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No. 7.—NOTES ON STRUCTURE OF NEOLENUS

(With Plates 91 to 105)

BY
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By CHARLES D. WALCOTT

(With Plates 92, 94)

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ILLUSTRATIONS

INTRODUCTION

During the past twenty-five years I have published from time to time preliminary results of investigations, even though I realized that a few months' additional work might give data for more reliable conclusions and protect me from reasonable criticism. I thought it better to present the data with tentative conclusions and stimulate others to investigation rather than to wait for a time of relief from administrative duties. A recent contribution on "Appendages of Trilobites"[1] is an example of hurried investigation under pressure of many duties, also of indifferent illustration brought about by conditions incident to the great world war and my absence during publication while engaged in field-work. I regarded it as probably my last word on the subject for with a large accumulation of notes, illustrations and fossils from the Cambrian formations it did not seem probable that I would return to the subject again. When, however, my old friend, Dr. Charles Schuchert, questioned the presence of epipodites on the limbs of *Neolenus*,[2] I decided to ask three well-known invertebrate paleontologists to make a detailed examination of the material and record their opinion as to whether there was sufficient evidence to warrant the conclusion that in addition to the endopodite and exopodite of the limb of *Neolenus* there was also present another element that was clearly an epipodite. The three paleontologists, Messrs. E. O. Ulrich, Rudolf Ruedemann, and R. S. Bassler, very generously consented to make the investigation and their report under the title, "Notes on Ventral Appendages of *Neolenus*," is as follows:

NOTES ON VENTRAL APPENDAGES OF NEOLENUS SERRATUS

We, the undersigned, recognize, excluding antennules and caudal rami, three kinds of appendages in *Neolenus serratus*, namely, endopodites, exopodites, and "epipodites." Besides these there is in specimen 58580 (pl. 18) an appendage that Dr. Walcott interpreted as an endite or one of a smaller set of epipodites but which we believe to be in this specimen merely the round outer lobe of a displaced exopodite. We observed no convincing evidence of "exites" as a distinct kind of appendages. The parts shown in the upper half of figure 3, plate 20 (representing specimen No. 65515) and which seem to be the basis of the "exites" shown in diagram plate 31, we conceive as a protopodite and the next two succeeding segments of an endopodite that was displaced in such a manner as to take an anterior direction and so that it lies flat (instead of vertical as usual) in the matrix.

REGARDING DISTINCTNESS OF "EPIPODITES" FROM THE EXOPODITES

In general outline—disregarding the setiferous fringe—the two sets of appendages are essentially similar. Both consist of a larger pedunculate inner lobe and a shorter more rounded terminal lobe. The outline of the conjoined lobes is rather regularly, and on the whole gently, arcuate on the anterior side, but the opposite edge or fringed side is biarcuate with an angular indentation at the point of articulation between the two lobes. However, it is to be observed that the specimens show considerable variation in the form, or rather

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[1] Smithsonian Misc. Coll., Vol. 67, No. 4, pp. 115-216, Dec., 1918.

[2] American Journ. Sci., Ser. 4, Vol. 47, 1919, p. 231.

outline, of these appendages. This seems due mainly to differences in the angle that the relatively flat bodies held at the time of entombment to the plane of sedimentation and to consequent modifications produced by the compression in the outline which, of course, represents a vertical projection. There doubtless also was some original difference in the form and size of the bodies depending on their relative position in the animal. The size of the exopodites increases in anterior direction to the front of the thorax.

Now, as to structural differences between the two sets of appendages:

(1) In the exopodites the surface of the lobes is plain and even, but under the lens shows minute anastomosing subimbricating ("terrassen") lines with a dominant transverse direction—such as are commonly found on tests of crustaceans. No traces of such lines are observable in the epipodites.

(2) The setiferous fringe in the exopodites consists of two distinctly separate and different parts, one arising from the edge of the proximal, the other from the edge of the distal lobe. The fringe on the posterior edge of the main or larger lobe consists of long, closely approximated, now flat and laterally in contact, band-like fimbriæ or setæ, which at a minimum are as long as the width of the body of the lobe and may reach twice that length. These fimbriæ seem to have been firmly attached to the lobe and without any basal contraction or articulation, and they are smaller, hence more numerous in a given space, in the posterior than in the more anterior exopodites. At the first of the thoracic segments about 27 of these fimbriæ were counted in 10 millimeters. At the last of the thoracic segments and on the pygidial appendages the number increases to about 40 in the same space. This increase in number of fimbriæ is relative rather than absolute, being essentially proportionate to the size of the exopodite. In the epipodites the corresponding fringe consists of minute, well-separated, relatively short, cylindrical, acutely pointed spines. The maximum length of the spines does not exceed one-sixth the width of the lobe bearing them. In both the exopodites and the epipodites the fringe of setæ on the distal lobes is essentially of the same nature as that on their respective proximal lobes. However, it will be observed that in both cases the former are finer and on the exopodites also very much shorter.

(3) The surface of the epipodites exhibits no trace of the transverse inosculating lines which are generally present on the exopodites, being, so far as these wrinkles are concerned, entirely smooth under magnification. On the other hand certain structures are rather clearly indicated on the epipodites that are wholly wanting on the exopodites. Most important of these is a line of denser substance running some distance within and parallel to the margin of both lobes. On closer inspection small denticles are observed projecting from one side of this inner line. From these and other corroborating facts observed it is inferred that both surfaces of the epipodites bore two spiniferous carinæ which united on the smaller lobe. Except at these carinæ the walls of the epipodites seem to have been exceedingly thin and at least more tenuous than those of the exopodites. On account of their isolated and exposed position, not being held together like the exopodites by long overlapping fringes of setæ, and lying between the endopodites and outside the exopodites, they were much more liable to be lost.

These epipodites have been observed in only one specimen. This specimen evidently shows the lateral aspect of the legs, as proven by their curvature and the row of ventral spines on their concave sides. It also shows that the epipodites lie in the same plane with the legs, one interpolated between each pair of the latter and as they expose their broader sides must obviously have held a similarly vertical position. This inference seems almost unavoidable when we consider further that any other orientation of the leaf-like epipodites would have interfered with the movement of the legs. Again, it finds support in the fact that the marginal spines of the epipodites are found on one edge only, and this is on the ventral side the same as on the legs, which being the exposed side is where they would naturally be expected to occur.

On the other hand, the exopodites, as indicated in all of many specimens, were disposed horizontally. These two sets of appendages, therefore, were not only in separate planes, but in each segment approximately perpendicular to each other. This fact, coupled with their obvious weakness of attachment, tenuity of substance, and their isolated and exposed position would seem sufficiently to account for the relative infrequency of display of epipodites in specimens preserving appendages.

Regarding the exopodites several of the specimens suggest that the setiferous fringe is double—in other words, composed of two similar fringes, the one underlying, the other overlying the lobes of the next posterior exopodite.

(Signed by) E. O. ULRICH.
RUDOLF RUEDEMANN.
R. S. BASSLER.

June, 1919.

COMMENTS ON PRECEDING NOTES

The painstaking, thorough study made by Messrs. Ulrich, Ruedemann, and Bassler in June, 1919, led them to conclude that the difference between the exopodites and the large epipodites of the limb of *Neolenus serratus* was of such a fundamental character that the epipodites could not be considered as identical with the exopodites. After reading their notes on my return in October, 1919, from three months' absence in field-work I again examined the specimens and confirmed the conclusions given in my paper of 1918[1] and corroborated by the independent study of Messrs. Ulrich, Ruedemann, and Bassler to the effect that the ventral thoracic limb of *Neolenus serratus* has an endopodite forming a walking leg, a large two-jointed exopodite with fringes of long, slender filaments or fimbriae on the large proximal joint and fine short filaments on the small distal joint, also a large epipodite consisting of two joints resembling those of the exopodite in form but differing radically in the marginal filaments of the proximal joint, the inner lines of fine carinal spines[2] and the tenuous character of the entire appendage.

They consider that the evidence for a small epipodite in the restoration of the limb of *Neolenus serratus* is not sufficiently sup-

[1] Smithsonian Misc. Coll., Vol. 67, No. 4, 1918, pl. 20, figs. 3, 4; pl. 21, fig. 6; pl. 23.

[2] Shown in fig. 4, pl. 20 (idem), but by oversight not mentioned in text or description of plate.

ported by the one specimen supposed to show it (pl. 18, fig. 1), and in this I am in agreement. The suggestion that the flattened lobes on the sides of the specimen represented by figures 3 and 4, plate 20,[1] in advance of the endopodites and epipodites might be an exite attached to the protopodite was made only as a possible interpretation, and I cannot differ seriously with Dr. Schuchert or Messrs. Ulrich, Ruedemann, and Bassler in their conclusion that the so-called lobes (exites) represented only a protopodite and displaced segments of one or more endopodites. This is a fair interpretation of the specimen and in future restorations of *Neolenus serratus* both the suggested and so-called small epipodites and exites should be eliminated.

I here wish to express my sincere appreciation of the work of Messrs. Ulrich, Ruedemann, and Bassler, in their study of the material representing the ventral appendages of *Neolenus serratus.*

CORRECTION

In description of figure 1, plate 22, mention is made of the ends of three epipodites projecting beyond the exopodites. The removal of some of the overlying exopodites shows that the supposed distal joints of epipodites are distal joints of exopodites. The most important feature of this figure is the position of the exopodites above the endopodites which are seen projecting backward from beneath the fringes of the exopodites. This character is also shown by figures 1-3, plate 19, and figure 6, plate 21.

STRUCTURE OF THE EXOPODITE AND EPIPODITE

The unsatisfactory reproduction of most of the illustrations of the 1918 paper on the "Appendages of Trilobites" has led to the making of new photographs of what may be termed the critical specimens of the exopodite and epipodite, several of which are reproduced on plate 92 of these notes. Figure 1 represents the two upper epipodites of figure 3, plate 20, of the 1918 paper[2] as clearly as it was possible for Dr. R. S. Bassler to photograph them; in figure 2 the spines of the carinae and the fine filaments on the outer margin have been brought out in relief by darkening the background; figures 3 and 3*a* represent an attempt by Mr. L. W. Beeson, Chief Photographer of the U. S. National Museum, to bring out more definite detail of the

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[1] Smithsonian Misc. Coll., Vol. 67, No. 4, Dec., 1918.

[2] Smithsonian Misc. Coll., Vol. 67, No. 4, 1918, pl. 20.

upper epipodite of figure 1. He has succeeded in securing a little more clearness but it is practically impossible to photograph and then reproduce the original more clearly than on plate 92. Figure 4 is a photographic enlargement of the lower epipodite of figure 4, plate 20, of the 1918 paper. I have outlined the carinae and the short spines as they are indistinct in figure 4, plate 20. These figures, 1-4, show quite a different structure for the epipodite from that of figures 5 and 6 of the exopodite. The general form of the joints in the two is roughly similar as they occur flattened and somewhat distorted in the shale.

Exopodite.—The exopodites represented by figure 6, plate 92, have been shortened and transversely wrinkled by compression, and the distal lobe pushed down. I think the normal outline of the proximal joint of an exopodite was similar to that represented by figure 6, plate 21 (loc. cit.), and for the distal joints, by figure 1, plate 23 (loc. cit.). I have endeavored to represent the form of the exopodite in text figure 13 and on plate 92 of this paper.

The filaments in the compressed specimens (pl. 92, figs. 5, 6) of the large proximal joint appear to be flat with rounded ends and round or cylindrical near where they are inserted into a sheath or socket in the posterior margin; the probabilities are that in their natural condition they were rather strong, slender tubes similar in general form and function to the branchial filaments of the lobster (*Homarus americanus* H. M. Edw.) or of *Meganyctiphanes norvegica* M. Sars in which the filaments are inserted along the thin margin of the epipodite of the thoracic appendages in a manner comparable with those of the exopodite of *Neolenus*. The epipodite of *Diastylis stygia* G. O. Sars, of the order Cumacea has branchial lamellae of a somewhat similar form.

The filaments of the distal joints are inserted along the ventral and outer margin. They are proportionally much shorter and more slender and needle-like than those of the proximal joint and are more like the slender spines that occur on the ventral edge of the joints of the endopodite.

The proximal joints of the exopodites of figure 6, plate 92, have been shortened and transversely wrinkled by lateral compression, and they also give the erroneous impression that the sheaths of the filaments extended nearly across the joint.

A diagrammatic outline of a portion of the body and filaments of a proximal joint of an exopodite is shown by text figure 11.

Epipodite.—The specimens of the epipodite of *Neolenus* were thoroughly studied by Messrs. Ulrich, Ruedemann, and Bassler, and much additional information is recorded in their report. During my recent examination a fortunate view by reflected light brought out the interesting fact that the marginal setae or spines of the proximal joint were inserted in the margin at the point of projection of the minute fluting of the margin, and that they were not spinous extensions of the exoskeleton of the epipodite. The fine spines or setæ of the "carinæ" are not as well preserved as those of the ventral margin nor is the character of their insertion in the exoskeleton known or indicated. It may be that they were inserted in

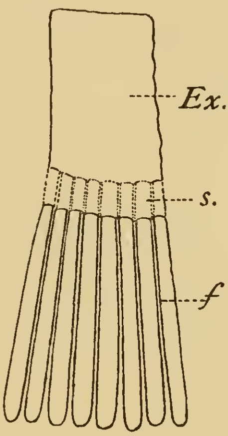

Fig. 11.—Diagrammatic outline of a portion of a proximal joint of a thoracic exopodite of *Neolenus*. *Ex* = body of joint; *s* = sheath into which the filaments (*f*) are inserted.

the same manner as the row of fine spines or setae crossing some of the endites of the trunk limbs of *Apus cancriformis*.

The fine spines or filaments on the lower (ventral) border of the proximal joint appear to be similar in form to those of the margin of the flabellum of the seventh trunk limb of *Apus cancriformis* or of the gill lobe of the second limb of *Apus lucasanus*. These resemblances are merely suggestive, but they assist in the interpretation of the fossil specimens.

The filaments or spines of the distal joint are long, fine and closely set in along the ventral and outer edge. They appear to be proportionally finer than the filaments of the distal joint of the exopodite.

A diagrammatic outline of a portion of the proximal joint of one of the epipodites is given in text figure 12, also a vertical section of the same; whether there were "carinæ" on both sides of the epipodite as on the endites of *Apus cancriformis* is not fully determined, but they are so represented on the restoration (fig. 12*b*).

The natural side outline of the epipodite is unknown but it was probably not very unlike that of the upper one of figure 1, plate 92. There is no evidence that this specimen has been distorted by compression or movement within the matrix; it has been flattened to a thin film as have nearly all specimens in the Burgess shale.

Comparison of exopodite and epipodite.—As already stated, the exopodite and epipodite of *Neolenus* have the same general form and if the filaments on the two were similar and the exopodite showed

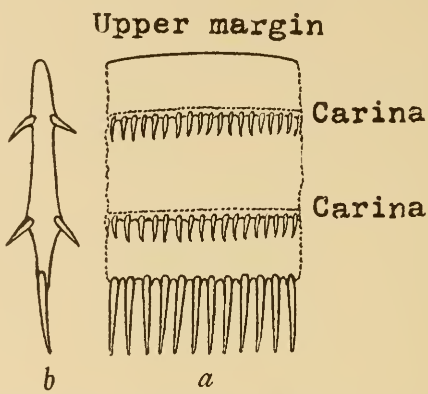

FIG. 12.—(*a*) Diagrammatic outline of a portion of the proximal joint of the epipodite of *Neolenus*. (*b*) Vertical section of fig. 12*a*.

traces of the presence of "carinæ" similar to those of the epipodite there would be no question raised as to the identity of the epipodites shown by figures 1 and 2, plate 92, and the exopodites shown by figure 6, plate 21, and plates 22, 23 of the 1918 paper. In addition to the epipodites being proportionally somewhat smaller and shorter, the fringing filaments of the epipodites are quite dissimilar. It has been suggested that the strong filaments of the exopodite have been broken or pulled off from joints of the specimen, represented by figure 1, plate 92. (See also figs. 3 and 4, pl. 20, of the 1918 paper.) A study of the fringing filaments or spines of the epipodite clearly shows that they are inserted in the margin of the exoskeleton at the crests of the fluted margin (text fig. 12) and that the large filaments of the exopodite are inserted between the crests (text fig. 11) and almost touch each other at the points of insertion. In my notes of the 1918 paper I did not pay attention to the details of structure of

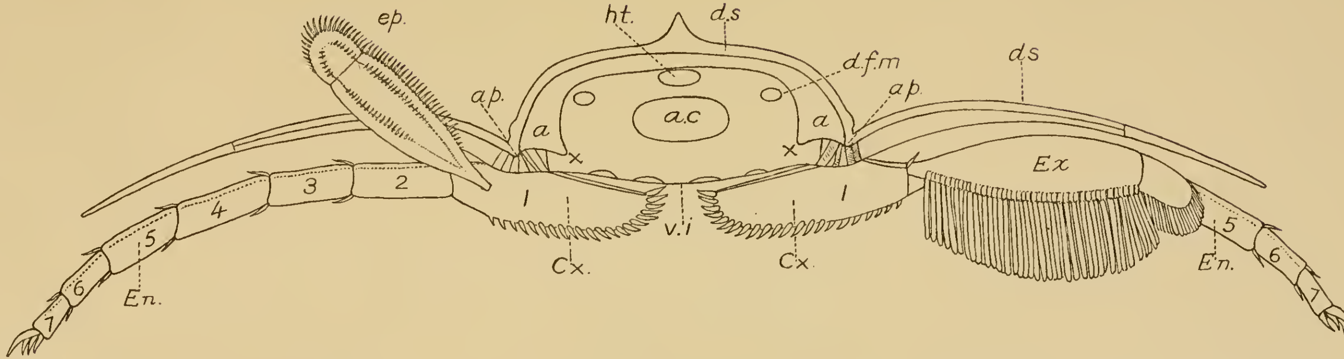

FIG. 13.—*Neolenus serratus* Rominger. *d. s.* = dorsal test. *a.* = articular fold and process at *x*. *a. p.* = axial process. *v. i.* = ventral integument. *a. c.* = alimentary canal. *ht.* = position of heart. *d. f. m.* = dorsal flexor muscle. *cx.* = coxopodite. *en.* = endopodite formed of six joints attached to coxopodite. *ep.* = epipodite attached to coxopodite. *ex.* = exopodite probably attached to side of basipodite (second (2) joint).

Both epipodite and exopodite are represented in an unnatural position; the epipodite may have been turned down but the fringed exopodite was undoubtedly subparallel to the ventral surface of the pleurosternites and above the endopodites. The epipodite is attached to the coxopodite and the second joint (2) basipodite supports the exopodite or the two latter are united at or near the point of union with the distal end of the coxopodite.

The articular fold (*a*) and process (*x*) are only cut across when the section is transverse to the axis of the tergite and along its anterior margin. In figure 13 both the articular fold and the dorsal test of the transversely median line of the tergite are shown, although they cannot both be cut by the same transverse line. See text figure 16, p. 384.

This is a posterior view of a transverse section of the thorax. The fine spines of the epipodite should be on the lower margin in the figure. (See text fig. 14.)

the fringing filaments of the exopodite and epipodite as it seemed so clear that the two were dissimilar, as shown by the figures on plates 20, 21, 23, that I decided to let the illustrations tell their own story.

There are a number of specimens showing the exopodites and there is not one that shows evidence of a spinous "carina" or of fringing filaments broken away from the margin of the large proximal joint so as to give anything like the appearance of the short marginal setæ or spines of the proximal joint of the epipodite.

Transverse section of the thorax of Neolenus.—Text figure 13 is a restoration of a posterior view of the appendages of the thorax of *Neolenus* differing from that published in 1918[1] in the omission of the small hypothetical exite and the small tentatively assumed epipodite; there are also changes of detail in the exopodite and epipodite. The interior boundary lines of the exopodite that were introduced by the draftsman and overlooked have been omitted and the character of the spines and filaments more clearly defined.

Diagram of thoracic limb.—The thoracic limb shown by the diagrammatic outline of text figure 14 follows the interpretation of the limb given in figure 13. The limb is straightened out so as to present the ventral side of the coxopodite and endopodite; the filaments of the exopodite are above the dorsal side of the endopodite and the epipodite is flattened out so as to show its outline and "carinal" spines. The exact points of attachment of the exopodite and epipodite have not been determined, but I think they are approximately as represented in figures 13 and 14, and on plate 92.

Diagrammatic ventral view of the appendages of Neolenus.—The figure on plate 94 is drawn on the same base as the restoration on plate 31 of the 1918 paper. The latter being unsatisfactory both in drawing and reproduction, a new figure has been prepared in which the small epipodite and exite of the former figure have been omitted for reasons already given (ante p. 369), and the coxopodites, endopodites, and large epipodites represented so as to give a clear view of each in approximately their supposed natural position. The endopodites are removed on the right side from six of the thoracic limbs so as to show the exopodites with their fringe of filaments projecting backward and overlapping; two of the cephalic limbs have an exopodite attached, the other two and those of the postero-cephalic limbs being omitted in order to avoid confusion; the two exopodites on the cephalic limbs probably extended outward on a

[1] Smithsonian Misc. Coll., Vol. 67, No. 4, 1918, pl. 18, fig. 2.

line with the endopodite, but they are represented as extending forward in order to bring them out more distinctly.

Six epipodites are represented on the left side, those of the other

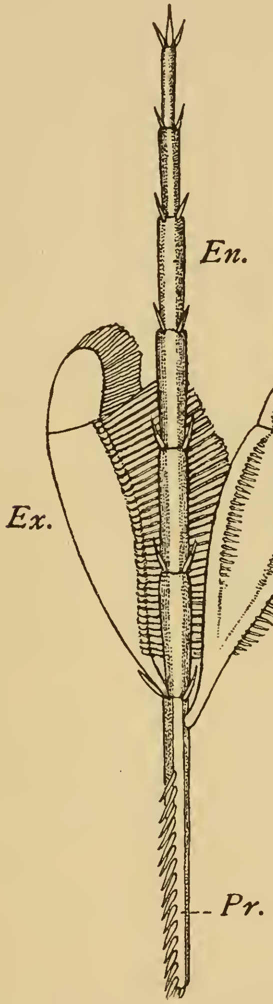

FIG. 14a.—Cross section of joints 1-5.

FIG. 14.—Diagrammatic outline of a thoracic limb.

limbs being omitted. In a natural state the epipodites were probably situated above the endopodites and exopodites.

Exopodites of Marrella.—The filaments of the anterior exopodites of *Marrella splendens* Walcott[1] are similar in form to those of the

[1] Idem, Vol. 67, No. 4, 1918, p. 140.

exopodite of *Neolenus serratus* (Rominger), and appear to be arranged along the margin of the joints in the same manner. These will be further illustrated and described in a paper following this, which it was my intention to publish as Number 5 of this volume, but which was deferred on account of an opportunity to collect more specimens of *Marrella* during the field season of 1919. Attention is called here to the conclusion based on a large number of specimens that the so-called epipodite of the limb of *Marrella* mentioned in the paper of 1912[1] is formed of a number of exopodites with their filaments matted down together.

AFFINITIES OF THE TRILOBITES

Dr. W. T. Calman[2] in a review of my paper on the "Appendages of Trilobites" calls attention to the absence of a carapace in the trilobite as one of the most important differences from what the primitive crustacean may be supposed to have been like[3] as he considers it a reasonable conclusion that the fold must have been present in the ancestral stock of the Crustacea.

