OKLAHOMA GEOLOGICAL SURVEY
CARL C. BRANSON, *Director*

CIRCULAR 66

CHITONS FROM THE KINDBLADE FORMATION (LOWER ORDOVICIAN), ARBUCKLE MOUNTAINS, SOUTHERN OKLAHOMA

by

ALLYN G. SMITH
and
DONALD F. TOOMEY

The University of Oklahoma
Norman
1964

CONTENTS

ILLUSTRATIONS

TEXT-FIGURES

PLATES

Chitons from the Kindblade Formation (Lower Ordovician), Arbuckle Mountains, Southern Oklahoma

Allyn G. Smith* and Donald F. Toomey†

ABSTRACT

During the process of acid etching of blocks of Lower Ordovician Kindblade Limestone from the Arbuckle Mountains of southern Oklahoma, more than 100 silicified chiton (polyplacophoran) plates were recovered. The bulk of the chiton plates occurs in a stratigraphic sequence 450 to 500 feet above the base of the Kindblade Formation, which is characterized by an abundance of the quasi sponge *Calathium* Billings, 1865.

Previously, only nine Ordovician chiton occurrences have been reported from North America. The Oklahoma fauna is represented by more specimens than the total of the other nine occurrences. From this fauna two new genera and five new species have been described. All are placed under the family Gotlandochitonidae. The new forms are: *Paleochiton kindbladensis,* new genus, *Ivoechiton oklahomensis, I. calathicolus, Eochiton arbucklensis,* new genus, and *Gotlandochiton hami.*

Analysis of the fossil Polyplacophora presented in *Treatise on Invertebrate Paleontology* (Smith, 1960) did not include keys to families, genera, or species of Paleozoic chitons. This defect is partially remedied in this publication with the inclusion of keys to the families Chelodidae, Gotlandochitonidae, Scanochitonidae, and Preacanthochitonidae and the genera included therein. During this study all Ordovician chiton specimens previously described from North America were reexamined.

The Kindblade chiton plates are found in rocks of complex lithology. These rocks are an intergrading series of boundstones, packstones, and wackestones. The boundstones are represented by laminated, stromatolite-like structures, containing the encrusting blue-green alga *Girvanella.* If the boundstones can be regarded as stromatolitic sensu stricto, it can be postulated that the chiton-bearing rocks were deposited on the tidal flat, and that the contained fauna in the associated packstones and wackestones was derived from the adjacent sublittoral biotope.

* Associate curator, California Academy of Sciences, San Francisco, Calif.
† Department of Geology, Rice University.

INTRODUCTION

This study is an outgrowth of a comprehensive research project, by the junior writer, on the Lower Ordovician sponges from the Cool Creek and Kindblade Formations of the Arbuckle Mountains, southern Oklahoma.

During the course of routine field work occasional chiton plates were noted on the outcrop, particularly in the lower part of the Kindblade Formation in a zone marked by the occurrence of abundant quasi sponges of the genus *Calathium* Billings, 1865. Extensive formic acid etching of limestone blocks yielded approximately 110 silicified chiton plates and fragments. Inasmuch as chiton remains are relatively scarce from rocks of the Paleozoic Era, and especially from the Ordovician Period (only nine species have been described from the Ordovician of the world; Smith, 1960, p. 147), it was deemed desirable to have the material accurately described. In addition, the association of chitons with a varied fauna enables the writers to make what we believe to be a reasonable paleoecologic interpretation for the depositional environment of the chiton-bearing beds.

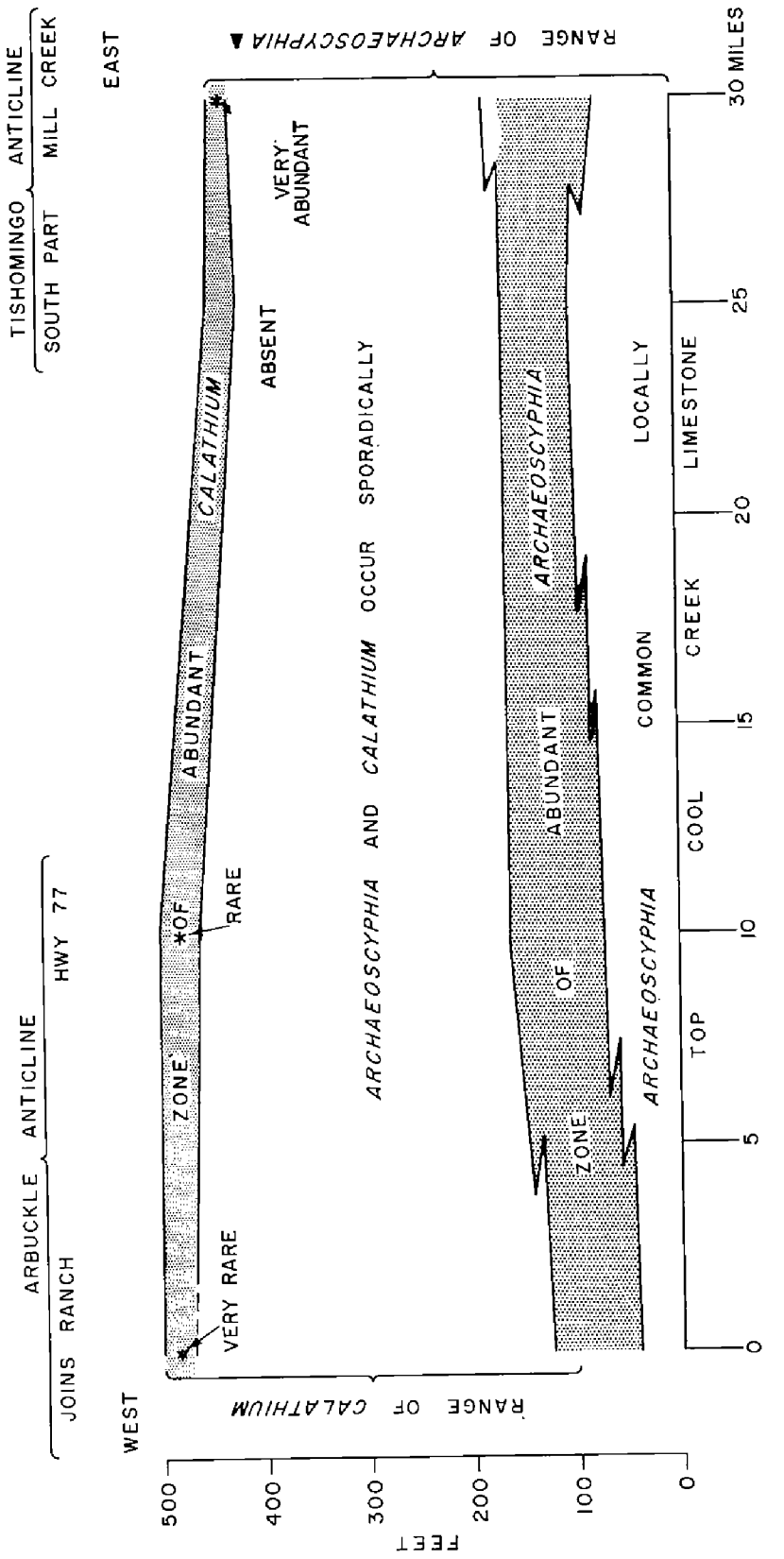
Register of Fossil Localities

Mill Creek Section

Zone of abundant *Calathium* 450 feet above base of Kindblade Limestone, SW¼ SW¼ SE¼ sec. 17, T. 2 S., R. 4 E., Murray County, Oklahoma, 6 miles west-southwest of Mill Creek village. Beds dip 12° homoclinally westward, in the northern part of the Tishomingo anticline. Silicified chiton valves are most abundant in gray limestones at the base of the *Calathium* zone. *Archaeoscyphia* occurs with *Calathium,* chiefly in sponge-algal limestone mounds.

Highway 77 Section

Zone of abundant *Calathium* 450 to 500 feet above base of the Kindblade Limestone, in limestone outcrops dipping 60° homoclinally southwestward on both sides of U. S. Highway 77, S½ NW¼ sec. 19, T. 2 S., R. 2 E., Carter County, Oklahoma. The zone diagonally crosses Highway 77 at a point 0.35 mile south of the Murray-



Text-figure 1. Distribution and abundance of chitons in relation to sponge beds in the lower part of the Kindblade Limestone, Arbuckle Mountains, southern Oklahoma.

Carter county line, on the south flank of the Arbuckle anticline. Silicified chiton valves occur in limestone beds with *Calathium* and *Archaeoscyphia.*

Joins Ranch Section

Zone of abundant *Calathium* 460 to 500 feet above base of the Kindblade Limestone on the original Joins Ranch, SE¼ NW¼ NE¼ sec. 4, T. 2 S., R. 1 W., Murray County, Oklahoma, 6 miles north of Woodford. Strata dip 30° southwestward and are well exposed, but are accessible only by primitive road. Chitons occur sporadically with *Calathium* and *Archaeoscyphia.*

Repositories of Type Specimens

The holotypes, some paratypes, and a few unassigned specimens are in the Invertebrate Paleontology Collection of The University of Oklahoma (abbreviated in the text as OU). The remaining paratypes are deposited in the Division of Invertebrate Paleontology of the United States National Museum (USNM) and in the Geology Type Collection, California Academy of Sciences (CAS), San Francisco.

