more likely to break in flight than an iron. Because of the cleavages in hexahedrites, there is some doubt about the survival of hexahedrites in flight. Thus, cleavages in this group of irons may account for their geographic distribution.

SIZE DISTRIBUTION OF HEXAHEDRITES

Data on the masses of hexahedrites have been summarized in table 15. Most of the large hexahedrites were never weighed; therefore the weight estimates reported may be inaccurate. Ten of these irons are said to have exceeded 100 kgs., but none of the 10 is as large as the giants in the octahedrite and ataxite groups. Surely, hexahedrites are neither easier nor harder to find than other types of irons. Possibly the limited range in their chemical composition restricted their number; nevertheless, if chemical composition limited their number, it could have no effect on their distribution.

Table 15.—*Hexahedrites arranged according to their weights.*

Weights of more than 1000 kg.:

Chico[1]
Coahuila[2]
Navajo
Otumpa[3]
Sikhote Alin[4]

Weights between 500 and 100 kg.:

Boguslavka
Mt. Joy

Weights between 100 and 50 kg.:

Bennett County
Hex River
Quillagua
Smithonia
Tocopilla
Uwet
Walker County

Weights less than 50 kg.:

Auburn
Aswan
Avče
Barraba
Bellsbank
Bingara
Braunau
Bruno
Cedartown
Central Missouri
(Nedagolla?)
Negrillos
Nenntmannsdorf
Okano
Opava
Pima County
Pirapora
Puripica
Chesterville
Cincinnati
Corrego do Areado
Coya Norte
Edmonton
Filomena
Forsyth County
Holland's Store
Hressk (Gressk)
Indian Valley
Richland
Rio Loa
San Francisco del Mezquital
San Martin
Scottsville
Sierro Gorda
Soper
Summitt
Iredell
Keen Mountain
Kendall County
La Primitiva
Lick Creek
Locust Grove
Lombard
Mayodan
Mejillones (1905) (1875)
Murphy
Tandil
Tombigbee River
Union
Villaneuva del Fresno
Warialda
Wathena
Yarroweyah

[1] Said to weigh about 2 tons.
[2] Several masses larger than 1000 kg. and many smaller pieces in excess of 100 kg.
[3] Many individuals, total weight in excess of 15 tons.
[4] Many tons.

ANGLE OF APPROACH

If a hexahedrite entered our atmosphere at a low angle, the fractured material on its surface would separate, and the fragments that survive the passage through the atmosphere would fall far short of the main mass. The large body would go much farther into our atmosphere before further breaking up or would fall to the ground intact. The widely scattered geographic groups of hexahedrites must be explained by some process that brings one large mass or a cluster of separate similar irons along a trajectory that has a low angle of approach to the earth. Chance recovery of hexahedrites does not explain the distribution of these meteorites.

INCLUSIONS

As far as we know, hexahedrites have the same metallic inclusions as octahedrites with the exception of cohenite, which is relatively abundant in octahedrites but quite rare in hexahedrites. The reason being that iron carbide is more soluble in gamma iron (taenite) than in alpha iron (kamacite), the chief constituent of hexahedrites.

The absence of any appreciable silicate inclusions also may be significant. Although the Spanish meteorite Colomera was classified as a hexahedrite with silicate inclusions, a restudy showed it to have an octahedral pattern and a composition in the octahedrite range. Since the included silicate is olivine, the Colomera iron may be a pallasite, but the 151-gram sample in the U. S. National Museum is too small to be useful in typing a meteorite weighing 134 kg.

RADIATION AGES OF HEXAHEDRITES AND OCTAHEDRITES AND TIME OF DAY OF FALLS

Wänke (1960) noted that by plotting the log N_{Ne} against radius, all meteorites with the same radiation age lie on a straight line. Wänke's plot shows that nearly all the octahedrites lie in a narrow band and thus may have the same radiation age, but that the hexahedrites and ataxites lie definitely lower and thus may have a different history.

Wänke also observed that octahedrites fell between 12 and 24 hours of the day, whereas hexahedrites fell between 2 and 12 hours, or during the morning.

SUMMARY

Seventy hexahedrites are considered in this study. Some of those listed in the Prior–Hey (1952) catalog were omitted because they were incorrectly classified in their original descriptions. When specimens were unavailable for study, it was necessary to rely either upon the author's notes made during visits to other collections, upon published analyses, or upon an interpretation of pictures showing the metallography of the meteorites. When a seemingly reliable analysis reported more than 6 percent nickel, or when a picture showed either plessite or taenite in abundance, the meteorite was no longer considered to be a hexahedrite. If neither a picture nor an analysis of the iron was available, the Prior–Hey classification or the original description was accepted.

Obviously the hexahedrites are not scattered at random over the world. Unfortunately, at this time we do not know how other types of meteorites are distributed. Formerly it was assumed that a shower of iron meteorites would scatter like the stony ones. However, the evidence here presented suggests that hexahedrites have a different fallout pattern from that of stony meteorites, but for reasons not yet known.

Because the four hexahedrites located in Canada and our adjacent northern States are so widely separated that they do not make a convincing case for a meteorite shower, they were not counted. Table 16 gives the number of hexahedrites in each of the areas where evidence exists that a shower of hexahedrites occurred. The hexahedrites from Chile, southeastern United States, Europe, two places in Africa, and Argentina seem to be geographically grouped in a fallout pattern.

Table 16 shows the numbers of hexahedrites which, by grouping, appear to have fallen in showers. If, to these 50 cases, the 6 which were seen to fall are added, we have 56 hexahedrites out of a total of 70. This means that approximately 80 percent of these irons either

TABLE 16.—*The numbers of hexahedrites from the different geographic areas which may be related.*

1 Mexico–Texas, Oklahoma	6
2 Southeastern U. S.	18
3 Chile	12
4 Australia	5
5 Europe	5
6 Africa	4
Total	50
Witnessed falls (excluding the Nedagolla[1])	6
Number accounted for as possible falls	56, or 80 percent
Hexahedrites scattered at random	14, or 20 percent

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[1] See page 8.

fit into fallout patterns or were witnessed falls. Such a percentage can hardly be a coincidence.

The fact that hexahedrites are chemically simple and apparently without silicate inclusions raises the possibility that hexahedrites may represent fragments from the core of a larger body. Most theorists agree that the core should be essentially free from silicates, and from a standpoint of quantity, core material should be less abundant than material from the surrounding shells. The hexahedrites meet these two rather basic requirements of core material.

Many of these topics have been presented before societies and symposia since 1950. Critical comments generally can be divided into two types: (1) Meteoritic statistics are too limited to support these groupings; (2) Conditions necessary to accomplish these selected fallout groupings of hexahedrites are difficult to reconcile with basic concepts of astrophysics.

Perhaps some of these criticisms are still valid, but new finds of hexahedrites, as well as investigations of other scientists, have produced more facts to support these proposals than to disprove them. Thus, more investigators seem to agree with the theme here proposed than to disagree with it.

Many assume that meteorites are equally distributed over the earth but because they are discovered by accident, their recovery is limited to fairly settled regions of the surface of the earth. However, these 70 hexahedrites are not uniformly scattered over the area from which meteorites have been recovered. About 70 percent of them are concentrated into 6 geographic areas, and the points of fall or discovery within these areas suggest that they fell as a shower.

The long axes of these strewn fields exceed those of the observed falls of any meteorite, yet are about equal to the paths of several observed fireballs and some of the witnessed displays of falling meteorites. The long axes of the scatter of the individuals in the different geographic areas lie in essentially a northeast–southwest direction.

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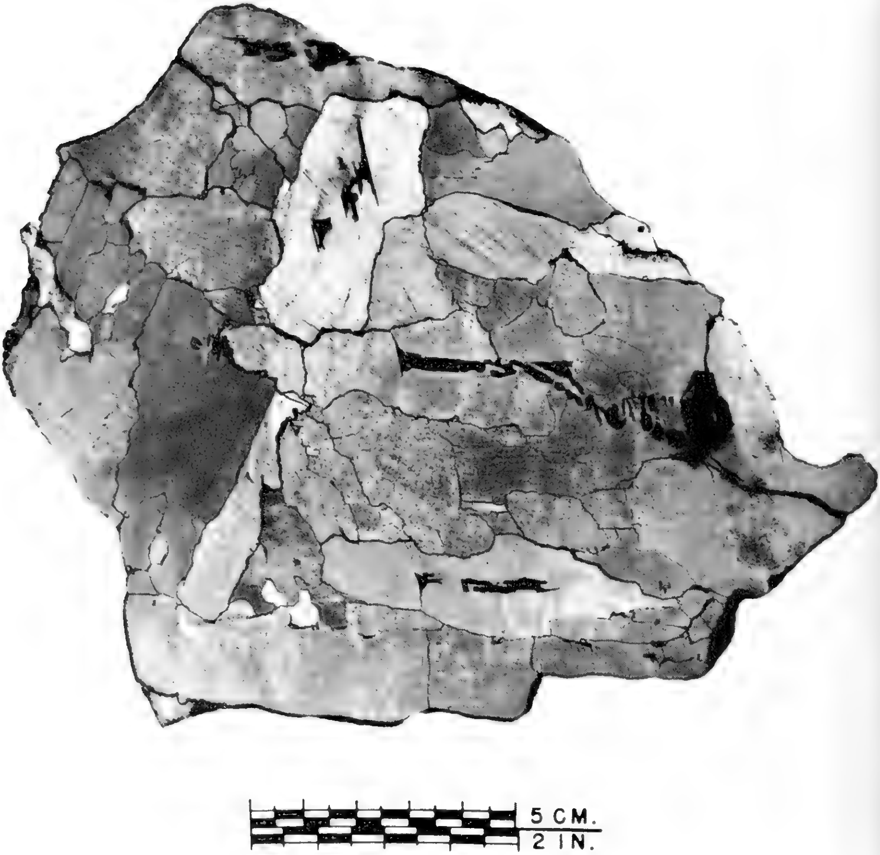
Lake Murray, Oklahoma
Coarse octahedrite with skeletal schreibersite inclusions. (Photograph courtesy of Institute of Meteoritics, University of New Mexico.)

Bellsbank, South Africa
Hexahedrite with large, irregular schreibersite inclusions.

Saint Luzia, Brazil

Skeletal schreibersite inclusions, with large kamacite areas enclosing them, disrupt the orderly octahedral pattern of the kamacite.



Central Missouri
Hexahedrite with large schreibersite inclusions.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
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(WITH EIGHT PLATES)

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INTRODUCTION

Fossil oysters are among the most common and well preserved faunal elements in Cretaceous sediments. With few exceptions, however, they have been ignored in evolutionary studies and biostratigraphy. Although countless species have been described, the taxonomy of the group is confusing and inconsistent. It seems ironic, therefore, that they are one of the groups most suited to modern population systematics. The present investigation attempts to demonstrate the feasibility of detailed systematic and evolutionary study, faunal zonation, and regional correlation based on oysters. It employs simple biometric analysis of large collections, from numerous localities, distinct stratigraphic levels, and diverse sediment types. I have chosen for this purpose a typical lophid species group centered around *Lopha lugubris* (Conrad), and including *L. bellaplicata bellaplicata* (Shumard), *L. bellaplicata novamexicana* n. subsp., and varieties of these forms.

The *Lopha lugubris* lineage is the predominant ostreid species group in Middle and Upper Turonian (Upper Cretaceous) sediments of the Western Interior and western Gulf Coast. These plicate oysters are abundant and well preserved at various stratigraphic levels in the upper Eagle Ford Shale of Texas, the Mancos Shale of New Mexico, and the Carlile Shale of Colorado, New Mexico, and, rarely, Kansas. They are ideally suited for a modern systematic study because the structural complexity of lophid oysters is greater than in many other ostreid types. Detailed analysis of this group provides a good test for the systematic, taxonomic, and evolutionary utility of morphologic features not previously considered by many ostreid workers.

Oysters of the *Lopha lugubris* group characteristically have a rounded, subovate, or subquadrate outline, asymmetrical prosocline shells with curved, opisthogyrate beaks and umbones (exogyroid in some forms), and coarse, bifurcating, radial plicae originating at the umbone on left valves, but variably developed on right valves. The shell is lamellate and moderately inequivalve, with the right (upper) valve flatter and slightly smaller than the left (lower, attached) valve. The valves are denticulate, with small cardinal areas, and a subcentral, comma-shaped muscle impression.

The lineage first appears in Western Interior and Gulf Coast sediments during the late Middle Turonian (zone of *Collignoniceras hyatti* Stanton). The youngest known representatives occur in middle Upper Turonian sediments (zone of *Prionocyclus wyomingensis elegans* Haas). It may range into even younger Carlile strata in the Western Interior, as indicated by scattered reports of small plicate oysters (indeterminate) in uppermost Turonian beds.

The *Lopha lugubris* lineage appears to have had a Gulf Coast origin, or center of dispersal, in the United States, and reached its maximum development in abundance and size in these southern waters. Its immediate ancestor is unknown. Possibly, the lineage arose from the European group of *L. syphax* (Coquand) (Early Cenomanian) or from some Early Cretaceous lophid stock, such as *Lopha marcoui* (Böse). There is a distinct gap, however, in our knowledge of the evolution of *Lopha* in sediments of Cenomanian age where representatives of this genus are not common.

ACKNOWLEDGMENTS

I am greatly indebted to Drs. Norman F. Sohl and William A. Cobban of the United States Geological Survey, and to Dr. Richard S. Boardman of the United States National Museum, for their excellent criticism of the manuscript and many suggestions during the course of the study. Conversations with Dr. H. B. Stenzel of the Shell Development Company were very helpful. Collections were kindly donated to the National Museum by Dr. Bob F. Perkins of the Shell Development Company and loaned by Dr. Donald E. Hattin of the University of Indiana. Specimens that I collected during the period 1958 to 1960 are on loan through the courtesy of the University of Michigan Museum of Paleontology. The drawings

were made by Larry Isham, the photographs by Jack Scott, both of the United States National Museum.

BIOSTRATIGRAPHY

Members of the *Lopha lugubris* group have equivalent stratigraphic distribution in Turonian sediments of Colorado, New Mexico, and Texas (fig. 1). The restricted ranges, broad geographic distribution, and abundance of individual species and subspecies render them useful as stratigraphic tools in regional correlation. In some areas they are the best available indices.

Stratigraphic distribution in Texas.—Lopha bellaplicata novamexicana n. subsp. has not yet been found in Texas. *Lopha bellaplicata bellaplicata* (Shumard) is the oldest known representative of the group on the Gulf Coast, marking a discontinuous faunal zone (zone 9 of Adkins and Lozo, 1951, p. 155) at the top of the Eagle Ford Shale (late Middle and early Late Turonian; Cobban and Reeside, 1952, chart 10b). It has been reported from the upper Arcadia Park Limestone and Shale Member, the upper South Bosque Marl Member (questionably), and the upper few feet of the "Condensed Zone" of Adkins and Lozo (1951, p. 155). Generally the species occurs only in the upper 25 feet of the Eagle Ford, but locally it has been reported ranging through as much as 70 feet of section. It apparently does not range into the Austin Chalk, although reworked fragments of shells have been found in a thin conglomeratic calcarenite bed ("reworked Eagle Ford" zone) which locally lies between the Austin and Eagle Ford, and which has been assigned by many workers to the former.

Lopha bellaplicata bellaplicata is known to occur only in upper Middle Turonian sediments in Texas, above the zone of *Collignoniceras woollgari* (Mantell) (early Middle Turonian) and locally below a widespread disconformity which, in the Western Interior, forms the Middle–Upper Turonian boundary. Faunal associates in the U. S. National Museum and U. S. Geological Survey collections from Texas include an undescribed species of *Inoceramus* closely related to *I. dimidius* White (and ancestral to it), *Cardium pauperculum* Meek, and *Cyprimeria*? sp. or *Tapes* sp. cf. *T. cyprimeriformis* Stanton, all characteristic of the middle Carlile Shale (Blue Hill and Codell Members) in the southern Western Interior. *Lopha blacki* (White) morphologically intergrades with *L. bellaplicata bellaplicata* and comes from approximately equivalent upper Eagle Ford strata. It is here considered a synonym of *L. bellaplicata bellaplicata.*

The zone of *Lopha lugubris* lies predominantly above that of *L. bellaplicata bellaplicata,* but their ranges overlap slightly (fig. 1). At two known localities in Texas, the species are found together in the upper 2 or 3 feet of the Eagle Ford Shale. They are distinct in this zone of overlap, and do not intergrade. *L. lugubris* does not range below this level, as does *L. bellaplicata bellaplicata.* It ranges upward, however, above the range of *L. bellaplicata bellaplicata,* through the calcarenite bed between typical Eagle Ford Shale

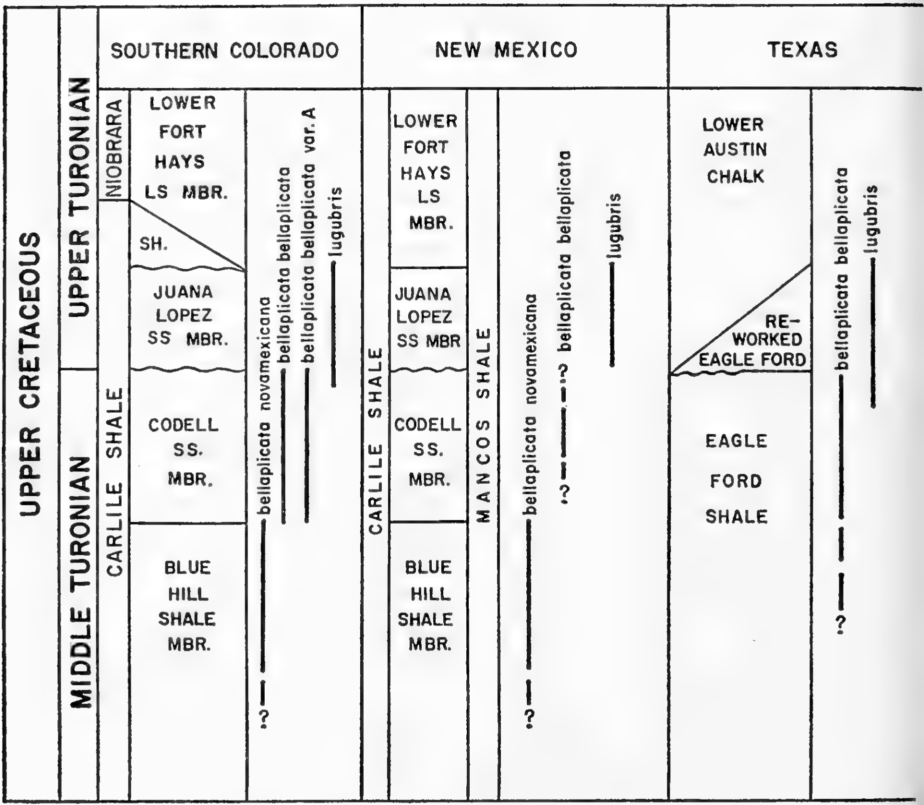


Fig. 1.—Stratigraphic range of oysters in the *Lopha lugubris* group from Colorado, New Mexico, and Texas, and proposed correlations. Colorado stratigraphy taken along the east flank of the Front Range (Cañon City, Pueblo, Huerfano Park areas). New Mexico section interpolated from Cerrillos and Carthage sections of Rankin (1944) and from stratigraphic data on collections made between Cerrillos, N. Mex., and Trinidad, Colo. Texas section generalized for central and northeast Texas.

and Austin Chalk (fig. 1). A disconformity of unknown magnitude separates the Eagle Ford and the calcarenite at many places. Specimens of *L. lugubris* from this calcarenite are complete and do not exhibit signs of wear. They appear to have lived during deposition of the calcarenite rather than having been reworked from typical upper Eagle Ford Shale, as some workers have suggested. A similar situation exists in the Juana Lopez Member (Carlile Shale) of the Western Interior. The precise age of the "reworked Eagle Ford" calcarenite has not yet been established, but it appears to be lithologically and faunally the southern equivalent of the Juana Lopez.

Stratigraphic distribution in the Western Interior.—The stratigraphic distribution of the *Lopha lugubris* group in the Western Interior is the same as that observed in the Texas Cretaceous sequence (fig. 1), as are the general progression of ammonites and lithologies. The occurrence of *lugubris*-like oysters in Colorado, particularly in Huerfano Park, is of great importance, since it is only here that all members of the group have been found together geographically and their stratigraphic relationships accurately established. In this area, *Lopha bellaplicata novamexicana* occurs sporadically in septarian limestone concretions of the upper Blue Hill Shale Member (late Middle Turonian, lower part of the range of *Collignoniceras hyatti:* fig. 1). *L. bellaplicata bellaplicata* and the variety A are common throughout the Codell Sandstone Member ("Pugnellus Sandstone" of Stanton, 1893 [1894]: late Middle Turonian, upper part of the range of *C. hyatti*). *L. lugubris* questionably occurs in the uppermost Codell Sandstone (based on two poorly preserved specimens), and is common throughout the Juana Lopez Member (Juana Lopez Sandstone of Rankin, 1944; a calcarenite or limestone in Colorado) of the Carlile Shale. The upper and lower contacts of the Juana Lopez are disconformable throughout much of its geographic range in Colorado and northern New Mexico.

In northeastern and north-central New Mexico, and parts of the San Juan Basin, the Coloradoan sequence and distribution of the ostreid elements is similar to that in southern Colorado (fig. 1). The Juana Lopez Member is thicker in New Mexico, however, and locally consists of calcareous sandstone, or of interbedded calcarenites, shales, and sandy units. *Lopha lugubris* occurs throughout this member. Those from the base are possibly distinguishable from those occurring at the top of the sequence on the basis of relatively longer, coarser and less numerous radiating plicae on the older forms. Not enough specimens are available, however, to prove this statistically.

Elsewhere in New Mexico, where the Coloradoan sediments are more uniform (Mancos Shale of most authors), the distribution of members of the *L. lugubris* group is not as well established. *Lopha bellaplicata novamexicana* occurs in the middle Mancos, in the zone of *Collignoniceras hyatti* (late Middle Turonian). The range and position of *L. bellaplicata bellaplicata* is not precisely known, except that it occurs in the middle Mancos below the Juana Lopez calcarenites. *L. lugubris* occurs widely in the middle and basal upper Mancos, in calcarenites equivalent to the Juana Lopez Member. Here it is associated with *Prionocyclus wyomingensis wyomingensis* Meek, *P. macombi* Meek, and *Scaphites warreni* Meek and Hayden, a Juana Lopez assemblage. It has also been reported from slightly younger beds (zone of *P. wyomingensis elegans* Haas: middle Late Turonian).

Stratigraphic conclusions.—Comparison of the Texas, northeastern New Mexico, and south-central to southeastern Colorado Turonian sediments reveals a marked similarity in the sequence of ostreids, ammonites, sediment types (in part), and in the position of the Middle–Upper Turonian boundary, in many places marked by a disconformity. In these areas dark clay shale, locally sandy, silty, and containing lensing siltstones, silty limestones, and sandstones (upper Eagle Ford Shale; Codell Sandstone in many places) underlies this boundary. This unit contains *L. bellaplicata bellaplicata* and species of *Collignoniceras* (*C. hyatti*, *C.* sp.) in all areas and is locally underlain by sediments carrying *L. bellaplicata novamexicana.* Brown to rusty, sandy calcarenites and calcareous sandstones, locally containing fish tooth, bone, and phosphate pebble conglomerates overlie the boundary, especially where it is marked by a disconformity (Juana Lopez Member; "reworked Eagle Ford" zone), at many localities. This unit contains *L. lugubris* and species of *Prionocyclus* (*P. wyomingensis wyomingensis, P. macombi, P.* sp.) in the great majority of localities where it is found. In both Colorado (questionable occurrence) and Texas, *L. lugubris* is found rarely in the uppermost part of the lower unit (upper Eagle Ford equivalents), partially overlapping the range of *L. bellaplicata bellaplicata.*

I propose that the two sequences are correlative in the manner shown on figure 1, and that they may be correlated on the basis of lophid oysters as well as ammonites. Based on lithologic and faunal relationships, I suggest that the thin calcarenite locally present above the Middle–Upper Turonian boundary and disconformity in Texas should not be assigned to the Austin but rather to the Eagle Ford, forming the highest zone of that formation (zone of *Lopha lugubris*).

The Austin has been considered totally Coniacian in the past, although locally, the lowermost Austin chalks contain a Late Turonian fauna. The calcarenite unit is, without doubt, Late Turonian in age and faunally allied with pre-Austin sediments.

HISTORY

Attempts to treat the *Lopha lugubris* group in the past have encountered the many pitfalls inherent in taxonomic study of the Ostreidae. It has been treated as a single variable species (Stanton, 1893 [1894], pp. 58, 59) and as a series of related species, some of which appear valid, others merely environmental variants of described forms. The problems which have produced such inconsistency are those that have generally affected the taxonomy of ostreids in the past: Inability to distinguish environmental control on shell form from genetic shift; failure to define adequately the limits of specific variability through the study of small and geographically restricted samples rather than analysis of numerous, widely distributed "populations"; application of typologic paleontology; limited knowledge of modern representatives of the family; insufficient stratigraphic data; and others. It is not surprising that the group has a complex nomenclatural history in previously published studies.

Conrad's original description (1857, p. 156, pl. 10, figs. 5a, b) was based on a few small, densely plicate specimens with large attachment areas. These were obtained from calcarenites typical of the lower Juana Lopez member (upper Carlile Shale: zone of *Prionocyclus macombi* Meek and *P. wyomingensis wyomingensis*) in New Mexico and all belong to *Lopha lugubris* s. l. Shumard (1860, p. 608) later recognized a larger, more coarsely plicate, and somewhat older form, *Ostrea bellaplicata,* in the upper Eagle Ford Shale of Texas. White's *Ostrea blacki* (1880, p. 293, pl. 4, figs. 1, 2) appears to be erected on worn, smoother, ecologic variants of *L. bellaplicata bellaplicata.* The two forms occur in approximately time-equivalent strata.

These names were used by a number of authors without much change until Stanton (1893 [1894], pp. 58, 59) placed all members of the group into synonymy with *L. lugubris* Conrad, regarding them as ecologic variants of a single species. Stanton's concept has been generally perpetuated in this country, although the other names are used occasionally in fieldwork, on collection labels, and in unpublished faunal lists. In Mexico, however, Böse (1913, pp. 47, 48) recognized *L. lugubris, L. bellaplicata,* and *L. blacki* as distinct species, but overlooked the different stratigraphic ranges of the first two forms. Only mention has been made of the group since that time, and it has not been widely used in biostratigraphic work. The appearance of *L. lugubris* Conrad on most faunal lists compiled in this century has only limited stratigraphic value in that it is probably used in the concept of Stanton (1893) and indicates an age no more refined than Middle and Late Turonian.

STUDY OF FOSSIL OSTREIDAE

The Ostreidae, and in particular *Ostrea, Crassostrea,* and related genera, are among the most variable of shelled animals. The animal readily adapts to a number of environmental situations without significant change in morphology of the soft parts. Gross shell form, on the other hand, is greatly affected by the surrounding environment in many species. Long, narrow, straight shells are produced in strong currents; quiet water favors more rounded, broader shells; crowding produces elongate, irregular, laterally compressed forms; the depth and size of the mature shell is related in some groups to the amount of exposure in intertidal areas; high-energy shallow-water environments produce heavier-shelled, more prominently ribbed forms than do deep, quiet-water niches; some ostreids form imbricate frills to keep above soft mud and shifting sand bottoms, and so on. Many morphologic features of the shell, therefore, are highly variable within a single species, and must be analyzed with care. This is particularly true in regard to shell outline, convexity, and strength of surface ornamentation. Other structures, less affected by environmental variation (shell structure, prodissoconch, denticles, position and shape of muscle scar, cardinal area), form a more reliable basis for classification.

Finally, modern types of Ostreidae (*Ostrea, Crassostrea,* etc.) are generalized and successful animals, and have been exceptionally conservative in their evolution. They have undergone little basic change in shell form since they became established as an important group during the Mesozoic. Variants of living species are in many cases indistinguishable from certain Cretaceous forms when only a few shells are compared. Closely related species exhibit considerable morphologic overlap, and the differences between them are commonly subtle.

In studying the *Lopha lugubris* group, resolution of the problems inherent in biologic interpretation of the Ostreidae required analysis of large suites of specimens, including growth series, from many localities and sediment types, representing a broad range of environments. Only in this way could normal variation limits, ecologic control on shell form, and genetic shift be recognized. During the course of this study, I was fortunate to have at my disposal the large and well-documented collections of the U. S. National Museum, and Denver and Washington collections of the U. S. Geological Survey. These were supplemented by my own collections made over a period of 5 years in the Western Interior, and by small lots lent or donated for this study by various individuals. Several hundred measurable specimens, including ontogenetic series, form the basis for species descriptions and observations on stratigraphic distribution, variation, ecology, and evolution.

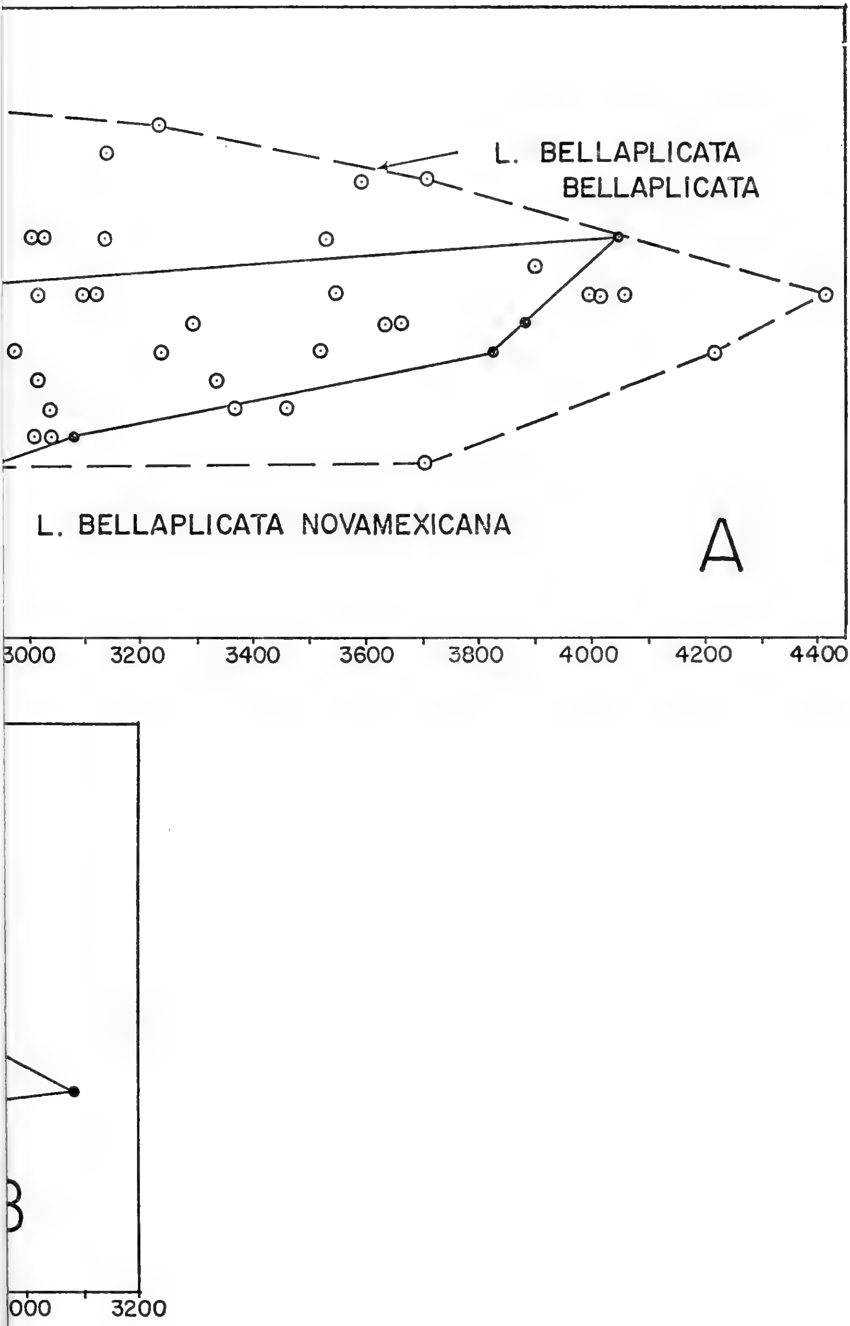
Time equivalency of the various fossil beds from one area to another was established on the basis of ammonites, species of *Inoceramus*, and widespread disconformities. The ammonite and inoceramid species used are widespread, well-established faunal indices occurring in a variety of sediment types (representing various environments) and apparently subject to minimal facies control.

Simple biometric analysis of all available morphologic features, using graphs, charts, and simple ratios, indicated structures which might be useful in lophid taxonomy, and proved to be sufficient for the recognition of specific differences, ontogenetic development, and evolutionary trends within the *Lopha lugubris* group. Features that were employed in these aspects of the study are: Maximum adult size; basic ornament pattern; normal valve outline; the distribution of convexity on both valves; juvenile ornamentation; extent of valve covered with plicae; number, size, and bifurcation rates of the plicae at given intervals; plication density in a given area or distance; gross characteristics of the concentric ornamentation; differences between the ornamentation of the auricles and main body of the shell; relative development of the auricles and auricular sulci; angle of inclination of the beaks and umbones, and independently of the valve; curvature and position of the beaks and umbones; angle of the posterodorsal slope; relative size and development of various parts of the cardinal area; density and extent of the denticles on the dorsolateral valve margins; relative size and position of the muscle scar; and in some cases, the relative size, position, and inclination of the attachment scar. To this list might be added comparison of various ratios, such as length to height, length of the auricle to length of the shell, and others.

Although ontogenetic studies have not been attempted to any extent with fossil oysters, distinct and commonly abrupt changes in shell morphology with growth are common, especially in the more ornate groups, and can probably be tied to developmental phases of the animal. In this study the terminology of Hyatt (1894, pp. 349-647)—nepionic (babyhood), neanic (youth), ephebic (adult), and gerontic (senile)—is used to characterize growth periods between major morphologic changes in the shell. In oysters, and more specifically in the *Lopha lugubris* group, the nepionic stage is represented by the prodissoconch, the neanic (spat) stage by part or all of the umbo. The nepionic–neanic transition is marked by development of adult hinge characters, change in shell shape (usually from rounded to dorsoventrally elongate), and development of coarser concentric ornamentation. The ephebic stage is characterized by adult ornamentation (the plicae in *Lopha*), change in shell shape including development of auricles, folds, etc, well-defined denticles and muscle insertion areas, and further differentiation of the cardinal elements. The neanic–ephebic boundary is marked in some lophids by the abrupt appearance of plicae, development of auricular salients in the marginal outline, and differentiation of the resilifer and lateral cardinal plates on the hinge line. The gerontic stage is characterized by flattening and flaring of the ventral and lateral shell margins, deterioration of the ornament pattern, decrease in prominence of the radial ornament, crowding and increase in prominence of the concentric ornament, and decrease in prominence of structures related to sexual maturity and reproductive function.

Graphs and drawings depicting ontogenetic trends in members of the *Lopha lugubris* group are shown in figures 2-4, 6, 9, 11-18.

Geographic variation and environmental control on shell morphology were determined by comparing a number of "populations" from time equivalent but lithologically distinct sediments in different areas (fig. 14). Only *L. bellaplicata bellaplicata* exhibits significant variation in both respects. Comparison of related forms from a number of different stratigraphic levels, but from similar sediments (roughly representing similar environments) is the most satisfactory method of demonstrating evolutionary change in the lineage. Unfortunately, this method is not wholly applicable to the *L. lugubris* group, since there is little overlap of exact sediment type between faunal zones. Evolution of this group, therefore, is necessarily determined by comparing total variation plots of forms from different stratigraphic levels, irrespective of lithology (figs. 2-9). Such a system of separating evolutionary change from geographic or environmental variation is



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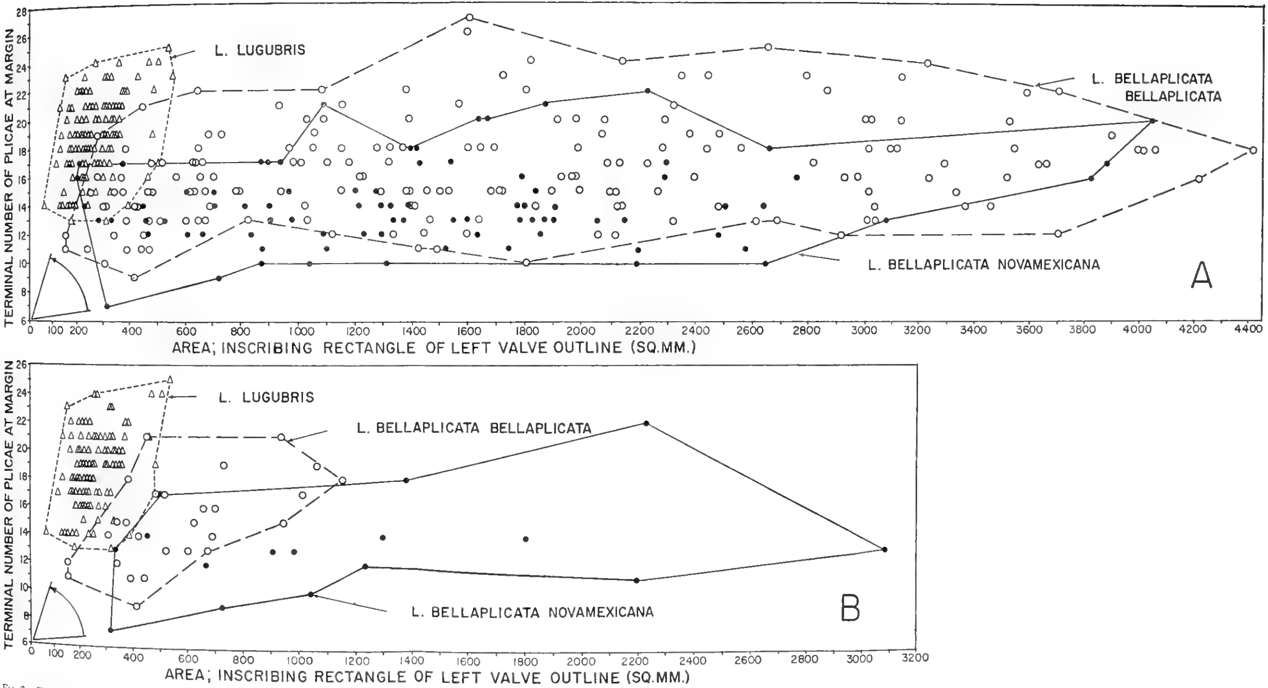

FIG. 2.—Evolution of the *Lopha lugubris* group. Increase in the density of the plicae, number per unit area, on left valves of progressively younger species. A, Scattergram for all specimens measured, from Colorado, New Mexico, Texas. B, Scattergram of Colorado sample only. Arrows in lower left-hand corner of each graph indicate direction of increasing plication density as shown by hypothetical regression lines visually fitted to plots of terminal species in group.

admittedly somewhat idealized. Obviously, it is not possible to evaluate properly all the environmental factors acting on these shells in different areas. The chemical environments of two very similar sandstones may have been entirely different and may have had a profound effect upon the type of shell produced in each area. Analysis of chemical aspects of the paleoenvironment is difficult or impossible in most coarse clastic sediments, and is well beyond the scope of this study. It should be understood that in dealing with environment here, I am dealing in generalities and am cognizant of the limitations this places on the accuracy of my interpretations.

Gross morphologic similarities in form, ornament pattern, development of the auricles, the cardinal area, and the muscle scar, in addition to detailed morphologic overlap in marginal variants of consecutive species clearly point out the close relationships of members in the *Lopha lugubris* group and suggest that they represent a continuous evolutionary sequence, without major break.

EVOLUTION

Several of the morphologic characters which are most important in the differentiation of species and subspecies of the *Lopha lugubris* group demonstrate significant evolutionary trends (figs. 2-9), most of them chronoclinal. These reflect, in part, gradual adaption of the lineage to a slowly changing regional environment characterized by regression and shallowing of the interior seas, increased wave and current action, and increased turbidity. The scope of these changes from one level to another is well beyond the normal ecologic variation caused by similar shallow water conditions in any member of the group during its existence.

In graphing evolutionary trends in the *Lopha lugubris* group, structures were compared wherever possible at equivalent ontogenetic stages on the three principal species and subspecies. Comparison of the terminal number of plicae at the margin of adult valves represents such a plot and can be analyzed irrespective of the differences in size range shown by *L. lugubris* when compared to subspecies of *L. bellaplicata.*

In addition to these plots, it seemed desirable to employ another type of comparison in which structures of adult valves from the three forms of *Lopha* were contrasted at equivalent sizes (i.e., at 20 mm. height) (figs. 6a, 7c). The purpose of this type of plot is twofold: (1) It provides a basis for morphologic comparison of the species and subspecies at equivalent sizes, and a test of their genetic

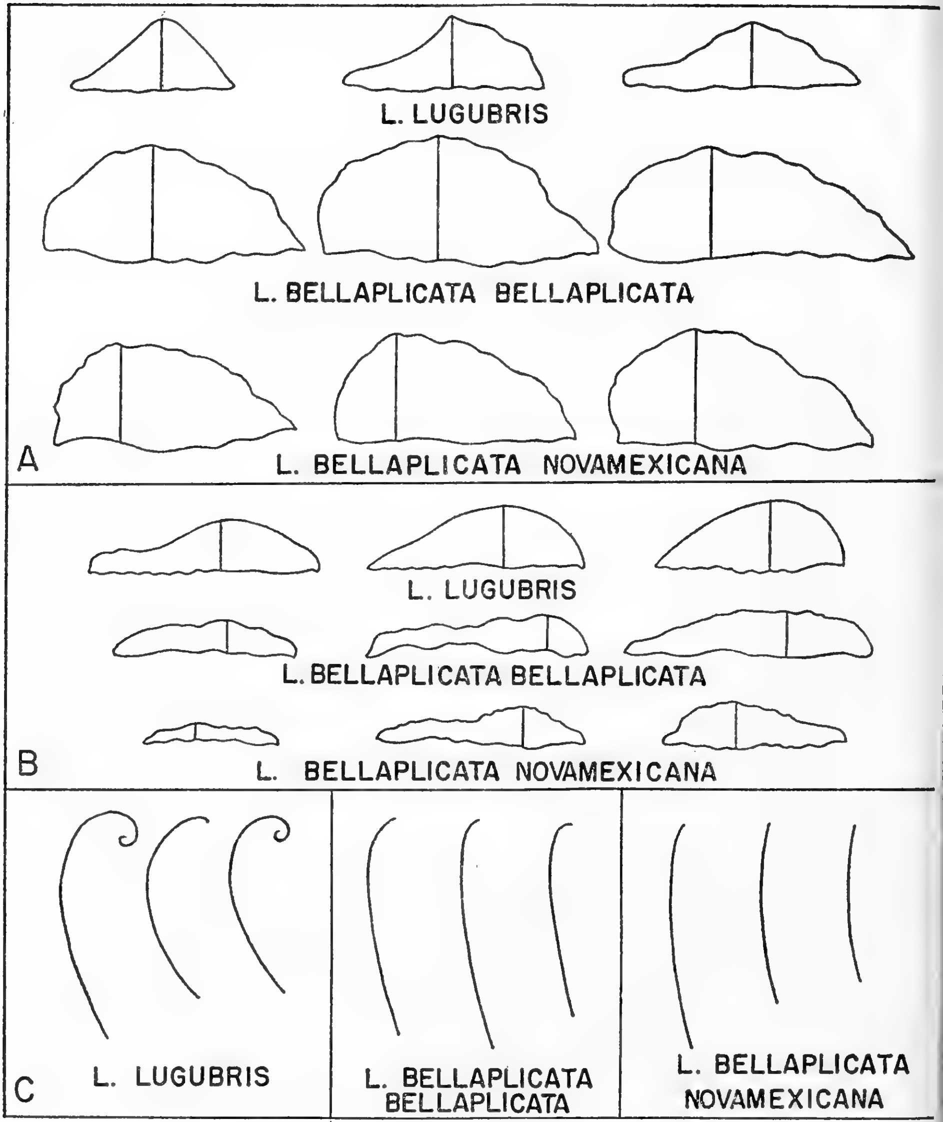

FIG. 3.—For explanation, see opposite page.

distinction. (2) At the same time it demonstrates evolutionary trends within the group in absolute measurements. These trends are not as well shown by this type of plot as they might be by comparing structures at the margins of adult shells, where morphologic differences are emphasized, but they are validly illustrated and significant because even this method essentially compares structures at an approximately equivalent stage of development.

Plots of structures comparing them at a constant height were made within the ephebic part of the shell for each species and subspecies; thus, only adult structures were compared. Ephebic development starts at about 10 to 15 mm. height on all forms, the difference in adult size between *L. lugubris* and *L. bellaplicata* (both subspecies) representing mainly differences in rate and amount of ephebic growth. Since *L. bellaplicata bellaplicata* and *L. bellaplicata novamexicana* have nearly equivalent size ranges, comparison of any structure at a given height on both is essentially a comparison made at equivalent ontogenetic stages. Because adult shells of *L. lugubris* attain a much smaller size, they theoretically should not be ontogenetically comparable with subspecies of *L. bellaplicata* at a given height. Such a comparison is valid however because the ephebic morphology of this species is strikingly constant. The plicae do not normally bifurcate (fig. 6b and c) and their number is relatively constant anywhere on the adult portion of the shell. In addition, beyond 20 mm. height, the width of the plicae and sulcae remains relatively constant. Since ephebic structures are so uniform in *L. lugubris,* and values obtained

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FIG. 3.—Evolutionary trends demonstrated by members of the *Lopha lugubris* group. A, Comparison of cross sections through normal left valves. Beak is to the left. Note general decrease in overall convexity, ventral migration of the high point of the valve (illustrated by vertical lines through cross sections) through time. B, Comparison of cross sections through right valves, beak to the right. Note increase in relative convexity and shift in high point of valve (illustrated by vertical lines through each cross section). C, Comparison of midline traces of typical left valves showing decrease in curvature of beaks, and in overall curvature of shell through time. Beaks dorsal in each case. Specimens: A, Top row, left to right, U.S.N.M. 132157, U.M.M.P. 43472, U.S.N.M. 132154; middle row, left to right, U.S.N.M. 132307, 132243, 8024b; bottom row, left to right, U.S.N.M. 132276, 132288, 132272. B, Top row, left to right, U.S.N.M. 132164, 132198, 132168; middle row, left to right, U.S.N.M. 132306, 132305, 132244; bottom row, left to right, U.S.N.M. 132265, 132286, 132287. C, *L. lugubris,* left to right, U.S.N.M. 132157, 132159, 132156; *L. bellaplicata bellaplicata,* left to right, U.S.N.M. 132225, 132224, 132222; *L. bellaplicata novamexicana,* left to right, U.S.N.M. 132275, 132267, 132263.

in measuring them do not vary significantly from one point to another, they are comparable at any given height with those of *L. bellaplicata* (either subspecies) regardless of whether or not they represent an equivalent stage of ephebic development.

The absolute height of the smooth stage increases in progressively younger species of the *L. lugubris* group (fig. 8), and its evolution is characterized by transgression of its ventral margin from the neanic to the ephebic part of the shell. The smooth stage terminates in the early to middle neanic stage of *L. bellaplicata novamexicana,* and in the middle to late ephebic stage of *L. lugubris.* Measurements of the height of the smooth stage used in plotting evolution are therefore not ontogenetically comparable for the three forms.

Correspondingly, the number of primary plicae arising at the edge of the smooth stage have also been measured at different ontogenetic stages. These are more readily comparable than the height of the smooth stage, however, because on many specimens of *L. bellaplicata* (both subspecies) and a few *L. lugubris* the number of primary plicae can be directly contrasted at the neanic–ephebic boundary. Although the plicae arise early in the ontogeny of the subspecies of *L. bellaplicata,* they do not undergo extensive bifurcation until the early ephebic stage. The number of plicae at the neanic–ephebic boundary therefore generally reflects the original number of primary plicae at the edge of the smooth stage. In *L. lugubris* the plicae normally arise at a later developmental stage, but on rare specimens with a small attachment scar, also arise near the neanic–ephebic boundary. In these specimens, the number of primary plicae is equal to the number found in specimens where the plicae arise at a later developmental stage. This indicates that the number of plicae is not ontogenetically controlled in *L. lugubris,* and relatively constant in number regardless of where they arise on the shell. Therefore, there is some validity in comparing the initial number of primary plicae on *L. lugubris* with subspecies of *L. bellaplicata,* despite the variation in ontogenetic stage at their first appearance.

Important evolutionary trends noted in progressively younger Turonian representatives of the *Lopha lugubris* lineage are:

1. Decrease in the maximum size attained by the species (fig. 2).

2. Slight decrease in the relative convexity of the left (lower, attached) valve, and ventral migration of the high point of the valve (figs. 3a, 4a, b).

3. Gradual increase in the relative convexity of the right (upper, free) valve, particularly in the umbonal region (fig. 3b).

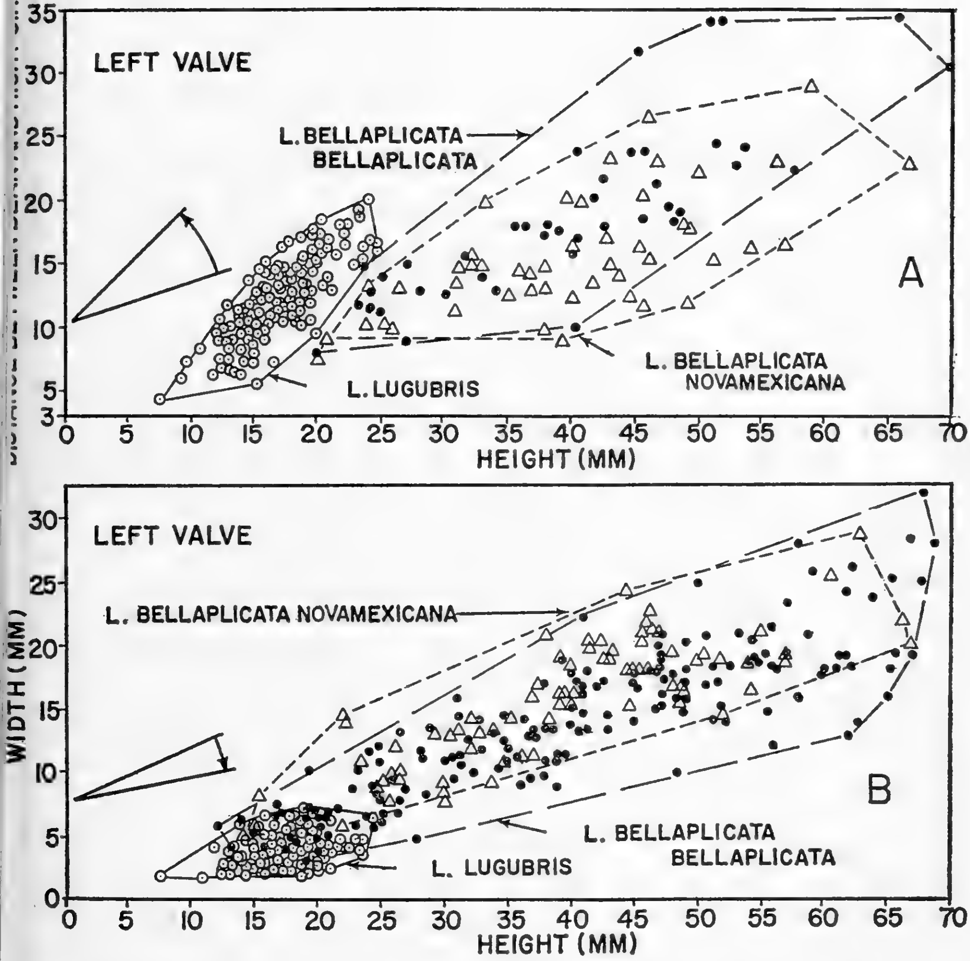

FIG. 4.—Evolution in the *Lopha lugubris* group. A, Scattergram showing relationship between valve height and the distance between the beak and high point of the left valve, measured parallel to height. Note ventral shift of the high point in progressively younger forms. Arrow in lower left-hand corner denotes direction of ventral migration of high point as illustrated by hypothetical regression lines fitted visually to plots of end members of group. B, Scattergram showing relationship between height and width of left valves. Note slight decrease in relative convexity of left valve in progressively younger forms. Arrow in lower left-hand corner denotes direction of decreasing convexity as illustrated by hypothetical regression lines fitted visually to plots of end members of lineage.

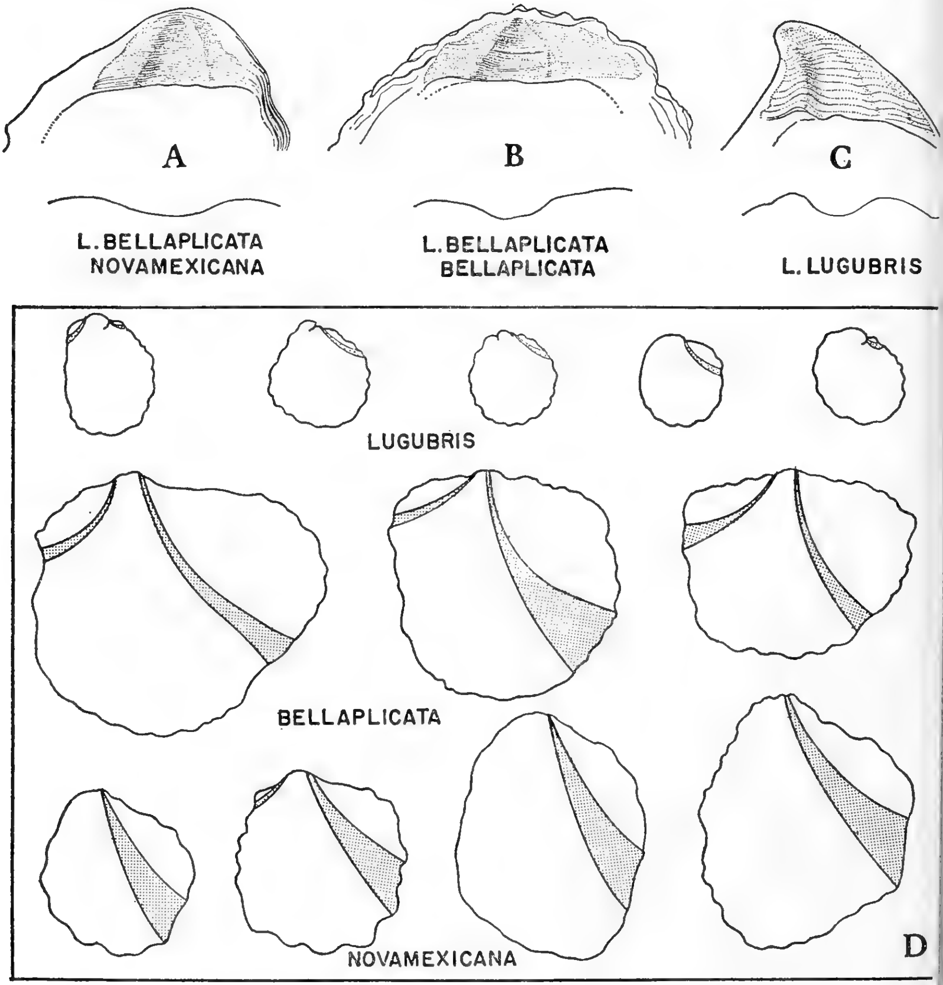

Fig. 5.—Evolution in the *Lopha lugubris* group. A, B, C, Drawings and cross sections of characteristic cardinal areas for species and subspecies within the group. Note gradual deepening, and increase in curvature of the resilifer in progressively younger forms. Also note increase in convexity of the lateral cardinal areas, from slightly arched lateral cardinal plates in the subspecies *novamexicana,* to distinct lateral cardinal folds in *L. lugubris.* D, Outline drawings of species and subspecies within the group, with the auricular sulci shaded. Note narrowing of the sulci in progressively younger forms, and variation in shape of the valves, of the posterior auricle, and in development of the anterior auricle. Specimens: A, U.S.N.M. 132263; B, U.S.N.M. 132243; C, U.S.N.M. 132167; D. Top row, left to right, U.S.N.M. 13274, 132154, U.M.M.P. 43472, 43464, U.S.N.M. 132157; middle row, left to right, U.S.N.M. 132229, 132225, 132308; bottom row, left to right, U.S.N.M. 132263, 132267, 132281, 132279.

4. Variation in the development of the auricles; a general trend toward reduction in size of the auricles, and elimination of the anterior auricle (fig. 5d). The size of the auricles increases from the subspecies *novamexicana* to subspecies *bellaplicata,* and decreases considerably in *L. lugubris.*

5. Reduction in the size (width, depth) of the auricular sulci, relative to shell size (figs. 5d, 6a).

6. Increase in the number of radiating plicae, including an increase in the number of primary plicae at the edge of the smooth stage, increase in number at any given distance below the beak, increase in total number developed at the margin of adult shells, and increase in the plication density (number per unit area) (figs. 2, 7).

7. Decrease in the average width of the radiating plicae, measured at a uniform distance below the beak in all species (fig. 7c).

8. Variation in the amount of bifurcation of primary plicae, with an overall trend toward decrease in bifurcation rate (figs. 6b, c). The bifurcation rate increases slightly from subspecies *novamexicana* to subspecies *bellaplicata,* then sharply decreases with the evolution of *L. lugubris.*

9. Increase in the absolute height and relative extent of the smooth stage on the early shell, particularly in left valves. This is the distance between the beak and the first abrupt appearance of plicae (fig. 8).

10. Some posterior migration of the beaks and umbos along the dorsal margin, and increase in the amount of curvature of these structures (figs. 3c, 5d, 9b).

11. Changes in the nature of the cardinal area: general, though not chronoclinal, increase in the size of the resilifer relative to the lateral cardinal areas; increase in the convexity and prominence of the lateral cardinal folds; development and accentuation of the marginal cardinal troughs between the lateral folds and the valve margin (figs. 5a-c).

12. Increase in the density of the denticles on the inner dorsolateral margins (fig. 9a).

Many of these trends are interpreted as adaptations to widespread environmental changes through Middle and Late Turonian time, established in the lineage through natural selection. They are adaptations shown by many living and fossil, shallow-water, epifaunal pelecypods. In the *Lopha lugubris* lineage they gradually evolved with the steady change from quiet-water, mud-bottom conditions (Blue Hill and lower to middle Mancos Shales), through near-shore,

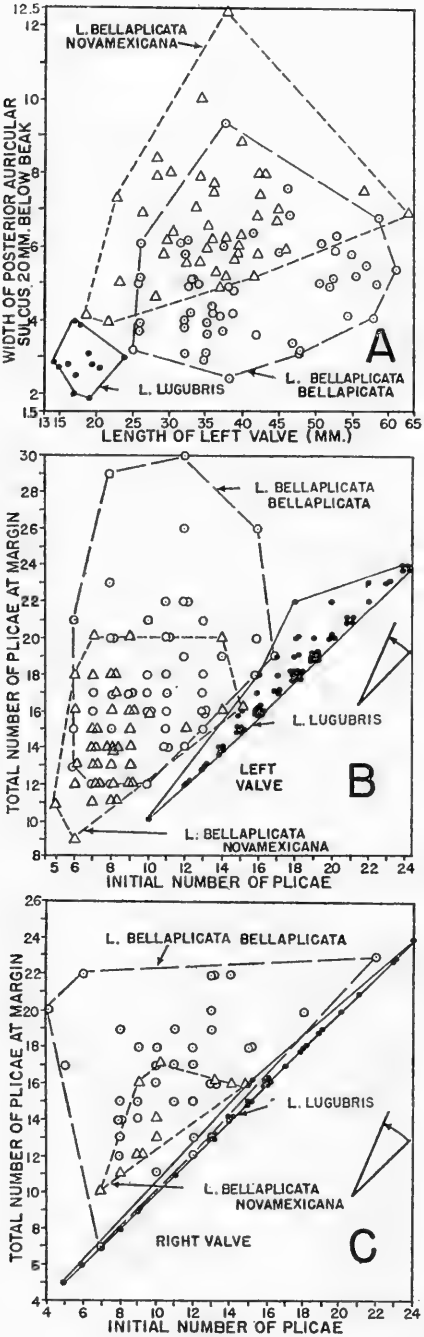

FIG. 6.—Evolution in the *Lopha lugubris* group. A, Variation plot showing relationship between the width of the posterior auricular sulcus 20 mm. below the beak and the length of the left valve, the most variable linear measurement. Note variation within each form and good separation of variation plots, lack of correlation between width and valve length, and decrease in the relative width of the sulcus at this point in progressively younger species and subspecies (the latter defined by differences in the vertical range of the individual variation plots). B, C, Comparison of the bifurcation rates of the radiating plicae on various members of the group, showing an increase in bifurcation of the plicae from *L. bellaplicata novamexicana* to the younger *L. bellaplicata bellaplicata* and then an abrupt decrease in bifurcation rate with the evolution of *L. lugubris,* in which the majority of specimens lack bifurcating plicae. Arrows on right central portion of B and C denote direction of increasing bifurcation rate as illustrated by hypothetical regression lines visually fitted to plots of terminal members of group.