I did not discuss the affinities of the trilobites at length as I wish to consider them in connection with other crustaceans from the Burgess shale. Attention was called to resemblances between the ventral appendages of the trilobite and those of modern crustaceans not so much as indicating their affinities as to show that elements such as epipodites for instance were present both on the limb of the trilobite and that of Anaspides.

The number of cephalic appendages for *Calymene* was fairly well determined by Walcott in 1881[4] from sections cut through the head, and determined conclusively for *Triarthrus* by Beecher in 1895[5] and inferentially for *Neolenus* by Walcott in 1918.[6]

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[1] Smithsonian Misc. Coll., Vol. 57, No. 6, 1912, pl. 26, fig. 4.

[2] Geol. Mag., London, Vol. 6, Dec. 6, 1919, pp. 359-363.

[3] Idem, p. 363.

[4] Bull. Mus. Comp. Zool., Vol. 8, 1881, p. 201, pl. 1, and restoration pl. 6.

[5] American Geol., Vol. 15, pp. 93-98, pl. 4.

[6] Smithsonian Misc. Coll., Vol. 67, No. 4, 1918, p. 127, pl. 16.

SUPPLEMENTARY NOTES

(WITH PLATES 91, 93, 95-105)

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The preceding notes were held in page proof during my absence in the Canadian Rockies during the field season of 1920 in hopes that trilobites with attached appendages might be found, but not a fragment of an appendage was seen. In this connection it may be of interest to state that I have collected only fourteen specimens of *Neolenus*[1] with more or less well preserved ventral appendages. It is, therefore, not surprising that it has not been possible to work out complete details of structure, or that there should be differences of opinion in relation to the interpretation of some of the specimens. To those who can do so we extend an invitation to visit the National Museum and study the specimens of *Neolenus*. The Beecher material of *Triarthrus* at the Peabody Museum, New Haven, Connecticut, and the Walcott material of *Ceraurus* and *Calymene* at the Museum of Comparative Zoology at Cambridge, Massachusetts, are also accessible to students.

On my return from the field in October, 1920, I learned that a memoir on the structure of the trilobite, by Dr. Percy E. Raymond, was in press. This caused me to still further delay publication, in the hope that some new evidence might be presented by Raymond. A copy of the memoir was received in January, 1921.[2]

[1] Throughout these supplementary notes when the genera *Neolenus, Calymene, Ceraurus,* and *Triarthrus* are mentioned, the species referred to are as follows: *Neolenus serratus* Rominger, *Calymene senaria* Conrad, *Ceraurus pleurexanthemus* Green, and *Triarthrus becki* Green.

[2] The Appendages, Anatomy and Relationships of Trilobites. Mem. Conn. Acad. Sci., Vol. VII, 1920.

On application to Dr. Samuel Henshaw, Curator of the Museum of Comparative Zoology, he generously permitted Dr. Raymond to send me all of the Walcott sections of *Calymene* and *Ceraurus*, which has given me the opportunity to complete the study of the slides abandoned in 1918, and to make an unusually fine set of photographs some of which are illustrated on plates 97, 100, 103 of these notes.

Dr. Schuchert very kindly sent me the Beecher types of *Triarthrus becki* for reexamination and photographing, and I may at a future time have some of the photographs reproduced along with new material that may be available.

In the preparation of the photographs I have been greatly indebted to the cordial cooperation and skill of Dr. A. J. Olmsted, Chief Photographer of the U. S. National Museum. Miss Frances Weiser has carefully redrawn in ink all my pencil sketches, and Mrs. Walcott has touched out many bright spots on the photographs caused by the light reflecting from sections of minute crystals of calcite.

THE RAYMOND MEMOIR

This is a fine contribution and gives evidence of prolonged, thorough study, keen observation, and a comprehensive grasp of detail and the broader aspects of the subject. Students of the crustacea may or may not agree with Dr. Raymond's conclusions on the "Relationship of the trilobites to other Arthropoda" and "that the trilobite is the most primitive of the arthropods," but they will find the memoir presents the evidence known to him and his interpretations and generalizations with unusual clarity of statement and illustration.[1]

This elaborate memoir clearly indicates how little we really know of the detailed structure of the trilobite, the small amount of material available for study, and what a splendid opportunity there is for the tireless investigator who will search the Paleozoic rocks of the world for exceptional layers in deposits like those of the Burgess shale, Utica shale and Trenton limestone.

The memoir needs an index despite its rather full table of contents. It would also be more convenient for reference if the descriptions of the figures on the plates each had a page reference to where they are described or mentioned.

[1] After studying the typical specimens of *Neolenus serratus* Rominger in which ventral appendages were preserved, Dr. Raymond wrote me under date of February 22, 1919, and sent sketches of his interpretation of the specimens, which is essentially the same as that given in his memoir.

I shall now comment upon a few of Raymond's observations and illustrations in order to present to the student a slightly different point of view of them.[1]

Epipodites.—In the preceding pages (pp. 366-374) reference is made to the large epipodites of *Neolenus,* the evidence for the existence of which was not satisfactory to Raymond, but which is so to Messrs. Ulrich, Bassler, Ruedemann, and Walcott. Raymond's diagrammatic outlines of the "so-called epipodite" (fig. 4, p. 26) (specimen No. 65515) was evidently drawn from the upper appendage shown by figure 1, plate 92 of these notes. He failed to recognize, or at least to indicate in his drawing, the well marked line of union of the proximal and distal joints, the two carinæ with their fine spines, and that the spines on the ventral margin were unlike the strong slender branchial tubes (filaments) of the exopodite (pl. 92, fig. 5).

Raymond's diagrammatic outline, figure 3, page 26, was probably drawn from the exopodite near the center of the specimen represented by figure 6, plate 92 of these notes. His statement that the fine "setæ"[2] of his figure 4 represent fragments of the "setæ" similar to those of the proximal and distal sections of figure 3, clearly indicates a confused conception of the nature of the branchial filaments of the exopodite and the fine slender spines of the epipodite. The character of the branchial filaments of the exopodite is shown in figure 5, plate 92, and text figure 11, page 371, and my interpretation of the delicate spines of the epipodite by figures 2 and 4, plate 92, and text figure 12, page 372 of these notes.

Raymond in his memoir agrees with the view of Messrs. Ulrich, Bassler, and Ruedemann (ante p. 366) that there is insufficient evidence to establish the presence of the small epipodite and the suggested exites of Walcott, in *Neolenus* and with Schuchert in objecting to the presence of the so-called exites and all epipodites large

[1] Throughout these supplementary notes reference to plates 91 to 105 is to plates accompanying this paper.

Walcott 1881 refers to paper published in 1881, Bull. Mus. Compt. Zool., Vol. VIII, No. 10.

Walcott 1918 refers to paper published in 1918, Smithsonian Misc. Coll., Vol. 67, No. 4, pp. 115-215.

Raymond 1920 refers to Dr. Raymond's Memoir, Conn. Acad. Sci., Vol. VII.

[2] Dr. Raymond uses the term "setæ" for the lamellar elements of the exopodites. Dr. W. T. Calman (Geol. Mag. Vol. VI, 1919, p. 361) in reviewing Walcott's paper of 1918 calls attention to his use of the term and suggests that "the form of the elements is very different from that usually indicated by the term setæ."

or small. His restorations of the ventral surface of *Neolenus* consequently omit the large epipodites recognized by Walcott and Messrs. Ulrich, Bassler, and Ruedemann.

Articular socket.—Figure 2, page 24 of Raymond is an outline sketch of two of the endopodites of *Neolenus* (specimen No. 58589) in which a notch is noted (in the figure) on the lower margin of the outer end of the proximal joint (coxopodite) and a corresponding projection on the opposite upper margin. I did not note the "notch" when studying the specimen (No. 58589) in 1917, but I now find that it is shown in three of the limbs (text fig. 15, p. 383) at the point of union of the coxopodite[1] and basipodite. Carefully reexamining the specimen and uncovering the posterior margin of the proximal joint of the next three anterior limbs, I found on all what appears to be the "notch" or "articular socket of the coxopodite" of Raymond, where the second joint (basipodite) unites with the first joint (coxopodite), and that there is not a "notch" on the margin of the coxopodite as described by Raymond on the evidence afforded by limb marked *D* of our text figure 15 (specimen No. 58589). There is a slight thickening or irregularity on the upper or anterior margin of the coxopodite that may have been the margin of the opening for the insertion of the muscles uniting it to the axial processes[2] of the dorsal test of the axial lobe.

I have called attention to this so-called "articular socket" of Raymond, elsewhere referred to by him as a "ball-and-socket" joint (p. 126), as it appears to be the evidence that led him to reverse the natural position of the coxopodite in his restorations of *Neolenus* (figure 7, p. 30, figure 8, p. 31) so that the ventral side is uppermost and the dorsal side below, while the remaining joints of the endopodite are in a natural position as shown by specimen No. 58589 (see text figure 15) and No. 58588 (plate 93, figure 2).

Raymond states (p. 25) "Because the spines on the endobases are dorsal it does not follow that those on the endopodite were, for the position of the coxopodite in a crushed specimen does not indicate

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[1] Dr. Calman (Treatise on Zoology, Lankester, Pt. VII, 1909, p. 146) gives a diagram of a malacostracan thoracic limb in which the coxopodite and basipodite form the protopodite, and the exopodite is attached to the basipodite. As I considered that the endopodite and exopodite of *Neolenus* were attached to the long proximal joint of the thoracic appendage, it followed that I considered the proximal joint of *Neolenus* to be the protopodite and formed of a combined coxopodite and basipodite. This has led to my often using the term incorrectly.

[2] Walcott, 1875, Notes on *Ceraurus pleurexanthemus.* Ann. New York Lyc. Nat. Hist., Vol. XI, p. 162, pl. XI.

the position of the endopodite even of the same appendage." The above was written in connection with his description of specimen No. 58589, in which the coxopodites of four cephalic limbs are shown, also the attached endopodites. I have had photographs made of the coxopodites and endopodites which are reproduced as text figure 15 and figure 2, plate 91 in which it does not seem at all probable that all four of the coxopodites have been reversed although thoroughly flattened by compression in the sediment; on the contrary they are in a normal position in relation to the endopodite; the coxopodite *D* has the marginal spines finely preserved as shown by figure 2, plate 91. The coxopodites of specimen No. 58588, illustrated by our figure 2, plate 93, clearly prove their position in relation to the endopodite, and that it is the same as in specimen No. 58589 (text figure 15).

Raymond considers that he has recognized the "ball-and-socket" joint in two of Walcott's thin sections of *Calymene* (slide No. 63, figure 15, p. 53) and *Ceraurus* (slide No. 128, figure 17, p. 58). The evidence for this is very unreliable, as in many sections of both *Calymene* and *Ceraurus* a hollowing out occurs where any projecting point approaches closely to a fragment of what was a portion of an appendage or a filling of the visceral cavity. This is shown in figure 8, plate 2, Walcott, 1881, and figure 3, 4, 5, plate 91; figure 18, plate 95, of these notes. There does not appear to be evidence either in the specimens of *Neolenus* or the sections of *Calymene* or *Ceraurus* to sustain the "ball-and-socket" joint theory.

Attachment of ventral limbs to dorsal test.—I inferred in 1881 that the coxopodite was attached to the ventral membrane by "a small round process projecting from the posterior surface of the large basal joint, and articulating in the ventral arch somewhat as the legs of some of the Isopods articulate with the arches in the ventral membrane." This incorrect view was based on several sections (Walcott, 1881, plate 2, figures 3 and 6; plate 3, figure 9; plate 5, figures 1 and 3) where a narrow extension appears to unite the appendage and the ventral surface. Other sections suggest that the coxopodites of the cephalic region were attached in *Calymene* near their proximal end (Walcott 1881, plate 1, figures 6, 7, 8) while those of the thorax were attached further out towards the distal end (Walcott, 1918, plate 26, figures 6, 7).

Walcott (1918 p. 159) wrote:

> The exact form of attachment to the ventral integument is unknown, but as stated under *Neolenus* it was probably narrow and long and connected the dorsal side of the protopodite with the ventral integument and interior supports somewhat as the limbs of *Apus* and *Limulus* are attached to the body.

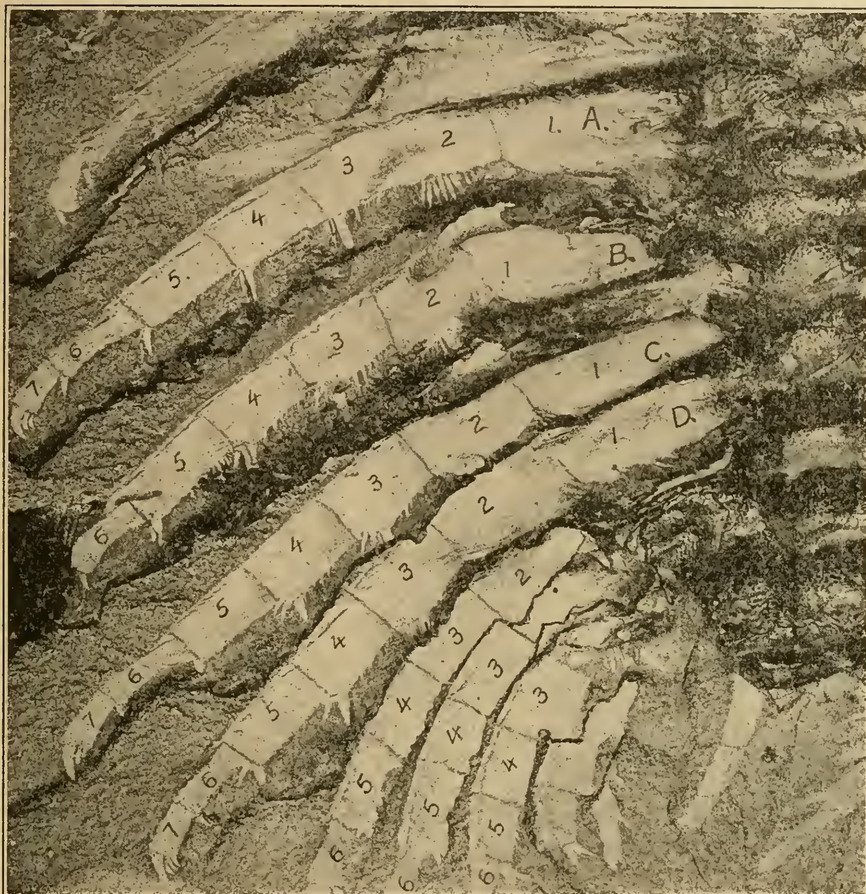

FIG. 15. (× 5) *Neolenus serratus.* This is a reproduction of a photograph of a portion of specimen No. 58589 illustrated by Walcott (1918, pl. 18) by a retouched photograph in which the coxopodites were too much "restored" by the artist. I succeeded recently in removing a little of the adhering dorsal test of the specimen so as to give a better view of the coxopodites of three of the limbs *A, B* and *C* (figure 15). These, as well as the posterior coxopodite *D,* show the notch of Raymond to be at the junction of the coxopodite (1) and basipodite (2), also that the coxopodite (1) is in a natural position in relation to the basipodite (2) and not reversed as assumed by Raymond in his restorations of *Neolenus* (figures 7 and 8, pages 30, 31). The line of the union of the ends of the joints of the endopodite and the distal end of the coxopodite are usually very distinct when seen by reflected light, but it is impossible to get all details in any one photograph as may be seen by comparing the coxopodite *D* of figure 15 with *D* of figure 2, plate 91.

A, B, C, D. Coxopodites of the four posterior limbs of the thorax.

1 = coxopodite.
2 = basipodite.
3 = ischiopodite.
4 = meropodite.
5 = carpopodite.
6 = propodite.
7 = dactylopodite.

I have not used the term appendifer proposed by Raymond (p. 20) as it does not appear to be the process to which the coxopodite of the ventral limb articulated as he supposed. In fact there are two processes, the one beneath the dorsal furrow at the union of the mesotergite and pleurotergite, and the usually more prominent one on the ventral crest of the fold formed where the articular extension of the mesotergite arches over to unite with the mesotergite (see figs. 1, 3, 4, 5, of plate 102); this latter process may be called the mesotergite process, and the one beneath the dorsal furrow the axial process. I have not seen any evidence that either process extended down to or through the ventral integument. They appear to have been points of attachment for the internal muscles and the axial process afforded

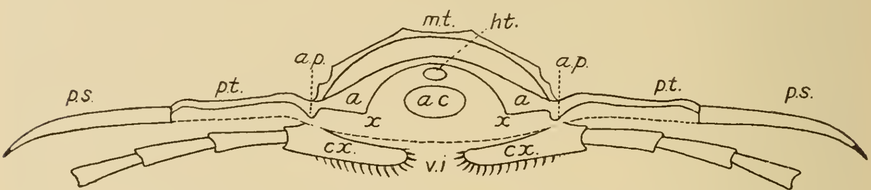

FIG. 16.—*Ceraurus pleurexanthemus* Green. Diagrammatic outline of a transverse section of thorax that cuts across the deepest part of the ventral fold of the anterior articular extension of the mesotergite. A section a little in advance or back of this would not touch the lateral downward extensions of the fold *a. a.* or the low processes on the latter at *x. x.* The axial processes *a. p.* are on the anterior margin of the mesotergite at its union with the pleurotergite *p. t.* The spinous extension of the pleurotergite is lettered *p. s.* and the mesotergite *m. t.*

The relations of the dorsal test and its ventral processes to the ventral membrane and appendages are shown by the dotted outlines. *v. m.* = ventral membrane. *cx.* = coxopodite.

a strong base for the muscles connecting the coxopodite of the ventral limb to the dorsal test. The mesotergite process was not as favorably situated and not as firmly supported as the axial process to serve as a base for the muscles of the ventral limb. A diagrammatic outline of the dorsal test and the two processes that is based on figure 4, plate 102 is here inserted as text figure 16. This illustrates at *a. p.* the axial process and at *x.* the mesotergite process, formed by the downward extension of the sharp fold of the anterior extension of the mesotergite as an articular process upon which the posterior reflexed margin of the mesotergite rests both when the thorax of the trilobite is straightened out and when it is enrolled. An outline of this structure is shown by figures 3 and 4, plate 96.

That many transverse and longitudinal sections of the thorax of *Calymene* and *Ceraurus* show a narrow attachment between the coxopodite and the ventral integument indicates that the coxopodite as well as its elongate connection with the ventral integument was when in a natural position slightly oblique to the longitudinal axis of the trilobite; this causes the peculiar subtriangular sections of the coxopodite and the narrow point of contact between it and the ventral integument. See figures 6 and 17, plate 95; figure 9, plate 99. A few slides have cut across the longitudinal line of the coxopodite and given such sections as those represented by figures 1, 3, 4, 6, 11 and 15, plate 26, Walcott 1918. Of these, figure 11 (figure 6, plate 101 of these notes) and figure 4, give the best longitudinal sections but none show clearly the point of contact of the coxopodite and the ventral integument, although it is suggested in figures 3, 4, 5 and 11, plate 26, 1918.

The ventral surface of the test of the thorax of *Ceraurus* is illustrated by figure 4, plate 102. Without such an illustration it would be exceedingly difficult to interpret the processes cut across in both *Ceraurus* and *Calymene*. Figure 5 of plate 102 also indicates the presence of strong points of attachment for muscles on the ventral side within the dorsal furrow ridge and on the axial process.

It is highly probable that the dorsal margin of the coxopodite, where the muscles passed through, was closely set into the edges of the elongate opening for the passage of muscles through the ventral integument, very much as in *Limulus*.

The genera *Neolenus* and *Isotelus* especially having almost no processes beneath the mesotergite, the muscles must have been attached directly to the dorsal test as in *Limulus,* and like the latter there must have been quite a distance between the ventral integument and the dorsal test that was largely filled in with muscles and the internal organs of the body. It is difficult to conceive of any kind of a direct joint between the proximal joint of the ventral limbs and the dorsal test.

On the basis of the above data and the known method of attachment of the limbs of *Limulus,* I venture to indicate the approximate position of the muscles that held the coxopodite of the limb of *Neolenus* in position and made it a strong, effective ambulatory leg (text figure 13, p. 373). This form of attachment to the ventral surface of the dorsal test, and in a less degree to the ventral integument, would give a strong fulcrum and the necessary firmness to enable the trilobite to use its endopodite as a walking leg and to push itself along on the surface of soft sand and mud, and to force the front of its cephalon into soft sediment when in search of food. Raymond mentions "the prowling of trilobites" around in mud in search of prey (p. 103). That some species crawled over and pushed their way into the mud and silt is beautifully shown by the records left on the argillaceous shales and sandstones of the Upper Cambrian (Walcott, 1918, plates 37-42). On many of these trails the imprint of the long coxopodites and endopodites is finely preserved (idem, plate 38, figures 3-6). It is an interesting coincidence that trilobite tracks and trails are often the most abundant on surfaces where annelid trails are most numerous (idem, plate 42, figure 3).

The processes beneath the mesotergite of *Cryptolithus tessalatus* Green are beautifully shown in some of Dr. Beecher's specimens; they are proportionally much larger than those of *Calymene* and *Ceraurus* and must have given a strong support for the muscles of the stout ventral limbs of this species.

Position of the limbs in life.—*Neolenus serratus* had a thin test, but when it is compared with the test of the king crab (*Limulus*) it has about the same thickness in specimens of the same approximate size. The test of the axial and pleural lobes of *Neolenus* was reinforced by rounded ridges and local increases in thickness that gave it strength and, when attached to the ventral integument by muscles, a rigidity that would permit of relatively great strain being applied to it without flexing or breaking. With the muscles of the coxopodite of the limbs of *Neolenus* extending through the ventral integument to the strong axial process and its base, the limb had a firm base of support and the animal could use its legs (endopodite and long coxopodite) to walk clear of the surface or push its way through the surface of soft mud or sand in search of food, or sink and emerge from it very much as *Limulus* does. Young specimens of *Limulus* with the most delicate test manage to push themselves into mud and sand so as to be nearly concealed from view, and from the study of the tracks and trails I have referred to as of trilobitic origin, it seems very probable that *Neolenus* and trilobites of a similar form had the same habits.

The position of the flat coxopodites and the flattened joints of the endopodites of *Neolenus* was probably nearly vertical with a slight backward slant; this is the position of the legs in *Limulus* and in the closely arranged limbs of *Apus,* and with a relatively slow moving, usually creeping, animal like *Neolenus, Isotelus* and allied forms, such an arrangement would not materially affect their movements by causing resistance in passing through the water when swimming. The section of the coxopodite and proximal joints of the endopodite of *Neolenus* is broad at the top, with deep, nearly straight, sides and a slightly rounded ventral edge; this gave great strength and kept the flat-lying shafts and fimbriæ of the exopodites from drifting down between the endopodites.

In considering the position of the appendages in life, one must always remember one great outstanding feature of trilobites, the thinness and flexibility of the ventral membrane. The appendages were not inserted in any rigid test but were held only by muscular and connective tissue. Hence we must premise for them great freedom of motion, and also relatively little power. The rigid appendifers, and the supporting apodemes discovered by Beecher, supplied fulcra against which they could push but their attachment to these was rather loose. (Raymond, p. 74)

Ventral integument.—Dr. Raymond (p. 50) refers to the ventral membrane of *Ceraurus* and *Calymene,* but does not discuss the work of Beecher[1] on the ventral integument of trilobites in which he describes five oblique and transverse thickenings on the mesosternites and homologizes them with apodemal structures of other crustacea, and suggests that they afforded points of attachment for the ventral muscles. If we consider the transverse arches in the ventral integument and the transverse thickening on them, it becomes apparent that the ventral integument of the axial lobe was much stronger than it is usually considered to be, and that it gave a firm base of support and the opportunity for a close articulation of the coxopodites of the ventral limbs, which were controlled by strong muscles passing from the coxopodite through the ventral integument to the ventral surface of the mesotergite and the axial process. A section of the ventral integument with the thickened sternites is illustrated by figure 4, plate 101 and figure 1, plate 105.

