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THE ONTOGENY AND ECOLOGY OF *WELLERIA AFTONENSIS* WARTHIN, A MIDDLE DEVONIAN OSTRACOD FROM THE GRAVEL POINT FORMATION OF MICHIGAN

BY

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VOLUME XIV

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CONTENTS

INTRODUCTION

Although the Middle Devonian ostracod *Welleria aftonensis* Warthin from the Gravel Point formation has been known for more than two decades and specimens are abundant, little is known about its ontogeny or ecology. The original description (Warthin, 1934, p. 208) is based on a valve of a male specimen. Nothing has been published heretofore on the form of the carapace in the adult female or in the immature instars. The presence of dimorphism, a requisite for assignment to the kloedeniid genus *Welleria,* is here designated for the first time.

This ostracod has an unusual occurrence. In the lower part of the Gravel Point formation, specimens are so numerous that the beds in which they are found have been called the *Welleria* zone (Kelly, 1940, p. 14) and the *Welleria aftonensis* zone (Kelly and Smith, 1947, p. 456). No other ostracods, no other invertebrates, no vertebrates, and no plant remains have been found associated with this ostracod. The environment, in which *Welleria aftonensis* flourished and other kinds of animals were absent, must have been uncommon. The rock containing the ostracods records the environment rather well. From the study of small structures in its matrix, its stratigraphic position, and its paleogeographic setting, we have arrived at a plausible reconstruction of conditions in this region during the early part of the Gravel Point age.

At least part of the neglect of *Welleria aftonensis* may be attributed to the composition of the matrix and fossils. It is with extreme difficulty that complete specimens are removed from the dense, fine-grained limestone in which they are embedded. Hence, although valves and carapaces are so plentiful that they give many surfaces of the limestone a pebbly texture, no complete carapace had heretofore been removed.

Our first, and most exacting, job was to isolate complete specimens. Crushing large blocks of the limestone exposed parts of many specimens. After disappointing trials, we gave up trying to separate single valves from the matrix. Complete carapaces, on the other hand, could be undercut with an electric vibrating tool, and the small fragments of limestone still adhering could be chipped off with a fine needle. After several weeks of work, each of us obtained over one hundred specimens, of which about one-fifth were complete or nearly so. We discovered that each carapace was a cast, composed of calcite, with little or no line of separation between the original valves and the steinkern. The crystalline nature of the calcite caused most of the casualties among the specimens on which we worked. The corners, the thinnest parts of the carapace, chipped off from an exasperatingly high percentage of the ostracods.

We also found that each specimen was separated from the matrix by a very thin film of oil. The oil proved to be both advantageous and disadvantageous. It enabled us to chip out the specimens and dislodge the adhering fragments of limestone, but it produced disappointing results in photography of the specimens. Evidently, the oil impregnated the calcite in each specimen, because we could not dispel it even when we washed the ostracods in carbon tetrachloride, alcohol, and detergent. When a coating of ammonium chloride was applied to a specimen, oil oozed out and discolored it. Photographs were taken immediately after the coating, and yet the ostracods were somewhat blotchy because of the oil.

Rocks in the *Welleria aftonensis* zone were studied by peels. Polished surfaces, both parallel to the bedding and at right angles to it, were etched and Darrah's peel solution poured over them. Along certain bedding planes there was such a concentration of petroliferous residue that the peel solution was colored brown, but most parts of the peel showed clearly the structures of the rock and the distribution of the ostracods.

We are greatly indebted to Dr. George M. Ehlers, Dr. Lewis B. Kellum, and Dr. Chester A. Arnold for a critical appraisal of this paper. The photographs in Plates II, III, and IV were made with equipment provided by the Horace H. Rackham School of Graduate Studies of the University of Michigan, for which we are very grateful.

All specimens used in this study are catalogued and deposited in the Museum of Paleontology of the University of Michigan.

LOCALITY

All specimens are from the same locality.

LOCALITY

Quarry about ¾ mile north of Afton, Cheboygan County, sec. 36, T. 35 N., R. 2 W., formerly known as the Campbell Stone Company Quarry and now operated by the Cheboygan County Highway Commission. Dark gray, fine-grained, dense limestone, thinly laminated and containing multitudes of specimens of *Welleria aftonensis,* which are so numerous in certain laminae that they give the rock a pebbly texture. Limestone layer about 10 inches thick, exposed in the north face of the quarry. Middle Devonian, Traverse group, Gravel Point formation. Layer called "Locality 8" by Warthin (1934, p. 224), "Welleria zone" near the top of the "Afton Beds" by Kelly (1940, p. 14), and "Bed 10" of the Gravel Point formation by Kelly and Smith (1947, p. 457).

SYSTEMATIC DESCRIPTION

Phylum ARTHROPODA

Class CRUSTACEA

Order OSTRACODA

Superfamily Beyrichiacea

Family Kloedeniidae

Genus *Welleria* Ulrich and Bassler, 1923

Type species.—By original designation, *Welleria obliqua* Ulrich and Bassler, 1923, p. 641.

Remarks.—Ulrich and Bassler (1923, p. 641) described *Welleria,* based on the type species from the Upper Silurian Tonoloway limestone, as follows:

> Form and lobation of valves of males essentially as in *Kloedenia* from which it differs in the character of the ventral swelling in the female. This, instead of forming a definitely outlined large subovate and prominent pouch covering the posterior two-thirds of the ventral slope, forms a low undefined swelling taking in nearly or quite the whole of the ventral two-thirds of the valves. At the base it is compressed and slightly overhangs the ventral edge.