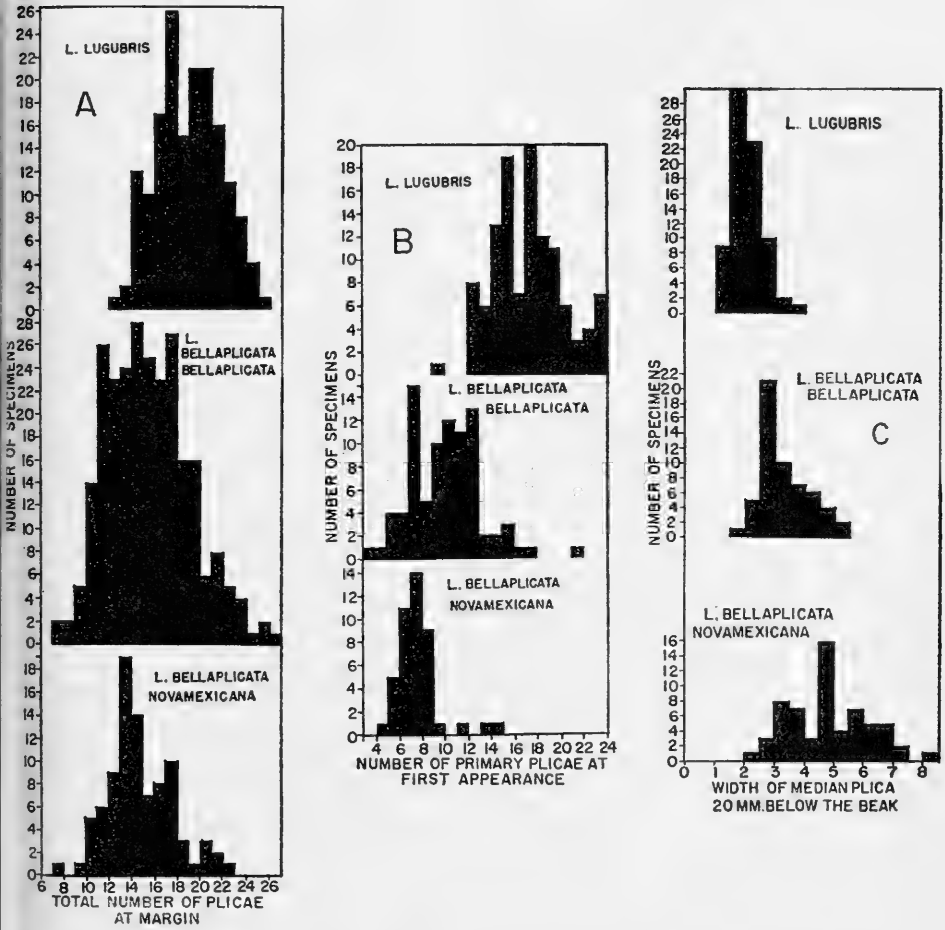

FIG. 7.—Evolution in the *Lopha lugubris* group. A, Increase in total number of radiating plicae developed at the margin of adult shells in progressively younger species of the lineage. B, Increase in the total number of primary plicae first appearing at the margin of the smooth stage on progressively younger species. C, Decrease in the width of the median plica measured 20 mm. below the beak on progressively younger species of the group. All measurements made on left valves.

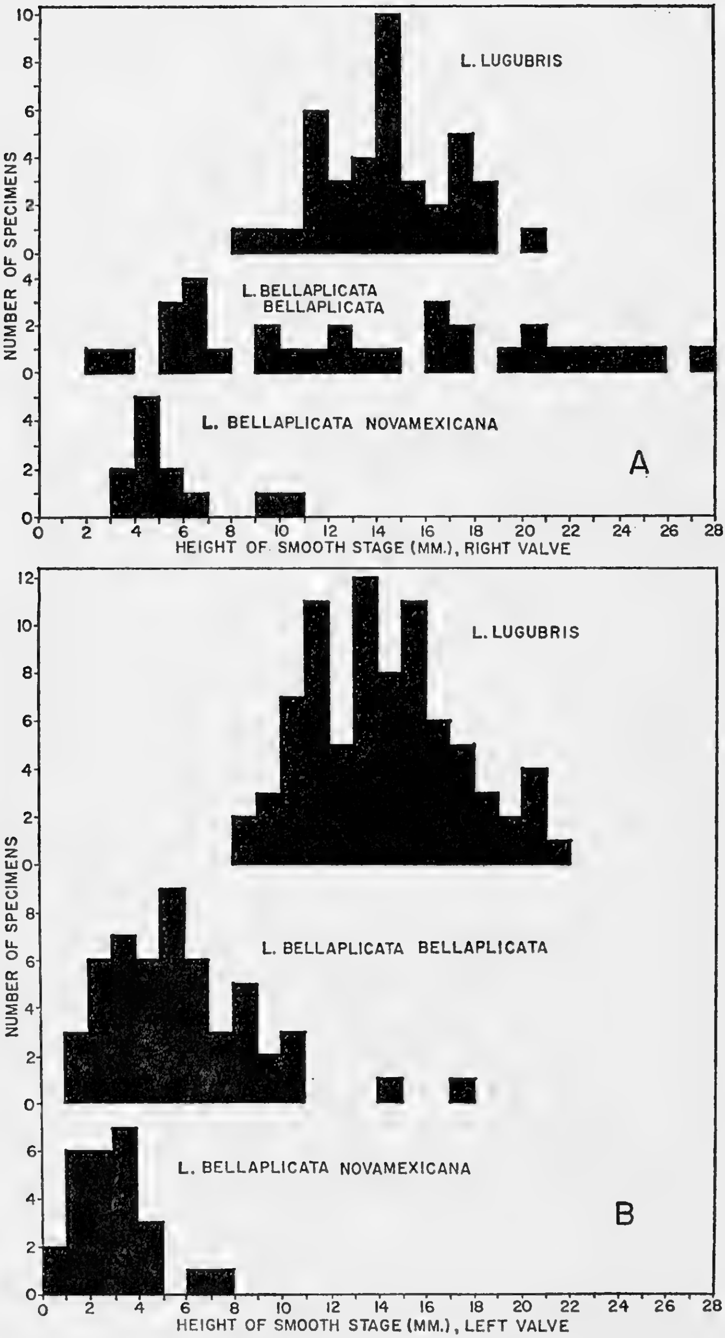

Fig. 8.—Evolution in the *Lopha lugubris* group. Increase in the actual height of the smooth umbonal area, dorsal to the abrupt appearance of radiating plicae, in successively younger species and subspecies. A, Right valve. B, Left (attached) valve, on which the trend is best observed.

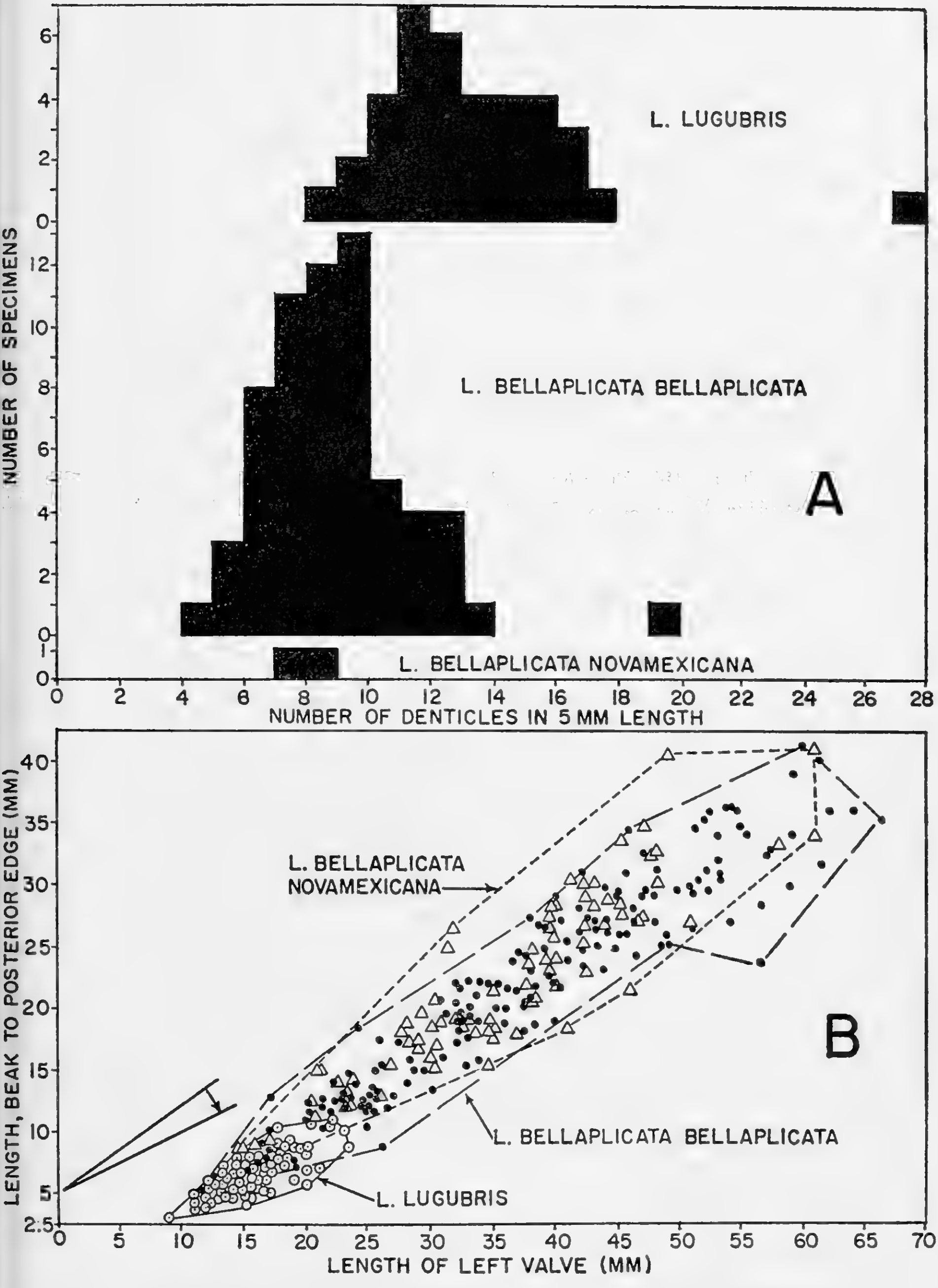

FIG. 9.—Evolution in the *Lopha lugubris* group. A, Increase in the density of the denticles along the inner lateral and dorsolateral margins in successively younger species. B, Ventral shifting of the beaks along the dorsal margin in successively younger species and subspecies, and decrease in the length of the posterior auricle. Arrow in lower left-hand corner denotes direction of central shifting of beak along dorsal margin as shown by hypothetical regression lines visually fitted to plots of terminal species in lineage.

moderate- to shallow-water environments with active currents (upper Eagle Ford Shale, Codell Sandstone, parts of the middle Mancos), to shallow-water, inner-sublittoral, high-energy conditions, including wave action, a great deal of reworking, and periods of nondeposition (Juana Lopez Member, "Reworked Eagle Ford zone").

Most of the trends thought to be selected for environmental changes concern themselves with improving the hydrodynamic stability, strength, and anchorage of the shell. Hydrodynamic stability of the shell in the face of increased current and wave activity was probably improved by the overall decrease in shell convexity, ventral migration of the high point, reduction of projecting surfaces such as the auricles, increase in relative symmetry of the shell, and evening of the overall shell surface by a great reduction in the prominence of the auricular sulci, interplical sulci, and plicae. Reduction in shell size may also have affected stability of the shell, though it is more likely tied to the restricted amount of available feeding time in active shallow-water environments as compared to that available in deeper, nonagitated waters.

The development of smaller and more numerous plicae by shallow-water ostreids in this lineage appears to be a twofold adaptation to a near-shore environment. Most obviously this results in strengthening of the shell, necessary for life in the presence of waves, strong currents, and continued buffeting, while at the same time eliminating coarse projections from the shell surface, producing a more even, less resistant surface over which water can flow. Even more important may be the role of plications as an adaptation to feeding in a turbid, high-energy environment. Development of extensively plicate and crenulate commissures in marine bivalves allows the animal to reduce considerably the gape of the valves during feeding over that required by forms with smooth margins, without greatly altering the total amount of open area between the valves for the influx of water. The advantages of reducing the gape while maintaining normal water intake in a turbid environment are apparent, since there is a corresponding reduction in the size and possibly the amount of foreign particles able to filter between the valves, and consequently a greater degree of protection against clogging of the feeding mechanisms and agitation of the mantle. This helps to offset the abundance of mobile detritus found in near-shore, high-energy environments, and allows the oyster to feed for longer periods of time, and tolerate greater turbidity, than nonplicate species subject to the same conditions.

Progressively younger members of the lineage display a gradual increase in the relative size of the attachment area, the general size and inclination of the area being unusually consistent within species and subspecies. Increase in the size of the attachment area, and decrease in the angle between the area and the commissure both appear to be adaptations to high-energy, near-shore conditions, providing a firmer anchor and lower, hydrodynamically more stable shell in the face of strong current and wave action. There is evidence in the *Lopha lugubris* group that these may be genetically controlled features of the shell as well as adaptive variations of individual members of the lineage.

Evidence favoring genetic control of inclination and size of the attachment area is found in the end members of the lineage. All observed specimens of *L. bellaplicata novamexicana* have a very small attachment area. The size of the area relative to the size of the adult shell possibly indicates early detachment of the shell from the substrate and a free-living adult stage. Were this purely an adaptive feature, one would expect it only in quiet-water environments, since a free-living shell of the *novamexicana* type in normal living position (convex left valve downward) would be highly unstable in the face of strong currents or wave action, and easily overturned and buried. Although sediments containing most *L. bellaplicata novamexicana* indicate quiet or slightly agitated water conditions, a few specimens occur in coarse-grained, coarse-bedded sandstones of high-energy environments. These maintain the small attachment area. Further, no adaptive counterpart of the subspecies having a large attachment scar is developed in the near-shore facies. Scar size thus appears to be independent of environment in this case.

Similarly, *L. lugubris* has an exceptionally large, gently inclined attachment area regardless of associated sediment type and inferred environment. These features indicate attachment throughout life, and are adapted to high-energy conditions. Sediments containing most specimens of *L. lugubris* reflect such an environment. The species is most common in cross-bedded, ripple-marked calcarenites and calcareous sandstones. A number of examples from thinly laminated shales and fine sandstones and siltstones, however, maintain the large, gently inclined scar, even though it was probably not necessary for firm anchorage in the more quiet water environments.

The change in inferred living habit from partially free to wholly attached, and the consistency in the character of the attachment area on these two forms, regardless of associated environment, suggest genetic control on the size and inclination of the area.

The middle member of the lineage, *L. bellaplicata bellaplicata,* exhibits more variation in scar size (pl. 3), with individuals that probably lived free during part of their adult life, and others that could well have been attached throughout life. These two forms coexist in the great variety of environments from which the species is known, but there is a notable increase in the relative percentage of individuals with large attachment areas in shallow-water sediments deposited under high-energy wave and current conditions (Codell Sandstone). Scar size thus appears to be largely adaptive and environmentally controlled in this subspecies.

Small shell size is considered by some ecologists as an adaptation to turbid, near-shore environmental conditions. This may be the case in the *L. lugubris* lineage where there is a distinct trend toward reduction in the average adult dimensions with the onset of shallow-water conditions during the Late Turonian. Shallow-water epifaunal elements are able to spend less time feeding than their counterparts in deeper, quieter waters. Long periods during which little feeding takes place are imposed on them by extended times of high turbulence and water agitation. This restriction on food intake has been related to the below average size of many shallow-water epifaunal pelecypod species which develop to normal proportions in quiet, offshore waters. This, of course, is purely an ecologic control on shell form. In the many cases, however, where the smaller of two closely related species or subspecies of epifaunal pelecypods lives closest to the inner sublittoral zones of constant water agitation and turbidity, small size seems to be a genetic adaptation to the environment. The smaller species, requiring less food, are better able to survive in environments presenting shorter and more irregular feeding opportunities.

The changes of other structures through time are well defined and easily recognized, but based on my present knowledge of the zoological characteristics of the group and of the Turonian environment, it is difficult to explain them in terms of adaptive features.

SHELL MORPHOLOGY

Standard terminology has been used wherever possible in describing species and subspecies of the *Lopha lugubris* group (see Newell 1937, 1942, Shrock and Twenhofel, 1953, for definitions of standard terms). A few new or rarely used terms are employed here for features not generally considered in ostreid description. It is desirable to briefly define these. In most cases this is simply accomplished by means of an illustration (fig. 10a, b, c, d), especially in regard to spacial divisions of the valve (fig. 10c; see explanation). Discussions are presented below for new terms employed, as a key to abbreviated ratios (tables 1-5) or where it seems possible that misunderstandings may arise in interpretation of a term in the descriptions as it is applied to the Ostreidae. The letters arranged alphabetically below refer to fig. 12, and tables 1-5.

A : AATS—The ratio of the approximate area of the left (lower) valve to the approximate area of the attachment scar, as determined by their inscribing rectangles, oriented with their sides paralleling height and length.

AA—Anterior auricle, or ear (fig. 10a); rarely developed and generally poorly defined flattening and projection of the dorsoanterior margin, generally separated from the main body of the shell by a small auricular furrow or sulcus.

ANS—Anterior slope of the valve (includes lower part of the anterior auricle, where developed); the portion of the shell between the dorsal and anteroventral slopes, and the crest (fig. 10c).

A : P—The ratio of the area of a rectangle inscribing the valve to the number of plications present at the valve margin.

AS—Auricular sulcus (figs. 10a-c); an external furrow or depression which separates the anterior and posterior auricles from the main body of the shell. In this group it is commonly expressed as a relatively deep, slightly enlarged interplical sulcus.

AVS—Anteroventral slope of the shell, between the median plication, crest, and anterior slope (fig. 10c).

CCP—Central cardinal plate. On the right valve, a flat surface developed in the central cardinal area, in place of a shallow resilifer.

CR—Crest of the valve; the highest area of the valve, either slightly convex or nearly flat, situated dorsocentrally (fig. 10c).

D—Denticles; small raised nodes, rounded to elongate, on the inner dorsolateral margins of the valves (fig. 10d).

DS—Dorsal slope of the valves (includes the attachment scar where present; fig. 10c).

HA—Hinge axis (cardinal axis), the axis of rotation of the valves (fig. 10d). The ligament lies dorsal, the main part of the resilium ventral. The only parts of the two shells always in contact. When the hinge line is straight, it may parallel this axis.

H : L—Ratio of valve height to valve length.

HP—High point of the valve (fig. 10c), marking the point of greatest convexity. This is usually within the crest on the median plication, and is a good reference point for delineating the various flanks of the valves.

H :DPAS—The ratio of the valve height to the greatest diameter of the posterior adductor muscle scar.

H : HATS—The ratio of the valve height to the height of the attachment scar, as measured on the left valve.

H : HD—The ratio of the valve height to the height of that part of the valve bearing denticles along the inner lateral margins.

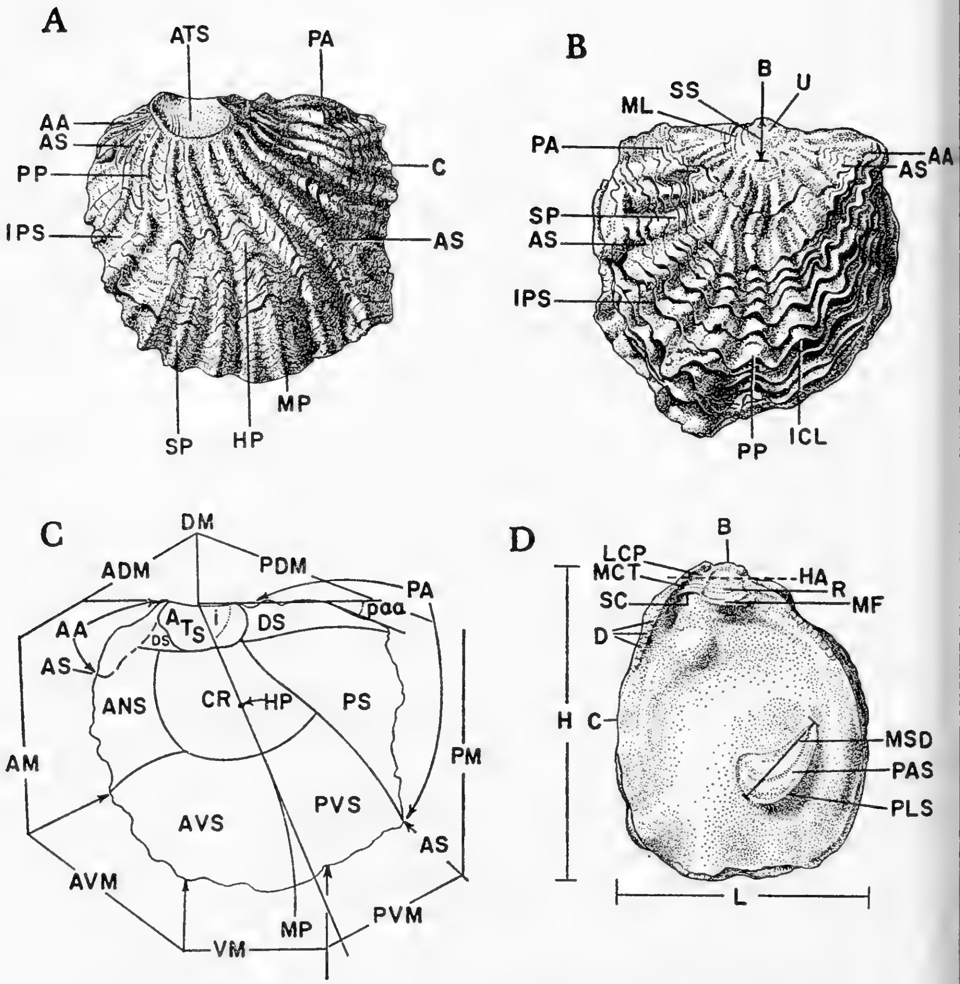

FIG. 10.—Morphology of oysters in the *Lopha lugubris* group, using specimens of *L. bellaplicata bellaplicata* for illustration (A, C, U.S.N.M. 132222; B, U.S.N.M. 132239; D, U.S.N.M. 8024d). A, External shell morphology of left valve. B, External shell morphology of right valve. C, Spatial divisions of valve referred to in text. D, Interior morphology of right valve. Symbols explained in detail under "Shell Morphology." AA, Anterior auricle. ADM, Anterodorsal margin. AM, Anterior margin. ANS, Anterior slope. AS, Auricular sulcus. ATS, Attachment scar. AVM, Anteroventral margin. AVS, Anteroventral slope. B, Beak. C, Commissure. CR, Crest of valve. D, Denticles. DM, Dorsal margin. DS, Dorsal slope. H, Height of valve. HA, Hinge axis. HP, High point of valve. *i*, Angle of inclination. ICL, Imbricating concentric lamellae. IPS, Interplical sulcus. L, Length of valve. LCP, Lateral cardinal plate. MCT, Marginal cardinal trough. MF, Midcardinal fold. ML, Microlamellae. MP, Median plica. MSD, Maximum diameter of posterior adductor muscle scar. PA, Posterior auricle. *paa*, Posterior auricular angle. PAS, Posterior adductor muscle scar. PDM, Posterodorsal margin. PLS, Posteroventral lip of the muscle scar. PM, Posterior margin. PP, Primary plica. PS, Posterior slope. PVM, Posteroventral margin. PVS, Posteroventral slope. R, Resilifer. SC, Subcardinal cavity. SP, Secondary plica. SS, Smooth stage of umbo. U, Umbo. VM, Ventral margin. All figures ×1.

H:HSS—The ratio of the valve height to the height of the smooth stage on the early portion of the valve.

i—The angle of inclination of the valve (fig. 10c); the angle between the plane of the hinge line (horizontal) and a line connecting the beak (or center of the attachment scar) with the most distant edge of the shell. This line generally roughly bisects the shell.

ICL—Imbricating concentric lamellae; the major concentric features of the ornamentation (fig. 10b).

IPS—Interplical sulcus; the trough between any two plicae. The auricular sulci are enlarged interplical sulci separating the auricles from the main body of the shell (figs. 10a, b).

LCP—Lateral cardinal plates (fig. 10d, 5a-c); triangular flat areas for ligament attachment on either side of the resilifer and midcardinal fold (right valve). These are highly variable in size, and commonly bordered laterally by a shallow groove (marginal cardinal trough).

L:LHL—Ratio of the length of the valve to the length of the hinge line.

L:LPA—Ratio of the length of the valve to the length of the posterior auricle.

MCT—Marginal cardinal trough. A shallow, narrow groove or trough on the cardinal area between the lateral cardinal plate and upturned lateral margin of the valve (fig. 10d).

MF—Midcardinal fold. The raised convex portion of the central cardinal area on the right (upper) valve, below the resilifer (where present). It occupies from one-fourth to the whole of the area.

ML—Microlamellae; very fine overlapping sheets of lamellar calcite. The major ornament on the smooth stage of the shell and between imbricating concentric lamellae over the rest of the shell (fig. 10b). They appear as simple growth lines in many cases.

MP—Median plica (figs. 10a, c); the major primary plication that runs down the approximate center of the valve, passing through its high point. It is usually the most prominent plica on the shell, and is a useful reference line for defining the various flanks.

MSD—Maximum scar diameter (fig. 10d); the longest diameter of the posterior adductor muscle scar, the least variable parameter of the scar to measure; useful in ontogenetic study.

PA—Posterior auricle (figs. 10a-c), or wing of the shell (in the sense of Newell, 1942, p. 22 as applied to the Mytilacea). This is a prominent, flattened, projecting salient of the posterior and dorsoposterior flanks of the shell, in some cases separated from the main body of the shell by an auricular sulcus.

paa—Posterior auricular angle (fig. 10c); the angle between the dorsoposterior margin of the posterior auricle and the plane of the hinge line (horizontal reference line).

PD—Plication density. The number of plications per unit approximate shell area ($H \times L$).

PLS—Posteroventral lip of the adductor muscle scar (fig. 10d). A raised ridge that bounds the scar posteriorly and ventrally in many species.

PP—Primary plica; one of the initial plications of the shell, arising at the edge of the smooth stage and extending to the shell margin. It may or may not give rise to other plicae by bifurcation (fig. 10a, b).

PS—Posterior slope of the shell, including the posterior auricle (fig. 10c).

PVS—Posteroventral slope of the valves, bounded by the median plica, crest, and posterior slope of the valve (fig. 10c).

SC—Subcardinal cavities; shallow re-entrants of the valve floor beneath structures of the cardinal area, predominantly below the midcardinal fold or lateral cardinal plates.

SP—Secondary plica; one that arises through bifurcation from a primary plication (figs. 10a, b).

SS—Smooth stage; that portion of the beak, umbo (in many cases the whole umbo), and adjacent parts of the valve that lack radiating plications (fig. 10b). This probably represents part or all of the shell of the spat.

T—Thickness; valve thickness is employed in this study as the actual thickness of the shell material. This is naturally variable in a single valve. Valve thickness should not be confused with shell or valve width.

W—Shell width; here defined as the broadest diameter of coattached valves when viewed along the plane of the commissure. It is the length of a diameter joining the high points of each valve and perpendicular to the plane of symmetry. The width of a single valve is measured similarly—between the high point of the valve and the commissure plane (or if the beak is overhanging, the plane passing along its most projecting edge).

SYSTEMATIC PALEONTOLOGY

Genus LOPHA Bolten, J. F.: Emended Kauffman, 1964

1798. Bolten, J. F. (=Roeding, P. F.), Museum Boltenianum sive catalogus cimeliorum e tribus regnis naturae, pt. 2, pp. 168, 169.
1898. Dall, W. H., Contributions to the Tertiary Fauna of Florida. Trans. Wagner Free Inst. Sci. Philadelphia, vol. 3, pt. 4, p. 672.
1936. Maury, C. J., Brazil Servico Geol. e Mineralog., Mon. 11, p. 157.
1937. Arkell, W. J., A monograph of British Corallian Lamellibranchia. Paleont. Soc., p. 180.
1940. Cox, L. R., The Jurassic Lamellibranch fauna of Kuchh (Cutch). Mem. Geol. Surv. India, ser. 9, vol. 3, p. 95.

Type species.—*Ostrea crista-galli* Linné, by subsequent designation, Dall, 1898, p. 672.

Diagnosis.—Shell normally small to moderate size, subequilateral to moderately inequilateral, slightly to moderately inequivalve, left valve slightly larger and more convex than right. Outline ovate, subround, or subquadrate; posterior auricle commonly developed. Beak opisthogyre to suberect. External ornament subequally developed on both valves, consisting of strong radiating plicae originating at the umbone and extending to the commissure, increasing by bifurcation and intercalation. Commissure trace undulating, more rarely zigzag. Shell structure predominantly lamellate (subnacreous layer), adjacent layers of gently inclined lamellae commonly with opposed dips.

Cardinal area of both valves consisting of central triangular resilifer and triangular, subequally developed, lateral cardinal plates. Resilifer of right valve commonly bounded ventrally by a low lip or partial midcardinal fold. Subcardinal cavities commonly absent. Dorsolateral inner valve margins subequally denticulate; denticles small, simple, ovoid to elliptical, their long axis perpendicular to commissure. Posterior adductor muscle attachment area posterocentral; outline comma-shaped; well defined.

Remarks.—Many recent workers have included *Lopha* (=*Alectryonia*) in synonymy with *Ostrea,* or considered it a subgenus or section of *Ostrea.* Modern representatives of *Lopha* lack a promyal chamber and are monoecious as are species of *Ostrea.* Ranson (1942, 1948) has demonstrated that the prodissoconch features of *Ostrea* and *Lopha* are similar as well. Paleontologists have continued to use the name however, since *Lopha* is quite distinct from *Ostrea* in shell sculpture, and the two do not intergrade. *Ostrea* rarely develops plications, and in cases where they are present, they do not approach those of *Lopha* in size or development. In addition, species of *Ostrea* are more equivalve, generally lack curved beaks and umbos, and have a flat commissure.

Perhaps the most important distinction between *Lopha* and *Ostrea* is in the shape of the muscle scar—comma-shaped in *Lopha,* consistently laterally elongate, ovate to kidney-shaped, and larger in *Ostrea.* This reflects basic differences in the anatomy of the muscle itself. In combination, these distinctions are sufficient to consider *Lopha* and *Ostrea* separate genera. Their similarities probably reflect a common ancestry somewhere in the Mesozoic.

The name *Alectryonia* has commonly been applied to oysters with the characteristics of *Lopha,* and the two are objective synonyms, having the same type species. The popularity attained by *Alectryonia* in recent years stems from Stenzel's acceptance of the name in place of *Lopha* (1947, p. 169, 177) under the rules of the International Commission of Zoological Nomenclature that existed at the time of his work. *Lopha* originally appeared in Bolten's Catalogue without description or definition other than "Lopha Der Hahnenkamm" (Lopha the cock's comb: Stenzel, 1947, p. 177). A list of several valid species followed, but with no indication as to which was the type. *Ostrea crista-galli* Linné, now considered the type species of *Lopha,* headed the list. Subsequently, *Alectryonia* Fischer de Waldheim was validly proposed in 1807 before *Lopha* was validated with formal description. The new rules of the Commission, however, published in 1961, do not demand formal description of a new genus as long as it is accompanied by listing of a valid species. Thus *Lopha* can be considered validly proposed as of 1798, and *Alectryonia,* proposed later with the same type species, becomes a junior objective synonym.

The restricted usage of *Lopha* here does not incorporate many groups that have previously been assigned to the genus because of their plicate shell, but which probably belong to distinct groups. Among these are the plicate *Pycnodonte,* which have vesicular shells, *Arctostrea,* a distinct lineage since the Jurassic, *Agerostrea,* a modification of the *Arctostrea* branch, and the narrow elongate "tree oysters" with their clasping shelly processes.

In published descriptions of *Lopha* or *Alectryonia,* certain morphologic features are given as diagnostic of the group which I do not consider significant at this taxonomic level. Curvature of the adult hinge line is too easily distorted by variation in direction of adult growth to be useful, especially for oysters growing in crowded conditions. The divaricate pattern of radiating ornamentation attributed to *Alectryonia* and *Lopha* is not characteristic of the genus but rather of *Arctostrea* and some *Rastellum.* The use of this as a diagnostic generic character reflects the time when these groups were all placed under *Lopha.* Clasping shelly processes are rarely developed around the attachment area of *Lopha* and are not diagnostic. They are more typical of the so-called tree oysters, which probably constitute a distinct group.

Characters of the shell which appear to be useful in distinguishing *Lopha* from similar forms, and in separating the genera of plicate oysters, are: General shell form; basic ornament pattern; relative development of component parts of the cardinal area; presence, morphology, and distribution of the denticles; presence or absence of subcardinal cavities; depth of the valves (especially the left valve); position, size, and shape of the posterior adductor muscle scar; shell structure; and in some cases juvenile ornamentation and nature of the commissure.

LOPHA LUGUBRIS Conrad

Plate 1, figures 1-18; plate 2, figures 1-17; plate 8, figure 12

Ostrea lugubris Conrad, U. S. Mex. Boundary Rep., vol. 1, p. 156, pl. 10, figs. 5a, b, 1857.—Coquand, Mon. Genre Ostrea Terr. Cret., p. 66, pl. 36, figs. 22, 23, 1869.—Meek, Macomb's Expl. Exped. from Santa Fe to Junction Grand and Green Rivers, p. 123, pl. 1, figs. 1a-d, 1876.—White, 4th Ann. Rep. U. S. Geol. Surv., p. 297, pl. 41, fig. 3, 1884.—Cragin, 4th Ann. Rep. Geol. Surv. Texas, p. 204 (in part), 1893.—Stanton, U. S. Geol. Surv. Bull. 106, pp. 58, 59 (in part), pl. 4, figs. 1-5, *non* figs. 6-10, 1893 [1894].—Logan, The Univ. Geol. Surv. Kansas, vol. 4, pt. 1, p. 455 (in part), pl. 91, figs. 1-5, *non* figs. 6-10, 1898.—Herrick and Johnson, Bull. Denison Univ. Sci. Lab., vol. 40, p. 202 (in part), 1900.—Johnson, School of Mines Quart., vol. 24, No. 2, pp. 186, 187, 1903a; Columbia Univ. Contr. Geol. Dept., vol. 10, No. 90, pp. 114, 115 (in part), 1903b.—Shimer and Blodgett, Amer. Journ. Sci. Arts, 4th ser., vol. 25, p. 61 (in part), 1908.

Ostrea (*Alectryonia*) *lugubris* Conrad, Böse, Bol. Inst. Geol. Mexico, No. 30, Algunas faunas del Cret. de Coahuila, pp. 47, 48, pl. 8, figs. 4-6, 1913.—Shimer and Shrock, Index foss. N. Amer., p. 395, pl. 154, figs. 4, 5, 1955.

Alectryonia lugubris (Conrad) Adkins, Handbk. Texas Cret. Foss., p. 104 (in part), 1928.

DESCRIPTION

Material.—Approximately 350 well-preserved specimens (measured) and an additional 200 to 300 poorly preserved valves from various localities in Texas, New Mexico, and Colorado, including most illustrated types of the species. Ontogenetic series and large variation suites are available from several New Mexico and Colorado localities.

General form.—Summary of measurements presented in table 1. Shell small, inequivalve, left (lower) valve slightly larger, much more convex than right valve. Valves slightly to moderately inequilateral, normally prosocline; beaks, umbos typically opisthogyre (exogyroid) (pl. 1, fig. 5). Left valves commonly round, subround, or broadly subovate, rarely subelliptical; right valves subovate to elliptical, slightly curved (pl. 1, figs. 1-6; pl. 2, figs. 1-3, 5-12 typical of species). Height normally greater than length. Anterior and ventral margins slightly to moderately and unevenly rounded, posteroventral corner narrowly rounded, posterior margin slightly concave to nearly straight on valves with posterior auricle, otherwise moderately curved. Dorsal margins short, rounded, moderately inclined anteriorly, gently sloping posteriorly over auricle, recessed posteriorly adjacent to beak, umbo.

Convexity.—Left valve moderately to highly convex, rarely flattened; high point subcentral, on ventral edge of attachment scar. Anterior, posterior, ventral, ventrolateral flanks moderately to steeply sloping; dorsal and dorsolateral flanks, including attachment scar, gently sloping. Right valve flat to moderately convex, normally slightly arched, with umbo more inflated (pl. 2, figs. 2, 6); rarely concave. Some right valves with upturned margins and submarginal trough.

TABLE 1.—*Summary of measurements on specimens of* Lopha lugubris (Conrad)

Character	Valve	No. of specimens	Range	Average
Height (H)	L	175	7.6-41.2 mm.	17.3 mm.
	R	161	7.4-23.9 mm.	15.2 mm.
Length (L)	L	173	7.5-23.3 mm.	14.9 mm.
	R	161	4.6-23.0 mm.	12.8 mm.
Width (W)	L	169	1.5-9.6 mm.	3.7 mm.
	R	160	1.0-6.2 mm.	2.7 mm.
Percent valves with $H > L$	LR	303		90.7%
Percent valves with $L > H$	LR	303		7.9%
Percent valves with $H = L$	LR	303		1.4%
Area, inscribing rectangle of valve ($H \times L$)	L	133	118.8-564.0 mm.	272.5 mm.
Length, beak to posterior margin (LBP)	L	163	2.5-11.0 mm.	6.5 mm.
Ratio, LBP : L	L	94	0.31-0.55 mm.	0.43 :1 mm.
Angle of inclination (i)	L	80	43°-97°	73.4°
	R	65	40°-93°	72.3°
Height of attachment scar (HATS)	L	157	4.4-20.0 mm.	12.3 mm.
Length of attachment scar (LATS)	L	157	4.0-17.5 mm.	9.5 mm.
Area, inscribing rectangle of attachment scar ($HATS \times LATS$)	L	100	17.6-285.4 mm.^{2}	121.9 mm.^{2}
Ratio, area of scar (inscribing rectangle) : area of valve (inscribing rectangle)	L	100	0.13 : 1-0.78 : 1	0.46 : 1
Percentage of valves with plicate exterior surface (not including those with only the margin plicate or crenulate)	L	175		81.7%
	R	161		23.0%
Height, smooth young stage (HSS), on dorsal part of plicate valves	R	40	9.4-21.1 mm.	15.0 mm.
	L	79	7.1-21.1 mm.	14.2 mm.
HSS on left valves with $HSS > HATS$	L	24	9.0-20.2 mm.	13.7 mm.
Ratio, HHS : H	L	80	0.60 : 1-1 : 1	0.80 : 1
	R	64	0.62 : 1-1 : 1	0.92 : 1
Number of primary plicae at first appearance	L	78	10-24	18.1
	R	38	13-24	16.9
Number of plicae at 10 mm. H (on shells where $HSS < 10$ mm.)	L	6	10-18	14.7
	R	3	13-16	14.7
Number of plicae at 20 mm. H	L	47	15-24	19.6
	R	16	14-24	18.8
Total number of plicae (marginal count)	L	130	10-24	18.8
	R	38	13-25	17.0
Number plicae in 20 mm. L at 20 mm. H (median plica central)	L	44	5.75-11.0	7.32
	R	19	5.25-8.5	6.8

Table 1.—*Summary of measurements on specimens of* Lopha lugubris (Conrad)—*continued*

Character	Valve	No. of specimens	Range	Average
Width of median plica at 20 mm. H..	L	50	1.2-3.5 mm.	2.1 mm.
	R	24	1.1-3.1 mm.	2.1 mm.
Percentage of plicate valves with bifurcating plicae	L	130		23.8%
	R	32		18.8%
Percentage increase in plicae by bifurcation (measured only on valves with bifurcating plicae)....	L	13	4.5-22.2%	9.22%
	R	2	6.7%	6.7%
Percentage of specimens with opisthogyre beaks and umbones........	L	157		78.9%
	R	161		72.7%
Percentage of specimens with orthogyre beaks and umbones........	L	157		3.3%
	R	161		3.7%
Percentage of specimens with prosogyre beaks and umbones...........	L	157		17.8%
	R	161		23.6%
Length of hinge line (LHL)........	L	33	2.3-8.5 mm.	5.1 mm.
	R	26	2.8-8.1 mm.	4.4 mm.
Ratio, LHL:L	L	34	0.15:1-0.55:1	0.33:1
	R	26	0.17:1-0.43:1	0.28:1
Extent of denticles on inner margins (in terms of valve height; HD)....	L	32	2.2-9.6 mm.	4.7 mm.
	R	25	1.2-10.2 mm.	4.6 mm.
Ratio, HD:H.....................	L	32	0.12:1-0.41:1	0.26:1
	R	25	0.08:1-0.51:1	0.26:1
Number of denticles in 5 mm. length along dorsolateral margins, just below cardinal area...............	L	18	9-17	13.2
	R	18	11-29	14.3
Maximum diameter of muscle scar (MDS)	L	32	3.0-7.8 mm.	5.1 mm.
	R	18	3.3-8.6 mm.	5.3 mm.

Auricles.—Anterior auricle rarely developed, most common on right valve. Auricle small, rounded, flattened salient of dorsoanterior margin (pl. 2, fig. 5), in some cases separated from shell by shallow, broad anterior auricular sulcus. Posterior auricle present on 59 percent of measured specimens; small to medium size, subtriangular, elongate, flattened, margin rounded, position dorsoposterior (pl. 1, fig. 4). Auricle rarely separated from main body of shell by shallow, broad auricular sulcus. Auricular sulci corresponding to enlarged interplical sulci on plicate valves.

Beaks, umbones.—Typically opisthogyre, rarely erect, more commonly prosogyre, predominantly exogyroid on left valves, attaining three-quarters to one and one-half volutions (pl. 1, fig. 5, text fig. 3c) on both prosogyre and opisthogyre shells; strongly curved where not exogyroid, Beaks, umbos moderately curved posteriorly on most right valves. Beak pointed (right valve) to narrowly rounded (left valve), situated centrodorsally or just posterior to midline. Prodissoconch rarely preserved, smooth, flat, separated from umbo by single prominent growth line or concentric constriction. Beak, umbo flat to concave on left valve, deformed on attachment scar; slightly to moderately inflated on right valve, in some cases separated from rest of valve by prominent constriction and/or abrupt change in ornament (pl. 2, figs. 2, 5, 6).

Attachment area.—Situated on dorsoposterior flank, large on most left valves (pl. 1, figs. 1-14), equal to one-half area of shell, flat to concave, gently inclined to plane of commissure (average angle 24°), outline rounded to subovate, similar to ultimate shape of valve. Ornament of attachment area reflects surface to which attached, normally *Ostrea* and *Inoceramus* shells; area marked with concentric lines and folds. No clasping processes developed. Attachment area commonly obscures beak, umbo.

Ornamentation, left valve.—Beak smooth; early part of umbo smooth, central and ventral portions covered with fine growth lines, small concentric undulations. Free surfaces of most valves covered with coarse, simple (primary), radiating plicae (pl. 1, figs. 1, 2, 4-6), originating abruptly at or near margin of attachment area and extending to commissure, rarely bifurcating; rare valves smooth, with plicae reflected as marginal crenulations, or with plicae greatly reduced in prominence (pl. 1, figs. 3, 11-14). All gradations known between smooth and fully plicate forms. Primary plicae straight to slightly curved, slightly broader than high, crests rounded, flanks steep, more prominent centrally than laterally, becoming higher, more angular, broader, more prominent with age. Secondary plicae smaller, lower than primaries, more rapidly expanding in size (pl. 1, fig. 4). Interplical sulci deep, steep-walled, narrower than plicae, angular to narrowly rounded at base. Commissure strongly undulating, rarely zigzag, at intersection with plicae.

Concentric ornament between edge of attachment area and plicate portion of valve with faint growth lines, microlamellae, more rarely with crowded, coarse, flat, major overlapping lamellae. Plicate portion of valve characterized by moderately spaced to crowded overlapping lamellae separated by very fine growth lines. Lamellae irregularly spaced, normally flat, terminally in contact with succeeding ones; rarely raised. Plicae rugose at intersection with lamellae.

Ornamentation, right valve.—Ornament of right valve distinct from that of left valve. Beak and early umbonal area smooth; central, ventral portions of umbo marked with faint growth lines, less commonly with small, low undulations and microlamellae, rarely with scattered coarse lamellae or undulations on ventral umbo. Majority of specimens lack radiating sculpture over rest of valve, but many of these have marginal crenulations near commissure (pl. 2, figs. 1, 8). Plicae variously developed on minority of specimens (pl. 2, figs. 2-7), never covering more than half of valve, commonly confined to marginal 5 mm. Plicae originate abruptly, on strongly plicate valves at edge of inflated umbonal area (pl. 2, fig. 5); plicae prominent, rounded, with steep flanks, becoming coarser with age, rarely bifurcating; secondary plicae smaller, more rapidly expanding than primaries. Plicae rugose at intersection with concentric lamellae; plicae of right valve more prominent, sharper, than those of left. Interplical sulci deep, narrow, sharp-based, steep-walled.

Concentric ornament variable, depending on extent of plicae. Low, evenly convex valves lacking plicae covered with faint concentric growth lines, microlamellae, low, broad undulations (pl. 2, fig. 11) except at margin where coarse, crowded lamellae occur. Valves with inflated, smooth umbo and flat flanks (pl. 2, fig. 2) exhibit coarse, crowded, major lamellae, raised growth lines, small prominent undulations on flanks; ornament more prominent near commissure. On plicate valves, prominent lamellae and/or concentric constrictions occur at inner margin of point of origin for plicae (pl. 2, figs. 5, 6). Growth lines and lamellae occur throughout plicate portion of valve.

Cardinal area.—Composed of subcentral resilifer and/or midcardinal fold (right valve), bounded laterally by flat to moderately arched lateral cardinal plates or folds for ligament attachment. Resilifer of left valve shallow to moderately concave, elongate-triangular with twisted apex, higher than long, slightly flared ventrally, equal to or larger than lateral cardinal plates or folds (pl. 1, fig. 16). Lateral plates, folds subequal, variable in relative size, flat to arched, obscure to prominent, triangular with curved dorsal apices, in some valves separated from lateral margins by narrow lateral cardinal grooves (pl. 2, fig. 17), otherwise merging with margin. Lateral cardinal areas of right valve similar, less commonly arched.

Central part of cardinal area variable in right valves, ranging from flat midcardinal plate to shallow concave resilifer with raised ventral lip or partial midcardinal fold (pl. 2, fig. 17). Rarely, entire midcardinal fold developed (pl. 2, fig. 14), slightly to moderately convex. Cardinal area of both valves marked by moderately strong, irregularly spaced, crowded, raised horizontal lines transected by finer, more crowded, more evenly spaced, raised vertical lines, forming reticulate pattern. Hinge line short, straight to slightly curved (concave ventrally), situated ventral to hinge axis.

Denticles.—Denticles present on inner dorsolateral margins of all valves, rarely extending below upper one-third of margin; small, simple, elongate perpendicular to shell margin, subround to ovate, crowded, distributed along commissure and in shallow trough just inside it; color whitish, lighter than surrounding shell.

Inner valve surface.—Commissure undulating, more rarely zigzag. Plicae reflected internally as rounded, low folds and sulci, nearly equal in extent to external trace of plicae, more prominent toward commissure. Fine, irregularly spaced, sinuous, pallial or vascular grooves transgress most of inner shell surface (pl. 1, fig. 17).

Muscle scar.—Monomyarian, posterior adductor muscle insertion area (scar) subcentral, slightly posterior to midline, comma-shaped to subcrescentic, moderately curved, slightly to moderately concave, prominent. Surface of area marked with faint concentric lines and microlamellae, crowded near ventral and posterior margins, their trace conforming to growth lines. Posterior and ventral part of area bordered by low, raised, lip; dorsal and dorsoanterior margins overlapped by inner shell layers.

Shell structure.—Valves of medium thickness, variation in thickness moderate. Shell thickest at cardinal area, moderately thick over attachment area, thinning laterally, posteriorly. Thickness of average left valve: at cardinal area 0.9 mm.; middle of attachment area 0.6 mm.; high point 0.5 mm.; 2 mm. from ventral margin, 0.5 mm. Periostracum, prismatic layer, hypostracum not observed on sectioned valves. Subnacreous layer forms greatest part of shell, consisting of flat to gently curved calcite lamellae, parallel to one another on free flanks of valve, and curved, slightly inclined plates in distinct sets or layers over attachment scar. Inclination of plates in one layer commonly opposed to those of adjacent layers (pl. 8, fig. 12). Cardinal area composed of slightly curved, subparallel, thin lamellae of calcite.

ONTOGENY

Lopha lugubris is the species least suited for ontogenetic study in this group owing to the size of the attachment scar, which obscures the nepionic and neanic development of many left valves, the lack of immature shells in the collections, and the limited size range of the species. Ontogenetic trends can be studied in the following structures, which are graphed or illustrated in figures 2-4, 6b, c, 9, 11-13.

Concentric ornament.—*Nepionic* shell smooth, transition to neanic marked by single growth line or small constriction. *Neanic* stage with fine growth lines, becoming coarser, more crowded, mixed with microlamellae ventrally. *Neanic–ephebic* boundary poorly defined. *Ephebic* stage with coarse growth lines, microlamellae and scattered macrolamellae, faint undulations, on left valve. Right valve with faint growth lines during *early ephebic* stage (ventral umbo), abrupt constriction of shell at *midephebic* stage, marking cessation of major growth in body size, prominent lamellae, growth lines in *late ephebic*. *Gerontic* stage characterized by crowded, coarse major lamellae, small undulations near margin, marking great reduction in rate of shell growth, sharp change in concentric ornament marks *ephebic—gerontic* boundary.

Radiating ornament.—Plicae appear abruptly in *middle* to *late ephebic* (most left, some right valves), rarely earlier, marking point where shell begins to grow free of substrate; plicae becoming higher, broader, sharper, and rarely bifurcating through *late ephebic, gerontic* stages.

Marginal outline.—(See fig. 11.) *Nepionic:* Prodissoconch subround. *Neanic:* Ventral growth exceeds lateral, outline vertically ovate, slight expansion of posterior flank. *Ephebic:* Ventral and posterior growth exceed that anteriorly and are nearly equal. Auricles form in *early ephebic* stage, expand with age. Relationship between expansion rate of auricle and overall lateral ephebic growth constant (fig. 12a). *Gerontic:* Outline remains essentially the same, slight flaring of ventral, ventrolateral margins.

Curvature of midline axis.—*Nepionic:* Slight, poorly known. *Neanic:* Moderate to great (fig. 3c), gradually decreasing in late *neanic* stage and through *ephebic* and *gerontic* stages, becoming slight.

Convexity.—On right valve (fig. 3b), gradual increase in degree of outward curvature from *nepionic* through *early neanic,* greatest in *late neanic, early ephebic,* gradually to abruptly decreasing through *late ephebic*. *Gerontic* stage marked by abrupt flattening, upturning of margin.

Internal structures.—Rate of expansion of muscle scar, hinge line, constant, and less than rate of shell growth during *neanic* and *early ephebic* stages, tapered off gradually during *late ephebic,* and *gerontic* stages (figs. 13b, c). Elements of cardinal area poorly differentiated in *neanic* stage, becoming well defined at later stages. Extent of denticles relative to height of shell, and density of denticles, greatest during *neanic, early ephebic* stages, gradually decreasing in later growth stages (fig. 13a).

Attachment scar.—Rate of size increase relative to total size of shell constant throughout *neanic, ephebic* stages, demonstrating continued growth of attachment area throughout life.

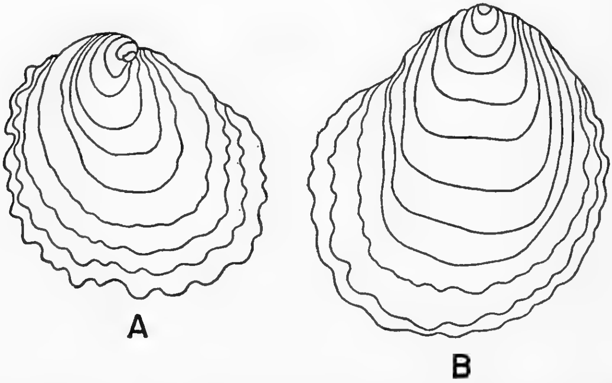

FIG. 11.—Ontogeny of *Lopha lugubris* (Conrad). Growth line traces at approximately 1.25 mm. intervals on representative left (A) and right (B) valves of the species, showing developmental history of the marginal outline. Drawings ×2. A, U.S.N.M. 132156; B, U.S.N.M. 132164.

REMARKS

Lopha lugubris (Conrad) is the most distinct member of the group and easily differentiated from related older species. In the Western Interior, it is the terminal member of the lineage known. On the Gulf Coast, however, *Lopha panda* (Morton) (Campanian, Lower Maestrichtian) possibly represents a stratigraphic extension of the lineage. Forms definitely connecting the two are presently unknown in this country.

Lopha lugubris may be distinguished from *L. bellaplicata bellaplicata* (Shumard) and *L. bellaplicata novamexicana* n. subsp. by its smaller size, greater relative height, much-reduced posterior auricle, general absence of an anterior auricle, subovate to subelliptical marginal outline, shorter, more inclined dorsolateral margins, subcentral and strongly curved to exogyroid beak and umbo, much larger and more gently inclined attachment scar, less convex left valves and relatively more convex right valves, relatively larger muscle scar, a less inflated midcardinal fold (where present), and in having the resilifer relatively larger than either lateral cardinal plate or fold. It may be further distinguished from older species by the external ornamentation of the valves. In *L. lugubris,* the majority of right valves lack plicae, and smooth left valves are common. Plicate valves may be distinguished from those of older species in the following manner: The plicae appear at a later stage of development, rarely bifurcate, and then only in the ephebic stage, and are smaller, narrower, and more numerous than those of other species. The auricular plicae are similar to those of the main body of the shell. *L. lugubris* is further distinct in generally lacking coarse concentric sculpture, and in having the plicae well defined on part of the valve interior.

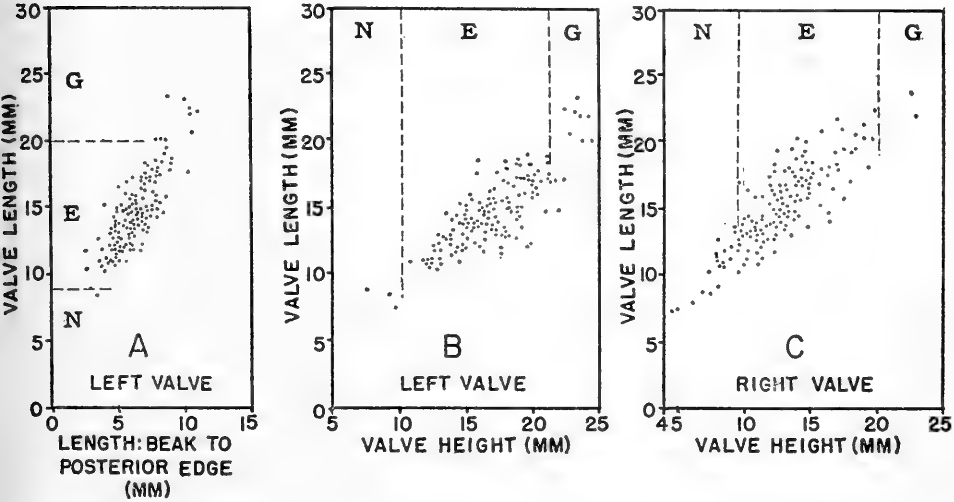

FIG. 12.—Ontogeny in *Lopha lugubris* (Conrad). A, Relationship between length of the left valve and the distance between the beak and posterior edge, measured parallel to the length. B, C, Relationship between height and length of the left and right valves, respectively. Approximate boundaries between ontogenetic stages marked by dashed lines. N = Neanic; E = Ephebic; G = Gerontic.

No species of oysters known to me are closely comparable to *L. lugubris,* although marginal variants of some North American and foreign species resemble it. Notable among these are *"Ostrea" semiplana* Sowerby, *L. bellaplicata bellaplicata,* and *L. panda* Morton.

No consistent ecologic control on any morphologic feature was

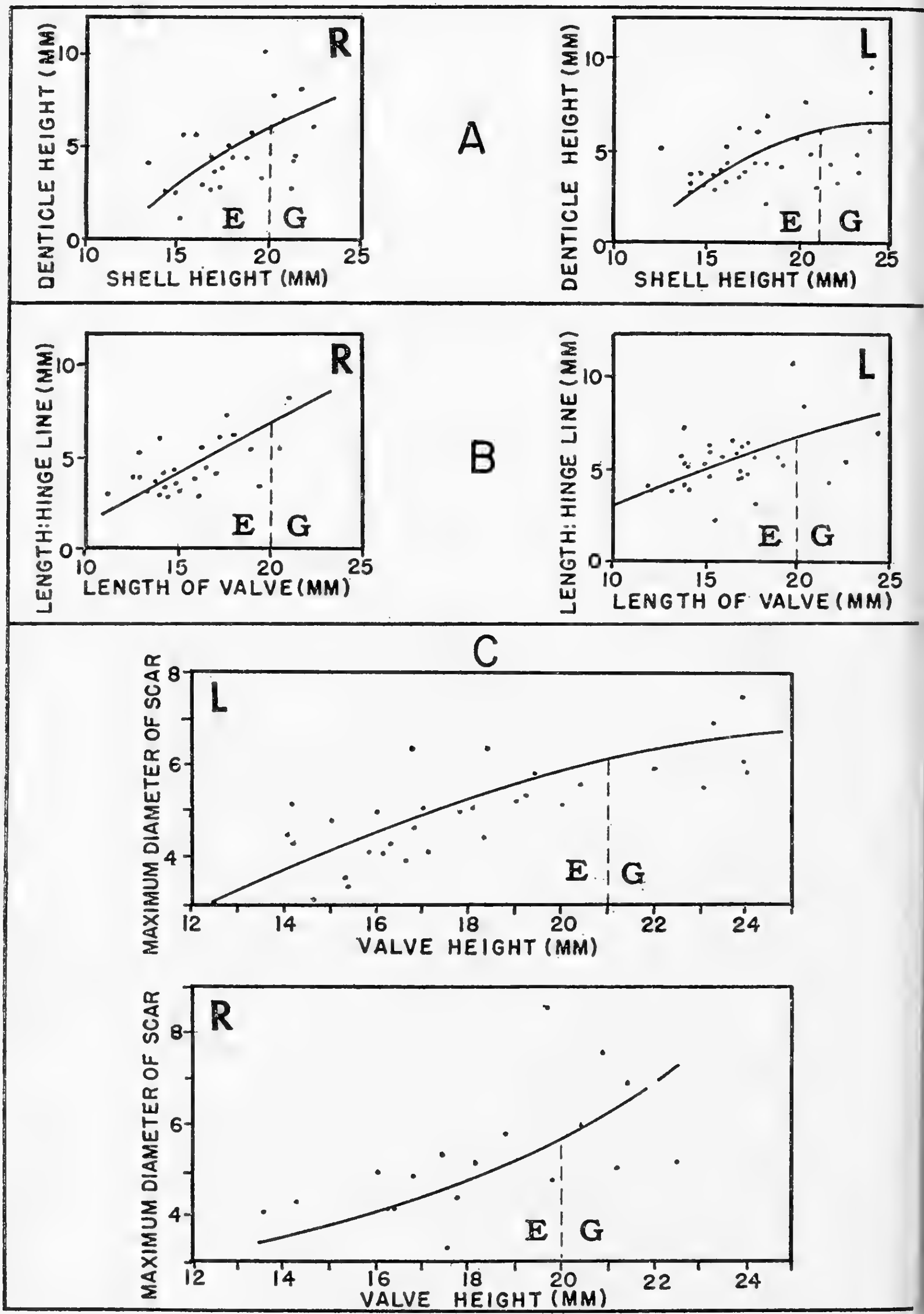

Fig. 13.—Ontogeny in *Lopha lugubris* (Conrad). A, Relationship between valve height and the amount of dorsal and lateral margin covered with denticles, measured parallel to valve height. B, Relationship between the length of the hinge line and the length of the valve. C, Relationship between the maximum diameter of the muscle scar and the height of the valve. All lines fitted visually. Approximate boundaries between ontogenetic stages marked by dashed lines. E = Ephebic; G = Gerontic; R = Right valve; L = Left valve.

noted in comparing suites of specimens from calcarenite, calcareous sandstone, dark shale, and conglomeratic calcarenite facies. The species is amazingly consistent in form for an ostreid. Similarly, there appears to be no recognizable geographic variation between Texas and northern Colorado. There is, however, some suggestion of stratigraphic variation which, when studied with large suites of specimens, may prove to be of subspecific importance. In Colorado and New Mexico, the species ranges through the Juana Lopez Member and its equivalents. In New Mexico, where the Juana Lopez includes a relatively thick series of calcarenites, shales, and calcarous sandstones, specimens of *L. lugubris* (particularly left valves) from the base of the section appear to be covered to a greater extent with radiating plicae than those from the top, which typically have the plicae limited to the valve margins. The younger specimens also have denser plication. Similar trends were noted at scattered localities in southern Colorado. The proper interpretation of these apparent trends must await larger collections, with better stratigraphic data, than are now available.

Specimens of *Lopha lugubris* commonly occur in great numbers in basal Upper Turonian calcarenites of the Juana Lopez Member and its equivalents. The valves are typically unbroken, separated, and oriented with the convex surface upward. They do not occur in beds or "colonies," and very few show any evidence of deformation due to crowding. In many cases, they are the only well-preserved, complete shells in the sediment.