Notes on individual specimens of Neolenus.—Dr. Raymond has given at length the results of his study of six of the best preserved specimens of *Neolenus* that have more or less of the ventral appendages preserved. I am in accord with most of his conclusions, but will mention a few points where there is a slightly different point of view.

SPECIMEN NO. 58589 (P. 24)[2]

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 18, fig. 1; pl. 20, fig. 1; pl. 91, fig. 2; text fig. 15

This is the specimen in which Raymond discovered the "articular socket" on the coxopodite. I have spoken of this (ante p. 381) as his interpretation reverses the natural position of the dorsal and

[1] Amer. Jour. Sci., Vol. 13, 1902, pp. 165-174, pls. 4-5.

[2] The specimen numbers refers to the catalogue number in the records of the U. S. National Museum, and the page reference to the Raymond Memoir.

ventral margins of the coxopodites, although the sketch (fig. 2, p. 24) shows them in their correct position in relation to the endopodite. Since Raymond studied this specimen I have removed a fragment of the dorsal test covering a portion of the coxopodites of the two anterior to those from which he made his sketch, and am now reproducing them as text figure 15 (p. 383) of these notes. A photograph of three of the four coxopodites and attached endopodites is illustrated by figure 2, plate 91, where on coxopodite *D* the proximal and ventral spines are shown; also see figure 2, plate 93, for relation of coxopodites and the endopodites. I think Raymond is correct in interpreting the small epipodite of Walcott as probably the terminal portion of an exopodite as I have already mentioned (ante p. 369).

If I understand the position of the "notch" that Raymond mentions as occurring on the coxopodite (our text figure 15 and figure 2 of plate 91), his measurement of the length of the coxopodite is 1.5 mm. too long, as the union of the coxopodite and basipodite was at the notch and not 1.5 mm. out from it.

SPECIMEN NO. 65514 (P. 26)

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 19, figs. 1-3

This is the specimen mentioned by Walcott (1918, p. 185, description of figure 3) as having two large epipodites. There are no epipodites shown on it or in the figures of it, nor is it mentioned in the text. I must have, as Raymond suggests, considered the ends of the exopodites as the ends of the epipodites; this occurred when writing the description of the plate figures.

SPECIMEN NO. 65519 (P. 27)

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 21, fig. 6

The exopodites of this specimen may be in a natural position but there is no certainty of it, as the fragments of the endopodites beneath the cephalon have been crowded forward and very much displaced.

SPECIMEN NO. 65520 (P. 27)

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 22, fig. 1

Raymond mentions the "low rounded appendifers at the anterior angle of each axial tergite." A close inspection and the study of other specimens in which the slender axial processes are preserved, indicates that the latter have been broken off from all of the downward projecting rounded bases situated on the ventral surface of the mesotergites of this specimen at their anterior margin and directly beneath the dorsal furrow. A low rounded ridge crosses each mesotergite at its point of union with the pleural extension of the segment, and an interior oblique ridge, corresponding to the pleural groove of the dorsal surface, merges into the base of the axial process, as does the rounded transverse ridge on the anterior margin of the axial segment, thus giving a strong rigid support to the base of attachment of the muscles extending from the coxopodite of the ventral limbs to the axial process of the dorsal test and the immediately adjoining surface of the mesotergite. The axial process is slender and slightly inclined into the axial lobe but not as much so as that of *Ceraurus;* it is as Raymond states, more rounded in the pygidium of this specimen but this is probably owing to the condition of preservation of this particular specimen.

The exopodites on the right side have been very much compressed and all bent forward and crowded to the right. Walcott considered that the distal ends of three epipodites projected from beneath the exopodite on the right side, but this is doubtful, and I accept Raymond's view that they are probably the distal joints of three of the exopodites.

SPECIMEN NO. 65515 (P. 28)

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 20, figs. 3, 4; pl. 92, fig. 1, 2, 3, 3*a*, 4

The appendages of this specimen have been described and discussed by Messrs. Ulrich, Ruedemann, and Bassler (ante pp. 366-368), and I have agreed to their opinion that the so-called exites of Walcott are not what I interpreted them to be. This is also the view of Raymond, and he also eliminates the epipodites, considering them to be merely exopodites without the fimbriæ. The specimen is a difficult one to photograph and to study, but on our plate 92, figures 1, 3, 3a, the attempt is made to reproduce the epipodites as photographed, also for comparison the exopodites of specimen No. 65521. It is unfortunate that Raymond did not make photographs of this and other critical specimens and reproduce them, as Walcott's figures of 1918 are nearly all badly reproduced. They should have been originally reproduced by the photogravure or similar process, but the war time cost was prohibititive. The exites of Walcott (1918, plate 20, figures 3, 4) appear to be the coxopodites of three of the ventral limbs, the anterior of which has attached to it the basipodite; the coxopodites have been shortened and compressed to a thin film.

SPECIMEN NO. 65513 (P. 30)

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 16, figs. 1, 2

The limbs, coxopodites and endopodites of this specimen all appear to have been crowded over from the left to the right side so as to be in reverse of their natural position; two of the legs are above and the two posterior beneath the exopodites. Whether they are "cephalic legs" as stated by Walcott (1918, description of fig. 1, plate 16) or thoracic appendages, cannot be determined. The displacement is not unlike that of the appendages of specimen No. 65514, as shown in the upper part of figure 3, plate 19, Walcott 1918.

There are a few other specimens worthy of notice as my observations in the paper of 1918 are too general to be of service in a review of the structure of the appendages of *Neolenus*.

SPECIMEN NO. 58588

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 15, fig. 1; pl. 17, fig. 3; pl. 91, fig. 1; pl. 93, figs. 1, 2

This slab, with its two fine trilobites preserving both thoracic and pygidial appendages, is of great interest. The upper one of the two specimens shown on plate 15 (1918) is the matrix, but our figure 1, plate 91, is a photograph of the trilobite itself with ventral appendages projecting from beneath or exposed by the exfoliation of the dorsal test.

Only a few traces of the exopodites remain and in these the fimbriæ are matted and rolled together in an indistinguishable, fibrous, cord-like appendage on the right side and widely but faintly distributed over the surface on the left side. The coxopodites and endopodites on the right side have been displaced and pushed outward and slightly backward so as to bring the proximal end of the coxopodite almost beneath the dorsal furrow; only a fragment of an endopodite projects from beneath the left side. The backward displacement of the appendages has brought eight of the legs opposite the pygidium, of which the five posterior belong with the pygidium. The sixth and seventh thoracic segments have been crowded into each other with the result that of the limb opposite the seventh axial segment of the thorax, only the broad shaft of the exopodite is partly preserved, the endopodite having been either torn away or pressed deep into the sediment and lost to view. Counting this lost leg, the three thoracic legs opposite the pygidium, and three of those opposite the thorax, we have seven thoracic legs, or one for each segment. There is a leg opposite both the first and second axial thoracic segments and the occipital segment of the cephalon, and one in advance of it, the proximal end of the coxopodite of which touches the dorsal furrow beside the glabella a little in advance of the occipital segment. The total is sixteen endopodites or legs, or one for each segment of the pygidium and thorax, and four for the cephalon, a fifth pair of cephalic appendages being represented by the long slender antennules. This is the only specimen thus far found of *Neolenus serratus* that has as large a number of the ventral limbs so nearly in their natural position. The fact that the ventral integument and limbs have been squeezed out and shifted to the right and slightly back from their natural position indicates that the muscles holding the appendages and integument in position had sloughed off under pressure; the marvel of it is that the coxopodites and endopodites held together so well.

After studying the specimen I found that the coxopodites and the proximal joints of the endopodite were in echelon with the ventral margin of each limb passing beneath the anterior dorsal margin of the next posterior limb. I then began to remove the covering anterior margin of some of the limbs so as to expose the ventral margin of the next anterior limb; this resulted in bringing into view several coxopodites and basipodites with their spinose ventral side. and what was of greater interest, the fact that the spinose margin of the coxopodite in undisturbed complete limbs was on the ventral side as in the basipodite and other joints of the endopodite, thus fully corroborating the evidence of specimen No. 58589, represented by our text figure 15 (see plate 91, figure 2). There is not any evidence of an "articular socket" on any of the coxopodites of specimen No. 58588, but the supposed "notch" of Raymond occurs on the ventral margin of several limbs at the union of the coxopodite and endopodite. Two of the cephalic limbs preserve the six joints of the endopodite and the coxopodite (figure 1, plate 93) in their natural relation to each other; the coxopodite is slightly shorter than that of the thoracic limb, and the entire limb is slightly shorter and smaller as indicated by the following measurements in millimeters.

	Cox.	Bas.	Ischi.	Mer.	Carp.	Pro.	Dactyl.	Total
Cephalic limb (2d) ..	8.	4.5	4.	4.	4.	2.75	2.	29.25
Thoracic (4th)	9+	4.5	3.75	3.75	4.	3.	2.5	30.5
Pygidial (2d)	4+	3.	2.5	2.5	3.5	2.5	1 75	19.75+

The ischiopodite and meropodite of the pygidial limb may have been shortened by compression and the carpopodite lengthened a little, but in all the limbs there is always a possibility of a slight distortion of the joints by compression; as a whole, however, they retain their form and proportions in a surprisingly accurate manner.

The enlarged figures on plate 93 bring out in fine detail the endopodites of *Neolenus*.

SPECIMEN NO. 57656

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 17, fig. 1

In the description of figure 1, plate 17, it is said that the caudal rami have been dragged backward, pulling with them a portion of the under edge of the body cavity. While this may be correct in part, the edge of the supposed body cavity or ventral integument is probably a displaced coxopodite with four joints of the endopodite on the right side and a fragment of a coxopodite with a joint of the endopodite on the left side.

SPECIMEN NO. 65521

Smithsonian Misc. Coll., Vol. 67, 1918, pl. 23, fig. 1

This is the ventral side of the test with the limbs partially preserved on the right side so as to show the ventral side of the outer portion of a number of the exopodites and a few of the endopodites. Walcott (1918, description of figure 1, plate 23) considered that the distal lobes of some of the larger epipodites were preserved, but I now agree with Raymond that there is not good evidence for this, and that the distal lobes are those of exopodites. The anterior exopodites on this specimen have their fimbriæ finely preserved, as is shown by figure 5, plate 92, of these notes.

Restoration of ventral surface of Neolenus.—The theoretical transverse section by Raymond of a thoracic segment and appendages (fig. 7, p. 30) has the coxopodite of the limb articulating with the downward projecting axial process (appendifer). The spine-bearing ventral side and curved proximal end of the coxopodite is represented in a dorsal position, which reverses the position of the coxopodite in specimen No. 58589 (our text figure 15, and figure 2, plate 91) both in relation to the dorsal test and the joints of the endopodite. In the Raymond restoration of the ventral surface (figure 8, p. 31) the coxopodites of the cephalic region are represented with the spinose ventral side sloping downward and forward with the shaft of the exopodite attached to the ventral side of the endopodite, as in figure 7, or, as I interpret the sketches, the coxopodite is drawn in its normal position beneath the cephalon in figure 8, and upside down in figure 7.

The restoration of the ventral surface of *Neolenus* by Raymond is most effective, as it shows the broad side of the coxopodite and endopodite, it being understood that both are in an unnatural position. The exopodites are diagrammatic but with their very deep (broad in the figure) proximal end joining the coxopodite, those of the thorax and pygidium must be in an artificial position. My impression is that the proximal end of the exopodite was a narrow rounded shaft as in our figures 13 and 14, pages 373, 375; for if it were flat and as deep as Raymond shows it, and attached to the deep, flat basipodite, it would be impossible for the exopodite with its flat, broad shaft and long fimbriæ to lie flat or horizontal above the endopodites without breaking away from the proximal end of the basipodite. If, on the contrary, it was attached to the limb in about the same manner as the exopodite of the first thoracic limb of *Anaspides tasmaniæ* G. M. Thomson (Walcott, 1918, plate 35, figure 2) it would have had the position and flexibility essential to its functioning effectively.

The position of the coxopodites in figure 8, page 31, is somewhat puzzling, as those of the cephalon are evidently intended to show the spiniferous margin as ventral and sloping forward, while those of the thorax and pygidium suggest that the spiniferous margin is dorsal and projecting forward. This position is also suggested by the position of the outline of the "articular socket" on the anterior margin near the distal end of the coxopodite.

Attention should be called here to the position of the basal joints of the thoracic limbs of *Apus* (Walcott 1918, plate 36, figure 4), which slope forward when viewed from the ventral side and have the spines on the ventral side and proximal end. I do not recall a crustacean limb that has a series of sharp spines on the dorsal side of the coxopodite or endopodite.

Raymond has inserted a metastoma and crowded the two anterior cephalic appendages against the posterior end of the hypostoma; this may be correct but as long as we have no evidence in *Neolenus* to base it upon it may be misleading.

In my restoration, plate 94, I have omitted the small epipodites and exites of the restoration of 1918 (plate 31), brought the inner ends of the gnathites of the cephalic limbs closer together and made a single round anal opening as the double opening of the 1918 restoration was based on a specimen (No. 58588) that a recent photograph shows to have been imperfect at that place. I have been misled a number of times by the effect produced by the direction from which the light strikes this specimen and also others when too hastily studied.

NOTES ON CERAURUS, CALYMENE, AND TRIARTHRUS BECKI

Illustrated on pls. 91, 95-103

Translucent sections cut from both *Ceraurus pleurexanthemus* and *Calymene senaria* show the alimentary canal, what may have been the heart and the main flexor muscles, and more or less of the outlines of the ventral integument and appendages.

The slides of *Calymene* will be arranged in their numerical order, and those of *Ceraurus* will follow. Most of the slides illustrated are described but a few are so simple that they are referred to only in the description of the figures on the plates or in the general text.

Unless otherwise mentioned all the slides are in the collection of the Museum of Comparative Zoology, Cambridge, Massachusetts.

CALYMENE SENARIA Conrad

Slide No. 5, M. C. Z. (plate 98, figure 6). Transverse section of a partially enrolled *Calymene* cutting an anterior segment of the thorax and diagonally through the cephalic appendages and the hypostoma; fragments of the slender epipodites occur on both sides above the oblique sections of the endopodites; some of the latter appear to indicate that one of the joints was hollow. There is a section of a small narrow cephalic limb just above the hypostoma on the right side and above are the sections of two large coxopodites, one of which on the left side has several obscure joints that are filled with small elongate oval-like bodies; the latter also occur scattered in clusters in the calcite and appear similar to those illustrated by figure 10, plate 98.

Slide No. 6, M. C. Z. (plate 101, figure 6). Transverse section of the cephalon of *Calymene*. This section is in some respects one of the best of the cephalic appendages of *Calymene*. It cuts across two pair of slender, short coxopodites that were presumably anterior and corresponding in position to the two small anterior cephalic limbs of figures 2 and 3, plate 101. The large upper pair of coxopodites appear to have been attached to the ventral surface (integument) near their proximal end; this is also suggested by slides No. 38 and 51 (Walcott 1918, plate 26, figures 6 and 9), also figure 7, plate 101.

The grouping of the proximal ends of the limbs in slide No. 6, also Nos. 38 and 51, strongly suggest oblique sections across the mouth with some of the surrounding gnathites. Slide No. 6 was illustrated by Walcott in 1881, plate 1, figure 6, and in 1918, plate 26, figure 11.

Slide No. 9, M. C. Z. (plate 101, figure 5; plate 95, figure 14). Transverse section of the cephalon of *Calymene* and the anterior mesotergite of the thorax cut so as to pass through the hypostoma, a portion of the three anterior limbs of the cephalon and the large coxopodite of the fourth pair of cephalic limbs; what may be a section of a portion of a displaced alimentary canal occurs as a short dark transverse crescent just beneath the mesotergite of the dorsal test: this is much like the crescent in figure 13, plate 95. This slide was imperfectly illustrated by Walcott, figure 9, plate 1, 1881. The section of the alimentary canal was omitted in the drawing supposed to represent a photograph of the slide.

Slide No. 20, M. C. Z. (plate 103, figure 14). Transverse section of an enrolled *Calymene*. This is valuable for the information it gives of the form of the cross section of the endopodites, which appears to have been nearly circular; the coxopodites were relatively flat and deep in section as indicated by the sections of *Calymene* on plate 101. See description of figure 14, plate 103, for further remarks on slide No. 20.

This slide was illustrated by Walcott 1881, plate 2, figure 10.

Slide No. 28, M. C. Z. (plate 99, figure 5. Walcott 1881, plate 3, figure 8. 1918, plate 27, figure 13). This is a section of one side of an enrolled specimen of *Calymene* in which the filaments of three or more exopodites have been cut across; a comparison should be made with the fine fimbriated exopodites of figure 1, plate 96, in order to better understand the exopodites of figure 5, plate 99, as the latter do not show the spiral structure of the arm; the first of the two right hand fimbriated appendages appears to have an elongate oval section which is probably of secondary origin; the right hand appendage may have been similar to the fimbriated appendage of figure 8, plate 100.

This has long been a very difficult section to understand, but with the discovery of the exopodite shown in figure 1, plate 96, the fimbriated structure is more readily interpreted.

Slide No. 29, M. C. Z. (plate 99, figure 9) of *Calymene* is partly represented by figures 8 and 9 of plate 97. The object of reproducing it entire is to show the transverse section of the longitudinally undulating integument of the mesosternite and its relation to the triangular sections of the coxopodites of the ventral thoracic limbs. This is a portion of figure 9, plate 3, of Walcott 1881, which is a drawing based on a photograph. A photograph of the entire section was published in Walcott 1918, plate 27, figure 4.

Beecher in his memorable article[1] on the "Ventral Integument of Trilobites," calls attention to this slide and considered that it indicated folds and that in some sections cut by Walcott a normal apodeme was indicated (loc. cit. p. 169).

The spiral arms of the exopodites and slender epipodites of this slide are illustrated by figures 8 and 9, plate 97. The shaft of the exopodite is shown in figure 8, with the sections of two spiral arms and beneath them the slender epipodites which are much better illustrated by figure 2 of this plate. In figure 9 there is a greater displacement of the spiral arms. It was on the appearance of these two arms, those of figure 10, plate 97, and those shown by figure 10, plate 3, Walcott, 1881, that I ventured to restore the exopodite with a double spiral. This is no longer tenable, as an exopodite with two arms of the character we now know them to be, is not probable and the evidence is insufficient. The slender arm next to the coxopodite may be a section of a thin edge of two or three joints of an endopodite. Walcott 1918, page 195, description of figure 4.

Slide No. 32, M. C. Z. (plate 97, figure 7. Walcott 1881, plate 4, figure 4; 1918, plate 27, figure 5*a*). Longitudinal section of the pleural lobe of a partially enrolled *Calymene* in which the spiral arms of two of the exopodites have been pushed out of their natural position, but fortunately they retain the proximal straight portion of the arm and its union with the spiral portion; one of these (the lower in figure 7) shows the proximal straight portion of the arm extended along and connected with five sections of the spiral portion; whether this is always the case is uncertain but from a comparison with the spiral arm of *Cyamus scammoni* Dall (see Walcott 1881, plate 4, figure 9) it may be that the simple straight portion of the arm passes directly into the spirals; further data is needed to determine just how the two parts are joined. Slide 29 (plate 97, figure 8) is in favor of the view clearly indicated by figure 7.

Slide No. 34, M. C. Z. (plate 105, figures 1 and 2). This is a thick longitudinal slice of the axial lobe of *Calymene*. One side is practically a duplicate of slide 35 (plate 101, figure 1) which was cut from the same specimen but on the opposite side of the median lobe. Both of these were a little to the right or left of the median

[1] Amer. Journ. Sci., Vol. 13, 1902, fig. 7, pl. 5.

line and do not cut the mesotergite process although they do pass through the sharp fold where the anterior articular extension of the mesotergite unites with the segment. (See Walcott 1881, plate 5, figure 6). The opposite side of No. 34 has 18 well defined mesosternite segments with an interarticular membrane uniting them, three faint posterior segments and traces of several coxopodites similar to the short sections of them in slide 36 (figure 4, plate 101).

What appears to be a section of the alimentary canal (figure 2) extends nearly the entire length of the thorax and pygidium; it is situated directly above the ventral integument. Fragments of two of three cephalic limbs occur beneath the cephalon. The mesotergites of the dorsal test have been drawn apart a little which has caused the ventral integument to pull away from the doublure of the posterior end of the pygidium. This also shows in slide No. 35 which was cut from the same specimen on the opposite side of the median axis of the dorsal test.

Slide No. 35, M. C. Z. (plate 101, figure 1). This beautiful longitudinal section of a partially enrolled *Calymene* cuts through the axial lobe of the dorsal test a little inside of the dorsal furrow for the anterior two-thirds or more of the length of the specimen, and then a little inward nearer the center of the axis of the pygidium; the ventral limbs are drawn forward and together so that they do not correspond in position with the mesotergites; there are 22 of the proximal portions of the limbs indicated, the anterior four of which are referred to the cephalon, thirteen to the thorax, and five to the pygidium. There were probably two or three more beneath the pygidium of which no traces are preserved. The section on the opposite side of the axial lobe of this trilobite (plate 105, figure 2) is almost identical with this (Walcott 1881, plate 5, figure 3), and the median section of the axial lobe (Walcott 1881, plate 5, figure 2; plate 105, figure 1) shows the thickened mesosternites of the ventral integument.

Most of the proximal joints (coxopodites) of the ventral limbs are joined to the ventral surface without any suggestion of intervening joint, but three have what appears to be a small very short joint between the coxopodite and the ventral surface; one of these appears very much like the anterior limb of the pygidium of figure 9, plate 103, where a short joint seems to be present between the coxopodite and the ventral integument.

Another interpretation of this is that the narrow connection between the coxopodite and the ventral side of the animal is a cross section of the space occupied by the muscles connecting the ventral integument and the axial processes and mesotergite of the dorsal test.

Slide No. 36, M. C. Z. (plate 101, figure 4; Walcott 1881, plate 5, figure 4). Longitudinal section of *Calymene* a little oblique to the median line of the axial lobe so as to cut the side of the hypostoma, the proximal parts of two of the cephalic limbs (one of which has been pulled out of place), six thoracic limbs, six of the thickened mesosternites and fragments of several limbs on the opposite side of the axial lobe from the cephalic and anterior thoracic limbs. This section is instructive as it illustrates the strong mesosternite segments and the direct contact of the coxopodites of the ventral thoracic limbs with the segments; slide 36 with slides Nos. 34 and 35, present a fine illustration of sections of the coxopodites parallel to the axis of the trilobite and of their relations to the ventral integument.

Slide No. 38, M. C. Z. (plate 101, figure 7). Transverse section through the cephalon, anterior thoracic segment of *Calymene* and obliquely across the hypostoma. The portion of the cephalic limbs cut across suggests the same structure as in slide No. 6, figure 6, plate 101, with one of the endopodites on the left side cut through so as to give the narrow section of the joints and the one on the right the broad section; the latter is not well shown in figure 7 as it too dark to photograph well. A drawing published by Walcott in 1881, plate 1, figure 8, shows the various parts more clearly. This drawing was republished in connection with a photograph in 1918, plate 26, figures 9, 10. The slender appendages on the left side in the drawing are also too dark to photograph. The difference in the right and left sides between the figures of 1918 and figure 6, plate 101, is owing to the light being transmitted through different sides of the translucent slide of rock.