The figured specimens and types are deposited as follows:

Paleochiton kindbladensis, new genus, new species

Holotype: OU 5211
Paratypes: USNM 144533
CAS 12586
OU 5212

Ivoechiton oklahomensis, new species

Holotype: OU 5219
Paratypes: USNM 144534, 144535
CAS 12587, 12588
OU 5220, 5221

Ivoechiton calathicolus, new species

Holotype: OU 5213
Paratypes: USNM 144536, 144537, 144538, 144539
CAS 12589, 12590, 12591
OU 5214, 5215
Joins Ranch specimen: OU 5216

Ivoechiton sp. (pl. 4, figs. 16-18): OU 5222

Gotlandochiton hami, new species
Holotype: OU 5223
Paratypes: USNM 144541, 144542, 144543, 144544, 144545
CAS 12593, 12594, 12595, 12596, 12597, 12598
OU 5224, 5225, 5226, 5227, 5232
Gotlandochiton sp. (pl. 7, figs. 16-18): OU 5228
Gotlandochiton? (pl. 8, fig. 5): OU 5230
Eochiton arbucklensis, new genus, new species
Holotype: OU 5217
Paratypes: USNM 144540
CAS 12592
Eochiton arbucklensis? (pl. 8, fig. 4): OU 5229
Eochiton? sp. (pl. 6, figs. 10-12): OU 5218
Genus and species indeterminate (pl. 8, figs. 1-3): OU 5231

Acknowledgments

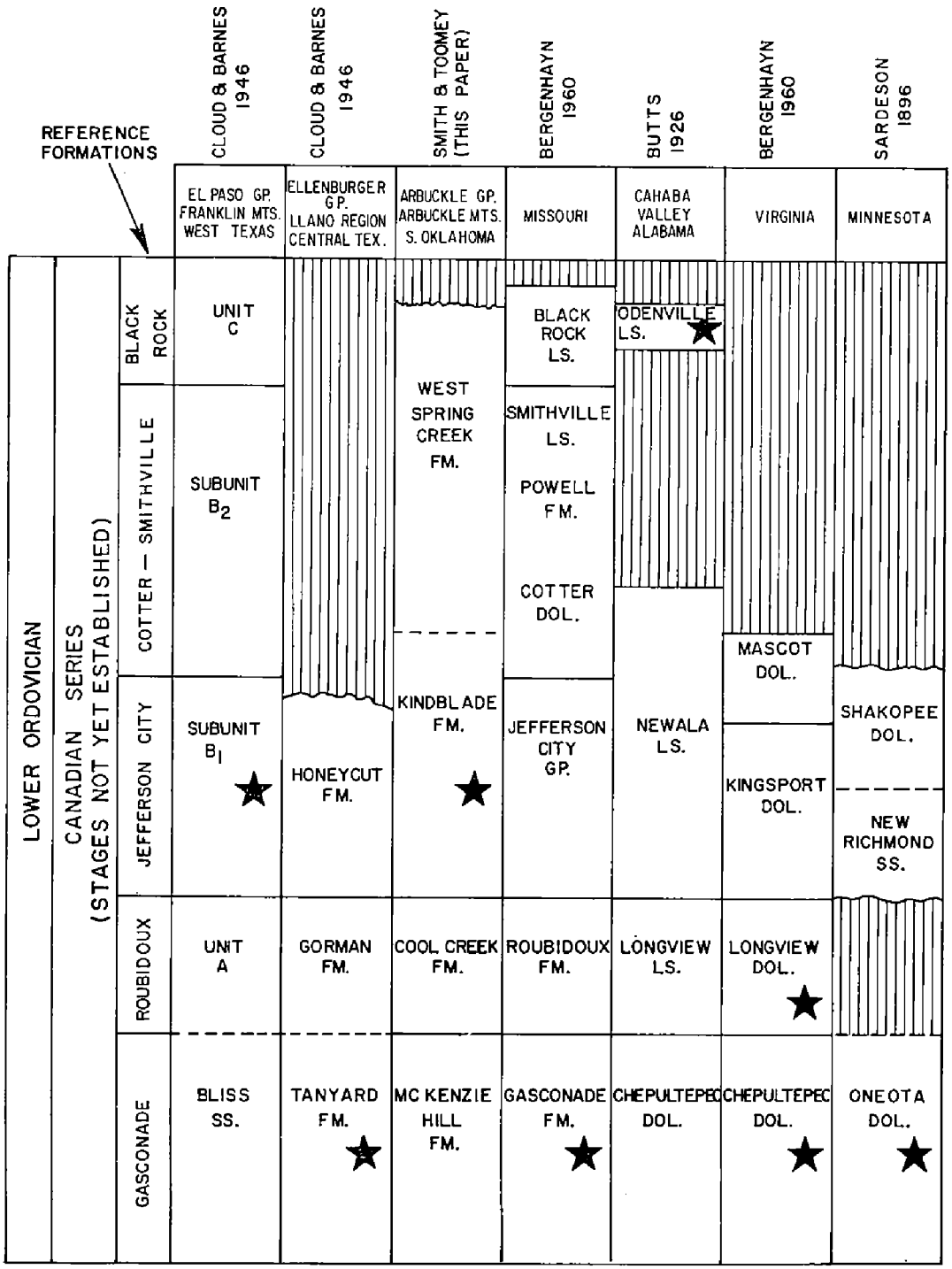
The writers wish to thank Dr. W. E. Ham of the Oklahoma Geological Survey for his assistance and encouragement during this study. In particular, appreciation is expressed to Dr. Ham for the time he spent in the field with the junior author during the period 1961-1962, and for supplying the measured-section data upon which figure 1 is based. Gratitude is also due to Shell Development Company, Houston, Texas, for assistance in photographing fossil specimens.

Stratigraphy

The Lower Ordovician formations in the Arbuckle Mountains are in the Arbuckle Group, and in ascending order they are named McKenzie Hill, Cool Creek, Kindblade, and West Spring Creek. Their total aggregate thickness is 5,200 feet in the southern part of the Arbuckle Mountains, where they consist almost entirely of limestones. In this area the Kindblade Formation is consistently 1,400 feet thick (Ham, 1950).

Chiton plates are abundant in the lower part of the Kindblade Formation, mostly as silicified disarticulated valves. A distinctive chiton zone occurs 450-500 feet above the base of the formation over the entire area, the chitons occurring with abundant specimens of the quasi sponge *Calathium* (text-fig. 1). All the chitons described herein are from this distinctive zone.

Associated fossils include: silicified algal? heads, lithistid sponges (*Archaeoscyphia*), silicified high-spired hormotomid gastropods, and nautiloid cephalopods (*Tarphyceras*). Formic acid etching of limestone blocks from this sequence has yielded additional faunal material consisting of numerous orthoid brachiopods, sponge spicules, and simple distacodid conodonts. Study of numerous thin



Text-figure 2. Stratigraphic distribution of reported Lower Ordovician chiton faunas (indicated by stars) in the United States.

sections has extended this list to include the algae *Girvanella* and *Renalcis,* pelmatozoan plates, other types of gastropods, and trilobites.

One exotic occurrence of a single chiton plate was noted in a thin section from the zone of abundant *Archaeoscyphia* 100 feet above the base of the Kindblade Formation at the Mill Creek section.

Lithology

Petrological examination of numerous thin sections from this horizon indicates a varied and complex lithology. Following the usage of Dunham (1962) the principal rock type can be designated as a fossiliferous (mainly sponges) mud-supported wackestone. However, lateral gradation demonstrates lithologic variation consisting of stromatolites and coarse calcarenites. Hence, the rock unit can also be designated as a boundstone or packstone. More realistically, the lithology illustrates a gradational spectrum strongly reflecting the environmental influence. The rock type is therefore a composite wackestone-boundstone-packstone.

Rocks that may be designated as a typical fossiliferous mud-supported wackestone have the following composition:

mud: 50-75 percent
silt grains (quartz): less than 5 percent
pellets and lithoclasts: less than 5 percent
sponges (including spicules): up to 25 percent
brachiopods, pelmatozoans, chitons, gastropods, and trilobites: 5-10 percent
alga (*Renalcis* and *Girvanella*): up to 5 percent

The rocks referred to as boundstones and packstones are intimately associated with one another. The boundstones (stromatolites) are small, club-shaped or digitate laminated structures (pl. 1, fig. 1) formed by filamentous blue-green algae (Johnson, 1961, p. 205- 206).

The algae interact with the mucilaginous mud, holding and binding the sediment on contact as the motile algae move up through the sediment laminae to form new laminae (Ginsburg, 1960, p. 26). Layers of quartz silt grains normally delineate the laminae. The bases of the stromatolites are interconnected, forming a network of potential sediment traps that may extend laterally for a number of feet. In a few thin sections of complete stromatolites, the outer periphery of the stromatolite shows up as a dark, dense border. Microscopic examination indicates that this dense border is composed entirely of the encrusting blue-green alga *Girvanella.* In a few

instances, *Girvanella* threads have penetrated to the interior of the stromatolite and have encrusted the silt laminae. This condition would tend to suggest that the *Girvanella* and the alga that formed the stromatolite may have had a commensal relationship. Logan (1961, p. 521), quoting Ginsburg (1960) and Black (1933), noted that a large number of algal species may be present in modern mat-sediment complexes; Ginsburg listed up to 28 species in algal mats from Florida, and Black listed 12 species from the Bahamas. However, most of this organic material is destroyed by bacterial decomposition prior to lithification. In many cases, only the silt laminae remain.

The sediment occurring between the stromatolites is classified as a packstone; that is, a sediment composed of skeletal grains that are in contact with one another but whose matrix consists of mud. Sediments of this type suggest that the environmental conditions were such that wave and current action were prime factors but that this physical energy was not great enough to winnow out the finer mud component completely. The grains consist of many types of shell debris, pellets, and abundant lithoclasts. The boundary between the boundstone and the packstone is sharp and distinct.

Chitons in Thin Section

Rare chiton plates were noted in a few thin sections, mainly from the Highway 77 section. These were identified mainly by their characteristic shape and distinctive silicification, especially under crossed nicols. No original microstructure is preserved. Originally, the chiton plates were probably aragonitic in composition, but they have been altered to large areas of calcite mosaic with numerous smaller islands or nuclei of chert (chalcedony) replacing the mosaic calcite (pl. 2). Some chiton plates showed even more silicification, indicating a somewhat erratic and random replacement process.

Interpretations of Paleoecology

Stromatolites and algal mat material are abundant within the chiton-plate horizon and seemingly are the most useful of paleoecologic criteria. Previous studies by Black (1933), Rezak (1957), Ginsburg (1960), and Logan (1961) indicate that algal mats and stromatolites are limited in distribution to the intertidal zone. Because early lithification of the algal-bound detrital sediment is

necessary to prevent collapse of the stromatolitic structure, this basic requirement delimits the environmental realm to the intertidal zone of tropical and subtropical seas where rapid precipitation of carbonate cement is known to occur (Logan, 1961, p. 518).