Of particular interest is the commonly developed reverse curvature of the valves, and the development of exogyroid beaks in either direction. In most species of oysters that develop tightly coiled or exogyroid beaks and umbones, the direction of coiling is relatively constant and appears to be genetically controlled. Exceptions to the rule are deformed specimens growing in crowded living conditions. There are examples of reverse curvature in many of these species, but it is rare in almost all of them. The unusual coiling behavior of *L. lugubris* therefore provoked an investigation to see whether it was due to a breakdown in normal genetic control over coiling direction, or whether the species was capable of attachment by either valve.

Well-developed reverse beak curvature is found in 17.8 percent of all left valves and 23.6 percent of all right valves of *L. lugubris*. In most of these, the coiling is exogyroid. In all cases of reverse curvature the muscle scar retains its position just posterior to the midline and there is no alteration in the structure of the cardinal areas on either valve. I conclude from this that the direction of curvature is variable and not rigidly controlled genetically in this species (although posterior curvature dominates). Consistency in the position of the muscle scar and cardinal characters on both valves, irrespective of coiling direction, indicates attachment is always by the left valve, as in other ostreids.

Stratigraphic and geographic occurrence.—Lopha lugubris ranges through the Juana Lopez Member and its equivalents (zones of *Prionocyclus wyomingensis wyomingensis:* early Late Turonian, and *P. wyomingensis elegans:* middle Late Turonian) in central, south-central, and eastern Colorado, western Kansas, and northern New Mexico. The primary types were reported to have come from beds containing *P. macombi* (*P. wyomingensis wyomingensis* zone). It has been found at an equivalent level in the Mancos Shale of western Colorado and New Mexico. In Huerfano Park, Colo., fragments questionably referable to this species were collected in the upper part of the "Pugnellus Sandstone" (Codell Sandstone Member, Carlile Shale; upper part of zone of *Collignoniceras hyatti)* associated with *L. bellaplicata bellaplicata.* The ranges of these species overlap slightly in Texas also, where *L. lugubris* is found in the upper 3 feet of the Eagle Ford Shale (late Middle Turonian, upper part of *L. bellaplicata bellaplicata* zone) and in the overlying conglomeratic calcarenite bed between typical Eagle Ford Shale and Austin Chalk. Hattin's report of this species from the Blue Hill Shale Member in Kansas (lower part of zone of *Collignoniceras hyatti;* 1962, p. 84) is based on a typical specimen of *L. lugubris* collected by J. B. Reeside, Jr. Pieces of matrix adhering to the specimen are rusty-brown calcarenite characteristic of the Juana Lopez Member in Colorado and at scattered Kansas localities, and the specimen probably came from a higher level than Reeside assumed. I have also examined specimens from the Fairport Chalk Member which Hattin assigned to this species (1962, p. 54). These belong to a distinct lineage and appear most closely related to the younger *"Ostrea" tecticosta* Gabb.

Specimens of *Lopha lugubris* used in this study were obtained from localities 1 through 39 and 48, described in detail at the end of this report.

Illustrated and measured specimens.—Lectotype, selected by Stanton (1894), U.S.N.M. 9822, the original of Conrad's plate 10, figure 5b (1857); Stanton's hypotypes, reillustrated (1893, pl. 4), U.S.N.M. 22859a (Stanton's fig. 5) 22859b (Stanton's fig. 3), 22860a (Stanton's fig. 2); Meek's hypotype (1876, pl. 1, fig. 1a), U.S.N.M. 20255; new hypotypes, U.S.N.M. 8354, 22008a, b, 22210a, b, 22211, 132154-132168 inclusive, 132174, 132198, 132258, 132285; U.M.M.P. 43463-43465 inclusive, 43470-43472, inclusive, 43476, 43484, 43486, 43487. Measured specimens, unfigured, U.S.N.M. 22210c, 132169-132173 inclusive, 132175-132197 inclusive, 132199-132210 inclusive: U.M.M.P. 43460-43462 inclusive, 43467-43469 inclusive, 43473-43475 inclusive, 43477, 43488, 43489, 43491. Specimens from the upper Codell Sandstone questionably referred to this species, U.S.N.M. 132211, 132212.

LOPHA BELLAPLICATA BELLAPLICATA (Shumard)

Plate 3, figures 1-18; plate 4, figures 1-8; plate 5, figures 1-15; plate 6, figures 7-24; plate 8, figures 10, 11

Ostrea bellaplicata Shumard, Trans. St. Louis Acad. Sci., vol. 1, p. 608, 1860.—White, 4th Ann. Rep. U. S. Geol. Surv., p. 292, pl. 47, figs. 1, 2, 3, 1884.—Cragin, 4th Ann. Rep. Geol. Surv. Texas, p. 199, 1893.—Böse, Algunas faunas del Cret. Sup. Coahuila, p. 48, 1913.—Winton, Univ. Texas Bull. 2544, p. 62, pl. 8, fig. 5, 1925.

Ostrea (*Alectryonia*) *bellaplicata* White, 11th Ann. Rep. U. S. Geol. Geogr. Surv. Terr. Idaho and Wyoming, pp. 276, 277, pl. 4, figs. 3a, b; pl. 8, figs. 2a, b, 1879.

Ostrea (*Alectryonia*) *blackii* White, Proc. U. S. Nat. Mus., vol. 2, p. 293, pl. 4, figs. 1, 2, 1880; 12th Ann. Rep. U. S. Geol. Geogr. Surv. Terr. Wyoming and Idaho, pt. 1, pp. 11, 12, pl. 14, figs. 1a, b; pl. 17, fig. 5a, 1883.

Ostrea blackii White, 4th Ann. Rep. U. S. Geol. Surv., p. 292, pl. 45, fig. 1; pl. 46, fig. 2, 1884.

Ostrea lugubris Conrad, Stanton, U. S. Geol. Surv. Bull. 106, pp. 58, 59, pl. 4, figs. 6-10, *non* figs. 1-5, 1893 [1894].—Logan, The Univ. Geol. Surv. Kansas, vol. 4, pt. 1, pp. 445, 446, pl. 91, figs. 6-10, 1898.—Hill, 21st Ann. Rep. U. S. Geol. Surv., pl. 40, fig. 9, 1901.—Herrick and Johnson, Bull. Denison Univ. Sci. Lab., vol. 40, p. 202 (in part), 1900.—Johnson, School of Mines Quart., vol. 24, No. 2, pp. 186, 187 (in part), 1903a; Columbia Univ. Contr. Geol. Dept., vol. 10, No. 90, Geol. of the Cerrillos Hills, New Mexico, p. 114 (in part), 1903b.—Shimer and Blodgett, Amer. Journ. Sci. Arts, 4th ser., vol. 25, p. 61 (in part), 1908.—Hopkins, Powers, Robinson, U. S. Geol. Surv. Bull. 736, pl. 3, figs. 1, 2, 1923.—Adkins and Lozo, Stratigraphy of the Woodbine and Eagle Ford, Waco Area, Texas, pl. 5, fig. 1, 1951.

Alectryonia lugubris, Adkins, Handbk. Texas Cret. Foss., p. 104 (in part), pl. 16, fig. 5; pl. 24, figs. 8, 9, 1928. Listed on pls. 16, 24, as *A. lugubris* (*bellaplicata*).

DESCRIPTION

Material.—Approximately 400 well-preserved specimens (measured) from localities in Texas, New Mexico, and Colorado, including large variation and ontogenetic series, fossil "populations," and most North American types of the species. Numerous additional fragments.

General form.—Summary of measurements presented in table 2. Shell attaining moderate size, average size decreasing from south (Texas) to north (Colorado) (fig. 14a, c); inequivalve, left valve slightly larger, much more convex than right; slightly to moderately inequilateral, prosocline to acline. Outline commonly round to ovate, subquadrate, rarely triangular (pls. 3-6; pl. 3, figs. 1, 3, 5, 9-15 typical); height slightly greater than length on majority of specimens. Anterior, ventral margins straight to slightly curved; ventrolateral margins moderately curved; posterior margin with moderately convex curvature in absence of auricle, moderately concave beneath auricle when developed. Dorsolateral margins normally straight to slightly curved, gently inclined (pl. 3, fig. 3), posterodorsal margin longest, equaling two-thirds to slightly over one-half total length of shell.

TABLE 2.—*Summary of measurements for* Lopha bellaplicata bellaplicata (Shumard)

Character	Valve	No. of specimens	Range	Average
Height (H)	L	171	12.2-69.0 mm.	38.7 mm.
	R	112	4.4-63.8 mm.	37.3 mm.
Length (L)	L	173	6.3-66.1 mm.	37.5 mm.
	R	112	4.0-58.9 mm.	34.6 mm.
Width (W)	L	162	3.0-28.5 mm.	13.4 mm.
	R	109	1.0-17.2 mm.	7.4 mm.
Percent valves with $H > L$	LR	186/265		70%
Percent valves with $H = L$	LR	13/265		5%
Percent valves with $H < L$	LR	66/265		25%
Area, inscribing rectangle of valve	L	171	153-4416 mm.^{2}	1670.5 mm.^{2}
	R	51	235-3637 mm.^{2}	1782.1 mm.^{2}
Length, beak to posterior margin (LBP)	L	172	5.2-40.4 mm.	22.1 mm.
	R	109	1.5-37.8 mm.	19.2 mm.
Ratio, LBP : L	L	150	0.33 : 1-0.76 : 1	0.58 : 1
Angle between dorsal and dorso-posterior margins	L	56	5-47°	23.1°
Angle of inclination (i)	LR	249	62-95°	79°
Percent of specimens with observable attachment scar	L	138/173		80%
Height of attachment scar (HATS)	L	123	1.0-42.6 mm.	7.8 mm.
Length of attachment scar (LATS)	L	137	1.1-36.0 mm.	10.1 mm.
Area, inscribing rectangle of attachment scar (HATS × LATS)	L	124	2-1367.5 mm.^{2}	111.9 mm.^{2}
Height of smooth portion of shell dorsad to plicate ornamentation	L	50	1.5-17.4 mm.	5.9 mm.
	R	36	0-36.8 mm.	24.7 mm.

Table 2.—*Summary of measurements for* Lopha bellaplicata bellaplicata (Shumard)—*continued*

Character	Valve	No. of specimens	Range	Average
Number of primary plicae at first appearance	L	50	6-17	10.6
	R	36	4-22	13.4
Total number of plicae (plicate valves only)—				
At 10 mm. height	L	44	8-19	14
	R	13	6-16	11.6
At 20 mm. height	L	48	10-21	15.8
	R	28	7-22	14.8
At 30 mm. height	L	37	12-27	17.9
	R	26	8-22	19
At 40 mm. height	L	18	13-22	18.4
	R	21	8-23	15.8
At 50 mm. height	L	6	14-23	18
	R	13	11-22	17.9
Total number of plicae at margin	L	173	9-27	16.4
	R	104	1-26	15.9
Number of plicae in 20 mm. length at 20 mm. height	L	78	3-8.5	5.6
	R	28	4-7	5.9
Percentage increase in plicae by bifurcation	L	50	12-263%	79.6%
	R	34	0-400%	72.1%
Width of posterior auricular sulcus, 20 mm. below beak	L	53	2.4-9.4 mm.	4.9 mm.
Width of median plica 20 mm. below beak	L	78	2.0-7.3 mm.	3.7 mm.
Inclination of beak, umbo:				
Percent opisthogyre	L	115/173		66.5%
	R	68/112		60.7%
Percent orthogyre	L	44/173		25.4%
	R	27/112		24.1%
Percent prosogyre	L	14/173		8.1%
	R	17/112		15.2%
Length of hinge line (LHL)	L	50	4.2-29.0 mm.	14.5 mm.
	R	43	5.1-28.5 mm.	15.0 mm.
Ratio, LHL: L	L	50	0.21:1-0.75:1	0.37:1
	R	43	0.16:1-0.60:1	0.37:1
Height of denticulate portion of margins (HD)	L	32	5.1-30.0 mm.	10 mm.
	R	41	1.8-33.0 mm.	12.8 mm.
Number of denticles in 5 mm. distance along margin	L	28	5-13	9
	R	34	6-20	9.7
Ratio, HD: H	L	32	0.15:1-0.69:1	0.30:1
	R	40	0.09:1-0.79:1	0.28:1
Maximum diameter of muscle scar (MDS)	L	63	5.2-20.3 mm.	14.0 mm.
	R	45	7.2-20.1 mm.	14.2 mm.
Ratio, MDS: H	L	63	0.23:1-0.42:1	0.31:1
	R	45	0.24:1-0.41:1	0.32:1

Rarely, dorsolateral margins moderately rounded or steeply inclined (pl. 5, figs. 7, 10). Left valve typically moderately to highly convex, rarely flattened (pl. 5, figs. 1, 2 typical). High point dorsocentral, commonly on crest of median plica. Slope of anterior, ventral flanks moderate, dorsal slope steep, posterior slope gentle, flattened on auricle. Right valves slightly concave, flat, or gently arched, in rare cases gently and irregularly undulating. High point of right valve on umbone.

Auricles.—Anterior auricle a flattened dorsoanterior expansion of margin and first few plicae; auricle small, rounded, semicircular, commonly absent, in most cases separated from body of shell by an enlarged interplical sulcus, the anterior auricular sulcus (pl. 3, fig. 15). Posterior auricle variable, normally well developed, ranging from indistinct, small, flattened area on dorsoposterior flank (pl. 3, fig. 13) to prominent, flattened, projecting dorsoposterior salient (pl. 4, fig. 2), straight dorsally, narrowly rounded posteriorly, slightly curved to concave ventrally, delineated by concave midposterior notch in valve outline. All gradations noted between the two forms. Auricle separated from body of shell by faint and shallow, to deep and prominent auricular sulcus, an enlarged interplical sulcus (pl. 3, figs. 11, 15), connecting umbo and midposterior notch.

Beaks, umbos.—Opisthogyre, rarely exogyroid (one volution). Beak of left valve flat, small, bluntly pointed to moderately rounded, commonly obscured by attachment scar. On right valve, posterior curvature of beak, umbo, greater than on left, rarely orthogyre or exogyroid, moderately convex, smooth or with faint growth lines (pl. 5, fig. 7). Left and right umbones typically moderately to highly inflated, rarely flat, right valve with greatest umbonal convexity. Umbonal axes moderately curved, opisthocline medially, acline ventrally on umbo. Beaks situated anterior to midline, about one-third the length from the anterior margin, slightly elevated above dorsal margin but not projecting.

Attachment scar.—Predominantly small, commonly minute or apparently missing, rarely large (pl. 3, fig. 17), position middorsal on early part of umbone; highly variable in shape, normally round to subovate, slightly concave, steeply inclined to plane of commissure. Attachment commonly to small, smooth oyster shells, other *Lopha,* elongate objects (sticks, etc., but without clasping processes) gastropods, and large pelecypods. Shell thin in area of scar, apparently reinforced with secondary calcite layers in some specimens. Shape, size of scar unrelated to that of adult valve, or to plication density.

Ornamentation, left valve.—Beak smooth or with fine growth lines; first 3-8 mm. of umbo with fine growth lines, flat microlamellae, faint concentric undulations, rarely faint radiating undulations (pl. 3, fig. 3). Majority of shell marked with coarse radiating plicae transected by prominent concentric lamellae (pl. 3, fig. 15). Plicae arise abruptly on early part of umbo, extend to commissure, increasing in number irregularly through bifurcation, especially on early plicate portion of valve, posterior auricle, and on ventral and lateral margins of large shells. Plicae high, rounded, steep-flanked, broader than angular interplical sulci between them, becoming coarser but lower, more rounded with age, faint or absent near margins of largest valves. Secondary plicae smaller, lower, narrower than primaries but more rapidly expanding, commonly equal to primary plicae in size at valve margin. Posterior auricular plicae smaller, narrower, more divergent, more extensively bifurcating, more curved than those of main body of shell (pl. 3, fig. 11). Plicae most prominent centrally and ventrally on valve; spinose, subnodose, fluted on rare left valves where intersected by coarse, raised concentric lamellae (pl. 3, fig. 6; pl. 4, fig. 4). Rare adult shells smooth, or with plicae faintly developed throughout (*L. blacki* types), expressed mainly as marginal crenulations.

Development of plicae preceded by formation of a few coarse, crowded lamellae on umbone. Concentric sculpture on plicate portion of valve consisting of prominent, moderately to widely spaced, concentric lamellae separated by numerous, very fine, crowded, irregularly spaced, growth lines and microlamellae (pl. 3, fig. 15). Major lamellae terminally in contact with succeeding ones, or raised above valve surface, forming flutes over plicae.

Ornamentation, right valve.—Right valve distinct from left in detail of ornament. Beak smooth or with faint growth lines. Umbo almost totally devoid of plicae; smooth stage higher than that of left valve (pl. 5, fig. 7). Umbo smooth or with very fine, crowded, growth lines and microlamellae; commonly with narrow zone of crowded, coarse lamellae ventrally, near point of origin of plicae. Plicate portion of valve marked by numerous, raised, closely spaced, major concentric lamellae (pl. 5, fig. 8), becoming crowded near margin of adult valves, much coarser than on left valve.

Plicae originate abruptly on ventral portion of umbo or below it; plicae very prominent, high, steep-sided, with sharp to narrowly rounded crests, fluted and spinose at intersection with major concentric lamellae. Interplical sulci narrower than plicae, deep, angular at base, more prominent than those of left valve. Radial elements most prominent at valve margin, becoming coarser with age.

Cardinal area.—Composed of central resilifer bounded laterally by flat to slightly arched, striated, triangular lateral cardinal plates. Resilifer of left valve shallow (most common) to moderately concave, triangular to subtriangular with bent dorsal apex, slightly flared base; moderately narrow (common) to broad (rare). Lateral cardinal plates subequal to moderately unequal (on shells with prominent posterior auricle), posterior plate largest; each plate larger than resilifer in most valves. Narrow marginal cardinal troughs commonly developed between lateral cardinal plates and margin of valve, most common on left valves. Cardinal area of right valve similar to left except for resilifer, which is commonly shallow (concave), flat, or rarely raised into a low midcardinal fold. Majority of right valves with shallow resilifer bounded ventrally by a raised lip (partial midcardinal fold).

Cardinal area marked with moderately strong, crowded, irregularly spaced, horizontal striae, raised lines, and narrow ridges of various sizes. Horizontal elements transected by faint, crowded, vertical lines. Ornament most strongly developed in adult shells, on lateral cardinal plates. Cardinal area color-banded on some specimens, with narrow, dark horizontal lines on lighter background. Hinge line short to moderately long (in presence of well-developed posterior auricle), straight to slightly curved (common), concave toward center of valve except below resilifer, where slightly convex (pl. 5, fig. 13).

Denticles.—Present on inner dorsolateral margins of both valves; small, simple, subround to elongate perpendicular to margin, in some valves their trace visible on lateral margin of shell, crossing lamellae. Interspaces equal to or slightly wider than denticles. Denticles situated on commissure and in narrow trough just inside it, generally restricted to dorsolateral margins, rarely extending well down margin, generally faint on young shells, best developed on adults, becoming indistinct on large old valves.

Commissure, interior surface.—Commissure situated at margin of left valve, just inside margin of right valve; normally undulating, rarely zigzag or flattened (old specimens). Plicae faintly expressed on interior of left valves near margins, more prominent on interiors of right valve, extending to center as rounded folds, sulci. Scattered, sinuous, pallial grooves faintly developed on a few valves.

Muscle scar.—Monomyarian, insertion area of moderate size, well defined, subcrescentic to comma-shaped if not worn (pl. 5, fig. 13), slightly concave, bordered ventrally, posteroventrally by low raised lip, overlapped dorsally and anteriorly by inner shell layers; position subcentral, in posteroventral quadrant of valve on corner nearest center. Surface of area coarsely striated with flat, crowded microlamellae, scattered raised ridges, their trace conforming to the growth lines; rare muscle scars exhibit faint radiating lines.

Shell structure.—Thickness moderately variable in single valve; greatest in cardinal area and vicinity of beak and umbone, thinning ventrally and laterally. Crest of left valve commonly thinner than shell immediately around it. Shell thickness of average left valve: cardinal area, 4.1 mm.; crest, 2.9 mm.; 10 mm. above ventral margin, 1.8 mm. Right valve: Cardinal area, 6 mm., center of valve 2.3 mm.; 10 mm. above ventral margin, 1.4 mm. Only subnacreous layer preserved, forming bulk of shell, consisting of subhorizontal to gently curved and inclined plates of calcite arranged en echelon in distinct to roughly defined layers. Inclination of plates in each layer opposed to that in every other, or every third layer adjacent to it (pl. 8, fig. 11). Individual calcite plates thin, moderately short, of irregular thickness, with irregular terminations. Layered arrangement of plates, and opposed inclination of units well defined over most of shell, less distinct in cardinal–umbonal area, where orientation of plates more uniform, not commonly with opposed inclination.

ONTOGENY

Numerous well-preserved specimens of *Lopha bellaplicata bellaplicata* in the collections used for this study retain the morphologic detail of the early ontogenetic stages. The small size, or apparent absence, of the attachment scar on many left valves is of additional help in ontogenetic study since it allows observation of even the earliest stages of the attached valve, an opportunity not afforded by many species of oysters. Graphs and figures depicting the ontogenetic development of *L. bellaplicata bellaplicata* are presented in figures 2-4, 6b, c, 9b, 14-17. Ontogenetic changes were observed in the following structures.

Concentric sculpture.—*Nepionic* shell smooth or with faint growth lines; *nepionic–neanic boundary* marked by a prominent growth line. Fine growth lines characterize *early neanic* development; *middle* and *late neanic* marked with more crowded growth lines, microlamellae, small folds and undulations, becoming progressively coarser. Abrupt appearance of plicae during *neanic* preceded by a few, closely spaced, moderately coarse lamellae or growth lines. *Ephebic* stage characterized by scattered coarse lamellae on left valve, some raised above shell surface, and by numerous, closely spaced, very prominent raised lamellae on right valve. Growth lines, microlamellae crowded between major lamellae. *Neanic–ephebic boundary* marked on many shells by first common occurrence of major lamellae. Lamellae become gradually coarser, more elevated, more crowded through *ephebic* development, probably recording a decrease in growth rate and increase in the length of resting periods with increasing age. *Gerontic* stage characterized by numerous, coarse, crowded lamellae and coarse growth lines near margin of old shells.

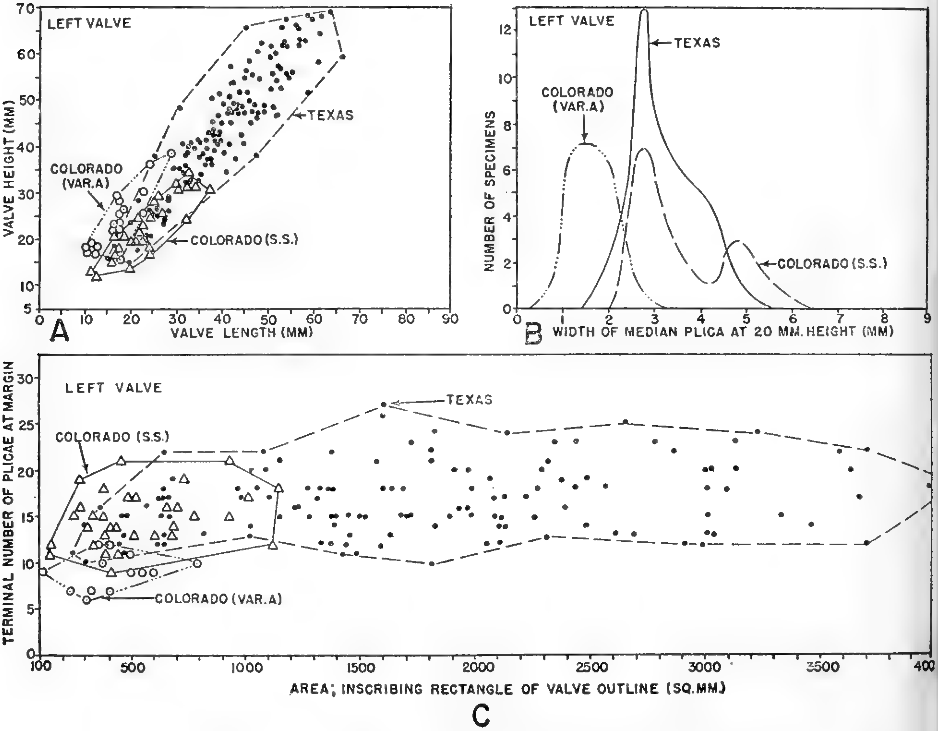

FIG. 14.—Geographic variation in *Lopha bellaplicata bellaplicata;* comparison of Texas and Colorado specimens of the typical form of the subspecies, and Colorado representatives of *L. bellaplicata bellaplicata* variety A. A, Variation in height to length relationship and size range. B, Variation in width of the median plica 20 mm. below the beak. C, Variation in size range, and in number of plicae relative to area of an inscribing rectangle of valve.

Radiating sculpture.—*Neanic* stage marks first abrupt appearance of plicae, anywhere from *earliest* to *late neanic* in left valves, at or near beginning of *ephebic* development in right valves. Plicae become gradually coarser with age to *late ephebic* stage on left valves (about 40 mm. height); beyond this they become fainter, broad, low folds, many of which disappear with continued deterioration of ornamentation during *gerontic* development. Plicae of right valve become coarser with age through at least *early gerontic* stage. Plicae bifurcate throughout development; bifurcation greatest in *late neanic* or *early ephebic* stage, again at *late ephebic* development, the former possibly marking a period of accelerated growth.

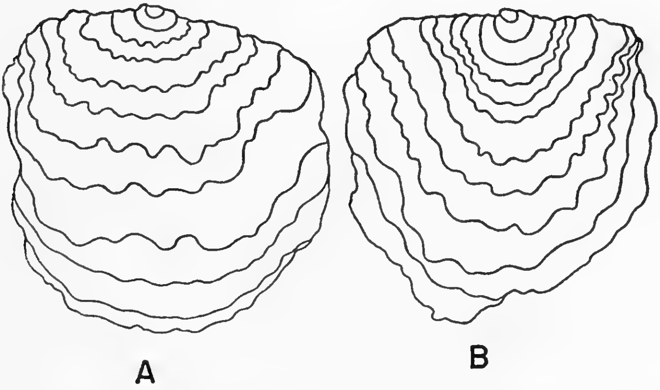

FIG. 15.—Ontogeny of *Lopha bellaplicata bellaplicata* (Shumard). Growth line traces at approximately 2.5 mm. intervals on representative left (A) and right (B) valves of the species. Traces show developmental history of the valve outline and the auricles. Drawings ×1. A, U.S.N.M. 132225; B, U.S.N.M. 132239.

Convexity.—Outward curvature of valves (convexity) slight in *nepionic* shell, on the left valve (fig. 3a) becoming moderate to great during *neanic* and *early ephebic* development, decreasing through *late ephebic* stage. Relatively abrupt flattening, flaring of flanks characterizes *gerontic* development. On right valves (fig. 3b), moderate outward curvature characterizes *neanic, earliest ephebic* stages; gradual to abrupt flattening occurs during most of *ephebic* stage, Upturning of valve margin and flaring are common *gerontic* characters.

Valve outline and auricles.—(Based on fig. 15.) *Nepionic* shell subround. *Neanic* shell ovate, with ventral growth exceeding lateral growth. Auricles appear as faint salients of dorsolateral margins in

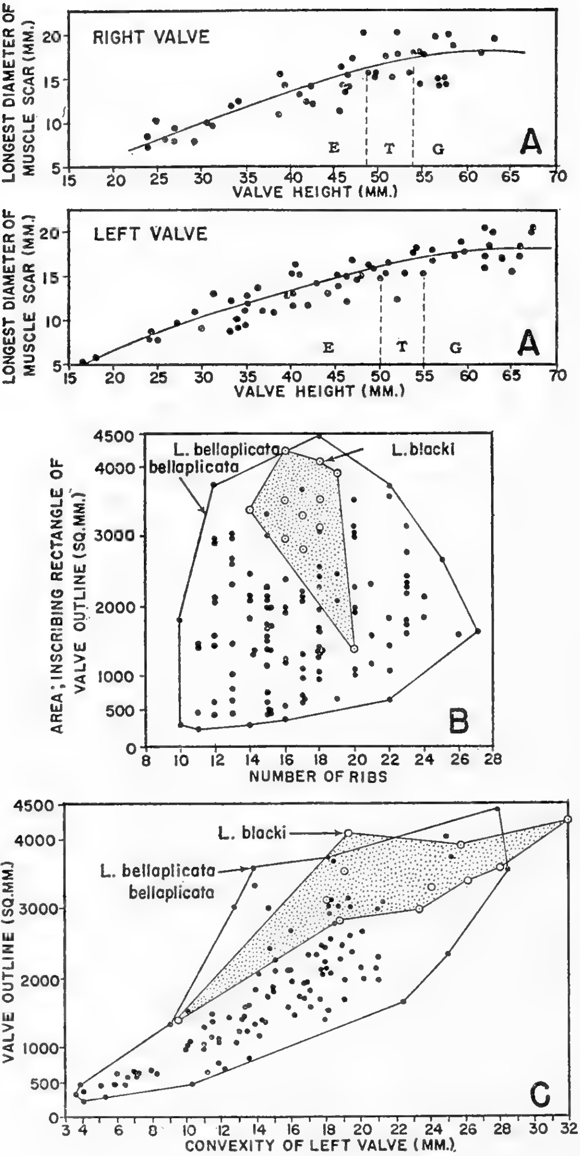

FIG. 16.—A, Ontogeny of the muscle scar in *Lopha bellaplicata bellaplicata* (Shumard), showing relationship between maximum diameter of the posterior adductor muscle scar and the height of the valve. Note the decline and virtual cessation of scar growth with increased size and age. Approximate boundaries between ontogenetic stages marked by dashed lines. E = Ephebic; T = Ephebic–Gerontic transition; G = Gerontic. B, Comparison of the plication density of *Lopha bellaplicata bellaplicata* with that of *L. blacki* (White), showing total overlap of the two forms. C, Comparison of the relative convexity of *L. bellaplicata bellaplicata* and *L. blacki,* showing nearly total overlap between the two forms.

late neanic or *early ephebic* stage, corresponding to development of plicae. During *ephebic* and *gerontic* development ventral and posterior growth exceeded that anteriorly and the auricles continued to expand at a constant, but greater, rate than normal lateral expansion.

Curvature of growth axis (*midline*).—(See fig. 3c.) Axis slightly curved in *nepionic* shell, more moderately curved during *neanic* and *early ephebic* development, slightly curved, becoming nearly straight through *ephebic* and *gerontic* stages. Inclination of *neanic* shell possibly opisthocline. *Ephebic, gerontic* shells prosocline.

Muscle scar.—Scar growth constant through *neanic, ephebic* stages, at a rate less than overall growth of shell; growth rate tapers off during *latest ephebic* stage (40 to 45 mm.), corresponding to decrease in rate of shell growth, and ceases altogether in *gerontic* stage (fig. 16a), after animal reaches maximum size. Muscle scar migrates ventrally through *neanic, ephebic* stages, with increase in shell size.

Cardinal area.—Elements of cardinal area distinct in *early ephebic* stage, becoming thicker, broader, better defined at a diminishing rate through life of animal. Length of hinge line gradually increasing through *middle ephebic* stage at a rate slightly less than overall lateral expansion of valve; during *late ephebic* and *gerontic* stages growth of hinge line continues, but at a rate greater than that of lateral expansion of valve (fig. 17c).

Denticles.—Present in all observed stages, forming throughout life and gradually extending farther down commissure with age. Rate of transgression of denticles down margin (denticle height vs. valve height at various growth stages) uniform and less than rate of ventral shell expansion during *neanic* through *mid-ephebic* stages (20-43 mm. height), accelerating and eventually exceeding rate of ventral shell growth in *late ephebic* and *gerontic* stages (fig. 19b). Density of denticles decreased at a variable rate throughout growth of shell to *gerontic* stage (fig. 17a), where it remained stable.

REMARKS

Lopha bellaplicata bellaplicata is the best-known species in the *L. lugubris* group. It is represented by a greater number of individuals, from more localities, and from a broader geographic range than any other member of the group. This is primarily due to its extensive occurrence in the upper Eagle Ford Shale of Texas, and the numerous collections available from that area.

L. bellaplicata bellaplicata may be distinguished from the morphologically similar subspecies *novamexicana* by its more rounded or

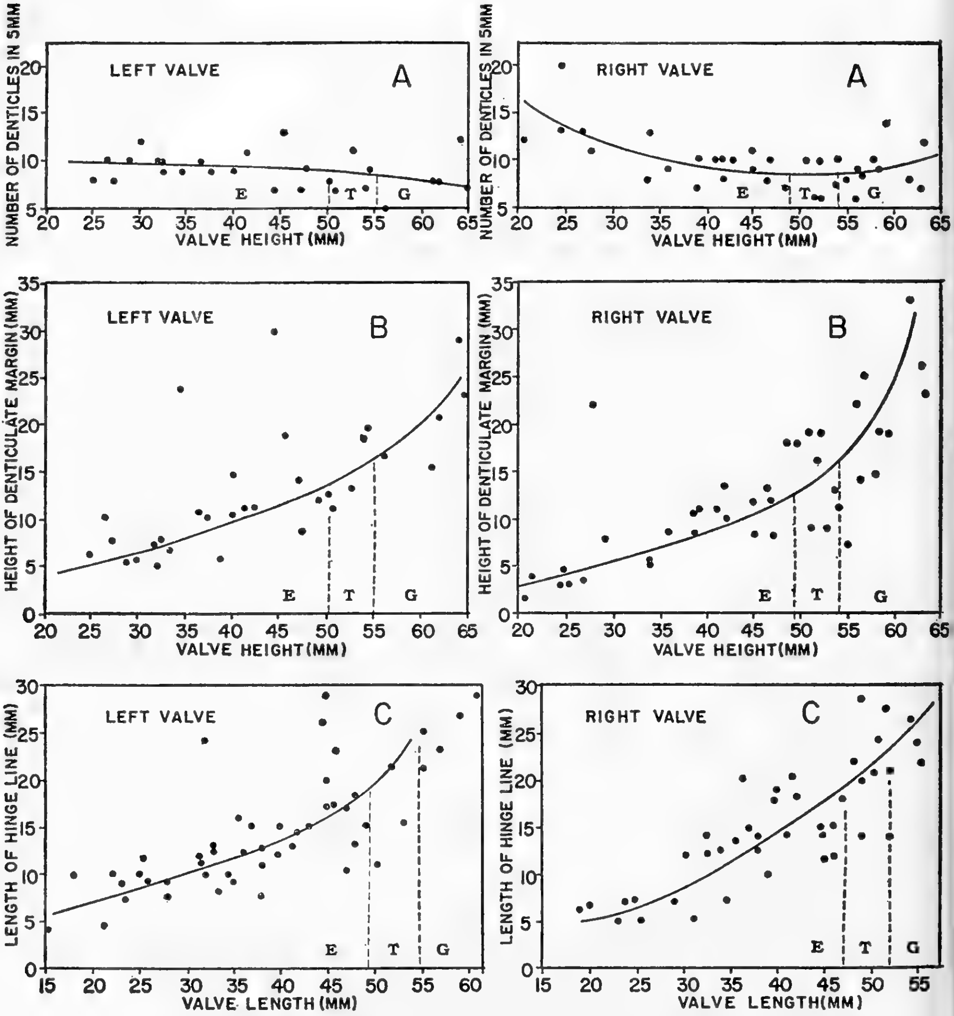

FIG. 17.—Ontogenetic development of *Lopha bellaplicata bellaplicata* (Shumard). A, Relationship between number of denticles in 5 mm. length (measured along margin) and valve height, showing decrease in density with age, and with increase in size. B, Relationship between the height of the valve and the extent of the denticulate portion of the margin, measured in terms of height, showing increase in extent of denticles with age and size. C, Relationship between length of hinge line and valve length, showing increase in size of hinge line relative to lateral expansion with age and size. All lines fitted visually. Approximate boundaries between ontogenetic stages marked by dashed lines. E = Ephebic; T = Ephebic-Gerontic transition; G = Gerontic.

subquadrate outline, less oblique shell, gently sloping posterodorsal margin, more projecting dorsoanterior margin and auricle, larger and better-defined posterior auricle, which is dorsoposterior rather than centroposterior in position, and by its less convex left valve, especially in the umbonal area. In the subspecies *bellaplicata,* the plicae originate at a later developmental stage, especially on the right valve, and are smaller, narrower, more numerous, more extensively bifurcating, and differentially developed on the auricles and main body of the valve. The posterior auricular sulcus is narrow and composed of a single, accentuated interplical sulcus.

The differences between *L. bellaplicata bellaplicata* and *L. lugubris* have previously been discussed under "Remarks" for the latter species. *L. bellaplicata bellaplicata* is easily distinguished from its variety A by being broader, rounder, less erect, auriculate, and in having better defined, much more numerous plicae.

Among foreign species of *Lopha, L. bellaplicata bellaplicata* is most closely comparable to *Lopha syphax* (Coquand), a Lower Cenomanian species which is larger, more coarsely and irregularly ribbed, and has a more pronounced anterior auricle. It further differs from the North American species in being proportionately higher, having a larger posterior auricle, and a more twisted umbone. This form may well be ancestral to the North American group of *L. lugubris.*

White (1880, p. 293; 1883, p. 12) gave the name *Ostrea* (*Alectryonia*) *blacki* (a *Lopha*) to a variant of *L. bellaplicata bellaplicata* which he considered distinct on the basis of its greater size, flatter valve, coarser and less numerous plicae, proportionately broader ventral dimension of the valves, and longer, more oblique dorsal margin. He evidently did not recognize the apparent age equivalency of the two forms. Cragin (1893, p. 199) and later writers have established that the two species both came from the upper Eagle Ford Shale of Texas. The present study validates this observation.

White's syntype lot of *L. blacki* consists of 26 specimens, most of them large, displaying late ephebic or girontic ornament, and obviously worn. Among these latter specimens are the ones White illustrated (1880, pl. 4, figs. 1, 2; 1883, pl. 14, figs. 1a, b, pl. 17, fig. 5a; 1884, pl. 45, fig. 1, pl. 46, fig. 2). His collection also includes, however, specimens identical to *Lopha bellaplicata bellaplicata,* and a complete morphologic gradation exists between the two forms in this and other collections from the upper Eagle Ford Shale.

Differences between the species cited by White break down under simple biometric comparison. The syntype lot of *L. blacki* contains predominantly large individuals, but all fall within the size limits of *L. bellaplicata bellaplicata* populations (fig. 16b). The plicae are not less numerous than those of *L. bellaplicata bellaplicata* (fig. 16c). They appear broader owing to the great amount of wear on certain valves. The valves are neither flatter (fig. 16b), nor broader ventrally than typical examples of *L. bellaplicata bellaplicata,* and there is total overlap in the inclination of the dorsal margin. Slight differences existing between these forms are probably the product of environmental control. Examples of *L. blacki* are from a relatively coarse argillaceous sandstone, while forms typical of *L. bellaplicata bellaplicata* occur in finer clastic and mud facies.

Lopha bellaplicata bellaplicata occurs in a number of different sediments over a broad area and provides a good basis for the study of environmental control on shell form. This opportunity is not presented by other members of the group, which occur in more uniform lithologies. Large collections of *L. bellaplicata bellaplicata* were obtained from buff calcarenitic chalk, gray carbonaceous and calcareous shale with numerous shell fragments, shaly calcarenite, sandy shale, and in argillaceous to calcareous quartz sandstone (Colorado). A single specimen from New Mexico was found in dark clay shale.

In collections from Texas, oysters from the calcarenitic marl units are thinner shelled, less convex, less inclined, and have less prominent posterior auricles than those from calcarenitic, sandy, or clay shale, and from thin calcarenites. Specimens from the latter lithology have the largest, thickest shells. These differences are probably related to differences in the energy conditions of the environment. Current and wave action was probably much stronger in the shallow-water environment where the calcarenites were formed than it was in the quieter, presumably deeper marl-forming areas. Thickening of the shell appears to be an adaption to this more active environment, its chief function being to strengthen the valves.

Specimens from New Mexico, found as gypsum replacements in dark clay shale, are typical of the species. The Colorado sample, however, shows significant environmental, and possibly geographic variation. Specimens from the Codell Sandstone Member ("Pugnellus Sandstone") of south-central Colorado attain a much smaller size than those from Texas and show a somewhat greater variation in marginal outline. The majority of specimens from Colorado, though smaller, are typical of the species and closely comparable morphologically to the Texas forms (compare pl. 3, figs. 1-15, with pl. 6, figs. 7-15).

Marginal variants of the Colorado sample, however, show structural features that are not within the range of variation observed for the Texas specimens. The most notable variant, here termed variety A, is a narrow, high form with relatively few plicae and no auricles (pl. 6, figs. 1-6, 19), possibly but not definitely a product of crowded growth conditions. This form is treated separately on subsequent pages.

A second unusual variant of Colorado *L. bellaplicata bellaplicata* assemblages is exceptionally long, with abnormally produced anterior and posterior auricles and, in some cases, very broad, rounded, plicae (pl. 6, figs. 11, 15). This form is also represented by a single specimen in the upper Blue Hill Shale, where it is probably a marginal variant of *L. bellaplicata novamexicana,* gradational into the younger *L. bellaplicata bellaplicata.*

Finally, rare specimens of *L. bellaplicata bellaplicata* from Colorado are nearly smooth, and lack well-developed plicae (pl. 6, figs. 17, 18, 21, 24), a condition not attained by Texas representatives of the species. This is most commonly expressed on right valves.

Analysis of these differences between Texas and Colorado representatives of *L. bellaplicata bellaplicata* is difficult, since it is not possible here to separate geographic variance from environmental variance. The shallow-water, high-energy environment indicated by the Codell Sandstone lithology and sedimentary structures is not duplicated in Texas, so there is no basis for comparison of environmental influences. I would not consider any of the unique variation in morphology shown by the Colorado sample as being particularly adaptive to the shallower, more turbid, active Codell environment. Modern oysters do not show such structural adaptations in similar niches. This is the only argument that can be presented in favor of the differences being geographic, and thus genetically controlled. Even if this were the case, I would not consider the differences between the Texas and Colorado samples to be of subspecific magnitude, especially since they are shown by a very small percentage of the specimens examined.

Stratigraphic and geographic occurrence.—In Texas, *L. bellaplicata bellaplicata* occurs in the upper 50 to 70 feet of the Eagle Ford Shale, being most common in the upper 15 to 25 feet, and forming prominent beds in the upper 2 to 5 feet at various localities. The species has been found in New Mexico at only one locality, in the dark shale of the Benton Subgroup (Mancos), on the Zuni Indian Reservation. In Colorado, the species is restricted to the "Pugnellus Sandstone"

(Codell Sandstone Member) of the Carlile Shale, where it is found in limestone and calcareous sandstone lenses throughout the unit.

In Colorado, the species has been found at localities 40-43, 55, and 58-61; in New Mexico, at locality 45; in Texas, at localities 15, 44, 46-54, 56, and 57, described in detail at the end of this report.

Illustrated and measured specimens.—The holotype is presumed to have been lost in the fire at the St. Louis Academy of Science. Neotype, here selected, a mature left valve (pl. 3, fig. 11), U.S.N.M. 132222. White's hypotypes, paired valves (1879; 1884), illustrated on plate 3, figure 13, U.S.N.M. 12383; White's "paratype" of *O.* (*A.*) *blacki* (1884, pl. 46, fig. 2), U.S.N.M. 8024b. Stanton's hypotypes (1893 [1894], pl. 4), U.S.N.M. 11822a (Stanton's fig. 8), U.S.N.M. 22860b, c, d (Stanton's figs. 9, 6, 4, respectively), 22861 (Stanton's fig. 7). New hypotypes, U.S.N.M. 8024a, c. d; U.S.N.M. 11882b; U.S.N.M. 22009a, b; U.S.N.M. 22011b; U.S.N.M. 132213-132221, inclusive, U.S.N.M. 132223-132244, inclusive; U.S.N.M. 132250, 132251, 132283, 132284, 132305-132308; U.M.M.P. (University of Michigan Museum of Paleontology) 38038, 38039, 38041, 43466, 43478, 43482, 43483. Measured specimens, unfigured: U.S.N.M. 8024e, U.S.N.M. 11882c, U.S.N.M. 22009; U.S.N.M 22011c; U.S.N.M. 22860e, U.S.N.M. 132245-132249, inclusive; U.S.N.M. 132291-132300, inclusive, 132304.

LOPHA BELLAPLICATA BELLAPLICATA var. A

Plate 6, figures 1-6, 19

DESCRIPTION

Material.—36 left and right valves, moderately well preserved, from the Codell Sandstone Member. ("Pugnellus Sandstone"), Carlile Shale, at a number of localities in Huerfano Park, Colorado. The collection includes mostly small individuals, forming a partial growth series.

General form.—Summary of measurements presented in tables 3, 4. Shell small, inequivalve, left (lower, attached) valve much more convex, slightly larger, less curved dorsally than right; most valves slightly inequilateral, prosocline to erect. Highly variable in outline: typically elongate-ovate along midline axis (pl. 6, figs. 1, 2, 5) less commonly broadly subovate due to lateral flaring of posterior or posteroventral margins (pl. 6, figs. 6, 19), or irregularly elongate due to crowded growing conditions. Height greater than length. Anterior margin steeply inclined, straight to slightly and irregularly curved, without anterior auricle. Ventral margin moderately to narrowly rounded, regular to irregular. Posterior margin with irregular outline, slightly concave (outward) dorsally, moderately to slightly convex ventrally (pl. 6, figs. 2, 6, 19). Dorsal margin short, straight to moderately curved, generally equal to width of attachment scar. On rare specimens, ventroposterior margin flared outward, considerably flattened, forming small, rounded, semicircular, pos-

TABLE 3.—*Summary of measurements on left valves of* Lopha bellaplicata bellaplicata *var. A*

Character	No. of specimens	Range	Average
Height (H)	21	15.4-38.4 mm.	23.4 mm.
Length (L)	22	10.1-29 mm.	17.0 mm.
Ratio, L:H	17	0.56:1-1.20:1	0.73:1
Width (W)	23	3.0-12.9 mm.	7.7 mm.
Area, inscribing rectangle of valve (A)	20	179.6-1128.1 mm.^{2}	432.9 mm.^{2}
Length; beak to posterior margin (LBP)	22	3.9-14.4 mm.	9.4 mm.
Ratio, LBP:L	21	0.39:1-0.71:1	0.53:1
Angle of inclination (i)	20	67-101°	82.3°
Height of attachment scar (HATS):			
Maximum vertical diameter	20	2.6-21.9 mm.	9.8 mm.
In plane of commissure	20	1.4-21.9 mm.	8.4 mm.
Length of attachment scar (LATS)	20	2.3-17.2 mm.	9.5 mm.
Area, inscribing rectangle of attachment scar (HATS × LATS)	20	6-354.8 mm.^{2}	110.6 mm.^{2}
Height, smooth young stage (HSS), dorsal part of valve	22	2.3-23.4 mm.	9.98 mm.
Height, plicate portion of valve	20	4.9-26.5 mm.	13.6 mm.
Ratio, H:HSS	20	0.108:1-0.777:1	0.432:1
Number of plicae at first appearance	22	4-12	8
Number of plicae at 10 mm. height	14	4-12	8.5
Number of plicae at 20 mm. height	16	5-12	9.6
Total number of plicae	22	4-14	9.3
Number of plicae in 10 mm. distance (length) 10 mm. below beak	13	3-6.75	4.8
Width of median plica at 10 mm. height	21	0.8-2.6 mm.	1.7 mm.
Percentage of plicate valves with bifurcating plicae	23		78.3%
Percentage increase in number of plicae by bifurcation	18	9.1-41.7%	17.9%
Curvature of beaks and umbones:	21		
Opisthogyre			81%
Orthogyre			9.5%
Prosogyre			9.5%

terior auricle separated from main body of shell by a broad, shallow, indistinct auricular sulcus, generally a broadened interplical sulcus or 2 sulci with the intermediate plication greatly reduced.

Right valve flat to slightly arched; convexity greatest in umbonal region; flanks flat, rarely concave near margin when ventral edge upturned. Left valve moderately to highly convex, convexity greatest at upper edge of attachment scar where prominent; otherwise crest and high point situated medially on lower third of valves. Anterior slope typically steep, ventral slope shallow, posterior slope steep dorsally, moderate to gentle or irregular ventrally, depending on development of posterior auricle.

TABLE 4.—*Representative measurements of right valves associated with* Lopha bellaplicata bellaplicata *var. A and possibly belonging to this form.*

Character	U.M.M.P. 43406	U.M.M.P. 43413
Height (H)	19.1 mm.	16.7 mm.
Length (L)	9.6 mm.	15.8 mm.
Width (W)	3.5 mm.	4.8 mm.
Height, cardinal area	2.2 mm.	
Length, hinge line	3.9 mm.	
Width, midcardinal fold	1.9 mm.	
Height, denticulate margin	7.1 mm.	
Number of denticles in 5 mm. distance	11	
Maximum diameter of muscle scar	6.9 mm.	
Minimum diameter of muscle scar	3.6 mm.	
Distance (height), dorsal edge of muscle scar to beak	8.1 mm.	
Angle of inclination (i)	82°	61°
Number of major lamellae in 5 mm. height (midvalve)		3

Beaks and umbos.—Beak, umbo unknown on left valve, obscured by attachment scar, apparently slightly recurved, orthogyre to slightly opisthogyre. Beak of right valve known from numerous, nearly smooth, associated upper valves; pointed to narrowly rounded, smooth, normally opisthogyre, moderately recurved. Umbone gently arched, in some valves separated from main body of shell by a constriction or large lamella.

Attachment scar.—Area of attachment terminal, small to medium size, round to subovate, flat to slightly concave, steeply inclined or vertical relative to plane of commissure, rarely moderately inclined. Scar surface smooth or with faint concentric markings of shell to which oyster attached; attachment to other *Ostrea* and *Inoceramus* shells. In some specimens scar area appears secondarily thickened by additional layers of lamellar calcite.

Ornamentation, left valve.—Variable: Beak and early umbo smooth, or with fine concentric ornamentation. Lower umbo and portion of valve between attachment scar and plicate flanks marked by numerous fine, crowded, overlapping lamellae, fine growth lines, and scattered concentric undulations or moderate size lamellae. All lamellae terminally in contact with succeeding ones.

Plicae commonly arise abruptly at or slightly below ventral edge of attachment scar (pl. 6, fig. 2). Plicae large, coarse, rounded, broader than interspaces between them, their width greater than their height, subequally developed to irregular (compare pl. 6, fig. 1, with fig. 2), bifurcating irregularly over entire valve; rate of bifurcation greatest dorsally. Secondary plicae rapidly expanding, rarely attaining size of primaries near commissure. Plicae become broader, lower, more rounded, indistinct near ventral and ventrolateral margins of a few valves, rarely disappearing altogether (pl. 6, figs. 2, 4). Interplical sulci narrow, sharp to narrowly rounded at base.

Concentric ornamentation on plicate portion of valve consisting of numerous crowded, subequally to irregularly spaced, fine to medium size, overlapping lamellae, most terminally in contact with succeeding lamellae, and scattered coarse, raised lamellae; latter particularly common near margin. Plicae finely fluted at intersection with major lamellae. Radial and concentric ornamentation of posterior auricle, where developed, more irregular than that of main body of shell; plicae smaller, more curved and sinuous, more extensively bifurcating. Concentric elements coarser on auricle.

Ornamentation, right valve.—Beak smooth; umbone with scattered fine growth lines and faint concentric undulations. Remainder of valve covered with numerous fine growth lines, scattered flat lamellae of several sizes, and low concentric undulations, irregularly spaced and unequally developed, becoming coarser toward valve margins. Some valves with several coarse lamellae crowded near margins.

Majority of specimens lack radiating ornamentation. A few right valves have traces of plicae near and on margins. Rare valves exhibit well-developed plicae similar to those of left valve; plicae arise abruptly near ventral and ventrolateral margins and extend to the edge. Variants of these associated right valves illustrated on plate 6, figures 3, 4.

REMARKS

The collections contain no valves with the interior preserved, and the thin, fragile nature of the shell makes it difficult to excavate one successfully. Presumably, the internal structures are the same as those on *L. bellaplicata bellaplicata* forma typica. Right valves were not found coattached with left valves. Their description is based on numerous smooth valves occurring in the same sediment and conforming in shape and size to typical left valves.

It seems advisable to describe separately this marginal variant of *L. bellaplicata bellaplicata* for two reasons. First, a continuous morphologic series cannot be established between the typical form of the species and variety A. The specimens illustrated on plate 6, figures 6 and 19, are the only ones that approach the typical form, and these show significant differences. Graphs and charts comparing structures of the two forms invariably show a bimodal distribution with little overlap (figs. 14a-c). There is a possibility, therefore, that the differences between the two forms are not totally environmental, but genetic, and that they were related and coexisting subspecies or species.

This possibility is further evident considering the apparent environment of deposition of the Codell Sandstone Member. The Codell contains a diverse normal marine, shallow-water invertebrate fauna. The deposit has all the characteristics of a shallow-water, inner sublittoral sand sheet formed under moderate- to high-energy conditions of current and wave action. Variety A and the typical form of the species occur together, represented by numerous well-preserved shells, in the same lenses of fossils. They appear to have lived together and were probably subject to the same environmental influences. *L. bellaplicata bellaplicata* var. A occurs characteristically in clusters, where the elongate form of the shell appears to be, in part, a product of crowding. But free-growing examples are also known, and these are equally elongate. The form, convexity, and ornamentation are more regular on the free-growing specimens. The differences between the two forms therefore do not appear to be ecologic, or wholly a product of growth habit, indicating that *L. bellaplicata bellaplicata* var. A may be genetically distinct from the typical form of the species. The small number of specimens available for study, their limited size range, and lack of knowledge concerning the shell interior do not permit verification of these differences, or formal description of a new species or subspecies. Based on modern observations, it seems more likely that a single variable ostreid species would occupy such a well-defined ecologic niche than that two closely related species or subspecies would be living together and competing for the same niche.

Recognition of the variety is of additional importance since it may be the source from which contemporary and younger species of *Lopha,* having generally similar features, originated. Such ostreids, mostly undescribed, occur at various localities and stratigraphic levels in the Western Interior and will be the object of future study. They are not found in older sediments.

The morphologic distinctions between *L. bellaplicata bellaplicata* and variety A have been previously discussed under "Remarks" for the former subspecies.

Stratigraphic and geographic occurrence.—The variety occurs throughout the Middle Turonian "Pugnellus Sandstone" (Codell Sandstone member) of the Carlile Shale at localities 41, 58, 59, 60, and 61 in Huerfano Park, Colo. Rare marginal variants of the Texas and Colorado collections of *L. bellaplicata bellaplicata* approach this form, but none attain it.

Illustrated specimens.—Left valves: U.S.N.M. 22011a, d; 132249; U.M.M.P. 38051, 38052; associated right valves, illustrated; U.S.N.M. 132259, U.M.M.P. 43413; hypotypes. Measured specimens, not illustrated: U.S.N.M. 132301-132303; U.M.M.P. 43406.

LOPHA BELLAPLICATA NOVAMEXICANA new subspecies

Plate 7, figures 1-19; plate 8, figures 1-9

DESCRIPTION

Material.—About 100 well-preserved specimens (measured), predominantly left valves, from 4 localities in New Mexico and 8 localities in Colorado, including ontogenetic series and 2 large suites of specimens from single localities.

General form.—Summary of measurements presented in table 5. Shell attaining moderate size; inequivalve, left (lower, attached) valve slightly larger, much more convex than right valve; slightly to moderately inequilateral, prosocline. Valves close-fitting, outline moderately variable; typically subovate, commonly subquadrate or elongate-ovate parallel to axis of inclination, rarely rounded (pl. 7, figs. 1-5, 10-12, 14-19; pl. 8, figs. 7-9 typical of subspecies). Height greater than length in most specimens. Anterior margin slightly curved dorsally and ventrally, moderately rounded medially. Ventral margin moderately and evenly rounded; ventroposterior corner more narrowly

TABLE 5.—*Summary of measurements for* Lopha bellaplicata novamexicana

Character	Valve	No. of specimens	Range	Average
Height (H)	L	67	14.2-90 mm.	39.5 mm.
	R	8	18.3-53.6 mm.	36.3 mm.
Length (L)	L	67	13.4-61 mm.	35.9 mm.
	R	8	20.7-51.5 mm.	32.5 mm.
Width (W)	L	67	5.0-28.9 mm.	15.7 mm.
	R	6	3-18.3 mm.	8.7 mm.
Percent valves with $H > L$	LR	59/75		78.6%
Percent valves with $H < L$	LR	16/75		21.4%
Percent valves with $H = L$	LR	0		0
Area, inscribing rectangle of valve ($A = H \times L$)	L	66	201-4050.4 mm.^{2}	1550 mm.^{2}
	R	8	379-2760 mm.^{2}	1125 mm.^{2}
Length, beak to posterior margin (LBP)	L	67	5.4-41.0 mm.	22.5 mm.
	R	8	11.2-34.0 mm.	19.2 mm.
Ratio, LBP : L	L	50	0.40 : 1-0.83 : 1	0.63 : 1
	R	8	0.53 : 1-0.66 : 1	0.58 : 1
Angle of inclination (i)	LR	64	59°-89°	76.5°
Percent of specimens with observable attachment scar	L	84		20.2%
Height of attachment scar (HATS)	L	13	1.0-12.1 mm.	4.7 mm.
Length of attachment scar (LATS)	L	17	2.1-22.3 mm.	7.3 mm.
Area, inscribing rectangle of attachment scar ($HATS \times LATS$)	L	24	2.1-265.0 mm.^{2}	39.3 mm.^{2}
Ratio, area, inscribing rectangle of scar : area, inscribing rectangle of valve	L	24	0.002 : 1-0.24 : 1	0.04 : 1
Height of smooth portion of valves dorsad to plicae (HSS)	L	26	1.0-7.3 mm.	2.7 mm.
	R	11	4.0-11.1 mm.	6.3 mm.
Ratio, HSS : H	L	26	0.03 : 1-0.18 : 1	0.08 : 1
	R	11	0.15 : 1-0.35 : 1	0.25 : 1
Number of plicae (total) :				
Primary plicae at first appearance	L	44	5-15	8.1
	R	11	7-15	10.4
Number of plicae at 10 mm. height	L	50	7-19	11.5
	R	11	8-15	12.0
Number of plicae at 20 mm. height	L	48	9-18	15.0
	R	10	10-17	13.4
Number of plicae at 30 mm. height	L	40	9-20	13.8
	R	4	10-15	12
Number of plicae at 40 mm. height	L	22	9-21	14.8
	R	0	0	0
Number of plicae at 50 mm. height	L	3	13-19	16.0
	R	0	0	0
Total number of plicae at margin	L	52	9-21	14.4
	R	11	10-17	13.9

Table 5.—*Summary of measurements for* Lopha bellaplicata novamexicana—*continued*

Character	Valve	No. of specimens	Range	Average
Number of plicae in 20 mm. length at 20 mm. height	L	64	3-8	4.75
	R	15	4-6	4.43
Width of median plica 20 mm. below beak	L	63	2.2-8.3 mm.	4.9 mm.
Percent increase in plicae by bifurcation	L	44	7-200%	84%
	R	11	6-77%	37%
Width of posterior auricular sulcus 20 mm. below beak	L	43	3.9-12.4 mm.	6.6 mm.
Inclination of beak, umbo (67 left valves, 8 right valves):				
Percent opisthogyre	L	41		61.2%
	R	3		37.5%
Percent orthogyre	L	14		20.9%
	R	5		62.5%
Percent prosogyre	L	12		17.9%
	R	0		0
Length of hinge line (LHL)	L	1		14.6 mm.
	R	1		10.7 mm.
Ratio, LHL:L	L	1		0.43:1
	R	1		0.33:1
Number of denticles in 5 mm. length	L	1		8
	R	1		9
Maximum diameter of muscle scar (MDS)	L	1		12.9 mm.
	R	1		12.8 mm.
Ratio, MDS:H	L	1		0.37:1
Ratio, area of scar : area of valve	L	1		0.08:1

rounded. Posterior margin straight to gently curved except in valves with prominent posterior auricle, where concave notch developed in outline at intersection with posterior auricular sulcus. Dorsolateral margins straight to slightly curved; dorsolateral corners narrowly rounded over auricles. Anterodorsal margin steeply to moderately inclined; inclination least in presence of auricle. Posterodorsal margin longest, moderately inclined with or without auricle.

Left valve moderately to highly convex (pl. 8, figs. 1-3); high point dorsocentral, just anterior to midline, on median plica. Anterior and dorsal flanks steeply sloping; ventral, posteroventral, posterodorsal flanks moderately sloping; posterior flank slopes steeply into auricular sulcus, becomes flat beyond this. Right valve flat to slightly concave dorsally and centrally, slightly convex ventrally, ventrolaterally, rarely with margins upturned, forming shallow submarginal trough. High point central to posterocentral.

Auricles.—Anterior auricle not commonly developed (20 percent of left valves, 5 percent of right valves), dorsoanterior in position, small, flat, subtriangular, terminally rounded, bearing 1 or 2 flattened primary plicae. Anterior auricular sulcus prominent, deeper, broader than adjacent interplical sulci (pl. 7, figs. 10, 11). Posterior auricle small to large, typically of moderate size, flat to slightly convex; outline subtriangular, with posterior apex situated centrally on posterior margin (pl. 7, figs. 3, 4, 10, 11). Auricular sulcus very prominent, composed of single broad interplical sulcus, or 2 adjacent interplical sulci with intermediate plica greatly reduced or absent (pl. 7, figs. 10, 11). Auricle smaller, less distinct on right valves than on left valves; rarely absent.