Recently, Kesling (1954, pp. 63-64) restudied the type species of *Kloedenia* and *Welleria,* analyzed their differences, and revised their descriptions. In his discussion he noted that the description of the pouch in each female valve of *Welleria* is correct but that the lobation of the male valve in *W. obliqua* is not "essentially as in *Kloedenia,*" as claimed by Ulrich and Bassler in the original description. He stated (p. 64): "The differences between *Welleria* and *Kloedenia,* as exemplified in their type species, are in the prominence of L2, the convexity of the posterior part of the valve, and the channel between the ventral lobe and the marginal ridge," and offered this revised description of *Welleria:*

Dimorphic beyrichiacean ostracods having all the free border smoothly curved, two short sulci (S1 and S2) limited to the dorsal part of each valve, and a smoothly arched ventral lobe including all the ventral part of the valve and dorsally confluent with at least L1 and L3. Ventral lobe in the female forming a pouch, more convex in its ventral part than that of the male, extending ventrally a little beyond the free edge, and dorsally confluent with the rest of the lateral surface.

Welleria aftonensis Warthin, 1934

(Pl. I, Figs. 1-72)

Welleria aftonensis Warthin, 1934, p. 208, Pl. I, Fig. 3; Warthin, 1937, Card 32; Kelly and Smith, 1947, p. 457; Kelly, 1949, p. 13.

Original description.—Warthin (1934, p. 208) described this species as:

Carapace large, subovate in lateral view; greatest height just posterior to the center; greatest thickness central; hinge line straight, three-fourths of the total length; anterior end nearly straight, forming a slightly obtuse angle with the hinge line; posterior end evenly rounded, meeting the hinge at an angle of about 135 degrees; surface of valves formed chiefly by three nodes, which are confluent ventrally; anterior node the largest, covering almost half the valve; median node semicircular above, not approaching the hinge as closely as the anterior; posterior node low, poorly defined; surface otherwise smooth. Length, 1.53 mm.; height, 1.11 mm.

This description is correct for most features, but it fails to mention dimorphism, a necessary characteristic of ostracods of the genus *Welleria*. Furthermore, the orientation is the reverse of that now generally recognized. The terminology used in this paper differs from that of Warthin and agrees with that of Kesling (1951) in his definition of terms applied to ostracod carapaces and (1956) in his revised description of the type genus. The nodes of Warthin are designated L1, L2, and L3.

Adult female.—Carapace subovate to subelliptical in lateral view, subquadrate in anterior view, and subovate in dorsal view. Hinge line straight, about four-fifths as long as the entire carapace. Free border of each valve smoothly curved except for the posterodorsal border, which is nearly straight. Anterodorsal, anterior, and anteroventral borders and posterior border subround with radius of curvature about equal to one-third the length of the valve; posteroventral border gently curved; posterodorsal border slightly convex, nearly straight; and ventral border gently convex, extending below and hiding part of the free edge.

Dorsal part of lateral surface in each valve divided into three lobes by two short sulci. Ventral part a smoothly convex lobe, the brood pouch. L1 extremely low, confluent with the ventral lobe (brood pouch) and separated from L2 by S1. L2 large, dorsal part semicircular and round, sloping evenly to S1 and S2, and situated well below the hinge line; ventral part confluent with the ventral lobe (brood pouch). L3 very large, broad, occupying a little less than one-half the length of the valve; arched upward from S2, gently sloping towards the posterior border, and confluent with the ventral lobe (brood pouch); dorsal part round, extending slightly above the hinge line; asymmetrical, its front border curved downward much more sharply than its rear.

Sulci short, narrow, confluent around the dorsal edge of L2. S1 shallow, curved around L2. S2 nearly central, distinct, deeper than S1. L2 bounded ventrally by a shallow depression, which could be interpreted as a ventral confluence of the sulci, in which case the L2 would be considered to be separated from the brood pouch below.

Brood pouch corresponding to the ventral lobe of the male and including all of the ventral part of the valve, projecting ventrally a little beyond the free edge of the valve, most convex in its ventral part.

Velate ridge on each valve, low, extending from the anterior to the posterior corner, subparallel to the free edge. Submarginal ridge, very low and with a conspicuous groove in its middle, extending from corner to corner, at the corners joined to the velate ridge, elsewhere separated from it by a narrow, shallow channel. In one specimen (Pl. I, Figs. 61, 64) minute structures on the anterodorsal and posterodorsal borders appear to be poorly preserved marginal denticles.

Posterior corner slightly protuberant as an extension of the hinge. Anterior cardinal angle about 130 degrees and the posterior cardinal angle about 115 degrees. Surface smooth.

Adult male.—Shape, size, lobation, velate and submarginal ridges like those of the female, except for convexity of the ventral lobe. Ventral lobe smoothly convex, but much less than the brood pouch in the female; nearly tangent to the free edge rather than projecting beyond. In dorsal and anterior views, carapace subovate to sublanceolate.

Dimorphism more readily determined from dorsal (or ventral) and anterior (or posterior) views than from lateral.

Immature instars.—Carapaces representing five immature instars found. In Plate I carapaces in the first instar shown in Figs. 1-6, second instar in Figs. 7-18, third instar in Figs. 19-30, fourth instar in Figs. 31-44, and fifth instar in Figs. 45-58. Characteristics like those of adult male, but differing in proportionate size. In young instars L2 and L3 are proportionately larger, sulci deeper, and posterior region narrower than in the adult male. During ontogeny the lobes shift progressively forward.