The preserved fauna and flora of the stromatolites and algal mats are indeed sparse. *Girvanella* is the only recognizable alga present, although the stromatolitic laminations attest to the former presence of other algal forms that were undoubtedly destroyed by bacterial decomposition before lithification. A few gastropods and other rare types of shell debris were observed in one of the stromatolites. Probably the gastropods represent the only indigenous faunal element that lived on the stromatolites. Most likely the gastropods grazed on the prolific algal heads in a manner similar to that of the vast accumulations of the gastropod *Batillaria* found on the Recent stromatolites on the western side of Andros Island in the Bahamas.

As noted above, the interareas between the stromatolites carry an abundance of marine fossils. It is believed that these fossils, many of them fairly well abraded and broken, have been derived from the adjacent sublittoral biotope. They include sponges, pelmatozoan fragments, brachiopods, chitons, gastropods, cephalopods, trilobites, and conodonts. Indeed, nearly all the forms listed above could not live in this harsh environmental realm of the intertidal zone with its pronounced hypersalinity, marked tidal oscillation, and ultimate subaerial exposure.

Tidal and storm waters tended to collect the fossil grains in the interarea depressions, and here stromatolitic growth and binding were inhibited.

In addition to the coarse fossil debris found in the interareas, numerous lithoclasts are also present. The lithoclasts are all well rounded and represent fragments of preexisting sediment from the adjacent sublittoral bottom that have been ripped up from the sea floor by normal wave or storm action, rolled around the bottom, and finally incorporated with the other allochthonous grains in the intertidal zone.

Known Occurrences of Lower Ordovician Chiton Valves in the United States

Discovery of this important chiton fauna in the Lower Ordovician of Oklahoma provides another record to add to the occurrences

previously reported from the United States. This distribution is shown graphically in text-figure 2. Prior records are as follows:

(1) Sardeson (1896, p. 102, pl. 6, figs. 8-10) described "*Asco-ceras*" *gibberosum* from the Oneonta Dolomite of Dresbach, Minnesota. The type specimen was lent to the senior writer for study by Professor R. E. Sloan of the University of Minnesota, Department of Geology. Without doubt this species belongs in the family Chelodidae, although certain of its characters make its assignment to the genus *Chelodes* Davidson and King, 1874, problematical. Other chiton valves from this same formation, and hitherto not reported, are provisionally referred to *Chelodes* and to *Gotland-ochiton.*

(2) Butts (1926, p. 99, pl. 18, figs. 30-31) reported a chiton valve from the Lower Ordovician Odenville Limestone near Leeds, Alabama. This was questionably referred to *Priscochiton* Dall, 1882 (*P.? mirabilis,* n. sp.); this genus was based on *Chiton canadensis* Billings, 1865, from the Middle Ordovician Black River Limestone, Pauquette Rapids on the Ottawa River, Quebec, Canada. *P. canadensis* was described from two triangular valves which were well figured by Wilson (1951, p. 16, pl. 1, figs. 1-3) and later reillustrated by Smith (1960, p. 53, figs. 36-10 a, b). Butts' specimen exhibits the characters of the family Chelodidae, but whether it belongs in the genus *Chelodes* or in another undescribed one is a question that can be answered only through further study of available material. Butts stated it "is fairly abundant about one mile southwest of Hebron Church, five miles southwest of Leeds." The holotype, lent for study through the courtesy of Dr. G. Arthur Cooper, is in the Division of Invertebrate Paleontology, United States National Museum (USNM 71467).

In his same report Butts also described *Priscochiton? sellaeformis* (p. 99, 125, pl. 31, fig. 7) from the Chickamauga Limestone, Mountain Terrace, Birmingham, Alabama, Middle Ordovician (Black River Group). Study of the holotype of this species, also in the United States National Museum (USNM 71523), leads to the conclusion that this, too, undoubtedly belongs in the family Chelodidae and not to *Priscochiton.* This genus is now tentatively assigned to the neoloricate family Lepidopleuridae (Smith, 1960, p. 54). Whether *P.? sellaeformis* is a true *Chelodes* cannot be stated at this time with any assurance, as still another genus may be indicated.

The Odenville and Chickamauga Limestone faunas, particularly the chitons, need additional study.

(3) In an excellent monograph on the Ellenburger Group of central Texas, Cloud and Barnes (1946, p. 282) recorded "chiton plates" from unit 19 of a measured sequence of the Tanyard Formation (Threadgill Member) from Moore Hollow section. These were neither described systematically nor illustrated.

In the same publication (p. 365) a single "chiton plate" was noted from unit 15 of a measured sequence of El Paso Group rocks (subunit B_1) from the southern end of the Franklin Mountains of West Texas. Again, neither a systematic description nor an illustration was included.

(4) Professor J. R. M. Bergenhayn of Lund University, Sweden (1960), described and illustrated the first Cambrian chiton fossils from North America and included species from the Ordovician as well. From the Lower Ordovician Gasconade Formation of Missouri one new family (Preacanthochitonidae), a new genus (*Preacanthochiton*), and two new species (*P. cooperi* and *P. depressus*) were added to the records. In addition, from the Lower Ordovician Chepultepec Formation of Virginia, one new species (*Chelodes intermedius*) was described and illustrated.

Of more than passing interest is the fact that of the eight occurrences of chiton valves in rocks of Early Ordovician age, three are associated with sponges. In the El Paso Group, subunit B_1, chitons are found with *Calathium;* in the Arbuckle Group, Kindblade Formation, both *Calathium* and *Archaeoscyphia* are associated with chiton valves; and in the Odenville Limestone, *Chelodes? mirabilis* and *Archaeoscyphia* (misidentified as *Calathium*) are found together.

Stratigraphically, chiton valves have been found in all the Lower Ordovician rocks except in correlative units of the Cotter, Powell, and Smithville Formations.

Systematics of Paleozoic Chitons

The relative rarity of chiton valves from Paleozoic rocks makes it desirable to place new occurrences on record and to assign them taxonomically in the best manner possible. In many instances such assignment is difficult owing to a lack of good preservation or to a paucity of material, or both. The former presents a problem with

the valves from Lower Ordovician Kindblade Formation of Oklahoma.

In assigning chiton valves to described taxa one must have as clear an idea as possible of the manner in which these taxa have been divided and of their occurrence geographically as well as geologically. The analysis of the fossil Polyplacophora in the *Treatise on Invertebrate Paleontology* (Smith, 1960) did not include keys to families and genera or species of Paleozoic chitons. This is partially remedied here in order to present as up-to-date a picture as possible from available fragmentary information.

Paleozoic chitons are placed in the order Paleoloricata Bergenhayn, 1955, embracing primitive chiton types lacking the lower, or articulamentum, shell layer that is present in the more modern types, hence not possessing insertion plates or sutural laminae of any kind which serve to hold the valves firmly into the surrounding girdle. The presence of an articulamentum shell layer seems to be a later evolutionary development. Most, if not all, chiton species, even in the Paleozoic, are characterized by an extension of the dorsal shell layer (tegmentum) over the posterior margin of the valve to the ventral side. This takes the form of a raised ridge or band on the ventral side of the posterior margin of a valve, which is normally present on all valves except the posterior or tail valve. It provides some indication of the extent to which successive valves overlapped in life—a character that can be used, along with shape, size, and thickness, in differentiating species and genera. In Paleozoic chitons this so-called apical area varies considerably in width, in some species occupying one-third to one-half the ventral surface, although in most Recent species the apical area is much reduced.

Almost nothing can be deduced with respect to the extent or the character of Paleozoic chiton girdles, especially the manner in which they were decorated. The single reported instance of a spiculose Ordovician species does not permit the present writers to make the broad assertion that this type of girdle was generally characteristic of Paleozoic species.

The Paleoloricata have been divided into two broad suborders: the Chelodina Bergenhayn, 1943, with eight valves, and the Septemchitonina Bergenhayn, 1955, created for a curious seven-valved species (perhaps a sand dweller) reported only from the Upper Ordovician of southern Scotland. With this possible exception, all

other Paleozoic species known can probably be assumed to have lived on or in a rock substrate. This is much the same type of habitat as that in which Recent chitons live, although, in addition, a few Recent species are found in seaweed holdfasts and on the stipes of eelgrass.

For the purpose of this discussion the suborder Septemchitonina can be disregarded. The following keys, therefore, cover the families and genera of the suborder Chelodina, based largely upon the configuration of intermediate valves as these occur most frequently.