Beaks and umbos.—Normally slightly opisthogyre, rarely prosogyre, orthogyre, or with strong posterior curvature; slightly projecting, incurved, commonly extending inward beyond plane of commissure on left valve. Beaks small, narrowly to broadly rounded, flat to slightly convex, smooth, situated one-third to slightly less than one-half the length from the anterior margin, commonly obscured on attachment scar. Umbo of left valve highly arched, prominent, plicate. Umbone of right valve flat, smooth to partially plicate. Curvature of umbonal axis gentle, dorsally orthocline to slightly opisthocline, ventrally prosocline.

Attachment scar.—Small, indistinct, commonly not visible or absent; round to subovate, flat to slightly concave, steeply inclined to plane of commissure; terminal and central in position, or on posterior slope of early umbo. Attachment to smooth, slightly convex surfaces, predominantly other oysters, smooth clams. Shell moderately thick over attachment area.

Ornamentation, left valve.—Beak smooth, earliest umbo bearing growth lines, fine concentric lamellae. Plicae originate abruptly on early umbo, at edge of attachment scar (where present), or rarely on middle umbo. Primary plicae typically large, narrow in early stages, broader than high on adult part of shell, becoming broader, more rounded, lower with age, extending to margin on largest valves. Crests of plicae moderately to narrowly rounded, flanks moderately inclined. Plicae bifurcate over entire valve; bifurcation rate high on umbonal and subumbonal areas, low and irregular over rest of valve. Secondary plicae smaller, narrower, more rapidly expanding than primaries, some attaining size equal to primaries near margin. Rare valves with sharp, narrow plicae over entire valve (pl. 7, fig. 11). Plicae of posterior auricle smaller, more curved, more irregular, and more extensively bifurcating than those of main body of shell.

Concentric sculpture over plicate portion of valve consisting of fine, crowded, irregularly spaced growth lines and flat microlamellae dorsally, becoming gradually coarser ventrally. Coarse, raised, major lamellae appear at midvalve (pl. 7, figs. 10, 18), and are scattered singly, or in groups of 2 or 3, over ventral half of valve, intercalated with growth lines and microlamellae. Major lamellae coarsest, most crowded near commissure. Plicae fluted at intersections with major raised lamellae.

Ornamentation, right valve.—Right valve distinct from left in detail of ornamentation. Beak smooth; umbo with fine growth lines, microlamellae, faint undulations, becoming coarser ventrally. Plicae arise abruptly at edge of umbo, preceded by a few coarse, crowded major lamellae and/or concentric ridges. 75 to 80 percent of valve plicate. Plicae coarse, higher than wide initially, becoming broader with age but remaining prominent; crests narrowly rounded to angular, flanks steep; plicae sparsely bifurcating throughout, generally near margins, much less than on left valve. Interplical sulci narrow, with angular to narrowly rounded bases. Concentric ornament of plicate flanks consisting of numerous, prominent, raised lamellae, moderately and unevenly spaced centrally, crowded ventrally, commonly marking major constrictions or change in slope of shell surface, more prominent on right than on left valve. Major lamellae intercalated with numerous crowded, growth lines and microlamellae. Plicae spinose, fluted at intersection with major lamellae. Typical right valves illustrated on plate 7, figures 8, 9.

Cardinal area.—Known from single right and single left valves; on left valve consisting of subcentral, broad, shallow, triangular resilifer, and equally large, flat, subequal (posterior largest), subtriangular, lateral cardinal plates. Surface of cardinal area marked with closely spaced, moderately strong horizontal lines of various sizes and by fine, crowded, subequally spaced, raised vertical lines. Cardinal area of right valve similar, but with ventral half of resilifer convexly folded, forming a low lip.

Denticles.—Denticles present on inner dorsolateral margins of both valves; small, simple, rounded to ovate, crowded, moderately convex, situated on commissure, rarely reflected on thick lateral edges of auricles.

Commissure.—Commissure at edge of right valve, just within edge of left valve; flat dorsolaterally, undulating at intersection with major plicae elsewhere. Internal expression of plicae variable, typically developed as low, rounded folds and sulci confined to valve margins, less commonly extending to center of shell, becoming more subtle inward. Thick-shelled specimens commonly with lamellate lateral edges of shell flattened in plane of commissure (pl. 7, fig. 5).

Muscle scar.—Monomyarian; posterior adductor scar large, situated centroposteriorly, or in upper part of posteroventral quadrant of valve (pl. 7, fig. 5); comma-shaped, arcuate, slightly concave, well defined, overlapped dorsally, anteriorly by inner shell layers, bordered ventrally by a low, raised lip. Surface striated, covered with fine, crowded, microlamellae and raised lines, irregularly spaced, conforming to trace of growth lines.

Shell structure.—Periostracum, prismatic layer, and hypostracum not observed. Subnacreous layer forms bulk of shell, consisting of several layers of slightly curved, inclined calcite plates arranged en echelon within each layer. Inclination of plates in each layer may be opposed to that of adjacent layers. Individual plates and layers flatter, more conformable around cardinal area and at ventral edge. Nacreous layer thin, composed of flat calcite lamellae. Shell thick; thickness of a typical left valve (height 38 mm., length 34 mm.) through the hinge area, 4.5 mm.; thickness at crest, 3.4 mm.; thickness 5 mm. above ventral margin, 2.3 mm.

ONTOGENY

A few significant ontogenetic trends regarding the external features of the shell are worthy of note. Internal structures of the valves are virtually unknown in this respect.

Concentric sculpture.—*Nepionic* stage smooth. *Neanic* stage with fine growth lines, microlamellae initially, becoming coarser toward *late neanic*. *Early* to *middle neanic* in left valve marked by a few, coarse, crowded growth lines, lamellae, and ridges just before abrupt development of plicae. *Ephebic* stage marked by development of scattered (left valve) to moderately spaced (right valve) major concentric lamellae in addition to fine ornament, possibly marking growth rests, and becoming somewhat more crowded in *late ephebic* as growth slowed. *Gerontic* stage marked by crowded, coarse lamellae and growth lines near margin.

Radiating sculpture.—Plicae abruptly appear in *early,* rarely *middle neanic* stage on left valves, at the beginning of *ephebic* development on right valves, becoming coarser, more prominent, broader, more rounded with age through the *middle ephebic* stage; becoming lower, more subtle during *late ephebic* and *gerontic* stages, especially on left valves. Bifurcation rate highest during *neanic,* low and irregular at later stages.

Convexity.—Outward curvature of shell growth moderate to great through *neanic* and *early ephebic* development, gradually decreasing in later growth (fig. 3a), becoming moderate to slight. No flattening and flaring noted in late growth stages.

Marginal outline; auricles.—(Based on fig. 18.) *Nepionic* shell subround, *Neanic* shell ovate, longer than high; lateral growth exceeded ventral growth during *neanic* and *early ephebic* stages. *Ephebic* stage marked by ventral growth exceeding lateral expansion and the latter becoming irregular. Auricles appear in *early ephebic* as more rapidly expanding salients of lateral margins, continue to grow at a more accelerated rate throughout life. *Gerontic* growth similar to that of *ephebic* stage.

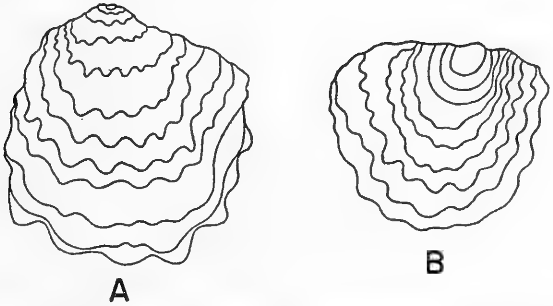

FIG. 18.—Ontogeny of *Lopha bellaplicata novamexicana* new subspecies. Growth line traces at approximately 2.5 mm. intervals on representative left (A) and right (B) valves of the subspecies, showing developmental history of the marginal outline and the auricles. Drawings ×1. A, U.S.N.M. 132267, B, U.S.N.M. 132265.

Curvature of growth axis (midline).—Curvature slight during *nepionic, neanic, early ephebic* stages, decreasing uniformly through *ephebic* and *gerontic* stages, becoming nearly straight (fig. 3c).

REMARKS

The distinction between *L. bellapliata novamexicana* and its most closely comparable relative, *L. bellaplicata bellaplicata* has been discussed in detail under the "Remarks" section of the latter subspecies. Basically, *L. bellaplicata novamexicana* is distinguished by its more oblique marginal outline, greater convexity of the umbonal region, larger, broader, less numerous plicae, reduced and more centrally situated auricles, much larger posterior auricular sulcus, and more inclined posterodorsal margin. The plicae arise at an earlier developmental stage than in *L. bellaplicata bellaplicata.* No other Cretaceous species of *Lopha* are closely comparable. Young shells of these two subspecies are nearly identical (compare pl. 3, figs. 1-9, with pl. 7, figs. 1-3), but average adult shells are readily distinguished. Marginal variants of the subspecies show overlap of many structures.

Shells of this subspecies are typically found complete, with both valves intact and well preserved. Although they are common at some localities, they have not been observed living gregariously in beds or "oyster reefs," and show no evidence of crowding. The small size of the attachment scar (in some cases too small to be observed, or preserved, on the beak) possibly indicates early detachment from the substrate and predominantly a free life.

Lopha bellaplicata novamexicana is known from three lithofacies: Fine- to medium-grained, well-sorted, cross-bedded marly sandstone; similar sandstone with an argillaceous cement and abundant carbonaceous debris; and sandy, argillaceous, limestone concretions or lenses (septarian) in a sandy shale matrix. The first two types are from New Mexico, and the concretions mark its occurrence in Colorado. The only observable morphologic differences between forms from the two States which may be environmentally controlled are (1) the sharper plicae on many Colorado examples (pl. 7, fig. 11), and (2) the tendency for some Colorado specimens to have a ventral "hump," or sharp break in slope about one-third the height from the ventral margin. On the steep slope below this break, the plicae on certain specimens show greater bifurcation than is normal for the subspecies. No such structure was noted on New Mexico specimens. These differences are difficult to evaluate in light of the sparse knowledge concerning the paleoenvironment to which this form was subjected. Similar irregularities in growth form are produced in some oysters exposed to abrupt changes in rate of sedimentation, in others periodically exposed in intertidal zones. This structure is genetically produced in certain species of *Inoceramus,* irrespective of environment. It is a gerontic feature of other pelecypods.

Stratigraphic and geographic distribution.—Lopha bellaplicata novamexicana is the oldest known member of the *L. lugubris* group. It is commonly found in the middle Mancos Shale of New Mexico, in the zone of *Collignoniceras hyatti* (Stanton) (late Middle Turonian), well below the occurrence of *L. lugubris.* Its position relative to *L. bellaplicata bellaplicata* in New Mexico is uncertain, however, since the latter is rare in this area, and the two have not yet been found associated.

The stratigraphic relationship between *L. bellaplicata bellaplicata* and the subspecies *novamexicana* can be established in Huerfano Park, Colo. Here, typical examples of *L. bellaplicata bellaplicata* are found throughout the Codell Sandstone Member ("Pugnellus Sandstone") (pl. 6, figs. 7-9, 12). Below this unit, in the upper part of the Blue Hill Shale Member, septarian limestone concretions contain scattered but characteristic examples of the subspecies *novamexicana* (pl. 7, fig. 11). The two forms do not have overlapping ranges in this area, although rare individuals transitional between them occur as marginal variants of each form. This occurrence suggests, therefore, that *L. bellaplicata novamexicana* is characteristic of the lower part of the *Collignoniceras hyatti* zone (Blue Hill Shale Member equivalents) and *L. bellaplicata bellaplicata* marks the upper part of the *C. hyatti* zone (Codell Sandstone Member: "Pugnellus Sandstone" of older authors). If future collections prove this to be true over a broad area in the Western Interior, these ostreids will have particular importance as stratigraphic markers, since the faunas of these two units overlap in almost every other respect. The subspecies *novamexicana* occurs at localities 62 through 73, described in detail at the end of this report.

Illustrated and measured specimens.—Holotype, a typical left valve with the interior excavated, U.S.N.M. 132267 (pl. 7, fig. 10). Figured paratypes, left and right valves, U.S.N.M. 22012; U.S.N.M. 132260-132266 inclusive; U.S.N.M. 132268-132282 inclusive; U.S.N.M. 132286-132288 inclusive. Measured, unfigured paratypes, U.S.N.M. 132252-132257 inclusive, 132290. University of Michigan Museum of Paleontology (U.M.M.P.) 43480, 43481. Sectioned specimen, discussed, U.S.N.M. 132289.

COLLECTING LOCALITIES

Collecting localities and stratigraphic information are cited as they appear in the Mesozoic catalogs of the U. S. Geological Survey and U. S. National Museum. In many cases, data available for older collections are brief and generalized. Many such collections have been omitted from this study for this reason. Others have been incorporated because it is obvious from the locality data and from associated matrix at what stratigraphic level they were obtained. Localities cited for the latter collections contain, in parentheses, stratigraphic data which is not listed in our catalogs and which represents my own interpretation, based on experience in the areas in question. For localities that I have not actually visited, this information is followed, in parentheses, by a question mark. I have collected from all other areas in the past 6 years, and feel certain of the stratigraphic assignments.

Lopha lugubris (Conrad)

1. U.S.G.S. 513—"Colorado Formation" (Juana Lopez equivalent ?), hills 6 miles each of Mexican settlements on road from Jemez to Copper City, N. Mex. 100 feet above massive gray sandstone standing on edge. Collected by J. W. Powell, 1887.
2. U.S.G.S. 747—"Colorado Formation" (Juana Lopez Member of the Carlile Shale), Rattlesnake Buttes, 18 miles east of Walsenburg Post Office, Colo. Collected by T. W. Stanton, 1890.
3. U.S.G.S. 827—"Colorado Formation" (Juana Lopez Member, Carlile Shale), near Malachite, Huerfano County, Colo. Collected by T. W. Stanton, 1891.
4. U.S.G.S. 833—100 to 600 feet above base of Colorado Shale (Juana Lopez equivalent ?), near Mancos, Colo. Collected by T. W. Stanton, 1891.
5. U.S.G.S. 1306—Benton (Subgroup: Juana Lopez Member, Carlile Shale), 12 miles northwest of Pueblo, Colo., lat. 38°25′, long. 104°47′. Collected by G. K. Gilbert, 1893.
6. U.S.G.S. 1380—Upper Benton (Subgroup: Juana Lopez equivalent ?), mesa 5 miles west of Drip Springs, lat. 37°38′, long. 104°30′, Colo. Collected by G. K. Gilbert, 1894.
7. U.S.G.S. 2005—Colorado (Group: Juana Lopez equivalent ?), about 150 feet above top of Dakota Sandstone, railroad cut north of Thompson Park, Colo. Collected by A. C. Spencer, 1897.
8. U.S.G.S. 2009—Colorado (Group), Mancos Shale (Juana Lopez equivalent ?), near F—down corral on middle Mancos (River ?), La Plata Quad., Colo. Collected by W. T. Lee.
9. U.S.G.S. 2015—Colorado (Group: Juana Lopez equivalent ?), west fork of Mancos (River ?), 10,700 feet elevation, Colo. Collected by W. Cross.
10. U.S.G.S. 2019—Colorado (Group: Juana Lopez equivalent in Mancos Shale), second fossil layer exposed northwest of Mancos, Colo. Collected by Mr. Cane, 1895.
11. U.S.G.S. 3673—(Colorado Group, Juana Lopez equivalent), *"Ostrea" lugubris* zone, Rio Puerco, about 5 miles above San Ygnacio, Albuquerque Quad., N. Mex. Collected by T. W. Stanton, 1906.
12. U.S.G.S. 4358—Benton (Subgroup), fine brown sandstone ledges 400 feet above Dakota Sandstone (Juana Lopez equivalent), Willow Creek at the old wagon road south of Blue Mountain, sec. 12, T. 3 N., R. 102 W., coal fields of northwest Colorado and adjacent territory. Collected by H. S. Gale, 1907.

13. U.S.G.S. 4456—Benton (Subgroup: Juana Lopez equivalent ?), horizon No. 2 (J. H. Gardner: unpublished), about 60 feet below main massive sandstone of Coloradoan age, 5 miles below Arnold's store, 10 miles northeast of Gallup, N. Mex. Collected by J. H. Gardner, 1907.
14. U.S.G.S. 6516—Upper part of the Benton (Subgroup: Juana Lopez equivalent), 150 to 200 feet above the Greenhorn Limestone, branch of Vermejo Creek, about 12 miles northwest of Vermejo Park Post Office, N. Mex. Collected by T. W. Stanton, 1910.
15. U.S.G.S. 7539—Eagle Ford Shale, layer No. 1, quarry of the Texas Portland Cement Co., 2.5 miles due east of Eagle Ford, Dallas County, and 3 miles west of Trinity River at Dallas, Tex. Collected by L. W. Stephenson, 1911.
16. U.S.G.S. 7579—Basal bed of the Austin Chalk, on Walnut Creek, about 1 mile east of Watters' Station, Travis County, Tex. Collected by L. W. Stephenson, 1911.
17. U.S.G.S. 7993—Colorado (Group: Juana Lopez equivalent), in 50 feet of yellow calcareous shaly sandstone, zone of *Prionocyclus wyomingensis* and *Scaphites warreni,* about 3.5 miles south of Casa Salazar, Mt. Taylor Quad., N. Mex. Collected by W. T. Lee and T. W. Stanton, 1912.
18. U.S.G.S. 9250—Mancos Shale, 300 to 400 feet above the base, near Delta, Colo. Collected by G. H. Stone, 1915.
19. U.S.G.S. 10368—Colorado (Group: Juana Lopez equivalent ?), 14 miles S. 20° W. from Shiprock Mt. (Wilson Peak), sec. 5 or 8, T. 9 N., R. 4 W., Navajo Meridian, near the base of Beautiful Mt., San Juan Basin, N. Mex. Collected by W. E. Bryant, Dobbin, and J. B. Reeside, Jr., 1920.
20. U.S.G.S. 10506—Mancos Shale, 300 feet above Dakota Sandstone, *Scaphites* zone (Juana Lopez equivalent), 1.5 miles west of Durango, NW1/4 SE1/4 sec. 18, T. 35 N., R. 9 W., Ignacio Quad., Colo. Collected by J. B. Reeside, Jr., 1920.
21. U.S.G.S. 12883—Reworked Eagle Ford Shale zone in the base of the Austin Chalk, exposures in bank of creek east of railroad, south of Colorado River, south of Austin, Travis County, Tex. Collected by L. W. Stephenson, 1924.
22. U.S.G.S. 13663—(Juana Lopez equivalent), 2 miles north of Whitewater, Grand Junction region, Colo. Collected by J. B. Reeside, Jr., 1926.
23. U.S.G.S. 14691—"Blue Hills Shale" (Carlile Shale, questionably from pockets of Juana Lopez Limestone at top of so-called Blue Hill Shale of older authors), *Lopha lugubris* zone, near Beloit, Kans. Collected by by J. B. Reeside, Jr., 1929.
24. U.S.G.S. 15923—Mancos Shale, 348 feet below Gallup Sandstone (Juana Lopez equivalent ?), triangulation point, Gallup, approximately center of sec. 12, T. 14 N., R. 2 W., southern San Juan Basin, N. Mex. Collected by C. B. Hunt and party, 1931.
25. U.S.G.S. 18876—"Codell ? Sandstone" (Juana Lopez Member at top of Codell), thin beds 30 feet below highly fossiliferous zone (of Mancos Shale), on Biltabito Road, 15 miles west of junction with highway to Gallup, 15 miles west of Shiprock bridge, San Juan County, N. Mex. Collected by N. W. Bass, 1943.

26. U.S.G.S. 20562—Upper Cretaceous (Juana Lopez equivalent ?), approximately 2 miles west-southwest of Hagan, sec. 6, T. 12 N., R. 6 E., Tejon Grant, N. Mex. Collected by C. E. Stearns, 1946.
27. U.S.G.S. 24443—Frontier Sandstone (Juana Lopez equivalent ?), 1.75 miles northwest of Newcastle, SE1/4 sec. 23, T. 5 S., R. 91 W., Glenwood Springs Quad., Colo. Collected by N. W. Bass, 1952.
28. U.S.G.S. 25592—Mancos Shale (Juana Lopez equivalent), 525 feet above base, section No. 2, southeast Gypsum Valley–Disappointment Valley area, aerial photo D.R.N. 2-10, San Miguel County, Colo. Collected by O. T. Marsh, 1955.
29. U.S.N.M. Cat. No. 8354—Colorado (Group: Juana Lopez equivalent), Colorado. Type specimen with no other locality data.
30. U.S.N.M. Cat. No. 9822—Upper Cretaceous (Juana Lopez equivalent), zone of *Prionocyclus macombi* ?, rocks east of Red River (Canadian), Santa Fe road, N. Mex. T. A. Conrad.
31. U.S.N.M. Cat. No. 20255—Middle Cretaceous, Colorado (Group: Juana Lopez equivalent), Vada del Chama, N. Mex.
32. Juana Lopez Member (top), Carlile Shale, Colorado Group, low cliff along the northwest side of Oak Creek, NE1/4 SW1/4 sec. 5, T. 27 S., R. 68 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1958.
33. Juana Lopez Member, Carlile Shale, Colorado Group, in a stream gully 1.3 to 1.5 miles north-northwest of Red Wing, on the Jones' Cattle Company Ranch, SW1/4 SE1/4 sec. 26, T. 26 S., R. 71 W. Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.
34. Juana Lopez Member, Carlile Shale, Colorado Group, ½ mile east of Maes' School, north of an unimproved dirt road, along the Fort Hays limestone hogback, SE1/4 sec. 11, T. 26 S., R. 69 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1958.
35. Juana Lopez Member, Carlile Shale, Colorado Group, along the Fort Hays Limestone hogback south of unimproved dirt road, 0.8 mile southeast of Maes' School, NW1/4 NE1/4 sec. 14, T. 26 S., R. 69 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1958.
36. Juana Lopez Member, Carlile Shale, Colorado Group, on the southeast side of Oak Creek, 0.2 mile southwest of Badito, NW1/4 NE1/4 sec. 8, T. 27 S., R. 68 W., Huerfano County, Colo. Collected by E. G. Kauffman, 1958.
37. Juana Lopez Member, Carlile Shale, Colorado Group, in a subsidiary stream valley of Pantleon Creek, north of an unimproved road crossing sec. 28, on the Jones' Cattle Company Ranch, S1/2 NW1/4 sec. 28, T. 26 S., R. 71 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.
38. Juana Lopez Member, Carlile Shale, Colorado Group, 2-3 miles north of Thatcher, Colo., in Juana Lopez–Fort Hays limestone hogback, on east side of dirt road leading north from general store and Thatcher School, 50 to 100 yards east of road. Collected by E. G. Kauffman, 1961.
39. Juana Lopez Member, Carlile Shale, Colorado Group, 2-3 miles north of Thatcher, Colo., on west side of dirt road leading north from Thatcher

School, in two fault or slump blocks, 0.5 and 0.7 mile west of road. Collected by E. G. Kauffman, 1961.

Lopha bellaplicata bellaplicata (Shumard)

15. U.S.G.S. 7539 (same as listed for *Lopha lugubris*)—Eagle Ford Shale, layer No. 1, quarry of Texas Portland Cement Company, 2.5 miles due east of Eagle Ford, Dallas County, and 3 miles west of Trinity River at Dallas, Tex. Collected by L. W. Stephenson, 1911.
40. U.S.G.S. 741—Colorado Group (Codell Sandstone Member, Carlile Shale), near Charles Smith's Ranch, on Muddy Creek, 10 miles above Gardner Post Office, Huerfano Park, Huerfano County, Colo. Collected by T. W. Stanton, 1890.
41. U.S.G.S. 743—Colorado Group (Codell Sandstone Member, Carlile Shale), 1 mile east of Quillian's Ranch on Williams Creek, Huerfano Park, Huerfano County, Colo. Collected by T. W. Stanton, 1890.
42. U.S.G.S. 1310—Benton (Subgroup: Codell Sandstone Member, Carlile Shale), near 3-R Ranch, lat. 38°2′, long. 104°57′, Colo. Collected by G. K. Gilbert, 1893.
43. U.S.G.S. 1318—Benton (Subgroup: Codell Sandstone Member, Carlile Shale), near Turkey Creek, lat. 38°30′, long. 104°49′, Colo. Collected by G. K. Gilbert, 1893.
44. U.S.G.S. 439b—(Eagle Ford Shale), 2 miles east and 3 miles south of Denison, Tex. Collected by R. T. Hill, 1886.
45. U.S.G.S. 8081—Benton ? (Subgroup: Mancos Shale), on surface of steep slope at B-34, sec. 18, T. 10 N., R. 17 W., Zuni Indian Reservation, N. Mex. Collected by D. E. Winchester, 1912.
46. U.S.G.S. 10046—Eagle Ford Shale, 7 miles west of Palestine at the salt works, on ridge ⅛ mile northeast of plant, Texas. Collected by O. B. Hopkins, 1915.
47. U.S.G.S. 11096—Eagle Ford Sandstone, in pebble bed 15 to 25 feet below Ector Chalk, in big gully 1 mile southeast of Bells, Tex. Collected by O. B. Hopkins, 1918.
48. U.S.G.S. 11732—Upper 3 feet of the Eagle Ford Shale, in quarry of the Texas Portland Cement Company plant west of Dallas, Tex. Collected by T. W. Stanton, 1923.
49. U.S.G.S. 12942—Eagle Ford Formation, Palestine salt dome, east of salt works, at an old cabin, Anderson County, Tex. Collected by L. W. Stephenson, 1924.
50. U.S.G.S. 14553—Sand of upper Eagle Ford age, Whitesboro road, 1.75 miles west of Sherman, Grayson County, Tex. Collected by L. W. Stephenson, T. W. Stanton, and J. B. Reeside, Jr., 1929.
51. U.S.G.S. 19017—Upper part of the Eagle Ford Shale, North-South Road, 1.7 miles W. by S. of Ellsworth, 5.4 miles southwest of Denison, Grayson County, Tex. Collected by R. T. Hazzard, 1941 (?).
52. U.S.G.S. 22608—Eagle Ford Shale, 3 miles southeast of Mountain Creek Power Plant, Dallas County, Tex. Collected by Mrs. Renfro.
53. U.S.N.M. Cat. No. 8024—Eagle Ford Shale, Collin County, Tex.
54. U.S.N.M. Cat. No. 11882—Eagle Ford Shale, near Sherman, Tex.

55. U.S.N.M. Cat. No. 22861—Colorado Group (Codell Sandstone Member), at Carlile Springs, 18 miles west of Pueblo, Colo.
56. U.S.N.M. Cat. No. 12383—Eagle Ford Shale, Denison, Tex.
57. B. F. Perkins collection No. 55-206—Upper Eagle Ford Shale, Turonian, Jefferson Blvd., roadcut, Dallas County, Tex. Collected by B. F. Perkins, 1955. U.S.N.M. accession 241760.
58. Codell Sandstone Member ("Pugnellus Sandstone" of Stanton, 1894), Carlile Shale, Colorado Group, 50 to 100 yards southwest of Lower Pass Creek School, along Colorado State Highway 305, SE1/4 sec. 7, T. 27 S., R. 70 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959, 1961.
59. Codell Sandstone Member ("Pugnellus Sandstone" of Stanton, 1894), Carlile Shale, Colorado Group, in a stream gully 1.3 to 1.5 miles north-northwest of Red Wing, on the Jones' Cattle Company Ranch, SW1/4 SE1/4 sec. 26, T. 26 S., R. 71 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.
60. Codell Sandstone Member ("Pugnellus Sandstone" of Stanton, 1894), Carlile Shale, Colorado Group, in a subsidiary stream valley of Pantleon Creek, north of an unimproved dirt road crossing sec. 28 on the Jones' Cattle Company Ranch, S1/2 NW1/4 sec. 28, T. 26 S., R. 71 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.
61. Codell Sandstone Member ("Pugnellus Sandstone" of Stanton, 1894), Carlile Shale, Colorado Group, in a wooded area 0.4 mile east of Turkey Creek, NE1/4 NW1/4 sec. 22, T. 25 S., R. 69 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.

Lopha bellaplicata novamexicana new subspecies

62. U.S.G.S. 738—Colorado Group (septarian limestone concretion zone, upper Blue Hill Shale Member, Carlile Shale), near Badito, Huerfano County, Colo. Colected by T. W. Stanton, 1890.
63. U.S.G.S. 3295—Colorado Group (Mancos Shale ?), Carthage, N. Mex. Collected by W. T. Lee, 1905.
64. U.S.G.S. 3297—Colorado Group (Mancos Shale ?), $\frac{1}{2}$ mile south of 3295, Carthage, N. Mex. Collected by W. T. Lee, 1905.
65. U.S.G.S. 5303—Colorado Group, Benton (Subgroup: Mancos Shale), 710 feet above the Dakota Sandstone, SW1/4 NE1/4 sec. 9, T. 5 S., R. 2 E., New Mexico, P. M., 0.5 mile N. 30° from Manilla Mine, Carthage, N. Mex. Collected by J. H. Gardner, 1908.
66. U.S.G.S. D2042—Massive sandstone in the Mancos Shale, zone of *Collignoniceras hyatti,* just north of U. S. Highway 380, 7.75 miles east of San Antonio, Socorro County, N. Mex. Collected by W. A. Cobban.
67. Blue Hill Shale Member, Carlile Shale, Colorado Group, in septarian limestone concretions 10 to 15 feet below the top of the member, and in lenticular limestone beds at the Blue Hill-Codell Sandstone contact, lower part of the zone of *Collignoniceras hyatti,* 100 yards southwest of Lower Pass Creek School, just west of Colorado State Highway 305, SE1/4 sec. 7, T. 27 S., R. 70 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959, 1961.

68. Upper Blue Hill Shale Member, Carlile Shale, Colorado Group, in a 2-inch limestone overlying cone-in-cone beds, septarian limestone concretion zone, zone of *Collignoniceras hyatti,* stream gully 1.3 to 1.5 miles north-northwest of Red Wing, on the Jones' Cattle Company Ranch, SW1/4 SE1/4 sec. 26, T. 26 S., R. 71 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.
69. Blue Hill Shale Member, Carlile Shale, Colorado Group, zone of septarian limestone concretions in upper 10 feet of member, 1 mile east of Williams Creek, ½ mile south of unimproved dirt road, W1/2 NE1/4. sec. 12, T. 25 S., R. 70 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959, 1961.
70. Blue Hill Shale Member, Carlile Shale, Colorado Group, zone of septarian limestone concretions in upper 20 feet of member, along the Fort Hays Limestone hogback south of an unimproved dirt road, 0.8 mile southeast of Maes' School, NW1/4 NE1/4 sec. 14, T. 26 S., R. 69 W., Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1958.
71. Blue Hill Shale Member, Carlile Shale, Colorado Group, zone of septarian limestone concretions in upper 25 feet of member, below Codell Sandstone–Juana Lopez limestone hogback 0.5 mile north of Colorado State Highway 69, near center of sec. 31, T. 26 S., R. 68 W., 1.4 miles east of Farisita, Huerfano Park, Huerfano County, Colo. Collected by E. G. Kauffman, 1959.
72. Blue Hill Shale Member, Carlile Shale, Colorado Group, septarian limestone concretion zone in upper 15 feet of member, just below Juana Lopez-Fort Hays Limestone hogback, 2-3 miles north of Thatcher, Colo., 50 to 100 yards east of an improved dirt road leading north from general store and Thatcher School. Collected by E. G. Kauffman, 1961.
73. Blue Hill Shale Member, Carlile Shale, Colorado Group, septarian limestone concretions in upper part of member, 1 mile north of the Arkansas River, on slopes surrounding a dry tributary, SE1/4 NE1/4 sec. 25, T. 20 S., R. 66 W., Pueblo County, Colo. Collected by E. G. Kauffman and F. Collier, 1962.

Lopha bellaplicata bellaplicata var. A.

Collected in the Codell Sandstone Member, Carlile Shale, Colorado Group, at localities 41, 58, 59, 60, and 61, previously cited under *Lopha bellaplicata.*

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EXPLANATION OF PLATES

U.S.N.M. = United States National Museum
U.M.M.P. = University of Michigan Museum of Paleontology
U.S.G.S. = United States Geological Survey

Plate 1

Lopha lugubris (Conrad)

Fig. 1. Lateral view (×I) of a left valve with reverse curvature; a hypotype from a calcarenite bed between typical Austin Chalk and Eagle Ford Shale (locality 16, U.S.G.S. loc. 7579) ; U.S.N.M. 132154.

Fig. 2. Lateral view of a typical left valve (×I) ; Stanton's hypotype from Mancos, Colo. (locality 4, U.S.G.S. 833), the original of his plate 4, figure 3 (1893) ; U.S.N.M. 22859b.

Fig. 3. Lateral view (×2) of a left valve with abnormally small attachment area; a hypotype (locality 38) ; U.S.N.M. 132155.

Fig. 4. Lateral view (×1) of a typical left valve, the lectotype; the original of Conrad's (1857) plate 10, figure 5b, (locality 30, east of Red River, Santa Fe Road, N. Mex.) ; U.S.N.M. 9822.

Fig. 5. Lateral view (×2) of a typical left valve; a hypotype from the upper Eagle Ford Shale of Texas (locality 15, U.S.G.S. 7539) ; U.S.N.M. 132156.

Fig. 6. Lateral view (×2) of a left valve with well-developed reverse curvature of the exogyroid beaks and umbo; a hypotype from Huerfano Park, Colo. (locality 34) in the Juana Lopez Member (Carlile Shale) ; U.M.M.P. 43472.

Fig. 7. Lateral view (×2) of a typical left valve; a hypotype from the zone of *Prionocyclus wyomingensis wyomingensis,* near Casa Salazar, N. Mex. (locality 17, U.S.G.S. 7993) ; U.S.N.M. 132157.

Fig. 8. Lateral view (×2) of an unusually erect left valve; a hypotype from the upper 3 feet of the Eagle Ford Shale, Texas (locality 48, U.S.G.S. 11732) ; U.S.N.M. 132158.

Fig. 9. Lateral view (×2) of a left valve with a large, flat attachment scar and somewhat restricted plicae; a hypotype from the Juana Lopez Member, Huerfano Park, Colo. (locality 34) ; U.M.M.P. 43464.

Fig. 10. Lateral view of a left valve (×2) ; a hypotype from the Juana Lopez Member, Huerfano Park, Colo. (locality 34) ; U.M.M.P. 43472.

Fig. 11. Lateral view (×2) of a distorted left valve with plicae limited to the margins; a hypotype from Mancos, Colo. (locality 4, U.S.G.S. 833) ; U.S.N.M. 22210a.

Fig. 12. Lateral view (×2) of a nearly smooth left valve with only faint marginal plicae; a hypotype from the Juana Lopez Member, Huerfano Park, Colo. (locality 34) ; U.M.M.P. 43465.

Fig. 13. Lateral view (×2) of an erect left valve with a large scar and relatively few, restricted, marginal plicae; a hypotype from the Juana Lopez Member, Huerfano Park, Colo. (locality 36) ; U.M.M.P. 43476.

Fig. 14. Lateral view (×2) of a left valve with radiating ornament restricted to marginal crenulations; a hypotype from the upper Eagle Ford Shale of Texas (locality 15, U.S.G.S. 7539); U.S.N.M. 132159.

Fig. 15. Interior view (×2) of a large left valve showing internal reflection of ornamentation, marks of the attachment area, and the normal position of the muscle scar; a hypotype, the original of Stanton's plate 4, figure 5 (1893) (locality 4, U.S.G.S. 833); U.S.N.M. 22859a.

Fig. 16. Interior view (×2) of a left valve showing nature of cardinal area, denticles, muscle scar, and internal reflection of the ornamentation; a hypotype from Colorado (locality 29); U.S.N.M. 8354.

Fig. 17. Interior view (×2) of a left valve showing fine interior lines on inner surface, denticles, cardinal area, and muscle scar; a hypotype from the zone of *Prionocyclus wyomingensis wyomingensis* (Juana Lopez equivalent), near Casa Salazar, N. Mex. (locality 17; U.S.G.S. 7993); U.S.N.M. 132160.

Fig. 18. Interior view (×2) of a left valve; hypotype illustrated by Meek on plate 1, figure 1a (1876), from Vada del Chama, N. Mex. (locality 31); U.S.N.M. 20255.

Plate 2

Lopha lugubris (Conrad)

Fig. 1. Lateral view (×2) of an unusually elongate right valve showing strong lamellae developed at beginning of plicate stage of valve, and weak plicae; a hypotype from the upper Eagle Ford Shale of Texas (locality 15, U.S.G.S. 7539); U.S.N.M. 132161.

Fig. 2. Lateral view (×2) of a typical plicate right valve, showing abrupt formation of plicae at margin of smooth stage; hypotype illustrated by Stanton (1893, pl. 4, fig. 2), from Huerfano Park, Colo. (locality 3, U.S.G.S. 827); U.S.N.M. 22860a.

Fig. 3. Lateral view of a right valve (×2); a hypotype from Rattlesnake Buttes, Colo. (locality 2, U.S.G.S. 747); U.S.N.M. 22008a.

Fig. 4. Lateral view (×2) of an unusually elongate, curved, plicate right valve; a hypotype from the zone of *Prionocyclus wyomingensis wyomingensis* (Juana Lopez equivalent) near Casa Salazar, N. Mex. (locality 17, U.S.G.S. 7993); U.S.N.M. 132162.

Fig. 5. Lateral view (×2) of a coarsely plicate right valve showing sharp demarcation between smooth stage and plicate portion of valve; a hypotype from near Mancos, Colo., in the Juana Lopez equivalent (locality 10, U.S.G.S. 2019); U.S.N.M. 132163.

Fig. 6. Lateral view (×2) of a plicate right valve characteristic of the species, showing abrupt origin of plicae, and reflection of attachment surface on smooth stage of valve; a hypotype from the upper Eagle Ford Shale of Texas (locality 15, U.S.G.S. 7539); U.S.N.M. 132164.

Fig. 7. Lateral view (×2) of a right valve showing reflection of attachment surface on smooth stage, and restriction of plicae to marginal area. This form is intermediate between plicate and nonplicate types. A hypotype from near Mancos, Colo. (locality 4, U.S.G.S. 833); U.S.N.M. 22210b.

Fig. 8. Lateral view (×2) of a right valve with radiating ornament limited to crenulations in marginal lamellae; a hypotype from Huerfano Park, Colo. (locality 34); U.M.M.P. 43470.

Fig. 9. Lateral view (×2) of an elongate, nonplicate right valve; a hypotype from Huerfano Park, Colo. (locality 32); U.M.M.P. 43487.

Fig. 10. Lateral view (×2) of a smooth right valve showing reflection of attachment surface (probably an *Inoceramus* shell) on exterior of upper valve; a hypotype from near Mancos, Colo. (locality 4, U.S.G.S. 833); U.S.N.M. 22211.

Fig. 11. Lateral view (×2) of a smooth right valve showing nature of growth lines and fine lamellae; a hypotype from Huerfano Park, Colo. (locality 58) in the Juana Lopez Member; U.M.M.P. 43484.

Fig. 12. Lateral view (×2) of a small right valve with well-developed marginal lamellae, and faint crenulations on the anterior and ventral borders; a hypotype from Huerfano Park, Colo. (locality 33) in the Juana Lopez Member; U.M.M.P. 43471.

Fig. 13. Interior view (×2) of a thick right valve showing unusually deep but typically shaped posterior adductor muscle scar, traces of fine radiating incised lines on inner surface of valve; a hypotype from Rattlesnake Buttes, Colo. (locality 2, U.S.G.S. 747) in the Juana Lopez Member; U.S.N.M. 22008b.

Fig. 14. Interior view (×2) of a small right valve with unusually large cardinal area, typical muscle scar, and well-developed denticles (represented by notches); a hypotype from Rattlesnake Buttes, Colo. (locality 2, U.S.G.S. 747), in the Juana Lopez Member; U.S.N.M. 22008b.

Fig. 15. Lateral view (×2) of a typical right valve, nonplicate, and with reverse curvature; a hypotype from Huerfano Park, Colo. (locality 34), in the Juana Lopez Member; U.M.M.P. 43486.

Fig. 16. Interior view (×2) of a typical right valve showing nature of cardinal area, well-developed denticles, a typical muscle scar, and fine, sinuous, incised lines on the inner valve surface; a hypotype from the Mancos Shale, San Miguel County, Colo. (locality 28, U.S.G.S. 22592); U.S.N.M. 132258.

Fig. 17. Interior view (×2) of a right valve with unusually large resilifer and muscle scar, well-developed denticles; a hypotype from near Whitewater, Colo., from the Juana Lopez Member equivalent in the Mancos Shale (locality 22, U.S.G.S. 13663); U.S.N.M. 132165.

PLATE 3

(All figures ×1)

Lopha bellaplicata bellaplicata (Shumard)

Figs. 1, 3, 9, 11, 15, 18. Lateral views of typical left valves of the species, placed in a growth series; note characteristic outline, nature and extent of auricles and auricular sulci, small attachment scars, nature of plicae and height of smooth stage; all specimens hypotypes from the upper Eagle Ford Shale, 2.5 miles east of Eagle Ford, Dallas County, Tex. (locality 15, U.S.G.S. 7539). Catalog Nos.: 1 (U.S.N.M. 132213), 3 (U.S.N.M. 132215), 9 (U.S.N.M. 132220), 11 (U.S.N.M. 132222, the neotype), 15 (U.S.N.M. 132225), and 18 (U.S.N.M. 132228).

Fig. 2. Lateral view of a left valve, abnormally short owing to reduced posterior auricle; a hypotype from the upper Eagle Ford Shale, 2.5 miles east of Eagle Ford, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132214.

Fig. 4. Lateral view of a left valve with reduced posterior auricle, unusually large attachment scar and prominent umbo; a hypotype from the upper Eagle Ford Shale of Texas (locality 15, U.S.G.S. 7539, cited above); U.S.N.M. 132216.

Fig. 5. Lateral view of a worn left valve with unusually large smooth stage; a hypotype from the Eagle Ford Shale at Sherman, Tex. (locality 54), the original of Stanton's plate 4, figure 8 (1893); U.S.N.M. 11882a.

Fig. 6. Lateral view of a left valve with unusually large attachment scar; posterior auricle broken; a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539, cited above); U.S.N.M. 132217.

Fig. 7. Lateral view of an abnormal left valve; note unusual height, reduction of auricles, broad plicae, a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 57); U.S.N.M. 132218.

Fig. 8. Lateral view of an unusual left valve with broad plicae, fluted at their intersection with coarse concentric lamellae, and abnormally large smooth umbonal area. This form is possibly transitional to *Lopha panda* (Morton). A hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539, cited above); U.S.N.M. 132219.

Fig. 10. Lateral view of a typical left valve with abnormally projecting beak and early umbo; a hypotype from the upper Eagle Ford sands, 1.75 miles west of Sherman, Tex. (locality 50, U.S.G.S. 14553); U.S.N.M. 132221.

Fig. 12. Lateral view of a left valve, unusual in having a nearly centrally situated beak and broad plicae; a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539, cited above); U.S.N.M. 132223.

Fig. 13. Lateral view of White's hypotype (1879, pl. 4, figs. 3a, b) from the Eagle Ford Shale at Denison, Tex. (locality 56); U.S.N.M. 12383.

Fig. 14. Lateral view of a typical adult left valve; a hypotype from upper Eagle Ford sands, 1.75 miles west of Sherman, Tex. (locality 50, U.S.G.S. 14553); U.S.N.M. 132224.

Fig. 16. Lateral view of an unusually elongate, high left valve, more inclined than normal, and with a large attachment scar; a hypotype from Dallas County, Tex. (locality 57); U.S.N.M. 132226.

Fig. 17. Lateral view of a typical left valve with an unusually large attachment scar, a hypotype from the upper Eagle Ford Shale, 2.5 miles east of Eagle Ford, Dallas County, Tex. (locality 15, U.S.G.S. 7539, cited above); U.S.N.M. 132227.

PLATE 4

(All figures ×1)

Lopha bellaplicata bellaplicata (Shumard)

Fig. 1. Lateral view of a left valve from White's syntype lot of *Lopha blacki.* Note that other than the projecting beak and umbo, deformed by the

attachment scar, and the rounded nature of the plicae (worn), the nature of the valve is identical with those of *L. bellaplicata bellaplicata* illustrated on plates 3 and 4; hypotype (of *L. bellaplicata bellaplicata*) from the upper Eagle Ford Shale, Collin County, Tex. (locality 53); U.S.N.M. 8024a.

Fig. 2. Lateral view of a large left valve with unusually well developed posterior auricle and faint, worn plicae; hypotype from upper Eagle Ford sands, 1.75 miles west of Sherman, Tex. (locality 50, U.S.G.S. 14553); U.S.N.M. 132229.

Fig. 3. Lateral view of a typical left valve. Note change in prominence of plicae at midshell, giving rise to faint plicae similar to those on *L. blacki* (White). A hypotype from the upper Eagle Ford Shale, 2.5 miles east of Eagle Ford, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132230.

Fig. 4. Lateral view of an unusually flat left valve with abnormal prosocline inclination, a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 57); U.S.N.M. 132231.

Fig. 5. Lateral view of an adult left valve showing extensive bifurcation of plicae, and unusually reduced posterior auricle; a hypotype from the upper Eagle Ford Shale, 2.5 miles east of Eagle Ford, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132232.

Fig. 6. Lateral view of the smoothest specimen from White's syntype lot of *L. blacki*, considered here a smooth variant of *L. bellaplicata bellaplicata* (Shumard). The original of White's plate 46, figure 2 (1884). Hypotype from the upper Eagle Ford Shale, Collin County, Tex. (locality 53); U.S.N.M. 8024b.

Fig. 7. Lateral view of a large left valve showing large attachment scar but otherwise typical of the species; hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539, cited above); U.S.N.M. 132233.

Fig. 8. Interior view of a left valve showing nature and position of muscle scar, flattened lateral lamellae forming part of commissure, and unusually massive cardinal area with characteristic structures; a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 57); U.S.N.M. 132234.

PLATE 5

(All figures ×1)

Lopha bellaplicata bellaplicata (Shumard)

Figs. 1-4. Anterior (side) views of representative left valves, illustrating the range of variation in convexity. No. 1 is typical of the species. 1-3, Neotype and hypotypes from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132222 (fig. 1); U.S.N.M. 132228 (fig. 2); U.S.N.M. 132235 (fig. 3). 4, Hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 57); U.S.N.M. 132231.

Figs. 5-8. Lateral views of typical right valves, arranged in growth series. Note development of auricles (fig. 7 is atypical in this respect, having rounded auricles), anterior position of beaks, posterior curvature of beaks, nearly straight dorsal margin, height of smooth stage (greater than on average left valves), the abrupt appearance, prominence, and bifurcation of the plicae, and the well-developed concentric lamellae. Hypotypes from the upper Eagle Ford Shale, 1.5 miles east of Eagle Ford, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132236 (fig. 5); U.S.N.M. 132237 (fig. 6); U.S.N.M. 132238 (fig. 7); U.S.N.M. 132239 (fig. 8).

Fig. 9. Lateral view of a right valve from the syntype lot of *"Ostrea" blacki* White. Note the only difference between this specimen and typical right valves of *L. bellaplicata bellaplicata* is the height of the smooth stage. A hypotype of *L. bellaplicata bellaplicata* from the upper Eagle Ford Shale in Collin County, Tex. (locality 53); U.S.N.M. 8024c.

Figs. 10, 13. Lateral and interior views of an abnormal right valve lacking auricles and prominent plicae. Note nature of cardinal area and muscle scar, both characteristic for the species. A hypotype from the upper Eagle Ford Shale of Texas (locality 57, previously cited); U.S.N.M. 132240.

Fig. 11. Lateral view of a nearly smooth right valve of a mature shell, a marginal variant occurring with specimens illustrated in figures 5-8. Compare with figure 12, a syntype of *L. blacki* (White). Hypotype from the upper Eagle Ford Shale of Texas (locality 15, U.S.G.S. 7539, previously cited); U.S.N.M. 132241.

Figs. 12, 15. Lateral and interior views of a smooth right valve with faint plicae and well-developed interior features. Hypotype of *Lopha bellaplicata bellaplicata* from the upper Eagle Ford Shale of Collin County, Tex. (locality 53); U.S.N.M. 11882b.

Fig. 14. Lateral view of an unusually elongate right valve with characteristic ornamentation, somewhat worn; hypotype from the upper Eagle Ford Shale of Dallas County, Tex. (locality 15, U.S.G.S. 7539, previously cited); U.S.N.M. 132242.

PLATE 6

Lopha bellaplicata bellaplicata (Shumard), variety A

Fig. 1. Lateral view (×1) of a typical left valve, showing shape, plicae, narrow beak and umbo, and small attachment scar. A hypotype from the Codell Sandstone Member, Carlile Shale, Huerfano Park, Colo. (locality 41, U.S.G.S. 743); U.S.N.M. 22011a.

Fig. 2. Lateral view (×2) of a left valve with an unusually large attachment scar; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 59; U.M.M.P. 38052.

Fig. 3. Lateral view (×1) of a small plicate upper valve associated with *L. bellaplicata bellaplicata* var. A; a hypotype from the Codell Sandstone Member of Huerfano Park, Colo. (locality 58); U.S.N.M. 132259.

Fig. 4. Lateral view (×1) of a smooth, elongate right valve associated with specimens of *L. bellaplicata bellaplicata* var. A; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 61); U.M.M.P. 43413.

Fig. 5. Lateral view (×2) of a left valve with unusually broad plicae; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 59); U.M.M.P. 38051.

Fig. 6. Lateral view of a left valve (×1) with a prominent attachment scar; hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 41, U.S.G.S. 743); U.S.N.M. 22011d.

Fig. 19. Lateral view (×1) of a small left valve showing ventral flaring of the lateral margins; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 61); U.S.N.M. 132249.

Lopha bellaplicata bellaplicata (Shumard): forma typica

Fig. 7. Lateral view (×1) of a small left valve typical of the species, a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 40, U.S.G.S. 741); U.S.N.M. 22009a.

Fig. 8. Lateral view (×1) of a left valve with moderately large attachment scar: a hypotype figured by Stanton (1893, pl. 4, fig. 4) from the Codell Sandstone Member, Huerfano Park, Colo. (locality 41, U.S.G.S. 743); U.S.N.M. 22860d.

Fig. 9. Lateral view (×1) of a left valve, characteristic of the species; hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 61); U.M.M.P. 38038.

Fig. 10. Lateral view of an unusual left valve (×1) with abnormally elongate posterior auricle, broad, faint plicae; a hypotype from the Codell Sandstone Member, Carlile Shale, Huerfano Park, Colo. (locality 61); U.M.M.P. 43482.

Fig. 11. Lateral view (×1) of a mature left valve, slightly longer than average, similar to Texas specimen illustrated on plate 3, figure 12; hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 40, U.S.G.S. 741); U.S.N.M. 22009b.

Fig. 12. Lateral view (×1) of a typical left valve, a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 59); U.M.M.P. 38039.

Fig. 13. Lateral view (×1) of a nearly symmetrical left valve with a large attachment scar and unusually inflated umbone, a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 41, U.S.G.S. 743); U.S.N.M. 22011b.

Fig. 14. Lateral view (×1) of a mature left valve with unusually deep attachment scar, abnormally situated dorsoposteriorly; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 59); U.M.M.P. 38041.

Fig. 15. Lateral view (×1) of a large left valve with extended auricles, abnormally broad plicae, and subcentral beak; a Colorado variant of the species not yet found elsewhere; a hypotype from the Codell Sandstone Member, Carlile Springs, Colo. (locality 55); the original of Stanton's plate 4, figure 7 (1893); U.S.N.M. 22861.

Fig. 16. Interior view of a left valve (×1) showing normal cardinal area, denticles, internal reflection of ornamentation, and posterior adductor muscle scar, the hypotype figured by Stanton (1893, pl. 4, fig. 9), from the

Codell Sandstone Member, Huerfano Park, Colo (locality 41, U.S.G.S. 743); U.S.N.M. 22860b.

Fig. 17. Lateral view of a typical right valve from Colorado (×2) showing limited extent of plicae, concentric ornamentation, shape; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 61); U.M.M.P. 43466.

Fig. 18. Lateral view (×2) of a totally nonplicate right valve, otherwise typical of the species; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 59); U.M.M.P. 43483.

Fig. 20. Lateral view (×1) of a large, unusually high right valve, showing typical development of the concentric lamellae; a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132250.

Fig. 21. Lateral view (×1) of a nearly smooth right valve showing a few, sinuous, irregular plicae near margin; a hypotype from the Codell Sandstone Member, Huerfano Park, Colo. (locality 59); U.M.M.P. 43478.

Figs. 22, 23. Dorsal and posterior views (×1) of a small left valve with plicae less extensive than average, and an unusually large attachment scar; the hypotype illustrated by Stanton (1893, pl. 4, fig. 6), from the Codell Sandstone Member, Huerfano Park, Colo. (locality 41, U.S.G.S. 743); U.S.N.M. 22860c.

Fig. 24. Lateral view of a large, old right valve showing degeneration of radial ornamentation near margin, and increase in number and prominence of the concentric lamellae with age; a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132251.

PLATE 7

(All figures ×1)

Lopha bellaplicata novamexicana Kauffman, new subspecies

Figs. 1, 2. Lateral views of immature left valves, typical of the subspecies. Note general similarity to immature left valves of *L. bellaplicata bellaplicata* (pl. 3) but the smaller auricles and more inclined posterodorsal margin in the subspecies *novamexicana* at this and later growth stages. Paratypes from the zone of *Collignoniceras hyatti* (Stanton), Mancos Shale, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132260 (fig. 1), and 132261 (fig. 2).

Fig. 3. Lateral view of a young adult left valve, typical of the subspecies except for narrow auricular sulci. Note broad plicae. A paratype from the Colorado Group (Mancos?), Carthage, N. Mex. (locality 64, U.S.G.S. 3297); U.S.N.M. 132262.

Figs. 4, 5. Lateral and interior views of a typical adult valve showing broad, widely spaced plicae, few in number, inclined posterodorsal margin, broad posterior auricular sulcus, and the nature of the cardinal area and muscle scar. A paratype from the Mancos Shale, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132263.

Fig. 6. Lateral view of a small, incomplete, right valve showing broad plicae and short smooth stage. A paratype from the Mancos Shale, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132264.

Fig. 7. Lateral view of a small, unusually curved right valve with recurved beak and umbo, short smooth stage limited to umbo, and typical plicae. A paratype from the Colorado Group (Mancos Shale?), Carthage, N. Mex. (locality 64, U.S.G.S. 3297); U.S.N.M. 132262.

Fig. 8. Lateral view of an adult right valve similar in shape to those of *L. bellaplicata bellaplicata,* but with a much shorter smooth umbonal area. Note coarse lamellae, characteristic plicae. A paratype from the Colorado Group (Mancos) at Carthage, N. Mex. (locality 63, U.S.G.S. 3295); U.S.N.M. 132265.

Fig. 9. Lateral view of a right valve with reverse inclination (opisthocline) and enlarged anterior auricle. Note broad plicae, short smooth stage limited to umbo. A paratype from the Mancos Shale, zone of *Collignoniceras hyatti,* Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132266.

Fig. 10. Lateral view of a left valve, characteristic of the subspecies. Note broad plicae, few in number, broad posterior auricular sulcus, inclination of posterodorsal margin. The holotype, from a massive sandstone in the Mancos Shale, zone of *Collignoniceras hyatti,* Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132267.

Fig. 11. Lateral view of a left valve with narrow plicae, otherwise typical of the subspecies; a paratype from the septarian limestone concretion zone, upper Blue Hill Shale Member, Huerfano Park, Colo. (locality 62, U.S.G.S. 738); U.S.N.M. 22012.

Fig. 12. Lateral view of a left valve with narrow ribs, or plicae, occurring along with normal individuals of the subspecies in the Mancos Shale near Carthage, N. Mex. (locality 63, U.S.G.S. 3295). Compare this with figure 11, from the Blue Hill Shale Member, Huerfano Park, Colo. A paratype, U.S.N.M. 132268.

Fig. 13. Lateral view of an unusually broad variant of the subspecies from the Blue Hill Shale Member, Huerfano Park, Colo. (locality 69), closely comparable to marginal variants of *L. bellaplicata bellaplicata* from the Codell Sandstone in the same area (see pl. 6, fig. 15). A paratype; U.S.N.M. 132269.

Fig. 14. Lateral view of a high left valve with reduced posterior auricle; paratype from the Mancos Shale at Carthage, N. Mex. (locality 65, U.S.G.S. 5303); U.S.N.M. 132270.

Fig. 15. Lateral view of an exfoliated left valve, showing characteristic outline and radial ornamentation; a paratype from the Mancos Shale at Carthage, N. Mex. (locality 64, U.S.G.S. 3297); U.S.N.M. 132271.

Fig. 16. Lateral view of a robust left valve, characteristic of the subspecies; a paratype from the Mancos Shale, zone of *Collignoniceras hyatti,* Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132272.

Fig. 17. Lateral view of a left valve with posterior auricle larger than normal and density of plicae approaching that of *L. bellaplicata bellaplicata;* a paratype from the Mancos Shale, Carthage, N. Mex. (locality 65, U.S.G.S. 5303); U.S.N.M. 132273.

Fig. 18. Lateral view of a large left valve, characteristic of the subspecies; a paratype from the Mancos Shale at Carthage, N. Mex. (locality 64, U.S.G.S. 3297); U.S.N.M. 132274.

Fig. 19. Lateral view of an unusually high left valve, otherwise characteristic of the subspecies; a paratype from the Mancos Shale at Carthage, N. Mex. (locality 65, U.S.G.S. 5303); U.S.N.M. 132275.

PLATE 8

Lopha bellaplicata novamexicana Kauffman, new subspecies

Fig. 1-3. Anterior views of left valves illustrating the range in convexity, the great convexity of the umbonal region, and the dorsal position of the high point of the valve. All specimens from the Mancos Shale of New Mexico, zone of *Collignoniceras hyatti*. 1, U.S.N.M. 132282, from locality 66. 2, U.S.N.M. 132271, from locality 64. 3, U.S.N.M. 132276, from locality 66. All figures ×1.

Fig. 4. Lateral view (×1) of a left valve, characteristic of the subspecies except for fainter plicae; paratype from locality 66, U.S.G.S. D2042, Mancos Shale, zone of *Collignoniceras hyatti*, Socorro County, N. Mex. U.S.N.M. 132277.

Fig. 5. Lateral view (×1) of a left valve with large vertical attachment scar and unusually fine plicae; paratype from the Mancos Shale, zone of *Collignoniceras hyatti*, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132278.

Fig. 6. Lateral view (×1) of a large left valve transitional with *L. bellaplicata bellaplicata* in development of plicae and auricular sulci, but retaining characteristic shell form of the subspecies; a paratype from the Mancos Shale, zone of *C. hyatti*, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132279.

Fig. 7. Lateral view of a large left valve (×1) characteristic of the subspecies; a paratype from the zone of *C. hyatti*, Mancos Shale, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132280.

Fig. 8. Lateral view (×1) of a typical left valve with worn plicae; a paratype from the zone of *C. hyatti*, Mancos Shale, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132281.

Fig. 9. Lateral view (×1) of a typical large, adult left valve; a paratype from the zone of *C. hyatti*, Mancos Shale, Socorro County, N. Mex. (locality 66, U.S.G.S. D2042); U.S.N.M. 132282.

Lopha bellaplicata bellaplicata (Shumard)

Fig. 10. Thin section (×4) through the umbo and cardinal area of a large left valve; section parallel to the hinge line. Note major layers in subnacreous layer, and fine crystalline calcite sheets within them. Fine layers inclined to plane of major layers over umbo, parallel to this plane laterally; a hypotype from the upper Eagle Ford Shale, Dallas County, Tex. (locality 15, U.S.G.S. 7539); U.S.N.M. 132283.