ONTOGENY

Because the population was large and the occurrence of the species restricted, a study was made to analyze the grouping of the ostracods into instars. Height, length, and width were measured for the best carapaces recovered. In our evaluation (Table I) we found that the growth pattern in *Welleria aftonensis,* as represented in our selected specimens, is slightly irregular and does not conform exactly to the ideal pattern of ostracod instars, in which from one instar to the next the volume of the carapace increases to twice its former value and each dimension to about 1.26 times its former value. It was noted that the height and width remain

TABLE I

MEASUREMENTS OF CARAPACES OF *Welleria aftonensis* WARTHIN BY INSTARS
All measurements in millimeters.

	Number of Specimens	3	8	8	11	12	4	5
	Instar	1	2	3	4	5	Adult Male	Adult Female
Length	Range	.34-.37	.43-.50	.56-.66	.70-.80	.86-1.08	1.29-1.39	1.11-1.37
	Mean	.357	.456	.604	.765	.969	1.333	1.226
	Growth Rate		1.28	1.32	1.27	1.27	1.37	1.27
Height	Range	.22-.26	.27-.35	.37-.42	.43-.50	.55-.70	.84-.94	.81-.91
	Mean	.243	.311	.395	.484	.640	.888	.862
	Growth Rate		1.28	1.27	1.23	1.32	1.39	1.35
Width	Range	.22-.26	.28-.35	.37-.40	.45-.50	.53-.71	.78-.90	.80-1.10
	Mean	.243	.311	.393	.476	.641	.840	.934
	Growth Rate		1.28	1.26	1.21	1.35	1.31	1.46
Product (LXHXW)	Range	.017-.025	.033-.060	.077-.106	.135-.251	.320-.537	.833-1.098	.755-1.371
	Mean	.0211	.0441	.0938	.1762	.3975	.994	.987
	Growth Rate		2.09	2.13	1.88	2.26	2.50	2.49
Height/Length	Range	.65-.70	.63-.70	.61-.70	.61-.68	.63-.69	.65-.68	.66-.74
	Mean	.68	.68	.66	.63	.66	.67	.70

about the same in all instars, with the exception of the adult female, which is unusually wide because of the brood pouches. The ratio of height/length is extremely variable in all instars, the range for each instar overlaps that for each of the other instars, and the mean of the ratio decreases to the fourth instar and then increases so that the first instar and the adult male have about the same value. The average growth rate among immature instars is not significantly different from the ideal 1.26; for length it is 1.29, for height 1.28, and for width 1.28. The increase in volume, as measured by the product of the three dimensions, averages 2.09 among the immature instars, only a little more than the ideal 2.

The major discontinuity in the ontogenetic series is that between the ultimate instar and the adult. In this ecdysis the length increases 1.37, the height 1.39, the width 1.31, and the volume 2.50. The additional growth probably is directly related to maturity, whereby the developing genitalia and gonads are accommodated by a carapace larger than one might expect.

ECOLOGY

The conditions in which *Welleria aftonensis* lived are indicated by the burial attitudes of valves and carapaces of the ostracods and by the composition and sedimentary features of the rocks in which they are émbedded. Several lines of evidence are available for consideration. Each adds some light to reveal the general aspects of the Middle Devonian body of water through which swarms of these ostracods moved.

The astounding circumstance in the occurrence of *W. aftonensis,* as already pointed out, is the absence of other kinds of fossils amid the myriads of these ostracods. Such a limitation of species and profusion of individuals denotes an unusual marine environment, one which was toxic to all other species or one from which other species were excluded by physical barriers. Perhaps both toxicity and isolation helped to establish and maintain the population of *W. aftonensis.* It is known that ostracods, by closing their carapaces and hermetically sealing themselves inside, can survive for brief intervals in foul water that kills most other animals. Furthermore, many species of ostracods are pelagic and, hence, can be carried by waves during storms or high tides over bars and into basins that are cut off from the sea most of the time. No other common Devonian marine animals, such as corals, bryozoa, clams, brachiopods, snails, or trilobites, were buried in the sediments with *W. aftonensis;* even if other animals could not live in the water, their skeletons would have been carried into the area, at least sporadically, by waves and currents if there had been free access to the sea. One may presume, therefore, that the ostracods lived in the waters of an isolated basin. Probably the waters became foul at one time, killing off all animals except *W. aftonensis,* and later cleared, permitting the ostracod population to increase prodigiously. The organisms on which the ostracods fed must also have thrived in the environment, but, perhaps because of their microscopic size, or perhaps because of their lack of hard parts, they left no fossil record.

The sedimentary deposits of Middle Devonian age in Michigan offer a clue to the kind of isolated basins that existed then. The *Welleria aftonensis* zone occurs in the Traverse group of rocks, which consist of shales and limestones and which contain numerous reefs, many of them large. There were undoubtedly lagoons associated with some of these reefs. In addition, the rocks containing *W. aftonensis* have sedimentary features that can be interpreted as lagoonal.

The specimens of *Welleria aftonensis* occur as isolated valves and as carapaces (Pl. III, Figs. 1-6). In living ostracods the two valves are opened by the contraction of a ligament which links them together along their dorsal borders, and are closed by the action of internal muscles. When the animal dies the muscles relax and the valves are sprung apart by the ligament; then, in a little while, the ligament decays and the valves are free. From the occurrence of numerous carapaces of *W. aftonensis* it may be inferred that the living ostracods were entombed in sediment which held their valves in place, or that, before the ligament rotted away in dead ostracods, the force of currents swung the valves nearly together and the weight of accumulating deposits completed the closing. Some carapaces came to rest on their ventral surface (Pl. II, Fig. *2a*), some on their sides (Pl. II, Fig. *2b*), and a few on their ends (Pl. II, Fig. *2c*). Such random orientation must be attributed to soft mud on the sea floor, in which the carapaces were held in position until the deposit became consolidated.

