NEW LOWER AND MIDDLE CAMBRIAN CRUSTACEA

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INTRODUCTION

Among the numerous Cambrian fossils that have been accumulating in the United States National Museum during the last 15 years, there are many undescribed species and some of the specimens are remarkable for the preservation of thin tests or of soft body parts. In order to stimulate further search for the rarer fossils, and particularly for preservations of the softer parts of animals or of delicate plant tissues, it is planned to publish more or less related groups of these animals from time to time. Accordingly, in this paper I have assembled a group of species that centers mainly around the previously described genus *Tuzoia*, but which also includes several unrelated forms that were secured from the same localities as the others. This paper thus adds several new species preserving more than ordinarily thin tests of crustacea and a few with the still softer fleshy parts. Some are from the well known Burgess shale that has already furnished so many interesting animals and plants, but other formations, some of which have not previously been known to yield such fossils, are also represented.

This paper also contains information of interest aside from that naturally attaching to any description of the softer parts of such ancient animals, by presenting certain important stratigraphic facts in addition to further data regarding the geographic distribution and origin of the faunas to which these species belong.

Acknowledgment.—In the preparation of this paper I was kindly assisted by Dr. E. O. Ulrich in the matter of specific determinations as well as by much appreciated general criticism.

The Pennsylvania specimens of *Tuzoia* all belong to the Getz Collection in the Peabody Museum, Yale University. I was permitted to describe the two species represented, through the extreme kindness of Dr. Carl O. Dunbar, who had previously planned to describe them himself.

GEOGRAPHICAL DISTRIBUTION

The fossils described in this paper were secured from five general localities at four widely separated places in North America and Asia. For greater convenience and to prevent numerous repetitions precise descriptions of the several localities are grouped together in the following paragraphs:

List of localities

35k.—Middle Cambrian, Burgess shale: On west slope of the ridge between Mount Field and Wapta Peak, 1 mile northeast of Burgess Pass, near Field, British Columbia, Canada.

Well known fauna with numerous specimens of exceptionally preserved fossils of crustacea, annelids, sponges, algae, and many other forms. Characteristic trilobites: *Neolenus, Dorypyge, Elrathia,* and others.

67g.—Lower Cambrian, Eager formation: Brown and red (weathered) shales, 5 miles northeast of Cranbrook, British Columbia, Canada.

Contains an upper Lower Cambrian Mesonacid fauna, that includes some new elements.

25.—Lower Cambrian: Parkers Quarry, Georgia, Vermont.

Contains typical Mesonacid fauna.

12x.—Lower Cambrian, Kinzers formation: Getz Quarry, 1¾ miles north of Rohrerstown, Pennsylvania.

Contains the Vermont Mesonacid fauna.

12w.—Lower Cambrian, Kinzers formation: ¼ mile west of Fruitville, 3 miles north of Lancaster, Pennsylvania.

Same fauna and bed as 12x.

—Middle Cambrian: Mount Tang-shih-ling, near Yen-tai colliery, Liau-tung, Manchuria, China.

Dorypyge fauna.

—Middle Cambrian: Huo-lien-chai, Liau-tung, Manchuria, China.

Fauna same as preceding.

The specimens from Manchuria were collected at two near-by places by Prof. Riuji Endo, in the course of his field studies in the regions south of Mukden and they form a part of large and excellent collections whose species are now being described by Doctor Endo and myself. Both localities are located along the railway south of Mukden not far from Yen-tai, hence about in the center of Manchuria.

The Burgess shale locality in British Columbia, across the Pacific Ocean from Manchuria, is too well known to require any further discussion of its geographic situation.

The third locality is also in British Columbia, but many miles south of Burgess Pass, between Fort Steele and Cranbrook. This locality was first called to the attention of Dr. C. D. Walcott and some of the fossils were collected by Col. H. Pollen, formerly of Fort Steele.

The fourth group of localities is also separated from the two in British Columbia by the width of a continent. The two Pennsylvania localities are only a few miles apart along the strike and hence may be treated as one. Parkers Quarry in Vermont is another place that has been known for many years having become famous when *Olenellus thompsoni* was described from it. While it has been known for more than thirty years that the Mesonacid fauna was represented in Pennsylvania, it has only been in the last decade that the fauna has become well represented in the collections and the stratigraphic relations of the beds determined.

STRATIGRAPHIC CORRELATIONS

Relatively large collections, some of them brought together by many years of intensive collecting, are on hand from each of the regions described in the locality lists. Accordingly, we may assume with reasonable confidence that the faunas are fairly represented in our present collections. Yet taking the case of the Burgess shale from which the largest collections (over 35,000 specimens) have been obtained, as an example, we find that in spite of the intensive collecting extending over a number of years, new forms are still found by casual visitors to the outcrop. Strange to relate, all the *Tuzoia* specimens, except the holotype, turned up only after two full seasons' work. Keeping this example in mind we can the more readily comprehend the likelihood of finding further material at any of the places and thereby alter somewhat our present opinions of the exact composition of the several faunas.

The marvellous preservation of such a host of species in the Burgess shale gives that fauna a definiteness that is scarcely equaled by any other in the entire geologic column, even though its exact stratigraphic position in the Middle Cambrian may not yet be precisely fixed. The Burgess shale has usually been regarded as the exact equivalent of the *Ogygopsis* shale member of the Stephen formation which like this bed outcrops in only one restricted area—to the south across the Kicking Horse Valley. But a close scrutiny of the apparently identical faunas reveals the fact that many species formerly regarded as common to the two beds are really distinct, thus

creating some doubt as to the exact contemporaneity of these deposits laid down in two areas separated by only 6 miles. This discrepancy may, however, also be explained by a geographic arrangement whereby the one area was enabled to get more constant restocking from the common parent sea. No question, however, remains concerning the relative position of these beds in their respective sections. The Burgess shale definitely underlies the massive, usually unfossiliferous Eldon limestone, which closes the Middle Cambrian sequence at many places in the Canadian Rockies. Fossils have been reported in the Eldon from localities chiefly to the east and north of Field, and until these and the fossils of underlying formations are studied nothing further can be said concerning the age of the Burgess shale. However, with the information now in hand the statement that its position is above the middle of the Middle Cambrian seems undeniable.

At present it is not possible to say exactly what position the soft yellow shales from central Manchuria hold. From the scanty information in hand it would appear that these shales are either interbedded with or directly overlie the oolitic limestones containing *Dorypyge richthofeni*. In either case this bed is succeeded by a non-oolitic limestone containing the Asiatic *Drepanura* fauna, which apparently belongs to the Middle Cambrian and may therefor have been deposited at the same time as the Eldon, while the underlying oolitic and shaly beds, with a *Dorypyge* fauna, are to be correlated with the upper part of the Stephen. At any rate, considering the Manchurian section as now known, as being fairly representative of Middle Cambrian time, this yellow shale would hold a position somewhat above the middle of that division, and hence be in the same relative position as the Stephen formation. Additional data have recently been secured which we hope will throw more light on the problem and possibly clear up some of the uncertainties.