Key to Families - Suborder Chelodina Bergenhayn, 1943

1. Valves longer than wide; large and thick — Chelodidae
2. Valves generally wider than long:
   a. Small to medium in size, rectangular; the tegmentum with weak or clearly defined shell areas — Gotlandochitonidae
   b. Semicircular or triangular; tegmentum divided into clearly defined shell areas — Scanochitonidae
   c. Heart shaped or rectangular; tegmentum sculpture of distinctive small, rounded pustules — Preacanthochitonidae

Family Chelodidae Bergenhayn, 1943

Valves fairly large, elongate, massive, heart- or wedge-shaped; apical area large, covering as much as one-half or more of the posterior ventral side — *Chelodes*

Key to Genera-Family Gotlandochitonidae Bergenhayn, 1955

1. Tegmentum with no clearly defined shell areas:
   a. Valves longer than wide, rectangular, with acute jugal ridge and straight side slopes — *Paleochiton*
   b. Valves wider than long, generally round-backed, with rounded side margins; ventral side with a transverse rib or thickening, prominent to subobsolete — *Ivoechiton*
2. Tegmentum with clearly defined shell areas, generally consisting of a fairly prominent, raised, broadly triangular jugal area bounded by two lateropleural areas:
   a. Apical area more than 1.5 mm wide, extending across the posterior margin — *Eochiton*

b. Apical area less than 1.5 mm wide, extending across the entire posterior margin or present mainly in the vicinity of the valve apex *Gotlandochiton*

Key to Genera - Family Scanochitonidae Bergenhayn, 1943

1. Valves nearly semicircular; tegmentum with a broadly triangular, raised jugal area *Scanochiton*
2. Valves triangular; tegmentum with a raised, narrowly rectangular jugal area; sculpture of minute tubercles *Olingechiton*
3. Valves trapezoidal; jugal area depressed, concave, and broadly triangular, set off from the lateropleural areas by fairly prominent diagonal ridges *Haeggochiton*

Family Preacanthochitonidae Bergenhayn, 1960

Valves as described for the family. The principal feature, different from other genera, is the pustular tegmental sculpture reminiscent of certain Recent species of the genus *Acanthochitona.* *Preacanthochiton*

The above arrangement differs from that in the *Treatise on Invertebrate Paleontology* by the removal of *Ivoechiton* Bergenhayn, 1955, from the Scanochitonidae and its inclusion in the Gotlandochitonidae. This has been done because *Ivoechiton,* from the Upper Cretaceous of Sweden, is described as having a tegmentum not divided into distinct shell areas, a feature of the latter rather than the former family as these are now understood. Because the senior writer did not have the opportunity to study Bergenhayn's *Ivoechiton* valves, this placement must be a provisional one. The illustration of the unique valve of the type species (*I. levis*) in the *Treatise* (Smith, 1960, p. 51, fig. 34-2b) gives almost no information about its character. If Bergenhayn's reconstruction of *I. levis* is reasonably correct (Smith, 1960, fig. 34-2a), the chiton is shown to be similar in some respects to Recent species of the genus *Leptochiton* in the neoloricate family Lepidopleuridae. Some valves from the Kindblade Formation of Oklahoma are considered to resemble this chiton type sufficiently to warrant a provisional use of *Ivoechiton* for them, despite the difference in geological age and geographic location. Chiton genera may have had a cosmopolitan distribution in Paleozoic seas. This possibility is supported by the occurrence

of the genus *Chelodes* in the United States as well as in Europe. Furthermore, a long geological range for family groups, if not for genera, does not seem unreasonable in view of the occurrence, as far back as the Early Paleozoic, of well-developed chitons that exhibit many characters of those living today. Indeed, one genus of the order Neoloricata, *Lepidopleurus,* is said to have a geological range extending from the Carboniferous to the Recent.

Admittedly, the available evidence for any sort of objective taxonomic work is exceedingly sparse, but it is all we have on which to base judgments, which must remain tentative, until more and better material becomes available.

SYSTEMATIC DESCRIPTIONS

Class AMPHINEURA von Ihering, 1876
Subclass POLYPLACOPHORA de Blainville, 1816
Order PALEOLORICATA Bergenhayn, 1955
Suborder CHELODINA Bergenhayn, 1943
Family GOTLANDOCHITONIDAE Bergenhayn, 1955

PALEOCHITON A. G. Smith, new genus

Intermediate valves, longer than wide, rectangular, with rounded corners; jugum acute; side slopes straight, not separated into jugal, central, or lateral areas. Dorsal sculpture as in the suborder; otherwise smooth. Valve coverage total, indicated by a narrow, beveled apical area extending across the posterior margin ventrally. Ventral surface otherwise smooth with no transverse rib or thickening. No sutural laminae or insertion plates. End valves unknown. Geological range: Lower Ordovician. Type: *Paleochiton kindbladensis,* new species.

Paleochiton kindbladensis A. G. Smith, new species
Plate 3, figures 1-14

Holotype.—An incomplete intermediate valve of medium size, thickened longitudinally along the jugum and tapering toward the side margins, roughly rectangular, the anterior corners broadly lobed, the posterior ones slightly rounded; apex not mucronate, the jugum fairly acute with straight dorsal side slopes forming a jugal angle of about 114°. Dorsal sculpture consisting of two or three sharp ridges forming narrow ledges one above the other, roughly paralleling the perimeter of the side and anterior margins and close to them. Except for this feature, the lateropleural areas appear smooth, without sculpture or any evidence of separation into jugal, central, or lateral areas. Internally the valve is relatively smooth, although a prominent, somewhat beveled apical area is present in the form of a raised ridge 1.2 mm wide extending across the more or less straight posterior margin, indicating a small but complete overlap of this valve on the next posterior to it in the living animal.

There is no marked transverse internal rib or thickening. Measurements are: length, 13.4 mm; width, 11.2 mm; height 5.5 mm.

The holotype is deposited as OU 5211. It lacks most of the right side below the jugum and ahead of the posterior margin, which is complete.

Type material and locality.—The type lot consists of four specimens, here designated as a holotype and three paratypes. They were collected in the lower part of the Kindblade Formation, Mill Creek section, Arbuckle Mountains, southern Oklahoma. The age is Early Ordovician. Paratypes, all intermediate valves, are deposited as OU 5212, USNM 144533, and CAS 12586.

Remarks.—The four valves differ in completeness because of breakage or imperfect preservation. Following are comparative measurements:

Specimen	*Length (mm)*	*Width (mm)*	*Height (mm)*	*Width of Apical area (mm)*	*Divergence (degrees)*
Holotype					
OU 5211	13.4	11.2	5.5	1.2	114
Paratypes					
USNM 144533	10.2	9.5	4.7	1.3	107
CAS 12586	14.4	12.4	5.0	1.5	107
OU 5212	10.5	9.3	5.3		93

Any evidence of dorsal microsculpture that may have existed originally is absent, leaving only the major sculptural characters described. Whereas the posterior margins of the valves are generally straight, in one the apex is slightly mucronate; in another it is beveled posteriorly toward the margin, a feature that is insufficiently prominent to warrant calling it a tail valve with any confidence. The thickness of the valves at the jugum varies somewhat as the edge views shown on plate 3 indicate. This fact may be due to factors of age or of individual variation, or both. Regardless of these minor differences, all four valves undoubtedly belong to a single species, differentiated from others found in the same formation and from other described species in having a length greater than the width in a ratio averaging 1/1.4, with a range of 1/1.07 to 1/1.20. The occurrence of chitons having intermediate valves both longer than wide and wider than long in the same animal is not known; the liklihood of such a variation in valve configuration seems exceedingly remote.

Paleochiton kindbladensis does not appear to be closely related to any other described Paleozoic chiton species. It does not have the

thick, massive valves of *Chelodes,* nor does it have their heart or wedge shape, projecting apices, or their long apical areas. Other Paleozoic species have intermediate valves generally wider than long (sometimes almost square) with the exception of those described under the genus *Preacanthochiton,* which are mainly distinguished by their peculiar pustular dorsal sculpture.

Using Bergenhayn's formula for estimating the size of chitons from single valves (1960, p. 172), we judge that *P. kindbladensis* would have an approximate length, excluding the girdle, of 90 mm, or slightly more than 3½ inches, based upon the holotype.

IVOECHITON Bergenhayn, 1955

Ivoechiton oklahomensis A. G. Smith, new species

Plate 4, figures 1-15

Holotype.—An intermediate valve of medium size, wider than long, low-arched and broadly rectangular, the jugum not acute; side slopes convex, the lateral edges rounded; apex slightly mucronate; anterior sinus quite shallow. Tegmentum not divided into specific shell areas; no dorsal sculpture evident. Ventrally there is a fairly heavy transverse thickening of the valve centrally, tapering in thickness toward the rather blunt margins. No apical area preserved. The angle of divergence is approximately 123°. Measurements are: length, 7.1 mm; width, 13.0 mm; height, 4.9 mm; thickness at jugum, 1.8 mm.

The holotype is deposited as OU 5219. It is not complete, having a small hole punched through it, but has been selected as it shows the characters described for the species.

Type material and locality.—The type lot consists of seven specimens, all intermediate valves, here designated as a holotype and six paratypes. It comes from the lower part of the Kindblade Formation, Mill Creek section, Arbuckle Mountains, southern Oklahoma. The age is Early Ordovician. Paratypes are deposited as USNM 144534 and 144535, as CAS 12587 and 12588, and as OU 5220 and 5221.

Remarks.—No obvious head or tail valves are in the type lot. The preservation is so poor that no trace of what might have been original dorsal sculpture is left. Neither in the holotype nor in any paratype is an apical area indicated, a situation that might easily be

due to an accident of preservation. Consequently, no close estimate of the length of the animal in the living state is possible. One might hazard a guess that an adult may have been a chiton from 1½ to 2 inches long, exclusive of its girdle. Regardless of this lack of objective characters, the configuration of these valves indicates that they belong to a single species different from any heretofore described. Measurements of the type lot are as follows:

Specimen	*Length (mm)*	*Width (mm)*	*Height (mm)*	*Thickness at Jugum (mm)*	*Approx. Divergence (degrees)*
Holotype					
OU 5219	7.1	13.0	4.9	1.8	123
Paratypes					
USNM 144534	6.4	12.0	3.6	1.2	146
USNM 144535	6.6	12.0	4.9	2.3	110
CAS 12587	5.7	9.3	3.4	1.5	110
CAS 12588	5.6	9.0	4.1	1.4	115
OU 5220	4.6	8.7	3.4	1.3	119
OU 5221	6.5	15.3	5.0	1.8	100

From the above data it is clear that paratype USNM 144535 is a much thicker valve owing to its heavier transverse rib, although it has much the same dimensions otherwise as paratype OU 5221 (pl. 4, figs. 8, 15). Again, this difference in valve thickness is believed to be within the limits of individual variation, or to the factor of age, or both.

The reasons for assigning this species to the genus *Ivoechiton* have already been given, but it may be well to reemphasize that this allocation is tentative.

Ivoechiton sp.

Plate 4, figures 16-18

In the series of valves from the Mill Creek section is a unique, almost square intermediate valve, OU 5222, which has some of the aspects of *Ivoechiton oklahomensis*. Its measurements are: length, 7.8 mm; width, 7.9 mm; height, 3.0 mm; thickness at jugum, 1.5 mm. The angle of divergence is about 120°. From its round-backed appearance and the presence of a slight but nearly obsolete ventral transverse thickening, this valve is referred to the genus *Ivoechiton* with some doubt. As no other valve in the series is quite like it, a more specific allocation would be premature.