Many of the single valves are found stacked atop one another (Pl. III, Figs. 1-6). Some are convex downward (Pl. III, Fig. 4 at the upper left) and some are convex upward (Pl. IV, Fig. 2). In most stacks nested valves are consecutively smaller, with the next-to-largest fitted inside the largest, etc. (Pl. IV, Fig. 2). A few stacks contain adjacent valves of about the same size (Pl. IV, Fig. 1, at left side). Because the stacks are oriented in various attitudes in the rock, it appears that some of them were deposited as a single unit and later were moved. We believe that each stack originated when a large valve came to rest on the bottom of the lagoon with its inner (concave) side up and, in sequence, smaller valves being drifted along by gentle currents settled inside it. Evidently, the close contact produced by the shapes of these valves made them difficult to dislodge, so that when the force of the current increased the entire stack was picked up and carried along as a single stable unit. The shape of the valves undoubtedly controls the formation of stacks; if valves had frills, spines, or bulbous lobes, it would be impossible for one to nest inside another. Some carapaces enclose smaller ones (Pl. IV, Fig. 3). One can only conclude that the valves of the large carapace lay open on the lagoon floor but still hinged by the ligament, received smaller carapaces from weak currents, and were closed for the last time by a strong current just before burial.

The limestone with *Welleria aftonensis* contains numerous thin lenses of calcite (dark streaks in Pl. II, Fig. 1; Pl. III, Figs. 4-6). Whether these are primary or secondary is not known, but they indicate a high concentration of calcium carbonate. Certain layers in the limestone are marked by numerous tiny stylolites (Pl. IV, Fig. 5). Nearly all of the limestone is soluble in hydrochloric acid, and only a little clay and oil remain as insoluble residue. The composition agrees with that reported for lagoonal beds. Twenhofel (1932, p. 852) said, "Some lagoons, in whole or in part, particularly those associated with coral reefs, may have deposits consisting largely of calcium carbonate."

The impurities, mostly clay, in the limestone seem to be concentrated in small subangular inclusions which lack sharp boundaries. Most are smaller than 1 mm. in diameter, but a few are several millimeters long; some are long, thin, and slightly curved. The inclusions appear (Pl. II, Fig. 2, and Pl. III, Figs. 1-2, 4-6) as numerous light gray blotches smaller than the ostracod valves and carapaces. We believe the inclusions are remnants of thin layers of mud that were laid down on the shore, dried and cracked by the sun, and later broken into small fragments while being carried by waves and currents. They were laid down before they could be completely disintegrated by abrasion and slaking (or wilting, as defined by Twenhofel, 1932, p. 690). Their presence strongly suggests that the beds with *Welleria aftonensis* were deposited near the shore.

The limestone is finely laminated and contains some cross laminae (Pl. II, Fig. 1). All of the rock is petroliferous, and oil seeps from certain laminae when the rock is broken. Twenhofel (1932, p. 354) stated, in regard to conditions favorable for preservation of organic compounds: "Of these favorable conditions, the presence of quiescent, preferably stagnant, water in which the falling debris may accumulate is paramount, being in general hardly less important than excessive organic supply." The fine laminae, cross laminae, and abundance of hydrocarbons all signify a rather quiet shallow-water marine environment cut off from the sea.

There is little room for doubt that *Welleria aftonensis* lived in a large lagoon. The water level of the lagoon shifted slightly from time to time, perhaps regularly, spreading a thin layer of mud along the shore during high levels. The mud dried and cracked during low water stage and broke into small chips when the water rose again and waves reworked it. Before the chips were carried far enough to completely slake into clay, they were deposited.

Deposition was slow. Small differences in the kind of sediment available caused the lagoon floor to be covered with successive thin laminae of slightly different content. Gentle currents produced small cross laminae.

The water teemed with ostracods and the soft-bodied organisms, probably protozoa or algae, on which they fed. Through the years, the bodies of the dead animals accumulated on the bottom, and, not being completely consumed by bacteria, changed into oil. Much later, when other beds had been laid down atop the lagoonal deposits and the area was uplifted above sea level, some of the more soluble layers dissolved, leaving stylolites to mark their former positions.

LITERATURE CITED

KELLY, W. A. 1940. Tenth Annual Geological Excursion, Michigan Academy of Science, Arts, and Letters, to Afton-Onaway District, May 25 and 26, 1940. 19 pp. (mimeographed).

——— 1949. Annual Field Trip, Michigan Geological Society, Northern Part of Southern Peninsula of Michigan, June 16 and 17, 1949. 27 pp. (mimeographed), 4 maps.

——— and SMITH, G. W. 1947. Stratigraphy and Structure of Traverse Group in Afton-Onaway Area, Michigan. Bull. Amer. Assoc. Petrol. Geol., Vol. 31, No. 3, pp. 447-69, 6 figs.

KESLING, R. V. 1951. Terminology of Ostracod Carapaces. Contrib. Mus. Paleontol. Univ. Mich., Vol. 9, No. 4, pp. 93-171, 18 pls., 7 figs., 5 charts.

——— 1956. Part III. *Kloedenia wilckensiana* (Jones) and Its Relationships. Pp. 61-71, Pls. 6-8, *in* R. V. Kesling and P. L. Wagner, Silurian Ostracods Collected by Dr. Carl Ludwig Rominger from Glacial Deposits in Germany. *Ibid.*, Vol. 13, No. 2, pp. 33-79, 8 pls., 4 figs.