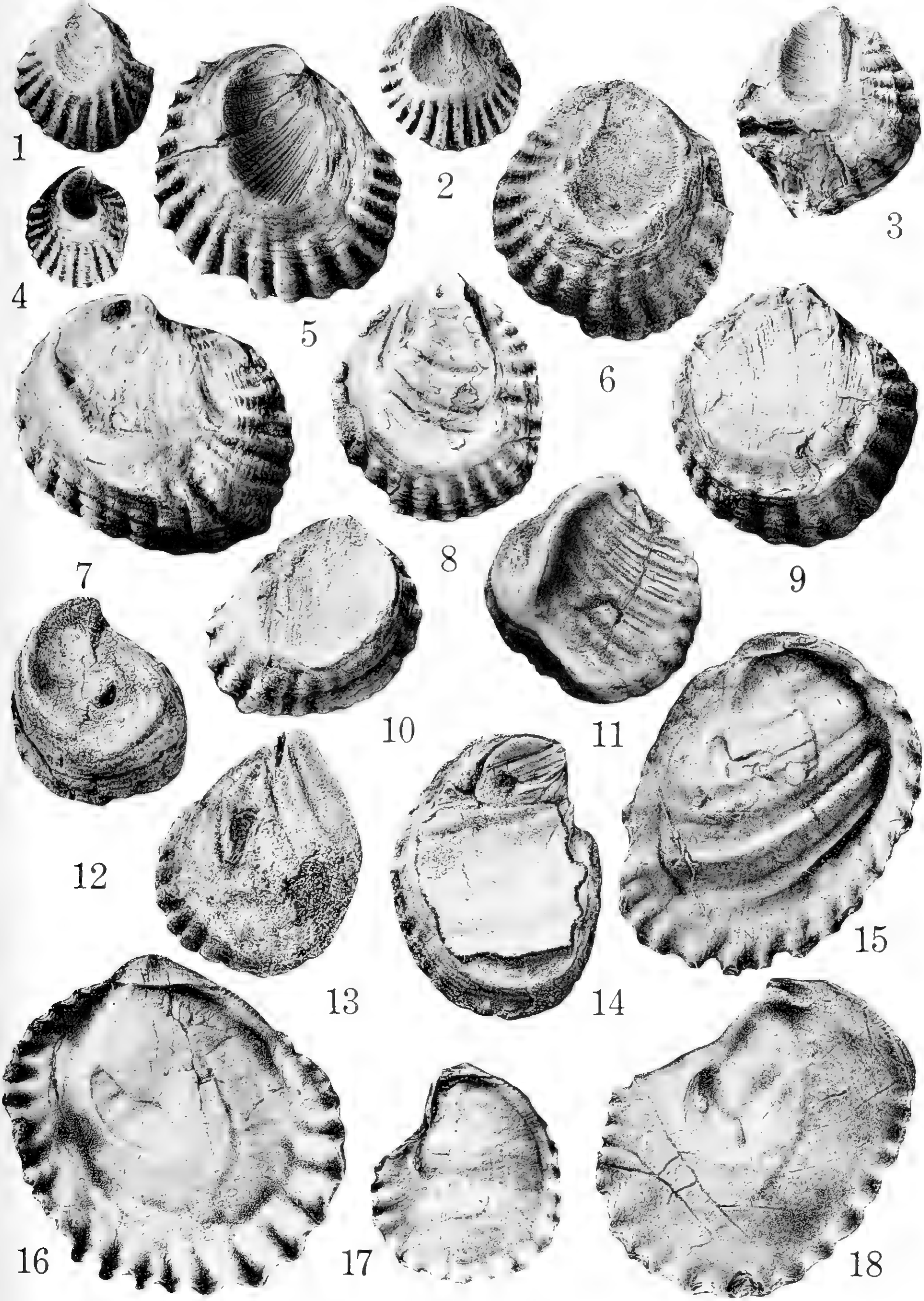
Fig. 11. Thin section (×4) taken along the median plica, showing the structure of the subnacreous shell layer, the "hingement" of the valves, position

of the ligament, and the position of the cardinal axis on the cardinal plate. Note that subnacreous layer is composed of distinct major calcite layers (lamellae) parallel to the surface of the shell; each layer is composed of fine fibrous-appearing calcite crystals or plates inclined to the plane of the major layers, and in many cases, with opposed inclination within or between major layers. A hypotype from sands of upper Eagle Ford age, Grayson County, Tex. (locality 50, U.S.G.S. 14553); U.S.N.M. 132284.

Lopha lugubris (Conrad)

Fig. 12. Thin section (×8) through part of the left valve, showing major calcite lamellae in subnacreous layer and minor inclined fibrous calcite crystals or plates within them, as described for figure 11. A hypotype from New Mexico (locality 1, U.S.G.S. 513) in the zone of *Prionocyclus wyomingensis.* U.S.N.M. 132285.

PLATES



Lopha lugubris (Conrad): Left Valve

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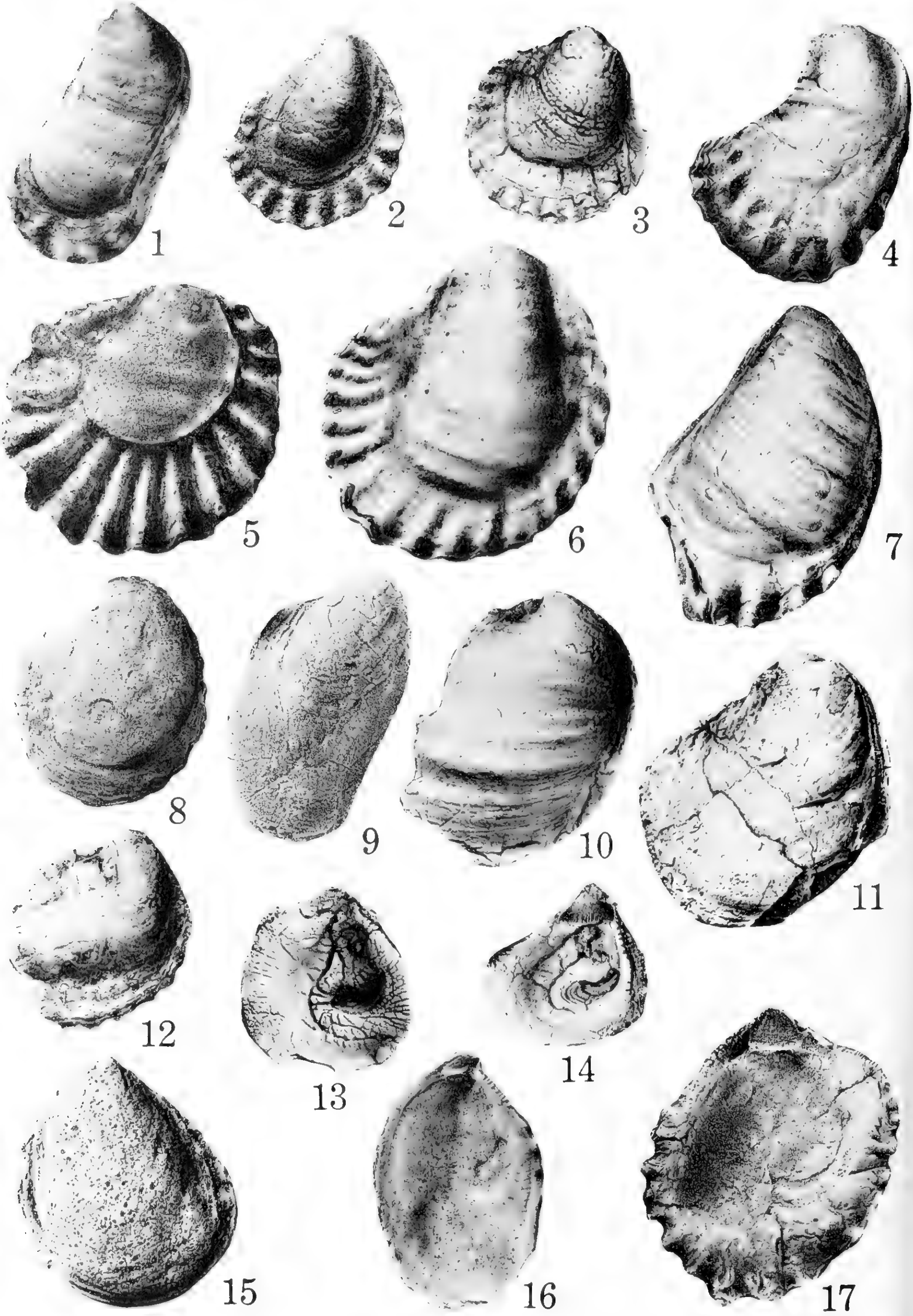

Lopha lugubris (Conrad): Right Valve

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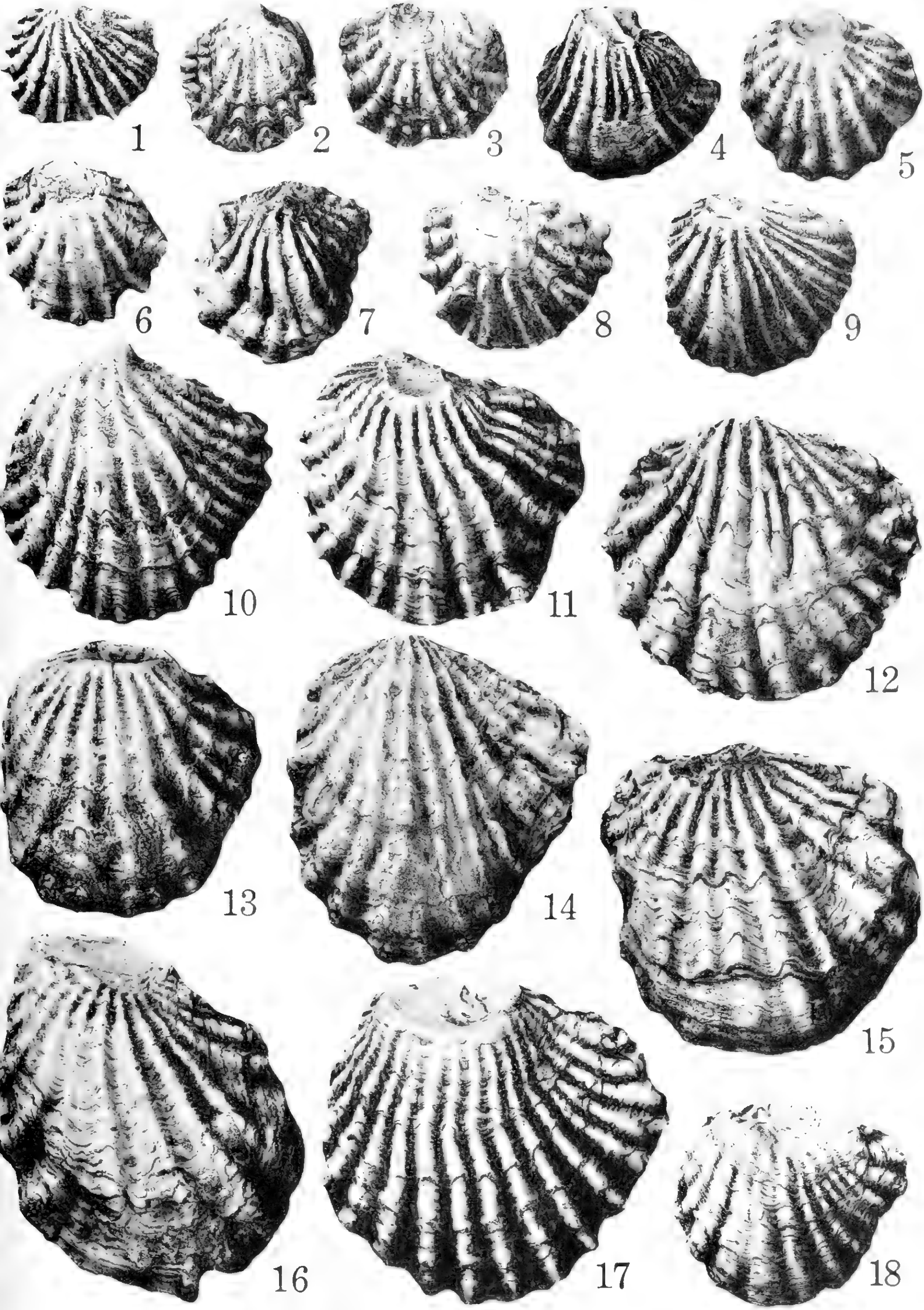

Lopha bellaplicata bellaplicata (Shumard): Left Valve, Texas

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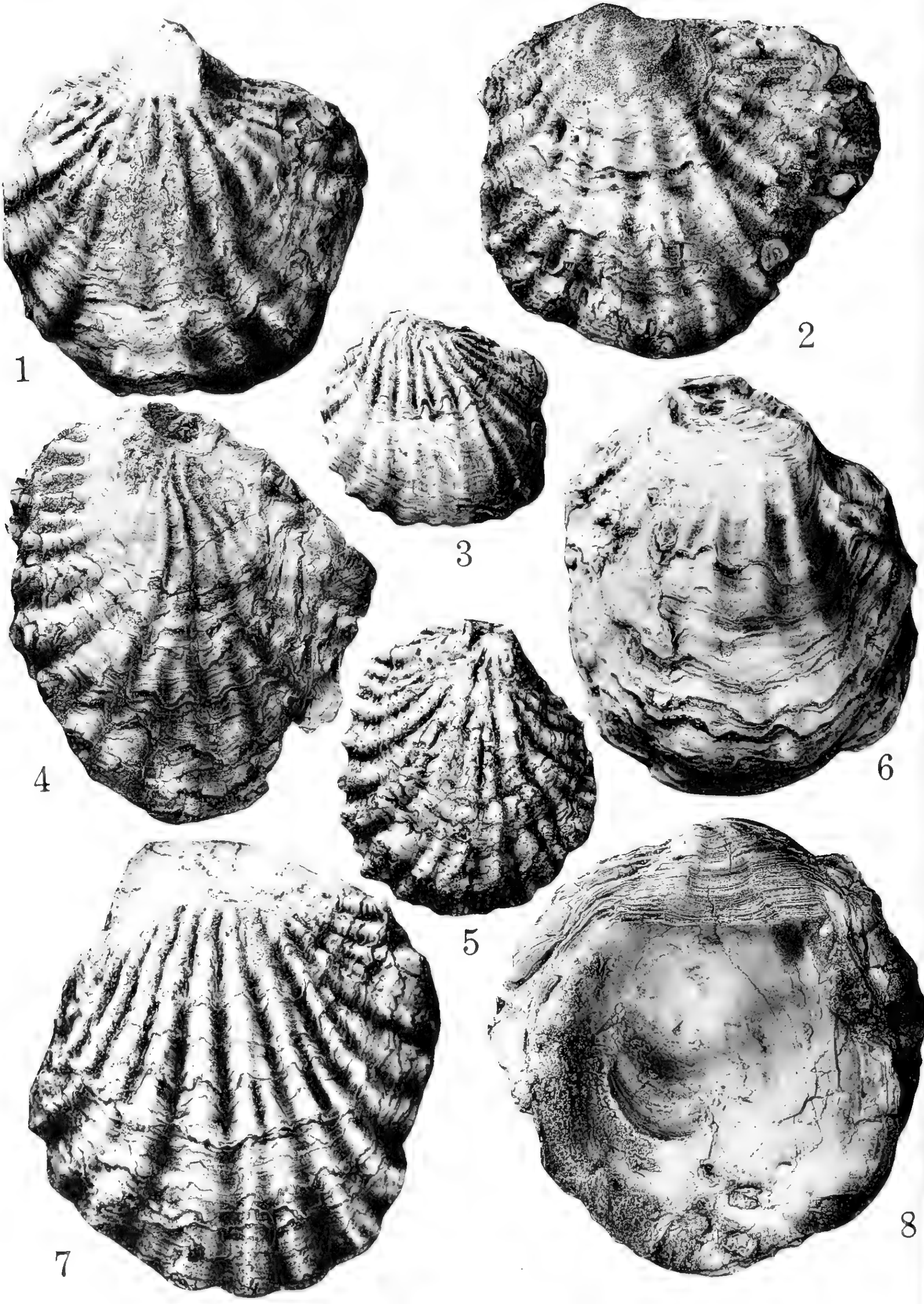

LOPHA BELLAPLICATA BELLAPLICATA (SHUMARD): LEFT VALVE, TEXAS

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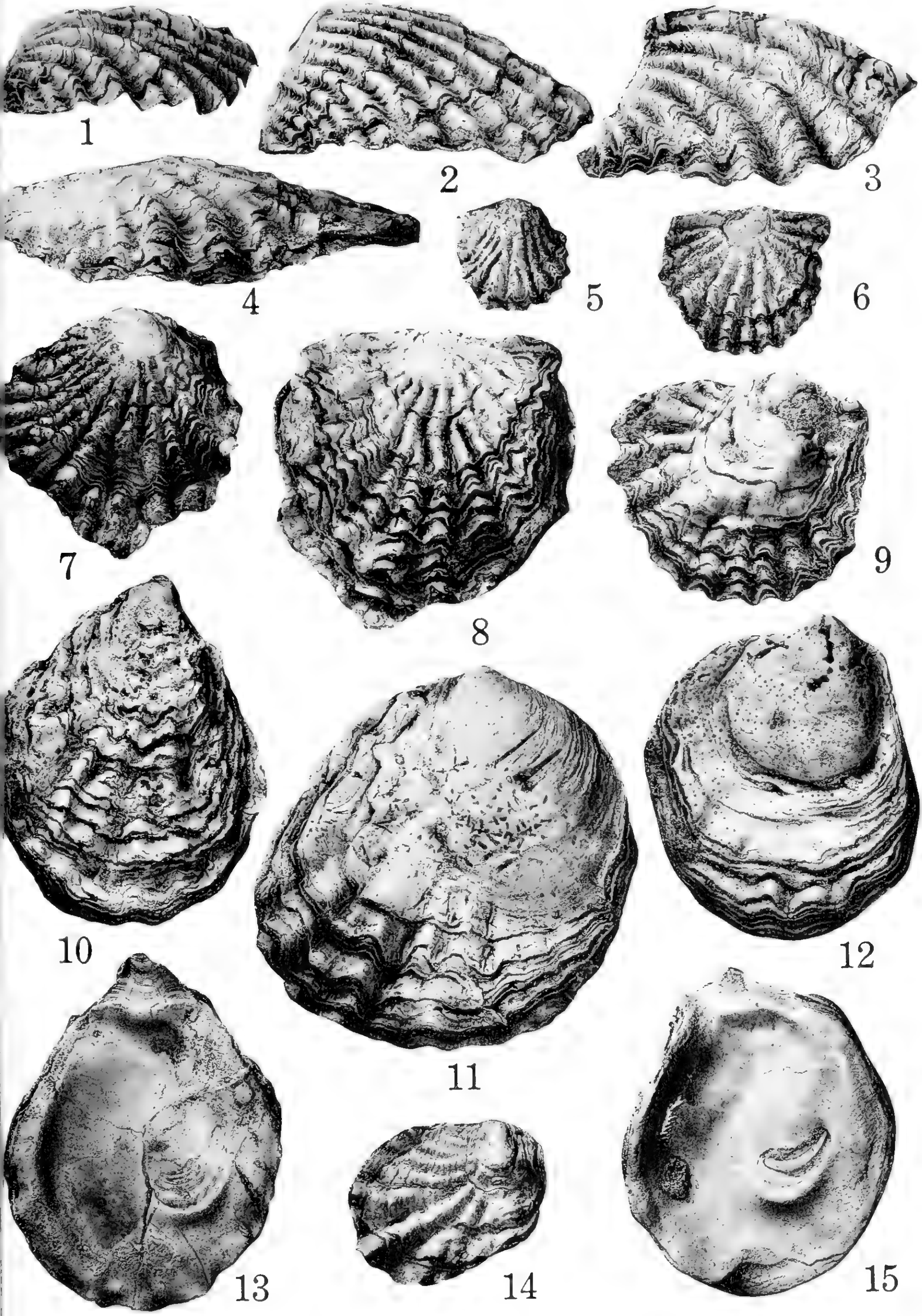

LOPHA BELLAPLICATA BELLAPLICATA (SHUMARD): LEFT AND RIGHT VALVES, TEXAS

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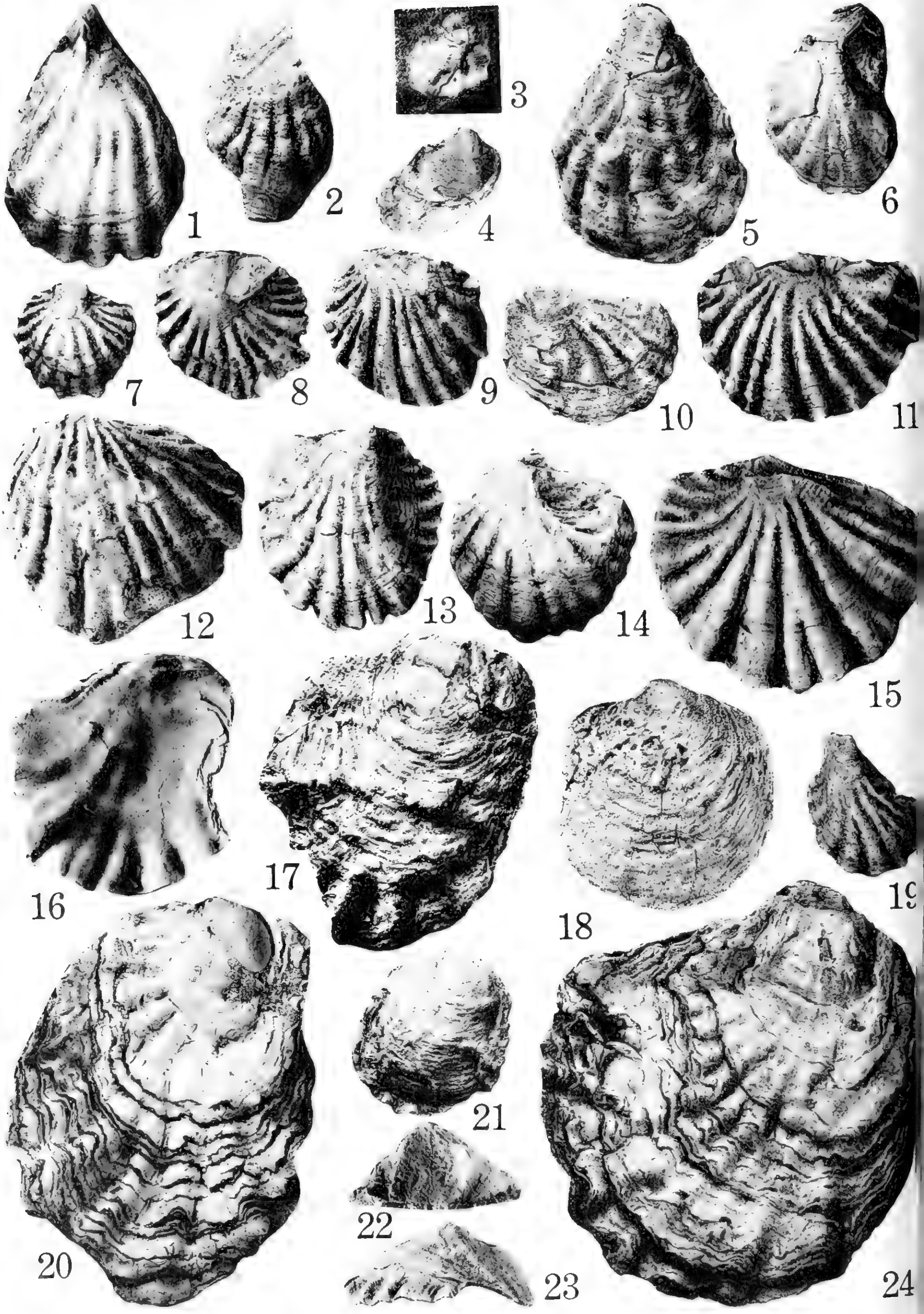

LOPHA BELLAPLICATA BELLAPLICATA (SHUMARD): VAR. A AND FORMA TYPICA: LEFT AND RIGHT VALVES. TEXAS AND COLORADO

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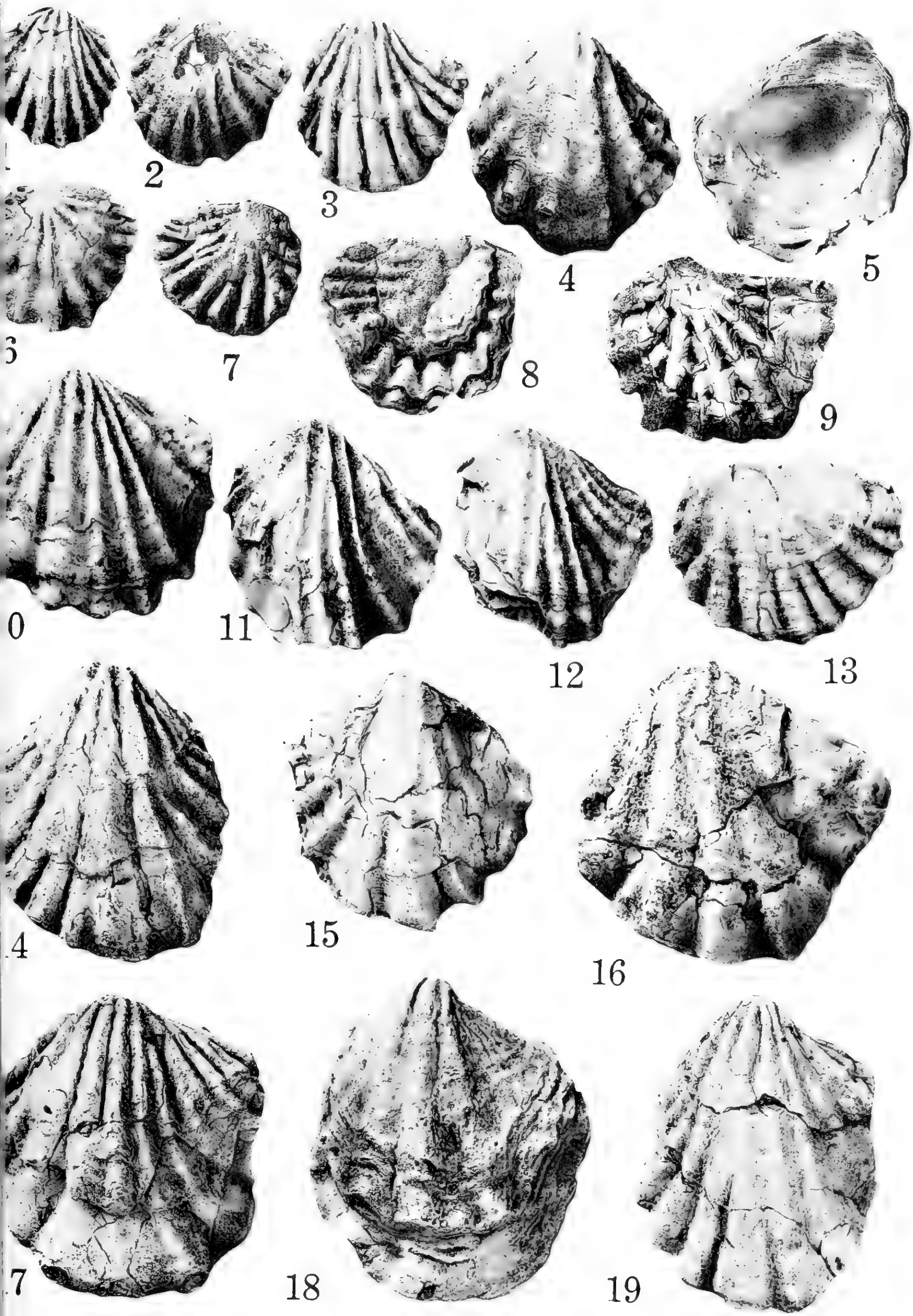

Lopha Bellaplicata Novamexicana Kauffman, N. Subsp.:
Left and Right Valves. Colorado and New Mexico

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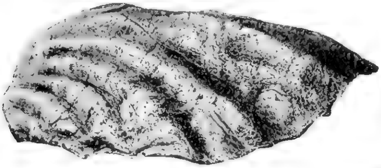
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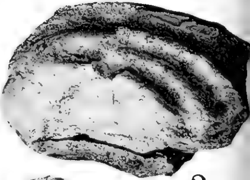
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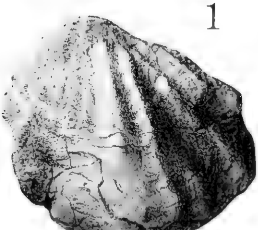
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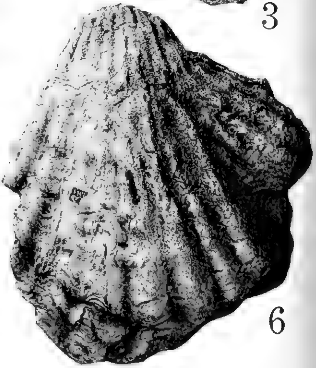
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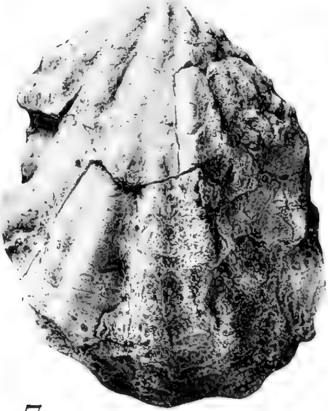
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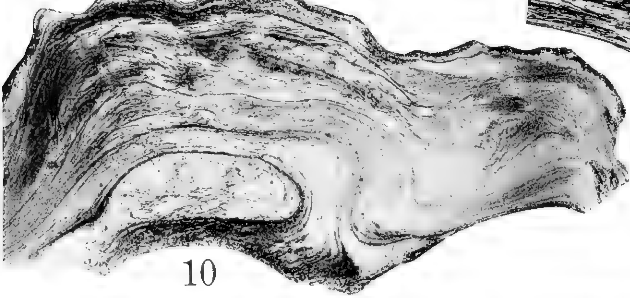
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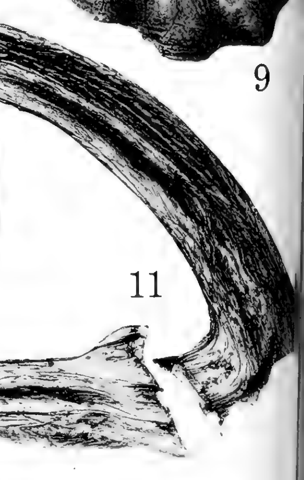
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LOPHA BELLAPLICATA NOVAMEXICANA KAUFFMAN, N. SUBSP.:
L. BELLAPLICATA BELLAPLICATA (SHUMARD): L. LUGUBRIS (CONRAD)

(SEE EXPLANATION OF PLATES AT END OF TEXT.)

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 148, NUMBER 7

Roebling Fund

AN ACCOUNT OF THE ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION, 1904-1953

By
C. G. ABBOT
Research Associate, Smithsonian Institution

(Publication 4656)

CITY OF WASHINGTON
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AN ACCOUNT OF THE ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION, 1904-1953

By Charles G. Abbot, D.Sc.
Research Associate, Smithsonian Institution

The Smithsonian's Astrophysical Observatory was founded by Secretary Samuel P. Langley in 1890. Until 1900 the Observatory's original research activities included developing and improving apparatus, and mapping the then little-known infrared spectrum of the sun. The bolometer, which Langley had invented about 1878, was given photographic registration, tamed to be as quiet and reliable as a mercury thermometer, and used to record small depressions where absorption lines occurred in the solar spectrum. The Observatory's highly exact determinations of the dispersion of rock-salt and fluorite prisms fixed the wavelengths of these absorption lines. Volume 1 of the *Annals,* describing all of this work, was published in 1900. Expeditions to North Carolina and to Sumatra observed the total solar eclipses of 1900 and 1901, and a small eclipse volume was published in 1903.

The Observatory then took up measurement of the intensity of the sun's radiation, the variability of it, and the transmission of radiation by the earth's atmosphere in the visible and infrared spectrum. The average intensity of solar radiation received by the earth, called the "solar constant," was then unknown between the limits 1.76 and 4.0 calories per square centimeter per minute. Solar constant research and the dependence of weather on solar variation principally occupied the Observatory from 1904 through 1953.

ADMINISTRATION OF THE OBSERVATORY, 1904-1953

FINANCIAL SUPPORT

A breakdown of the Observatory's financial support from 1904 through 1953 shows that the average yearly support for this period was $37,000.

Congressional appropriations	$1,148,000
Gifts by John A. Roebling	617,000
Grants by National Geographic Society	65,000
From Smithsonian funds	10,000
Other gifts	10,000
Total	$1,850,000

The finances were managed by the Smithsonian Disbursing Office.

STAFF

The number of persons employed for all purposes varied from 2 to 14.

BUILDINGS

With headquarters in Washington, instruments were designed and constructed there, and early observations were made there. However, most of the observing later was done on several high mountains in distant arid lands. In all, 16 structures were built in these far-off lonely places to house observers and instruments. A valuable suggestion by E. B. Moore led us to construct underground laboratories in sloping ground for the spectrobolometric apparatus. Thus we obtained constant temperature. We fed the sun-rays into these tunnels horizontally with coelostats.

ACTIVITIES OF THE OBSERVATORY, 1904-1953

INSTRUMENTS

Five kinds of pyrheliometers for measuring the intensity of sun-rays were designed. These included the silver-disk, the water-flow, the water-stir, the improved Ångström, and the automatic-balloon pyrheliometers. For measuring sky-radiation the pyranometer was designed. Other instruments designed included the vacuum bolometer, special extrapolator for spectral atmospheric transmission measures, apparatus for observing stars by day for guiding airplanes, a compact spectrobolometer for expeditions, eclipse apparatus, high intensity lamps for Fowle's infrared investigation, numerous supports for mirrors, and many other observing devices. All of these instruments were constructed by Andrew Kramer, instrument maker for the Observatory, 1891-1950, and after 1950 by Darnel Talbert.

PUBLICATIONS

Quarto volumes 2-6 of the *Annals,* prepared by C. G. Abbot, F. E. Fowle, and L. B. Aldrich, and volume 7, prepared by L. B. Aldrich and W. H. Hoover, were published 1908-1953. About 150 papers, mostly published in Smithsonian Miscellaneous Collections, were written by members of the staff.[1]

THEORETICAL FINDINGS

Langley showed about 1880 that, to determine the solar constant, the spectral transmission of the atmosphere must be measured. This was always done by us with a clock-operated recording spectrobolometer in Langley's Method (now often called the "long method"). Langley did not publish a complete theory of this method, and he used it erroneously in publishing his Mount Whitney Expedition of 1881. This error gave his preferred solar constant value 3.07 instead of 2.0 calories. The full theoretical demonstration, and examples of the correct application of Langley's method are published in *Annals,* volume 2.

Although Langley's method is fundamental, it requires several hours of observing while the sun's air mass or atmospheric path changes from (say) 3.5 to 1.5 times that for vertical sun. During this considerable time the transparency of the atmosphere always changes. If it grows clearer for small air masses the resulting solar constant is too large, and vice versa. Hence only large groups of solar constant measures by Langley's method can be trusted; these give mean values nearly correctly.

A brief method for measuring spectral transparency was required, so that several values of the solar constant could be obtained daily, with little atmospheric variation affecting any one of them. Then the day's mean value would be good.

From 1920 to 1924 the A.P.O. developed the "short method." This is empirical, depending on the fact that the brightness of the sky near the sun is greater as the sky becomes more hazy. It is found possible to draw curves suited at all times to yield transmission coefficients suited to each station occupied for all of the 40 wavelengths used in Langley's method. A "short method" measurement requires only one reading of the pyranometer of sky-brightness near the sun. So in the 10 minutes employed for making a spectrobolometric graph of

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[1] I will use the abbreviations "A.P.O." for Astrophysical Observatory, and "Pub." for publication.

the solar spectrum, with a reading of the pyranometer on a limited sky area surrounding the sun, a reading of the pyrheliometer on the sun itself, and a theodolite measurement of the sun's zenith distance, the observations are complete.

We made three or sometimes five determinations of the solar constant a day by the short method, and used their mean value for the day's result. From 1924 to 1952 over 9,000 mean daily values of the solar constant were obtained. Many of them were observed from three independent stations on the same day. It is shown by table 1, page 13 of Smithsonian Publication 4545,[2] that by comparing 1992 pairs of solar constant observations of the same day, made individually at stations separated by thousands of miles, some in the Northern, others in the Southern Hemisphere, and at all times of the year, the probable error of a single day's observation of the solar constant at one station is $\frac{1}{6}$ of 1 percent. All of the approximately 9,000 daily determinations, published in volumes 6 and 7 of *Annals,* were scrutinized at Washington, and unanimously approved for publication by a committee comprising L. B. Aldrich, W. H. Hoover, and Mrs. A. M. Bond.

TOWER TELESCOPE

Langley hoped that these 9,000 daily determinations would prove that a strong correlation could be found between daily solar constant values and simultaneous observations of the distribution of the intensity of solar radiation along the east-west diameter of the sun's disk. Some preliminary observations of that distribution were made in Washington in 1908. Later a tower telescope to form an 8-inch image of the sun was erected on our observatory on Mount Wilson, about 1913. From 1913 to 1920, on all observing days, the telescope also was adjusted between observations to form a solar image on the slit of the spectrobolometer. The telescope clock was then stopped, and the solar image was allowed to drift centrally over the slit. Thus was recorded ∩-shaped distribution curves in five wavelengths on each day that a solar constant value was obtained. See figure 52, Pub. 4545.[2]

Owing to inexactness of solar constant values due to the fluctuation of atmospheric transmission during the several hours required for solar constant measures by Langley's method (used exclusively on

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[2] *Solar variation and weather,* by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 146, No. 3. 1963.

Mount Wilson, 1905-1920) it was not then possible to be assured of the correlation between solar constant and diametral distribution. But when the family of harmonic variations in the solar constant values became known about 1940, the solar constant value was back-casted from 1920 to 1913, and such correlation seemed indicated. See figures 50 and 51, Pub. 4545.[2] Solar contrast observations were discontinued in 1920, and solar constant determinations have never been made anywhere in the world since 1955. So this correlation cannot now be fully proved.

PRINCIPAL RESEARCHES

Leading Operations of the Smithsonian Astrophysical Observatory, 1895 to 1955[3] (Smithsonian Pub. 4222) gives brief summaries of 82 researches, with bibliographic references to the original publications of them. I select here for notice a few of the most important researches which occupied the years 1904 to 1953.

1. Inventions of pyrheliometers, vacuum bolometer, pyranometer, honeycomb pyranometer, two-mirror coelostat, highly sensitive radiometer, and solar heat collector.
2. Absolute measurement in heat units to 1 percent of the solar constant, with probable error of a day's measurement at one station $\frac{1}{6}$ of 1 percent *relative* to other day's measures.
3. Fixing the limits of sun's radiating temperature as between 5800° and 7000° C. Abs. Four methods used.
4. Measurement of atmospheric spectral transmission in 40 wavelengths at 10 stations located between sea level and 14,500 feet elevation.
5. Determining the distribution and intensity of radiation in the solar spectrum at 10 stations, and outside the earth's atmosphere.
6. Short method for the solar constant, and also automatic balloon determination.
7. Discovery of solar variation between limits of 2.0 percent in amplitude.
8. Discovery of a 27-day period in "solar constant" variation.
9. Discovery of a numerous harmonic family of exact periods in solar variation with a master period of exactly 273 months.

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[3] *Leading operations of the Smithsonian Astrophysical Observatory*, 1895 to 1955, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 131, No. 1. 1955.

10. Discovery of these identical harmonic periods in terrestrial temperature, and in precipitation, and a method of long-range forecasts based thereon.
11. Discovery of opposing trends in terrestrial temperature, attending for 16 days after rising and falling trends in solar radiation.
12. Fowle's work on terrestrial radiation and its absorption.
13. Aldrich's measure of the earth's albedo.
14. Aldrich's work with the honeycomb pyranometer.
15. Aldrich and Hoover's work, in volume 7 of *Annals,* on the solar constant, and on solar and sky radiation at military camp sites.
16. Work of the Division of Radiation and Organisms, a subsidiary branch of the A.P.O., founded by Secretary Abbot in 1929.

CRITICISM OF CERTAIN METEOROLOGICAL FINDINGS

While many of the pieces of work are everywhere praised and accepted,[4] professional meteorologists have disparaged the alleged results indicated by numbers 2, 7, 8, 9, 10, and 11, listed above. I had hoped to overcome their doubts by my publication 4545.[2] However, recent private advices from responsible officers of the U.S. Weather Bureau, the American Meteorological Society, and the High Level Atmospheric Observatory at Boulder, Colorado, convince me that their doubts still remain. As I feel quite certain of the soundness of these A.P.O. results, I feel a duty to dispel these official objections. In the remainder of this paper new evidence will be presented.

A DEFENSE OF CERTAIN METEOROLOGICAL FINDINGS

SOLAR RADIATION AND ITS VARIABILITY

Numbers 2 and 7—The accuracy of A.P.O. measures of the solar constant, and the limits of its variation.

Referring to table 1, page 13 of Pub. 4545,[2] the probable error of one day's solar constant measure at one station (usually the mean of three independent observations) is $\frac{1}{6}$ of 1 percent. It is certified by 1992 pairs of solar constant measures on identical days made at four observing stations at all times of the year. One station is in the Southern, three in the Northern Hemisphere, and they are separated by thousands of miles. Table 1, just cited, is composed of four sec-

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[4] See expert opinions given in volume V of *Annals,* A.P.O., pp. 32-35.

tions whose individual mean values differ only through the small range from 76.0 to 77.9 parts in 10,000 of the solar constant.

As for the extreme limits of solar variation, I sent Dr. Roberts of High Level Observatory a rough plot of all Montezuma solar constant daily mean values, 1923 to 1952. He retains a copy of it. From numerous of these values, some as low as 1.910, some as high as 1.970, I believe it fair to set solar variation limits as above 2 percent. Dr. Franz Baur of the University of Frankfurt, A.M., Germany, has published 2.2 percent as his conclusion.[5]

On one occasion the solar constant appears to have gone as low as 1.870 calories in 1922 and 1923, for a considerable time. This unique depression may be associated with a long-range period in solar variation that would require scores or centuries of years of observation to verify.

PERIODIC SOLAR VARIATION

Number 8—The 27-day period in solar variation.

It has long been known that the sun's surface shows rotation varying in velocity from the sun's equator to its poles. At the equator the sun rotates in about 25 days, and in about 35 days at 80° latitude. A weighted value of the sun's rotation period, considering areas and latitude, may be taken at 27 days. In Pub. 2499,[6] I showed strong correlation in solar constant measures ranging continuously from +25 to −30 percent, with a period of 27 days. See figure 15, Pub. 4545.[2] This wide range was observed in Mount Wilson values *in 1915,* but **not** in other years, *1912-1920.*

Having discovered the master period, 22 years, 9 months (273 months) in solar variation about 1940, it seemed to me probable that the highly accurate solar constant measures made at Montezuma would show a 27-day period strongly in the year 1937 (1915+22 years), perhaps repeated several times. I have computed from records in volume 6 of the Observatory's *Annals* for four recurrences of the 27-day period in daily solar constant values observed at Montezuma from early April to late September of 1937. Table 1 and accompanying Figure 1 show the detailed and mean results. A 27-day periodic

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[5] *Met. Rundschau,* 17 January, Jahrb. 1, Heft 1964, pp. 19-25.

[6] *Solar rotation and solar variation. Periods 27 days and $\frac{273}{1250}$ and $\frac{273}{2500}$ months shown by correlation in 1915 and 1916,* by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 66, No. 6. 1918.

TABLE 1.—*The 27-day period in solar radiation during 1937.*[1]

Solar constants; Montezuma values

Day	Date	Calories	Date	Calories	Date	Calories	Date	Calories	Mean
1	Apr. 9	1.935	May 5	1.937	June 3	1.941	Sept. 1	1.942	1.938
2	—	—	—	—	4	1.944	—	—	1.944
3	—	—	—	—	5	1.945	—	—	1.945
4	—	—	—	—	6	1.956	—	—	1.956
5	—	—	—	—	—	—	5	1.938	1.938
6	14	1.930	—	—	8	1.955	6	1.941	1.942
7	15	1.951	11	1.947	9	1.953	7	1.951	1.950
8	16	1.934	12	1.940	—	—	8	1.948	1.941
9	17	1.947	13	1.942	11	1.944	9	1.950	1.947
10	18	1.946	—	—	12	1.950	10	1.943	1.945
11	19	1.946	15	1.948	13	1.949	11	1.947	1.948
12	20	1.942	16	1.949	14	1.942	12	1.951	1.948
13	—	—	17	1.950	15	1.940	13	1.946	1.944
14	—	—	18	1.950	—	—	14	1.948	1.949
15	23	1.928	—	—	—	—	—	—	1.928
16	24	1.948	—	—	18	1.949	16	1.948	1.948
17	25	1.947	—	—	19	1.941	17	1.957	1.948
18	26	1.945	22	1.958	—	—	18	1.947	1.950
19	—	—	—	—	—	—	19	1.947	1.947
20	28	1.948	—	—	22	1.945	20	1.946	1.946
21	29	1.940	—	—	—	—	21	1.951	1.946
22	30	1.946	—	—	—	—	22	1.946	1.946
23	May 1	1.934	27	1.949	25	1.946	23	1.943	1.943
24	2	1.932	28	1.949	—	—	24	1.943	1.941
25	—	—	29	1.943	—	—	25	1.930	1.937
26	—	—	30	1.946	28	1.942	26	1.937	1.942
27	5	1.937	31	1.949	—	—	27	1.938	1.941

---

[1] It is a pity but unavoidable that so many days were lost by clouds. Fortunately the *first* day of the 27 is very strong. It was observed in all four repetitions of the period with an over-all range between them of but 0.007 calorie. Figure 1 shows very stoutly the well-evidenced rise of ½ percent from both ends to the middle of the period. The individual points have an average deviation from the mean curve of figure 1 of only ½ of 1 percent of the solar constant.

variation, with an amplitude of about $\frac{1}{2}$ percent of the solar constant, appears as the mean result of four well-observed repetitions.

This new evidence and that of 1915 (Pub. 4545, fig. 15) seems to me to show decisively the 27-day rotation period in solar variation.

I have referred to the apparent 27-day effect on Washington precipitation at pages 45 and 46, and table 8 of Pub. 4545.[2] Using 27.0074 days as the exact period, I found good success in predicting the 175 days more apt to have rain in Washington than the other 190 or 191 days of the years 1942-1954. (See table 8, Pub. 4545.[2]) The formula failed only in 1952 and 1953 (possibly because of bomb explosions and fallout). Continuing to use the same formula in prediction for the year 1963, the whole group of preferred days proved displaced, recurring one day too early. But if the period is slightly changed to 27.0056 days it would have made no difference in forecasts prior to 1954, but in 1963 the preferred days (one day earlier) would have had 1.30 times the average precipitation falling in all others.

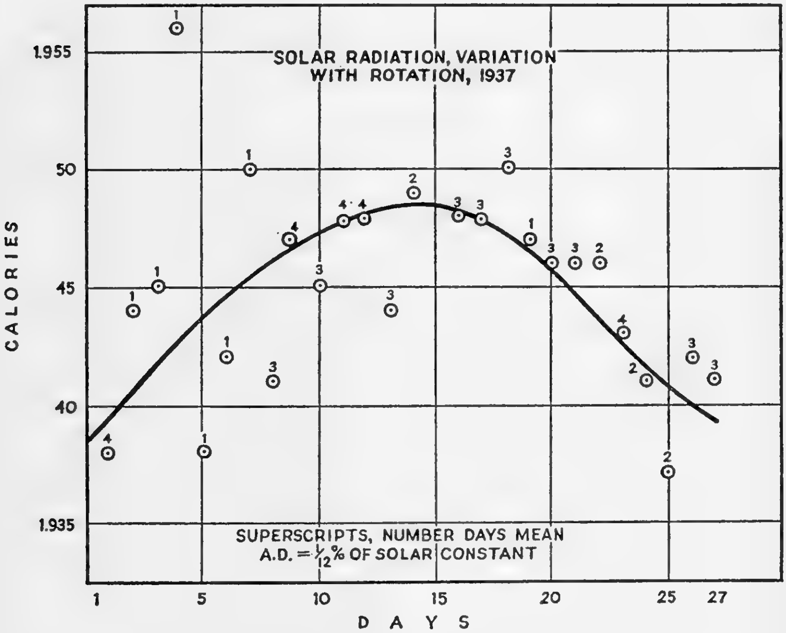

FIG. 1.—The 27.006-day period in solar variation.

OPPOSING SOLAR TRENDS

Number 11—Important opposed trends in solar variation.[7]

The A.P.O. at Washington devoted much effort after 1942 to studying such upward and downward trends in solar variation as are shown in figure 46, Pub. 4545,[2] not here reproduced. It was found that the temperature in Washington and several other United States and European cities responded to these solar trends by long-lasting marches, opposed like right and left hands. So many papers have been published on this observation that it seems superfluous to bring more evidence here. Figures 46, 47, and 49, and pages 52 to 57 of the text of Pub. 4545 [2] show that large opposed temperature changes occurred simultaneously in Europe as well as in the United States in response to over 300 cases of such opposite solar trends. (See fig. 45, Pub. 4545[2].) Pub. 3771 [8] presents a long investigation of the subject. It ends with a summary containing 18 sections. Not only solar constant measures, but solar faculae, calcium flocculi, and ionospheric phenomena act as triggers to set off these opposed long-continued large temperature variations.

In Pub. 4462 [9] of 1961 it is suggested that much better solar constant measures could be made from earth satellites than from mountains, because the atmosphere would be eliminated. If that were done, forecasts of detailed *world* temperature, depending on trends of solar variation, could be obtained covering 16 to 20 days in advance continuously. (The above cited fig. 49 of Pub. 4545 [2] is given originally in Pub. 4462.[9])

TERRESTRIAL WEATHER

Number 10—Harmonic periods and long-range forecasts.

We now come to the important claim of a harmonic family in weather changes identical in periods with such a family in solar variation, but showing far more percentage change in weather than in solar variation. Even more obnoxious to meteorologists has been the claim that useful weather predictions can be made from knowledge

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[7] I insert Number 11 before Number 10, because Number 10 is potentially our most important discovery, requiring extensive comment and deserving the most emphatic place of all our discoveries.

[8] *Weather predetermined by solar variation*, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 104, No. 5. 1944.

[9] *16-day weather forecasts from satellite observations*, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 143, No. 2. 1961.

of it, 10 or even 50 years in advance, or backwards. Recently, however, some meteorologists seem to be more favorably impressed.

Some confusion has been caused by over-riding periods.

It must be clear to all that if there actually is such a large harmonic family in weather periods, ranging in lengths from 4 months to the master period of 273 months, then a tabulation at individual stations of weather periods, e.g., of $\frac{273}{4} = 68\frac{1}{4}$ months must be overlaid by shorter periods, such as $\frac{273}{8}, \frac{273}{28}$, et cetera. So the primary tabulation for a 68¼-month period must necessarily look very rough. It may not even suggest a "hidden" period of 68¼ months unless those overlying shorter harmonics can first be removed.

I now refer the reader to the accompanying figures 2, 3, and 4, prepared from Jon Wexler's electronic tabulations of monthly "World Weather Records," 1870 to 1940. He obtained monthly normals of precipitation at Rome, Italy, Kief, U.S.S.R., Capetown, South Africa, and other stations, separately for years when Wolf sunspot numbers $\gtrless 20$. From these he obtained the departures in percentage of normal for all months, 1870-1949. These are divided into four groups which we call Category 1, Divisions 1 and 2; Category 2, Divisions 1 and 2. "Division" refers to first and second half of the interval 1870-1949. "Category" refers to Wolf numbers $\gtrless 20$ sunspot numbers.

Figure 2, for the 68¼-month period in Category 2, combines Divisions 1 and 2 at Rome, Italy. It shows five starting dates: June 1902, February 1908, October 1913, June 1919, and March 1925. A lack of recorded observations in later years before 1949 prevented using a sixth column. The mean of these 5 columns is plotted in the bottom full curve. No one seeing this curve could suppose it would easily be resolved, and would disclose a smooth sine curve of 68¼ months. But when the over-riding periods $\frac{273}{8}, \frac{273}{12}, \frac{273}{28}, \frac{273}{16}, \frac{273}{20}, \frac{273}{44}$ are successively computed and removed, as shown in figure 2, there results the beautiful smooth sine curve shown at the top of figure 3, representing only $\frac{273}{4}$ or 68¼ months. Its amplitude is over 30 percent of normal precipitation.

I am sure it will not be necessary to so particularly describe figures 3 and 4 relating to Kiev, U.S.S.R. and Cape Town, South Africa, which each include one group of Jon Wexler's electronic tabulations, being for the periods $\frac{273}{8}$ and $\frac{273}{9}$ months, respectively. They display over-riders, $\frac{273}{16}, \frac{273}{24}, \frac{273}{40}$, for Kiev, and $\frac{273}{18}, \frac{273}{27}, \frac{273}{45}, \frac{273}{63}$, for Cape Town. These two stations, cleared, show smooth sine curves, respectively, of amplitudes 25 and 16 percent of normal precipitation. I call attention

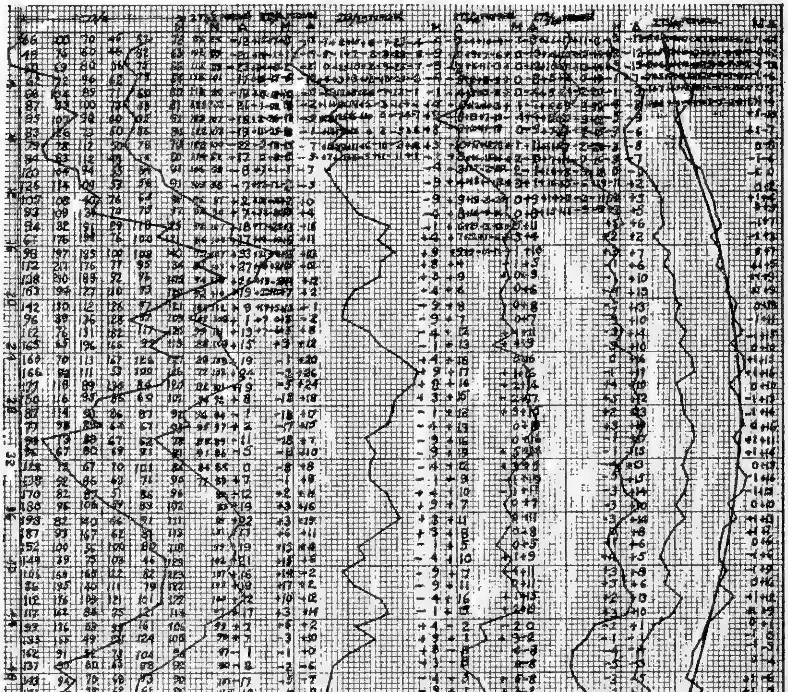

Fig. 2.—Rome, Italy. 68¼ Month Period Cleared.

to the far geographical separation of the three cities concerned in figures 2, 3, and 4. Similar results, not so fully exposed in the publishing of them as figures 2, 3, and 4, are shown for several U.S cities in figures 18, 19, 20, 23, 24, and 25 of Pub. 4545 [2] and for other stations not here cited. Altogether the figures just cited would display, necessarily as super-riders, the existence of nearly all of the 27 periods, harmonics of 273 months, which we use in forecasting weather. Similar clearing gives similar sine-curve results for long periods at all 54 stations so far forecasted.

Referring now to figure 21 of Pub. 4545,[2] it shows the actual plus and minus quantities which resulted from tabulations I made for St. Louis, working on them alone without electronic assistance. These 23 columns of figures, being added, gave a 20-year back-cast from the mean date 1897 of the precipitation at St. Louis, 1875-1879. It is nearly identical with the actual precipitation observed. As stated in Pub. 4211,[10] all that work was done on 5-month consecutive means

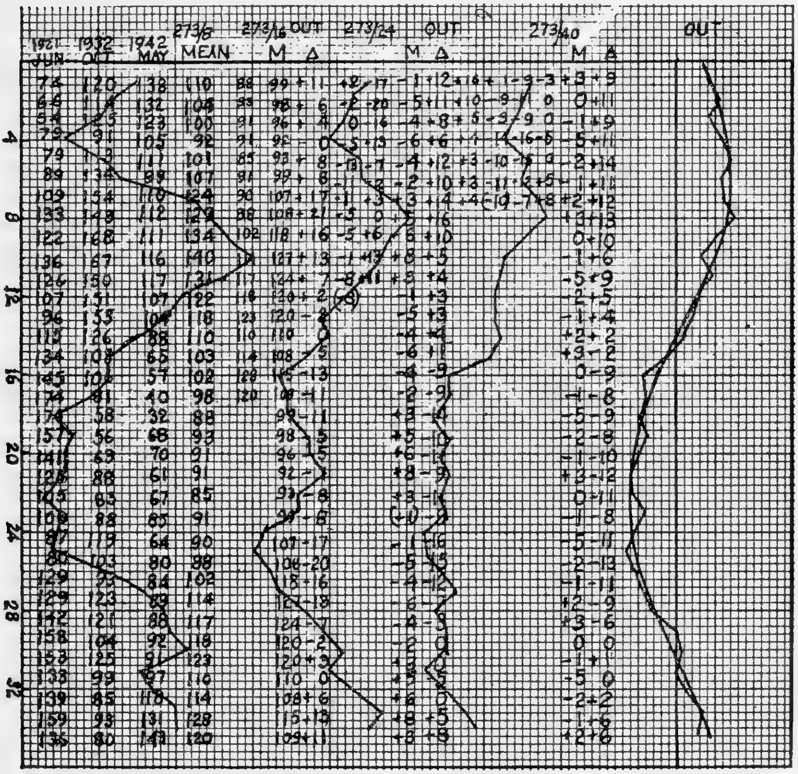

Fig. 3.—Kiev, U.S.S.R., Precipitation. 34⅛ Month Period Cleared.

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[10] *60-year weather forecasts,* by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 128, No. 3. 1955.

of the monthly records of St. Louis, 1854-1940. Such 5-month consecutive smoothing is also used in Jon Wexler's electronic tabulations for foreign stations, mentioned above. But that does not prejudice at all our discovery that very successful long-range forecasts can be made. See also figure 22 of Pub. 4545.²

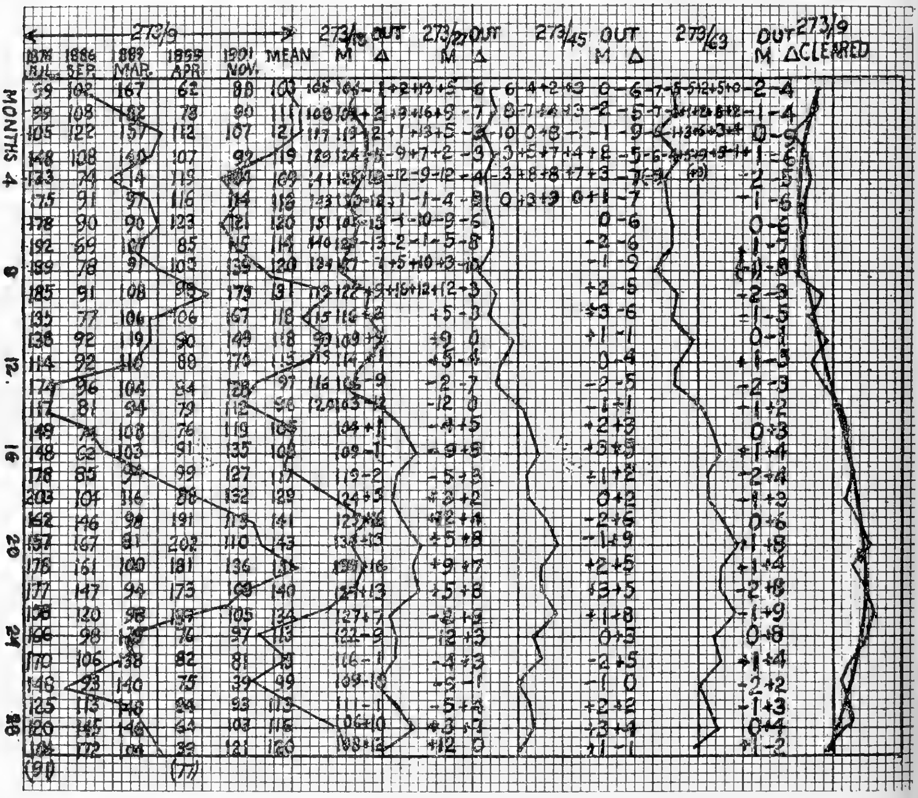

FIG. 4.—Cape Town, South Africa Precipitation. 30⅓ Months Cleared.

Landsberg, Mitchell, and Crutcher, in their paper on climatological data for Woodstock, Md., describe that station "as a member of the Weather Bureau's Climatological Benchmark Network." I feel very grateful to Dr. Landsberg that he has sent me two sheets of the monthly records of precipitation at Woodstock covering 1870 to 1963. Mr. Jon Wexler has prepared these records for my use to make an analysis with forecast through 1969. I have made such a forecast 1950 through 1969 for Woodstock, which shows correlation with observation from 1950 to 1963 of about +42 percent. Unfortunately displacements of obviously similar features made this correlation coefficient fully 10 percent lower than those for most U.S. stations. Rectifying these obvious displacements, I found a correlation coefficient of +72 percent for Woodstock.

Figures 2, 3, and 4 of the present paper, and figures 18, 19, 20, 21, 22, 23, 24, and 25 of Pub. 4545,[2] and many examples I have encountered in forecasts of precipitation for 54 cities show how over 30 regular periods, harmonics of 273 months, are "hidden" if one regards meteorological time as if it were a river running serenely forever in a smooth uniformly inclined channel. All researchers do so who neglect *time of the year, sunspot activity,* and *march of population,* all affecting atmospheric transparency, and neglect the *superposition of short-period harmonics* confusing longer ones.

CLASSIFIED REFERENCES FROM SMITHSONIAN PUBLICATIONS

A. Accuracy of the solar constant as measured.

(1) Annals, A.P.O., vol. 6, p. 163. Published 1942.
(2) Smith. Misc. Coll., vol. 134, No. 1, Pub. 4265, p. 2. Published 1956.
(3) Smith. Misc. Coll., vol. 146, No. 3, Pub. 4545, table 1, pp. 10-15. Published 1963.

B. "Hidden" periodicities.

In solar constant measures:

(1) Smith. Misc. Coll., vol. 117, No. 10, Pub. 4088. Published in 1952.
(2) Smith. Misc. Coll., vol. 128, No. 4, Pub. 4213, pp. 4 and 6, table 1, fig. 1, and pp. 9 and 10, fig. 2. Published 1955.