Ivoechiton calathicolus A. G. Smith, new species
Plate 5, figures 1-14

Holotype.—A fairly well-preserved intermediate valve, wider than long, with a rounded jugal ridge, straight side slopes, and a shallow, short anterior sinus. Apex pointed; side margins almost semicircular. The tegmentum is not divided into separate jugal and lateropleural areas. A shallow groove is close to the side and anterior margins of the valve and parallel to them. The right and left posterior edges are slightly swept back from the apex. No evidence of microsculpture is present. The jugal ridge becomes gradually more rounded away from the apex so that an edge view of the valve from the posterior margin is definitely V-shaped, whereas the edge view from the anterior margin is more of a spread U-shape. Ventrally, there is a well-defined, beveled apical area 1.9 mm wide along the posterior margin, and a heavy thickening of the valve centrally, which tapers gradually both anteriorly and posteriorly as well as toward the side margins. The valve edges are blunt along the anterior and posterior margins but are less so along the side margins. Measurements are: length, 8.0 mm; width, 11.8 mm; height, 6.3 mm; thickness at central part of jugal ridge, 2.5 mm. The side slopes diverge at an angle of about 90°.

The holotype is deposited as OU 5213.

Type material and localities.—Ten intermediate valves are in the type lot, which comes from the lower part of the Kindblade Formation, Mill Creek section, Arbuckle Mountains, southern Oklahoma. The age is Early Ordovician. The nine designated paratypes are deposited as USNM 144536, 144537, 144538 and 144539, as CAS 12589, 12590 and 12591, and as OU 5214 and 5215. In addition to the type lot, a single, small intermediate valve, OU 5216, referred to this species was collected in the Joins Ranch section in a zone of abundant *Calathium,* 485 feet above the base of the Kindblade.

Remarks.—All valves of this species are quite characteristic. The diagnostic characters, which differentiate them from other chiton valves from the Kindblade Formation, include a rather blunt jugal ridge with a pointed, slightly projecting apex, more or less straight side slopes, semicircular side margins, a V-shaped posterior edge view compared with a spread U-shaped anterior edge view, the strong ventral thickening, and a well-developed apical area. The species seems to be closely related to *Ivoechiton oklahomensis,* which

has more of a round-backed aspect and a less strong central thickening.

None of the paratypes has the dorsal groove described from the holotype, although slight evidence suggests that better preserved valves would show heavy growth ridges parallel to the side and anterior margins. Comparative measurements of all valves are:

Specimen	*Length (mm)*	*Width (mm)*	*Height (mm)*	*Thickness at Jugum (mm)*	*Width of Apical area (mm)*	*Approx. Divergence (degrees)*
Holotype						
OU 5213	8.0	11.8	6.3	2.5	1.9	90
Paratypes						
OU 5214	8.5	11.3	5.8	2.7	1.1	103
OU 5215	7.5	11.0	5.9	2.1	1.1	90
USNM 144536	8.4	12.6	6.3	1.9	1.2	108
CAS 12589	7.2	12.8	5.0	2.1	1.0	113
USNM 144537	8.5	12.7	5.9	1.7	-	108
CAS 12590	9.9	12.7	6.5	2.1	1.6	106
USNM 144538	6.2	10.8	4.2	1.5	-	123
CAS 12591	6.9	10.5	4.2	1.3	-	111
USNM 144539	7.7	-	-	2.5	-	111
Joins Ranch Specimen						
OU 5216	6.2	10.7	4.4	1.5	-	121

Measurements of the divergence of these valves are difficult to obtain accurately and are close approximations only. Both the median and the average of the divergence is 108°. The range of the thickness at the jugum is 1.3 to 2.7 mm (average, 2.0 mm) compared with a range of 1.2 to 2.3 mm (average, 1.6 mm) for *Ivoechiton oklahomensis.*

The specific name is derived from its probable habitat or its close fossil association with the quasi sponge *Calathium.*

EOCHITON A. G. Smith, new genus

Intermediate valves of medium size, broadly rectangular, with a prominent jugal ridge, straight side slopes, and a pointed, slightly mucronate apex. Dorsal surface divided into weakly raised, narrowly triangular jugal areas bounded by generally flat lateropleural areas, the latter with rather prominent growth ridges paralleling the side and anterior margins. Jugal angle, about 105°. Ventrally, the valves are much thickened by a heavy, transverse, rounded ridge across the center; there is a well-developed, beveled apical area. End valves unknown. Type: *Eochiton arbucklensis,* new species.

Eochiton arbucklensis A. G. Smith, new species
Plate 6, figures 1-9

Holotype.—A fairly well-preserved intermediate valve, wider than long, which exhibits the characters described for the genus. The side margins are gently rounded, with the posterior corners more broadly rounded than the anterior ones. The anterior sinus is weak, short, and extremely shallow. The right and left posterior margins are slightly swept back from the apex, forming a small angle with a vertical plane passing through it, the entire posterior margin being almost straight. The apex is distinct and slightly mucronate; the triangular jugal area forms an angle of about 35° and becomes somewhat flattened anteriorly. The lines of demarcation between this shell area and the lateropleural areas adjacent to it are not well defined. Two prominent growth ridges are parallel to the side and anterior margins and close to them on the dorsal side, with evidence of other weaker ones inside them in position on the lateropleural areas. Evidence of the existence of any microsculpture is absent. Ventrally, the thickening across the valve centrally is broad and tapers toward the rather blunt anterior and posterior margins. A most striking feature is the well-developed apical area, 1.8 mm wide near the apex, widening to 2.0 mm wide at the posterior corners of the valve. Measurements are: length, 8.8 mm; width, 11.4 mm; height, 6.3 mm; thickness at jugum, 3.0 mm. The jugal angle is approximately 106°.

The holotype is deposited as OU 5217.

Type material and locality.—The type lot consists of three intermediate valves, here designated as a holotype and two paratypes. They were collected along with valves of other chiton species in the lower part of the Kindblade Formation, Mill Creek section, Arbuckle Mountains, southern Oklahoma. Paratypes are deposited as USNM 144540 and CAS 12592.

Remarks.—The three valves forming the type lot are different from others found in the Mill Creek section. The heavy internal thickening, coupled with the rather wide apical areas, are a combination of characters that amply justify the creation of a new genus for them. The latter feature is evidence of a much greater overlap of the valves in the living state than exists in any other chiton from the lower Kindblade Formation. Measurements of the three valves are quite uniform, as the following data show:

Specimen	Length (mm)	Width (mm)	Height (mm)	Thickness at Jugum (mm)	Width of Apical area (mm)	Approx. Divergence (degrees)
Holotype						
OU 5217	8.8	11.4	6.3	3.0	1.8-2.0	106
Paratypes						
USNM 144540	10.4	13.6	6.7*	2.6	1.7-2.0	105
CAS 12592	8.9	14.0*	5.6	2.6	1.8-2.1	105

* Estimated

Paratype USNM 144540 (pl. 6, figs. 4-6) has the left margin broken off, although the right margin is complete. Its dorsal sculpture consists of four prominent growth ridges forming narrow, flat ledges below them in clapboard fashion. The ridge nearest the margin is doubled, a feature that may be the result of preservation as it does not occur on the other two valves. Paratype CAS 12592 (pl. 6, figs. 7-9) has lost its entire right side. Growth ridges are present but are less developed than on the other two valves. In this valve the shell area adjacent to the indistinct jugal area is slightly concave, resulting from a thickening of the valve toward the side margin. In all three valves the apex is somewhat everted when the valve is oriented in what appears to have been its normal position in life. This is a character exhibited by some species in the Recent genus *Chaetopleura,* among others.

Based upon the holotype measurements, *E. arbucklensis* is estimated to have been a chiton about 53 mm, or slightly over two inches, in length, exclusive of the girdle. Paratype CAS 12592 might have been 65 mm long, or about 2½ inches.

Eochiton? sp.

Plate 6, figures 10-12

A single specimen, OU 5218, from the Joins Ranch section is referred to the genus *Eochiton* with some doubt. Dorsally (pl. 6, fig. 10), it is divided into a well-developed triangular jugal area, and two straight-sided lateropleural areas, the latter sculptured with several growth ridges, as in *Eochiton arbucklensis.* Ventrally (pl. 6, fig. 12), this specimen has a most unusual configuration. The internal thickening is slight, lacking the strong internal transverse swelling of *E. arbucklensis,* but the posterior ventral margin has two well-marked apical areas, each about 1.5 mm wide. It seems obvious that parts of two separate valves have been fused into a single valve in this instance. Such a situation happens on rare occasions in Recent chiton teratology, usually resulting from an injury to the

animal at some stage in its growth. One should not overlook the possibility, however, that this doubled valve could be due to the process of fossilization. The inclination is toward the first theory because the evidence of fusion is not apparent on the dorsal surface at first glance, and because the valve thickness, which is only 1.1 mm at the sides, is certainly not doubled as might be expected in the fossilization of two adjacent valves, one almost on top of the other. If this is indeed an accident of growth, this specimen is the first of its kind to be reported in the fossil state.

Measurements of the specimen are: over-all length, 11.4 mm; length of what is undoubtedly a complete valve (the anterior one), 9.8 mm; width, 12.8 mm; height, 5.3 mm; thickness at jugum, 1.8 mm. The jugal angle is 111°.

More definite assignment to genus as well as to species is left open pending collection of additional valves that are equivalent in normal characters.

GOTLANDOCHITON Bergenhayn, 1955

Gotlandochiton hami A. G. Smith, new species

Plate 7, figures 1-15

Holotype.—A poorly preserved intermediate valve of medium size, somewhat wider than long, roughly rectangular, with a fairly sharp jugal ridge and almost straight side slopes diverging at an angle of 104°. Dorsally, the valve is divided into a faintly marked, triangular jugal area merging almost imperceptibly into the flat lateropleural areas on either side of it, forming an angle at the valve apex in the range of 30° to 40°. The apex itself is pointed and slightly projecting but not appreciably mucronate. The right side margin, which is complete, is not straight but is gently rounded centrally, with rather sharply rounded corners; it also tapers somewhat anteriorly, resulting in a posterior margin a little wider than the anterior one. Both anterior and posterior valve margins, though eroded, are approximately straight. No other dorsal surface sculpture is apparent other than the ill-defined jugal area.