TWENHOFEL, W. H. 1932. Treatise on Sedimentation. 2d ed. Baltimore: The Williams & Wilkins Company. xxix+926 pp., 121 figs.

ULRICH, E. O., and BASSLER, R. S. 1923. Paleozoic Ostracoda: Their Morphology, Classification, and Occurrence. *In* Maryland Geol. Surv., Silurian Volume, pp. 271-391, Figs. 11-25. Arthropoda, Class Crustacea, Superorder Ostracoda. *Ibid.*, pp. 500-704, Pls. 36-65.

WARTHIN, A. S., JR. 1934. Common Ostracoda of the Traverse Group. Contrib. Mus. Paleontol. Univ. Mich., Vol. 4, No. 12, pp. 205-26, 1 pl.

——— 1937. Beyrichiacea. *In* Type Invertebrate Fossils of North America (Devonian). Philadelphia: Wagner Free Instit. Sci. 105 cards.

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PLATES

EXPLANATION OF PLATE I

(All figures × 27½)

FIGS. 1-2. Left lateral and dorsal views of carapace in first instar, Topotype No. 33698.

FIGS. 3-6. Right lateral and dorsal views of two carapaces in first instar, Topotypes Nos. 33679 and 33677.

FIGS. 7-12. Left lateral and dorsal views of three carapaces in second instar, Topotypes Nos. 33713, 33716, and 33700.

FIGS. 13-18. Right lateral and dorsal views of three carapaces in second instar, Topotypes Nos. 33697, 33712, and 33724.

FIG. 19. Left lateral view of carapace in third instar, Topotype No. 33723.

FIGS. 20-21, 27-30. Right lateral and dorsal views of three carapaces in third instar, Topotypes Nos. 33690, 33681, and 33680.

FIG. 22. Right lateral view of carapace in third instar. Specimen destroyed by sectioning.

FIGS. 23-24. Left lateral and dorsal views of carapace in third instar, Topotype No. 33702.

FIGS. 25-26. Right lateral and ventral views of carapace in third instar, Topotype No. 33701.

FIGS. 31-32. Left lateral views of two carapaces in fourth instar, Topotypes Nos. 33684 and 33703.

FIGS. 33-38. Left lateral and dorsal views of three carapaces in fourth instar, Topotypes Nos. 33685, 33722, and 33694.

FIGS. 39-44. Right lateral and dorsal views of three carapaces in fourth instar, Topotypes Nos. 33682, 33692, and 33710.

FIGS. 45-47. Right lateral, ventral, and anterior views of carapace in fifth instar, Topotype No. 33714.

FIGS. 48-50. Left lateral, dorsal, and posterior views of carapace in fifth instar, Topotype No. 33687.

FIGS. 51-52. Right lateral and ventral views of carapace in fifth instar, Topotype No. 33704.

FIGS. 53-56. Right lateral and dorsal views of two carapaces in fifth instar, Topotypes Nos. 33688 and 33706.

FIGS. 57-58. Left lateral and dorsal views of carapace in fifth instar, Topotype No. 33683.

FIGS. 59-60. Right lateral and dorsal views of adult male carapace, Topotype No. 33721.

FIGS. 61-64. Right lateral, ventral anterior, and left lateral views of adult female carapace, Topotype No. 33676.

FIGS. 65-68. Dorsal, right lateral, anterior, and ventral views of adult female carapace, Topotype No. 33689, in which the two valves are agape.

FIGS. 69-72. Right lateral, dorsal, ventral, and anterior views of adult female carapace, Topotype No. 33696. The anterior corners of the two valves are broken off.