In weather:

(2) Smith. Misc. Coll., vol. 117, No. 16, pp. 11-18, 5 tables, 8 figs., Pub. 4095. Published 1952.
(3) Smith. Misc. Coll., vol. 121, No. 5, pp. 2-5, table 1, fig. 1, Pub. 4103. Published 1953.
(4) Smith. Misc. Coll., vol. 128, No. 3, pp. 1, 2, Pub. 4211. Published 1955.
(5) Present paper, Number 10 "Harmonic periods and long-range forecasts."

C. Weather forecasts do not require solar observations.

Their independence from all *solar* measures except Wolf numbers. ≳20.

(1) Smith. Misc. Coll., vol. 121, No. 5, line 22, p. 2; line 15, p. 11, Pub. 4103. Published 1953.

D. High positive correlation with events.

(1) Smith. Misc. Coll. vol. 128, No. 3, pp. 4-5, Pub. 4211. Published 1955.
(2) Smith. Misc. Coll., vol. 139, No. 9, p. 1, Pub. 4390. Published 1960.
(3) Smith. Misc. Coll., vol. 146, No. 3, pp. 60, 63, 64, Pub. 4545. Published 1963.
(4) Smith. Misc. Coll., vol. 143, No. 5, p. 5, fig. 4, Pub. 4471. Published 1961.

I have (unpublished) the correlation coefficient between back-cast and observation for St. Louis monthly precipitation, 24 months, 1878 and 1879. It is based on all records 1854 to 1939, centering at 1897. It is + 87.5 ± 6.5 percent.

E. Average deviations of forecasts from events are no greater at wide departures from normal, or after long lapse of time.

(1) Smith. Misc. Coll., vol. 143, No. 5, pp. 1, 6, table 1. Pub. 4471. Published 1961.

(2) Smith. Misc. Coll., vol. 128, No. 3, Pub. 4211. Published 1955.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
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Roebling Fund

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FORECASTING FROM HARMONIC PERIODS IN PRECIPITATION

By C. G. Abbot

Research Associate, Smithsonian Institution

This paper presents evidence showing that the identical family of harmonic periods found in solar variation is also present strongly in terrestrial precipitation, and may be used for long-range forecasting. I wish to direct attention of those interested in water supply to figures 7 and 8, and to the Conclusion of this article. Figures 7 and 8 show in A the march of yearly precipitation at two stations for 36 years. The curves A in figures 7 and 8 are made from recorded observations *after it happened.* The curves B, which are for practical purposes nearly identical with curves A, could be predicted and were actually predicted from records of observations *made long ago before the events happened.*

1. PERIODS IN SOLAR VARIATION

Volumes 5, 6, and 7 of the Annals, Smithsonian Astrophysical Observatory, tabulate over 9,000 days' measures of the solar constant of radiation. At page 13 and figure 1, Smithsonian Publication 4545, it is computed that the daily accidental error of a measure of the solar constant from one solar station is 0.007 calorie. Considering the number of stations responding, and the loss of days by clouds or other causes, the accidental probable error of mean monthly values is estimated at 0.05 percent of the solar constant.

Mr. Jon. Wexler has electronically smoothed the monthly solar constant values, 1921 through 1952, by the formula $c^1 = 1/10\,(a+2b+4c+2d+e)$ which gives the central month, c, $\frac{2}{3}$ as much weight as the total weight of the other four. His results are given by table 1 and figure 1.

In the year 1922 an exceptional depression of about 8 percent in figure 1 is seen. This may possibly indicate the existence of a solar period of long duration. The results from 1923 to 1955 display many cases of long trends with amplitudes of solar variation up to 3 percent. Figure 8a of Publication 4545 shows that the monthly values of the solar constant repeated themselves, approximately, in great detail with an interval of 273 months.

TABLE 1.—*Smooth Solar Constant*

Date	Solar constant	Date	Solar constant	Date	Solar constant	Date	Solar constant	Date	Solar constant	Date	Solar constant
1921 J	+39	1927 J	−43	1933 J	+18	1939 J	+3	1945 J	+1	1951 J	+22
F	+31	F	−40	F	+15	F	−12	F	+4	F	+26
M	+20	M	−33	M	+2	M	−17	M	−2	M	+23
A	+8	A	−20	A	−7	A	−21	A	+1	A	+1
M	+6	M	−14	M	−8	M	−22	M	0	M	−10
J	−5	J	−8	J	−3	J	−25	J	0	J	−10
J	+7	J	−7	J	+6	J	−23	J	0	J	0
A	+14	A	−6	A	+10	A	−21	A	−5	A	+6
S	+35	S	−4	S	+23	S	−9	S	−8	S	+1
O	+51	O	−10	O	+29	O	−4	O	−10	O	−5
N	+53	N	−9	N	+33	N	+3	N	−3	N	−8
D	+38	D	−15	D	+31	D	+3	D	−10	D	−6
1922 J	+13	1928 J	−17	1934 J	+25	1940 J	−1	1946 J	−14	1952 J	−8
F	−5	F	−16	F	+17	F	−6	F	−24	F	−19
M	−30	M	−8	M	+14	M	−8	M	−24	M	−24
A	−58	A	−3	A	+10	A	−2	A	−9	A	−13
M	−86	M	+3	M	+13	M	+6	M	+2	M	−5
J	−117	J	+2	J	+17	J	+9	J	+8	J	−4
J	−134	J	−9	J	+16	J	+11	J	+3	J	−14
A	−126	A	−17	A	+16	A	+9	A	−2	A	−16
S	−118	S	−19	S	+24	S	+9	S	−2	S	−20
O	−106	O	−12	O	+33	O	+6	O	+2	O	−16
N	−94	N	−3	N	+36	N	+5	N	+14		
D	−87	D	−1	D	+32	D	+9	D	+20		
1923 J	−69	1929 J	−3	1935 J	+23	1941 J	+10	1947 J	+15		
F	−74	F	−14	F	+12	F	+10	F	−2		
M	−63	M	−18	M	+6	M	+10	M	−17		
A	−63	A	−22	A	+2	A	+6	A	−18		
M	−53	M	−24	M	+3	M	+9	M	−13		
J	−52	J	−31	J	+3	J	+15	J	−8		
J	−34	J	−31	J	+2	J	+22	J	−8		
A	−14	A	−33	A	+4	A	+22	A	−7		
S	+6	S	−31	S	+3	S	+20	S	−4		
O	+5	O	−27	O	+8	O	+21	O	+4		
N	−2	N	−18	N	+13	N	+21	N	+13		
D	−10	D	−11	D	+15	D	+23	D	+19		
1924 J	−9	1930 J	−10	1936 J	+7	1942 J	+17	1948 J	+23		
F	−7	F	−11	F	−1	F	+8	F	+26		
M	−1	M	−13	M	−6	M	−3	M	+25		
A	+2	A	−8	A	−2	A	−1	A	+28		
M	+16	M	+3	M	+3	M	+7	M	+30		
J	+24	J	+14	J	+8	J	+16	J	+37		
J	+27	J	+18	J	+9	J	+18	J	+40		
A	+25	A	+13	A	+9	A	+13	A	+35		
S	+26	S	+6	S	+12	S	+8	S	+32		
O	+35	O	+7	O	+16	O	+7	O	+29		
N	+41	N	+12	N	+22	N	+8	N	+34		
D	+47	D	+17	D	+22	D	+2	D	+37		
1925 J	+48	1931 J	+12	1937 J	+15	1943 J	−2	1949 J	+32		
F	+48	F	+7	F	+3	F	0	F	+25		
M	+38	M	+6	M	−11	M	+3	M	+9		
A	+21	A	+9	A	−18	A	+8	A	+1		
M	+12	M	+19	M	−17	M	+15	M	+1		
J	+10	J	+21	J	−8	J	+24	J	−2		
J	+12	J	+23	J	−4	J	+24	J	0		
A	+13	A	+22	A	+1	A	+23	A	−1		
S	+11	S	+21	S	+4	S	+18	S	−2		
O	+5	O	+17	O	+7	O	+15	O	+4		
N	+3	N	+13	N	+10	N	+13	N	+14		
D	−2	D	+10	D	+13	D	+17	D	+22		
1926 J	−11	1932 J	+3	1938 J	+8	1944 J	+18	1950 J	+21		
F	−26	F	−8	F	+6	F	+20	F	+5		
M	−30	M	−15	M	+2	M	+12	M	−8		
A	−35	A	−16	A	−6	A	+7	A	−14		
M	−31	M	−14	M	−10	M	+7	M	−10		
J	−26	J	−8	J	−12	J	+7	J	−4		
J	−19	J	−4	J	−9	J	+6	J	−4		
A	−14	F	−7	A	−5	A	0	A	0		
S	−21	S	−10	S	+4	S	−6	S	+1		
O	−34	O	−16	O	+14	O	−3	O	+9		
N	−42	N	−9	N	+21	N	+5	N	+9		
D	−46	D	+7	D	+16	D	+9	D	+12		

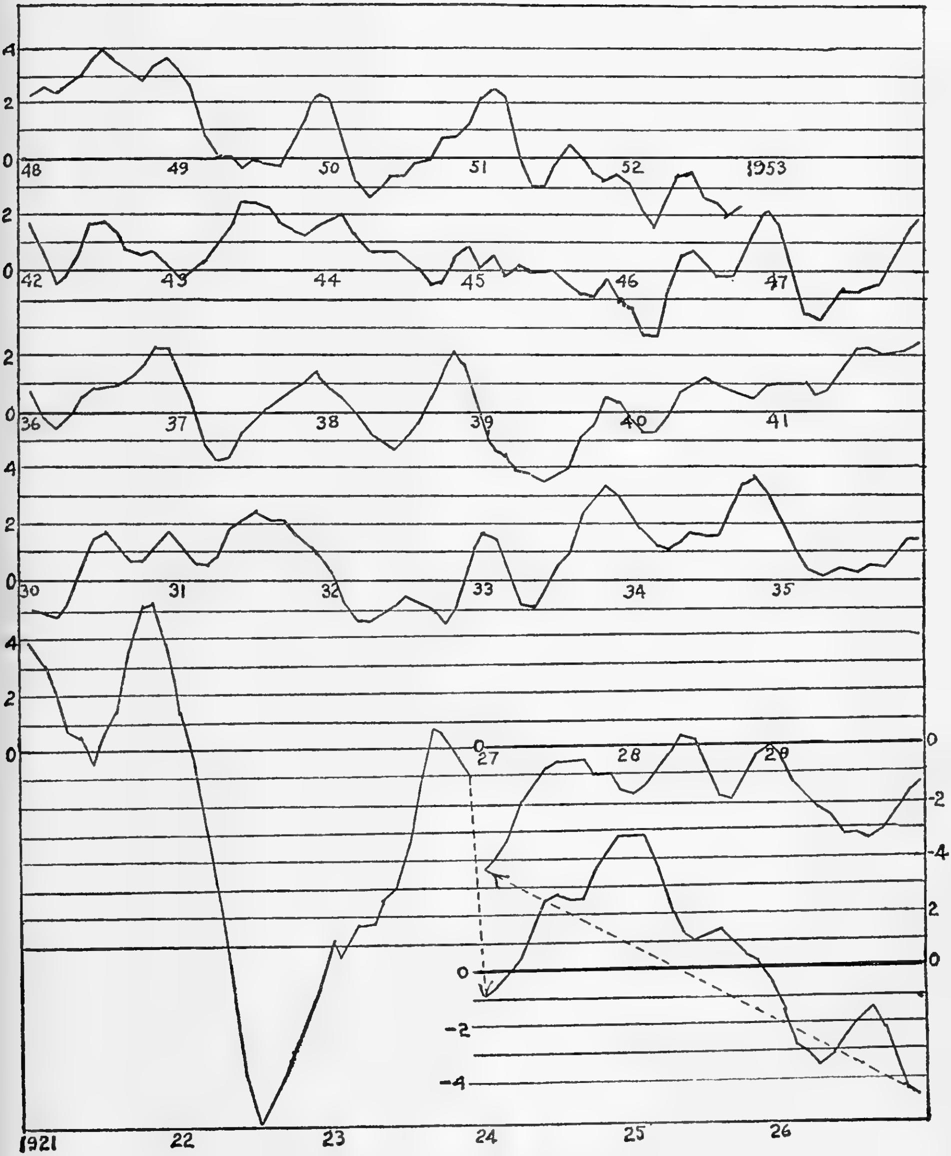
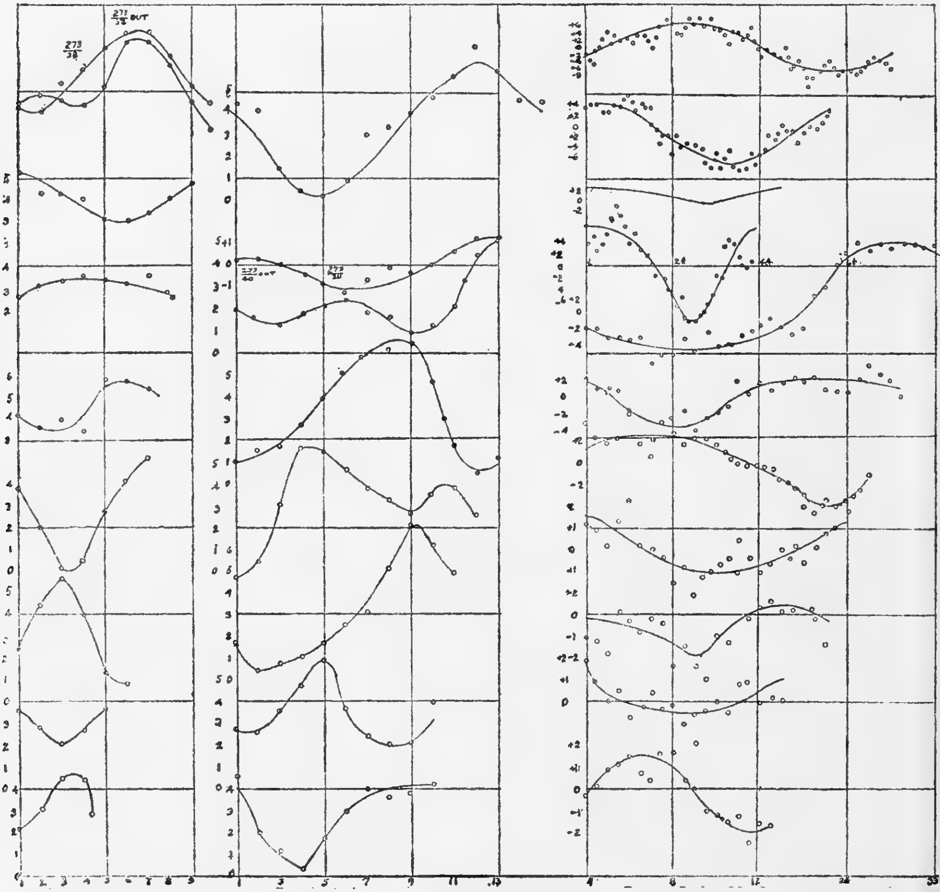


Fig. 1.—Smoothed solar constant.
Scale: 2 = $\frac{1}{10}$ solar constant.

I have now analyzed Wexler's smoothed values to see if 27 exact submultiples of 273 months, which I have long believed in, are verified. The number of repetitions decreases from 77, for $4\frac{1}{3}$ months, to 5 for $\frac{273}{4} = 68\frac{1}{4}$ months. With only 3 repetitions for 91 months, I omitted $\frac{273}{3}$. All periods longer that $15\frac{1}{6}$ months had one or more over-riders, exactly their submultiples in length, whose amplitudes I



Section 1. $\frac{273}{63}$ to $\frac{273}{28}$. Section 2. $\frac{273}{27}$ to $\frac{273}{18}$. Section 3. $\frac{273}{15}$ to $\frac{273}{4}$. Sub-periods removed.

Monthly solar constants, smoothed, 1923 to 1952. Formula: $C' = \frac{1}{100}(A+2B+4C+2D+E)$.

Ordinates scale: $\frac{1}{100}$ Solar constant = 2.

FIG. 2.—Solar periodic variation.

computed and subtracted, in a method illustrated below in figure 3 for 54⅗ months. My results, all closely approximating to sine curves, are shown in figure 2.

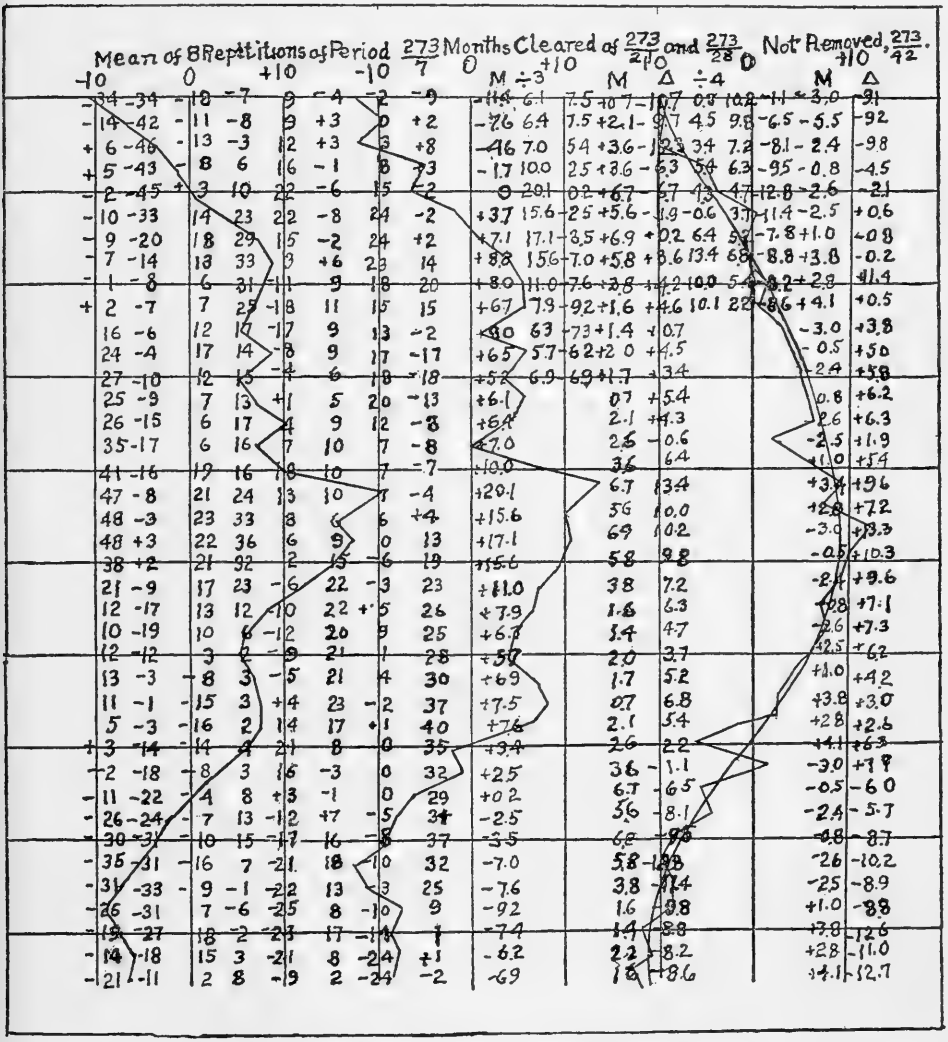


Fig. 3.—A solar constant period cleared of submultiples.
Amplitude: 0.20 percent.

The harmonics of 273 months are shown in figure 2 to range in amplitude from 0.10 to 1.05 of 1 percent of the solar constant. All are far greater than the accidental error of monthly solar constant measures as given above. And as each harmonic period is the mean of many determinations, their amplitudes have probable errors far too small to be due to chance.

2. PERIODIC TERRESTRIAL PRECIPITATION

Convinced 20 years ago of existing solar periodic variation, I noticed in the long monthly records of Peoria, Ill., an indication of a period of about 23 years in precipitation. I then tried during several years to find other periods there. They appeared to exist, but to suffer variable displacements associated with changes in atmospheric transparency. Persevering, ways avoiding these difficulties were found, leading at length to a method of long-range forecasting which I used with surprising success on the records of St. Louis. See Smithsonian Publication 4545, figures 21, 22, and 25, and explanatory text.

Prof. Wexler, of State University of Arizona, interested his son, Jonathan Wexler, in my forecasting. Jon. Wexler, a student in electronic programming, saw how the computing might be greatly aided. Since 1955, he has prepared for my forecasts the long records of precipitation of 55 stations in all parts of the world. I have described in the publication "Solar Energy," volume 1, No. 1, 1956, and volume 2, No. 1, 1957, the tedious process used for my forecasts. Smithsonian Publication 4390 gives forecasts, 1950 to 1967, for 32 stations in the United States. But while over 5,000 copies of it were sold, besides 1,500 copies freely distributed by the Institution, professional meteorologists are still skeptical, notwithstanding evidences of useful value given in pages 1 to 6 of Smithsonian Publication 4471. Hence it seems good to present now, in detail, evidence that the identical family of harmonic periods found in solar variation is also present strongly in terrestrial precipitation, and may be used for long-range forecasting.

Figure 4 plots the forms and amplitudes of 26 periods in the precipitation of Rochester, N.Y., 1884-1955, as computed by Jon. Wexler in 222 separate tabulations. Period $\frac{273}{3}$ months is omitted from figure 4 because repetitions are too few for good evidence. Period $\frac{273}{4}$ is found in evidence at Rochester only as represented by the shorter over-riding periods $\frac{273}{8}$ and $\frac{273}{12}$. Yet $\frac{273}{4}$ is strong itself in St. Louis precipitation. See Publication 4545, page 32, and at other stations.

I give in figure 4 only the periods in Category 2. These, about 60 percent of the whole record, relate to intervals when Wolf sunspot numbers exceed 20. The other 40 percent (in Category 1) were also computed and used in the forecast below. But as their forms and amplitudes are similar to those of Category 2, I omit printing them here. I give in table 2 details of interest regarding the periods plotted in figure 4.

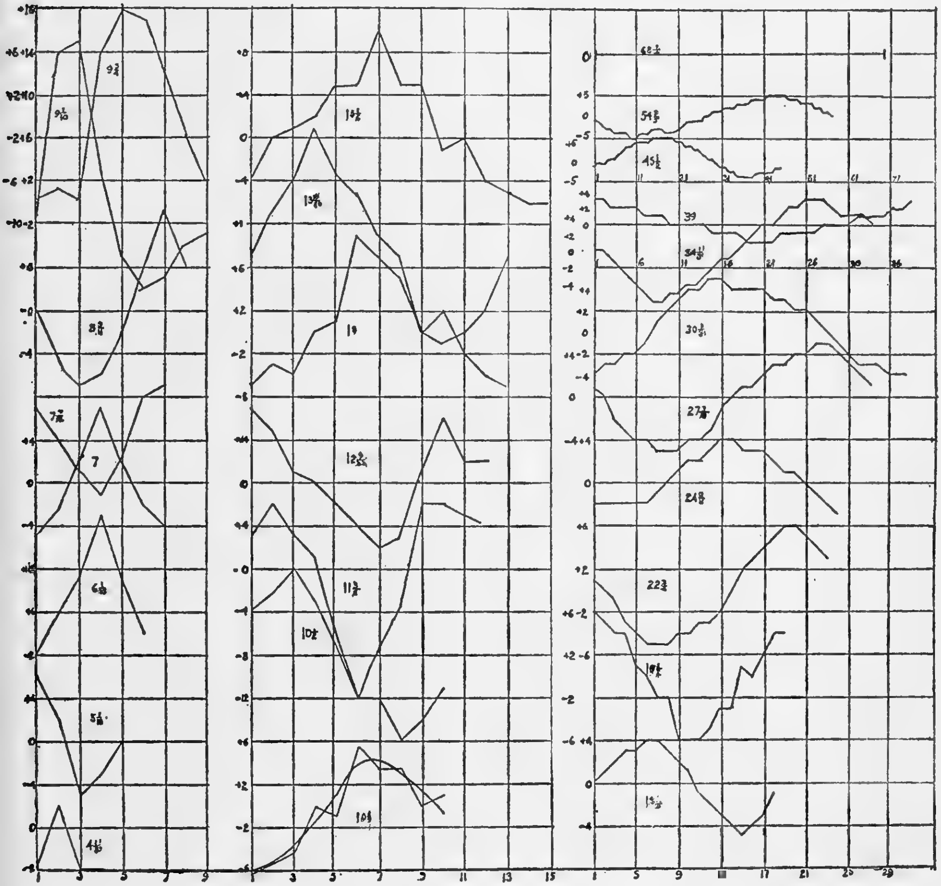


FIG. 4.—Rochester harmonic periods, 1884-1956.
Ordinates percent normal precipitation.

In Section 3 of figure 4 ($18\frac{1}{5}$ to $68\frac{1}{4}$ months) all periods had overriding subperiods, such as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{5}$. These were removed and not shown. Figure 3 illustrates by numbers and forms the method of clearing long periods from over-riders, applicable both in radiation and in precipitation.

3. LONG-RANGE PREDICTION OF PRECIPITATION

It is urged by experts in meteorology that exact measurements of precipitation are so difficult, its local distribution so extraordinarily irregular, its jumps between zero and super-normal amplitude so erratic that 50 years of observation are hardly enough to give satisfactory monthly normals. Hence they prefer to do research with temperature and pressure, hoping through atmospheric circulation to find a path to advance in the forecasting of precipitation. My former chief, the late Dr. S. P. Langley, encouraged me to hope that knowledge of solar radiation and of its atmospheric transmission might

TABLE 2.—*Harmonic Periods in Rochester, N.Y., Precipitation Exact Fractions of 273 Months, Category 2 Only*

Number	Fraction	Period in months	Amplitude percent of normal precipitation	Number of repetitions per period
1	1/63	4 1/3	3	127
2	1/54	5 1/18	8	111
3	1/45	6 1/5	9	91
4	1/39	7	9	90
5	1/36	7 7/12	8	73
6	1/33	8 3/11	13	66
7	1/30	9 1/10	21	60
8	1/28	9 3/4	17	58
9	1/27	10 1/9	10	56
10	1/26	10 1/2	15	53
11	1/24	11 3/8	18	48
12	1/22	12 9/22	10	47
13	1/21	13	14	41
14	1/20	13 13/20	19	41
15	1/18	15 1/6	15	36
16	1/15	18 1/5	8	29
17	1/14	19 1/2	12	26
18	1/12	22 3/4	11	23
19	1/11	24 9/11	7	22
20	1/10	27 3/10	10	20
21	1/9	30 1/3	9	19
22	1/8	34 1/8	9	14
23	1/7	39	7	14
24	1/6	45 1/2	9	11
25	1/5	54 3/5	10	8
26	1/4	68 1/4	—	5
27	1/3	91	—	3

open a direct path to foreknowledge of precipitation, that highly important variable in agriculture and water supply.

This hope has now been realized by a combination of five discoveries of the twentieth century. For more than 10 years now it has been possible, with these five helps, to make useful forecasts longer than one generation in advance. The discoveries referred to are as follows:

1. Nearly a century of patiently continued weather records are now available. They embrace many stations in all continents, and are published in *World Weather Records.*

2. Both the sun's radiation and the long-continued weather records contain as many as 27 harmonic periods, exact submultiples of 273 months, of equal lengths in solar radiation and in weather.

3. While solar variation varies in amplitude, its phases appear constant. Weather phases, on the other hand, vary considerably as conditions alter in the atmosphere. These phase shifts, which may be as great as several months, differ with length of period, locality, time of the year, sunspot frequency, and growth of population. These difficulties require a large number of divisions to be made of the long weather records. Indeed, 222 tables for each station are required, as I have explained in previous publications.

4. The invention and development of the electronic computer makes it possible to handle the multiplication of phase differences, and any desirable smoothing of arrays of numbers in a few moments, instead of years, as when I computed alone for St. Louis forecasts, 1854 through 1957.

5. The introduction of the smoothing formula $\frac{1}{10}(a+2b+4c+2d+e)$ is highly valuable. In it the value c has $\frac{6}{10}$ as great weight as the four neighboring values combined. With an irregular variable, like precipitation, smoothing is necessary. But to avoid displacing phases by smoothing, it must avoid giving preponderant weight to values outside the central value.

Before demonstrating more, it may not be superfluous to point out that with nearly 100 years of records available, they may fairly be used, not only for prediction but to test the validity of predictions when made. For if all records of N years be employed in a prediction, the monthly records of a single year cannot affect the prediction for that year by more than $\frac{12}{12N}$. That quantity diminishes proportionally with the increase of N and reaches the negligible value of 1 percent when $N=100$.

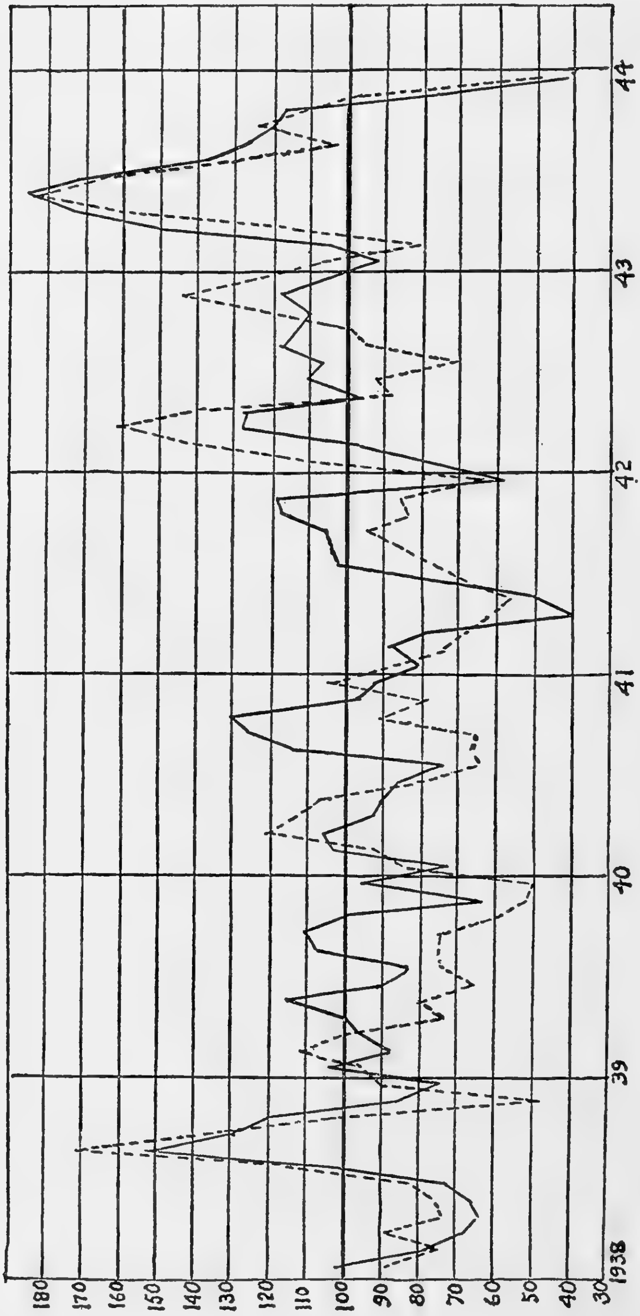


FIG. 5—Rochester, N. Y., precipitation.
Forecast—; Observed ------

Figures 5 and 6 give 6-year samples, graphically, of forecasts at Rochester, N.Y., and Nashville, Tenn., within the interval 1921 through 1956. That entire interval has been forecasted. Its forecast has been compared to observed departures from normal, and smoothed by the formula $\frac{1}{10}(a+2b+4c+2d+e)$. I give here only 6-year portions of the comparison for I wish to keep this paper as brief as possible. I fear that Smithsonian Publication 4545, on which I placed high hopes, is too long, so that no one but myself ever reads it. The forecasts given in figures 5 and 6 employ all the "World Weather" records. These comprise for Rochester, 1884 through 1956, 72 years, and for Nashville, 1870 through 1956, 86 years.

Readers may notice that due to the new smoothing formula, this comparison mostly avoids the distressing shifts of prominent features which sometimes amounted to 3 or 4 months in Publication 4390. Both stations are included in the tables given in Publication 4390, and Nashville is illustrated there in figure 29.

I have preferred to use Nashville forecast, 1950-1956, because it was given 1950-1957 in Publication 4390, plate 3. Now employing the new smoothing formula the new illustration is better. Besides, it shows in 1950 to 1952 shifts and differences in amplitude of features that may have resulted from hydrogen bombing by the U.S.A. and the U.S.S.R. about 1950. I have found similar indications in nearly all of 23 foreign stations I have forecasted.

Now I proceed to considerations which seem to me to clinch the case for the validity and usefulness of long-range forecasts of precipitation. Figures 7 and 8 give for both Rochester and Nashville: (A) percentage-yearly departures from the mean, 1921 through 1956, and 1921 through 1956, respectively, of the total rainfall observed. (B) Departures from the smoothed means (of 72 and 86 years respectively) of forecasts, 1921 through 1956. These are computed from *all monthly records* of 72 and 86 years respectively. (C) Values of (A) smoothed by $\frac{1}{10}(a+2b+4c+2d+e)$, and (D) values of (B) smoothed similarly.

First consider Rochester, figure 7, only. It will be seen from (A) and (B) that the mean of all yearly departures, 1921 through 1956, of (B), involving my forecast, is smaller than that of (A) observed. These results are 9.3 and 11.5 percent. But it is also quite obvious that if one confines attention to *large* departures, (B) has a much larger advantage over (A). These results support long-range predictions somewhat.

But what really clinches the case for the validity of my forecasting, and all it comprises, is the second pair of curves (C) and (D). For

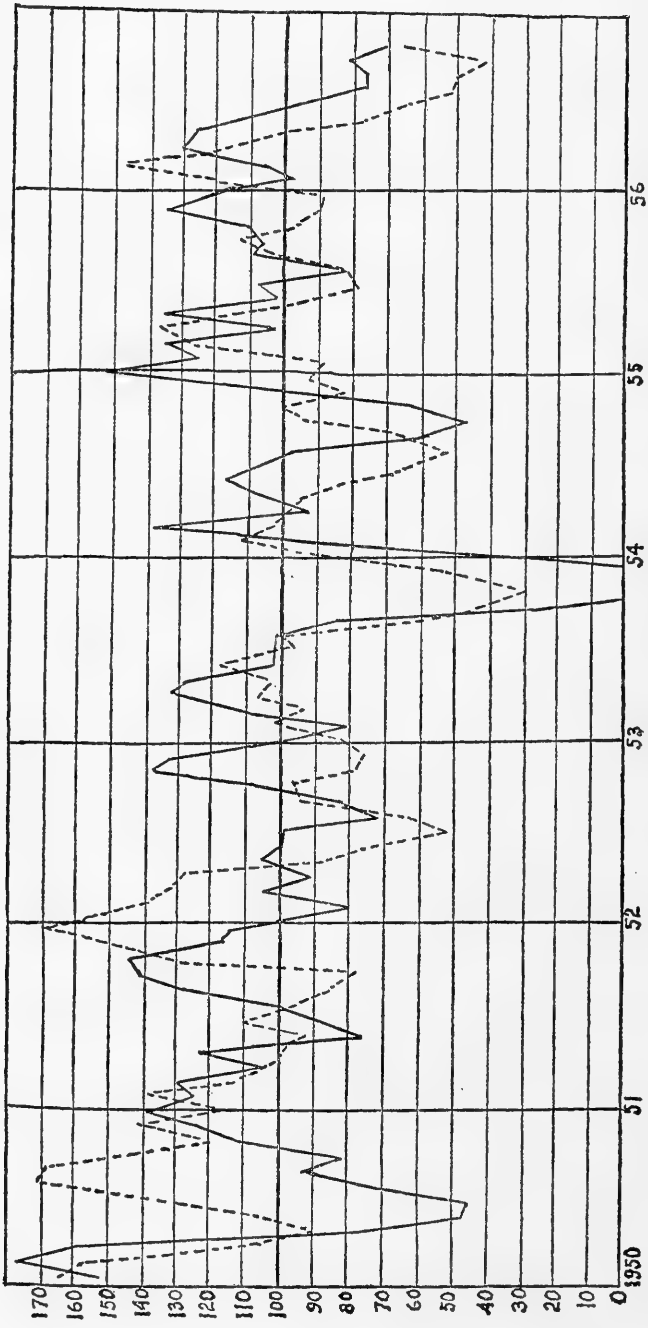


FIG. 6.—Nashville, Tenn., precipitation.
Forecast—; Observed ------

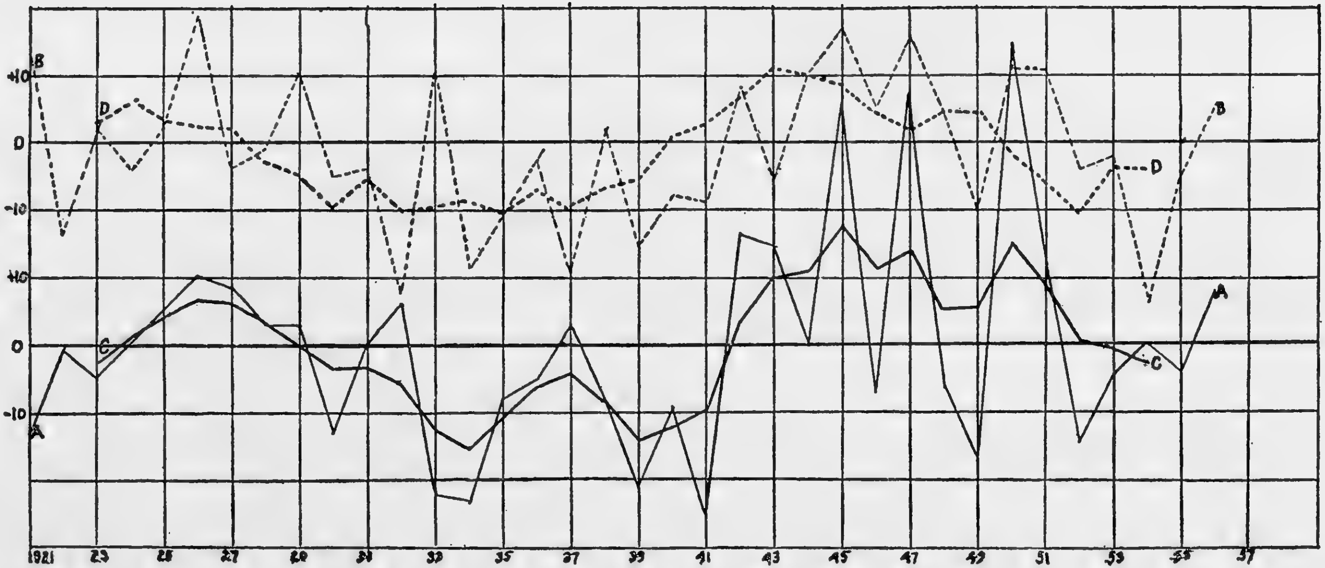
both curves show four major episodes. They are 1922 to 1928; 1928 to 1940; 1940 to 1949; and 1949 to 1954. Curve (C) is *rigidly conditioned by observation.* But curve (D), on the other hand, depends on *forecasting, based on all the monthly observations,* 1884 through 1956.

It shows in D, however, the same four great trends in precipitation as those actually observed to be *real* in (C). If the *forecasts* making up curve (D) were not sound, there is not one chance in a thousand that the two curves would be so similar. Moreover, the curve (D) has a smaller average departure from curve (B) than curve (C) has from curve (A), and curve (D) is far smoother than curve (C).

TABLE 3.—*Harmonic Periods in Solar Constant Exact Fractions of 273 Months, Category 2 Only*

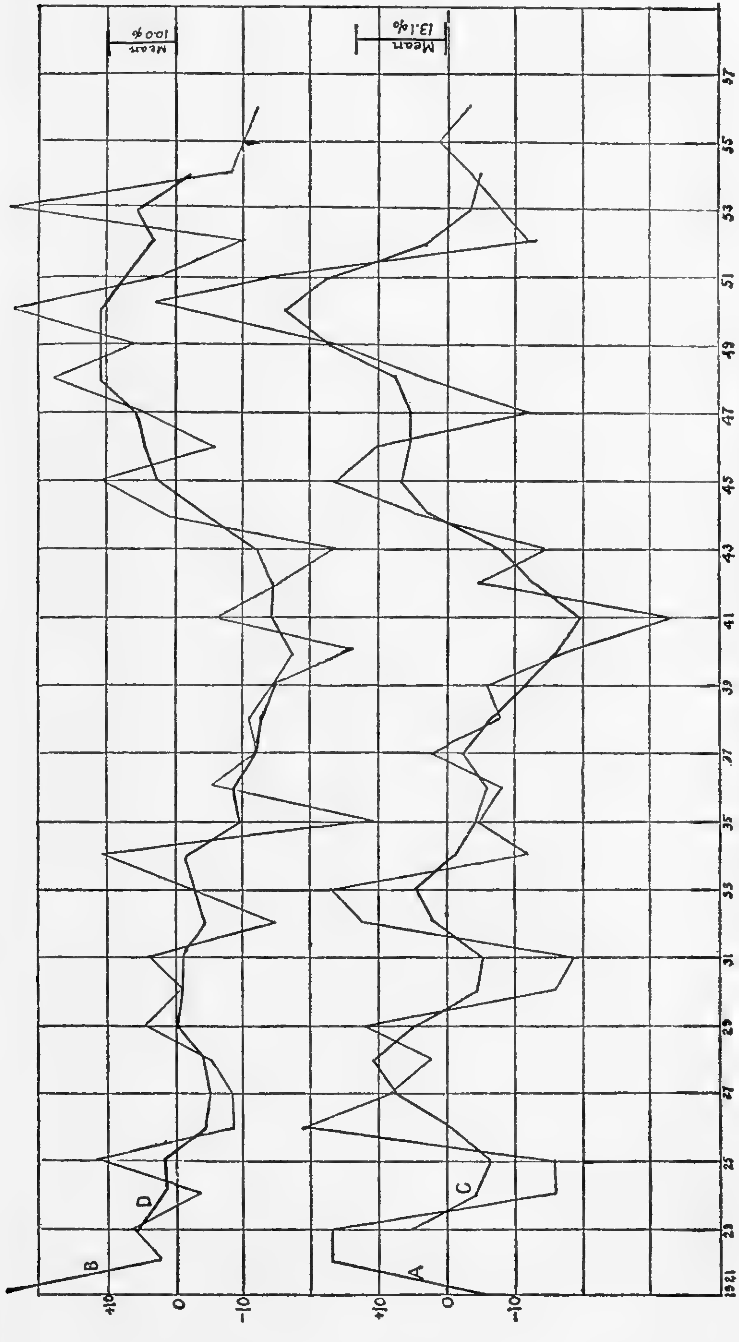
Number	Fraction	Period in months	Amplitude percent of solar constant	Number of repetitions per period
1	1/63	4 1/3	0.10	127
2	1/54	5 1/18	0.08	111
3	1/45	6 1/15	0.22	91
4	1/39	7	0.25	90
5	1/36	7 7/12	0.11	73
6	1/33	8 3/11	0.05	66
7	1/30	9 1/10	0.11	60
8	1/28	9 3/4	0.15	58
9	1/27	10 1/9	0.20	56
10	1/26	10 1/2	0.18	53
11	1/24	11 3/8	0.32	48
12	1/22	12 9/22	0.25	47
13	1/21	13	0.27	41
14	1/20	13 13/20	0.10	41
15	1/18	15 1/6	0.20	36
16	1/15	18 1/5	0.17	29
17	1/14	19 1/2	0.10	26
18	1/12	22 3/4	0.10	23
19	1/11	24 9/11	0.11	22
20	1/10	27 3/10	0.15	20
21	1/9	30 1/3	0.13	19
22	1/8	34 1/8	0.24	14
23	1/7	39	0.75	14
24	1/6	45 1/2	0.20	11
25	1/5	54 3/5	0.35	8
26	1/4	68 1/4	0.65	
27	1/3	91		

Now we turn to Nashville in figure 8, with its four curves of the same letters as Rochester. Obviously the same remarks hold almost *in toto.*



A & C observed & smoothed. B & D, forecast from 1884, smoothed.
Smoothing, $\frac{1}{10}(a+2b+4c+2d+e)$

FIG. 7.—Rochester, N. Y., yearly precipitation.



A & C observed & smoothed. B & D, forecast from 1884, smoothed.
Smoothing, 1/10 $(a+2b+4c+2d+e)$

FIG. 8.—Nashville, Tenn., yearly precipitation.

CONCLUSION

I feel that I may now justly claim to have made with my associates three discoveries of merit:

1. The sun's radiation varies far beyond accidental errors of observation, in numerous harmonic periods exactly related to 273 months.
2. Harmonic periods of these identical lengths exist, and with much greater percentage amplitude, in long records of the precipitation at scores of stations in all parts of the world.
3. Useful forecasts for many future years may be made when amplitudes and forms of these harmonic periods are determined from official records of precipitation for many past years.

It is shown that such forecasts are as close to observation at intervals when wide departures from the normal occur, as when the precipitation is nearly normal. (See Smithsonian Publication 4471, page 6, 1961.)

It would be interesting if some expert in mathematics should discover why terrestrial precipitation reacts so strongly to small percentage changes in the solar constant. I suggest a possible explanation in Smithsonian Publication 4135, page 3.

Mathematics may even be necessary in order to trace effects of certain human actions which may make records of the past inaccurate for future forecasts. Such may be super-powerful nuclear bombs, combustion of long train-loads of oil to propel spacecraft, and means used to effect changes in weather to improve it, as now proposed. All these may change atmospheric circulation and make past records useless for forecasting in the future.

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SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 148, NUMBER 9

Charles D. and Mary Vaux Walcott Research Fund

NEW LOWER CAMBRIAN TRILOBITE FAUNULE FROM THE TACONIC SEQUENCE OF NEW YORK

(With 12 Plates)

By
FRANCO RASETTI

Johns Hopkins University, Baltimore, Md.
Honorary Research Associate, Smithsonian Institution

(Publication 4662)

CITY OF WASHINGTON
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INTRODUCTION AND ACKNOWLEDGMENTS

The Lower Cambrian formations of the Taconic sequence in New York are among the most thoroughly investigated deposits of this age in eastern North America. After the classic faunal studies of Ford and Walcott in the second half of the last century, no essentially new faunules were discovered. Lochman (1956) described several new species and gave a general review of the known Lower Cambrian fossils of the sequence, occurring in what was formerly known as the Schodack Formation, now subdivided (Zen, 1964) into several units. All the species may be considered members of a single assemblage, named from the characteristic olenellid trilobite *Elliptocephala asaphoides.*

The discovery of an essentially new Lower Cambrian trilobite faunule was therefore unexpected. In 1956 Mr. Thomas W. Talmadge noticed the presence of fossiliferous limestone outcrops on a hill south of North Chatham, Columbia County. In 1963 Dr. John M. Bird collected small samples from two of these outcrops and submitted them to the U.S. Geological Survey for identification of the fossils. Dr. A. R. Palmer prepared and examined the specimens and recognized in one of the collections the presence of trilobites unlike any of those previously known from the Lower Cambrian of the Taconic sequence or any other region. He suggested to the writer a study of the new faunule. Collections much larger than the original ones were made by Dr. Bird and the writer, until most of the accessible, fossiliferous portions of the limestone outcrop had been recovered and examined. Hundreds of trilobite specimens, representing about 30 species, largely new and belonging to new genera, form the object of the present study.

The writer is indebted to the American Philosophical Society for grant No. 3454-P which defrayed field and laboratory expenses. He thankfully acknowledges the enthusiastic cooperation of Dr. John M. Bird in quarrying the limestone and searching for other fossiliferous localities. Thanks are also due to Dr. A. R. Palmer for suggesting this study and for valuable discussions on Cambrian faunas; to Mr. Thomas W. Talmadge for information on the results of his stratigraphic studies in the East Chatham quadrangle and for accompanying the writer on a field excursion; to Dr. George Theokritoff for information on an undescribed Lower Cambrian faunule from Washington County, New York; to Dr. E-an Zen for discussions on the Taconic sequence; and to Mr. A. W. A. Rushton of the British Geological Survey for communicating specimens and photographs of an undescribed faunule from England which shows interesting affinities with the one described herein.

OCCURRENCE AND PRESERVATION OF THE FOSSILS

The Cambrian strata in the northwestern quarter of the East Chatham 7½-minute quadrangle are notable for the development of regularly bedded limestone units, an unusual feature in the Cambrian of the Taconic sequence in Columbia and Rensselaer Counties, New York, where fossiliferous limestone generally occurs only in conglomerates. Among the localities where such limestone beds form outcrops is a hill (Griswold farm) about 1 mile southeast of North Chatham, Columbia County. The summit of the hill is a plateau where limestone beds interstratified with black shale form scattered outcrops. The beds strike north-south and dip steeply (50°-60°) east. All the fossils described herein (with the exception of one species from Quebec, Canada) were recovered from a limestone bed traceable through intermittent outcrops over a distance of several hundred feet. Even though fossils of the same faunule were observed at several places along this bed, only one block of limestone, about 1 foot thick, 5 feet long, excavated to a depth of 3 feet, supplied all the described fossils, the remainder of the limestone usually being too fine-grained to yield fossils. About 400 pounds of rock were removed and examined. The limestone is dark-gray, finely granular to aphanitic, in some portions the bedding being clearly marked by layers of more abundant insoluble material or fossil fragments, elsewhere indistinct. Most of the fossils were concentrated in small pockets.

The fossiliferous outcrop is located 27 mm from the west edge and 164 mm from the north edge of the East Chatham 7½-minute USGS quadrangle, scale 1 : 24,000 (USGS collections 3810, 4216; writer's collection cs-4). The faunule from this bed is referred to hereafter as the *Acimetopus bilobatus* faunule from one of the most common and characteristic trilobites.

The most common fossils are small inarticulate brachiopods, especially an acrotretid and less abundant linguloid forms. Trilobites are also copious in some portions of the rock, but most of the specimens are too fragmentary for identification. Evidently the tests were transported by currents for considerable time and distance before being covered by the sediment. All the trilobites are dismembered, except one cephalon with two thoracic segments attached. Nevertheless, many of the compact eodiscid cephala and pygidia did not suffer excessive damage. In exposing the fossils, the matrix invariably separates at the boundary of the outer surface of the test, hence ornamentation is well preserved. Some of the specimens suffered slight flattening or fracturing in the slumping or compaction of the sediment. Distortion due to tectonic deformation of the rock is present to a slight degree in some of the material.

The size of the trilobites presents an unusual situation. The Eodiscids are, on the average, large for the family. Examples of *Litometopus longispinus* indicate that the species attained a length of 50 mm, almost gigantic for an Eodiscid. Most of the examples are much smaller, but very small, immature specimens seem to be lacking, cephala or pygidia below 3 or 4 mm in length being rare. All the Olenellids on the contrary are of small size, fairly complete cephala not exceeding 4-5 mm in length. It seems difficult to attribute this fact to the delicate nature of the olenellid tests and their consequent fragmentation, since no fragments indicating individuals of medium or large sizes were observed. In the well-known conglomeratic limestones at Schodack Landing and Troy, even though the trilobite tests are excessively fragmentary and no large cephala have been recovered, the presence of adult examples of *Elliptocephala asaphoides* is proved by the frequent occurrence of fragments of their large pleurae. Nor can the lack of very small Eodiscids and large Olenellids be attributed entirely to sorting by current action, since very small brachiopods and relatively large Eodiscids are rather common.

AGE AND CHARACTER OF THE FAUNULE

The present information is insufficient to determine the precise relative age of the new faunule with respect to other known Lower Cambrian faunules of North America, and in particular of the Taconic sequence. The scanty stratigraphic evidence that might supply such information is summarized below.

Other fossiliferous strata form outcrops east of the bed yielding the *Acimetopus* faunule, and a greater variety of Cambrian fossils was obtained from limestone blocks in the surrounding stone walls, partly derived from beds not presently exposed. The next bed to the east, 45 feet higher stratigraphically than the *Acimetopus* stratum (under the unconfirmed assumptions that the intervening beds form an orderly stratigraphic succession and that the strata are not inverted), yielded a *Pagetides* faunule, also collected at several other localities in the northeastern quarter of the East Chatham quadrangle. *Pagetides elegans* and another species of the genus are by far the most common identifiable fossils in this faunule; Olenellid fragments, *Bonnia* and *Prozacanthoides* have been observed. The third fossiliferous limestone bed, which under the above assumptions would be about 450 feet higher stratigraphically than the *Acimetopus* bed, yielded *Pagetia* and *Peronopsis,* almost certainly indicative of the Middle Cambrian. Trilobites of the typical *Elliptocephala asaphoides* assemblage, such as *Elliptocephala* itself, *Calodiscus lobatus,* or *Serrodiscus speciosus,* have never been seen at the locality, either in outcrops or loose blocks; they are known in the East Chatham quadrangle only from the exposures of the Ashley Hill Conglomerate (Dale, 1904; Zen, 1964) whose type locality lies in the northeastern quarter of the quadrangle.

The structure of the area is exceedingly complicated, as may be observed, for example, in a deep cut on the road from North Chatham to Malden Bridge, which exposes a considerable thickness of limestone beds interstratified with black shale. The strata appear closely folded, causing some intervals to be repeated in reverse order, even though the dip seems to remain fairly constant. It would be difficult to discern such structures from scattered outcrops as observed at the *Acimetopus* locality, where one might readily be misled to infer an orderly succession. Limestone beds in the road cut yielded a *Pagetides* faunule, hence they may be equivalent to a portion of the section on the Griswold farm. For these reasons, the succession of faunules outlined above, i.e., in ascending order the *Acimetopus, Pagetides,* and *Pagetia-Peronopsis* faunules, is only suggested as tentative. Talmadge (private communication) from purely stratigraphic and structural evidence had previously reached the conclusion that by and large the strata on the Griswold farm become progressively younger toward the east, which would confirm the suggested order. He also considers all these strata higher than the Ashley Hill Conglomerate. Since the latter holds the *Elliptocephala* fauna not only in boulders, but also in a regularly bedded limestone interval at the base of the conglomerate, one might conclude that the latter fauna is older than the *Acimetopus* and *Pagetides* faunules.

The *Elliptocephala asaphoides* assemblage extends through a considerable thickness of strata in Washington County (Lochman, 1956; Theokritoff, 1964). It is possible that the difference between the *Acimetopus bilobatus* faunule and that assemblage is one of environment rather than age. A faunule reported by Theokritoff (1964) from Washington County, believed to be somewhat younger than the typical *Elliptocephala asaphoides* assemblage, shows no particular resemblance to the one described herein.

The *Acimetopus bilobatus* faunule is notable for the number and variety of trilobites of the family Eodiscidae, of which 9 new genera, 20 new named species, and an unnamed one are described herein, all based on cephala. A few unassigned pygidia, in part possibly representing additional species, are also described. None of the Eodiscidae can be referred to previously known species, even though several are referable to the well-known genera *Calodiscus* and *Serrodiscus.*

The Olenellidae are represented by numerous fragments of small individuals, referable to three species, none of which is the common *Elliptocephala asaphoides* known from numerous localities in the Taconic sequence of Washington, Rensselaer, and Columbia Counties. Immature Olenellid cephala cannot be specifically identified by comparison with adult individuals, and even the generic reference may remain doubtful, since several of the genera were based on the features of the entire exoskeleton. Two of the species are tentatively referred to *Paedeumias* and one to *Olenellus;* none shows close resemblance to named species.

The opisthoparian trilobites are represented by four undetermined species of *Bonnia,* a pygidium referred to *Kootenia,* and a peculiar pygidium belonging to an undescribed genus of uncertain affinities.

Conspicuously absent from the *Acimetopus bilobatus* faunule are Eodiscids with eyes and facial sutures, which constitute the family Pagetiidae, even though species of *Pagetides* are the most common trilobites in the nearest fossiliferous outcrop. Also totally absent are the ptychoparioid trilobites, so common in the late Lower Cambrian deposits of the Appalachian and Cordilleran provinces. No fragments referable to the Agnostids were observed.

Even though the *Acimetopus bilobatus* faunule has few, if any, species in common with the *Elliptocephala asaphoides* assemblage, the latter is still the Lower Cambrian fauna of North America which it resembles most closely. Possibly all the species, and many of the genera, are different, but the same families are represented, approximately in the same relative abundance: the Eodiscidae and Olenellidae are common, *Bonnia* and *Kootenia* are rare in both cases. The *Acimetopus bilobatus* faunule shows far less affinity with the late Lower Cambrian fauna of the Pacific province (cratonic facies of Lochman and Wilson, 1958), which is characterized by the abundance of Ptychoparioids and *Bonnia,* frequently includes *Kootenia, Protypus,* and *Prozacanthoides,* and also *Pagetia* and *Pagetides.* The resemblance is not very close either with the typical late Lower Cambrian fauna of the Acado-Baltic province (eugeosynclinal facies of Lochman and Wilson), chiefly characterized by the Protolenidae, where the Eodiscids are represented both by oculate (*Hebediscus*), and blind genera (*Calodiscus, Cobboldites, Serrodiscus*). In North America faunules of this type are known from Massachusetts and eastern Newfoundland (Hutchinson, 1962). The evidence favors the reference of the new faunule, like the *Elliptocephala asaphoides* assemblage, to an "intermediate realm" (Lochman and Wilson, 1958) between the cratonic and eugeosynclinal sedimentary provinces.

Through the courtesy of Mr. A. W. A. Rushton, the writer was able to examine specimens and photographs of a remarkable new faunule discovered in the Purley Shales of Warwickshire, England. The faunule includes several new species of Eodiscidae, of which two belong to new genera, one is a *Serrodiscus* remarkably similar to *Serrodiscus subclavatus* described herein, and another is definitely referable to *Acidiscus,* closely resembling *Acidiscus hexacanthus* in possessing two pairs of marginal cephalic spines. The Eodiscidae in the Purley Shales are associated with *Ellipsostrenua* and *Condylopyge.* Even though all the previously described species of this agnostid genus occur in the Middle Cambrian, the remainder of the faunule is suggestive of a late Lower Cambrian age. A fairly close time equivalence of the two faunules may be indicated by the presence of closely related Eodiscidae.

SYSTEMATIC DESCRIPTIONS

GENERAL STATEMENT

All the fossils described herein were deposited in the U.S. National Museum collections, excepting one specimen from Quebec which is in the collections of the Geological Survey of Canada.

All the illustrations show the outer surface of the test.

The abbreviations (tr.) for transverse, (sag.) for sagittal, and (exsag.) for exsagittal qualify such terms as "wide," "short," etc., whenever the direction of the measurement might otherwise be misinterpreted.

Family EODISCIDAE Raymond, 1913

The Eodiscidae are the most numerous and interesting of the trilobites described herein, as they show a greater variety of forms than the genera previously known. Hence the characters observed in the different parts of the exoskeleton are briefly discussed.

All the species described herein are represented by separate cephala and pygidia; hence the number of thoracic segments is unknown.

Owing to the large number of species occurring in the same bed, matching of cephala and pygidia presented a problem. In several cases assignments with varying degree of probability could be made. Criteria for associating cephala and pygidia that were used are general shape, size, surface ornamentation, and frequency of occurrence. It is unlikely that the collection contains a pygidium for every cephalon or vice versa. To avoid the risk of nomenclatural confusion, no taxa were based on pygidia; those pygidia that could not be assigned to cephala are described and illustrated but not named.

Features of the various parts of the exoskeleton are discussed below.

Glabella.—The glabella shows considerable variety of form. It may be tapered as in *Bolboparia,* where it is short in proportion to the length of the cephalon; more or less parallel-sided as in most of the species; or even somewhat expanded toward the front as in *Serrodiscus subclavatus* and *Bathydiscus dolichometopus.* Lateral furrows are usually short and shallow or absent. However, in *Acimetopus, Analox,* and some species of *Calodiscus,* the glabella is divided by a deep transverse furrow into an anterior and a posterior lobe. A tendency in this direction had been observed, for example, in *Calodiscus lobatus* and its form *agnostoides* (Lochman, 1956), in *C. helena, C. meeki,* and even in *Serrodiscus speciosus* (Rasetti, 1952).

In these cases there may even be two shallow furrows across the glabella. The sharp and deep transglabellar furrow of *Acimetopus bilobatus* and *Calodiscus reticulatus,* and the somewhat shallower one of *Analox bipunctata,* seem to represent more advanced stages of this type of glabellar lobation. A sharp transverse furrow was previously known in *Opsidiscus bilobatus* (Westergard, 1946) and *Tannudiscus tannuolaicus* (Pokrovskaya, 1959). It is not clear whether the transglabellar furrow in these Eodiscids, and the possibly homologous furrow in the Agnostids, result from modification of one of the pairs of glabellar furrows, or are independent of them, representing a secondary segmentation. The doubt is suggested by the probable secondary nature of the segmentation of the pygidial axis in the Agnostids (Palmer, 1955).

In *Acimetopus* the glabellar lobation is the most specialized of any described Eodiscid, the broad transglabellar furrow possessing a pair of small, rounded lobes at the sides.

In *Stigmadiscus,* and to a lesser extent in *Acidiscus,* the two pairs of lateral glabellar furrows assume the form of short, fairly deep pits, a feature unusual in the family even though it occurs in other groups of trilobites.

Another unusual character for the Eodiscids is the extension of the posterior portion of the glabella into an upright spine, observed in *Acidiscus, Acimetopus,* and *Bolboparia.* In *Acidiscus* there is, in addition, an occipital spine, whereas in *Acimetopus* and *Bolboparia* the occipital ring is short and simple.