The Cranbrook locality has yielded a most interesting Lower Cambrian fauna that contains some new elements, particularly a new Mesonacid genus, but which in general agrees with what we ordinarily expect in a Lower Cambrian Mesonacid fauna. This same fauna has been collected from red and gray limestones and from sandstones in the vicinity of the Upper Columbia Lake and seems to continue northward into the Dogtooth Mountains, as the equivalent of the lower Mount Whyte fauna, with the possibility that it is also the same as the Hota[1] fauna at Mount Robson. At Cranbrook the relatively soft *Tuzoia* beds, composing the Eager formation,[2] outcrop but poorly and consequently their relative position is not

[1] Walcott, 1913, Smithsonian Misc. Coll., vol. 57, no. 12, p. 338. When this fauna was described the formation was erroneously given as Mahto.

[2] Schofield, S. J, 1922, Canadian Geol. Surv., Bull. 35, p. 12.

definitely indicated, but since the lower part of the Burton formation outcropping nearby apparently contains a fauna of similar age, while the upper portion contains the Middle Cambrian *Albertella* fauna, it becomes apparent that here the upper Mount Whyte, (*Kochiella* fauna),[3] is absent.

The rare Pennsylvania fossils herein described or referred to are all in the Kinzers formation,[4] which has the typical Mesonacid fauna that is comparable with the Eager formation just mentioned. Beside the *Tuzoia*, *Anomalocaris*, and merostome described from this formation in this paper several other unusual fossils have been found, including notably a sponge and a species of some Holothurian possibly belonging to the genus *Peytonia*. Both the eastern and western Mesonacid faunas have now furnished such fossils that clearly show that the Burgess shale fauna was derived from the same ocean.

Several other Lower Cambrian collections from western North America, made in fine grained argillaceous rocks that break with sufficiently large smooth surfaces to preserve them, give us specimens of phyllopods, among which such genera as *Hurdia*, *Hymenocaris*, *Isoyxs*, together with several new ones, are represented or suggested. In eastern Yun-nan, southern China, Mansuy [5] has found several phyllopods in the *Redlichia* beds, quite similar to those from the western American Mesonacis bearing beds, and in addition a merostome that he described as *Amiella prisca*. Thus it will be seen that many of the "lower" crustacea as well as algae, sponges, jellyfish, and worms were already important in the Lower Cambrian seas, and if we should ever be so fortunate as to find another Burgess shale preservation in these older rocks we may expect a great array of organisms. It will also be observed that indications point to the direct descent of the Burgess shale fauna from these older Mesonacid assemblages. It might be added that certain trilobites in the Eager beds seem to belong somewhere between the Mesonacidae and such Middle Cambrian forms as *Zacanthoides*.

All the faunas here discussed, both the Lower and Middle Cambrian, lived in epicontinental seas whose waters were apparently extensions of the Arctic Ocean.

BIOLOGICAL RELATIONS OF THE FOSSILS

Knowing very little about the structure and systematic relations of the crustacea, I hesitate to say anything in this connection regarding the biological significance or relationships of the fossils presented in this paper, but a few general observations may be in order.

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[3] Walcott, 1917, Smithsonian Misc. Coll., vol. 67, no. 3, p. 63. The Mount Whyte has a Mesonacid fauna in its lower part and the zone with *Olenopsis* (=*Kochiella*) *agnesensis* in the upper.

[4] Stose and Jonas, 1922, Journ. Washington Acad. Sci., vol. 12, no. 15, p. 359.

[5] Mansuy, 1912, Mem. Serv. Geol. L'Indochine, vol. 1, fasc. 2.

Tuzoia when first described was referred to the Leptostraca, and subsequent studies have confirmed this position.[6]

Henriksen (p. 11) suggests that *Anomalocaris* belongs to the same group and that it may be the body of *Tuzoia* or *Carnarvonia*. Walcott[7] associated several phyllopod carapaces, which have since been referred to *Hymenocaris* and *Isoxys*, with *Anomalocaris* prior to the discovery of the numerous entire specimens of *Hymenocaris* in the Burgess shale. In support of Henriksen's idea that *Anomalocaris* may be the body of *Tuzoia* it may be stated that three of the four localities yielding *Tuzoia* have thus far also furnished *Anomalocaris* and that the latter has been found independently only on Mount Stephen.

Genus TUZOIA Walcott, 1912

Tuzoia Walcott, 1912, Smithsonian Misc. Coll., vol. 57, no. 6, p. 187.
Tuzoia Henriksen, 1928, Vidensk. Medd. fra Dansk naturh. Fören., vol. 86, p. 16.

Large phyllopod with carapace consisting of two convex valve-like portions. Shell thin, and lateral portions semi-oval, narrowed anteriorly, probably curved evenly downward from the dorsal line; each valve increasing in convexity from the edges toward the keel that extends almost the full length of the shell in an approximately central position; posterior margin usually has several large spines; smaller spines may edge all but the extreme anterior portion of the margin; strong spines along the dorsal line in many species; also on the central keel in some species, sometimes their broad bases unite to form a scalloped frill. Surface usually reticulate; the meshes on the keel and near the dorsal line usually smaller and more crowded than on other parts of the shell. No external eyes or muscle scars observed.

Comparisons.—Comparing *Tuzoia* with *Protocaris* we notice that the shape of the valves, their relative size and the presence of a keel make the two forms look much alike. However, *Protocaris* lacks the reticulations and marginal spines which are persistent features of *Tuzoia* and thus offers an easily applied means of distinguishing them. If *Anomalocaris* is actually the abdominal portion of *Tuzoia* considerable differences of body structure exist. Both specimens of *Protocaris* thus far obtained retain the soft body, whereas none of the numerous *Tuzoia* specimens do, which in itself points to a difference of structure.

Attitude of valves in burial.—Some of the specimens were entombed in such a position that both valves were flattened together

[6] Henriksen, Critical Notes upon Some Cambrian Arthropods. Vidensk. Medd. fra Dansk naturh. Fören., vol. 86, 1928, p. 15.
[7] Mount Stephen Rocks and Fossils. Canadian Alpine Journ., vol. 1, no. 2, 1908, p. 2.

laterally. In these cases the original convexity of the valvelike portions of the carapace was reduced to almost paper thickness, the originally high keel being more or less displaced from the normal with attendant crowding together of the more dorsal and ventral portions of the thin shell. In many other instances the two valves were buried in more or less normal vertical position that resulted in the two valves being pressed flat dorso-ventrally so that the dorsal line traverses the middle of the fossil and the circumference or periphery represents the original convexity of the conjoined valves. In such cases, moreover, the normally converging ventral portions beyond the keel were folded back underneath the diverging dorsal halves of the valves. In such dorso-ventrally compressed specimens the periphery usually is made by the serrated keel.

Genotype.—*Tuzoia retifera* Walcott, 1912.

Stratigraphic range.—Lower and Middle Cambrian.

Geographic distribution.—Middle Cambrian in Manchuria and British Columbia. Lower Cambrian, British Columbia, and Pennsylvania.

TUZOIA RETIFERA Walcott

Plate 1, figures 1, 2; Plate 4, figure 3

Tuzoia retifera WALCOTT, 1912, Smithsonian Misc. Coll., vol. 57, no. 6, p. 187, pl. 33, fig. 2.

When Walcott first described this species in 1912 in the fourth preliminary paper based on the 1910 and 1911 collections from the Burgess shale quarry, he still had only the single specimen illustrated. Subsequently, among more than a score of additional specimens that appeared, some preserving the margins, certain ones apparently represent this species and consequently a more complete description may now be drawn. After careful scrutiny of the specimens that have marginal spines and of the original type I have come to the conclusion that in the latter the marginal spines have been broken away and that it was not originally without them.