PLATE I

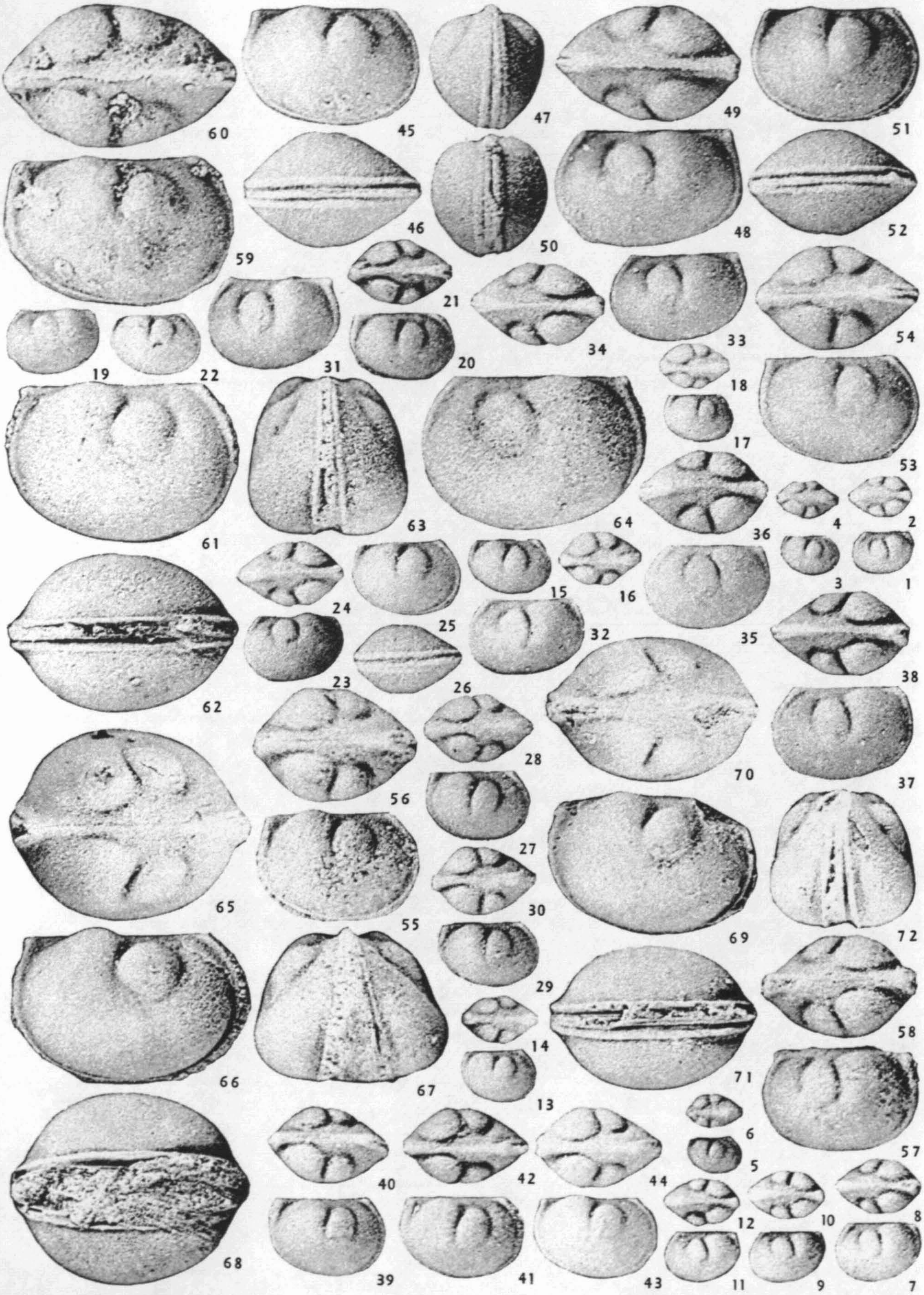
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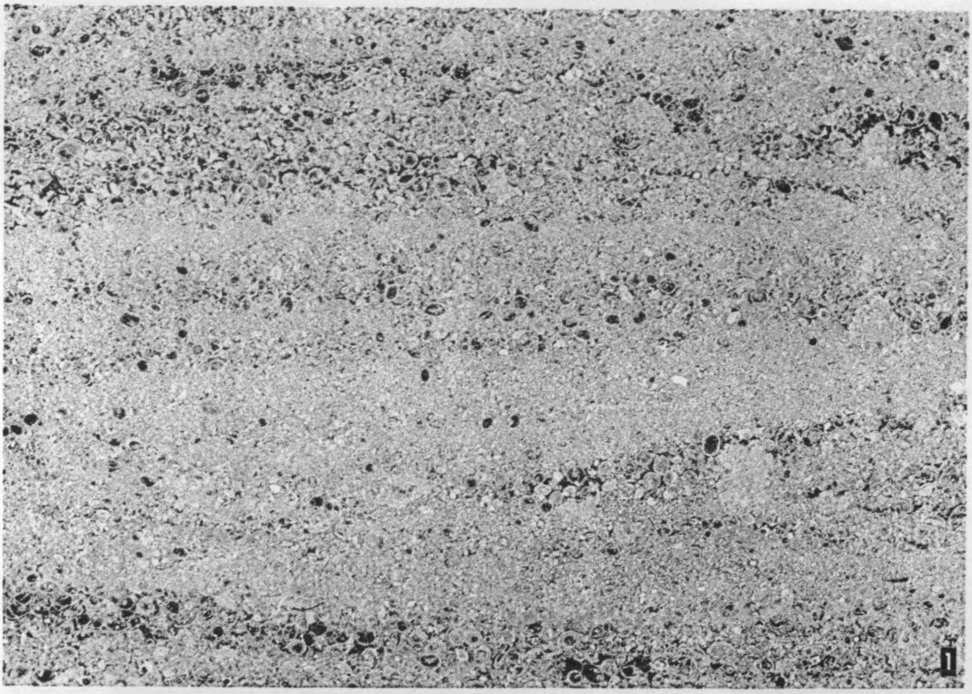
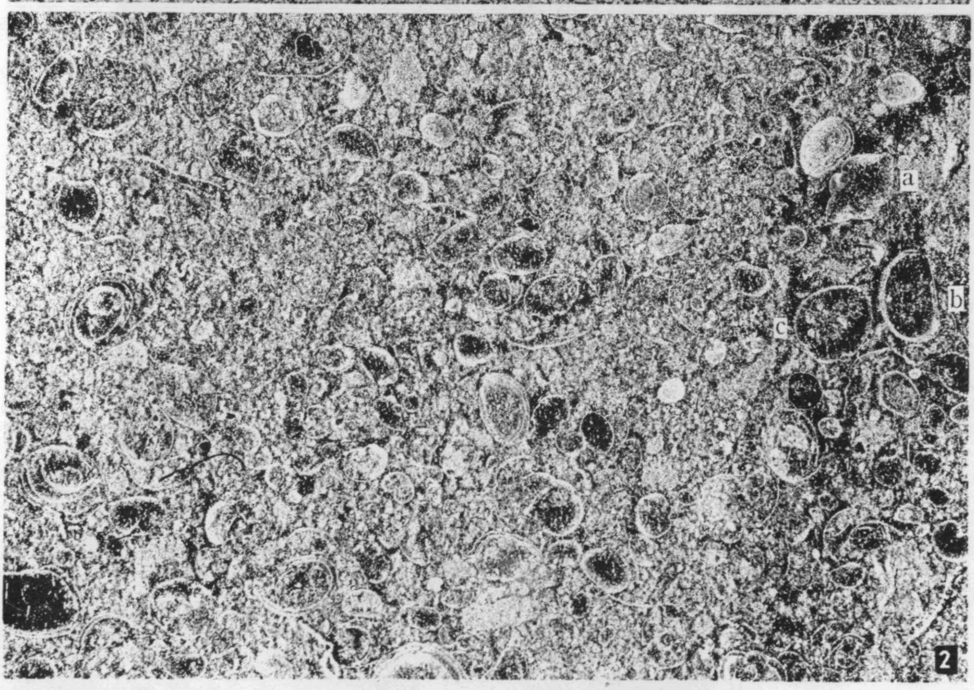
PLATE II