Cephalic border.—A definite border furrow and border around the cephalon are present in all genera excepting *Analox* where the lateral border is missing, although an anterior border of triangular shape and the posterior border are well developed. One of the striking features of the border in several of the new genera is the development of marginal spines at various positions.

One pair of short, lateral marginal spines is observed in *Acimetopus, Bolboparia, Litometopus,* and *Acidiscus birdi.* Two pairs are present in *Acidiscus hexacanthus* and *Oodiscus subgranulatus.* As the spines vary in position, it is questionable whether they can be homologized among the different species.

The posterior cephalic border shows variable features that can not be readily homologized among the different genera. In many of the species it bears a pair of spines, which may vary in position from less than halfway from the axial furrow to the genal angle (in *Oodiscus, Bathydiscus,* and *Stigmadiscus stenometopus*) to the proximity of the genal angle as in *Serrodiscus subclavatus, Acimetopus biloba-*

tus, Bolboparia superba, Acidiscus birdi, Litometopus longispinus, and *Stigmadiscus gibbosus.* Presumably the spine should be considered homologous in all these genera, but there are no decisive arguments in favor of this assumption. In *Oodiscus* and *Bathydiscus* the base of the spine coincides with the position of a sharp geniculation, the portion of the posterior border distal to this point being sharply bent downward and somewhat forward. In *Litometopus longispinus* and, to a lesser extent, in *Serrodiscus subclavatus,* the posterior border presents an unusual feature consisting of a narrow ridge separated from the main part of the border by a short, transverse furrow. The distal end of this ridge produces a slight rearward projection of the posterior margin. In one specimen of *Serrodiscus subclavatus* preserving two thoracic segments attached to the cephalon, the ridge on the cephalic margin is seen to correspond to the fulcrum on the anterior margin of the first thoracic segment. A similar feature is present at the articulation between the first and second thoracic segments. In *Litometopus longispinus* the tooth on the posterior cephalic border is more conspicuous. In both species the "genal" spine is located more distally than these features.

Pygidium.—The pygidia present less variety than the cephala. The axis is always well defined except in one unassigned pygidium where the axial furrow is barely indicated. In *Acimetopus* and *Bolboparia* there is a large, upright spine on the second axial ring. In *Serrodiscus subclavatus* there is a long spine on the posterior part of the unsegmented axis. In *Acidiscus* there are spines on several of the axial rings. Border furrow and border are well differentiated in all pygidia. A well-developed articulating facet is present in all genera; this is the most obvious feature for distinguishing pygidia from cephala in doubtful cases. Marginal spines, sometimes visible from above, more often appearing as extensions of the doublure and hence ventral in position, may be present. In most species the doublure is reflexed as usual in trilobite pygidia. However, in *Analox bipunctata* and the pygidium attributed to *Bathydiscus dolichometopus,* the pygidial doublure forms an almost vertical face rather than being reflexed inward to parallel the dorsal exoskeleton. In neither species this feature is present in the cephalon, where the doublure appears to be narrow and not sharply defined, the dorsal test being gradually downrolled.

Ornamentation.—The outer surface of the test may be smooth, punctate, finely granulate, coarsely granulate with granules of one size (*Acimetopus*) or different sizes (*Bolboparia*). The larger of these granules seem broken at the tip and may represent the bases of short spines. *Calodiscus reticulatus* has a strong reticulate ornamentation.

Classification.—The Eodiscidae of North America have so far been referred to five genera (Rasetti, 1952): *Calodiscus* Howell, 1935 (type species, *Agnostus lobatus* Hall); *Dawsonia* Hartt in Dawson, 1868 (type species, *Microdiscus dawsoni* Hartt in Dawson); *Eodiscus* Hartt in Walcott, 1884 (type species, *Eodiscus pulchellus* Hartt in Walcott=*Microdiscus scanicus* Linnarsson); *Serrodiscus* R. and E. Richter (type species, *Eodiscus* (*Serrodiscus*) *serratus* R. and E. Richter); and Weymouthia Raymond, 1913 (type species, *Agnostus? nobilis* Ford). Of these five North American Eodiscid genera, *Dawsonia* and *Eodiscus* occur exclusively in the Middle Cambrian *Paradoxides* beds; the other genera are Lower Cambrian.

Genera that have been proposed for Eodiscidae from Europe and Asia are *Cobboldites* Kobayashi, 1943 (type species, *Microdiscus comleyensis* Cobbold); *Metadiscus* Kobayashi, 1943 (type species, *Microdiscus sculptus* Hicks); *Ladadiscus* Pokrovskaya, 1959 (type species, *Ladadiscus limbatus* Pokrovskaya). To these genera the writer would add *Tannudiscus* Pokrovskaya, 1959 (type species, *Tannudiscus tannuolaicus* Pokrovskaya), originally assigned to the family Opsidiscidae (Pokrovskaya, 1959), which seems of questionable validity since *Opsidiscus,* which has vestigial eyes but no facial sutures, could be referred either to the Pagetiidae or the Eodiscidae, the presence of a transglabellar furrow having little significance. *Tannudiscus* has no trace of eyes and should be placed in the Eodiscidae even if a separate family Opsidiscidae were recognized.

The nine new genera described herein approximately double the size of the family and it was considered whether the additional knowledge suggested some grouping of the genera that would indicate evolutionary trends. On the basis of present knowledge there seems to be no basis for a meaningful arrangement of the genera. The glabellar lobation, which in general is one of the important taxonomic features in trilobites, seems of little significance, as shown by the gradual transition from generalized lobation to the specialized lobation where all furrows have disappeared but for a deep, straight transglabellar furrow (*Calodiscus reticulatus*). Other characters, such as shape and relative length of the glabella, cephalic border furrow and border, glabellar, occipital and marginal cephalic spines, ornamentation, etc., seem even less significant, as also are believed to be the pygidial features. Even an arrangement of the genera based on characters of little evolutionary and taxonomic significance would be difficult to carry out because genera that are alike in one feature are apt to be strikingly different in one or several others. For this reason the genera are described herein in alphabetical order.

ACIDISCUS Rasetti, new genus

Description.—Cephalon of moderate convexity, semielliptical. Glabella not reaching the anterior border, subcylindrical, with two short, somewhat pit-like pairs of lateral furrows, in the two known species possessing a small upright spine on its posterior portion. Occipital furrow wide; occipital ring well defined, bearing a spine. Posterior border straight from the axial furrow to the base of the genal spine. Lateral cephalic border with one or two pairs of marginal spines.

Pygidium with long, multisegmented axis. Geniculation situated rather distally; facet well developed. Pleural regions unfurrowed; border and border furrow well developed, of average width. Surface smooth or with weak ornamentation. The narrow doublure may be extended into short spines.

Type species.—Acidiscus birdi Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York. Also in the Purley Shales of Warwickshire, England (Rushton, private communication).

Discussion.—This genus is obviously a close relative of *Serrodiscus.* The pygidium is much the same as in that genus. The cephalon, however, has important distinctive features, the most significant being the development of glabellar and occipital furrows. Another distinctive character is the tendency to develop spines on the glabella, occipital ring, at the genal angle, and on the cephalic border. The glabellar furrows also indicate relationship to *Stigmadiscus;* in several features *Acidiscus* may be considered transitional between the latter genus and *Serrodiscus.*

ACIDISCUS BIRDI Rasetti, new species

Plate 1, figure 2; plate 6, figures 11-19

Available material.—Numerous cephala and pygidia, of which a few are fairly complete.

Description.—Cephalon semielliptical. Glabella rising well above the cheeks, very convex transversely, tapered in anteriormost portion, narrowly rounded in front, occupying with occipital ring more than two-thirds of cephalic length. Two pairs of distinct, short, somewhat pit-like lateral furrows; the posterior pair longer, directed backward almost to meet occipital furrow, hence defining small, elongate-triangular basal lobes. The glabella reaches maximum elevation near the posterior end, at the level of the posterior pair of lateral furrows, where it possesses a small upright spine. Occipital furrow deepened into a pair of small pits laterally, wide medially; occipital ring of moderate length (sag.), extended into a spine incomplete in all specimens. Cheeks convex, not separated medially by a preglabellar depression, sloping steeply to border furrow in posterior portion. Border lying in a plane, slightly convex, widest medially, narrowing toward the genal angles, possessing a pair of small lateral spines anterior to the level of the front end of the glabella. A series of five or six pairs of low tubercles, as usual in species of *Serrodiscus,* is visible on the lateral border. The posterior border furrow is directed outward and slightly forward from the axial furrow, thus forming an angle with the posterior cephalic margin and giving the posterior border an elongate-triangular shape. Posterior cephalic margin straight from axial furrow to base of short, outward-directed genal spine.

Pygidium similar to cephalon in general shape, somewhat more distinctly subtriangular. Axis narrow and long, barely failing to reach the posterior border furrow, fully segmented for the entire length, composed of 12 rings including the terminal one. There is a short, upright spine on each of the first seven axial rings. Pleural regions convex, totally unfurrowed. Border furrow deep, border relatively narrow, of almost even width. Articulating facet well developed. Border extended downward and inward into narrow doublure forming a series of blunt spines not visible except by removing the matrix under the border; terrace lines on doublure following the serrated outline.

Surface of test mostly smooth, except for granules visible in some specimens on the last few axial rings and sometimes on the posteriormost portion of the pleural regions. Length of largest (incomplete) cephalon 18 mm, width 20 mm. Length of largest pygidium 12 mm, width 16 mm.

The species is named for Dr. John M. Bird who collected the holotype.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 145987. Paratypes: U.S.N.M. 145988.

ACIDISCUS HEXACANTHUS Rasetti, new species

Plate 7, figures 1-6

Available material.—Two cephala and one pygidium.

Description.—It is sufficient to point out the differences from the type species. Shape and convexity of cephalon and pygidium the same as in *A. birdi.* Glabella and occipital ring, including the spines, almost identical. Cephalic border bearing, in addition to an anterior pair of spines as in *A. birdi,* a second pair halfway between the first pair and the genal angle. Posterior cephalic border and genal spine as in preceding species. Lateral border lacking tubercles.

Pygidium (referred to the species on account of the ornamentation) with entirely segmented axis, also showing 12 rings including the terminal section. Axial spines developed on the first six instead of seven rings. The character of the pygidial doublure has not been ascertained.

Surface of cheeks and pleural regions of pygidium covered with small, sparse, but sharply elevated granules. The ornamentation is less marked in the holotype cephalon than in the paratype cephalon and pygidium. Similar individual variations in the identical type of ornamentation were observed in *Oodiscus subgranulatus.*

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 145989. Paratypes: U.S.N.M. 145990.

ACIMETOPUS Rasetti, new genus

Description.—Cephalon and pygidium strongly convex. Glabella divided by a deep, wide transglabellar depression into anterior and posterior lobes. Anterior lobe bulbous, not reaching the anterior border. Transglabellar depression subdivided laterally into two pairs of furrows, isolating a pair of small lobes; these furrows are confluent medially into one broad furrow. Posterior glabellar lobe strongly elevated and extended into a long, uptilted spine. Occipital ring short (sag.), well defined by occipital furrow, not spinose, partly concealed in dorsal view by the rearward extension of the glabella. Cheeks strongly convex, confluent anteriorly without any trace of a preglabellar depression, in their posterior portion overhanging the border furrow. Border well developed, defined by a deep border furrow, approximately lying in a plane, wide anteriorly, tapering toward the genal angle, extended into a pair of small lateral spines. Near the genal angle the lateral border furrow is confluent with the deep posterior border furrow; the border at this point is greatly reduced.

The posterior cephalic margin is straight, lacking geniculation, and extends into a short, outward-directed genal spine.

Pygidium with strongly elevated axis, furrowed for entire length and showing in type species nine segments; axis almost reaching the border, possessing a strong upright spine on the second ring. Pleural regions strongly convex and steeply downsloping; border furrow deep, border of even width, lacking spines. Surface strongly granulate.

Type species.—*Acimetopus bilobatus* Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—The genus is characterized by the glabella deeply divided into anterior and posterior lobes, a feature present in some forms of *Calodiscus,* and also well developed in *Analox.* However, *Acimetopus* is unique in the development of the extra pair of small lateral lobes in the transglabellar depression.

ACIMETOPUS BILOBATUS Rasetti, new species

Plate 2, figure 3; plate 4, figures 1-14

Available material.—Numerous, well-preserved cephala and pygidia. The assignment of the two shields to one species is unquestionable because of the unique ornamentation among the members of the faunule.

Description.—Features indicated in the generic description are not mentioned. The anterior glabellar lobe is exceedingly convex, falling vertically to the preglabellar field, moderately rounded anteriorly and slightly wider than the posterior lobe; the latter is more nearly straight-sided. The glabellar spine varies somewhat in size and attitude among the specimens; on the average it is directed upward at an angle about 30° and is sharply pointed. The border spines are situated somewhat in advance of the midpoint of the anterior glabellar lobe and are short and rapidly tapered.

The pygidial axis is deeply furrowed for the entire length, the furrows being deeper laterally. The second segment has a strong, long upright spine whose base somewhat encroaches on the adjacent ring furrows; it was not possible in any case to extract the entire spine from the matrix. The pleural regions are so convex that they somewhat overhang the border furrow, which is deep and wide. Border convex, relatively narrow.

Entire surface covered with large, elevated granules of one size. Length of largest cephalon, exclusive of glabellar spine, 9.5 mm, width 10 mm. Length of largest pygidium 7.5 mm, width 7 mm.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 145991. Paratypes: U.S.N.M. 145992.

ANALOX Rasetti, new genus

Description.—Cephalon of moderate overall convexity, well rounded, somewhat narrowing toward the front. Glabella terminating in the merged axial and border furrows, divided into posterior and anterior lobes by a wide, moderately deep transglabellar furrow; no other furrows present. Posterior glabellar lobe strongly elevated and extended backward into a broad spine. Occipital ring short, barely differentiated under the rearward extension of the glabella. Anterior border swollen medially, defined by a pair of furrows directed outward and forward from the anterior angles of the glabella, not reaching the cephalic margin but ending abruptly in a pair of pits. Lateral border absent; cephalic margin in this portion downrolled into the doublure. Posterior border furrow and border well developed; geniculation distally located; genal spine absent. Border furrow extended for a short distance forward from the genal angle and then fading out.

Pygidium about equally wide and long, rather strongly convex; posterior outline regularly rounded. Axis relatively narrow, defined by a narrow but deep axial furrow, not greatly raised above the general convexity, in type species showing seven rings plus a terminal section, lacking nodes or spines. Border present but exceedingly narrow, defined by an equally narrow border furrow. Doublure forming a vertical face, not extended into spines.

Type species.—Analox bipunctata Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—The glabella with its transglabellar furrow is like certain forms herein attributed to *Calodiscus.* The unique feature of the genus is the lack of a lateral cephalic border. The pygidium in dorsal view resembles the pygidia of *Pagetides,* but has the unusual vertical doublure.

ANALOX BIPUNCTATA Rasetti, new species

Plate 2, figure 2; plate 6, figures 1-10

Available material.—Numerous, well-preserved cephala and pygidia. This is one of the more common species of the *Acimetopus bilobatus* faunule.

Description.—Most of the features were indicated in the generic diagnosis. Glabella defined by a broad, fairly deep axial furrow;

anterior glabellar lobe barely rising above the cheeks; posterior lobe extended into a broad spine tilted at about 30°; the spine appears to be bluntly terminated, although this portion is not well preserved in any of the cephala. The cephalic margin lies approximately in a plane. The pygidial axis has rings well defined by straight ring furrows becoming gradually shallower toward the rear, deeper medially, and shallower near the axial furrows. The axis does not reach the posterior border, although it appears almost to do so in dorsal view on account of the strongly downsloping marginal portions of the pleural regions. The excessively narrow lateral border furrow and border maintain an almost even width throughout. The anterior border furrow instead is relatively wide; the anterior pygidial margin has a straight transverse course from the axial furrow to the geniculation, which is closer to the lateral margin than to the axial furrow. The facet is well developed.

The surface of the test is finely punctate, this ornamentation both in the cephalon and pygidium being more marked on the pleural than the axial parts. Length of the larger cephala, exclusive of glabellar spine, 4 mm, width 5 mm. Length of largest pygidium 3.5 mm, width 4 mm.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 145093. Paratypes: U.S.N.M. 145094.

BATHYDISCUS Rasetti, new genus

Description.—Cephalon with considerable relief. Glabella with almost undifferentiated occipital ring prominent, slightly expanded forward, reaching the anterior border, unfurrowed. Cheeks convex and downsloping. Border convex, wide, well defined by a border furrow inbent on either side of the anterior portion of the glabella to merge with the axial furrow. In anterior view, the medial portion of the border is seen to be slightly arched, instead of lying in a plane as in most Eodiscids. Posterior cephalic border with sharp geniculation and short, erect spine located close to axial furrow as in *Oodiscus.* Surface of test smooth.

Pygidium tentatively assigned to the type species with long, well-defined, unfurrowed axis not reaching the border furrow. Border furrow narrow laterally, widened posteriorly; border narrow, slightly elevated. Doublure not reflexed to parallel the dorsal exoskeleton as in most Eodiscids, but almost vertical, with a slight inward slope, wide everywhere except in the posteriormost portion. This attitude of the doublure gives the pygidium as a whole an unusual depth.

Type species.—*Bathydiscus dolichometopus* Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—The cephalon indicates close relationship to *Oodiscus* as evidenced by the same general shape, characters of glabella and occipital ring, position of the geniculation and spine on the posterior border. The chief difference is the extension of the glabella encroaching upon the anterior border furrow and the peculiar inbend of the latter at the sides. Another important feature is the arched anterior border, which does not occur in *Oodiscus.* If the pygidium is correctly assigned, its peculiar doublure represents one of the most characteristic features of the genus.

BATHYDISCUS DOLICHOMETOPUS Rasetti, new species

Plate 1, figure 3; plate 9, figures 1-16

Available material.—Several cephala and about an equal number of pygidia.

Description.—Cephalon highly convex, semielliptical, well rounded in front. Glabella strongly elevated, slightly pear-shaped, well rounded in front, totally unfurrowed. Occipital furrow very shallow at the sides, obsolete medially; occipital ring very short, continuing the longitudinal profile of the glabella, extended farther backward than the cheeks. Cheeks very convex, laterally sloping down vertically to the border furrow. Border furrow well impressed, laterally paralleling the cephalic margin, anteriorly inbent at each side to merge with the axial furrow that separates the front of the glabella from the border. Border convex, wide, lacking tubercles. Cephalic doublure very narrow, normally reflexed. Border in anterior view arched medially, paralleled by the border furrow which rises on each side to meet the axial furrow. The pygidium is referred to the species chiefly on account of the position of the geniculation and the fit of the up-arched anterior border of the cephalon and down-arched posterior border of the pygidium, an arrangement that must have ensured a close fit of the two shields in enrollment. Pygidium widest at anterior end, semielliptical, with strong relief. Axis elevated, well defined by the axial furrow, tapered, occupying about three-fourths of the pygidial length, unfurrowed. Articulating half-ring short (sag.), defined by a deep articulating furrow. Pleural regions convex and downsloping. Anterior border with sharp geniculation at one-third the distance from the axial furrow to the lateral margin; articulating facet well developed. Border narrow and but slightly elevated laterally, defined by a very shallow border furrow, but elevated at the level of the posterior end of the axis. Beyond this elevation the border appears concave upward in posterior view, while the border furrow widens and the border becomes almost flat medially. Doublure wide, sloping but slightly inward and forming an almost vertical face. The edge of the doublure does not partake of the downward curve of the posterior border, hence the doublure is much narrower in its posteriormost portion. Doublure with irregular terrace lines and smooth margin. Upper surface of cephalon and pygidium perfectly smooth. Length of largest pygidium 11 mm.

Occurrence.—Collections cs-4 and USGS 4216, North Chatham.

Types.—Holotype: U.S.N.M. 145995. Paratypes: U.S.N.M. 145996-7.

BOLBOPARIA Rasetti, new genus

Description.—Cephalon with strong relief. Glabella well tapered, pointed in front, highest posteriorly where it extends into an upright spine. Lateral furrows short, of generalized pattern. Occipital furrow distinct, occipital ring short (sag.) and simple. Cheeks as a whole forming a subquadrate area in dorsal view, rising from a low posterior part to their highest point near the anterolateral angles, here bulging and overhanging the lateral border. The relatively long (sag.) preglabellar field is a broad depression separating the bulging cheeks. Anterior portion of border expanded; border narrowest laterally under the bulge of the cheeks, widening again toward the genal angle, extended into a pair of small, lateral spines and near the genal angle carrying one or more pairs of tubercles. In front of the genal angle the lateral border furrow merges with the posterior border furrow, at considerable distance from cephalic margin. Posterior border furrow directed obliquely outward and forward from the axial furrow, sharply turning outward after merging with the lateral border furrow, and reaching the lateral cephalic margin well in advance of the genal angle which bears a small spine.

Pygidium semielliptical, strongly convex transversely. Axis well defined, long, with numerous rings, the second bearing a large spine. Pleural regions unfurrowed; border narrow, extended into minute, downward-directed spines. Surface of test densely granulate in the three known species.

Type species.—Bolboparia superba Rasetti, new species.

Occurrence.—Later Lower Cambrian of New York and Quebec.

Discussion.—This is probably the most distinctive of all the new genera of Eodiscidae described herein. The short, downsloping glabella and the bulging cheeks give it a very peculiar aspect. Among previously known forms it might perhaps be compared with *Calodiscus walcotti* Rasetti (1952), unfortunately known from a single, somewhat incomplete cephalon. This form also has a pointed, but much longer, glabella, whose posterior portion is extended into a spine. The cheeks, however, have a normal shape.

BOLBOPARIA SUPERBA Rasetti, new species

Plate 3, figure 1; plate 5, figures 1-6

Available material.—A few cephala, small and more or less fragmentary excepting the holotype which is a large, almost perfect example. Also a thoracic segment attributed to the species.

Description.—Cephalon somewhat wider than long, widest at the posterior third, slightly narrowed toward the genal angle, pointed in front. Glabella occupying about two-thirds of the cephalic length, defined by a very deep axial furrow, well tapered, pointed in front, extended into a slender almost vertical spine just in front of the occipital furrow. Lateral furrows short, merging with the axial furrow; two pairs relatively deep, one additional pair barely visible. Occipital furrow straight, deeper at the sides, but not quite connecting with the axial furrows; occipital ring wider medially, with rounded outline. Cheeks bounded by an irregular line, consisting of strongly oblique posterior border furrow, followed by an almost longitudinal section of the lateral border furrow; at this point the cheeks are widest, then narrow again for a considerable, fairly straight portion; then the outline curves sharply inward in correspondence with the highest part of the bulge and becomes fairly straight, transverse in the anterior portion. The border furrow is well marked all around the cheeks and attains its maximum depth anterolaterally. The border extends into a pair of small, slender spines located somewhat back of the level of the anterior end of the glabella. Two rounded tubercles are located in the wider portion of the lateral border just in front of the posterior border; as mentioned in the generic diagnosis, a deep furrow separates here the lateral border, elevated into the posterior tubercle, and the posterior border, carrying the short genal spine.

Entire surface very densely covered with granules of various sizes; the largest appear broken at the tip and may represent the bases of short spines. Length of largest (holotype) cephalon 9.0 mm, width 11.0 mm.

A peculiar thoracic segment is attributed to the species because the ornamentation of the pleura is similar to that of the cephalon. On each side of the axis there is an oblique furrow, directed outward and forward, reaching the axial furrow at the anterior corner of the ring. The pleura is flat and horizontal for most of its length, with a furrow paralleling and close to the posterior margin. The anterior margin has a very sharp geniculation, where it bends backward and downward, forming a marked facet. At the fulcrum a very narrow ridge is set off near the anterior margin by a shallow furrow, a feature also observed in *Serrodiscus subclavatus.* The distal end forms a short, sharp spine directed outward and backward.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 145998. Paratypes: U.S.N.M. 145999.

BOLBOPARIA ELONGATA Rasetti, new species

Plate 3, figure 2; plate 5, figures 7-12

Available material.—A few cephala, of which two reasonably complete, and three tentatively assigned, incomplete pygidia.

Description.—The cephalon is so similar to the type species that it is sufficient to point out the differences. Cephalon somewhat longer than wide. Glabella proportionately narrower and longer than in *B. superba,* bearing the same kind of lateral furrow and posterior spine. Anterior cephalic outline somewhat more sharply pointed; cheeks bulging anteriorly but not as much as in the type species; outline at the anterolateral corners turning even more abruptly than in that species. Posterior portion of border furrow even more oblique than in *B. superba,* forming an angle of 45° with the axis of the body. Widened posterior portion of lateral border bearing two pairs of tubercles as in preceding species. Genal angle not well preserved. Length of largest cephalon 8 mm. Ornamentation as in preceding species.

Three incomplete examples of a pygidium undoubtedly belong to *Bolboparia* as they match the unique ornamentation of the cephala. However, the reference to *B. elongata* rather than *B. superba,* suggested by the relatively narrow shape, is tentative. Axis moderately wide, slightly tapered, defined by deep axial furrows, almost reaching the posterior border, furrowed for entire length, showing approximately 12 rings; end portion not well preserved. A broad-based spine on the second ring encroaches on the adjacent ring furrows. Pleural regions attaining a vertical slope, almost concealing the border in dorsal view. Border furrow well impressed; border vertical, extended into about 12 pairs of minute spines. Length of largest pygidium 8 mm.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 146001. Paratypes: U.S.N.M. 146002.

BOLBOPARIA CANADENSIS Rasetti, new species

Plate 5, figures 13, 14

Available material.—A single, well-preserved cephalon.

Description.—Cephalon relatively broad and short as in *B. superba.* Glabella somewhat longer in proportion to the cranidium, long and narrow, subconical, pointed in front. Three pairs of lateral furrows impressed, the posteriormost pair deep, short, pit-like, the other two similar but increasingly shallow. The glabellar spine is broken off, but its base shows that it was large and equally located as in *B. superba.* Occipital furrow straight, of even width throughout; occipital ring short and simple. Outline of the cheeks of the same general type as in *B. superba,* but differing in several details. The posterior portion, from the axial furrow to the widest point of the cheeks, is almost straight, since there is hardly any change of direction between the posterior border furrow and the posterior portion of the lateral furrow. Where these furrows meet, there is the usual deep furrow directed toward the cephalic margin; but in the present species this furrow extends also inward and forward, forming a broad, shallow depression across the cheek reaching the axial furrow at the level of the middle pair of glabellar furrows. At the widest point, the cheek outline forms a narrowly rounded angle, continues straight forward and somewhat inward to the anterolateral corners where the cheek attains its highest elevation, and then curves to a transverse inward course as in *B. superba.* As a whole the cheeks acquire thereby a peculiar subhexagonal outline. The border furrow and border are much like the other species, except that there is only one, large tubercle at the posterior end of the lateral border. The small lateral border spines are in the same position as in *B. superba.* Ornamentation identical with the other two species of the genus. Length of cephalon 4.5 mm, width 4.8 mm.

Occurrence.—The single known specimen was collected by Mr. Claude Hubert when mapping an area near the south shore of the St. Lawrence River in Quebec. The collection, designated as 63-F24, is stated to be made from a calcarenite bed a half mile north of Elgin Station, L'Islet County. The locality is about 60 miles northeast of

Levis. Unfortunately no other identifiable fossils were recovered from this bed, although trilobite fragments presumably representing Olenellids were observed. Lower Cambrian strata are known from this general area, and were designated by the writer (Rasetti, 1964) the Charny formation, to avoid the confusion associated with names previously in use. The easternmost occurrence of identified Lower Cambrian beds in place (the *Botsfordia pretiosa* shale) previously reported was about 20 miles northeast of Levis; hence Mr. Hubert's finding extends the known presence of Lower Cambrian strata 40 miles northeast. Lower Cambrian fossils at many other localities farther east are only found in boulders in Lower Ordovician conglomerates.

It should be pointed out that the only Lower Cambrian Eodiscid trilobites previously known from the Charny formation (Rasetti, 1945) belong to the family Pagetiidae. The same applies to the forms described (Rasetti, 1948) from conglomerate boulders. However, Raymond (1913) mentioned the presence of a blind Eodiscid, *Serrodiscus speciosus,* in the boulders at Bic. The writer, who collected thousands of Lower Cambrian trilobite specimens from that and nearby localities, was unable to find this species or any other blind Eodiscid. Search in the collections of the Geological Survey of Canada and the U.S. National Museum failed to yield any such material from the Bic locality. Hence the writer (1948) did not include *Serrodiscus speciosus* in the list of species from the Lower Cambrian of the Quebec conglomerates.

Recently two good specimens of *Serrodiscus speciosus,* one cephalon and one pygidium, bearing labels of the Bic locality and preserved in the characteristic, light-gray limestone prevailing in those conglomerates, were discovered in the collections of the New York State Museum. The writer was able to examine these through the courtesy of Dr. Donald W. Fisher. It is thus now ascertained that there are at least two blind Eodiscids in the Lower Cambrian of Quebec.

Type.—Holotype: Geological Survey of Canada No. 19887.

Genus CALODISCUS Howell, 1935

Type species.—*Agnostus lobatus* Hall.

CALODISCUS FISSIFRONS Rasetti, new species

Plate 9, figures 17-21

Available material.—A few cephala, mostly fragmentary, and two tentatively assigned pygidia.

Description.—Glabella divided by a broad transverse furrow into anterior and posterior lobe; lobation more marked in larger individuals. Anterior lobe rounded, slightly narrower than posterior lobe; the latter rising steeply and extended upward and backward beyond the occipital ring; whether this extension is rounded or pointed at the extremity could not be determined, as this portion is incompletely preserved. One pair of short lateral furrows is visible on the posterior lobe. Occipital ring short (sag.), mostly masked in dorsal view by the glabellar extension, directed inward and backward at the sides. Cheeks strongly convex, in their posterolateral part overhanging the border furrow. Border expanded medially and causing a slight median inbend of the border furrow which here forms a depression by merging with the axial furrow; border narrowing gradually toward the genal angle. Posterior cephalic border poorly preserved. Surface of test faintly reticulate; lateral border with four or five pairs of low tubercles.

Pygidium tentatively referred to the species on account of similar ornamentation with axis well defined by deep axial furrows, showing about seven rings plus a terminal unsegmented section, almost reaching border. The first three rings may have had a node. Anterior border furrow deep and wide, with well-developed geniculation and facet. Lateral and posterior border furrow and border narrow throughout. Pleural regions unsegmented, very convex like the cheeks.

Width of largest cephalon 9.5 mm; length of holotype cephalon 4.6 mm, width 5.6 mm. Length of largest pygidium 5.0 mm, width 6.0 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This species differs considerably from *C. lobatus* in the shape of the glabella, divided by a broad transverse furrow and with the rear lobe extended backward above the occipital ring. However, the presence of one or more, shallow transglabellar furrows is a feature present in species obviously congeneric with *C. lobatus,* and even in the form *agnostoides* of this species which Lochman (1956) showed to intergrade with the typical form. *Calodiscus helena* (Walcott) has a broad, very shallow transglabellar furrow and a rearward extension of the glabella, although not as pronounced as in the present species, and on the whole the cephala of *C. helena* and *C. fissifrons* are very similar. The pygidium of *C. helena,* however, differs considerably in the broad, paucisegmented axis from any pygidium observed at the North Chatham locality.

Types.—Holotype: U.S.N.M. 146004. Paratypes: U.S.N.M. 146005.

CALODISCUS RETICULATUS Rasetti, new species

Plate 1, fig. 1; plate 7, figures 12-18

Available material.—A few cephala, mostly fragmentary.

Description.—Glabella divided by a deep, wide transverse furrow into two lobes. Anterior lobe subovate, very convex, anteriorly sloping down almost vertically to the broad depression formed by the coalescence of the axial and border furrows. Glabella constricted at the transverse furrow. Posterior lobe widening backward from the transverse furrow, rising steeply, extended well beyond the general outline of the cephalon; seemingly rounded at the posterior end, although this portion is not completely preserved in any of the specimens. Occipital ring differentiated under the rearward glabellar extension, at least at the sides where it is directed rather backward than inward. Cheeks very convex, at least posteriorly where they overhang the lateral border furrow. Border expanded medially as in preceding species, slightly convex, narrowing toward the genal angle, lacking tubercles. Posterior border set off by a wide, deep furrow, rather wide in distal portion; genal angle narrowly rounded, lacking spine.

Surface of test covered with raised lines forming a reticulate pattern. The largest cephalon has a width of 10.5 mm and a length of approximately 10 mm.

Occurrence.—Collections cs-4 and U.S.G.S. 4216, North Chatham.

Discussion.—This species is closely related to the preceding, differing in the deeper division of the glabella by a transverse furrow, greater elevation of the two glabellar lobes, reticulate ornamentation, and lack of tubercles on the border. Clearly the present species is so strikingly different from *Calodiscus lobatus* that, were intermediate forms unknown, reference to the genus would hardly be suggested. However, when one considers the series *Calodiscus lobatus, C. lobatus agnostoides, C. helena, C. fissifrons,* and *C. reticulatus,* it appears difficult to decide where to place a possible generic boundary.

Types.—Holotype: U.S.N.M. 146006. Paratypes: U.S.N.M. 146007 and 146008.

CALODISCUS OCCIPITALIS Rasetti, new species

Plate 9, figures 22, 23

Available material.—One cephalon.

Description.—Cephalon semielliptical, of low convexity. Glabella elevated above the cheeks, higher posteriorly, with little longitudinal convexity, parallel-sided in the posterior two-thirds, anteriorly tapering to a fairly sharp point, occupying about two-thirds of the cephalic length, unfurrowed. Occipital furrow deeper laterally, impressed throughout; occipital ring extended into a robust, horizontal spine longer than all the rest of the cephalon. Cheeks lowest medially, slightly convex, their outline forming a sharp angle at the posterolateral corner. Border furrow well impressed; border convex, fairly wide, of about even width but for a slight narrowing toward the genal angle, bearing a few, indistinct tubercles. Posterior border furrow deep and wide; posterior border with geniculation about halfway between axial furrow and genal angle, the latter lacking a spine. Surface of test smooth. Length of cephalon (exclusive of occipital spine) 3.4 mm, width 3.8 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This form seems referable to *Calodiscus* even though it differs in several features from all previously described species. Its chief distinguishing characteristics are the relatively short glabella, well-impressed occipital furrow, excessively long occipital spine, narrowness of the border furrow, and even width of the border.

Types.—Holotype: U.S.N.M. 146003.

LEPTOCHILODISCUS Rasetti, new genus

Description.—Cephalon of moderate convexity. Glabella defined by deep axial furrow but not rising much above the cheeks, narrow and long, tapered, pointed in front, not reaching the anterior border, unfurrowed. Occipital furrow deep; occipital ring extended into spine. Cheeks everywhere convex, not separated in front by a preglabellar depression. Border very narrow, wire-like, well defined by narrow border furrow, narrowest in frontal portion, somewhat widened laterally. Posterior border furrow deep; posterior border widening distally, with geniculation near genal angle. Surface of test in type species punctate.

Type species.—*Leptochilodiscus punctulatus* Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—This simple eodiscid cephalon does not seem referable to described genera. Compared with *Calodiscus,* it shows important differences that are sufficient to doubt a close relationship. In *Calodiscus* the anterior border is much wider, usually widest medially, and the cheeks are separated in front of the glabella by a more or less extended preglabellar depression. The glabella of *Leptochilodiscus* is unusually long and pointed. The deep occipital furrow and spinose occipital ring also are not suggestive of *Calodiscus.*

LEPTOCHILODISCUS PUNCTULATIS Rasetti, new species

Plate 1, figure 5; plate 11, figures 1-7

Available material.—Four cephala in fair state of preservation.

Description.—Cephalon of about equal length and width, well rounded anteriorly. Glabella rising steeply above the occipital furrow, then sloping down toward a low anterior end without much longitudinal convexity, tapered at low, almost uniform rate but for a barely perceptible constriction at one-third the distance from the anterior end, reaching not far from the anterior border furrow. Occipital furrow deep and wide; occipital ring at lower level than glabella, extended into a slender, moderately long spine. Axial furrow deep except in its anteriormost portion. Cheeks rising above the axial furrow, convex transversely, in posterior portion sloping down steeply to border furrow. Border defined by narrow but fairly deep border furrow, convex, wire-like, very narrow in frontal portion. A unique, though inconspicuous, feature of the border is a slight widening that occurs at the point where the margin forms an angle of 45° with the sagittal line; here a small pit, distinguishable in all specimens, occurs on the upper surface. The portion of the border posterior to the pit remains wider than the frontal border. Another characteristic feature of the border is its sinuous outline in frontal view; the border curves slightly downward medially, upward at the sides of the median downbend, then again downward to assume a smooth course laterally. The slight crushing of the test in some specimens has made these features visible in dorsal view also. Posterior cephalic border with straight margin from axial furrow almost to genal angle, at this point reaching maximum elevation and sharply turned downward and forward to join the lateral border, possibly extended into a genal spine. Posterior border furrow deep and wide. Surface of cheeks definitely pitted in all specimens; similar but shallower ornamentation on glabella. Length and width of largest cephalon 4.4 mm.

Occurrence.—Collections cs-4 and U.S.G.S. 4216, North Chatham.

Types.—Holotype: U.S.N.M. 146009. Paratypes: U.S.N.M. 146010 and 146011.

LITOMETOPUS Rasetti, new genus

Description.—Cephalon relatively wide, almost semicircular, with considerable relief. Glabella long and narrow, slightly tapered, reaching the anterior border furrow which therefore merges medially with the axial furrow. Glabellar and occipital furrows entirely obsolete. Cheeks convex; border wide, convex, downrolled into the doublure. Posterior cephalic border with a blunt tooth, extended at the genal angle into strong spine.

Pygidium similar in shape to cephalon, more tapered posteriorly. Axis reaching posterior border, unfurrowed, well defined by axial furrow. Border furrow well impressed; border flat, fairly wide; doublure sloping inward at about 45° to vertical, with serrated margin. Size large for an Eodiscid.

Type species.—Litometopus longispinus Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—This form is a close relative of *Serrodiscus,* sharing with that genus the shape of the glabella, the general structure of the pygidium, and a slightly serrated doublure. Chief differences are the width and convexity of the cephalic border, the entire lack of preglabellar field, the unusual tooth at the posterior cephalic border, and the strong genal spine. The last two features also distinguish the genus from *Cobboldites comleyensis,* which has an equally long glabella and a similar pygidium. The very large size of *Litometopus* contrasts with the small size of the known examples of *Cobboldites.*

LITOMETOPUS LONGISPINUS Rasetti, new species

Plate 3, figure 3; plate 8, figures 1-9

Available material.—A few cephala and a larger number of pygidia.

Description.—Cephalon 1.3 times wider than long, with uniformly rounded anterior and lateral outline. Glabella widest at the undifferentiated occipital ring, with slightly concave lateral outline, rounded in front, well defined by the axial furrow, convex in both directions. Cheeks very convex, sloping down steeply to the deep border furrow. Border wide anteriorly, narrowing toward the genal angle, convex, downrolled into doublure, showing a pair of small lateral spines somewhat anterior to the cephalic midlength. Border furrow becoming very shallow at the genal angle; genal spine strong, curving inward, not greatly tapered, when complete probably equaling the cephalon in length. Posterior border furrow well impressed; posterior border straight from axial furrow to near base of genal spine, where it forms an obtuse tooth set off by a narrow, short furrow. Surface of test sparsely punctate, more distinctly in larger individuals. The largest (holotype) complete cephalon has a length of 8.3 mm and a width of 10.7 mm. However, a large cephalon in the collection, crushed by the slumping of the sediment in such manner that the anterior portion was bent under the posterior part, but nevertheless recognizable, has a width of 30 mm excluding the genal spines.

Pygidium 1.4 times wider than long. Axis well defined by the axial furrow, just touching the border furrow, not showing segmentation except for the articulating half-ring. Pleural regions convex. Anterior border with sharp geniculation at two-fifths the distance from axial furrow to lateral angle; facet well developed. Lateral border flat, defined by sharp change in slope, widening from anterior angle to midlength, then narrowing again, narrowest medially. Doublure somewhat wider than border, marked with terrace lines that follow the blunt serrations of the margin. Surface pitted like the cephalon. Length of largest pygidium 16 mm, width 22 mm.

From the proportions of the various parts and the size of the largest cephalon, the presence of individuals about 50 mm long may be inferred. This may be the largest size for an Eodiscid ever reported.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 146012. Paratypes: U.S.N.M. 146013.

OODISCUS Rasetti, new genus

Description.—Cephalon tending to a subquadrate shape. Glabella with undifferentiated occipital ring ovate, occupying more than one-third of the cephalic width, strongly elevated, totally unfurrowed. Preglabellar field short (sag.). Cheeks convex and downsloping. Border furrow and border well defined all around the cephalon; lateral border may show one or two pairs of short spines; in one species the frontal border bears a pair of tubercles. Posterior border with sharp geniculation and short spine at one-third the distance from axial furrow to rounded genal angle.

Pygidium with tapered, unfurrowed axis not reaching posterior border. Border furrow and border as in cephalon; border lacking marginal spines.

Type species.—*Oodiscus subgranulatus* Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—The type species and others included in the genus have a rather simple structure which, nevertheless, distinguishes them clearly from previously known Eodiscidae such as *Serrodiscus* and *Calodiscus*. The glabella is wider relative to the entire cephalon than in these genera, and has an oval shape; the undifferentiated occipital ring extends farther back than usual relative to the cheeks. The geniculation of the posterior cephalic border, marked by a short spine, is much closer to the axial furrow than in previously known Eodiscidae. The pygidium, compared with *Serrodiscus,* has a shorter axis and lacks marginal spines.

OODISCUS SUBGRANULATUS Rasetti, new species

Plate 1, figure 4; plate 10, figures 1-10

Available material.—Several cephala and pygidia more or less completely preserved.

Description.—Cephalon somewhat widening forward from the genal angle, widest slightly in front of the midlength, well rounded anterolaterally, with almost straight portion of frontal outline. Glabella ovate, somewhat pointed in front, not reaching anterior border furrow, strongly elevated above the cheeks, sloping down from posterior to anterior end. Occipital furrow barely indicated by a pair of exceedingly shallow lateral depressions, very short (sag.), rounded. Cheeks strongly downsloping posteriorly, gradually flatter toward the anterior part; no preglabellar depression. Border somewhat convex, well defined by border furrow, of even width around the anterior half of the cephalon, narrowing toward the genal angle, bearing two pairs of small, short marginal spines, one pair at the level of the cephalic midlength, a second pair halfway between the first and the genal angle. Lateral border furrow continued into posterior border furrow; the latter directed outward and forward from axial furrow, curving outward distally, hence as a whole convex forward. Posterior border horizontal in inner third, then sharply downturned to reach the much lower level of the genal angle; a small, upright spine at the geniculation, usually broken in extracting the specimen from the matrix. Genal angle narrowly rounded.

Pygidium assigned to the species on the basis of similar shape and identical ornamentation, less convex than cephalon, about parallel-sided in anterior half, well rounded posteriorly. Axis widest at the base, not greatly elevated, tapered, unfurrowed, occupying two-thirds of pygidial length. Anterior border straight, transverse from axial furrow to geniculation which is relatively close to axial furrow, distally slanted backward and with marked facet, paralleled by well-impressed anterior border furrow; remainder of border furrow and border as in cephalon; border lacking spines. Doublure reflexed in usual manner.

Cheeks and pleural regions of the pygidium covered with small, sparse granules, of density variable in different individuals. The pygidia usually show one or two small median nodes on the anterior portion of the axis when the preservation is perfect. Length of largest cephalon 8.0 mm, width 8.8 mm. Length of largest pygidium 8.0 mm, width 8.0 mm.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 146014. Paratypes: U.S.N.M. 146015.

OODISCUS BINODOSUS Rasetti, new species

Plate 10, figures 16-18

Available material.—Three cephala, of which only the holotype well preserved. Pygidia may be present, but cannot be identified among similar species of the genus.

Description.—The cephalon is so similar to the type species that only the differences are listed. Glabella narrower and of more uniform elevation throughout its length, slightly longer, almost reaching the anterior border furrow. Border furrow and border somewhat wider; anterior border bearing a pair of low, closely spaced tubercles that somewhat encroach upon the border furrow. Lateral border spines seemingly absent. Posterior border furrow straighter than in type species; geniculation with small, upright spine. Surface of test smooth. Length of largest cephalon 6.5 mm.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 146016. Paratypes: U.S.N.M. 146017.

OODISCUS LONGIFRONS Rasetti, new species

Plate 10, figures 20, 21

Available material.—A few cephala, none of which well preserved.

Description.—Glabella of the same shape as in the type species, but longer, just reaching the anterior border furrow. Border furrow and border somewhat wider than in *O. subgranulatus;* anterior border furrow showing a slight median inbend where it merges with the axial furrow; anterior border lacking nodes. Lateral border seemingly lacking spines, but none of the specimens are well preserved enough for this feature to be established with certainty. Geniculation of posterior border as in the two preceding species. In the holotype a pair of low, inconspicuous nodes is present on the downsloping portion of the posterior border between the geniculation and the genal angle, but this feature is indistinct in the paratypes.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 146018. Paratypes: U.S.N.M. 146019.

OODISCUS, species undetermined No. 1

Plate 11, figures 8-11

Available material.—A few pygidia, of which two well preserved.

Description.—Axis very prominent, unfurrowed, slightly tapered, rounded posteriorly, not reaching the posterior border furrow. Pleural regions convex and downsloping. Anterior border with geniculation relatively close to axial furrow and well-developed facet. Border furrow wide, relatively shallow. Border flat, rather wide. Anterior angles of pygidium sharp. Doublure sharply reflexed, apparently with smooth margin. Length of largest specimen 8.2 mm, width 8.0 mm. Surface of test smooth.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This pygidium seems definitely to belong to *Oodiscus,* but it cannot be determined to which, if any, of the species based on the cephala it should be referred. Compared with the pygidium assigned to *O. subgranulatus,* it has a more prominent and longer axis.

Disposition of material.—Figured specimens: U.S.N.M. 146020.

OODISCUS, species undetermined No. 2

Plate 11, figures 12, 13

Available material.—A few pygidia.

Description.—The pygidia in question do not appreciably differ in shape from those referred to *O. subgranulatus,* but lack the ornamentation of the cephala and pygidia of that species. Hence they may belong to a similar species, possibly *O. binodosus,* that has a smooth cephalon. The assignment cannot be decided on the basis of the available evidence.

Occurrence.—Collection cs-4, North Chatham.

Disposition of material.—Figured specimens: U.S.N.M. 146021.

Genus SERRODISCUS R. and E. Richter, 1941

Type species.—*Eodiscus (Serrodiscus) serratus* R. and E. Richter.

SERRODISCUS SUBCLAVATUS Rasetti, new species

Plate 2, figure 1; plate 8, figures 10-19

Available material.—Numerous cephala and pygidia, including one cephalon with two thoracic segments attached.

Description.—Glabella with totally undifferentiated occipital ring defined by an exceptionally deep axial furrow, strongly convex transversely, unfurrowed, slightly narrowed from the occipital ring to the level of the posterior third, then slightly expanded forward, sharply narrowed and somewhat pointed in front, reaching the border furrow. Cheeks very convex, posteriorly overhanging the border furrow, anteriorly separated by a narrow (tr.) preglabellar depression formed by the merging of the axial and border furrows. Border strongly convex, fairly wide, defined by a deep border furrow, contributing to the great relief of the cephalon. Tubercles on the border moderately elevated, generally seven or eight pairs present, about equally spaced. Posterior border furrow deep; posterior border straight from axial furrow to sharp geniculation which is located not far from genal angle and is marked by a short spine. A characteristic feature of the border is a very narrow, shallow furrow parallel and close to the posterior margin that sets off a slight, obtuse expansion. The articulated specimen shows that this feature corresponds to a similar one at the fulcrum of the anterior margin of the first thoracic segment. However, the geniculation of the posterior cephalic border with its spine is situated farther outward. In front of the spine the cephalic border curves downward and forward to join the lateral border which as usual is at a lower level; no sharp angle is formed, and the cephalic border is narrowest at this point.

First thoracic segment with anterior margin distally from the abovementioned fulcrum sharply bent backward to form a well-developed facet. Axis not preserved. Second segment showing a very convex axial lobe and deep axial furrow. Pleural articulation between first and second segment with features similar to those present between the cephalon and the first segment, but more distally located. Anterior margin beyond the geniculation bent downward but not backward. Posterior margin with geniculation situated still farther outward, distally strongly bent forward and downward. Third thoracic segment not preserved.

Pygidium with strong relief. Axis prominent, defined by deep axial furrow, convex in both directions, totally unfurrowed, not quite reaching the border furrow. Articulating half-ring expanded medially by a rearward median inbend of the articulating furrow. Axis bearing a strong median spine at about four-fifths of its length; this spine is broken off in all pygidia except one specimen where it could be partly restored. Pleural regions strongly convex, near posterior end forming a narrow, convex band between the end of the axis and the border furrow. Border furrow deep; border narrower than in cephalon, extended downward into a series of short spines somewhat visible in dorsal view by producing a wavy outline; seven or eight pairs of such spines are usually present. A. R. Palmer (private communication) suggested to the writer that such spines may fit the reverse side of the tubercles of the cephalic border when the animal is enrolled. The structures in the present species may support this interpretation since the tubercles and spines are in about equal numbers and similarly spaced.

Surface of cephalon and pygidium densely covered with fine granules. Length of largest cephalon 11 mm, width 11 mm. The entire pygidia recovered are somewhat smaller.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—Even though the close affinity to typical species of *Serrodiscus* can hardly be doubted, this form presents numerous differences from all those previously described. The most conspicuous features are the great convexity of the cephalon, depth of the axial furrows, unusual length and somewhat clavate shape of the glabella, and unfurrowed pygidial axis bearing a spine. The most similar form is an undescribed species from the Purley Shales of England (Rushton, private communication).

Types.—Holotype: U.S.N.M. 146022. Paratypes: U.S.N.M. 146023.

SERRODISCUS SPINULOSUS Rasetti, new species

Plate 7, figures 7-11

Available material.—A few cephala and one pygidium.

Description.—Glabella with undifferentiated occipital ring widest at posterior end, narrowed forward for a short distance, then parallel-sided, strongly tapered in frontal portion and rather pointed medially, unfurrowed. Glabella of moderate convexity, anteriorly reaching the border on account of a sharp median inbend of the border furrow which thus merges for a short distance with the axial furrow. Occipital ring bearing a short spine. Cheeks slightly convex, downsloping. Border widest medially on account of the above-mentioned feature of the border furrow, narrowing toward the genal angle, bearing several pairs of very low, somewhat indistinct tubercles. Posterior border wide (exsag.), extended into short, sharply pointed genal spine. No geniculation features on posterior cephalic margin between axial furrow and genal spine. Cephalic border narrowest at posterolateral angles in front of genal spine.

Pygidium referred to the species with long, totally unfurrowed axis almost reaching posterior border. Articulating half-ring expanded medially as in preceding species. Pleural lobes of moderate convexity; border furrow well impressed. Border fairly wide, convex, extended ventrally into a series of short spines, producing in dorsal view a waviness of the margin. Seemingly there was a spine on the posterior part of the axis.

Surface of test of cephalon and pygidium perfectly smooth. Length of largest cephalon 5.6 mm, width 5.2 mm. Length of pygidium 4.7 mm, width 5.6 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This form is fully typical of *Serrodiscus* in all respects excepting one unusual feature, the inbend of the anterior border furrow causing it to merge with the axial furrow. Other distinguishing features are the occipital and genal spines, the shape of the glabella, and the unfurrowed pygidial axis.

Types.—Holotype: U.S.N.M. 146026. Paratypes: U.S.N.M. 146027.

SERRODISCUS LATUS Rasetti, new species

Plate 10, figures 12-15

Available material.—Three cephala, of which one excellently preserved.

Description.—Glabella with totally undifferentiated occipital ring slightly tapered, straight-sided, well defined by deep axial furrows, somewhat pointed in front, almost reaching the border, unfurrowed. Cheeks convex, rising somewhat above the axial furrows, steeply sloping to border furrow at the sides. Border furrow deep all around the cheeks, medially almost meeting the axial furrow. Border somewhat convex and on the average horizontal, widest medially and but slightly tapering to the genal angle, bearing a few pairs of low tubercles. Posterior border furrow and border about as wide as lateral border; posterior cephalic margin straight and transverse from axial furrow to geniculation, then turning downward and forward to the genal angle which bears a minute spine. Surface of test smooth. Length of largest cephalon 5.0 mm, width 6.2 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—The cephalic features agree with *Serrodiscus,* but in the absence of a pygidium it is questionable whether the species should not rather be referred to *Calodiscus,* or possibly *Cobboldites.* The cephalon differs markedly from *C. speciosus* and other described species in the general outline, regularly curved in front rather than pointed, deep axial furrows, and great convexity of the cheeks.

Types.—Holotype: U.S.N.M. 146024. Paratypes: U.S.N.M. 146025.

SERRODISCUS, species undetermined

Plate 10, figure 19

Available material.—One incomplete cephalon.

Description.—Glabella approximately parallel-sided, rounded in front, not greatly elevated, occupying with the occipital ring two-thirds of the cephalic length. One pair of glabellar furrows, very broad and shallow, is impressed all across the glabella. Occipital furrow visible as a pair of shallow, broad depressions at the sides. Occipital ring somewhat elevated medially, rounded, lacking node or spine. Cheeks moderately convex, preserved only in their anterior part. Preglabellar field flat, fairly extended. Border furrow shallow; border wide, flat, apparently lacking tubercles. Anterior outline of cephalon unusually pointed medially. Surface of test smooth. Length of cephalon 5.6 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This cephalon cannot be referred to any described species, but is too incomplete to warrant a name. The proportions of the various parts are somewhat like *S. speciosus,* but the glabella is shorter and less tapered, the entire cephalon more nearly triangular, the border wider, and the occipital ring is raised at the posterior margin.

Disposition of material.—Figured specimen: U.S.N.M. 146028.

STIGMADISCUS Rasetti, new genus

Description.—Cephalon semielliptical, lacking lateral spines. Glabella approximately parallel-sided, rather pointed in front, rising above the downsloping cheeks, elevated in front of the occipital furrow. Glabellar furrows impressed as two pairs of deep lateral pits close to the axial furrow. Occipital furrow similarly deepened into a pair of pits. Occipital ring well differentiated, bearing a node or spine. Cephalic border narrow, defined by shallow border furrow. Posterior border bearing a pair of short spines, located either about halfway between the axial furrow and the genal angle, or close to the genal angle. Surface of test smooth. Other parts of exoskeleton unknown.

Type species—Stigmadiscus stenometopus Rasetti, new species.

Occurrence.—Late Lower Cambrian of New York.

Discussion.—The genus is proposed for two species whose most distinctive character is the pit-like structure of the glabellar furrows, a feature so far never observed in the Eodiscidae. The type species shows marked affinity with *Acidiscus,* where the glabellar furrows are relatively short and deep and the occipital furrow has a similar structure. The other described species, *Stigmadiscus gibbosus,* shows some resemblance to an Agnostid cephalon in the proportions of the various parts. Whether this similarity is purely accidental, or we are dealing with an Eodiscid evolving into an Agnostid, cannot be decided at present, especially in the absence of thorax and pygidium.

STIGMADISCUS STENOMETOPUS Rasetti, new species

Plate 3, figure 5; plate 12, figures 1-7

Available material.—Several cephala, of which two fairly complete.

Description.—Cephalon of low convexity. Glabella relatively narrow, slightly tapered from the occipital ring to the anterior pair of lateral furrows, very slightly expanded in front, somewhat pointed, occupying about two-thirds of cephalic length. Axial furrow deep posteriorly, shallower anteriorly. Longitudinal profile of glabella rising gradually from front to back, where it reaches its highest elevation in the form of a rounded ridge that drops abruptly to the level of the occipital furrow. In some of the specimens there is an indication of a small, broken spine at this highest point, whereas other individuals where the test at this place is well preserved do not show a spine. Occipital ring moderately long (sag.), bearing a short spine. Cheeks slightly convex, downsloping; lateral border narrow, of even width, defined by a border furrow that becomes progressively shallower and broader forward. Posterior border furrow deeper than lateral border furrow, almost straight, slightly convex forward, joining the lateral border furrow near the genal angle which is fairly sharp but seemingly not extended into a spine. Posterior cephalic border wider and better defined than lateral border, extended into a short, horizontal spine located somewhat closer to the axial furrow than to the genal angle. The portion of the posterior border beyond the spine is somewhat slanted forward. Surface of test smooth. Length of holotype cephalon 9.0 mm, width 9.9 mm. The largest glabella indicates a cephalon 12.5 mm in length.

Occurrence.—Collection cs-4, North Chatham.

Types.—Holotype: U.S.N.M. 146029. Paratypes: U.S.N.M. 146030.

STIGMADISCUS GIBBOSUS Rasetti, new species

Plate 3, figure 4; plate 12, figures 8-13

Available material.—About half a dozen cephala, mostly in mediocre state of preservation.

Description.—Cephalon equally wide and long, moderately convex, semielliptical. Glabella narrowed forward in its posteriormost portion from the wider occipital ring, almost parallel-sided in its medial part, rapidly tapered and somewhat pointed in its anterior fourth. Two posteriormost pairs of lateral furrows deep, short, pit-like; no indication of other pairs. A broad transglabellar depression is located somewhat in advance of the anterior pair of lateral furrows. The glabella rises in bulbous shape behind this depression and drops sharply to the occipital furrow. The occipital furrow is impressed at the sides in form of a pair of small pits, shallower than the glabellar furrows, not connecting with the axial furrow, and is extended medially into a shallower, still well-impressed portion. Occipital ring short, bearing a small node. Cheeks rather flat in front of the glabella, not forming a definite depression. Border furrow shallow and poorly defined anteriorly, gradually becoming narrower and deeper toward the genal angle. Border poorly defined, somewhat convex, reduced in width toward the genal angle. Posterior border furrow directed outward and forward, forming a considerable angle with the posterior cephalic margin and hence producing an elongate, triangular posterior border which extends into a short spine located very close to the genal angle. The posterior cephalic margin slopes down somewhat in connecting the posterior with the lateral border. Surface of test smooth. Length and width of largest cephalon 6.8 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This form seems closely related to the type species, with which it shares the pit-like glabellar furrows and the elevation of the posterior portion of the glabella. In other respects there are conspicuous differences, which made the writer hesitate whether the two should be referred to the same genus. In *Stigmadiscus gibbosus* the glabella is larger in proportion to the whole cephalon, the occipital ring is shorter and lacks a spine, the glabellar boss is defined both in front and back, instead of rising gradually in the frontal part as in *S. stenometopus*. Perhaps the most significant difference of all is in the position of the spine on the posterior cephalic border, in the present species close to the genal angle so that it may be called a "genal" spine. These various differences give to *Stigmadiscus gib-*

bosus a somewhat Agnostid-like aspect that is completely lacking in the type species.

Types.—Holotype: U.S.N.M. 146031. Paratypes: U.S.N.M. 146032.

Undetermined pygidia

Several pygidia, undoubtedly belonging to the family Eodiscidae and possibly to some of the named species, are described hereafter. Possible assignments are suggested in some cases.

Undetermined pygidium No. 1

Plate 11, figures 17-21

Available material.—Three examples.

Description.—Pygidium of strong convexity especially in the transverse direction. Axis strongly prominent, moderately tapered, reaching the posterior border furrow, showing eight rings plus a terminal section defined by exceedingly shallow furrows; articulating half-ring short (sag.), articulating furrow straight. Pleural regions convex, laterally sloping down vertically to border furrow. Border very narrow, ventrally extended into 8 to 10 pairs of short, somewhat backward-directed spines. Outline of border arched in posterior view. Surface of test with very shallow puncta, not equally distinct in the available specimens. Length of largest pygidium 4.4 mm, width 4.4 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—The narrowness of the border and the shallowly punctate surface suggest the possibility that this is the pygidium of *Leptochilodiscus punctulatus.*[1]

Disposition of material.—Figured specimens: U.S.N.M. 146033.

Undetermined pygidium No. 2

Plate 11, figures 14-16

Available material.—Three more or less complete examples.

Description.—Pygidium with considerable relief. Axis prominent, relatively wide, tapered to a rather sharp point, almost reaching the posterior border furrow, composed of six rings plus a terminal sec-

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[1] Copious material, collected from another locality after this paper was written, unquestionably supports this assignment.

tion. Ring furrows with peculiar structure, deepening to pair of pits at the sides some distance from the axial furrow; the medial portion of the ring furrow narrower and shallower, concave toward the front. The axial rings bore spines of decreasing length, broken off in the available specimens. Pleural regions unfurrowed, downsloping; border furrow narrow but deep; border narrow, but expanded into four pairs of wide, short, somewhat blunt spines about evenly spaced. The spines are directed outward, not downward as in many species of *Serrodiscus*. Surface of test smooth. Length of largest pygidium 5.7 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—It is questionable whether this peculiar pygidium belongs to any of the cephala known from the locality.

Disposition of material.—Figured specimens: U.S.N.M. 146034.

Undetermined pygidium No. 3

Plate 10, figure 11

Available material.—A single, well-preserved example.