Ventrally, an apical area 0.5 mm wide extends clear across the straight part of the posterior margin of the valve, indicating a total overlap on the next valve but with extremely narrow valve coverage. A low, broadly rounded thickening of the valve occurs transversely

and slightly posterior to its center line; it tapers toward the side margins, leaving the edges fairly thin but not sharp. No indications of an articulamentum shell layer with its normal accompaniment of insertion plates and sutural laminae are present. Measurements are: length, 8.6 mm; width, 12.4 mm; height, 5.3 mm; thickness at jugum, 1.5 mm.

The holotype is deposited as OU 5223. It is not complete as the entire left and posterior margins are badly eroded but this particular valve has been selected as the holotype because it exhibits the characters that appear to be diagnostic for the species.

Type material and localities.—The type lot consists of 17 intermediate valves, here designated as a holotype and 16 paratypes. It was collected in the lower part of the Kindblade Formation, Mill Creek section, Arbuckle Mountains, southern Oklahoma. The age is Early Ordovician. Paratypes are deposited as USNM 144541-144545, CAS 12593-12598, and as OU 5224-5227, 5232.

In addition to the type lot, a series of six intermediate valves from the Highway 77 section interval within the Kindblade Formation, in a zone of abundant *Calathium,* is also assigned to this species.

Remarks.—Because all the valves in the type lot are imperfect in some respects, it is necessary to rely on the better preserved features in most of them for an idea of general valve configuration as well as the extent of individual variation. Only four of the better paratypes have therefore been illustrated on plate 7 in addition to the holotype. Measurements of the holotype and seven paratypes are as follows:

Specimen	*Length (mm)*	*Width (mm)*	*Height (mm)*	*Thickness at Jugum (mm)*	*Approx. Divergence (degrees)*
Holotype					
OU 5223	8.6	12.4	5.3	1.5	104
Paratypes					
OU 5224	8.7	12.7	5.8	1.5	101
OU 5225	10.3	-	-	1.7	-
OU 5226	10.0	11.4	5.1	1.6	106
OU 5227	8.2	12.4	4.9	1.1	104
USNM 144541	7.5	10.6	4.9	1.2	100
CAS 12593	8.5	12.3	5.0	2.4	105
USNM 144542	10.3	14.9	5.9	1.9	111

Only five valves in the type lot have the apical area, or part of it, preserved. This ranges in width from 0.5 to 1.0 mm and seems to be one of the distinguishing features of *G. hami* along with a

fairly sharp jugal ridge, a pointed but not a projecting apex, no evidence of major sculptural features on the dorsal side except an indistinct, triangular jugal area, and straight side slopes with a slight narrowing of the valves anteriorly. This last feature is well shown by paratype OU 5225 (pl. 7, figs. 7, 9) in spite of the fact that only the right half of this valve is preserved, the valve margins of this half being complete and apparently uneroded. Ventrally, the valves of paratype OU 5224 (pl. 7, fig. 5) and paratypes USNM 144541, USNM 144542, and CAS 12593 have a fairly well-developed thickening, similar to that described for the holotype. Paratypes OU 5225-5227 (pl. 7, figs. 7-15) have hardly any such thickening. This feature is most apparent in paratype CAS 12593 as the preceding measurements show. Without more and better material to indicate otherwise, the degree of the ventral thickening of valves of *G. hami* is believed to be within the limits of individual variation in the species and possibly also of the age factor. The remaining paratypes of the series do not furnish any significant additional information.

The six specimens from the Highway 77 section agree in general characters and individual variation with those in the type series from the Mill Creek section. Two of these valves are flatter than average, however, having angles of divergence of about 92° and 94°. Otherwise, they answer the general description of *G. hami.* In all probability, the chiton valves shown in cross section on plates 1 and 2 are this species.

An estimate of the probable length of *G. hami,* exclusive of the girdle, indicates a chiton a little longer than 60 mm, or about 2⅜ inches.

The species is named for Dr. William E. Ham of the Oklahoma Geological Survey in recognition of his contributions to the existing knowledge of the geology and paleontology of his State.

Gotlandochiton sp.

Plate 7, figures 16-18

A single intermediate valve, OU 5228, from the Mill Creek section is much narrower than those identified as *Gotlandochiton hami.* It measures: length, 5.5 mm; width, 10.8 mm; height, 4.2 mm; thickness at jugum, 1.1 mm. The angle of divergence of the side slopes is about 108°. Although there is no indication of the triangular jugal area of *G. hami,* internally the valve is slightly

thickened, as called for in this species. No apical area is preserved. The shortness of this valve in relation to its width sets it apart from others collected with it. Without additional valves that are at all similar, the conservative course to follow at this time is merely to call attention to it as evidence of another possible new species.

Genus and Species Indeterminate
Plate 8, figures 1-3

Another single intermediate valve belonging in the Gotlandochitonidae, OU 5231, from the Mill Creek section is also unique, having a different configuration from the previously described specimens collected in the same horizon. This valve has the straight-sided lateropleural areas swept back anteriorly, the anterior margins forming an angle of about 30° with a vertical plane through the apex, giving the valve a broadly mucronate aspect. A jugal area is present but not prominent, being narrowly triangular, pointed at the apex and broadening toward the anterior edge, forming an angle of about 13°. The anterior margin of the valve is incomplete on the left side but appears to have broad anterior lobes with a curved sinus between, accenting the general swept-wing appearance. A well-developed apical area 0.9 mm wide extends ventrally along the posterior margin, indicating a small but total valve coverage. Otherwise, the interior of the valve has smooth, flat sides except for a low, rounded, transverse, narrow ridge, slightly thicker and more pronounced under the jugum and situated not quite one-third of the valve length anterior to the apex. No dorsal sculpture is evident other than the division into indistinct jugal and lateropleural areas. The jugum is sharp angled at the apex, becoming more rounded at its anterior end. Measurements are: length, 11.8 mm; width, 11.7 mm; height, 6.9 mm. The angle of divergence is 87°.

Because this valve is so different from others obtained from the Mill Creek section, the better approach at this time is to leave its assignment to both genus and species open until more like forms can be collected. With additional comparable material the taxonomic position of both genus and species can be determined with a greater degree of confidence.

CONCLUSION

The chiton fauna of the Lower Ordovician Kindblade Formation from the Arbuckle Mountains of southern Oklahoma is interesting and varied. The occurrence of two new genera and five new species, with the possible addition of at least one new genus and three new species, at present based upon exotic valves, adds materially to existing knowledge of the numbers and probable distribution of chitons in the Paleozoic.

The number of chiton valves collected in the lower part of the Kindblade Formation upon which fairly definite conclusions can be based is 48. In addition, there are many unidentifiable fragments. The absence of head and tail valves in the series seems unusual; theoretically, one might expect the preservation of end valves to intermediate valves in the ratio of one to three. End valves are particularly important in taxonomic work as they exhibit features not found on intermediate valves; a lack of them is a serious drawback in arriving at sound conclusions on the differences between genera and species. Whether this lack in the present instance is due to the accident of collecting or to factors of preservation poses a question that cannot be answered, but the latter cause is suspected.

It is obvious that more collecting in the lower part of the Kindblade will produce further and perhaps more specific information on the chiton fauna preserved in it.

REFERENCES

BERGENHAYN, J. R. M., 1960, Cambrian and Ordovician loricates from North America: Jour. Paleontology, vol. 34, p. 168-178, 20 figs.

BILLINGS, ELKANAH, 1865, Paleozoic fossils, vol. 1; containing descriptions and figures of new or little known species of organic remains from the Silurian rocks, 1861-1865: Canada, Geol. Survey, p. 394, fig. 370.

BLACK, MAURICE, 1933, The algal sediments of Andros Island, Bahamas: Royal Soc. London, Philos. Trans., ser. B, vol. 222, art. 6, p. 165-192, pls. 21, 22, 16 text-figs.

BUTTS, CHARLES, 1926, The Paleozoic rocks, *in* Geology of Alabama: Ala. Geol. Survey, Spec. Rept. 14, p. 40-230, pls. 3-76, text-figs. 2-4.

CLOUD, P. E., JR., and BARNES, V. E., 1946, The Ellenburger Group of central Texas: Texas, Univ., Bur. Econ. Geology, Pub. 4621, 473 p., 45 pls., 8 text-figs., 3 tables.

DUNHAM, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Classification of carbonate rocks, a symposium, Ham, W. E., ed.: Amer. Assoc. Petroleum Geologists, Mem. 1, p. 108-121, 7 pls., 1 table.

GINSBURG, R. N., 1960, Ancient analogues of Recent stromatolites: Internat. Geol. Cong., 21st, Copenhagen, Rept., pt. 22, p. 26-36, 15 figs.

HAM, W. E., 1950, Geology of the Arbuckle limestone in the Arbuckle anticline: Tulsa Geol. Soc., Digest, vol. 18, p. 49-53, 2 figs.

JOHNSON, J. H., 1961, Limestone-building algae and algal limestone: Colo. School Mines Foundation Inc., Dept. Pubs., 295 p., 139 pls.

LOGAN, B. W., 1961, *Cryptozoon* and associated stromatolites from the Recent, Shark Bay, Western Australia: Jour. Geology, vol. 69, p. 517-533, 2 pls., 3 text-figs.

REZAK, RICHARD, 1957, Stromatolites of the Belt series of Glacier National Park and vicinity, Montana: U. S. Geol. Survey, Prof. Paper 294-D, p. 127-154, pls. 18-25, text-figs. 49-55.

SARDESON, F. W., 1896, The fauna of the Magnesian series: Minn. Acad. Nat. Sciences, Bull., vol. 5, pt. 1 (1892-1894), p. 92-105, pls. 5, 6.