EXPLANATION OF PLATE II

FIG. 1. Peel of vertical polished surface of rock as seen by reflected light. The darkest areas are clear calcite. Cross laminae can be seen in the lower half of the figure. × 3.

FIG. 2. Peel of horizontal polished surface as seen by reflected light. The small light blotches are inclusions, presumed to be remnants of mud that dried, cracked subaerially, and was later reworked by waves. A carapace with its ventral surface downward is shown at *a*, one with its lateral surface downward at *b*, and one with its end (anterior?) downward at *c*. Near the left border are two stacks of valves. × 10.

EXPLANATION OF PLATE III

(All figures × 10)

FIG. 1. Peel of horizontal polished surface as seen by reflected light. In the left central area is a carapace with larger valves stacked on both of its valves; an enlargement is seen in Pl. IV, Fig. 1.

FIG. 2. Peel of vertical polished surface as seen by reflected light. In the lower half of the figure can be seen a stack of four closely spaced valves, all convex upward; an enlargement is seen in Pl. IV, Fig. 2.

FIG. 3. Peel of vertical polished surface as seen by transmitted light. Near the center of the figure there are three valves stacked convex side downward, overlain by two valves stacked convex side upward.

FIG. 4. Peel of vertical polished surface as seen by reflected light. In the upper left area are three valves stacked convex side downward. In the ventrocentral area is a carapace enclosed within a larger one.

FIG. 5. Peel of vertical polished surface as seen by reflected light. Carapaces and valves are particularly concentrated in this section of rock.

FIG. 6. Peel of vertical polished surface as seen by reflected light. Near the center is a large carapace enclosing two smaller ones of different sizes; an enlargement is seen in Pl. IV, Fig. 3. In the lower right there is a stack of four valves convex downward, overlain by one valve convex upward.