The original description of the species relies exclusively on the illustrations to present the characters of the animal. A formal description even now will add nothing to what can be ascertained from the present illustrations, particularly when these are studied in conjunction with the foregoing generic outline. Several characters may be emphasized by being specifically pointed out here. First, the three posterior marginal spines, the central one in direct line with the keel, may be noted. One or two smaller spines occur forward of these. Along the margin, between both sets small spines or crenulations mark the edge. None of the specimens available permit a definite determination of the presence or absence of spines along the dorsal line where we usually find them in other species.

Whether the imperfect specimen illustrated on Plate 4, Figure 3, really should be regarded as belonging to this species can not be decided with certainty because of its incompleteness, but a careful study of it indicates that it likely does.

Horizon and locality.—Middle Cambrian, Burgess shale; (loc. 35k) near field, British Columbia.

TUZOIA BURGESSENSIS, new species

Plate 2, figure 1; Plate 3, figure 1

Comparing this species with *T. retifera* we first note that it is longer and narrower and that the reticulations of the keel appear to be more numerous and stronger. The posterior marginal spines are about the same in both species but the small spines are larger and more regular both in size and spacing than in the genotype. Those of intermediate size appear to be absent. This species also has several blunt spines along the dorsal line the extensions of which are not as long or slender as in *T. retifera.*

Horizon and locality.—Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Holotype and paratype.—Cat. No. 80477, U.S.N.M.

TUZOIA CANADENSIS, new species

Plate 2, figures 2, 3

This second new species determinable in the Burgess shale material on hand is represented by only three or four fragmentary specimens, yet its specific characters may readily be seen.

Since the general shape and character of the reticulations of this species do not differ materially from the same features in both of the foregoing species its right to specific rank rests on others. The most prominent of these is the possession of four instead of three posterior spines which are longer and slenderer than in the preceding species and they are followed anteriorly by perhaps twelve or more of intermediate size, widely and evenly spaced along the margin, ending with one situated forward of the keel. Between these large and intermediate spines the usual small ones occur, in this case being most like those in *T. retifera.* The spines along the dorsal line are also longer and more slender, and perhaps more numerous than in *T. burgessensis.*

Horizon and locality.—Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Holotype and paratype.—Cat. No. 80478, U.S.N.M.

TUZOIA MANCHURIENSIS Resser and Endo [8]

Plate 3, figures 2, 3

Several rare, fragmentary valves collected at two localities in central Manchuria, constitute the material on which this species is founded. It is quite possible that they represent more than one species. Comparing the Manchurian species with those from the Burgess shale we note that in general shape it differs little from the genotype, but due to the fact that all the specimens preserve only the anterior portions of the valves nothing can be determined regarding the number and characters of the marginal spines. The reticulations are quite similar also, the smaller ones on the keel perhaps being more suddenly differentiated from those on the remainder of the test than usually occurs in the American species. It is the appearance of the keel in the two specimens illustrated that injects some uncertainty as to their specific identity, and this can only be cleared up by securing more material.

Horizon and locality.—Middle Cambrian; Huo-lien-chai and Mt. Tang-shih-ling, near Yen-tai, Manchuria.

Holotype and paratype.—Cat. Nos. 80481, 80482, U.S.N.M.

TUZOIA POLLENI, new species

Plate 5, figures 1–3

This fine Lower Cambrian species is represented in the collections by four practically complete specimens besides a few instructive fragments.

In shape and general appearance it is most like the Middle Cambrian genotype. It differs in its stronger reticulations, more particularly in its four instead of three large posterior spines—in which respect it is like *T. canadensis*—and most of all in the size and abundance of the spines along the dorsal line where five or more may be counted in the anterior half of the line. These spines were considerably longer than indicated in the illustrations, if the small fragment in the collections is properly interpreted as to species and position in the test. None of the specimens clearly preserve dorsal spines in the posterior third or more of the line, and since other species also lack spines in that place it may be assumed that if any were present in this species they were smaller than the anterior ones.

The specific name is given in honor of the discoverer of these interesting fossils in the Lower Cambrian of British Columbia.

Horizon and locality.—Lower Cambrian, Eager formation; (loc. 67g), near Cranbrook, British Columbia.

Holotype and paratypes.—Cat. No. 80485, U.S.N.M.

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[8] This species is here described in collaboration with Dr. R. Endo, and will be cited as *Tuzoia manchuriensis* Resser and Endo.

TUZOIA NODOSA, new species

Plate 5, figure 4

A second species based on one small complete valve must be established from the Lower Cambrian Cranbrook material.

It is readily distinguished from other species by the large and numerous spines along the dorsal line and by its great width which exceeds any other species. It has four posterior marginal spines like *T. polleni*, but the remainder of the margin seems to be smoother. It also has short blunt spines on the keel.

Horizon and locality.—Lower Cambrian, Eager formation; (loc. 67g), near Cranbrook, British Columbia.

Holotype.—Cat. No. 80486, U.S.N.M.

TUZOIA SPINOSA, new species

Plate 6, figure 4

Another species appears to be represented by two fragmentary valves in the red weathered shales of the Eager formation from Cranbrook. At first, owing to the large spines on the keel, it was thought that the specimens belonged to *T. undosa*, but a more careful comparison indicates that the differences first observed in the marginal spines actually exist and are not merely a matter of preservation. These spines are arranged in two sets, one a widely and irregularly spaced large set between which a smaller more even set occurs.

Horizon and locality.—Lower Cambrian, Eager formation; (loc. 67g), near Cranbrook, British Columbia.

Holotype.—Cat. No. 80489, U.S.N.M.

TUZOIA PRAEMORSA, new species

Plate 6, figure 3; Plate 7, figure 2

Two fine Burgess shale specimens were first regarded as representing a new genus before the manner of folding under compression and the fact that the keel is sometimes spinose were determined. The plate descriptions indicate the manner of folding in both specimens.

This species can not be confused with any other in the Burgess shale because of its scalloped frill on the keel and the marginal spines. It is much more like *T. getzi* from the Lower Cambrian.

Horizon and locality.—Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Holotype and paratype.—Cat. No. 80488, U.S.N.M.

TUZOIA GETZI, new species

Plate 7, figure 3

Several specimens have been secured from the Lower Cambrian in southeastern Pennsylvania and two of them represent another species

of *Tuzoia* that at first sight recalls the Middle Cambrian *T. praemorsa* and the Lower Cambrian *T. spinosa*. It can not be confused with *T. retifera* and it allies because of the presence of more marginal spines and the frill on the keel.

Comparing *T. getzi* with *T. spinosa*, beside the common possession of keel spines, we find but little chance for confusion since the latter has two sets of marginal spines. There is more resemblance to *T. praemorsa* both in the shape, size, and distribution of the reticulations and particularly in the scalloped frill on the keel, but right here we find an easy way to distinguish the two; *T. getzi* has perhaps a dozen spines or scallops along the keel while *T. praemorsa* has only about seven.

The specific name is given in recognition of the interest of Noah L. Getz in collecting the fossils, as rock was quarried on his farm, which resulted in the finding of this and many other fine specimens.