SMITH, A. G., 1960, Amphineura, *in* Mollusca 1, pt. I *of* Treatise on invertebrate paleontology, Moore, R. C., ed.: Geol. Soc. America and Univ. Kans. Press, p. 141-176, text-figs. 31-45.

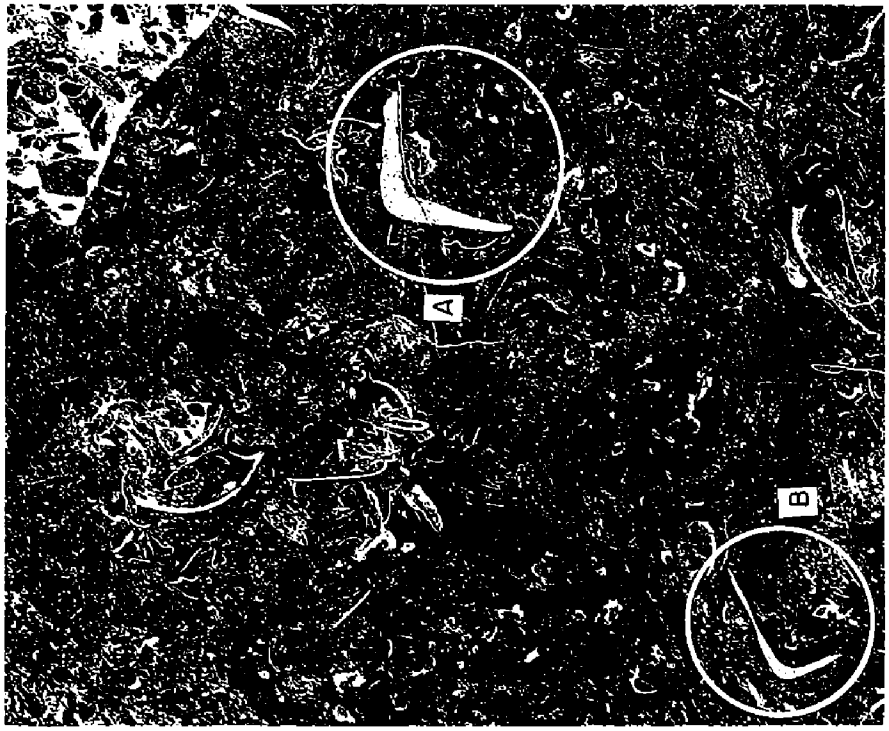
TWENHOFEL, W. H., chm., and others, 1954, Correlation of the Ordovician formations of North America: Geol. Soc. America, Bull., 65, p. 257-298, 1 pl., 2 figs.

WILSON, A. E., 1951, Gastropods and *Conularia* of the Ottawa formation of the Ottawa-St. Lawrence Lowland: Canada, Geol. Survey, Bull. 17, 149 p., 19 pls., 7 text-figs., 4 tables.

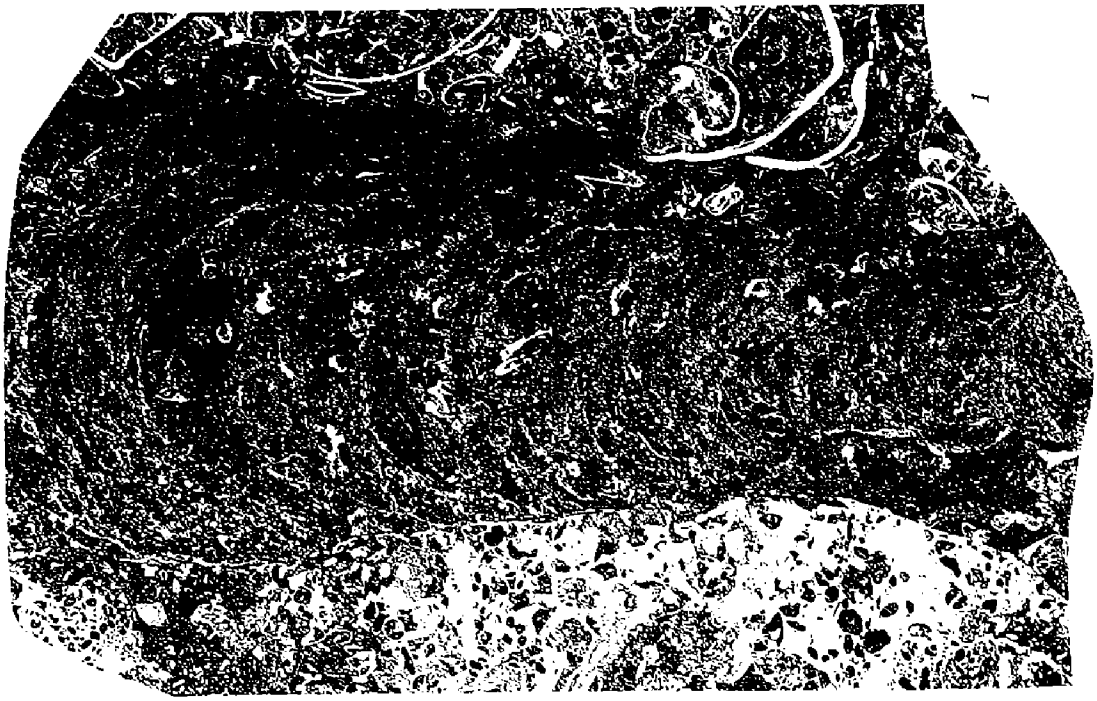
PLATE 1

Figure 1. Stromatolitic colony (boundstone) with distinctive laminations. Laminae delineated by quartz silt grains (tiny white flecks). Dense border along right side of colony is encrusting blue-green alga *Girvanella*. Note calcarenitic channels (packstone), containing much shell debris and lithoclasts, on either side of colony. Arbuckle Mountains, Highway 77 section; interval within Kindblade Formation, 462 feet above the base, x4.

Figure 2. Fossiliferous wackestone with included chiton plates in cross section (A, B), much shell debris, swirls of stromatolitic (boundstone) material, and calcarenite (packstone) in the upper right-hand corner. Arbuckle Mountains, Highway 77 section; interval within Kindblade Formation, 500 feet above the base, x4.



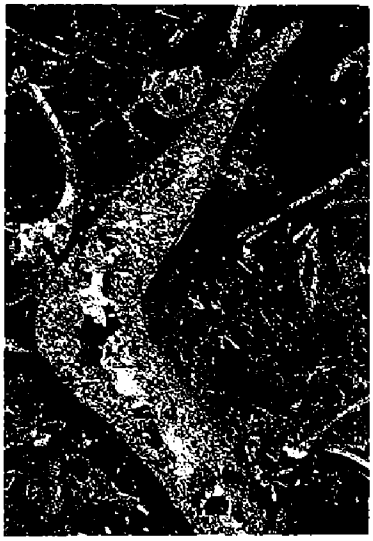
2



1

2

4



1

3

Plate 2

Figures 1-4. Thin-section photomicrographs of cross sections of chiton plates in both plain light (2, 4) and polarized light (1, 3) showing a complete absence of original shell microstructure. Original shell composition was probably aragonite, which was later converted by diagenesis to mosaic calcite. Mosaic calcite now partly replaced by nuclei of chert. Chitons are probably *Gotlandochiton hami*, new species. Arbuckle Mountains, Highway 77 section; interval within Kindblade Formation, 500 feet above the base, x6.

PLATE 3

Page

Paleochiton kindbladensis A. G. Smith, new genus, new species 20

Figures 1-4. Holotype OU 5211. Length, 13.4 mm.
1. Dorsal view.
2. Edge view of posterior margin showing maximum thickness of valve and angle of divergence of side slopes.
3. Ventral view showing extent of apical area.
4. View of left side of valve showing tegmental sculpture.

Figures 5-7. Paratype USNM 144533. Length, 10.2 mm.
5. Dorsal view.
6. Edge view of posterior margin.
7. Ventral view showing apical area.

Figures 8-11. Paratype CAS 12586. Length, 14.4 mm.
8. Dorsal view.
9. Edge view of posterior margin.
10. Ventral view.
11. Right side.

Figures 12-14. Paratype OU 5212. Length, 10.5 mm.
12. Dorsal view.
13. Edge view of posterior margin.
14. Ventral view.

1

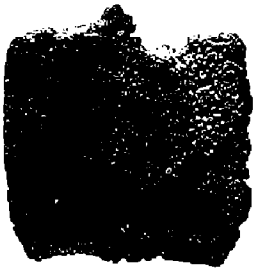
2

3

4

5

6



7

8

9

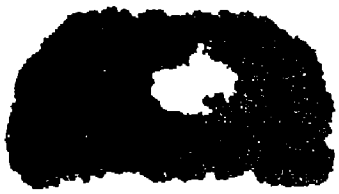
10

11

12

13

14



1

2

3

4

5

6

7

8

9

10

11

12

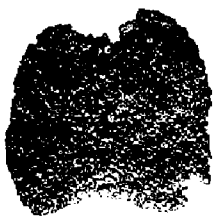
13

14

15

16

17



18

PLATE 4

Page

Ivoechiton oklahomensis A. G. Smith, new species 22

Figures 1-3. Holotype OU 5219. Width, 13.0 mm.
1. Dorsal view.
2. Edge view of posterior margin.
3. Ventral view.

Figures 4-6. Paratype USNM 144534. Width, 12.0 mm.
4. Dorsal view.
5. Edge view of posterior margin.
6. Ventral view.

Figures 7-9. Paratype USNM 144535. Width, 12.0 mm.
7. Dorsal view.
8. Edge view of posterior margin showing maximum thickness of valves in the series.
9. Ventral view.

Figures 10-12. Paratype CAS 13587. Width, 9.3 mm.
10. Dorsal view.
11. Edge view of posterior margin.
12. Ventral view.

Figure 13. Paratype CAS 12588. Width, 9.0 mm. Edge view of posterior margin.

Figure 14. Paratype OU 5220. Width, 8.7 mm. Edge view of posterior margin.

Figure 15. Paratype OU 5221. Width, 15.3 mm. Edge view of posterior margin.