Slide No. 45, M. C. Z. (plate 99, figure 2; plate 100, figure 3). Oblique transverse section through the posterior part of the thorax and the upper posterior margin of the cephalon of *Calymene*. The filamentous appendages on the right side of figure 2, plate 99, are enlarged in figure 3, plate 100, to show details of structure; the lobe or base of the appendage is attached to the side of the mass filling the visceral cavity beneath the axial lobe, but whether a short shaft or arm connected the lobe with the coxopodite of one of the thoracic limbs cannot be determined from this slide, but from the appearance of the sections in figures 4, 6, 8, plate 100, it is probable that such was the case. The manner of the insertion of the slender filaments or tubes into the lobe is shown by figures 5, 6. In looking at this slide it must be borne in mind that the trilobite was enrolled, that five segments of the thorax are cut across and that the filaments or tubes are long, relatively strong and do not resemble the filaments of the spiral arms of the exopodites.

This slide was illustrated by a drawing in Walcott 1881, plate 3, figure 1, and again in 1918, plate 27, figure 11.

Slide No. 53, M. C. Z. Part of a transverse section through the cephalon and an anterior thoracic segment of *Calymene*. The section cuts on the right side a mutilated coxopodite so as to give a roughly triangular outline, and below it on the left two smaller joints that may be portions of the coxopodites of two of the cephalic limbs; below and on the right there is a broadly jointed appendage that from the direction of the upper joint evidently belonged with the cephalic limbs, as it is within the cephalon and quite unlike the thoracic endopodites. This slide is illustrated by Walcott 1918, plate 26, figure 12, by a print made from a plate that represents the appendages in black with a white matrix, whereas the slide shows a black matrix with the appendages in white calcite.

Slide No. 63, M. C. Z. (plate 91, figure 3; plate 99, figure 4). Transverse thoracic section of *Calymene,* the most interesting feature of which is the displaced coxopodite of a ventral limb which has a depression midway of the upper margin into which a projection from the ventral surface projects forming the " ball-and-socket " joint of Raymond (page 53, figure 15) ; the narrow sections of two additional pairs of coxopodites occur below and a number of slender appendages on each side which may be drawn out spiral arms of exopodites.

Slide No. 118, M. C. Z. (plate 95, figure 16). Transverse section of Calymene with two dots in the space beneath the mesotergite of the dorsal test that may represent the position of the dorsal flexor muscles, and an arched, dark, line tentatively referred to as the heart. This is the " dorsal sheath " of Raymond's diagrammatic drawing of this slide (figure 21, page 79).

Slide No. 153, M. C. Z. (plate 98, figure 5; plate 103, figure 10). Raymond, page 79, figure 23. The descriptions of the figure 5, plate 98 and figure 10, plate 103, mention the principal features of this slide of *Calymene*.

Slide No. 200, M. C. Z. (plate 103, figure 12). This slide of *Calymene* is sufficiently described in the description of figure 12, plate 103.

Slide No. 211, M. C. Z. (plate 104, figures 1-3) is an oblique transverse thoracic section of *Ceraurus* which has cut across the articular fold of the mesotergite and the mesotergite process on the right side (figure 1) (see plate 101, figures 1-8) ; and two distorted coxopodites with several of the endopodites, exopodites and elongate epipodites; the latter are best seen in figures 2 and 3 with their elongate proximal joint which is very narrow at its proximal end and broad at the distal end where the evenly jointed portion of the epipodite unites with it; these proximal joints should be compared with figures 1-4, 6, plate 97. A portion of a spinose ventral margin of one of the joints of the endopodite is seen in the lower right hand corner of figure 2. The light colored flocculent parts in figures 2 and 3 result from the strong light passing through very thin parts of the slide.

CERAURUS PLEUREXANTHEMUS Green

Slide No. 13, M. C. Z. (plate 95, figure 6). Transverse thoracic section of *Ceraurus* showing what appears to be a partially compressed alimentary canal, an oblique triangular section of a coxopodite of a ventral limb on the right side, with fragments of an endopodite, and on the left side a distorted endopodite. Sections of slightly undulating ribbon-like appendages that may be portions of epipodites occur on both sides beneath the pleurotergites. This slide was illustrated by Walcott 1918, plate 26, figure 14.

Slide No. 16, M. C. Z. (plate 102, figure 10). Longitudinal section of *Ceraurus* cutting the side of the axial lobe of the dorsal test so as to section the mesotergite process of the articular fold, which gives two small rounded subtriangular outlines similar to those of figure 2, plate 102. When cut more obliquely the section of the processes are more elongate as in figures 6, 8, 9. Another interesting feature of slide No. 16 is the section of a long coxopodite of a thoracic limb with its narrow attachment to the ventral surface of the body and broad proximal end. The joints of the limb are undoubtedly distorted and merged so as to lose their individuality. This section was illustrated by Walcott 1881, plate 2, figure 16.

Slide No. 18, M. C. Z. (plate 103, figure 9). This is an instructive longitudinal section of *Ceraurus* in which the proximal portions of the ventral limbs of the pygidium are cut across; the sections of the coxopodites appear to represent the narrow, flat section and not the broad section seen in many transverse sections of the dorsal test.

An interesting and valuable feature of this slide are the clearly defined mesosternites. The posterior one of the pygidium has what appears to be a thin scale of the ventral integument adhering to it; the second from the posterior end blends in with the base of the ventral limb, and the third almost, but the fourth and fifth are clearly defined and separated by a sharp line of demarcation which is less well shown between the first, second and third sternites. The mesotergites of the dorsal test were crowded apart so that the mud of the matrix was forced under them and into the filling of the visceral cavity.

Particular attention is called to the short, narrow, transverse line between the coxopodite of the anterior limb and the mesosternite as it suggests a short joint, a feature also suggested by the next posterior limb by it narrowing between the coxopodite and the mesosternite. See also description of slide No. 35, page 397.

Slide No. 22, M. C. Z. (plate 99, figure 1; plate 100, figures 1, 2; Walcott 1881, plate 3, figure 2; 1918, figure 12, plate 27). Slightly oblique transverse section of the cephalon on the line of the eyes and anterior portion of the thorax of a partially enrolled *Ceraurus*. The cephalic limbs are grouped about the point that may have been the mouth, very much as in slide No. 6 (plate 101, figure 6), but the section is more oblique and cuts the deeper vertical section of the coxopodites (gnathites), and the hypostoma is cut almost on the plane of its marginal rim. There is a short transverse body near the end of the hypostoma between the proximal ends of the pair of gnathites that strongly suggests that a metastoma has been cut across; it has been replaced by clouded calcite which makes it difficult to photograph. The lower (in the photograph) left coxopodite has been pushed inward and impaled on the mesotergite process.

The fimbriated appendages in the space on each side between the axial lobe and the outer margin of the dorsal test must have been lying nearly horizontally beneath the dorsal test and attached to the coxopodites of either the posterior cephalic or anterior thoracic limbs. These fimbriated lobes (epipodites) are illustrated on plate 100, figures 1 and 2, and described under the heading fimbriated epipodites.

Slide No. 23, M. C. Z. (plate 100, figure 8; Walcott 1881, plate 3, figure 3. 1918, plate 26, figures 1 and 2). This is a transverse section of the cephalon and four segments of the thorax of *Ceraurus;* the coxopodites of six pair of limbs have been cut across, the right hand one of the posterior pair (Walcott 1918, plate 26, figures 1 and 2) showing a triangular section with a faint, slender, spiral arm of an exopodite projecting from its outer proximal margin; on the opposite side the coxopodite is badly distorted and broken up, but connected with it there is a support to a narrow vertical lobe or plate that carries numerous slender filaments, a photograph of which is reproduced as figure 8, plate 100. There is also a row of somewhat similar filaments next to the side of the cephalon and below the eye; these filaments were probably attached to several lobes similar to the one illustrated. The relations of the various parts mentioned is shown by figure 2, plate 26, Walcott 1918.

Slide No. 27, M. C. Z. (plate 95, figure 1; plate 103, figure 4) is a transverse section of a partially enrolled specimen of *Ceraurus* that has one of the best preserved sections of a large alimentary canal of a trilobite known to me. It is subcircular or broadly oval, with a narrow, short midway extension on either side that may have been an hepatic tube or the filled-in cavity of a flexor muscle; it has within it near the upper side a white, delicate convex or arching line that is a section of the articular extension of the mesotergite that is slightly out of its normal position, and above the canal and between it and the dorsal test there is a dark arching line that is a little longer than one-third the length of the arching mesotergite of the dorsal test; it may be a transverse section of the anterior incurving posterior margin of the mesotergite. (See plate 96, figures 3, 4). Raymond (p. 79, figures 21, 22) refers to these dark arched lines as dorsal (figure 21) or abdominal (figure 22) sheaths.

Slide 27 also cuts across on the left side a palmate fringed appendage (figure 5, plate 100) that is similar to the one illustrated by Walcott (1881, plate 3, figure 2; 1918, plate 27, figure 12). Eight filaments were attached along the outer fluted edge of a roughly triangular palmate base. A fragment of a similar structure occurs on the appendages of the two adjoining segments. The outlines of two of the ventral segments (mesosternites) are shown as well as the base of the ventral limbs.

Slide No. 80, M. C. Z. (plate 99, figure 6; plate 100, figure 6). Transverse thoracic section of *Ceraurus* in which the coxopodite of a distorted ventral limb is cut across, also the lobe of a fimbriated epipodite of the type illustrated by figures 2, 4, 5 of plate 100. On the opposite side of the section a somewhat similar structure has been pushed up against the side of the filling of the axial lobe of the dorsal test.

Raymond figures this slide as a diagrammatic drawing (page 49, figure 12) to illustrate what he considered to be a section of an exopodite and some of its "setæ" in a longitudinal section.

Slide No. 109, M. C. Z. (plate 97, figure 2; plate 98, figure 1). Transverse thoracic section of *Ceraurus* in which the coxopodites of the ventral limbs were displaced and distorted and several joints of the endopodites of five pairs cut across at different angles to the axis of the limb; several appear to have been hollow and filled with infiltered mud; on the left side there are three slender jointed epipodites (figure 2, plate 97), and on the right side fragments of slender epipodites and exopodites. Some of the joints or endopodites on the right side have slender spines attached to their lower inner margin, as seen in the section.

Slide No. 110, M. C. Z. (plate 95, figure 11). Oblique transverse thoracic section of *Ceraurus* in which the alimentary canal has been compressed and the ventral surface pushed up beneath the mesotergite of the dorsal test carrying the oblique sections of the ventral coxopodites with it; sections of portions of the exopodites that suggest spirals are cut across beneath the pleurosternite on the left side and fragments of endopodites below the coxopodites.

Slide No. 111, M. C. Z. (plate 104, figure 4; Walcott 1881, plate 2, figure 2; 1918, plate 27, figure 1). Transverse thoracic section of *Ceraurus* showing an unusual section of an endopodite, with five joints and faintly two distal joints that probably belong with the others, although they may not, as a short space separates them; above the endopodite there is a fragment of a spiral exopodite, and above this and between it and the ventral surface of the pleurotergite, fragments of three slender epipodites. In Raymond's interpretation of this slide he considered the lower slender epipodite to be the arm, and the cut across sections of the spiral of the arm of the coxopodite beneath, the filaments of an exopodite. (Page 58, figure 18).

Slide No. 112, M. C. Z. (plate 95, figure 15). Transverse section of the axial lobe of *Ceraurus* in which a dark narrow transverse area in the white calcite suggests a greatly compressed alimentary canal, or possibly but not probably, the heart, as indicated in figure 16 and 17; also a fimbriated appendage on the left side similar to that in figure 1.

Slide No. 114, M. C. Z. (plate 95, figure 19). Transverse thoracic section of *Ceraurus* in which sections of the supposed dorsal flexor muscles are represented by two large dark dots one on each side of the axial lobe of the visceral area; one or two similar dots occur in other sections (figures 16, 17, 18). The two lower dots are supposed to be sections of the mesotergite processes. A subtriangular section of two coxopodites of the ventral limbs are indistinctly shown, also what may have been the shaft of an exopodite on the left side apparently attached to the coxopodite.

Slide No. 115, M. C. Z. (plate 95, figure 17). Transverse section of *Ceraurus* cutting through the hypostoma and anterior portion of the cephalon on the left side and the anterior thoracic mesotergite of the thorax; the two small dark lateral dots in the axial lobe are referred to the dorsal flexor muscles, and the larger dot below on the right side to a section of a mesotergite process or a ventral flexor muscle; the dark arched line separated from the mesotergite by a narrow strip of calcite may possibly represent the heart. On the right side there is a triangular section of a coxopodite, and on the left side portions of two of the cephalic limbs that have considerable width. The upper fragment is probably a portion of a thoracic coxopodite. What may be the shaft of an exopodite occurs just beneath the filling of the pleural space on the left side.

Slide No. 117, M. C. Z. (plate 95, figure 10). Transverse thoracic section of *Ceraurus*. This section is of interest on account of the position of what was probably the alimentary canal, which has been distorted and crowded up against the mesotergite of the dorsal test. The position of the mesotergite process on each side is indicated, and in a general manner the base of the ventral limbs. Two downward curving points near the median line of the ventral integument suggest the proximal end of the coxopodites.

Slide No. 119, M. C. Z. (plate 95, figure 18). Transverse thoracic section of *Ceraurus* in which the position of two supposed dorsal flexor muscles are represented by irregularly rounded dark spots that are considered to have been holes left by the decomposition and removal of the muscles, the holes being subsequently filled by the infiltration of the silt forming the matrix. The spots in this slide should be compared with similar spots in figure 19. The two lower dark spots are supposed to be sections of the mesotergite processes. A partly triangular section of a ventral coxopodite is preserved on the left side, and 8 mm. to the left of the point of the coxopodite there is a fragment of an endopodite which has a notch into which another distorted fragment of an endopodite projects, thus forming a fine illustration of the "ball-and-socket" joint of the appendifer and coxopodite as described by Raymond (page 54, figure 15, page 53), except that the appendifer is not present and the socket is simply an indentation in a fragment of joint of the endopodite.

Slide No. 120, M. C. Z. *Ceraurus*. See description of plate 98, figure 4, page 442.

Slide No. 123, M. C. Z. (plate 102, figure 5). Transverse section of three slightly displaced thoracic segments of *Ceraurus* the upper one of which has on the right the thickened base of an axial process, and inward from it the fold of the mesotergite process, and below in the mass of calcite filling the space between the mesotergite and the ventral integument two sections of the mesotergite process. The lower segment has on the left side (in the figure) a knob-like section of the axial process and inward from it a mesotergite process on each side of the median line; the section cuts across the two mesotergite processes at such an angle as to give the effect of having cut obliquely across a short tube; figures 1 and 3, plate 102, show sections of this process cut at a different angle. In slide 123 (figure 5) the fold of the mesotergite articular extension is clearly shown.

Slide No. 147, M. C. Z. (plate 101, figure 8). Transverse section of an enrolled *Ceraurus* that is interesting on account of the sections of the coxopodites of the ventral thoracic limbs.

Slide No. 168, M. C. Z. (plate 103, figure 7). Longitudinal section of the cephalon, hypostoma and the anterior portion of the axial lobe of the thorax of a partially enrolled *Ceraurus*. The proximal ends of the cephalic limbs have been pushed in above the hypostoma and very much distorted; the thoracic limbs have been cut across at the coxopodite at such angle as to show the point of attachment of the shaft of the exopodite to the coxopodite in the three anterior limbs and doubtfully in the fourth posterior limb; just where the actual point of attachment to the coxopodite was is not revealed by this slide.

Slide No. 169, M. C. Z. *Ceraurus*. (plate 102, figure 6). See description of figure on plate 102, page 447.

Slide No. 174, M. C. Z. (plate 103, figure 6). Longitudinal section of the cephalon and thorax of a partially enrolled *Ceraurus* showing the proximal portion of two cephalic limbs and their position in relation to the hypostoma. The entire section is not illustrated by figure 6 as the limbs are displaced and the fragmentary sections of the joints are not instructive.

Slide No. 193, M. C. Z. (plate 102, figure 9). Longitudinal section of a partially enrolled *Ceraurus* which cuts through the side of the axial lobe within the dorsal furrow; above the hypostoma and between it and the posterior margin of the cephalon, four thick, evidently distorted, coxopodites have been cut across, and beneath the thorax six or seven imperfect coxopodites; the mesotergites of the dorsal test have been drawn apart so that their anterior articular projections are almost free from contact with the posterior part of the segment next in advance. A section of the fold of the articular projection occurs between the fourth and fifth segments and there are five sections of the mesotergite process anterior to it; the anterior section of the processes has apparently been pushed forward; a sharp mud-filled break in the cephalon occurs in advance of the posterior glabellar segment. The thick or broad sections of the two anterior limbs above the hypostoma should be noted as they are quite unlike the narrow anterior limbs of sections 15, 17, figures 2, 3, 5 and 6, plate 101.

Slide No. 198, M. C. Z. (plate 103, figure 8). This is another longitudinal section of *Ceraurus* in which the section of the cephalic limbs above the hypostoma are broad and strong as in slide No. 193, plate 102, figure 9. All the portions of the joints of the limbs exposed appear to have been forced out of shape and all form lost except that of a flexible tube stuffed with animal matter now replaced by calcite.

Slide No. 202, M. C. Z. (plate 95, figure 8). Transverse, slightly oblique thoracic section of *Ceraurus* in which the supposed alimentary canal has been compressed and forced below its normal position; on the left side the outline of the mesotergite process is unusually definite and may be compared with that in figure 10. The dorsal test of this section is finely preserved and there is more of the calcite representing the contents of the space between the pleurotergite and the ventral integument than is usually seen.

Slide No. 204, M. C. Z. (plate 97, figure 3; plate 98, figure 7). Transverse thoracic section of *Ceraurus* with subtriangular section of two large coxopodites, to the left one of which there is attached at the upper left side a short arm that has a faintly outlined slender prolongation that is presumably one of the slender epipodites; two other similar objects occur, one above and one below the arm mentioned. On the opposite side there is an indication that a slender arm was attached to the upper right side of the coxopodite and extended beyond as a slender appendage, suggesting that it had two or more joints (figure 3, plate 97); below this there is a slender appendage with a strong proximal joint that appears to have been undulating so as to give a section of an arm broken into short parts; a similar arm occurs below, also in figure 4, plate 97 (slide No. 208); the strong proximal joint is also seen in figures 1 and 4. The relative size of the coxopodites and the slender epipodites is well shown in this slide.

Slide No. 205, M. C. Z. (plate 95, figure 2; plate 102, figure 3) is a transverse thoracic section of *Ceraurus*. It has a transverse section of the alimentary canal beneath the axial lobe; four black dots on the right side nearly on the line of the dorsal furrow, and one a little to the right that may represent the flexor muscles of the mesotergite process; oblique sections of the coxopodites of several thoracic limbs, and in the space beneath the pleural lobe traces of displaced endopodites; the pair of lower coxopodites indicate their approximate position in relation to each other when in a natural position. A fine section of what may be a mesotergite process (appendifer) extends obliquely into the axial space at the lower right side of the mesotergite of the dorsal test (plate 102, figure 3). The section is slightly oblique to the longitudinal axis of the trilobite, which gives a peculiar appearance to the section of the test on the right side.

Slide No. 208, M. C. Z. (plate 97, figure 4; plate 98, figure 3). This transverse thoracic section of *Ceraurus* has a fine section of one of the slender epipodites with a large proximal joint, also a broken section of an undulating slender epipodite and below the latter a distorted spiral arm of an exopodite; there is also the skeleton outline of an endopodite with five or more joints, and the coxopodite. An undulating ventral integument beneath the axial lobe is suggested by the manner in which some calcite is crowded up against an irregular dark line of rock crossing from side to side. A portion of what may have been the filling of the alimentary canal occurs a little beneath the mesotergite of the dorsal test.

Slide No. 228, M. C. Z. (plate 95, figure 13). Transverse thoracic section of axial lobe of *Ceraurus* in which the supposed alimentary canal has been crowded up against the articular extension of a mesotergite of the dorsal test and taken the form of a crescent with a very definite outline.

Slide No. 231, M. C. Z. (plate 102, figure 8). Slightly oblique, longitudinal, thoracic section of *Ceraurus* cutting across several mesotergites of the dorsal test in such a manner as to show the three right hand segments, the outline of an oblique section of the anterior articular extension of the tergite and beneath on the left hand three sections of the mesotergite process. Compare this with the other figures on plate 102.

Slide No. 244, M. C. Z. (plate 95, figure 4; plate 102, figure 1). This is a transverse section of a partially enrolled *Ceraurus* cutting four thoracic segments nearly on the plane of the dorsal surface of the pleural lobes of the test and one upturned (down in the figure) segment beneath which there is a fine illustration of a section of the alimentary canal. The sections of the fold at the union of the articular extension with the body of the mesotergites are exceptionally good and serve to interpret the sections represented by figures 3, 6, 8, 9 and 10 of plate 102, and with figure 4, to visualize the mesotergite process as a downward lateral extension of the fold at the base of the anterior articular extension of the mesotergite.

Spiral branchiæ.—These appear to have given Raymond more concern than any other of my interpretations of the appendages exposed by the sections cut through specimens of *Calymene* and *Ceraurus*. I deeply sympathize with him as I found them most difficult to visualize and interpret. The reason for my originally accepting the "spiral" interpretation is as follows: When thinning down transverse and an occasional longitudinal section of *Calymene* and *Ceraurus* with emery dust on a glass plate, I occasionally noticed a row of minute oval dots on the section. As the removal of the surface of the slide progressed, the dots began to elongate transversely and more or less obliquely (see figure 1, plate 96), then to narrow at the center, and soon a double row of round dots appeared that indicated a cross section of a spiral. Continuing the cutting the dots became elongated, and soon reunited and narrowed to oval dots and finally disappeared, as the removal of the surface cut deeper into the specimen. From these progressive sections I inferred that coils of a more or less compact spiral wire-like filament had been cut through.

Subsequently I found that by cutting across closely coiled spirals of wire set in plaster (1918, plate 27, figures 10, 10*a*) most of the spiral-like structure seen in the sections of *Ceraurus* was duplicated in detail.

During the cutting of sections over a period of several winters, this experience was repeated from time to time and sketches made of the successive exposures of the apparent spiral structure, but I could not preserve all the data found while grinding down the sections as there were no facilities available to me for photographing opaque sections.

I did not observe any branchial filaments attached to the spirals cut or progressively worn through from side to side, but many filaments that were free or attached to others parts were cut both longitudinally, obliquely, and transversely. The filaments were rarely seen attached to any kind of a base, but occasionally they were as shown by figure 12, plate 27 of the paper of 1918 (which is a drawing from a photograph of a thin section); see also figures 11 and 13 on the same plate, though I did not associate these with the spirals.

I knew very well in 1918 that the spirals might possibly be explained as oblique sections of filaments such as occur on the exopodites of *Triarthrus* or *Neolenus*, as had been suggested by authors, but the conclusion that there was a spiral-like appendage independent of the blade or arm with filaments attached to the proximal joint of the limbs in *Calymene* and *Ceraurus*, was so firmly impressed on my mind that I could not abandon it.