Horizon and locality.—Lower Cambrian, Kinzers formation; (loc. 12x) near Rohrerstown, Pennsylvania.

Holotype.—Cat. No. 10044, Peabody Museum, Yale University.

TUZOIA ? DUNBARI, new species

Plate 7, figure 1

A single specimen from the Kinzers formation represents another species that should, perhaps, be referred to a new genus. The specimen is an impression of the exterior of an extremely spinose form. I am unable to decide whether this represents an entire valve, in which case it, of course, belongs to a new genus, or whether it comprises only that part of the shell between the dorsal line and the keel.

Comparing this form with the more spinose species of *Tuzoia*, we note first the extraordinary extension of the dorsal line into long, upturned spines such as we find in some living crustacea. Assuming that the longer spines occur on the rear margin and that the outer edge extends only to the keel, we note the very long spine in the usual position between the dorsal extension and the keel. If this is only the inner part of the test one or more marginal spines should occur beyond the keel. At least five spines edge the anterior margin exclusive of the dorsal extension. If the foregoing interpretation of the shell is correct, then the broad-based spine along the lower margin belongs to the keel and would indicate the presence of a frill.

The specific name is given in honor of Dr. Carl O. Dunbar, of Yale University, who so kindly permitted me to describe this fossil in this study of the group to which it belongs.

Horizon and locality.—Lower Cambrian, Kinzers formation: (loc. 12x) near Rohrerstown, Pennsylvania.

Holotype.—Cat. No. 10046, Peabody Museum, Yale University.

ANOMALOCARIS Whiteaves

ANOMALOCARIS PENNSYLVANICA, new species

Plate 5, figure 5

A small, poorly preserved example of this peculiar animal was secured from the Kinzers formation in Pennsylvania and placed in Doctor Walcott's collections many years ago. Little can be said about it since its characters are not well shown, but the observation may be made that the appendages, of which there are 12 or 13 pairs, are relatively longer than in any of the described species. The rear segment appears to be rather deeply notched.

Horizon and locality.—Lower Cambrian, Kinzers formation; (loc. 12x) near Rohrerstown, Pennsylvania.

Holotype.—Cat. No. 80487, U.S.N.M.

ANOMALOCARIS CRANBROOKENSIS, new species

Plate 2, figure 4

Only one specimen of this form has been found in the Eager formation. This species has about fourteen or fifteen abdominal segments and blunter appendages than *A. pennsylvanica.* The caudal segment is much like that figured by Walcott [9] for *A. whiteavesi.*

This like the preceding specimen is not well preserved so that it is difficult to determine its features. The interesting thing in this connection is the occurrence of these rare animals in such old beds and associated in both cases with *Tuzoia.*

Horizon and locality.—Lower Cambrian, Eager formation; (loc. 67g) near Cranbrook, British Columbia.

Holotype.—Cat. No. 80479, U.S.N.M.

Genus PROTOCARIS Walcott, 1884

Protocaris Walcott, 1884, Bull. U. S. Geol. Surv., No. 10, p. 50.
Protocaris, Walcott, 1886, Bull. U. S. Geol. Surv., No. 30, p. 147.
Protocaris Woodward, 1888, Mon. British Pal., Phyllopoda, Pal. Soc., p. 2.

Walcott's drawing of the genotype published in 1884 has been copied many times and much has been written about it. The single carapace of *Roddyia* described in the following pages brought up the question whether or not it was a *Protocaris.* It was quite a surprise on looking at that specimen for the first time, to note at once that it had two valves and was almost conspecific with the Burgess shale *P. pretiosa.* Since hitherto *P. marshi* was always regarded as an *Apus*-like form with an undivided carapace, naturally the previous descriptions need revision. Walcott, however, indicated a possible relationship of this primitive crustacean with "the Nebalidae

[9] Canadian Alpine Journ., vol. 1, no. 2, 1908, pl. 2, fig. 4.

through *Hymenocaris*, *Peltocaris*, *Ceratocaris*." Thus, while this form was classified with *Apus* its true position was hinted at from the beginning.

The better preserved Burgess shale specimen allows us to get a more complete conception of the major features.

Genotype.—*Protocaris marshi* Walcott. (See pl. 6, figs. 1, 2.)

Geographic and stratigraphic distribution.—Lower and Middle Cambrian. Vermont and British Columbia.

PROTOCARIS PRETIOSA, new species

Plate 4, figures 1, 2

A single Burgess shale specimen preserving the soft body, both within the carapace and the abdominal portion that extended beyond, apparently belongs to the genus *Protocaris*.

Both valves of the carapace are preserved. The left one is flattened out evenly, but the right is crushed in an oblique direction. In general shape and the presence and position of a keel, this shell conforms to *Tuzoia* but both reticulations and marginal spines are lacking.

It was possible to remove the matrix that had filtered between the carapace and the soft body of the animal within and which preserved an impression of the underside of the left valve, thus exposing the body itself. None of the head parts are well shown, since in flattening the original convexity the anterior portion was crowded together, thereby effacing the delicate structures. Omitting the head parts the remainder of the body is divisible into a thoracic division with numerous segments all limb-bearing, an abdominal portion also composed of many segments which appear to have had much shorter or no appendages and finally a third bifurcated caudal division. This latter has practically the same shape as is *Waptia fieldensis*.

Comparing this species with the genotype, *P. marshi*, we can see but few important differences. This new species seems to have the valves more rounded in front, but *P. marshi* is crushed down on the sides and may thereby be somewhat changed from its original outline. The different aspect of the abdominal portions of the two species is accounted for by the fact that *P. marshi* was flattened vertically while *P. pretiosa* suffered pressure at an oblique angle.

Horizon and locality.—Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Holotype.—Cat. No. 80483, U.S.N.M.

RODDYIA, new genus

While the single specimen on which this genus is based leaves much to be desired, it is so unlike anything else from these beds or that has

previously been described that its description and naming seems desirable.

The undivided carapace, the apparent structure features that appear as elevations on the test and its surface ornamentation all indicate that it is a merostome. If so it is considerably older than any of this group hitherto found.

Such generic characters as may be observed will be presented in the specific description.

The name is given as a slight recognition of the important work done for many years by Dr. H. Justin Roddy, now curator of the museum and professor of geology at Franklin and Marshall College, in discovering the interesting fossils occurring in the Lower Cambrian of the Lancaster region. Doctor Roddy has the happy faculty of interesting people in natural science and therefor the author, together with hundreds of others, owes much to him for his unfailing encouragement in the early years of geologic work.

Genotype.—Roddyia typa, new species.

Range.—Lower Cambrian. Southeastern Pennsylvania.

RODDYIA TYPA, new species

Plate 2, figure 5

Cephalic shield undivided. The prominences noticeable in the specimen may represent a raised central portion lobed somewhat in the manner of *Aglaspis*.[10] Surface covered with slightly irregular raised lines.

This form should be compared with *Molaria*, *Habelia*, and *Emraldella* of the Burgess shale, but none of these preserve their cephalic shields sufficiently well to make any real comparisons. So far as may be ascertained *Roddyia* seems to be more like *Molaria* than the others, but even then the similarity is only superficial.

Horizon and locality.—Lower Cambrian, Kinzers formation; (loc. 12x) near Rohrerstown, Pennsylvania.