PLATE III

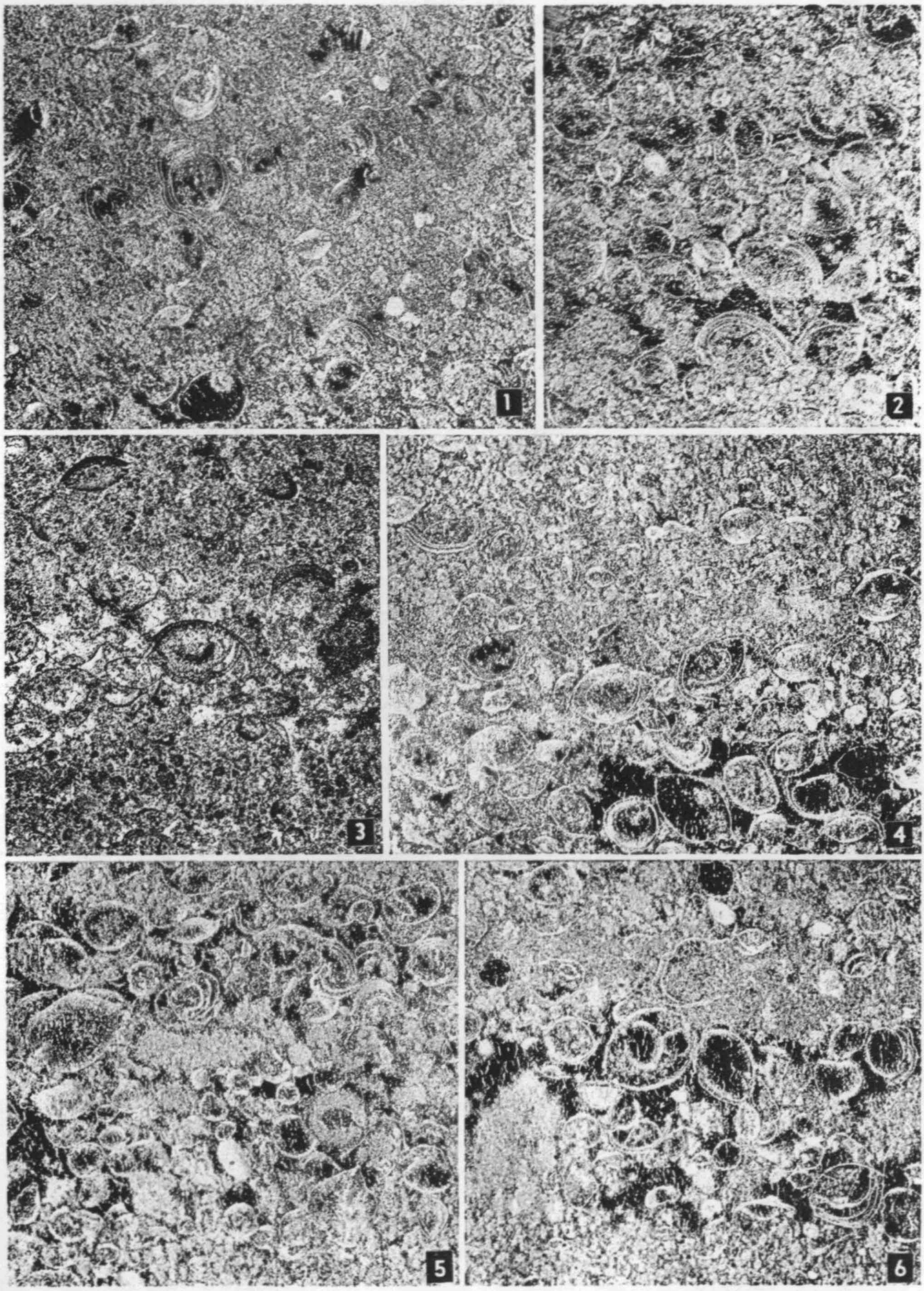
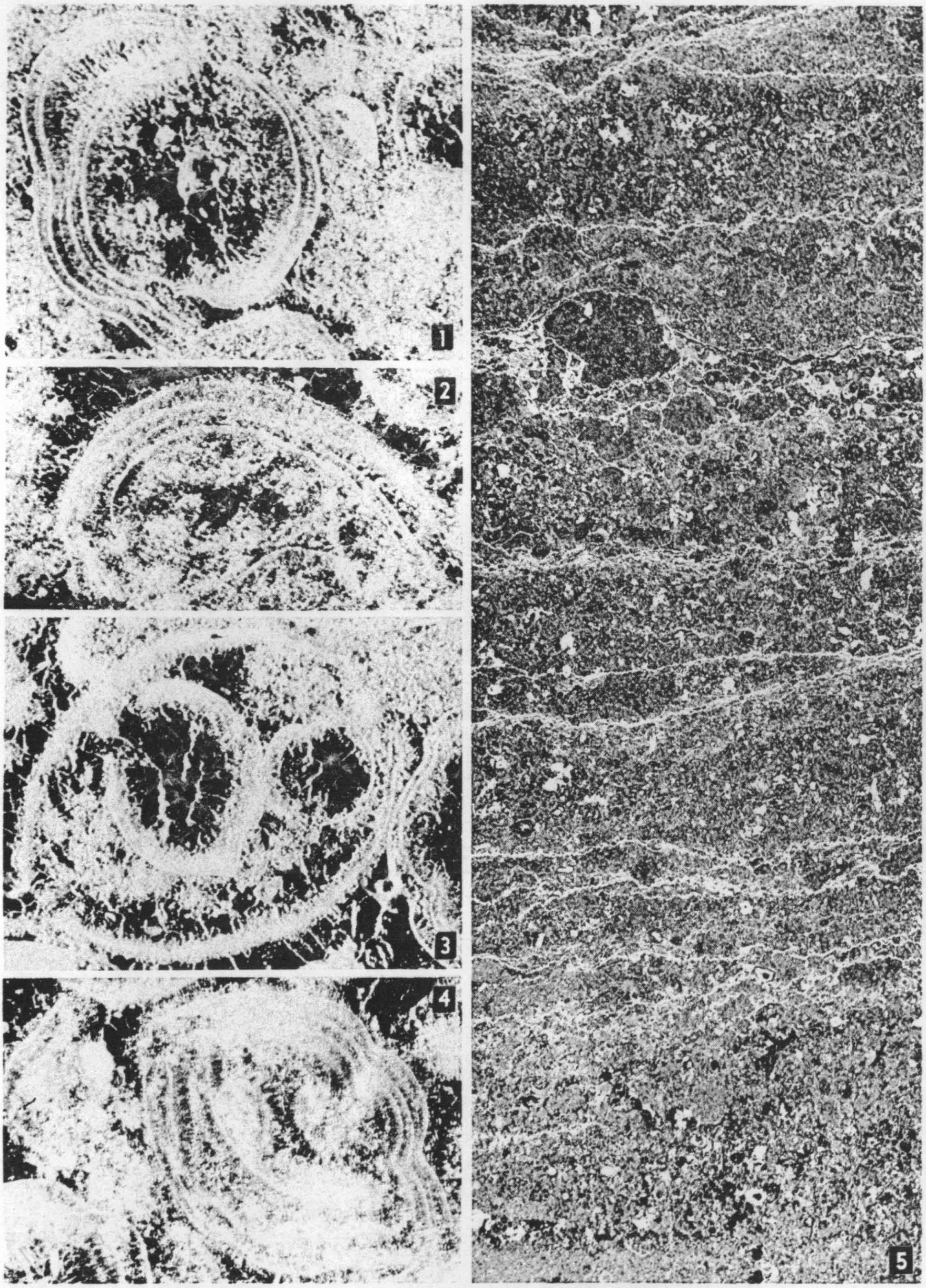


PLATE IV



EXPLANATION OF PLATE IV

(All figures $\times$ 40 except as noted)

FIG. 1. Peel of horizontal polished surface as seen by reflected light; an enlargement of part of Pl. III, Fig. 1. The carapace shown here has three valves stacked on its left side and one on its right.

FIG. 2. Peel of vertical polished surface as seen by reflected light; an enlargement of part of Pl. III, Fig. 2. A stack of four closely spaced valves.

FIG. 3. Peel of vertical polished surface as seen by reflected light; an enlargement of part of Pl. III, Fig. 6. A large carapace, not completely closed, with two smaller carapaces inside it.

FIG. 4. Peel of vertical polished surface as seen by reflected light. A large carapace with three valves enclosed on the right and two on the left.

FIG. 5. Peel of vertical polished surface as seen by reflected light, showing stylolites. Stylolites are developed around inclusions and more or less along laminae. $\times$ 4.