Raymond (pp. 48-50) assembles a formidable array of arguments against the possibility of the presence of spiral exopodites, but after reading them I was still unconvinced but realized that the presence of a spiral-like structure in *Calymene* and *Ceraurus* was rendered exceedingly doubtful to the general student and that it was relegated to the class of disproved theories. As a last resort I decided to make thin sections of a number of specimens of *Calymene* collected by William P. Rust for the National Museum many years ago, and a few of *Ceraurus,* all of which came from the locality and layer of rock worked by Walcott prior to 1876. This was undertaken in the hope that a section might be cut across on the plane of an elongated arm of the exopodite and, if present, an attached fringe of filaments. Spirals were found and a few stray unattached filaments, but it was not until the next to the last slide of *Calymene* was rubbed down thin that a series of undoubted spirals was seen in shadowy outline; a little reduction in the thickness of the slide and the spirals became more distinct and a fringe of filaments was indicated; a further reduction and the filaments extended back to the spirals and joined them, and I had in my hand the evidence that I had searched for from 1873 to 1879 and at intervals since. (See plate 96, figure 1). The arm of the exopodite of *Calymene senaria* as it appeared in the section was clearly and unmistakably a spiral-like structure with a filament attached to the side of several segments of the spiral; all the spiral phenomena I had observed in my early work are beautifully shown in this slide by a series of round and elongated single and double rows of dots, faint and distinct spiral structure, and what was new, the mode of attachment of the filaments to the spiral arm.

Exopodite of Calymene.—The slide referred to in the preceding paragraph (U. S. National Museum, Catalogue No. 68379) is represented by figure 1, plate 96, and a restoration of a portion of the exopodite by text figures 17, 17*a*.

There are portions of nine exopodites cut across in the slide at a more or less oblique angle to the axis of the arm and attached filaments. The exopodites had been pushed back into the half enrolled posterior portion of the trilobite and displaced so that they were beneath the axial lobe with their longitudinal axes subparallel to the axial lobe of the dorsal test. As seen in the section (figure 1, plate 96) the upper arm (1) is represented by a row of small round white dots with a few oblique transverse segments on the left end, and transverse faint oblique lines that give a spiral appearance to the section of the arm. The second exopodite (2) has about 26 obliquely transverse segments and spiral structure indicated. The third (3) exopodite has a distinct spiral with about 24 oblique segments; the spiral structure is more pronounced in the fourth (4) and the 30 segments are more strongly outlined and some are broader, but the spiral structure is preserved about midway of the length of the arm; the fifth (5) exopodite has about 40 segments indicated and the section shows 16 or more long slender filaments a number of which are connected directly to the segments of the arm, but the section does not cut across the exact point of contact with the seg-

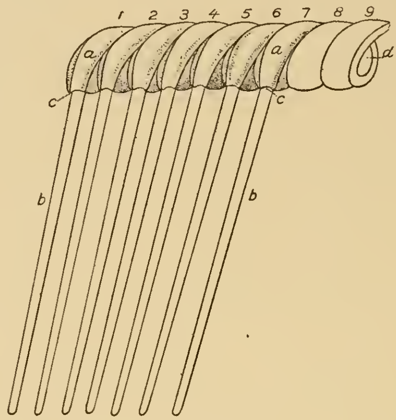

FIG. 17.—Diagrammatic outline of a dorsal view of a portion of a thoracic exopodite of *Calymene*. 1-9 = close coils of a spiral arm. 1-7 = bases (a) of seven branchial tubes (b) attached to dorsal side of the coils of the spiral arm. *a* = supporting base of branchial tube attached to spiral arm. *b* = branchial tube inserted in *a* at *c*. *d* = hollow interior of spiral arm of exopodite.

ments of the arm in a manner to clearly indicate the character of the union betwen them; this is found in the sixth (6) exopodite which has six filaments and portions of transverse spiral segments. The cut is diagonally across the segments and brings into view the thickened sheaths of three segments with the point of insertion of the

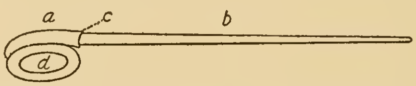

FIG. 17*a*.—Sectional view of diagrammatic outline of exopodite represented by fig. 17. (Lettering the same.)

filament into the supporting sheath. The seventh, eighth and ninth exopodites expose only a few segments of the arm, and afford no additional data on the structure of the exopodite.

My interpretation of the structure that when cut across gives a spiral outline in the sections of the exopodites in this slide is graphically shown by text figures 17, 17*a*.

The spirals seen in so many sections of *Ceraurus* and *Calymene* result from cutting across rounded, narrow, oblique coils of a hollow, spiral arm of the exopodite to which the bases or sheaths of

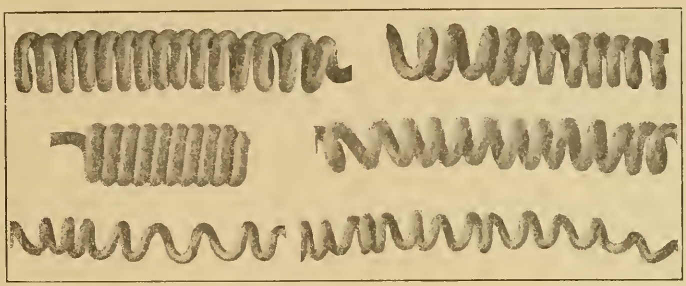

FIG. 18.—Photograph of several spirals formed of wire and flattened more or less by compression. These spirals suggest the probable form of the spiral arms of the exopodite of *Calymene* and *Ceraurus*.

long slender filaments (tubes) are attached; each obliquely arranged segment of the spiral is in vertical section, a portion of a spiral that was more or less flattened on the dorsal and ventral sides; the filaments were attached to the posterior end of a base or sheath attached to the dorsal side of the spiral coils of the arm; this is indicated by exopodite numbered 5 of figure 1, plate 96, and more definitely by

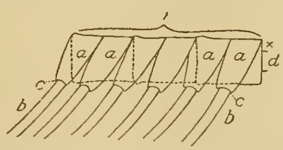

FIG. 19.—Diagrammatic outline of a dorsal view of a portion of the exopodite of *Triarthrus*. $a =$ three segments of the supporting arm. $b =$ supporting bases of branchial tubes, two attached to each joint of the supporting arm. $c =$ point of insertion of branchial tube into base *a*. $d =$ hollow interior of arm of exopodite.

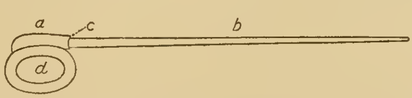

FIG. 19*a*.—Sectional view of diagrammatic outline of transverse section of exopodite represented by fig. 19. (Lettering the same.)

number 6, where the point of insertion of the slender filament is shown as well as can be in a section; the dorsal position of the sheath or base of the filaments is corroborated by the arm of the exopodite of *Triarthrus becki,* where it rests on and is attached to the dorsal side of the segmented section of the arm (see plate 95, figures 20-23).

The relation of the exopodites to the endopodite and coxopodite is not seen in slide No. 68379, but it is indicated by several sections one of which is represented by figure 2, plate 26, figure 4, plate 27, Walcott 1918 and plate 97, figure 8.

Exopodite of Ceraurus.—Many sections of the spiral arm of the exopodite of *Ceraurus* have been made since I began sectioning specimens in 1873, but none of them showed the connection between the spirals and the slender tubes or filaments, but the section of *Calymene* described above gives the key to the structure and indicates that the spirals of *Ceraurus* are sections of the arms of the exopodites and have exactly the same structure as those of *Calymene,* as may be seen by comparing the spirals of *Calymene* (figures 4, 5, 5*a*) with those of *Ceraurus* (figures 3, 6, 8, 9, plate 27, Walcott 1918).

Structure of exopodite of Calymene and Ceraurus.—None of the sections of either species clearly shows the proximal segment or shaft of the arm of the exopodite, but several afford data from which we may assume its character with a fair degree of certainty. Section 23 (M. C. Z.), Walcott 1918, plate 26, figure 2; sections 29, 30, 31 (M. C. Z.), Walcott 1881, plate 3, figures 9, 10; plate 4, figure 3, of *Calymene;* section 32 (M. C. Z.), Walcott 1881, plate 4, figure 4, of *Ceraurus,* figures 7, 8, 9, 10, plate 97 all indicate a simple slender elongate segment between the coxopodite and the obliquely transverse hollow spiral segments of the filamentous portion of the arm; fragments of the spiral portion of the arm are cut across in a number of sections but it was not until the restudy of the sections in connection with these notes that I succeeded in getting satisfactory photographs of the shaft and the connection between it and the spiral of the arm of the exopodite. These are reproduced in figures 7 and 8, plate 97, and indicate that several turns of the spiral arm were attached to the distal end of the shaft. The coil of the spiral appears to have been quite close when the animal was alive, but when subjected to the vicissitudes following death and entombment in the soft sediment, the spiral was loosened and often drawn out as illustrated by the spirals figured by Walcott in 1918, plate 27, figures 3-9, and on plate 97, figures 7-11 of these notes.

The elongate base of the filaments of the exopodite of *Triarthrus* are oblique to the axis of the arm, and the structure was probably the same in the exopodite of *Calymene* and *Ceraurus.*

The filaments of the exopodite of *Calymene* and *Triarthrus* are very slender tubes and in section give a beautiful fringe of fimbriæ as shown by figure 13, plate 27, Walcott 1918, and figure 1, plate 96, of this paper.

Arm No. 5 of figure 1, plate 96, of *Calymene* indicates that 39 or 40 segments have been cut across, and the proximal section exposed is evidently not the first one, but from its position I presume that there are not many more before the union with the shaft connecting the spiral arm with the coxopodite, so we may assume that the arms of the thoracic exopodites had between 35 and 40 segments (=coils of the spiral arm).

As far as may be determined from the evidence afforded by many sections of *Calymene* and *Ceraurus* cutting the arm of the exopodite, it is very rarely that the layer of sheaths or supports of the filaments (tubes) remained attached to the arm of the exopodite. The attachment of the sheaths to the spiral arm must have been relatively delicate and easily broken when the arms were displaced and the branchial tubes dragged about by movement in the soft sediment in which they were being embedded. This condition explains the presence of so many of the strong spiral arms of the exopodites and the absence of the supporting sheaths and the fringing tubes or filaments.

In the case of *Triarthrus becki* the animal settled down quietly on the surface of the mud and was not disturbed except by flattening out under pressure of accumulating sediment, which process sometimes displaced the limbs by sliding them out from beneath axial lobe; usually the endopodite and exopodite retain their natural position, being displaced only by the downward or upward pressure of the outer ends of the thoracic pleuræ or the margin of the pygidium or cephalon.

Exopodite of Triarthrus.—Raymond suggests that the spirals seen in sections of *Calymene* and *Ceraurus* are the result of cutting (p. 50) across the "setæ" of the exopodite, but he does not refer to the structure of the exopodite of *Triarthrus* in which there is a closely jointed rounded arm of many segments upon the upper side of which there is superimposed (plate 95, figures 20-23) diagonally and closely arranged slender, convex supports or sheaths of long, slender, round filaments similar to those cut across in *Calymene* (plate 96, figure 1). This structure was illustrated by Walcott (1918, plate 29, figures 2, 2*a* and 11) but he did not then compare it with the exopodite of *Calymene* and *Ceraurus,* as the connection between the fringing filaments of the arm of the exopodite of *Calymene* and the associated spirals was unknown. There is no evidence that the same kind of a jointed arm as that of the exopodite of *Triarthrus* was present in the exopodite of *Calymene* and *Ceraurus* but that there was a supporting spiral arm strengthened by the attached layer of sheaths of the fringing filaments appears to be well established.

The dorsal side of the arm of the exopodites of *Triarthrus* is finely illustrated by Beecher's photographs as reproduced by Raymond, plate III, figures 1, 5, 6; plate IV, figure 6, but none of them appear to show the many jointed supporting arm, nor do I find a reference to it by either Beecher or Raymond. It occurs on specimen No. 221, illustrated by Raymond, plate 5, figure 5, but his reproduction is too poor to show it clearly. Compare this figure with that on plate 95, figure 20 of this paper, as they appear to represent the same view of the exopodite.

In nearly all specimens of *Triarthrus* showing the exopodites it is the dorsal side that is exposed and the layer of basal sheaths of the filamentous tubes is so closely attached to the jointed supporting arm of the exopodite that the arm is entirely concealed from view except when occasionally the long distal segment of the arm projects a little beyond the distal end of the exopodite. It was only by a fortunate find that I became aware of the existence of the arm in *Triarthrus* and its relations to the sheath layer above it. The specimens showing it may be described as follows.

Specimen No. 65523, U. S. N. M. (plate 95, figures 22, 23) of *Triarthrus* has two of the jointed arm supports of the exopodite lying above the endopodites; the posterior one has eleven closely united joints, the length of each one of which is about 1.5 times as great as its diameter and the distal end has a slight raised rim against which the proximal end of the next joint impinges; the anterior arm has seven or eight joints that taper gradually to a short slender terminal joint. The arm with 11 joints has the bases or sheaths of 22 rounded tubes or filaments just above its anterior side, which indicates that there are about two tubes or filaments to each joint of the arm. The layer of supporting diagonal tubes of the filaments or tubes of each arm has been pressed forward so as to be almost clear of the jointed arm support, only a few of the round filaments resting on its dorsal side.

Specimen No. 65529, U. S. N. M. (plate 95, figure 20) shows three exopodites which have been displaced and pushed along parallel to the outer margin of the ventral surface of the dorsal test. The supporting arm has been compressed so as to slightly distort the joints and make them transversely a little oblique to the axis of the arm;

the series of bases of the tubes or filaments are also oblique in the same manner as those undisturbed in specimen No. 65523. The long exopodite of figure 20, plate 95, shows the ventral side of the supporting arm and its anterior upper edge where the layer of bases of the branchial tubes was attached to the arm.

Specimen No. 68387, U. S. N. M. (plate 95, figure 21) has two flattened arms of thoracic exopodites entirely concealed except at the distal end by the layer of obliquely aligned bases of the branchial tubes; of the latter there are more than forty, about two-thirds as long as that portion of the exopodite between the shaft at the proximal end and the round slender distal joint of the arm. The tubes are very slender, more or less flexuous, and terminate in a rounded blunt point; they may be compared with the branchial tubes of the exopodite of the thoracic limbs of *Marrella splendens*.

Pygidial endopodites of Triarthrus.—Raymond (p. 42) calls attention to the difference in interpretation of the development of the endopodites of small pygidia by Beecher and Walcott, Beecher considering them true endopodites in the specimen studied by him (No. 222, plate IV, figure 5, of the Raymond memoir) and Walcott considering the possibility of their being the transverse segments of the supporting arm of the exopodite (Walcott 1918, page 142, plate 29, figures 4, 5). Raymond states : " On careful examination, however, the specimen shows, as Beecher indicated, a series of endopodites in undisturbed condition (our plate 4, figure 5)."

A careful study of specimen 222 convinces me that Beecher and Raymond are correct in their interpretation of that specimen, and that the exopodite of specimen No. 65524, U. S. National Museum (Walcott 1918, plate 29, figure 5) has an apparently identical structure.

When I spoke of Beecher's interpretation I had in mind his figures 1 and 3 of 1894 (Amer. Jour. Sci., Vol. 47, 1894, plate 7) and his comparison with the larval endopodite of *Apus* (figure 4).

Anal plate.—Raymond illustrates what he calls the anal plate (figure 11, page 44, specimen No. 65525, U. S. N. M.) and states that the hemispheric mound at the middle of the anterior half is perforate for the opening of the posterior end of the alimentary canal. I find an uneven, somewhat jagged, depression near the posterior central part of the convex body of the " anal plate," but it is not clear that there is a perforation. Specimen No. 65524 (Walcott 1918, plate 29, figures 4, 5) has a similar structure but the " hemispheric mound " is covered with minute granulations and a longitudinal median depression extends the length of the convex portion ; the marginal spines on this specimen appear to be the proximal portion of five of the pygidial limbs. The spines on specimen No. 65525 also appear susceptible of being interpreted as the coxopodites of very minute pygidial limbs.

It may be well to consider that the so-called anal plate may be the ventral integument of the posterior part of the pygidium which has been squeezed out from beneath the pygidium bringing some of the minute pygidial limbs along with it and that the dome may be the cast of the posterior portion of the axial lobe of the pygidium formed by the pressing of the ventral integument into it. More specimens are needed in order to arrive at a final conclusion.

NOTES ON INDIVIDUAL SPECIMENS OF TRIARTHRUS BECKI Green

Through the courtesy of Dr. Charles Schuchert of the Peabody Museum, Yale University, I have had the opportunity of looking over the type specimens of this species prepared and studied by Dr. Charles E. Beecher and recently illustrated by Raymond from the Beecher photographs. Some of the specimens have been photographed by Dr. A. J. Olmsted, chief photographer of the U. S. National Museum, who has obtained very excellent results. The specimens are excedingly difficult to photograph as the yellow pyrite and black, often shiny, shale reflect the light badly and usually the surface of the appendages is roughened by the finely botryoidal structure of the pyrite. I should like to reproduce a number of the photographs but that is impracticable in this paper. A few fragments are illustrated on plate 104, figures 12-15.

Specimen No. 211 (plate 104, figure 15). This is a portion of the specimen including the gnathites, the posterior portion of the hypostoma, the margin of which is broken away and a peculiar ribbed surface between the inner ends of the gnathites that may be formed by stout short spines attached to the inner end of the gnathites. No. 211 is illustrated by Raymond, plate II, figure 5.

Specimen No. 218 (plate 104, figure 13). This is a portion of the photograph that includes two of the posterior thoracic limbs that are in a peculiar position. The coxopodite, basipodite, and ischiopodite are turned up so as to show the thin ventral edge of the joints; the meropodite is tipped over so as to show the broad side of the joint which is nearly at right angles to the ischiopodite; the carpopodite is also lying on its side and is followed by the propodite and dactylopodite. It appears evident that the first three joints of the limb retained their natural position and the proximal four were bent back and are flattened broadside on the shale. The exopodites have retained their natural position on the dorsal side of the limb.

Raymond's interpretation of these limbs is shown by a diagrammatic drawing (figure 43, page 157) in which he has introduced a very short basipodite as the result of figuring the short ventral side of the joint and not noting that the dorsal side of the joint has slipped by and overlapped the ischiopodite.

Specimen No. 219 (plate 104, figure 14). This is a part of a photograph showing the apodemes very clearly. Raymond reproduces a photograph by Beecher (plate II, figure 6; plate IV, figure 4) which does not show them as well as in the original photograph.

Specimen No. 222 (figures 12, 12*a*, plate 104). These photographs are reproduced as the specimen shows the thin ventral edge of the joints of the endopodite, also by changing the point of view the flat anterior side of the joints. In figure 13 both the thin ventral edge of the three proximal joints of the limb are shown, also the flat side of the two succeeding joints.

Raymond illustrates No. 222 on plate IV, figure 5.

FIMBRIATED EPIPODITES OF CALYMENE AND CERAURUS

In addition to the spiral filamentous exopodites, several sections show a fringe of long rather strong fimbriæ attached to a more or less subtriangular base. The most striking examples are illustrated by figures 1-6, plate 100, of this paper. Raymond has given an interpretation of these in the restoration of the exopodite of *Ceraurus* (plate XI) which is represented as relatively short and about one-half the length of the endopodite; it is fringed with strong expanding filaments, the conception for which was probably derived from slide No. 22, illustrated by Walcott by a somewhat diagrammatic drawing in 1881, plate 3, figure 2, and 1918, plate 27, figure 12 and now by figure 2, plate 100. Several other slides show a somewhat similar structure; No. 21 (1918, plate 27, figure 11), No. 27 (Walcott 1921, plate 100, figure 5), No. 112 (Walcott 1921, plate 100 figure 4). All of which are of *Ceraurus* except Nos. 27 and 112 of *Calymene*. In each slide the supporting base of the fimbriæ or filaments is cut across at such an angle as to give a roughly subtriangular outline with the filaments attached on the broad outside margin. In slide No. 22 (plate 100, figure 2) the upper 12 filaments on the right side appear to be attached to a base and the lower four are probably the distal ends of filaments belonging to an adjoining base. In slide 45 (plate 100, figure 3) the filaments appear to belong to three bases; in slide No. 27 (plate 100, figure 5) they are attached to two, and in slide 112 (plate 100, figure 4) to one base. In none of these slides is there an indication of a long, broad arm or shaft of an exopodite such as is drawn in Raymond's restoration of *Ceraurus* (plate XI), or the long, narrow shaft in *Calymene* (figure 16, page 55), but several other slides appear to show sections of an elongate slender shaft, No. 109 (plate 97, figure 2), No. 12 (Walcott 1918, plate 27, figure 1) ; slide No. 12 may have been the one from which Raymond drew his figure 18, page 58, but which he refers to slide No. 111. The latter slide has a long slender appendage apparently attached to the section of the coxopodites beneath both the right and left pleural lobes. None of the slender appendages of these slides appear to have filaments attached to them, and several appear as though an undulating or straight ribbon-like tube had been cut longitudinally or slightly oblique to their axis and others are undoubtedly jointed; some resemble sections that might have been cut from the long cylindrical filaments of the branchiæ of *Cyamus diffusus* Dall (Walcott 1918, plate 28, figure 10).

In my paper of 1918 (page 150) the fimbriated appendages were considered to represent the epipodite of the ventral limbs, but Raymond (pp. 48-50) considers that they represent a section across the shaft of the exopodite with attached "setæ." The segmented spiral character of the arm of the exopodite of *Calymene* now being known, and the presence of a similar exopodite in *Ceraurus* being inferred from the spiral-like section of the arms, although the fringe of filaments has not been found attached to it, we have to interpret the other fimbriated appendages independently of the exopodites, as they do not appear to represent sections of the latter.

The exact form of the plate or body of this appendage cannot be accurately determined by the sections, but all of those seen have a roughly subtriangular section with a slender attachment to the coxopodite, or it may have been the basipodite as the two joints cannot be separated in the sections showing the fimbriated appendages under consideration. I am not convinced that the fimbriated appendages are undoubtedly epipodites but I do think that they are not exopodites. It has been suggested that they might be a modification of the exopodite attached to the cephalic limbs; this may be, but in one instance at least (figure 5, plate 100) they are *clearly* beneath a thoracic segment; in this section (No. 27, M. C. Z.) the slender arm of an expodite is shown on the right side and a little of the spiral structure of the arm.

It is not at all probable that the spiral arm of the exopodite of the thoracic limbs with its basal sheath and slender tubes would be replaced by such a structure as that shown by figures 1-6, plate 100. There is nothing in common between them except the fringing filaments.

The fringed epipodites of *Calymene* and *Ceraurus* (plate 100) are not unlike the epipodites of some of the thoracic limbs of the Euphausiacean *Meganyctiphanes norvegica.*[1] These epipodites are referred to as branchia; they are formed of a short base attaching them to the coxopodite of the thoracic limb and a transverse bar of varying form to which are attached numerous slender tubular filaments. Our figure 8, plate 100, may be compared with Dr. Calman's figure 141, *B* and *C*. The endopodite and exopodite of this species

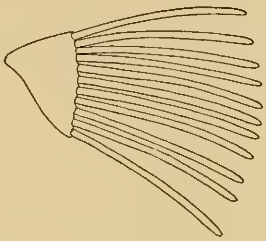

FIG. 20.—Outline of diagrammatic restoration of a fimbriated epipodite of *Ceraurus* based on figs. 1, 2 and 6, pl. 100.

are attached directly to the coxopodite. The epipodites hang freely at the sides of the body and are not covered by the carapace as are the podobranchiæ of the Decapoda and the trilobite.