Holotype.—Cat. No. 80480, U.S.N.M.

[10] See Whitfield, 1882, Geol. Surv. Wisconsin, vol. 4, p. 192, pl. 10, fig. 11.

DESCRIPTION OF PLATES [11]

PLATE 1

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Tuzoia retifera Walcott 7

FIG. 1. Left valve retaining the three large rear spines. In this specimen the keel was pressed down toward the lower margin, giving it a more curved shape and a more ventral position than it had in a perpendicular view of the undistorted shell and thereby the reticulations have been almost obliterated in the crushed portions and nearly effaced in places beyond this area. A specimen of the abundant gastropod, *Scenella varians*, projects through the shell near its lower margin. Plesiotype, Cat. No. 80484, U.S.N.M.

2. A new photograph of the original holotype figured by Walcott. In this specimen the larger marginal spines are apparently broken off. The keel is pressed almost vertically downward, thereby causing but little distortion on any part of the shell except near the front end where the reticulations show crowding. An examination of the margin indicates that both valves are present. Holotype, Cat. No. 57720, U.S.N.M.

Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

PLATE 2

Tuzoia burgessensis, new species 8

FIG. 1. A well preserved specimen with the left valve uppermost. In the flattening the keel was crushed down directly to the rear. Note the three strong marginal spines and the rather regular smaller spines along the remainder of the outer margin; also the absence of intermediate spines. Several of the blunt spines along the dorsal line can be seen. Holotype, Cat. No. 80477, U.S.N.M.

Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Tuzoia canadensis, new species 8

2. Cast of exterior of rear portion of left valve, showing the four large posterior spines. Some of the smaller more regular spines are visible forward along the lower margin. Paratype, Cat. No. 80478, U.S.N.M.

3. Major portion of right valve. Several intermediate marginal spines are visible anterior to the fourth large posterior spine. Holotype, Cat. No. 80478, U.S.N.M.

Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Anomalocaris cranbrookensis, new species 12

4. Usual lateral view of this animal. Twelve or thirteen segments anterior to the bifurcated caudal division. Somites and appendages may not be quite correctly outlined as specimen is little distinct from matrix. Holotype, Cat. No. 80479, U.S.N.M.

Lower Cambrian, Eager formation; (loc. 67g) near Cranbrook, British Columbia.

Roddyia typa, new species 14

5. Dorsal view of cephalic shield (×2). Holotype, Cat. No. 80480, U.S.N.M.

Lower Cambrian, Kinzers formation; (loc. 12x) near Rohrerstown, Pennsylvania.

[11] All figures are natural size unless otherwise indicated.

PLATE 3

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Tuzoia burgessensis, new species 8

FIG. 1. A large left valve. Keel pressed directly downward. Folding to accommodate this reduction in convexity resulted in a crowded zone about half way to the margins. Paratype, Cat. No. 80477, U.S.N.M.

Middle Cambrian, Burgess shale; (loc. 35k), near Field, British Columbia.

Tuzoia manchuriensis, Resser and Endo MSS 9

2. Upper anterior quadrant of left valve. Note long extension of dorsal line and narrowed keel. Paratype, Cat. No. 80481, U.S.N.M.

3. Major portion of left valve. Reticulations on keel and general surface partially visible. Note worm borings. Holotype, Cat. No. 80482, U.S.N.M.

Middle Cambrian, Matrix; soft yellow shale. Fig. 2, from Huo-lien-chai, and fig. 3, from Mount Tang-shih-ling, near Yen-tai, Manchuria.

PLATE 4

Protocaris pretiosa, new species 13

FIG. 1. Abdominal portion of body and both valves of this interesting form. Right valve extended and practically undistorted. Left valve which rests at an oblique angle to the bedding plane crushed down and thereby extended rearward.

2. Counterpart of same specimen as figure 1, with shell removed to expose most of the body. Note the numerous segments and the bifurcated caudal extremity. Holotype, Cat. No. 80483, U.S.N.M.

Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Tuzoia retifera, Walcott 7

3. Major portion of a poorly preserved specimen referred to the species with some doubt, in which the two valves became flattened out on the same plane. In this case the original convexity of each valve was reduced by overthrust faulting along the keel, together with parallel folding in other areas thus almost effacing the reticulations. Plesiotype, Cat. No. 80484, U.S.N.M.

Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

PLATE 5

Tuzoia polleni, new species 9

FIG. 1. Large right valve in which the spines and reticulations are well preserved. Holotype, Cat. No. 80485, U.S.N.M.

2. Small right valve from which the marginal spines have mostly been broken away. Note the numerous small and embryonic specimens of a Mesonacid showing on and through the thin shell. Paratype, Cat. No, 80485, U.S.N.M.

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FIG. 3. A third somewhat larger right valve with the cast of the exterior of the left shown in the upper front corner. Note the large spines along the dorsal line. Paratype, Cat. No. 80485, U.S.N.M.
Lower Cambrian, Eager formation; (loc. 67g) near Cranbrook, British Columbia.

Tuzoia nodosa, new species 10

4 (× 2). Small right valve. Note the very large dorsal spines and those on the keel. Holotype, Cat. No. 80486, U.S.N.M.
Lower Cambrian, Eager formation; (Loc. 67g) near Cranbrook, British Columbia.

Anomalocaris pennsylvanica, new species 12

5 (× 2). Side view of animal. Specimen poorly differentiated from rock hence the poor illustration. Holotype, Cat. No. 80487, U.S.N.M.
Lower Cambrian, Kinzers formation; (loc. 12x) near Rohrerstown, Pennsylvania.

PLATE 6

Protocaris marshi Walcott 12

FIG. 1. Unretouched photograph of the single specimen.

2. Retouched photo of same, to bring out certain features that may be seen only by turning the specimen at various angles to the light. Holotype, Cat. No. 15400, U.S.N.M.
Lower Cambrian; (Loc. 25) Georgia, Vermont.

Tuzoia praemorsa, new species 10

3. Valves flattened into one plane. Distal portions beyond keel folded underneath. Note how the broad keel spines unite to form a wide frill. Surface covered with fine pseudomorphic needle crystals. Holotype, Cat. No. 80488, U.S.N.M.
Middle Cambrian, Burgess shale; (loc. 35k) near Field, British Columbia.

Tuzoia spinosa, new species 10

4. Fragments of two valves. Keel spines on right-hand specimen preserved in unremoved matrix, overhanging outer portion of shell. Rock bright red and hence difficult to photograph. Holotype, Cat. No. 80489, U.S.N.M.
Lower Cambrian, Eager formation; (loc. 67g) near Cranbrook, British Columbia.

PLATE 7

Tuzoia? dunbari, new species 11

FIG. 1. Impression of exterior of valve. Note the extraordinary spines. Reticulations faint and difficult to photograph because outlined in bright yellow. Holotype, Peabody Museum, Yale University, No. 10046.
Lower Cambrian, Kinzers formation; (loc. 12x) near Rohrerstown, Pa.