Ivoechiton sp. 23

Figures 16-18. Specimen OU 5222. Length, 7.8 mm; width, 7.9 mm.
16. Dorsal view.
17. Edge view of posterior margin.
18. Ventral view.

PLATE 5

Page

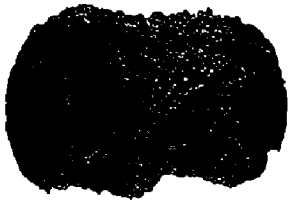
Ivoechiton calathicolus A. G. Smith, new species 24

Figures 1-3. Holotype OU 5213. Width, 11.8 mm.
1. Dorsal view.
2. Edge view of anterior margin.
3. Ventral view showing the well-defined apical area.

Figures 4-6. Paratype OU 5214. Widdth, 11.3 mm.
4. Dorsal view.
5. Edge view of anterior margin.
6. Ventral view.

Figures 7-10. Paratype OU 5215. Width, 11.0 mm.
7. Dorsal view.
8. Edge view of anterior margin approximating a spread U-shaped aspect.
9. Edge view of posterior margin approximating a V-shaped aspect.
10. Ventral view.

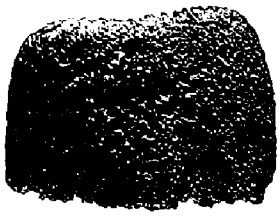
Figures 11-14. Joins Ranch specimen OU 5216. Width, 10.7 mm.
11. Dorsal view.
12. Edge view of anterior margin.
13. Edge view of posterior margin.
14. Ventral view.



1

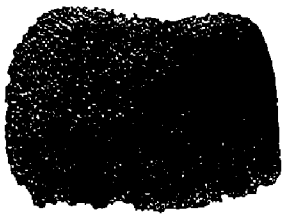
2

3

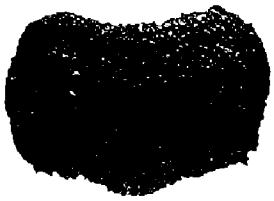


4

5



6



7

8

9

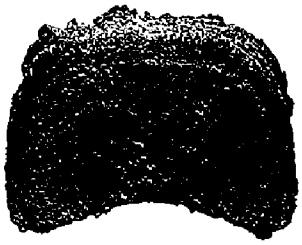
10

11

12

13

14



1

2

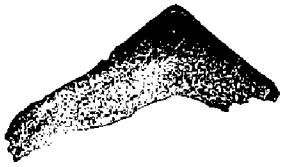
3

4

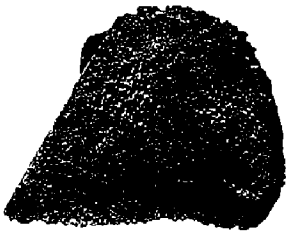
5

6

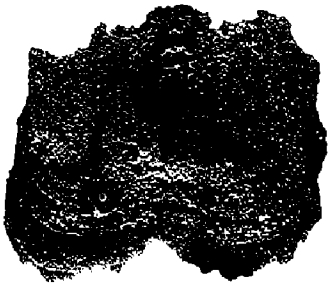
7



8



9



10

11

12

PLATE 6

Page

Eochiton arbucklensis A. G. Smith, new genus, new species 26

Figures 1-3. Holotype OU 5217. Width, 11.4 mm.
1. Dorsal view showing sculptural ridges.
2. Edge view of posterior margin.
3. Ventral view showing extent of apical area.

Figures 4-6. Paratype USNM 144540. Width, ca. 13.6 mm.
4. Dorsal view.
5. Edge view of posterior margin.
6. Ventral view.

Figures 7-9. Paratype CAS 12592. Width, ca. 14.0 mm.
7. Dorsal view.
8. Edge view of posterior margin.
9. Ventral view.

Eochiton? sp. 27

Figures 10-12. Specimen OU 5218. Width, 12.8 mm.
10. Dorsal view.
11. Edge view of posterior margin.
12. Ventral view showing doubling of the apical area.

PLATE 7

Page

Gotlandochiton hami A. G. Smith, new species 28

Figures 1-3. Holotype OU 5223. Width, 12.4 mm.
1. Dorsal view.
2. Edge view of posterior margin.
3. Ventral view.

Figures 4-6. Paratype OU 5224. Width, 12.7 mm.
4. Dorsal view.
5. Edge view of posterior margin.
6. Ventral view.

Figures 7-9. Paratype OU 5225. Length, 10.3 mm.
7. Dorsal view of right side of incomplete valve illustrating probable original shape.
8. Edge view of incomplete posterior margin.
9. Ventral view showing one-half of complete apical area.

Figures 10-12. Paratype OU 5226. Width, 11.4 mm.
10. Dorsal view.
11. Edge view of posterior margin.
12. Ventral view.

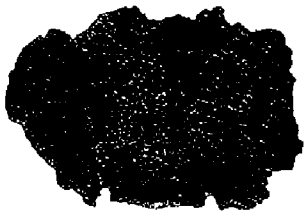
Figures 13-15. Paratype OU 5227. Width, 12.4 mm.
13. Dorsal view.
14. Edge view of posterior margin.
15. Ventral view.

Gotlandochiton sp. 30

Figures 16-18. Specimen OU 5228. Width, 10.8 mm.
16. Dorsal view.
17. Edge view of posterior margin.
18. Ventral view.

1

2

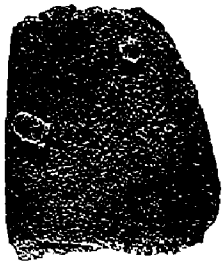


3

4

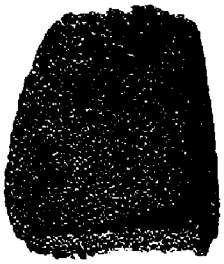
5

6

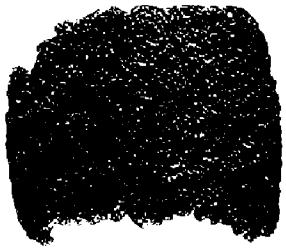


7

8

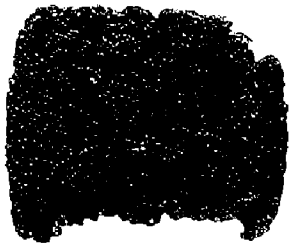


9

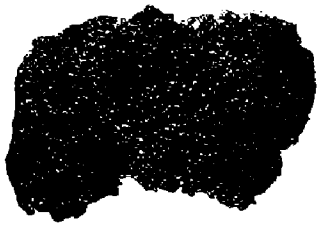


10

11



12



13

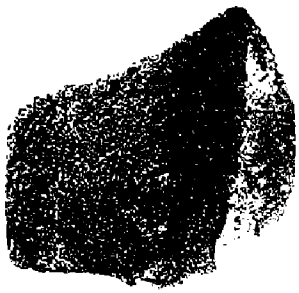
14

15

16

17

18

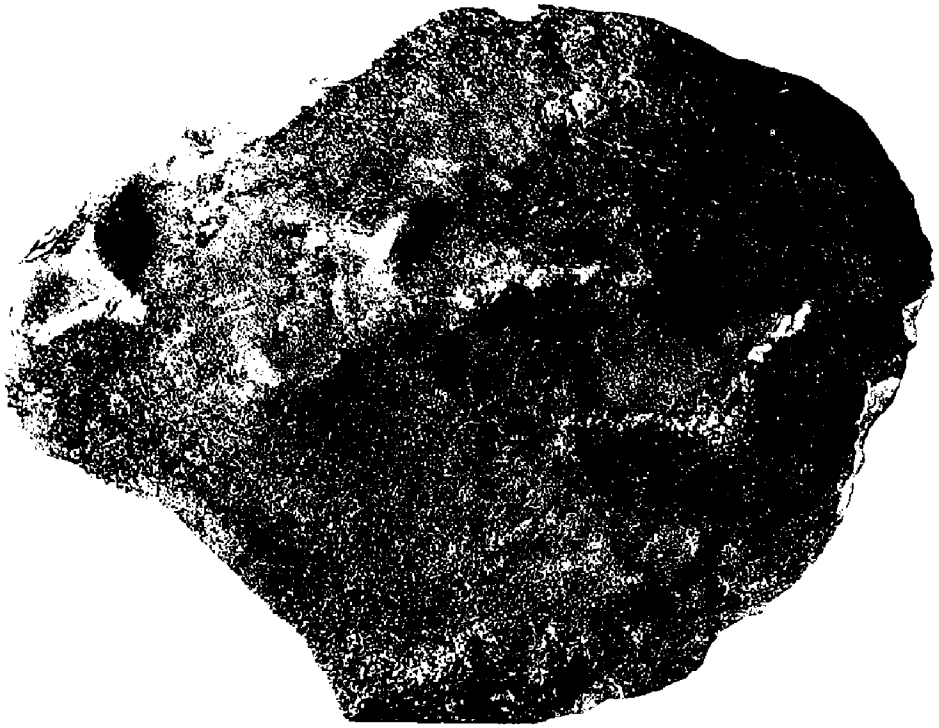


1

2

3

4



5

PLATE 8

Page

Figures 1-3. Family Gotlandochitonidae, genus and species indeterminate. OU 5231. Width, 11.7 mm. 31
1. Dorsal view.
2. Edge view of posterior margin.
3. Ventral view showing swept-wing configuration of the valve and the extent of the apical area.

Figure 4. Matrix with portions of valves in situ. Specimen OU 5229, x3. Three valves are in place with indications of a fourth. The thickness of the valves along the jugal ridge places them in the genus *Eochiton*, possibly *E. arbucklensis*. This and figure 5, following, illustrate specimens from the Mill Creek section, 450 feet above the base of the Kindblade Formation, in a zone of abundant *Calathium*.

Figure 5. Matrix with a more or less complete intermediate valve (at right) and remains of another (at left). Specimen OU 5230, x3. The sinuous ridge between these two valves represents the ventral casts of two or more other intermediate valves no longer in place. This fossil chiton is probably a *Gotlandochiton* of indeterminate species.