Description.—Pygidium of low convexity, almost semicircular. Axis defined anteriorly by very shallow axial furrows, the remainder undifferentiated from the pleural regions. Articulating half-ring and furrow well defined. Anterior outline straight in dorsal view, with geniculation about halfway between axial furrow and anterior angle, with border bent downward but not appreciably backward. Border furrow well impressed, border flat, of almost even width throughout. Doublure vertical, narrow, with smooth margin. Surface of test smooth. Length of pygidium 7.0 mm, width 10.3 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—In the general shape this pygidium recalls *Litometopus longispinus,* but differs markedly in the lesser convexity and especially in the almost complete obsolescence of the axial furrows. It should presumably be associated with a cephalon with poorly differentiated glabella, but no such form is present in the collection.

Disposition of material.—Figured specimen: U.S.N.M. 146035.

Family OLENELLIDAE Vogdes, 1893

Olenellids are relatively common in the faunule, but owing to the thinness of their test, they are usually much more fragmentary than the Eodiscids. Cephala of three different species have been identified.

These are all represented by small, evidently immature specimens. No fragments of either cephala or thoracic segments seem to indicate the presence of animals much larger than the cephala illustrated.

Genus **PAEDEUMIAS** Walcott, 1910

Type species.—*Paedeumias transitans* Walcott.

PAEDEUMIAS, species undetermined No. 1

Plate 12, figures 23-25

Available material.—Fairly numerous, complete cephala from 1.5 to 4 mm in length.

Description.—Glabella well-defined, narrow, parallel-sided, with frontal lobe not wider than the posterior lobes. Frontal lobe ovate, defined by a furrow deep at the sides, shallow but distinct medially. Next three lobes of about equal length, separated by deep, transverse furrows at the sides, not extended medially. Occipital furrow similar to the preceding glabellar furrows; occipital ring apparently extended into a short spine, not well preserved in any of the cephala. Palpebral lobes separated by a shallow depression from frontal glabellar lobe, with curvature increasing backward, almost reaching the posterior cephalic margin. There is a fairly wide, well-defined space between the glabella and the palpebral lobe. Border wide, convex, of about the same width frontally and laterally. Distance from anterior end of glabella to anterior border furrow almost equal to length of frontal glabellar lobe. A median ridge connecting the front end of the glabella with the border furrow is visible at least in the larger specimens. From the posterior end of the palpebral lobe a narrow outward-directed ridge reaches the posterior cephalic margin at the base of a moderately long intergenal spine. Beyond this spine, the posterior margin turns slightly forward to the base of the genal spine, which is less conspicuous than the intergenal spine.

The preceding description was based on cephala about 4 mm in length. In a fairly well-preserved cephalon 1.5 mm in length illustrated herein, the intergenal spines are very close to the genal angle; in addition, there is a pair of small procranidial spines. These changes in the relative size and position of the spines, as far as can be ascertained from the meager material available, seem to parallel those observed by Palmer (1957) in the ontogeny of *Olenellus gilberti.*

Occurrence.—Collection cs-4, North Chatham.

Discussion.—The reference to the genus is chiefly suggested by the considerable length of the preglabellar field and the presence of a preglabellar ridge; however, these may be juvenile features. The present form is almost identical with an immature cephalon attributed to *Paedeumias* from a conglomerate boulder near Levis, Quebec, figured by the writer (Rasetti, 1948, pl. 2, fig. 5). If this cephalon is conspecific with the larger one from the same locality (Rasetti, 1948, pl. 2, fig. 6), the reference to *Paedeumias* seems well founded. Comparison with immature cephala of *Elliptocephala asaphoides* shows that the present species differs in several respects.

Disposition of material.—Figured specimens: U.S.N.M. 146036.

PAEDEUMIAS?, species undetermined No. 2

Plate 12, figures 19, 20

Available material.—A few, incomplete cephala.

Description.—Glabella flat, hardly elevated above the cheeks, defined by a shallow axial furrow only in the portion corresponding to the posterior lobe; the two preceding lobes extend, undifferentiated from the cheek, as far as the palpebral lobe. Glabella tapered, with frontal lobe considerably narrower than the posterior lobe and the occipital ring. Three pairs of glabellar furrows increasing in depth rearward, fairly well impressed at the sides, fading out medially, oblique and approximately parallel to each other. Occipital furrow of identical character; occipital ring as long as the last glabellar lobe, bearing a node. Palpebral lobes broad, scarcely elevated, posteriorly reaching the level of the midlength of the occipital ring. A narrow rim, set off by a narrow furrow, encircles the palpebral lobe. All the cephala are broken at the outer edge of this rim, i.e., at the upper boundary of the visual surface of the eye, where the facial suture is located in opisthoparian trilobites; the remainder of the pleural portions of the cephalon is completely missing. The area comprised between the glabella and the palpebral lobe is very narrow, and defined only posteriorly as previously indicated. Length of glabella plus occipital ring 5-6 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This form has features unusual among the Olenellids of the late Lower Cambrian, especially the tapered glabella and the well-defined narrow rim around the palpebral lobe. It cannot be identified with any described species known to the writer.

Disposition of material.—Figured specimens: U.S.N.M. 146037.

Genus **OLENELLUS** Billings, 1861

Type species.—*Olenus thompsoni* Hall.

OLENELLUS, species undetermined

Plate 12, figures 21, 22

Available material.—A few, incomplete cephala.

Description.—Glabella well defined by a deep axial furrow, on the average somewhat expanded forward. Frontal lobe large; second lobe short and wide, set off by narrow, fairly deep lateral furrows at the sides both from the frontal lobe and the third lobe; both pairs of furrows become very shallow medially. The second lobe expands laterally to touch the palpebral lobe, from which it is separated by an oblique furrow, extension of the first pair of glabellar furrows. Third and fourth glabellar lobes narrower, bounded by the axial furrow laterally, far from reaching the palpebral lobe; third pair of lateral furrows and occipital furrow similar to second pair of furrows. There was a node, broken off in the available specimens, across the occipital furrow, rather than on the occipital ring as usual. Palpebral lobes wide, long, set off by a very shallow furrow from the frontal glabellar lobe, showing a poorly defined rim, set off by an exceedingly shallow furrow, representing about one-third of the width of the palpebral lobe. Other cephalic parts not preserved. Length of glabella plus occipital ring 4-5 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—The features of this species, as far as can be observed on the incomplete cephala, agree with *Olenellus,* but reference to other genera of the family cannot be excluded. The shape of glabella and palpebral lobe shows a marked resemblance to *Holmia kjerulfi* (Linnarsson).

Disposition of material.—Figured specimens: U.S.N.M. 146038.

Family DORYPYGIDAE Kobayashi, 1935

Genus **KOOTENIA** Walcott, 1889

Type species.—*Bathyuriscus (Kootenia) dawsoni* Walcott.

KOOTENIA, species undetermined

Plate 12, figures 14, 15

Available material.—A single, incomplete pygidium.

Description.—Pygidium of relatively low convexity. Axis wide, moderately tapered, straight-sided, composed of six well-defined rings plus a terminal section, reaching the posterior border furrow. All the axial rings except the last have a median node. Pleural regions in proximal portion not downsloping at all, convex and downsloping only in marginal portion. Five pairs of pleural furrows very broad and moderately deep; narrow interpleural furrows well defined especially in the proximal portion. Border furrow broad and poorly defined; border flat, extended into several pairs of spines of about equal size, evenly spaced, and directed perpendicularly to the margin. All spines are broken and their length cannot be ascertained; the bases of five pairs of spines are visible, but there must have been another pair on the anterior, unpreserved portion of the border. The distance between the spines of the sixth pair is much greater than the distance between successive pairs.

Surface of test with ornamentation that consists of shallow puncta on the axial rings and becomes rather of reticulate type on the pleural regions. Length of pygidium 6.0 mm, width 10 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This pygidium is referred to *Kootenia* which it resembles more than any other described genus, but its unusual features might suggest a new genus if the cephalic parts were known. Compared to the described forms of *Kootenia,* the axial rings are proportionately much wider and shorter, the pleural regions are flat rather than convex in their proximal portion, and the interpleural furrows are unusually developed. In particular, there is little resemblance to the species of *Kootenia* or *Fordaspis* described from the Lower Cambrian of the Taconic area (Lochman, 1956).

Disposition of material.—Figured specimen: U.S.N.M. 146039.

Genus BONNIA Walcott, 1916

Type species.—*Bathyurus parvulus* Billings.

Several species of *Bonnia* seem to be represented by cranidia, associated with one form of pygidium definitely referable to the genus. It cannot be determined whether all the cranidia belong to *Bonnia* rather than to *Kootenia,* since the two are not always generically distinguishable in the absence of the pygidium. For these reasons each cranidium is described as an undetermined species of *Bonnia* and the pygidium is not referred to any of the cranidia.

BONNIA, species undetermined No. 1

Plate 11, figures 23-25

Represented by several examples, mostly too immature for specific identification. Entire cranidium proportionately wide and short.

Glabella slightly expanded forward, with traces of lateral furrows. Occipital furrow deep laterally, shallow medially; occipital ring but partially preserved. Fixigenae convex and downsloping, about half the glabellar width. Ocular ridges low and broad, paralleling the border furrow. Border not well preserved, seemingly very narrow at least in front of the glabella. Palpebral lobes shorter than average for the genus; posterior area wider (tr.) than occipital ring. Surface of test with indistinct ornamentation. Length of largest cranidium 3.5 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This form cannot be identified with any of the species of *Bonnia* previously described, in particular with the numerous species illustrated by the writer from the conglomerates of Quebec (Rasetti, 1948). The chief characteristic is the breadth of the cranidium, the glabella and the fixigenae.

Disposition of material.—Figured specimens: U.S.N.M. 146040.

BONNIA, species undetermined No. 2

Plate 11, figure 22

Represented by an immature example. Cranidium of average shape for the genus. Glabella but slightly expanded, of average convexity, unfurrowed. Occipital furrow narrow but well impressed; occipital ring incomplete, possibly spinose. Fixigenae, palpebral lobes, and anterior border of average form. Length of cranidium 2.7 mm. Surface of test smooth.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—In the general proportions and lack of ornament this form might be compared with *Bonnia similis* Rasetti. As far as can be ascertained from one small, somewhat imperfect cranidium, it seems to differ in the more posterior position of the palpebral lobes.

Disposition of material.—Figured specimen: U.S.N.M. 146041.

BONNIA, species undetermined No. 3

Plate 12, figure 16

Possibly represented by a few, incomplete examples. The description is based on the best specimen illustrated herein. Glabella of average convexity, slightly expanded in posterior half, slightly tapered anteriorly, with but traces of lateral furrows. Occipital furrow wide and deep throughout; occipital ring long (sag.), extended into a short, somewhat blunt spine. Fixigenae relatively narrow; anterior border narrow in front of the glabella, wider laterally. Posterior area not preserved. Test with shallow puncta, close together so that the ornamentation, which is not very conspicuous, might be described as intermediate between punctate and granulate; anterior border with irregular raised lines. Length of cranidium 5.5 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This form might be compared with *Bonnia busa* (Walcott) which, however, has visible glabellar furrows and stronger ornamentation.

Disposition of material.—Figured specimen: U.S.N.M. 146042.

BONNIA, species undetermined No. 4

Plate 12, figure 18

Represented by a single, incomplete, somewhat deformed example. Glabella seemingly more convex both transversely and longitudinally than in the preceding form, although this feature may have been accentuated by slight lateral compression. Glabella on the average parallel-sided, with exceedingly shallow lateral furrows. Occipital furrow deep and broad; occipital ring incomplete, seemingly triangular and presumably spinose. Fixigenae incompletely preserved; anterior border of average width, strongly slanted backward laterally. Surface of test finely granulate, the granules on the posterior part of the glabella showing a tendency to become arranged in irregular, transverse ridges. Length of cranidium 7.5 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—The proportionately short and wide, strongly convex, nonexpanding glabella seem to distinguish this form from described species. It is quite possible that, were the pygidium known, this form should be referred to *Kootenia.* The cranidium does not greatly differ from *Kootenia troyensis* Resser, as redescribed and figured by Lochman (1956), but no pygidia resembling that species were found in the collection.

Disposition of material.—Figured specimen: U.S.N.M. 146043.

BONNIA, undetermined pygidium

Plate 12, figure 17

Represented by a few examples, the only complete specimen being the one illustrated. Pygidium with relatively narrow, somewhat tapered axis showing three rings plus a terminal unsegmented section, reaching the border furrow. Pleural regions with four pairs of pleural furrows, counting the anterior border furrow, and but traces of one pair of interpleural furrows. Border furrow shallow, border flat, seemingly lacking the small spine at the anterolateral angle. Ornamentation indistinct. Length of complete pygidium 2.8 mm, width 4.6 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This unmistakable pygidium of *Bonnia* presumably belongs to one of the cranidia described herein. It may be compared with the pygidium of *Bonnia senecta* (Billings) illustrated by the writer (Rasetti, 1948) which it resembles in the narrow axis and well-impressed pleural furrows.

Disposition of material.—Figured specimen: U.S.N.M. 146044.

FAMILY, GENUS, AND SPECIES UNDETERMINED

Undetermined pygidium No. 4

Plate 6, figures 20, 21

Available material.—Several incomplete examples.

Description.—Entire pygidium subtriangular, of moderate convexity. Axis well defined, somewhat tapered, straight-sided, almost reaching the posterior margin. Axial rings numerous, probably 13 or 14, all well defined by ring furrows that, at least in the anterior portion of the axis, show a median backward inflection. At least the first few rings seem to have borne a node or spine. Pleural regions downsloping, with straight, narrow, somewhat backward-directed pleural furrows that, at least for the first 10 segments, correspond to the ring furrows on the axis. About 11 or 12 pleural furrows are visible; there is no trace of interpleural furrows. All furrows end in a broad, poorly defined border furrow that sets off a narrow, somewhat convex border. The anterior outline of the pleural lobes shows a sharp geniculation very close to the axial furrow; past the geniculation the margin turns backward in a wide curve and finally assumes the straight backward and inward course that gives the pygidium a subtriangular shape. Surface of test smooth. The length of the largest pygidium, if complete, would be about 14 mm, the maximum width 12 mm.

Occurrence.—Collection cs-4, North Chatham.

Discussion.—This peculiar pygidium cannot be referred to any described genus of Cambrian trilobites, and not even a plausible family assignment is suggested. It is virtually certain that this is not the pygidium of an Olenellid or Ptychoparioid trilobite, and it seems unlikely that it belongs to one of the numerous Eodiscids present in the collection.

Disposition of material.—Figured specimens: U.S.N.M. 146000.

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EXPLANATION OF PLATES

GENERAL STATEMENT

To avoid unnecessary repetition, locality and collection numbers are only indicated for the few illustrated specimens that are not part of the writer's collection cs-4 from the North Chatham locality. Three specimens (pl. 7, fig. 18; pl. 9, figs. 14-16; pl. 11, figs. 6, 7) are from U.S.G.S. collection 4216 at the same locality. One specimen (pl. 5, figs. 13, 14) was collected near Elgin Station, Quebec, Canada.

All figured specimens show the outer surface of the test.

Plate 1

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Fig. 1. *Calodiscus reticulatus* Rasetti, new species 24
Dorsal and lateral views of cephalon, ×3.

Fig. 2. *Acidiscus birdi* Rasetti, new genus, new species 11
Lateral and dorsal views of cephalon; pygidium; ×2.

Fig. 3. *Bathydiscus dolichometopus* Rasetti. new genus, new species . . 17
Dorsal, frontal, and lateral views of cephalon; posterior, lateral, and dorsal views of pygdium; ×4.

Fig. 4. *Oodiscus subgranulatus* Rasetti, new genus, new species . . . 29
Dorsal, frontal, and lateral views of cephalon; pygidium; ×4.

Fig. 5. *Leptochilodiscus punctulatus* Rasetti, new genus, new species . . 26
Cephalon, ×6.

Plate 2

Fig. 1. *Serrodiscus subclavatus* Rasetti, new species 31
Dorsal and oblique anterior views of cephalon; oblique posterior and dorsal views of pygidium; ×4.

Fig. 2. *Analox bipunctata* Rasetti, new genus, new species 15
Dorsal and lateral views of pygidium; lateral and dorsal views of cephalon; ×6.

Fig. 3. *Acimetopus bilobatus* Rasetti, new genus, new species 14
Dorsal and lateral views of pygidium; oblique and dorsal views of cephalon; ×4.

Plate 3

Fig. 1. *Bolboparia superba* Rasetti, new genus, new species 19
Dorsal and oblique views of cephalon, ×4.

Fig. 2. *Bolboparia elongata* Rasetti, new species 20
Pygidium, ×5.

Fig. 3. *Litometopus longispinus* Rasetti, new genus, new species . . . 27
Dorsal and lateral views of cephalon; pygidium; ×2.

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Fig. 4. *Stigmadiscus gibbosus* Rasetti, new species 37
Dorsal and lateral views of cephalon, ×5.

Fig. 5. *Stigmadiscus stenometopus* Rasetti, new genus, new species . . 36
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PLATE 4

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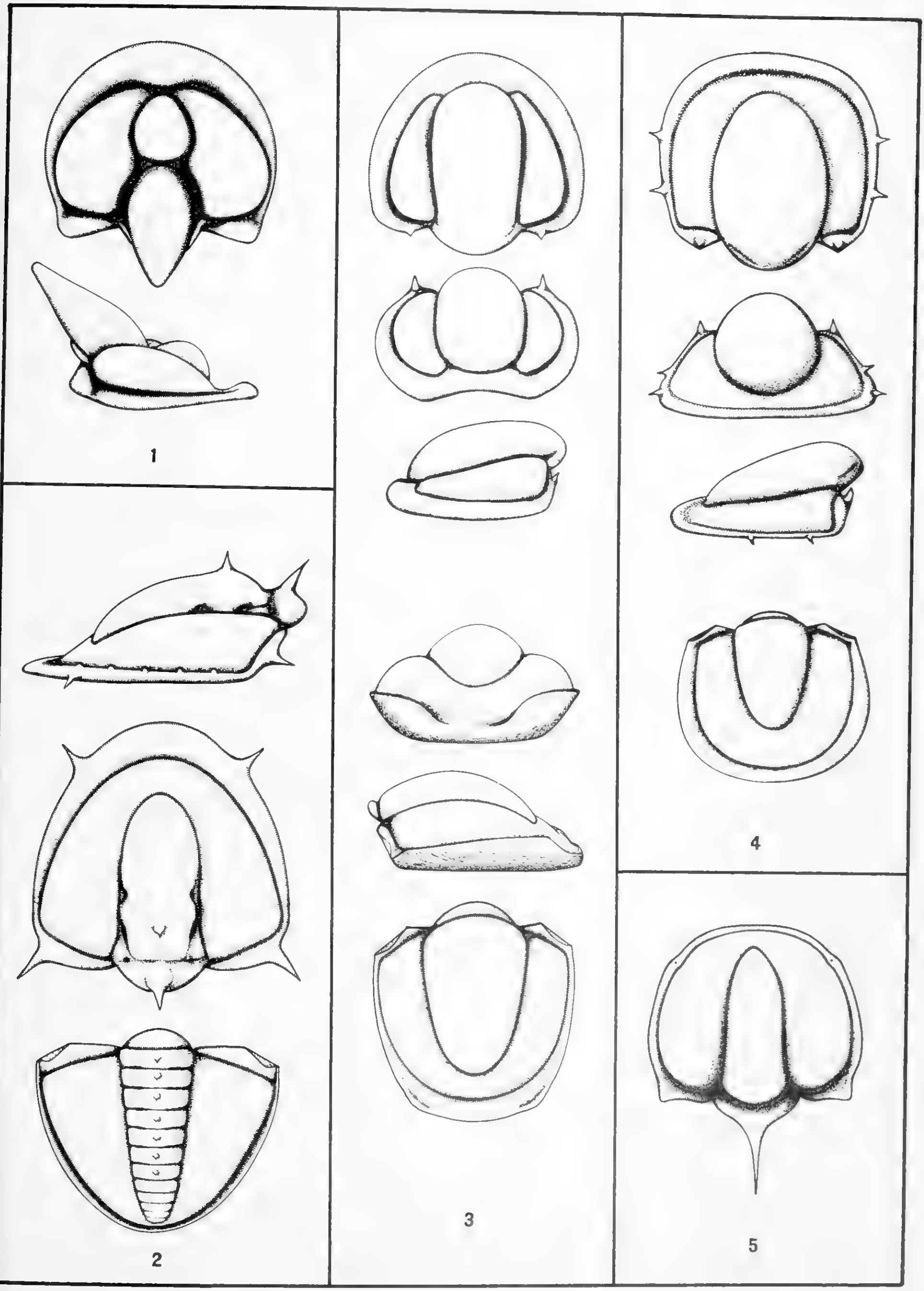

Calodiscus, Acidiscus, Bathydiscus, Oodiscus, and Leptochilodiscus

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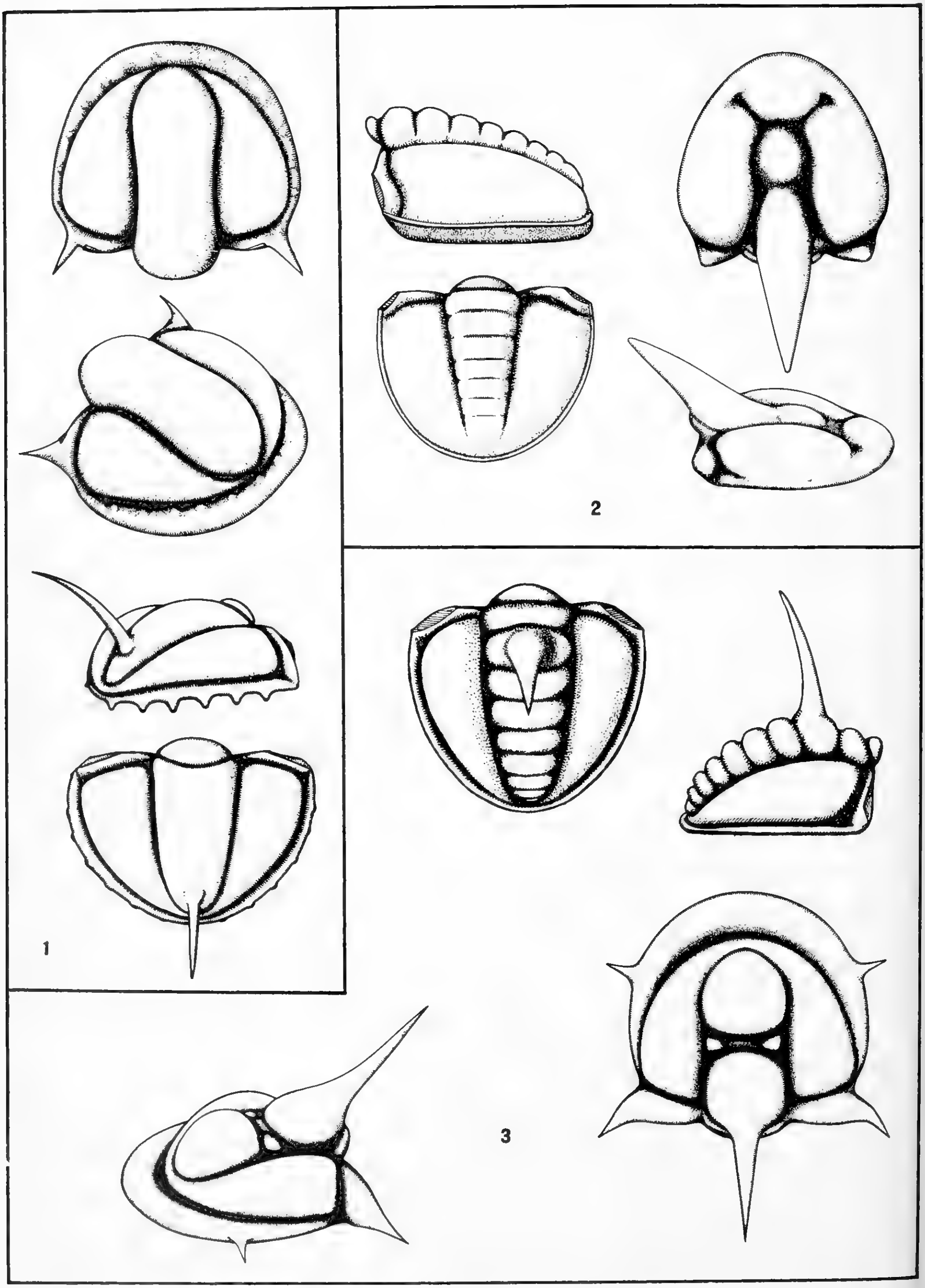

SERRODISCUS, ANALOX, ACIMETOPUS

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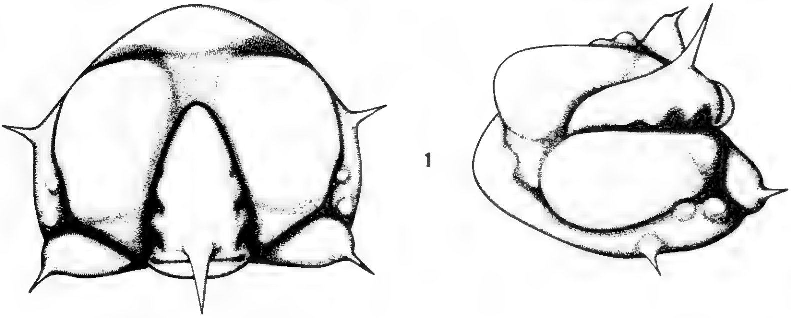
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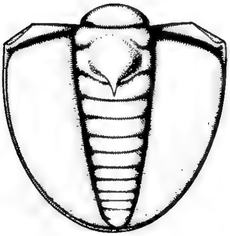
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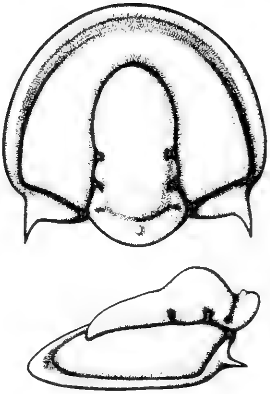
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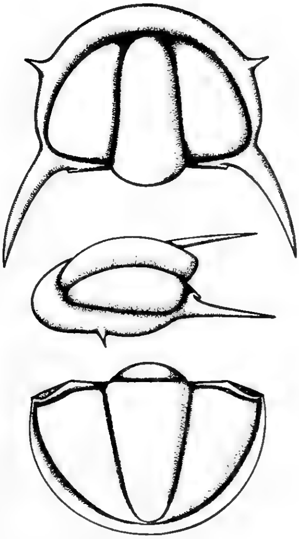
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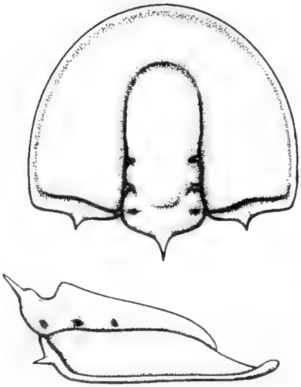
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BOLBOPARIA, LITOMETOPUS, STIGMADISCUS

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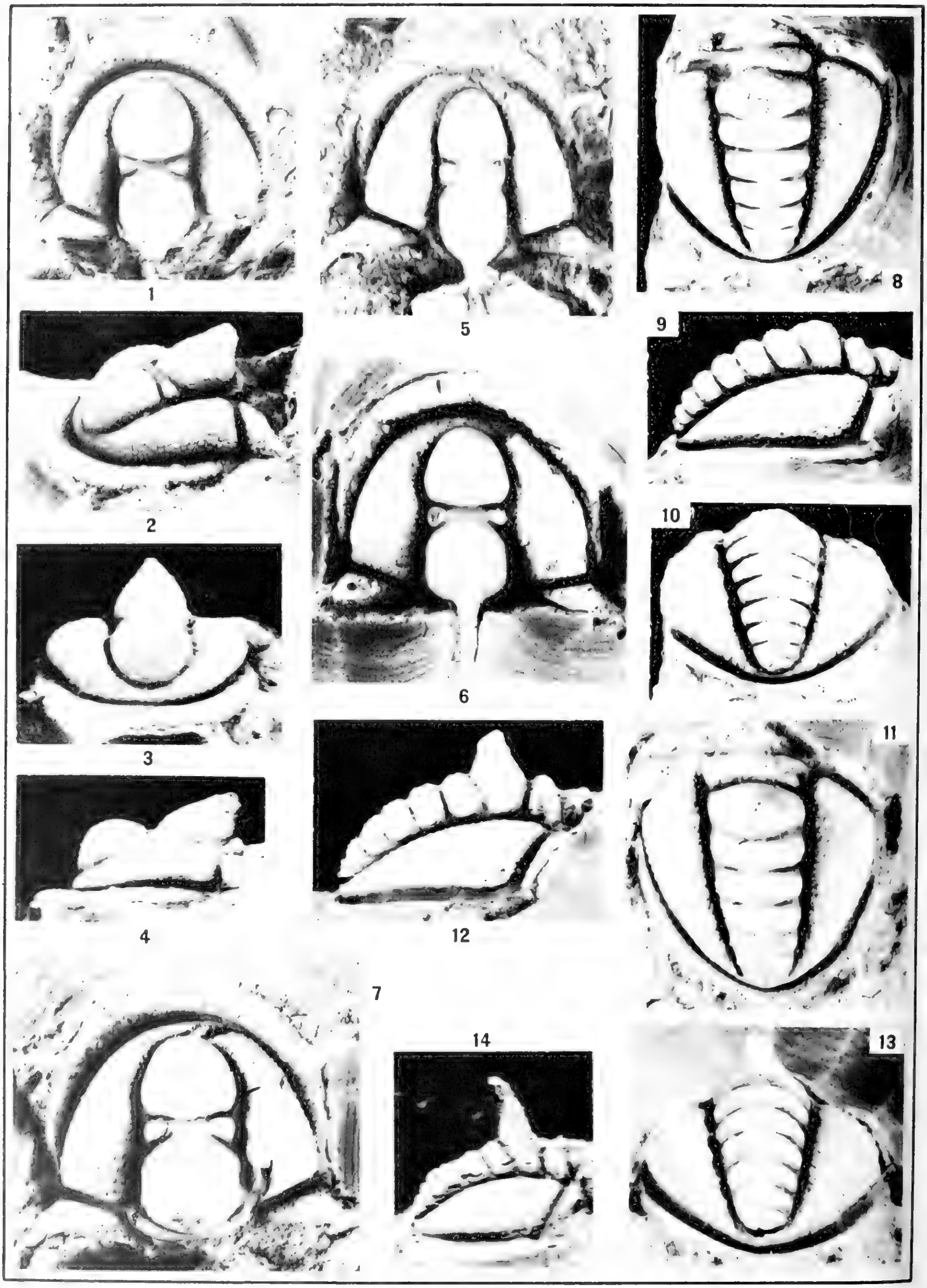

EODISCIDAE (ACIMETOPUS)

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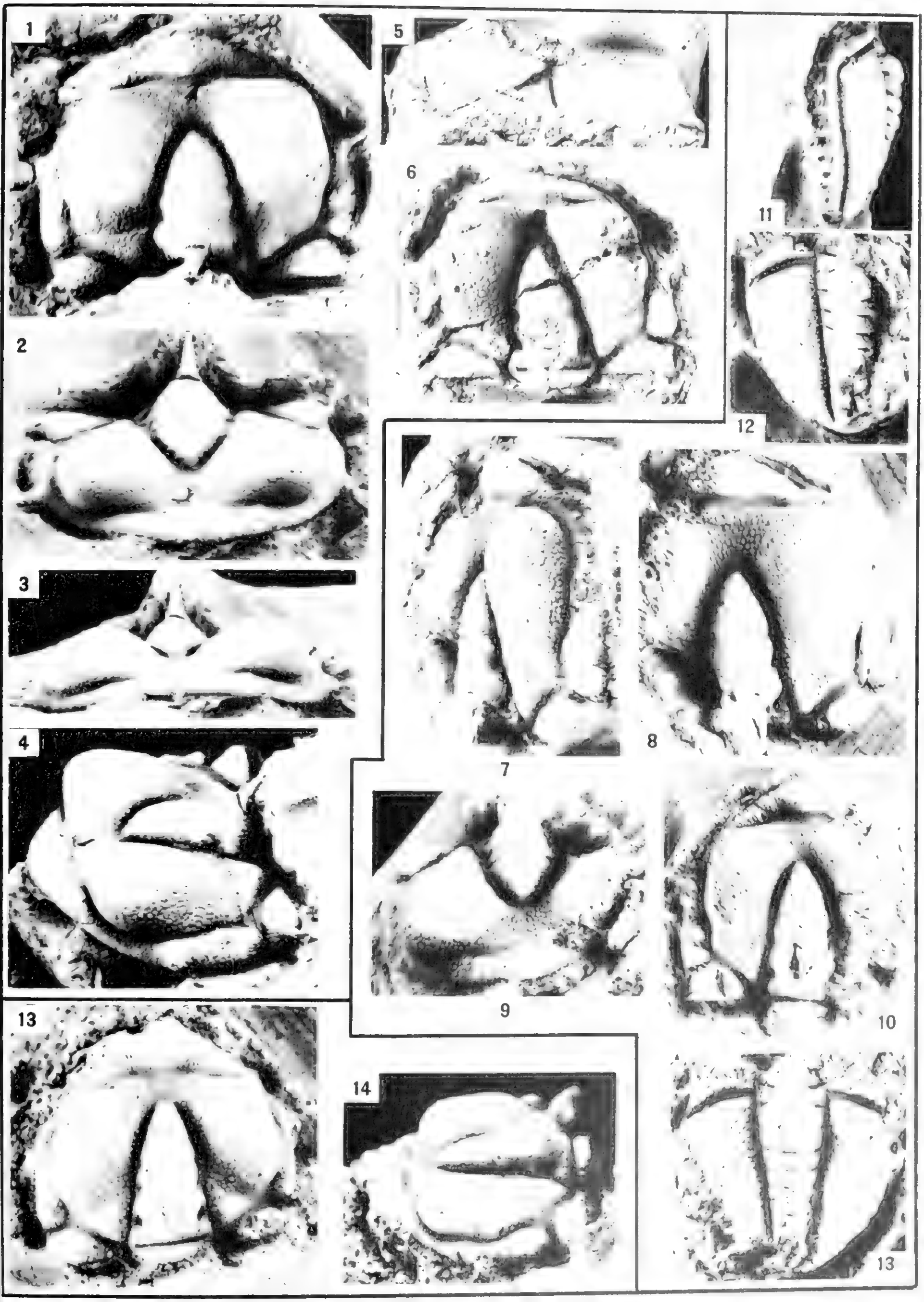

EODISCIDAE (BOLPARIA)

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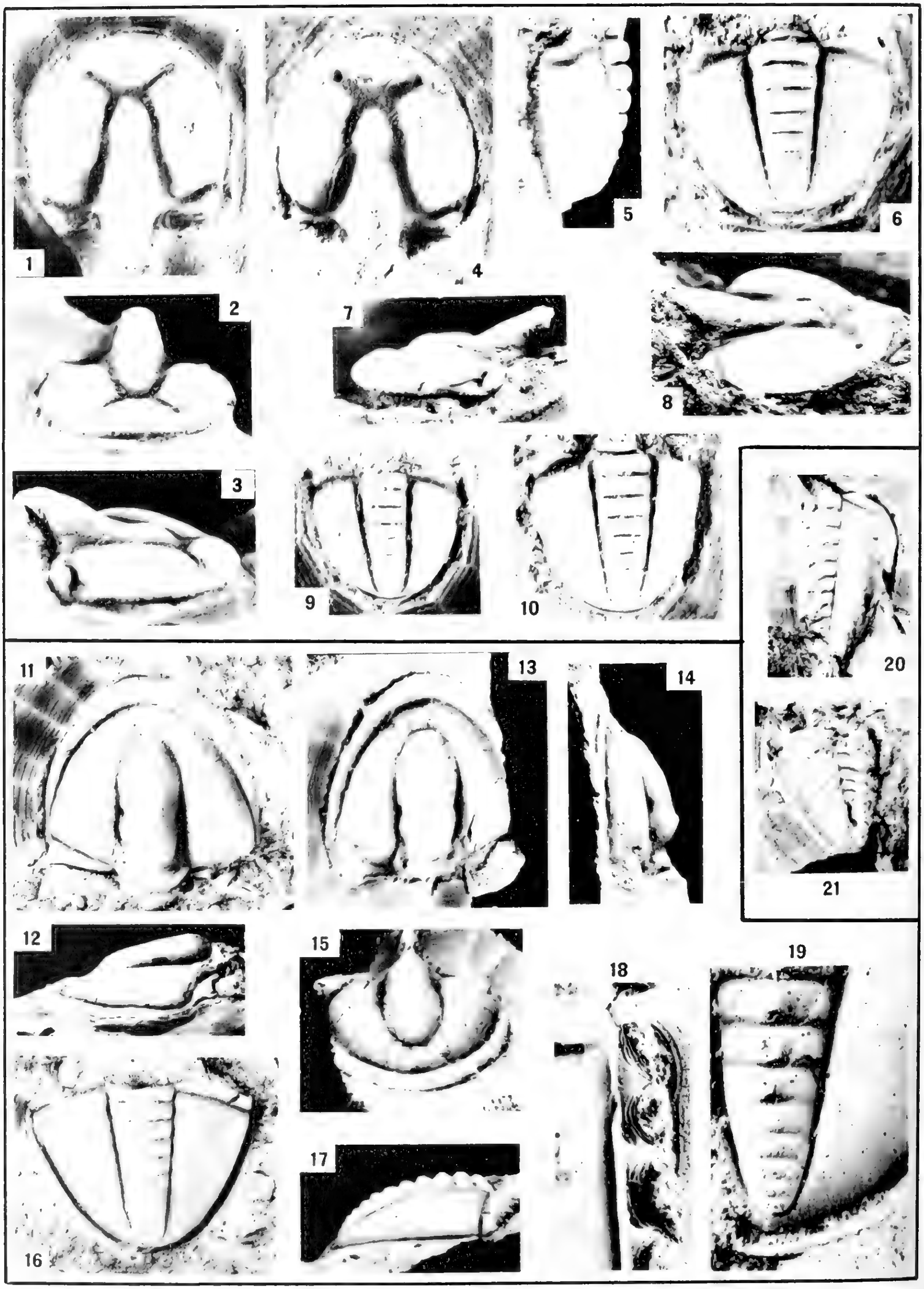

EODISCIDAE (ANALOX, ACIDISCUS); UNDETERMINED TRILOBITE

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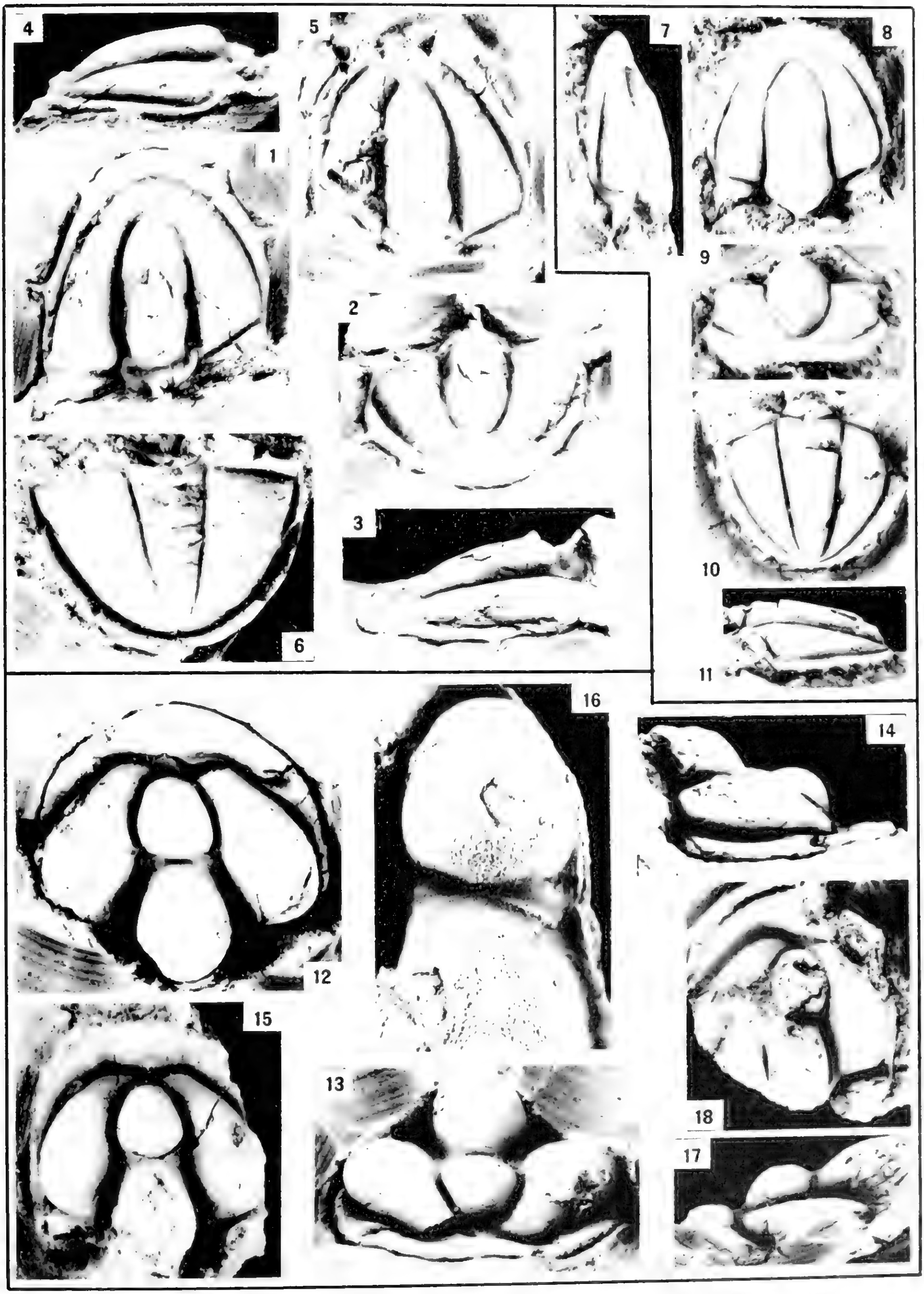

EODISCIDAE (ACIDISCUS, SERRODISCUS, CALODISCUS)

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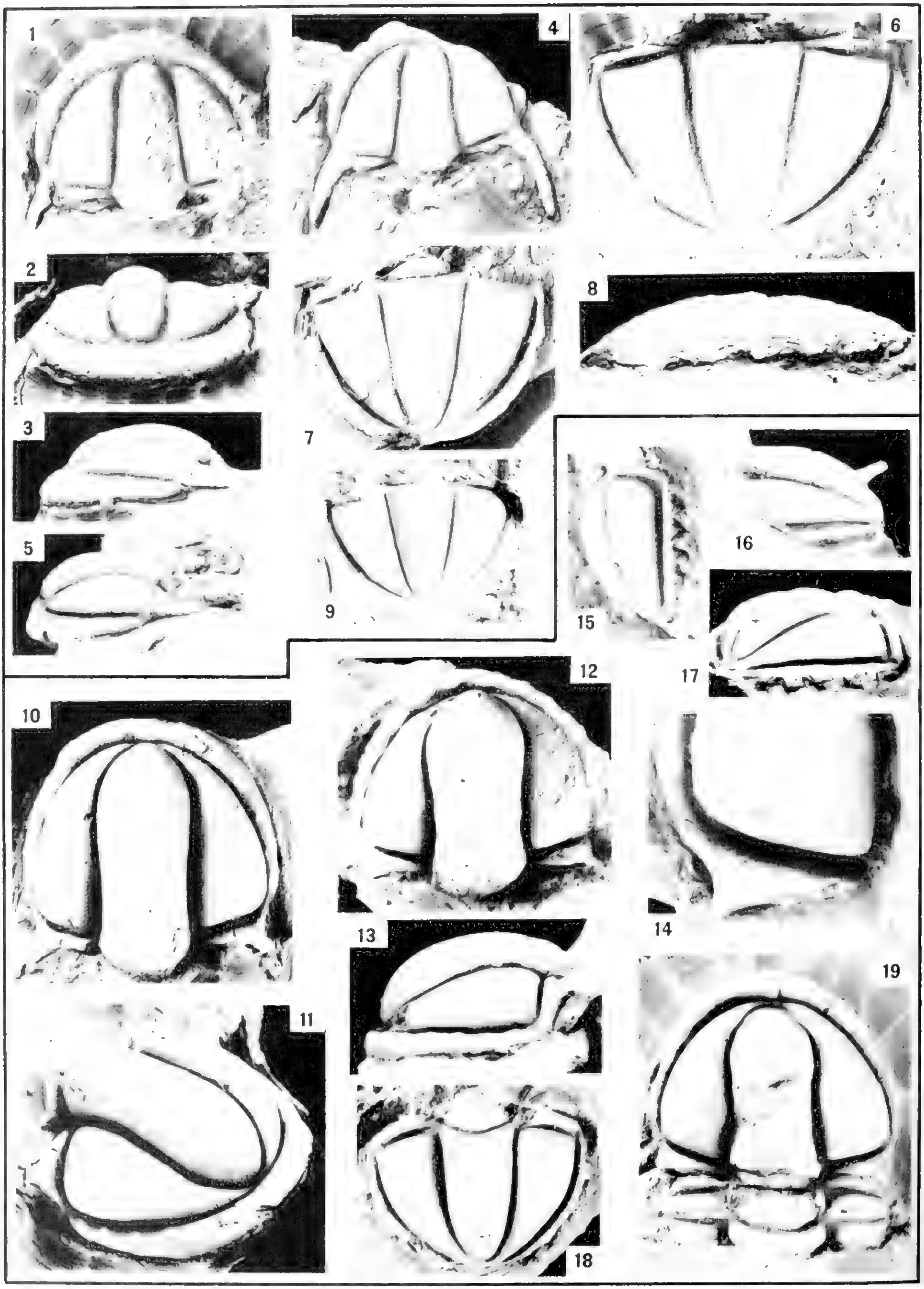

EODISCIDAE (LITOMETOPUS, SERRODISCUS)

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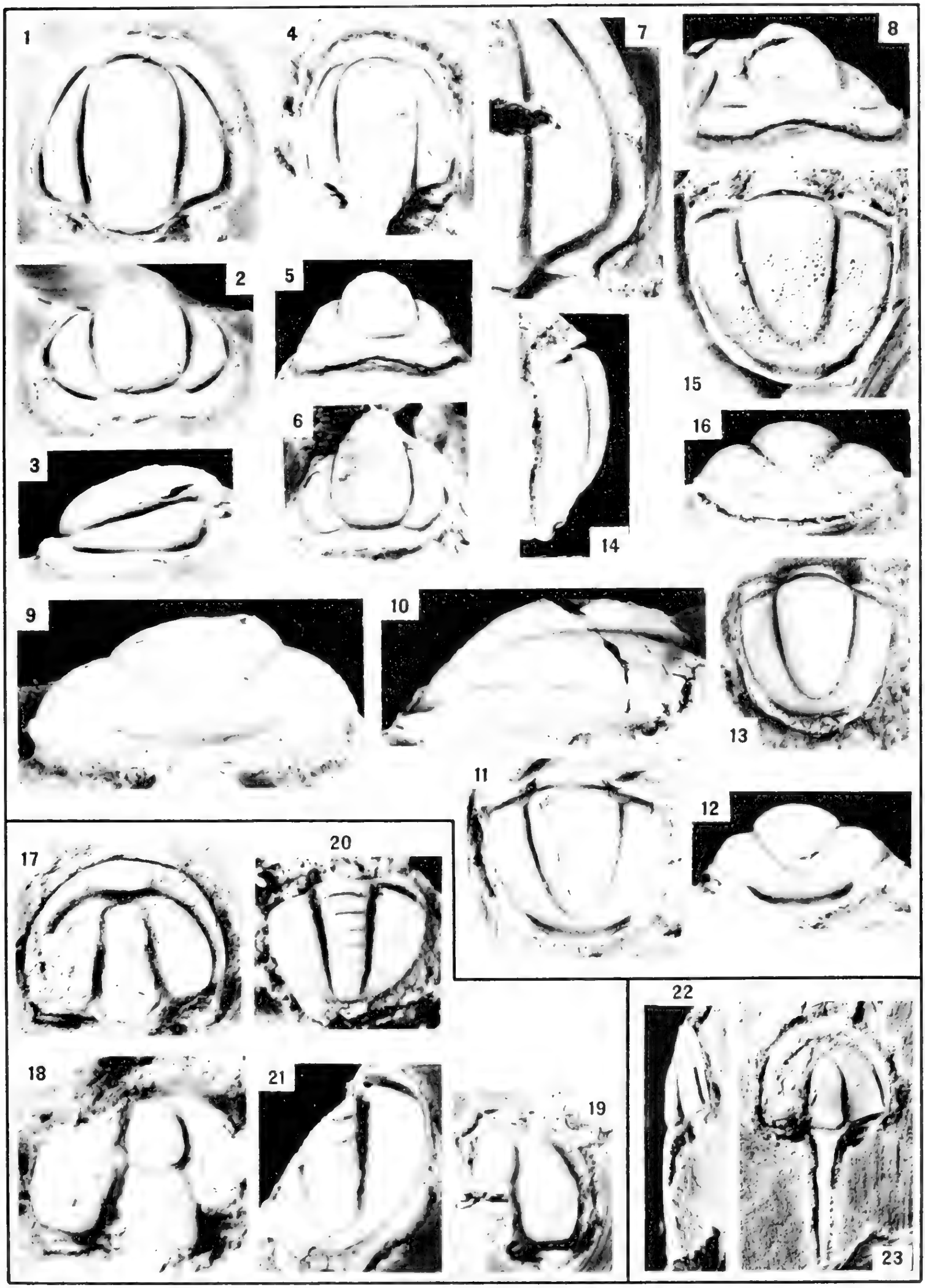

EODISCIDAE (BATHYDISCUS, CALODISCUS)

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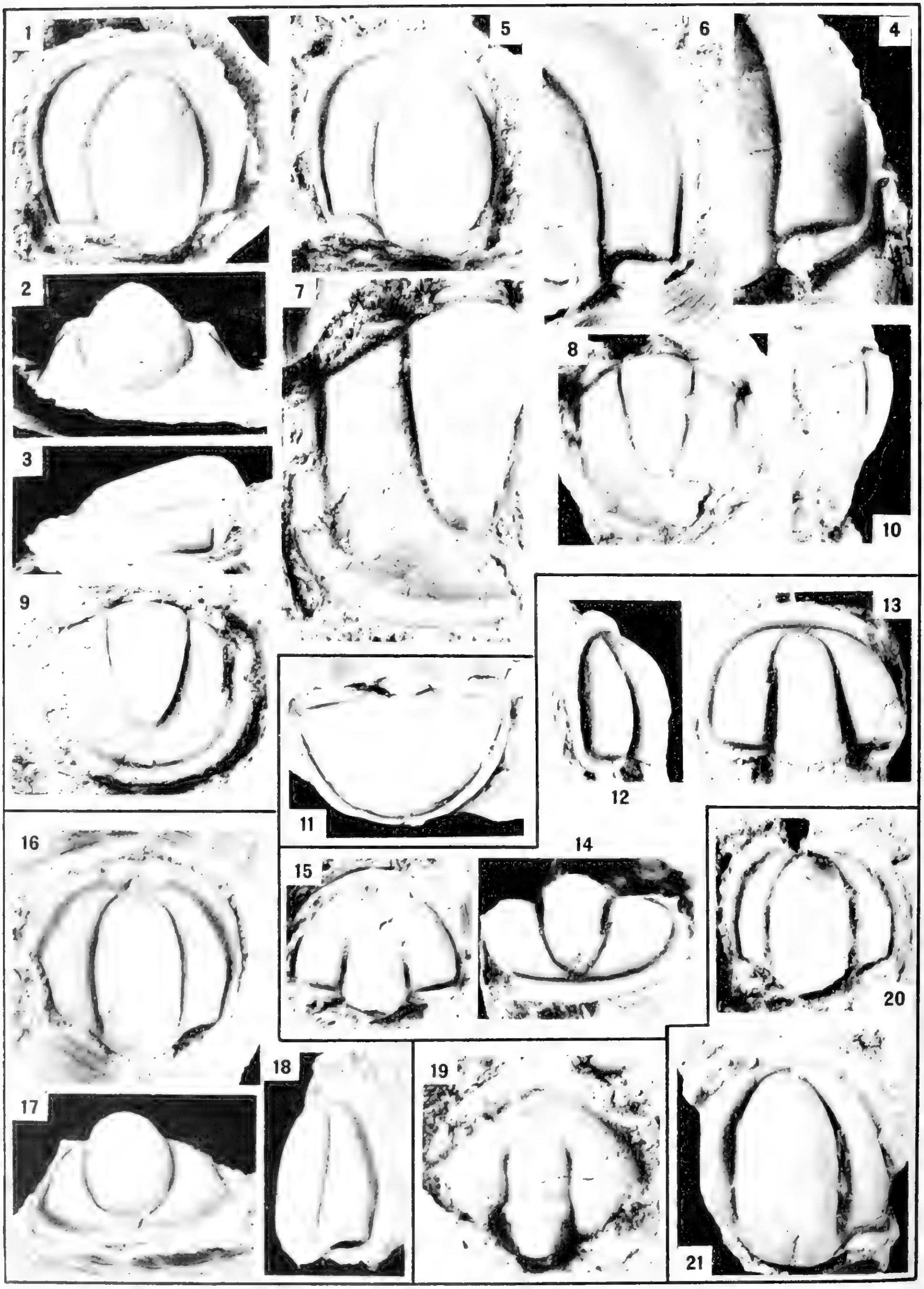

Eodiscidae (Oodiscus, Serrodiscus, undetermined genus)

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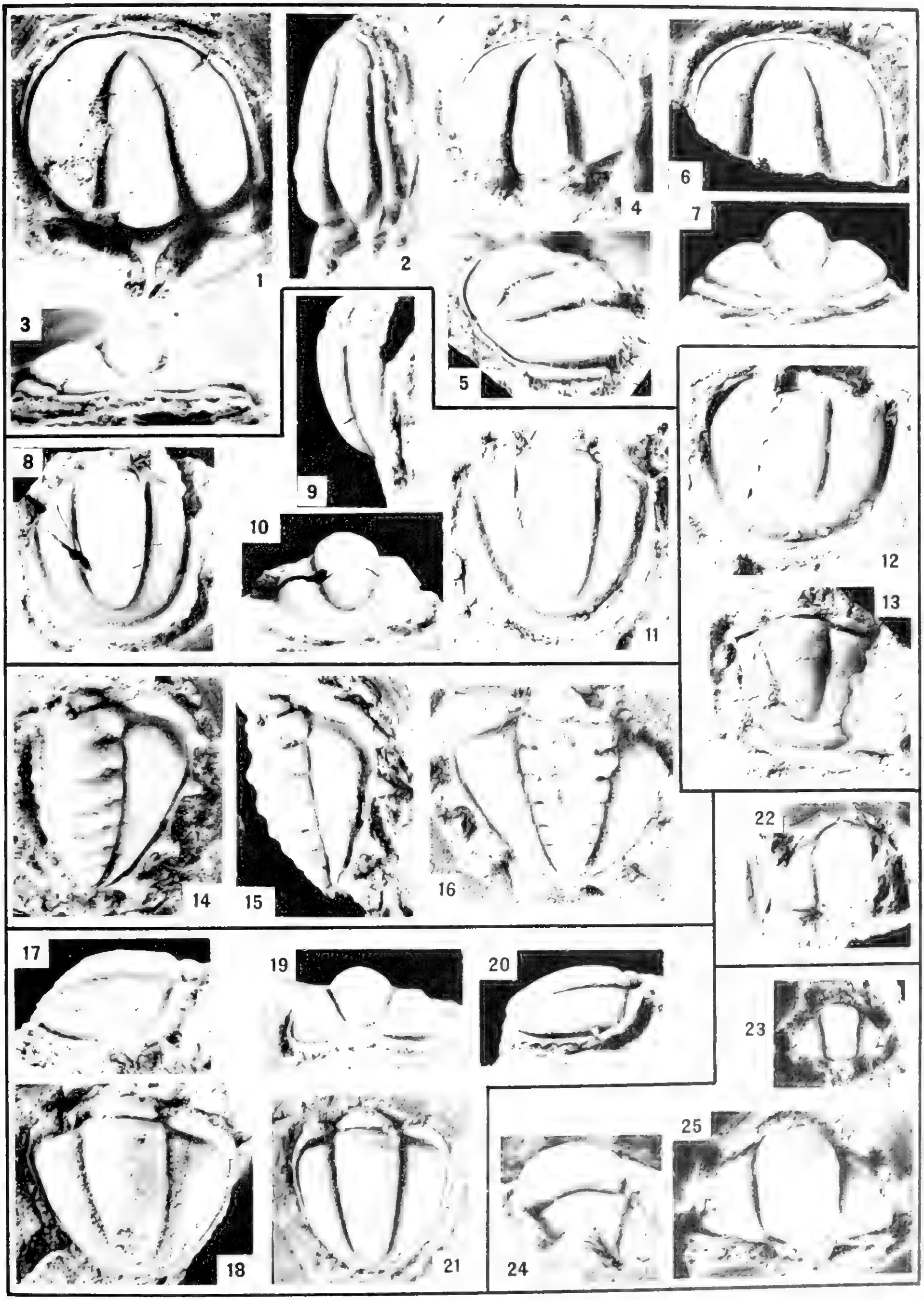

EODISCIDAE (LEPTOCHILODISCUS, OODISCUS, UNDETERMINED GENERA); DORYPYGIDAE (BONNIA)

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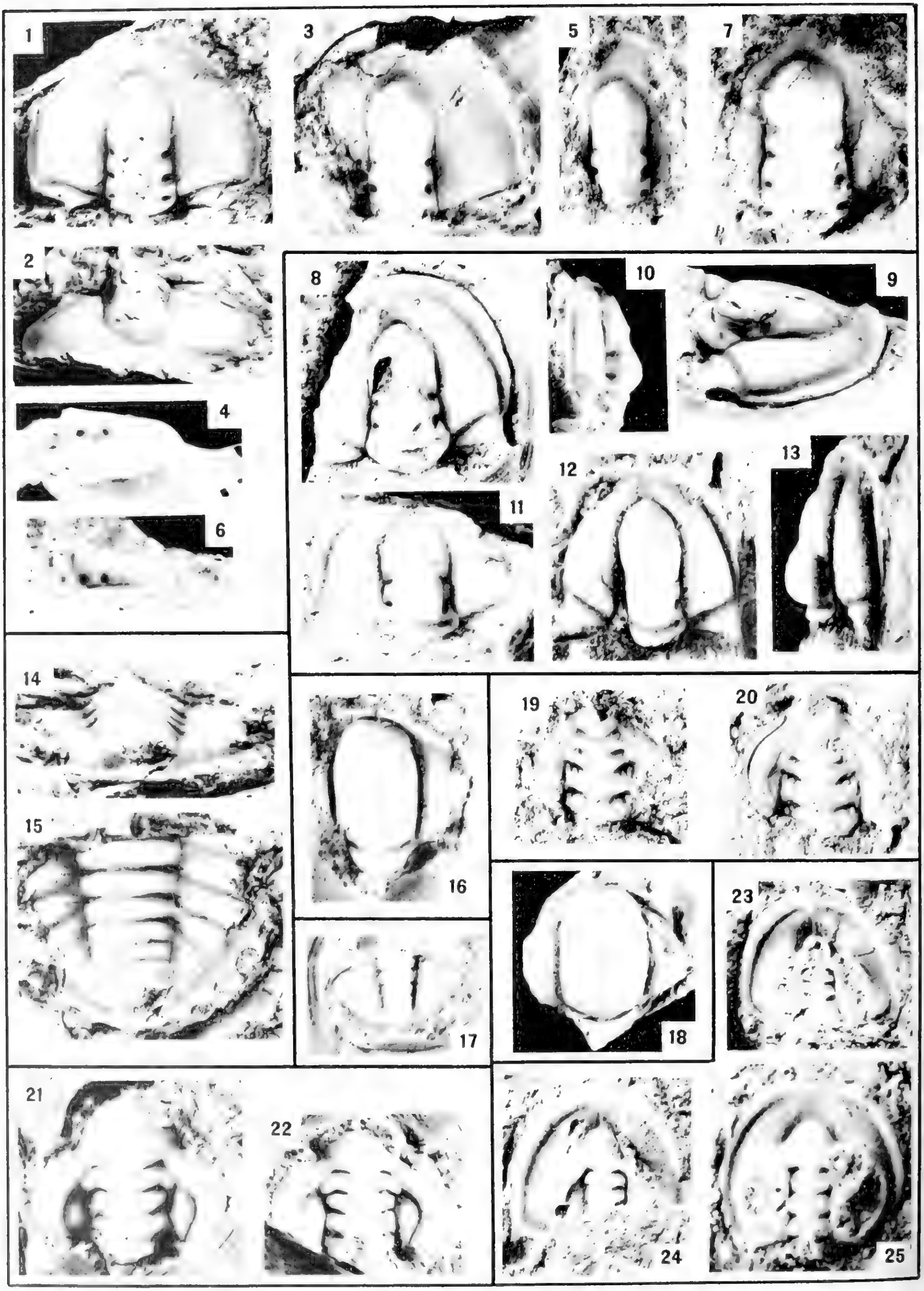

EODISCIDAE (STIGMADISCUS); DORYPYGIDAE (BONNIA, KOOTENIA); OLENELLIDAE (OLENELLUS, PAEDEUMIAS)

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