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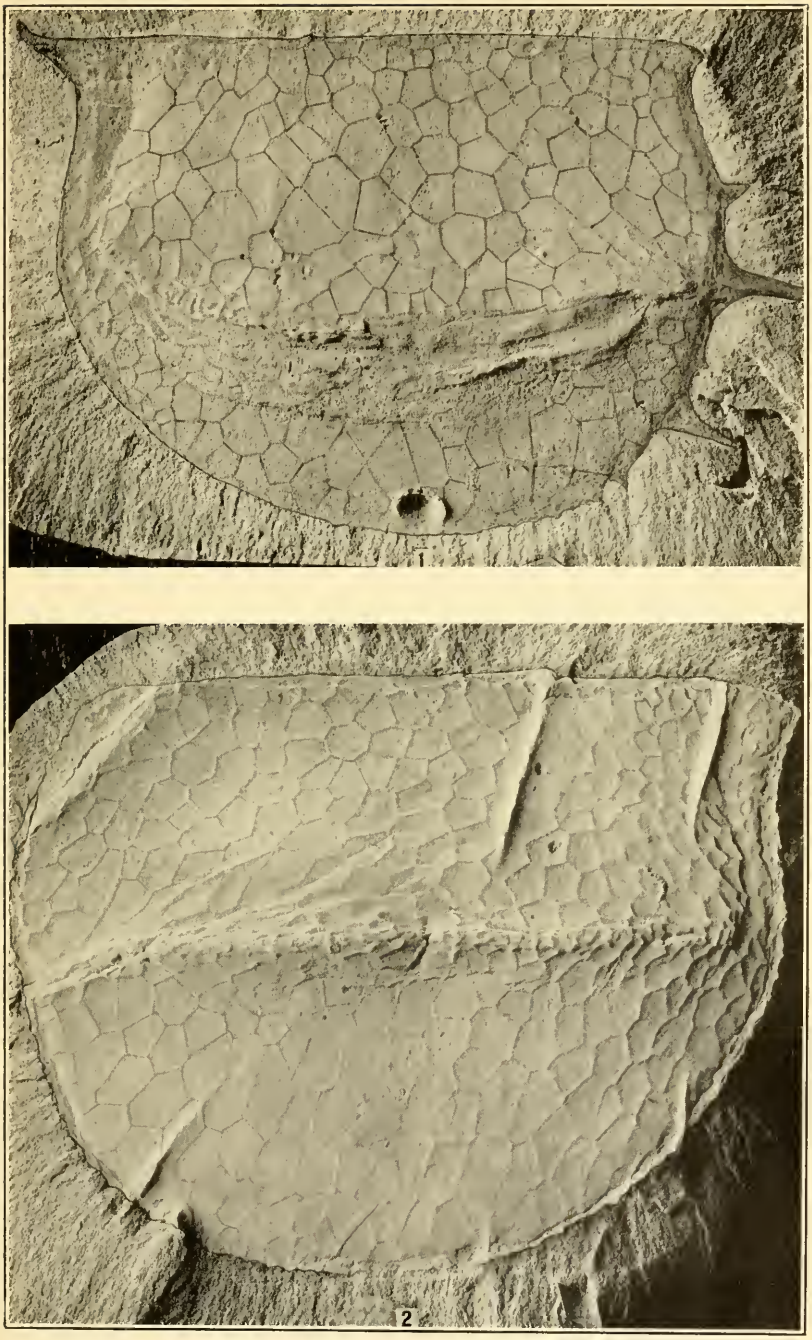
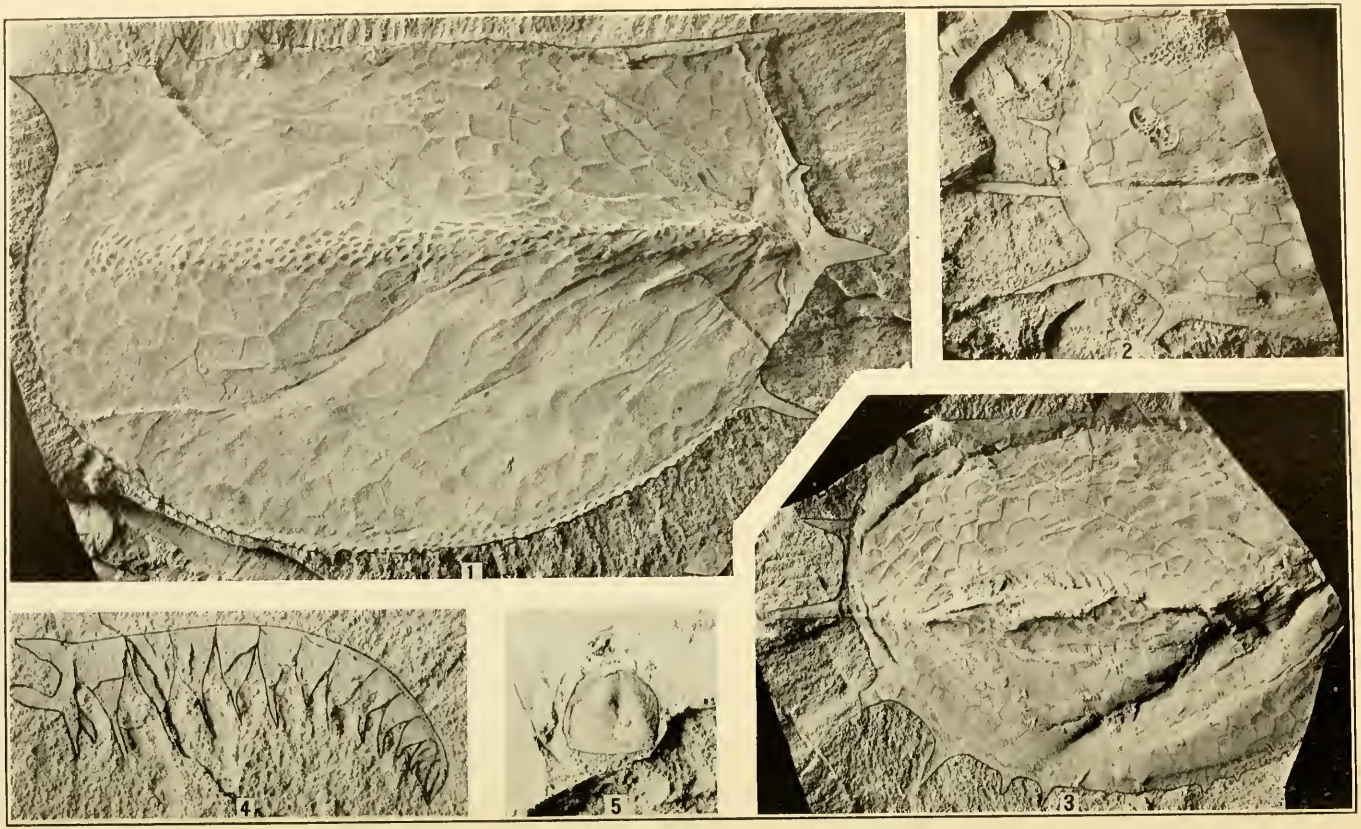