The long slender jointed epipodites have a superficial resemblance to the branchiæ of the Amphipod *Paracyamus boopis*. (See Calman *idem.*, page 227, figure 135).

JOINTED EPIPODITES OF CALYMENE AND CERAURUS

Another distinct feature brought into prominence by recent photographs is that of the long, slender, rounded jointed appendages that occur in both *Calymene* and *Ceraurus*. In slide 109, plate 98, figure 1, these appendages are faintly seen, but with a very strong arc light they can be successfully photographed as shown by figure 2, plate 97. They are formed of long joints slightly expanded at their distal end and about three times as long as their diameter; these were attached to a larger proximal joint, figures 1, 3, 6, plate 97; figures 1-3, plate 104, and appear to have been nearly as long as the exopodite and to

[1] W. T. Calman, Treatise on Zoology, Lankester, pt. VII, 1909, fig. 141, p. 246.

have had five or more joints. The test of the joints was thin and readily distorted, as seen in figures 1, 3, 4, plate 97.

Some of the sections, figures 3, 4, plate 97, appear to have cut an undulating tube in which no joints are cut across. The few slides illustrated on plates 97, 104 exhibit the principal characters but they do not indicate as clearly as a direct comparison that these slender epipodites are smaller than the spiral arm of the exopodites and very much smaller than the jointed endopodite or leg of the trilobite; this is shown by figures 4, 7, 9, plate 98.

A jointed epipodite of this character is unknown to me, but as it cannot be an endopodite or exopodite and is a distinct recognizable form of appendage attached to the coxopodite, I think it best to tentatively refer to it as a peculiar form of epipodite situated above the exopodite beneath the ventral surface of the pleurotergites. Its function may have been to keep the branchial filaments or tubes of the exopodites clear of sediment and by gentle movement provide a constant supply of fresh water to them.

THORACIC LIMBS OF NEOLENUS, CERAURUS, CALYMENE AND TRIARTHRUS

The limbs of text figure 21 are very diagrammatic but they express my present conception of the parts that compose the thoracic limbs of the four genera named. It may be that the limbs of *Ceraurus* and *Calymene* will seem too complicated for a primitive crustacean, but all the elements shown appear to be present in the thin sections illustrated; the problem now is largely a question of interpretation and allocation of parts on the limbs. Dr. W. T. Calman states that the presence of epipodites and gnathobases suggests that the primitive crustacean limb was more complex than the simple biramous type.[1] Whether this view is correct or not the fact remains that the limb of the trilobites is far advanced along the line of evolution of the crustacean limb, also that the ancestors of the trilobite lived long before the advent of the Cambrian sea over the surface of the present continental areas. There is no attempt to show the details of the various parts of the limb, as they are outlined in the photographs of the sections on the plates and the diagrammatic text figures 11-14 for *Neolenus,* 16, 20 for *Ceraurus,* 17 for *Calymene,* 19 for *Triarthrus.*

[1] Treatise on Zoology. Lankester, pt. VII, 1909, pp. 8, 9.

Neolenus. (*A* of text figure 21). Ventral view of the coxopodite and six segments of the endopodite. The broad, flat arm of the exopodite is represented as attached to the limb at the proximal end of the basipodite and both join the distal end of the coxopodite in

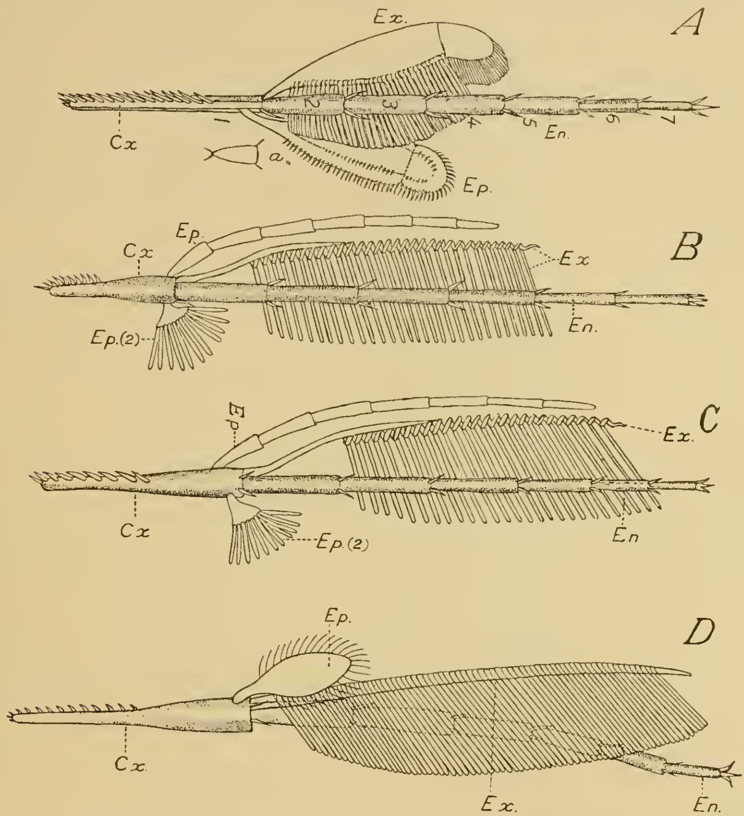

FIG. 21.—Thoracic limbs of *A* = *Neolenus; B* = *Ceraurus; C* = *Calymene,* and *D* = *Triarthrus.*

Legend. *cx.* = coxopodite. *en.* = endopodite. *ex.* = exopodite. *ep.* = fimbriated epipodite. *ep.* (2) = jointed epipodite.

In fig. *A,* 1 = coxopodite. 2 = basipodite. 3 = ischiopodite. 4 = meropodite. 5 = carpopodite. 6 = propodite. 7 = dactylopodite with terminal spines. Figs. *B, C, D* have the same joints in the endopodite as fig. *A.*

A, B and *C* are ventral veins, and *D* a dorsal view of the limb.

such a manner as to leave the fringed exopodite free to maintain a horizontal position above the endopodite; above and dorsal to the exopodite the plate-like epipodite is located; whether this is its natural position or whether it was located so as to be more or less between the endopodites is unknown, but from the location of most epipodites on the limbs of recent crustaceans it was presumably above both the endopodite and exopodite. A section of the coxopodite which is assumed to be sub-triangular in outline is outlined at (a).

Ceraurus. (*B* of text figure 21). Ventral view with the exopodite above the endopodite and the elongate slender epipodite outlined in the figure above the exopodite; although in a natural position it was probably just above the exopodite, which would place it back of it in the outline sketch; the second or fimbriated epipodite is represented as attached to the posterior side of the coxopodite near its distal end; several sections indicate that it may have been attached to the posterior margin of the broad dorsal or upper side of the coxopodite. (See figure 1, plate 99; figures 1 and 2, plate 100.)

The spiral arm of the exopodite shows only its lower or ventral side and the drawing of it and the attached slender tubes is purely mechanical; the manner of attachment of the tubes to the spiral arm is indicated in text figures 17, 17*a* of the exopodite of *Calymene*.

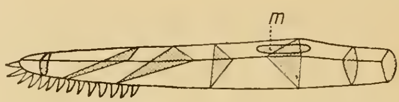

Fig. 22.—Outline of a coxopodite with sections drawn across it at various angles for the purpose of illustrating how varied the outline of the sections may be when a fossil coxopodite is cut at different angles. Some of these are shown in figs. 6 and 9, pl. 99; all on pl. 101; figs. 1 and 11, pl. 104.

Calymene. (*C* of text figure 21). The description of the thoracic limb of *Ceraurus* applies very closely to the limb of *Calymene;* they undoubtedly differ in details but in the sections it is difficult to determine to what extent except in the endopodites, and that the coxopodite of *Ceraurus* is probably shorter than that of *Calymene.* The joints of the endopodite of *Calymene* appear to have been rounder and less flattened and expanded at the distal end.

Triarthrus. (*D* of text figure 21). The thoracic limb of *Triarthrus,* like that of *Neolenus,* is known from more or less flattened specimens of it, while the limbs of *Calymene* and *Ceraurus* have been seen only in sections cut across them at various angles. The coxopodite is elongate, flattened so as to be deep on the sides, broad on the dorsal side, and thin on the ventral margin; the four proximal joints of the endopodite are flattened and the two distal joints rounded in cross section. The exopodite is more complicated than usually appears on the specimens showing the dorsal view, which is the one represented by *D,* figure 21. The dorsal view shows a long arm crossed diagonally by numerous narrow joint-like segments, and these are extended into long, slender, round filaments that judging from the branchial tubes of recent crustaceans, were slender tubes; on the dorsal side the narrow segments are not seen, but longer segments of a closely jointed arm that is well shown by figure 20, plate 95, of these notes, and in several of Beecher's specimens; the uncompressed undistorted form of the arm is best shown by figures 22, 23,

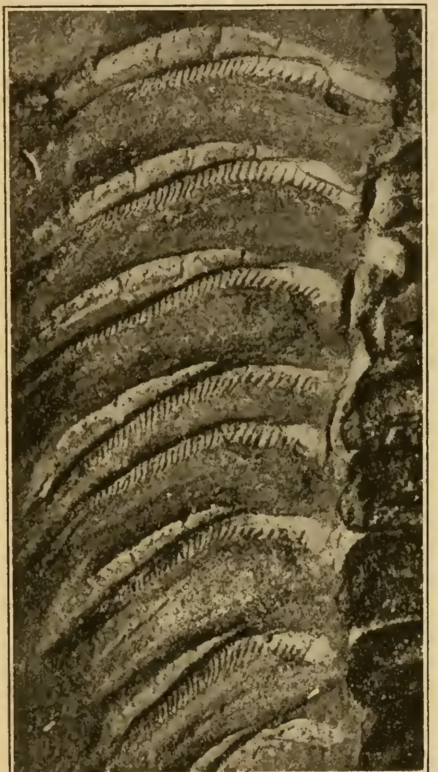

Fig. 23.—(× 12) Exopodites of *Triarthrus becki* Green. Photograph from specimen No. 204. Peabody Museum, Yale University.

plate 95, which is a dorsal view, the narrow segments having been detached from and pushed up off the jointed arm beneath.[1]

Raymond's diagrammatic outline of the thoracic limb of *Triarthrus* (page 126, figure 33) has on the exopodite a long solid proximal segment with fringing filaments corresponding to those of the closely jointed distal portion of the arm; this is based on specimen No. 204

[1] These are not true segments but a series of closely joined supporting sheaths of the fringing filaments. See exopodite of *Triarthrus*, fig. 23.

of Beecher, which is represented by a diagrammatic outline on page 155, figure 42. A careful study of the exopodites on specimen 204 and a comparison of them with the ventral side of other exopodites, shows them to be preserved in a natural condition up to the point where a secondary deposit of pyrite has merged the diagonally arranged supporting bases of the filaments into a continuous surface. On one of the posterior of the exopodites of 204 the process of merging the bases of the filaments is confined to the anterior side of the arm, and a few of them have escaped altogether. Sometimes the secondary deposit of pyrite forms a roughened botryoidal surface and in others it may be quite smooth.

From a study based on all the specimens available I think that the layer of supporting sheaths extends up to the point where the last proximal filament occurs and that the diagrammatic illustration (figure 33) of Raymond is incorrect.

The presence of an epipodite on the thoracic limb of *Triarthrus* has not been confirmed by additional evidence since the appearance of my paper of 1918, plate 30, figure 19. I have examined the specimen (No. 65525, U. S. N. M.) several times and can only repeat what I said in the description of the figure: " Photograph of a specimen that appears to indicate the presence of epipodites." It may be that the work that is soon to be done on a large number of specimens of *Triarthrus* may reveal more of this peculiar structure and prove or disprove that it represents an appendage independent of the endopodite and exopodite. Beecher largely obtained his remarkably fine results by working down on the ventral side of the trilobite, which would prevent his finding any small epipodite that might be attached to the dorsal side of the distal end of the coxopodite. As a tentative suggestion I still retain the outline of a small epipodite on the limb of *Triarthrus*.

SUPPOSED SPIRAL BRANCHIÆ IN SPECIMEN OF CALYMENE FROM OHIO

Mr. S. A. Miller called attention to a specimen of *Calymene* from the Cincinnatian series of Ohio, in which the fixed cheeks of the cephalon had been worn through so as to expose what he thought might be the cast of a spiral appendage.[1] The illustration strongly suggests that it is the arm of an exopodite such as occurs in the sections of specimens from the Trenton formation of central New York, but the examination of the specimen now at the U. S. National

[1] Journ. Cincinnati Soc. Nat. Hist., Vol. V, 1882, pl. 5, fig.8.

Museum shows that the ends of the posterior thoracic pleuræ have been pushed up against the inside of the pleural lobe of the cephalon so that when seen from above in the closely enrolled specimen they resemble the segments of the arm of the exopodite of *Calymene.* Dr. E. O. Ulrich was first to explain this curious and misleading specimen.

INTERNAL ORGANS

Alimentary canal.—Dr. Raymond adopts the view of Bernard (1894) and Jaekel (1901) that the alimentary canal of the trilobite was large, and publishes a drawing of a section of *Ceraurus* and one of *Calymene* (figures 22, 23, page 79) in support of it. My diagrammatic figure (1881, plate 4, figure 6; 1918, plate 28, figure 3) merely indicates the position and not the character of the canal, although figure 7, plate 3, 1881 shows the large "intestine" of *Ceraurus.* As I had occasion since 1918 to study the alimentary tract of crustaceans associated with *Neolenus serratus,* I also examined the photographs of many of the translucent sections of *Calymene* and *Ceraurus* to ascertain what light they might throw on the general question of the internal organs of the trilobite. The result is that I am now illustrating a number of the sections on plate 95, and describing them somewhat in detail: the evidence of the alimentary canal will first be considered.

In all of the many hundreds of sections of trilobites that I cut from the dark, fine grained Trenton limestone the visceral cavity beneath the axial lobe and the ventral appendages had been replaced by white calcite which outlined the parts with wonderful distinctness in contrast with the dark limestone matrix; the dorsal test and hypostoma were also usually replaced by calcite and often blended in with the calcite filling the visceral cavity, but sometimes distinctly separated from it by a clearly defined line; when any interior organ such as the alimentary canal was filled with food and mud while feeding or by infiltration after the death of the animal with fine, black calcareous ooze or silt, the canal retained its outline as shown by figures 1, 2, or it may have been distorted and forced out of place by compression, figures 3-12, plate 95. The section of figure 1 was probably at about the fourth thoracic segment, and it is probably the least compressed and distorted transverse outline of the alimentary canal of *Ceraurus* in the collection. The round dot on each side may be the section of an hepatic tube or sections of the flexor muscles. A very delicate white line indicating a firm structure arches from the two round lateral dots through the upper part of the dark alimentary canal that is a section of the articular projection of the next posterior mesotergite which has been pushed down a little; in figure 2 (specimen No. 205) the alimentary canal is nearly round and compares favorably with the section of figure 1; in figures 4-7, the canal has been somewhat flattened out by compression, also in figure 8, which is a slightly diagonal section; figures 8, 9, 10, show the canal displaced and distorted. What may be a portion of the canal or the heart in *Calymene* occurs in the upper portion of the axial lobe in the sections represented by figures 16, 17. As far as known to me none of the sections show the alimentary canal beneath the cephalon, but as Raymond states (pp. 80, 81), this is well shown in *Cryptolithus* from Bohemia. The restorations by Raymond, figure 24, page 81, of a longitudinal section, and figure 29, page 93, of a dorsal view of the alimentary canal are probably as nearly correct as can be made from available data.

Abdominal sheath.—The reproduction of the drawings (page 79, figures 21, 22) by Raymond of the "abdominal sheath," traced from photographic enlargements of slides No. 118 and No. 97, are not very conclusive evidence of the presence of such a sheath. The "dorsal sheath" of slide No. 118 is shown by our figure 16 plate 95, where it seems to represent an arched space filled in with the dark soft mud that constituted the matrix in which the trilobite was buried. The sheath of slide No. 97 may be a section of the articular extension of an adjoining mesotergite. There is in slide No. 27 (figure 1, plate 95 and figure 4, plate 103) a similar slender line arching over the upper part of the section of the alimentary canal that appears to have a definite outline like that of sections of the dorsal test (see figures 3, 4, plate 96).

Figures 3 and 4, plate 96, illustrate how it is possible that the so-called abdominal sheath is merely a section of the anterior part of the mesotergite where a vertical section cuts through the dorsal test, its anterior ventral extension and posterior articular extension. Such a section when cut transversely would give a section such as that of figure 4, plate 103.

Hepatic glands.—Under the heading of gastric glands (page 82) Raymond gives an historical outline of opinions of authors on the interior genal markings of trilobites, and concludes that they more likely represent either traces of the gastric cæca or of the circulatory system, and that the present evidence seems to be in favor of assigning to them the function of lodging the glands which secreted the principal digestive fluids. He speaks of similar markings occurring in *Naoria* and *Burgessia* of Walcott (1912, plates 27, 28), but does not state that the hepatic cæca of those genera are not markings on the test but are in the structure of the substance filling the space between the dorsal test and ventral membrane. Reference will be made to the probable hepatic glands of the trilobite in a paper that I now have in preparation on *Marrella, Burgessia, Naoria* and other Middle Cambrian crustaceans.

Heart.—Raymond states (page 85): "Nothing has been seen in the sections of *Ceraurus* and *Calymene* suggesting a heart." I thought the same until I noticed in slide No. 115 of *Ceraurus,* and No. 118 of *Calymene* (figures 16 and 17, plate 95), a dark, rather strong, arched line above the position of the alimentary canal that did not appear to be chitinous or to have any relation to the dorsal test. In both slides the arched line terminates at what may be sections of the dorsal flexor muscles of the axial lobe of the thorax; it is rather sharply marked by its dark color in contrast with the white calcite of the visceral cavity, and has a substantial thickness. It is customary to think of the elongate heart of a crustacean as circular or oval in outline, and it was not until I saw Dr. J. S. Kingsley's [1] drawing of the heart of *Limulus* as it appears in a transverse section of the abdomen that it occurred to me that the elongate arched line of slides 115, 118, might represent the heart of the trilobite. In the abdomen of *Limulus* the heart is transversely flattened and, with the large branchio-cardiac veins, extends nearly across the visceral cavity. This is merely a suggestion, but as I do not think the arched lines beneath the axial lobe of the dorsal test can represent the abdominal sheath or the articular anterior extension of the mesotergite, the theory that they may represent the heart may be worth consideration.

The heart of *Squilla mantis* is elongate, tubular and extends nearly the whole length of the thoracic and abdominal regions.[2] One can readily imagine such a heart flattening and curving over a mud-distended alimentary canal when the space was narrowed by compression between the dorsal test and ventral integument of the trilobite.

Musculature.—Dr. Raymond has presented the known evidence of muscles of the trilobite, but as he has not illustrated slide No. 114 which he mentions, I am giving a reproduction of a photograph of it in which the four dark spots occur, the upper two of which may represent the dorsal flexor muscles (figure 19, plate 95), also figures of five slides in which one or more similar spots occur. In slide No. 119, figure 18, plate 95, four dark spots occur almost as in slide No.

[1] Anniversary Mem. Boston Soc. Nat. Hist., 1880, pl. 2, fig. 4.

[2] Calman, Treatise on Zoology, Lankester, pt. VII, 1909, 324.

114; in figure 2, plate 95, of slide No. 205, three such spots occur on the right side along with two irregular spots; figure 17, slide No. 115, has a large ventral spot and two small dorsal spots; figure 16, slide No. 118, has two dorsal spots, and slide No. 27, figure 1, has twin circular dots on each side of the axial visceral cavity that indicate two ventral muscles near the cephalon. Raymond states that slides numbered 131, 140 and 199 also show similar spots.

The presence of these dark spots indicates a hollow tube-like opening in the substance of the matter filling the visceral area into which the silt filtered and replaced the muscle which had been removed after decomposition. When considering an explanation of the origin of the spots, I took a small alcoholic specimen of *Limulus* and cut out the dorsal carapace so as to leave the alimentary canal and flexor muscles exposed; the liver had decomposed so that the four strong flexor muscles were in strong relief; I then turned to Packard's drawing of a cross section through the cephalothorax in front of the heart, etc., of *Limulus*[1] and found the sections of four flexor muscles in the same relative position as the four spots in the sections of *Ceraurus*. In *Limulus* sections cutting across the flexor muscles further back beneath the cephalothorax show them in a different position, but I think we may reasonably infer that the spots in *Ceraurus* indicate the position of its flexor muscles. The replacement of casts of tubes and other organs in soft bodied animals by infiltration after the animal has been buried in silt or fine mud is beautifully illustrated by the replacement of tubes, etc., in the Middle Cambrian fossil medusæ.[2]

In some instances (figures 17, 18, 19, plate 95) the lower rounded triangular spots may be sections of the inward extension of the axial processes of the mesosternites of the dorsal test, as indicated by the sections represented by figures 1, 2, 3, 5-7, 10, plate 102. The upper spots do not permit of this explanation, and some of the ventral ones may be filled-in holes left by the decay of the muscles.

USE OF PYGIDIUM IN SWIMMING

Raymond presents several arguments in support of the theory that trilobites with large pygidia used them in swimming (pages 72, 73), but it is not easy to imagine a trilobite using its pygidium as an active agent in swimming or darting backward through the water to escape its enemies. The large pygidia were encumbered with a load of limbs

[1] Anniversary Mem. Boston Soc. Nat. Hist. IV, 1880, pl. 2, fig. 2.

[2] Monogr. U. S. Geol. Survey, Vol. 30, 1898, pl. 4, figs. 7-12; pl. 17, fig. 3*a*.

composed of at least a separate endopodite and exopodite that were more adapted to creeping or walking and swimming forward than to being flattened against the ventral surface of the pygidium so as not to act as a drag in any quick motion of the pygidium or the backward movement of the animal. All the restorations of the trilobite by Beecher, Raymond, and Walcott indicate a ventral surface with the appendages so arranged as to facilitate a relatively slow forward movement when swimming or crawling. The species with large pygidia were well adapted to lying close to the bottom partly buried in the sand, mud or silt, which would have given them ample protection.

The species with small pygidia greatly outnumber those with large pygidia, and they survived in great numbers, although powerful enemies existed as far back as Middle Cambrian time. *Sidneyia inexpectans*[1] must have been a strong, rapid swimmer, and with its broad fan-like caudal fin could have readily overtaken and captured with its great chelate cephalic limbs any swimming trilobite.

COXOPODITES AND TRAILS OF TRILOBITES

Raymond long ago called attention, in the description of a new species of *Isotelus,* to the relation between the long "gnathobases" of *Isotelus* and certain markings on sandstones from the Chazy formation.[2] I had not noted this when preparing my paper of 1918 on the Appendages of Trilobites, and hence did not refer to it. I then called attention to tracks and trails supposed to have been made by trilobites, and spoke of the curious and interesting trails in which the impression of long endopodites (coxopodites) were very numerous, and gave several illustrations of them.[3] Some of the trails are so strikingly similar to what a trilobite would naturally make that there does not appear to be any other interpretation of them as there is no form in the associated invertebrate life that I can imagine making such trails.

ISOTELUS MAXIMUS Locke

Raymond concludes that the endopodites of *Isotelus* were composed of cylindrical segments (page 75), but I find that the specimen of *Isotelus maximus* Locke (Walcott 1918, plates 24, 25; U. S. National Museum Catalogue No. 33458) shows very distinctly verti-

[1] Smithsonian Misc. Coll., Vol. 57, 1911, pls. 2-5.

[2] Ottawa Naturalist, Vol. 24, pp. 131-133.