TUZOIA RETIFERA WALCOTT

FOR EXPLANATION OF PLATE SEE PAGE 15



MIDDLE AND LOWER CAMBRIAN CRUSTACEA

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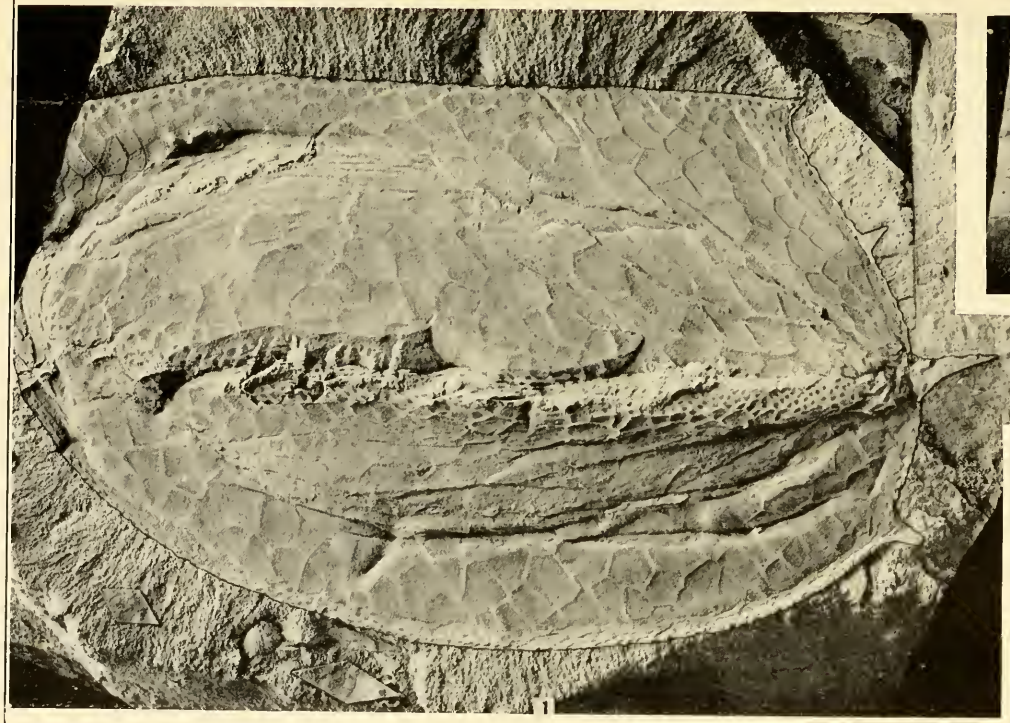

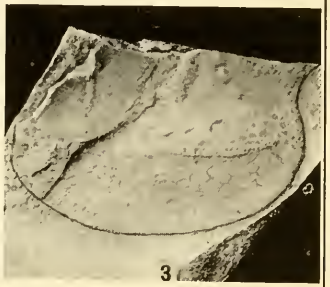

TUZOIA FROM BRITISH COLUMBIA AND MANCHURIA

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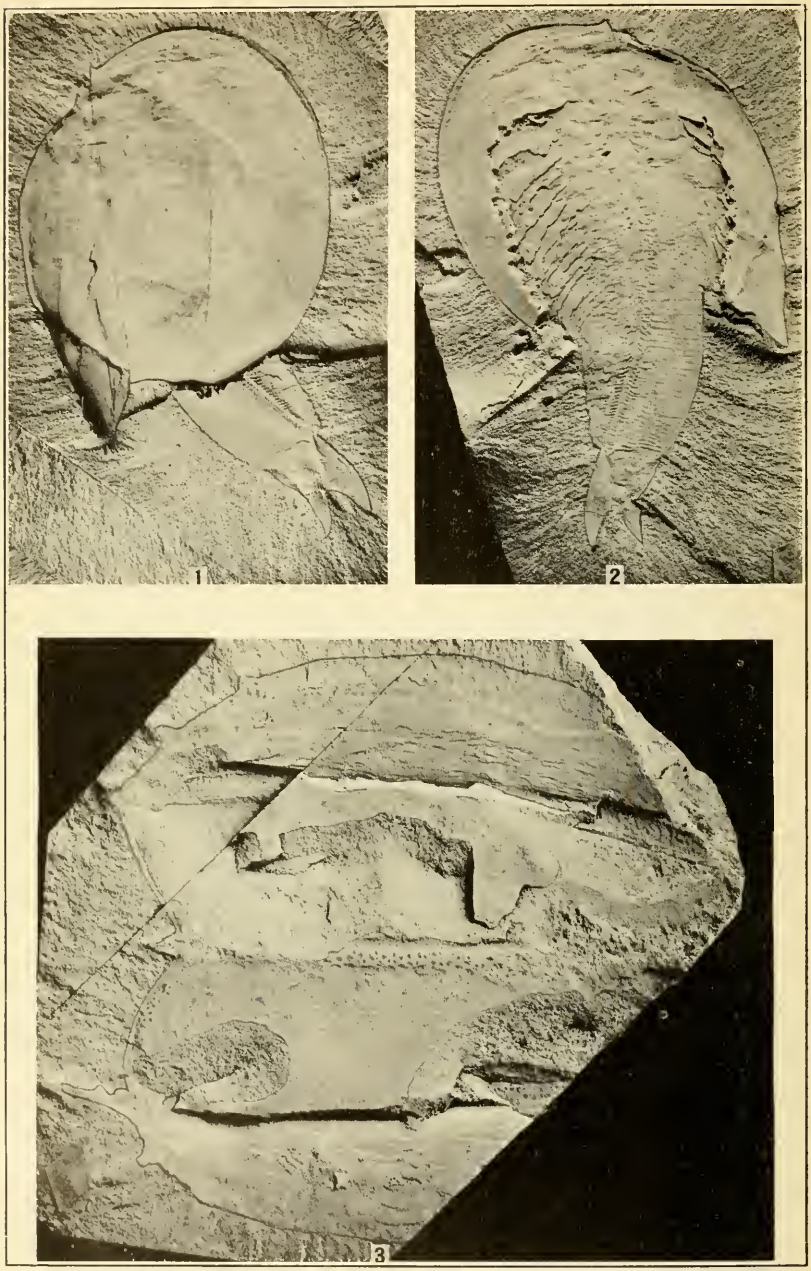

BURGESS SHALE CRUSTACEA

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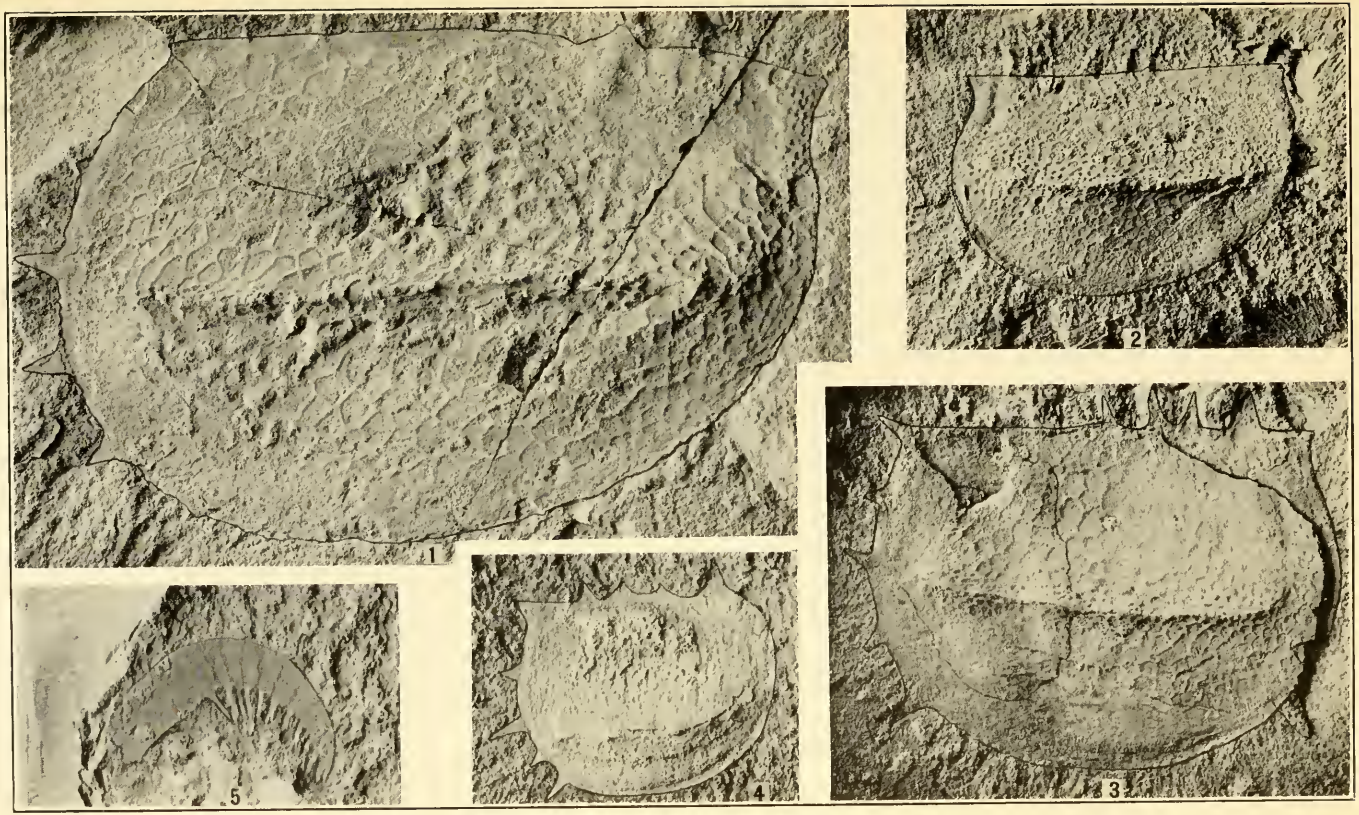
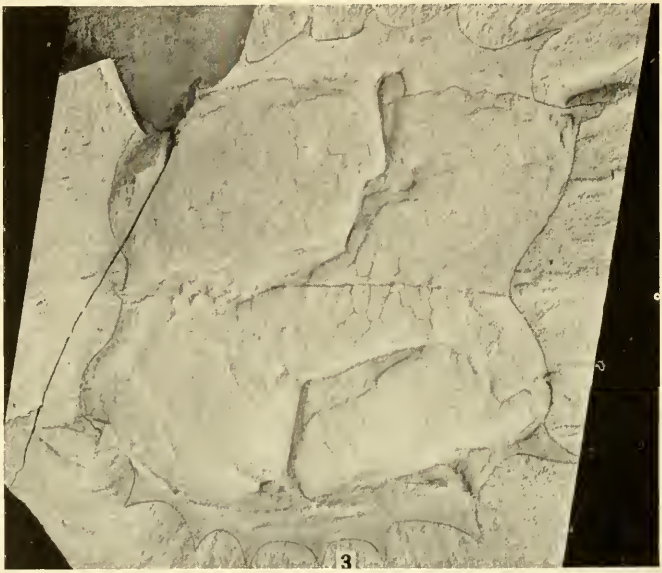


LOWER CAMBRIAN CRUSTACEA

FOR EXPLANATION OF PLATE SEE PAGES 16 AND 17



LOWER AND MIDDLE CAMBRIAN CRUSTACEA

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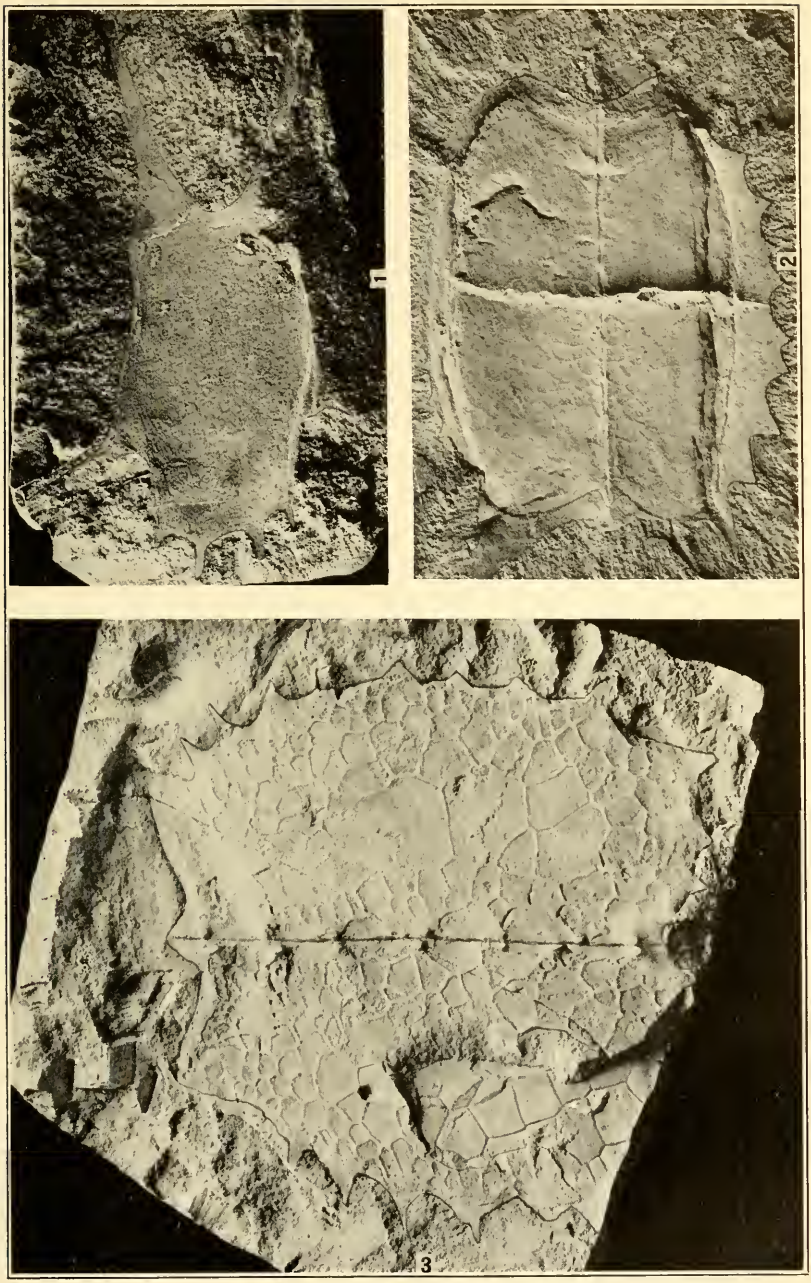

LOWER AND MIDDLE CAMBRIAN CRUSTACEA

FOR EXPLANATION OF PLATE SEE PAGES 17 AND 18