[3] Smithsonian Misc. Coll., Vol. 67, No. 4, 1918, pls. 38-40.

cally flattened coxopodites and a slight flattening of the basipodite and of three proximal joints of the endopodites; the other joints of the endopodites appear to be rounded on the ventral side, but none of them show a complete transverse section of the joints; it is also to be recalled that the appendages of this specimen underwent more or less maceration and compression when embedded in the calcareous mud that now forms its matrix, and that it also was more or less abraded before being rescued from quarry rubbish and the wagon seat of the teamster who picked it up.

Raymond was unable to see the slender markings (page 36) that Walcott represented in the diagrammatic figure of the appendages of *Isotelus maximus* (Walcott 1918, plate 25), but I find they are still on the specimen and can readily be seen by reflected light when the surface of the rock is washed clean of dirt and finger marks and kept wet; the slender fimbriæ-like exopodite markings were evidently above and not below the endopodites, although the Walcott figure (Science, Vol. 3, 1884, page 280, figure 1) has the slender fimbriæ apparently below the two posterior endopodites on the right side of the figure, but the endopodites are outlined in the drawing from a slight and faint impression on the rock that leads to the distal joints which are imperfectly preserved. If the entire endopodites were present they would be above the fimbriæ in the drawing, or below them if the animal was in a natural position.

The coxopodites of *Isotelus* were probably used to aid in pushing the trilobite forward when on a sandy or muddy surface, as shown by trails on the surface of sandstones of the Middle and Upper Cambrian (Walcott, 1918, plates 37-40), but I think the short stout legs enabled the animal to creep about without difficulty both on the bottom under water, and in the shallows on the beach between tides.

ORDOVICIAN CRUSTACEAN LEG

Raymond (pages 56, 57) had difficulty in dealing with the slender crustacean legs (endopodites) that occur on the surface of limestone shale from the Trenton Point Pleasant formation near Covington, Kentucky. Walcott illustrated (1881, plate 6, figure 5) two of the legs, stating (page 207) that they compared with the leg as restored in *Calymene*. Walcott again in 1918 figured five of the legs (plate 36, figures 2 *a-d*) as they occur on specimen No. 65532 (U. S. National Museum catalogue) and gave a restoration of the leg (figure 1) with its eight joints which include a long slender distal joint (dactylopodite); a propodite about half as long as the distal joint; three joints (carpopodite, meropodite, ischiopodite) a little longer than the propodite; a sixth joint (basipodite) about as long as the propodite; a short seventh joint (coxopodite), and a still shorter eighth joint which corresponds to the precoxal joint of the thoracic leg of *Nebalia bipes,* as described by Hansen.[1] This leg is unlike that of the limb of any known trilobite as it has neither the long, strong coxopodite nor the broad joints of the endopodite. It also differs in the character of the joints and the manner of their articulation.

Raymond (page 57) was unable to count more than seven joints on any of the specimens of the legs; he evidently failed to see the small precoxal joint which occurs on four of the legs.

NOTE ON OCCURRENCE OF THE OLDEST KNOWN TRILOBITE

The oldest Cambrian fauna containing trilobites is the *Nevadia weeksi* fauna of Nevada. This fauna continues far below the *Mesonacis gilberti* fauna of the upper portion of the Lower Cambrian and there are no trilobites known from the 5000 feet (1524 m.) of strata in which it occurs except genera of the Mesonacidae, *Nevadia, Holmia, Olenellus,* except a fragment of a *Ptychoparia* somewhere in the upper 400 feet.[2]

Nevadia weeksi Walcott has a large cephalon, twenty-eight thoracic segments, a very small plate-like pygidium without a defined segment.[3]

Holmia rowei Walcott has a large cephalon, sixteen thoracic segments and a very small pygidium with one distinct segment.[4]

The above two species are all that were found in the lower strata. A fragment of what may have belonged to an *Olenellus* occurs 1000 feet (304.8 m.) or more above and over 3000 feet (914.4 m.) above the cephalon of a trilobite tentatively referred to *Olenellus, O. claytoni.*[5]

There are no traces in this primitive fauna of any trilobite with a large pygidium and the early stages of growth of the young of the Mesonacidae all have a very large cephalon and a minute pygidium.

The genera *Microdiscus* and *Eodiscus* appear in the later formations of the Lower Cambrian series. It would seem that if these

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[1] Ann. and Mag. Nat. Hist. (6) XII, 1893, p. 422.

[2] Smithsonian Misc. Coll., Vol. 53, No. 5, 1908, p. 189.

[3] Smithsonian Misc. Coll., Vol. 57, No. 6, 1910, pl. 23.

[4] Idem, pl. 29.

[5] Idem, pl. 40, figs. 9-11.

forms with a large pygidium were the primitive type of the trilobite they should occur in great variety and numbers in the earlier Cambrian faunas.

Raymond has assembled an interesting series of observations to sustain the view that the primitive trilobite was a flat, free swimming form with a subequal cephalon and pygidium, and his discussion will serve to stimulate the search for more and more primitive faunas in the older sedimentary formations.

CONCLUSION

The additional data added in these notes relates to the thoracic limbs of *Neolenus,* the spiral exopodites and epipodites of *Calymene* and *Ceraurus,* the exopodites of *Triarthrus,* and the large, clear photographs of the thin section of *Calymene* and *Ceraurus.* The items mentioned are not at all sensational in character but they add to our knowledge of the structure of the limbs of the trilobite. Each item has taken much time and energy to work out as it involved the examination of many specimens, the cutting of thin sections, and the taking of many photographs.

Copies of the principal photographs will be sent to at least sixteen of the museums of the world where special attention is given to invertebrate paleontology, in order that students may have access to some of the evidence on which my conclusions are based as direct from the specimens as it is possible to present it.

My interest in the organization of the trilobite has been revivified by this study and I hope to add a little more to what is now known, in the course of two or three years.

DESCRIPTION OF PLATE 91

PAGE

Neolenus serratus Rominger 369-375, 380-394

FIG. 1. (Natural size.) Photograph of a specimen preserving more or less of 15 ventral limbs, the antennules and one of the caudal rami on the right side. One ventral limb has been torn away at 7 and the shaft of an exopodite is partly preserved above limb No. 9; the latter is clearly shown in fig. 2, pl. 93. The 4 anterior or cephalic limbs as enlarged are shown by fig. 1, pl. 93, and the 8 posterior limbs by fig. 2, pl. 93. The numbers 1-4 = cephalic limbs; 5-11 = thoracic limbs; 12-16 = pygidial limbs.

The matrix of this specimen is on the upper portion of a piece of shale illustrated by pl. 15 of this volume (Smithsonian Misc. Coll., Vol. 67, 1918). U. S. National Museum, Catalogue No. 58588.

2. (× about 6.) The coxopodite *B, C, D,* of text fig. 15 (p. 383) enlarged and lighted from the lower right side so as to bring out the ventral and proximal spines on the coxopodite *D.* The lower ventral margin of coxopodite *C* passes beneath *D,* so as to conceal its ventral row of spines. Coxopodite *B* is free but molded over the impression of the pleural segment of the dorsal test; it has a few ventral spines, as has the basipodite (2), and the ischiopodite (3), and the meropodite (4).

The lettering and numbering is the same as for text fig. 15 (p. 383)

The specimens illustrating *Neolenus serratus* are from locality 35k, Middle Cambrian: Burgess shale member of the Stephen formation, on the west slope of the ridge between Mount Field and Wapta Peak, 1 mile (1.6 km.) northeast of Burgess Pass, above Field, British Columbia, Canada.

Calymene senaria Conrad 394

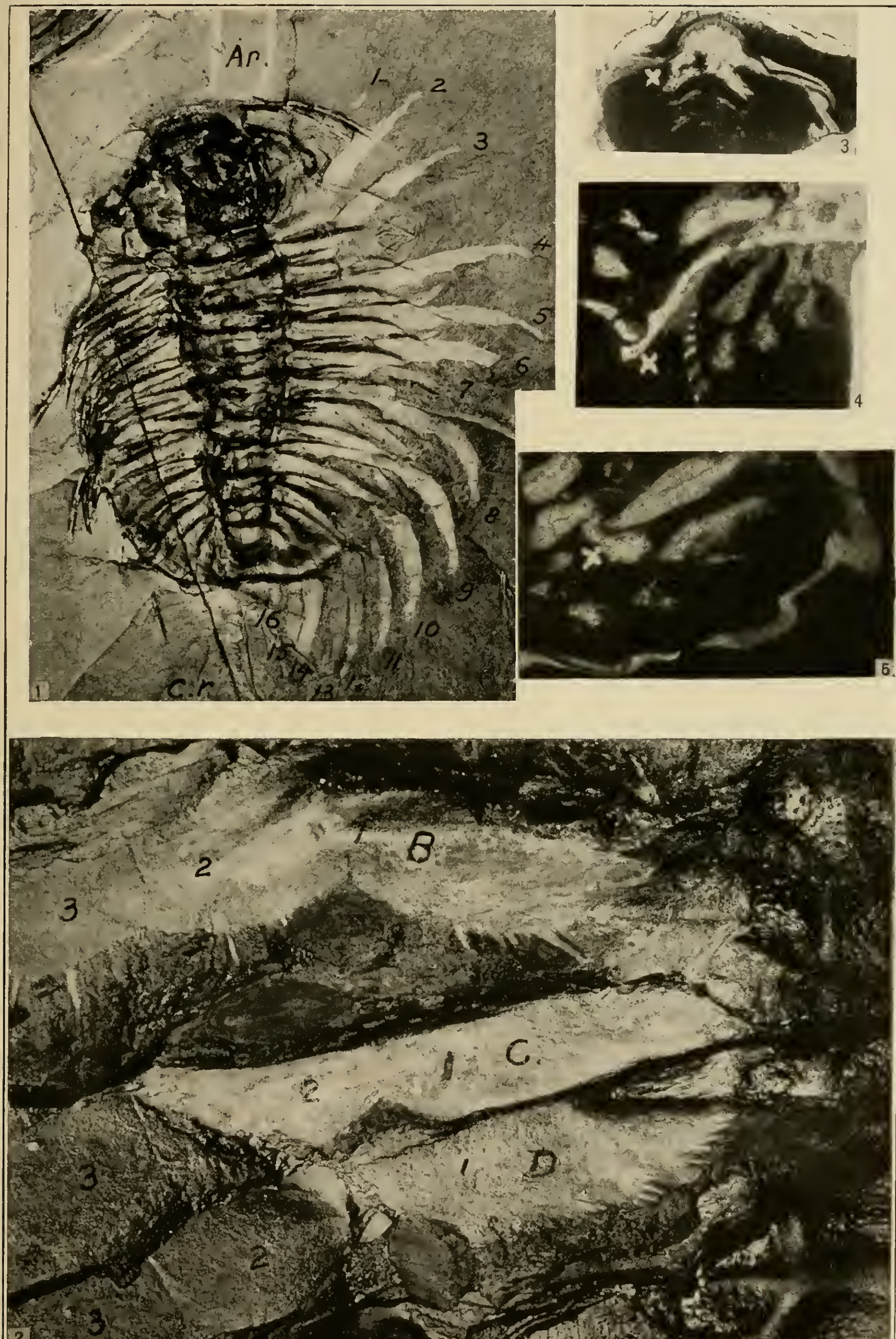
FIG. 3. (× 6.) (See fig. 4, pl. 99). Transverse thoracic section on which Raymond (p. 53, fig. 15) based the "ball-and-socket" joint theory of the mode of attachment of the ventral limb of this species. The joint being at x. (See also figs. 4 and 5). (Slide No. 63, M. C. Z.).

4. (× 8.) Portion of a transverse thoracic section in which a "ball-and-socket" joint-like effect occurs near the distal end of an endopodite at x. (Slide No. 48, M. C. Z.)

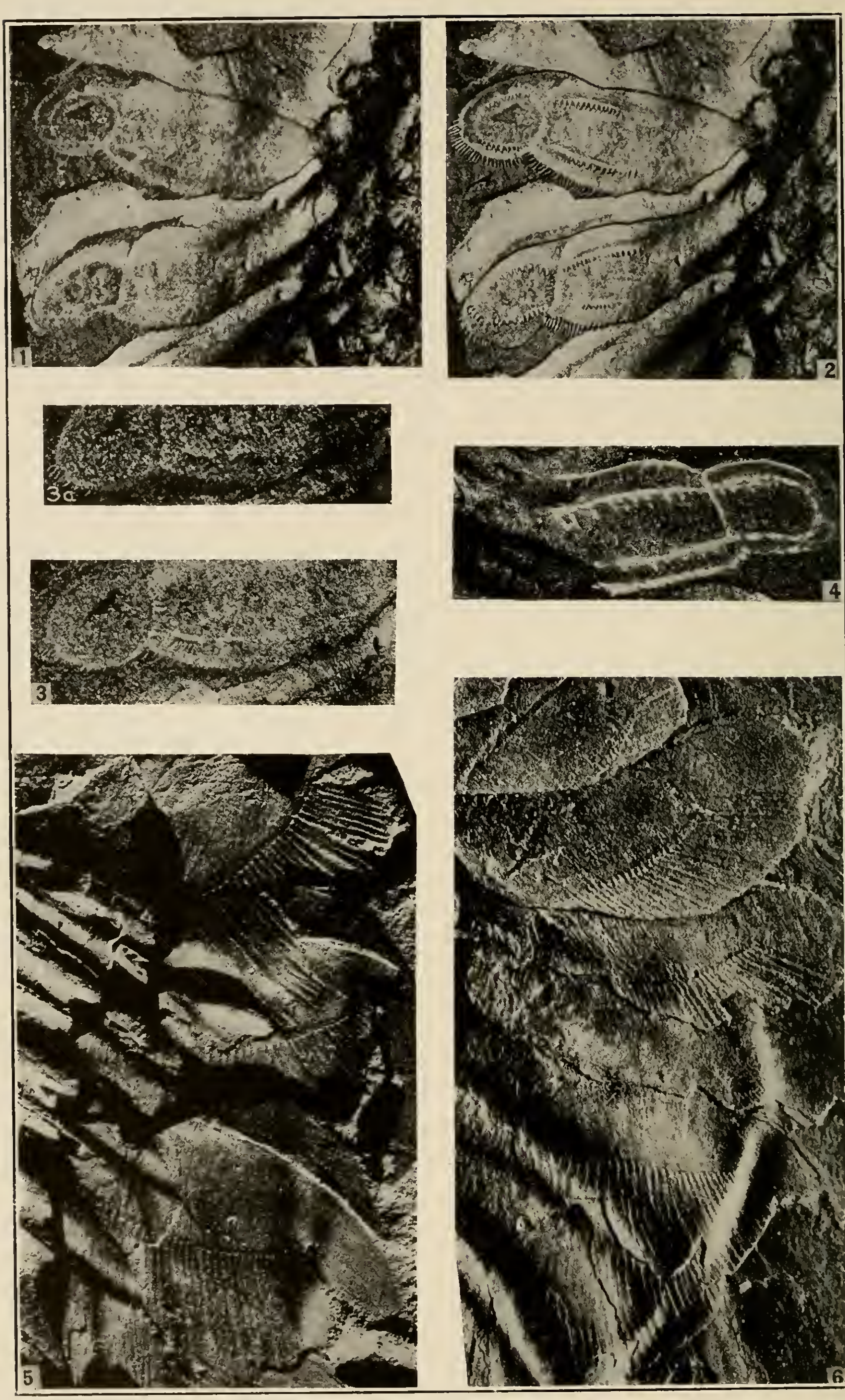
Ceraurus pleurexanthemus Green 400

FIG. 5. (× 6.) Portion of a transverse thoracic section in which a "ball-and-socket" joint-like effect occurs where a broken and distorted endopodite comes close to another fragment of an endopodite at x. (Slide No. 239, M. C. Z.)

The specimens illustrated are from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.



LIMBS OF NEOLENUS, CERAURUS AND CALYMENE



EXOPODITES AND EPIPODITES OF NEOLENUS

DESCRIPTION OF PLATE 92

PAGE

Neolenus serratus (Rominger) (see pl. 20 of this volume, published in 1918) 369-375, 380-394

FIG. 1. (× 3.) Untouched photograph of two of the large epipodites of the thoracic limbs, showing their tenuous character, minute marginal and carinal spines, the lines of the carinae, and the distinctness of the large proximal and small distal joints... 389

2. (× 3.) Same photograph as that represented by fig. 1, on which the minute marginal and carinal spines have been outlined by darkening the background.

The specimen represented by figs. 1 and 2 is the same as that represented by fig. 3, pl. 20, Smithsonian Misc. Coll., Vol. 67, No. 4, 1918, U. S. National Museum, Catalogue No. 65515. Photograph by R. S. Bassler.

3. (× 3.5.) Untouched photograph of a slightly greater enlargement of the upper epipodite of fig. 1, in which the base of the carinal spines is more clearly indicated.

3a. (× 3.5.) Untouched photograph of the lower margin of the epipodite represented by fig. 3, in which the fine spines are more clearly defined. The spines should be compared with laminated filaments of the exopodite as shown on figs. 5 and 6. Photograph by L. W. Beeson. U. S. National Museum, Catalogue No. 65515.

4. (× 3.5.) Photograph of the matrix of one of the lower epipodites on the specimen illustrated by figs. 3 and 4, pl. 20, of brochure No. 4 of this volume (67), enlarged so as to show the carinal spines which have been retouched to bring them out more clearly.

Photograph by L. W. Beeson. U. S. National Museum, Catalogue No. 65515.

5. (× 3.) Untouched photograph illustrating narrow, fringing lamellar filaments of the thoracic exopodites. This enlargement is from the upper portion of the specimen represented by figs. 1 and 2, pl. 23, of brochure No. 4 of this volume (67). The exopodites are lying above and on the endopodites. Nearly all details of structure were lost in the reproduction of the original figures.................................... 392

Compare lamellar filaments with fine fringing spines of epipodites, figs. 1-3. U. S. National Museum, Catalogue No. 65521. Photograph by L. W. Beeson.

6. (× 4.) Untouched photograph of posterior exopodites on the specimen represented by fig. 3, pl. 19, of this volume, in which the exopodites are lying above and on the endopodites. The photograph was made from the matrix. The lamellar elements or filaments of the posterior margin are clearly shown. In both of the exopodites the distal joint has been pressed slightly out of position and the short fringing filaments appear as a portion of the body of the joint which gives a false impression as to its form. U. S. National Museum, Catalogue No. 65514. Photograph by L. W. Beeson.. 388

The specimens represented on this plate are all from locality 35k, Middle Cambrian: Burgess shale member of the Stephen formation, on the west slope of the ridge between Mount Field and Wapta Peak, 1 mile (1.6 km.) northeast of Burgess Pass, above Field, British Columbia, Canada.

DESCRIPTION OF PLATE 93

Legend

ex = exopodite.	*car* = carpopodite.
cox = coxopodite.	*pro* = propodite.
bas = basipodite.	*dac* = dactylopodite.
mer = meropodite.	*cl* = terminal claws.
isch = ischiopodite.	

PAGE

Neolenus serratus Rominger 369-375, 380-394

FIG. 1. (× 3.3) Reproduction of a photographic enlargement of the four anterior limbs of the right side of fig. 1, pl. 91, (Specimen 58588) to illustrate the form of the cephalic limbs, which is similar as far as known, except in a few minor details, to that of the limbs of the thorax and pygidium... 390

2. (× 3.3) Reproduction of a photographic enlargement of the eight posterior limbs of the right side of fig. 1, pl. 91, to illustrate the spiniferous coxopodites and the close attachment of the endopodites to them. The jointing of the endopodites is clearly preserved, also the ventral margin of the endopodites, but their dorsal (anterior in the figure) margin has been cut away from the coxopodite and basipodite of three of the limbs where they rested on the ventral (posterior in the figure) margin of the next anterior limb and concealed the margin and spines of the ventral side. Three of the limbs show the "notch" of Raymond between the coxopodite and basipodite. Note the strong group of spines on the basipodite and ischiopodite and that the grouping of the ventral spines midway of the basipodite is successively nearer the distal end of the ischiopodite, meropodite, carpopodite, and propodite where it is at the end of this joint and the two succeeding distal joints. The large spine with the smaller spines corresponds to the ventral angle of the flattened joints of the endopodite of *Triarthrus becki*.[1]

The specimens illustrating *Neolenus serratus* are from locality 35k, Middle Cambrian: Burgess shale member of the Stephen formation, on the west slope of the ridge between Mount Field and Wapta Peak, 1 mile (1.6 km.) northeast of Burgess Pass, above Field, British Columbia, Canada.

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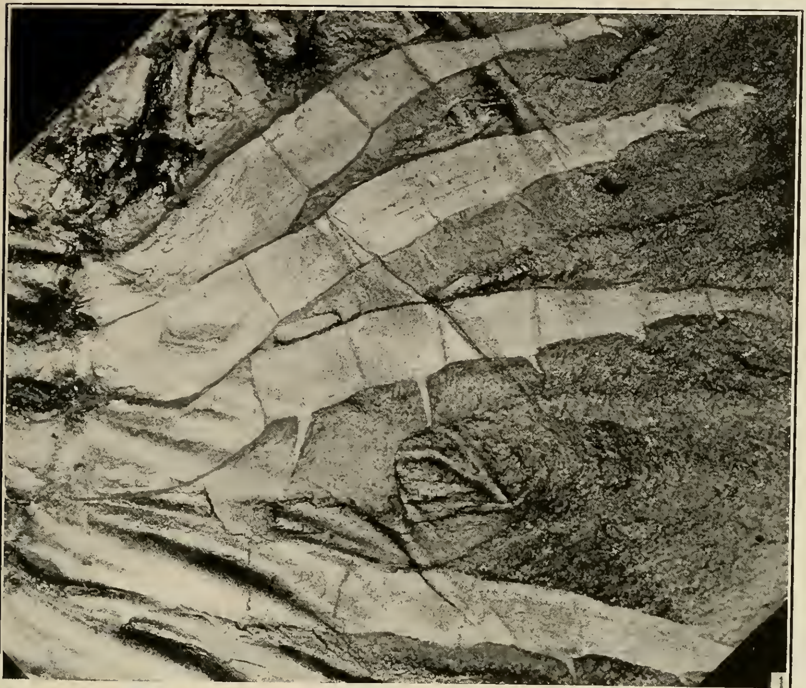
[1] Walcott, Smithsonian Misc. Coll., Vol. 67, 1918, pl. 30, fig. 20.



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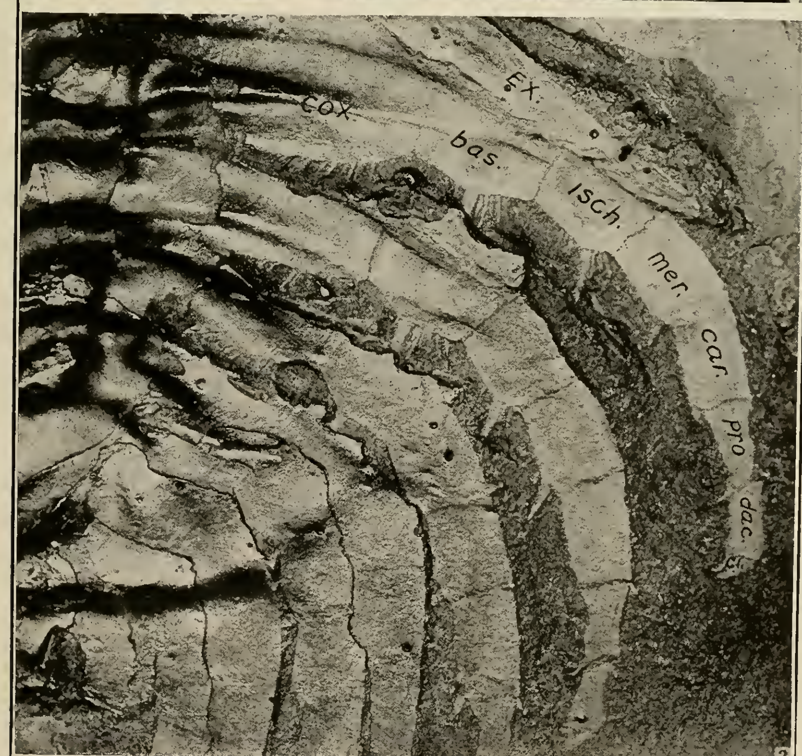

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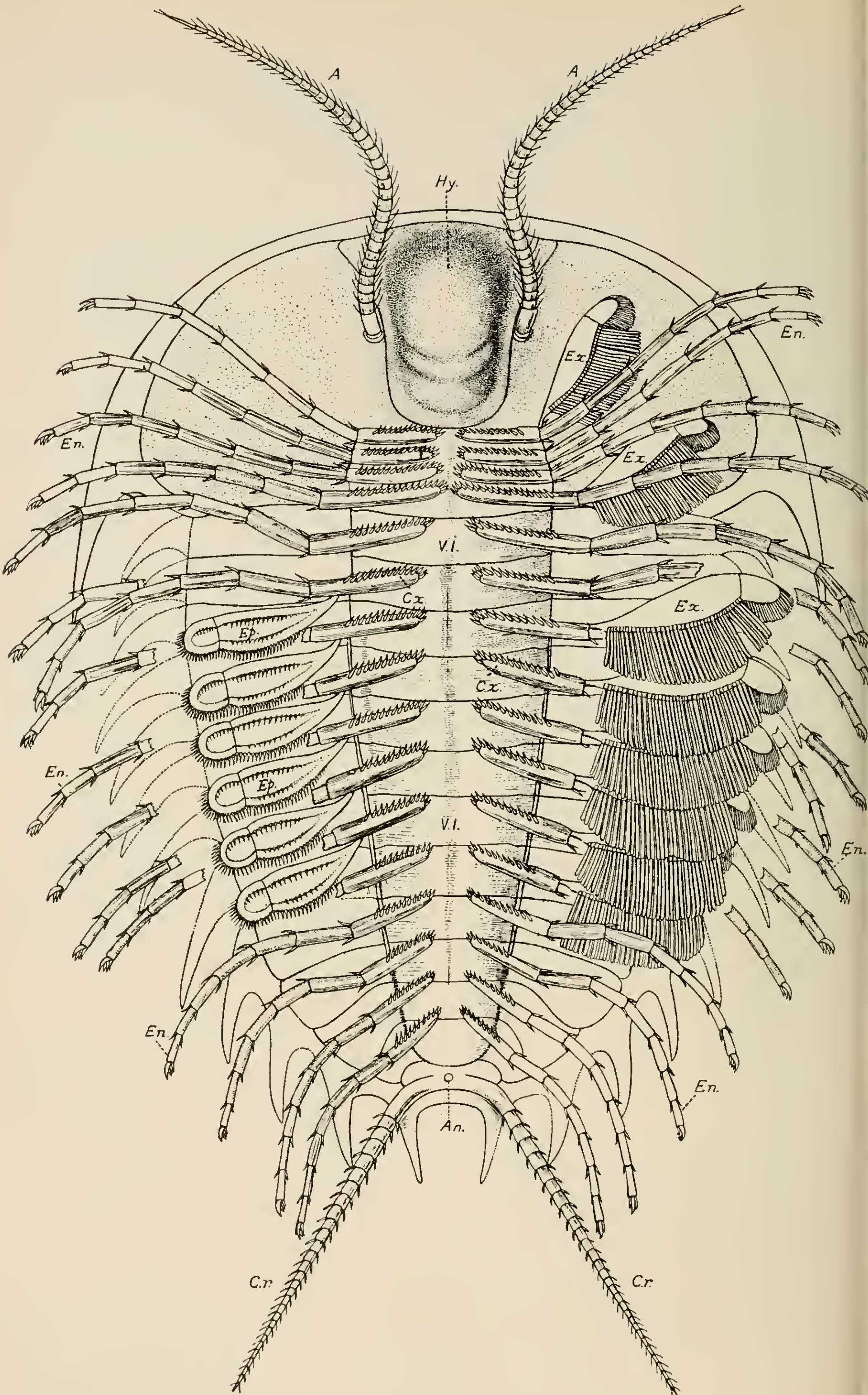
LIMBS OF NEOLENUS SERRATUS



RESTORATION OF VENTRAL SURFACE OF NEOLENUS SERRATUS (Rominger)

DESCRIPTION OF PLATE 94

Legend

d. s. = dorsal shield.	*en.* = endopodite.
hy. = hypostoma.	*ep.* = epipodite.
a. = antennules.	*ex.* = exopodite.
an. = anal aperture.	*cx.* = coxopodite.
c. r. = caudal rami.	*v. i.* = ventral integument.

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Neolenus serratus (Rominger) 392

FIG. 1. (About twice the large-sized specimens of the species.) This outline restoration differs in details from that published in 1918 (pl. 31) and in the omission of the small epipodite and exite attached to the coxopodite of the post-cephalic limbs.

The observer should note that the coxopodite and endopodite are seen from their narrow lower or ventral side; that the exopodites lie nearly in a horizontal position above the endopodites and that the epipodites are in a nearly flat position between the ventral membrane and the exopodites.

The arrangement of the cephalic limbs is diagrammatic, being based on their known position in *Triarthrus becki* and incomplete data for *Neolenus*.

DESCRIPTION OF PLATE 95

PAGE

Ceraurus pleurexanthemus Green 394-412

FIG. 1. (× 4.) Transverse section at about the fourth thoracic segment of a partially enrolled specimen showing alimentary canal; filamentous appendages on the left side close to the coxopodite of the thoracic limb and on the right side a spiral-like structure similar to that in fig. 1, pl. 96. In the lower part of fig. 1 there are circular dots on the line of the dorsal furrows of the dorsal test that may indicate the position of flexor muscles. (Slide No. 27, M. C. Z.)

2. (× 4.) Transverse thoracic section of an enrolled specimen with a distorted section of the alimentary canal. (Slide No. 205, M. C. Z.)

3. (× 4.) Diagonally transverse thoracic section with a small rounded section of what may represent the alimentary canal. (Slide No. 65, M. C. Z.)

4. (× 4.) Transverse thoracic section cut obliquely down through the axial lobe. (Slide No. 244, M. C. Z.)

5. (× 4.) Transverse thoracic section with the alimentary canal compressed as in fig. 6. (Slide No. 83, M. C. Z.)

6. (× 3.) Transverse thoracic section preserving the outline of a somewhat compressed alimentary canal, section of a coxopodite of a ventral limb and sections of ribbon-like slightly undulating appendages referred to as epipodites. See figs. 3 and 4, pl. 97. (Slide No. 13, M. C. Z.)

This section was illustrated by a drawing based on a photograph by Walcott, 1881, pl. 2, fig. 3, and a photograph in 1918, pl. 26, fig. 14.

7. (× 6.) Transverse thoracic section in which the alimentary canal has been greatly distended and distorted; see figs. 9 and 12. (Slide No. 135, M. C. Z.)

8 and 10. (× 3.) Transverse thoracic section in which an inward extension or process of the articular fold of the dorsal test is preserved on the left side at the union of the mesotergite and pleurotergite and above the coxopodite of the ventral limb. What may be the displaced alimentary canal is indicated by the transversely oval black space beneath the dorsal test of the axial lobe. (Slides M. C. Z. No. 117 = fig. 10, and No. 202 = fig. 8.)

9. (× 10.) Transverse thoracic section in which the upper margin of the enlarged alimentary canal appears to have been crowded up against the articular extension of a segment of the dorsal test as in figures 5, 6, 13. (Slide No. 39, M. C. Z.)

10. (See fig. 8.)

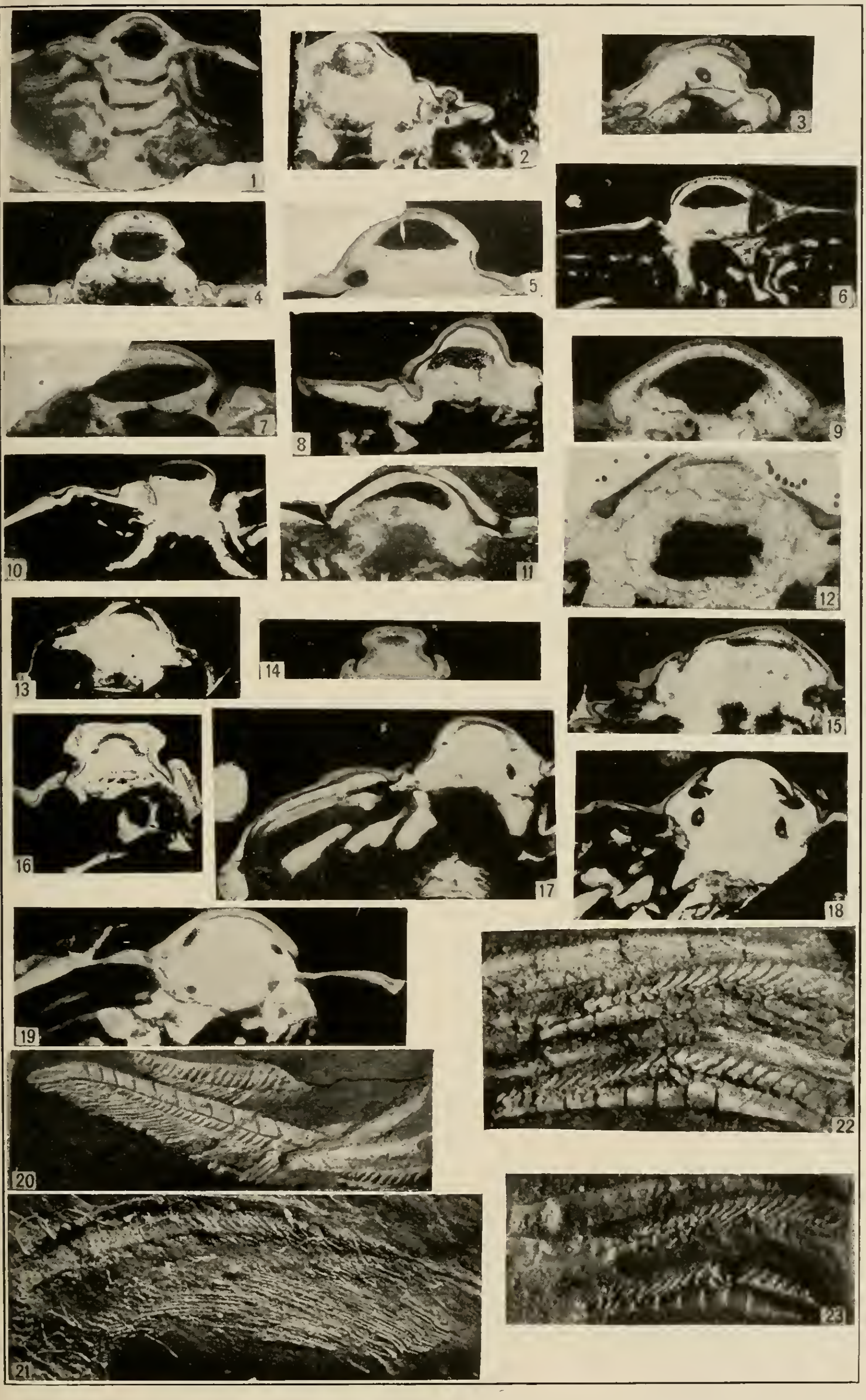
11. (× 4.) Transverse thoracic section of an enrolled specimen showing oblique compressed section of the alimentary canal and traces of coxopodites of ventral limbs. (Slide No. 110, M. C. Z.)

12. (× 10.) Transverse thoracic sections with a curiously distorted and displaced alimentary canal. (Slide No. 148, M. C. Z.)

13. (× 3.) Transverse cephalic section showing portion of a displaced alimentary canal crowded up against the articular extension of one of the mesotergites. (Slide No. 228, M. C. Z.)

15. (× 4.) Transverse thoracic section to illustrate what may represent a collapsed alimentary canal crowded high up in the visceral space of the axial lobe. (Slide No. 112, M. C. Z.)

17. (× 4.) Transverse thoracic section showing supposed position of two dorsal flexor muscles, a triangular section of a coxopodite, and on left side portions of three ventral limbs. (Slide No. 115, M. C. Z.)



SECTIONS OF TRILOBITES

PAGE

Calymene senaria Conrad....................................... 394-412

Fig. 14. (× 5.) Transverse section showing an elongate collapsed alimentary canal crowded up into the thoracic axial lobe; the entire section is shown by fig. 5, pl. 101. (Slide No. 9, M. C. Z.)

This section was illustrated by a drawing based on a photograph by Walcott, 1881, pl. 1, fig. 9.

16. (× 3.) Transverse thoracic section showing position of two supposed dorsal flexor muscles and what may be a trace of the transversely arched heart. (Slide No. 118, M. C. Z.)

18. (× 4.) Section similar to that represented by fig. 19, except that the two dark ventral spots are not quite in the same position. Attention is called to other details in the description of the slide. (Slide No. 119, M. C. Z.)

19. (× 4.) Transverse thoracic section showing supposed position of dorsal flexor muscles, section of coxopodites of ventral limbs, and points of fold of articular projection of a mesotergite. (Slide No. 114, M. C. Z.)

The slides represented by figures 1-19 were made by me and are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

The sections illustrated are of trilobites from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.

Triarthrus becki Green...413-415

Fig. 20. (× 15.) Exopodite with the joints of the supporting arm, flattened and appearing in a slightly oblique position instead of vertical as in figs. 22 and 23, also diagonally arranged branchial tube bases and slender flattened tubes. This specimen was illustrated by Walcott, 1918, Smithsonian Miscellaneous Collections, Vol. 67, pl. 29, fig. 11.

21. (× 12.) Long slender branchial tubes matted together so as to give the appearance of fine flat filaments of which there are about 40 attached to the bases attached to the arm of the exopodite. U. S. National Museum, Catalogue No. 68387.

22. (× 10.) Specimen illustrated by fig. 23 lighted from right side so as to show the joints of the supporting arm of the exopodite, also the bases of the branchial tubes, more in detail. This specimen was illustrated by Walcott, 1918, Smithsonian Miscellaneous Collections, Vol. 67, pl. 29, fig. 3. U. S. National Museum, Catalogue No. 65523.

23. (× 8.) This specimen reveals the ventral side of the jointed supporting arm of two of the exopodites and the dorsal layer of bases of the branchial tubes or filaments which have been displaced and pushed forward from the supporting arm; a portion of two of the endopodites projects from beneath the exopodites.

The specimens illustrated by figs. 20-23 are from locality 373, Ordovician: Utica shale; 3 miles (4.8 km.) north of Rome, Oneida County, New York.

DESCRIPTION OF PLATE 96

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Calymene senaria Conrad 394-412

FIG. 1. (× 15.) Photograph of a translucent longitudinal section of a partially enrolled trilobite in which the exopodites have been displaced and nine of them cut across so as to illustrate the spiral structure of the supporting arm. Exopodite number 5 has a number of the branchial tubes or filaments attached to the arm, and number 6 apparently cuts across the plane of the insertion of three of the branchial tubes into the supporting base. A few fragments of endopodites are cut across in the upper right corner of the photograph. More of the latter occur further forward in the slide as shown in fig. 2. The dorsal test of this specimen was exfoliated except a little of it on the pygidium as shown in fig. 2. (Slide No. 68379 U. S. N. M.) This slide was made March 8, 1921.

2. (× 4.) This is the same section as that illustrated by fig. 1. It illustrates how difficult it is to obtain a good photograph of the ventral limbs in a small enlargement of the section of the trilobite in the slide.

3. (× 10.) Enlargement of a longitudinal section of three segments of the axial lobe to illustrate the posterior under fold of the dorsal test and how transverse sections cut at I, II, and III would give two sections of the dorsal test, the lower one or the articular projection of the mesotergite apparently misled Dr. Raymond in interpreting it as an abdominal sheath. If the section had been cut nearer the center of the axial lobe it would have shown the articular extension of the axial segments about the same as in fig. 4. (Slide No. 68807, U. S. N. M.)

Ceraurus pleurexanthemus Green 394-412

FIG. 4. (× 10.) Longitudinal section of the axial lobe cutting the dorsal test of the cephalon and that of three anterior thoracic segments. The vertical white lines I, II, III, pass through the dorsal test of each segment in the same manner as the black lines of fig. 3. They cut the infolded posterior margin and the arched anterior articular extension of the mesotergite. This explains the section of the dorsal test with the "Abdominal sheath" of Raymond and an occasional second "sheath" as shown in transverse sections of the thorax. (See figs. 1, 3, 4, plate 95, and Raymond's figs. 21, 22, p. 79.)

Two sharply elevated tubercles with their hollow interior and minute canal penetrating the cephalic test are also finely preserved. Slide No. 159, M. C. Z.)

The specimens illustrated on this plate are from the Ordovician; upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.

SECTIONS OF TRILOBITES

DESCRIPTION OF PLATE 97

PAGE

Ceraurus pleurexanthemus 394-412

FIG. 1. (× 18.) Enlargement of the round, slender jointed epipodites that occur on the right side of section represented by fig. 4, pl. 98. The relative size of the endopodite, spiral arm of exopodite and these slender appendages is shown by fig. 4, pl. 98. Fig. 2 of pl. 97 shows the jointed character of the epipodites much more definitely. (Slide No. 120, M. C. Z.)

2. (× 16.) Enlargement of the round, slender jointed epipodites that occur on the right side of section represented by fig. 1, pl. 98. The three appendages in this section prove their jointed character and that they are hollow and either round or oval in cross section. (Slide No. 109, M. C. Z.)

3. (× 16.) Enlargement of two sections of round, slender undulating epipodites and a portion of one above that has been sectioned more on the line of its median axis. The position of these epipodites in the trilobite is shown by fig. 7, plate 98. (Slide No. 204, M. C. Z.)

4. (× 18.) Section somewhat similar to that represented by fig. 3, except that it has a section of a distorted spiral arm of an exopodite. The position of these parts of the ventral limb is shown by fig. 3, pl. 98. The difference in direction is owing to the photographs having been made with the light passing through from opposite sides of the slide. (Slide No. 208, M. C. Z.)

5. (× 18.) A round, jointed appendage that occurs near the hypostoma. Walcott suggested in 1918, p. 195, fig. 15, that it might have been an antennule. Raymond suggests, 1920, p. 52, that it is an endopodite. (Slide No. 78, M. C. Z.)

6. (× 18.) Another example of the slender epipodites in which the jointed structure is not preserved; the relations of these to the axial lobe of the trilobite is shown by fig. 8, pl. 98. (Slide No. 135, M. C. Z.)

11. (× 18.) Portions of three spiral arms of the exopodite, the upper one of which shows traces of spiral structure. The slide, including the spiral arms, was illustrated by Walcott in 1881, pl. 3, fig. 5. (Slide No. 25, M. C. Z.)

Calymene senaria Conrad.......................................394-412

FIG. 7. (× 18.) Portions of the arms of two spiral exopodites showing the manner of attachment of the spiral arm to the shaft joining the arm to the coxopodite. These were illustrated by Walcott in 1881, pl. 4, fig. 4; 1918, pl. 27, fig. 5*a*. (Slide No. 32, M. C. Z.)

8. (× 18) Section cutting spiral arms of exopodites and slender elongate epipodites; the section containing these parts has been imperfectly illustrated by Walcott, 1881, pl. 3, fig. 9; 1918, pl. 27, fig. 4. (Slide No. 29, M. C. Z.)

9. (× 18.) Opposite side of the section of fig. 8; this shows the spiral arms of exopodites and what may be a section of the narrow side of the joints of an endopodite. (Slide No. 29, M. C. Z.)

10. (× 16.) Two spiral arms of exopodites. The upper spiral probably belongs to a different exopodite from the lower one as the latter has its shaft in position. This slide was illustrated by Walcott in 1881, pl. 4, fig. 3, and in 1918, pl. 27, fig. 5. (Slide No. 31, M. C. Z.)

The slides represented by figures 1-11 were made by me and are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

The sections illustrated are of trilobites from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.

SECTIONS OF TRILOBITES (Exopodites)

DESCRIPTION OF PLATE 98

PAGE

Ceraurus pleurexanthemus Green..................................394-412

FIG. 1. (× 6.) Transverse thoracic section cutting obliquely across several endopodites and on the right side fragments of exopodites. On the left side there are two slender, short, jointed appendages that show the outlines of the longitudinal section of the joints; the lower one has three clearly defined joints and the longer upper one four joints. (See fig. 2, pl. 97.) In addition there is an oblique section of a coxopodite on the left side that has fine short spines on the proximal end and adjoining ventral margin. (Slide No. 109, M. C. Z.)

2. (× 6.) Slender short jointed appendage similar in form to those on the left side of fig. 1. It has five joints, and I formerly thought it might possibly indicate an antennule (Walcott, 1918, pl. 27, fig. 15). (Slide No. 78, M. C. Z.) See also fig. 5, pl. 97.

3. (× 6.) Transverse thoracic section of a partially enrolled specimen cutting across the coxopodite and endopodite of a thoracic leg, parts of a spiral-like section of the arm of an exopodite, and the proximal portion of a hollow slender appendage similar to that in figs. 1 and 2. (Slide No. 208, M. C. Z.)

4. (× 6.) Transverse thoracic section of coxopodites and on the right side several spinose joints of an endopodite of a thoracic limb (See fig. 11, pl. 103); on both sides just beneath the ventral pleural lobes there is a slender ribbon-like appendage that is jointed on right side and attached at its proximal end to a strong base which is probably a section of the coxopodite (See fig. 1, pl. 97); a similar appendage occurs below in the section on the right side and below that a section of an elongate spiral-like arm apparently terminating in a drawn out portion of the spiral arm. (Slide No. 120, M. C. Z.) See fig. 1, pl. 97.

5. (× 6.) Transverse thoracic section showing distended alimentary canal, an axial process on the right side, some fragmentary remains of the arm of exopodites, and on the inner side of an endopodite a crescent shaped fimbriated margin. (See fig. 10, pl. 103.) (Slide No. 153, M. C. Z.) This slide was represented by a diagrammatic drawing in the Raymond Memoir, fig. 23, p. 79.

6. (× 4.) Transverse section cutting across the anterior portion of the thorax and some of the cephalic limbs of a partially enrolled specimen. The endopodites of the thoracic limbs are shown in transverse and oblique sections to the right and to the left of the cephalic appendages above the hypostoma; above the latter there are several slender appendages comparable with those of figs. 1, 3 and 4. (Slide No. 5, M. C. Z.) This slide was illustrated by Walcott, 1881, pl. 1, fig. 5.

7. (× 4.) Transverse oblique thoracic section of coxopodites with undulating slender appendages beneath the pleural lobes. (Slide No. 204, M. C. Z.) See fig. 3, pl. 97.

8. (× 8.) Transverse section cutting slantingly across the thorax so as to show on the left side a distorted coxopodite with slender appendages projecting into the area beneath the pleural lobes. (Slides No. 135, M. C. Z.) See fig. 6, pl. 97.

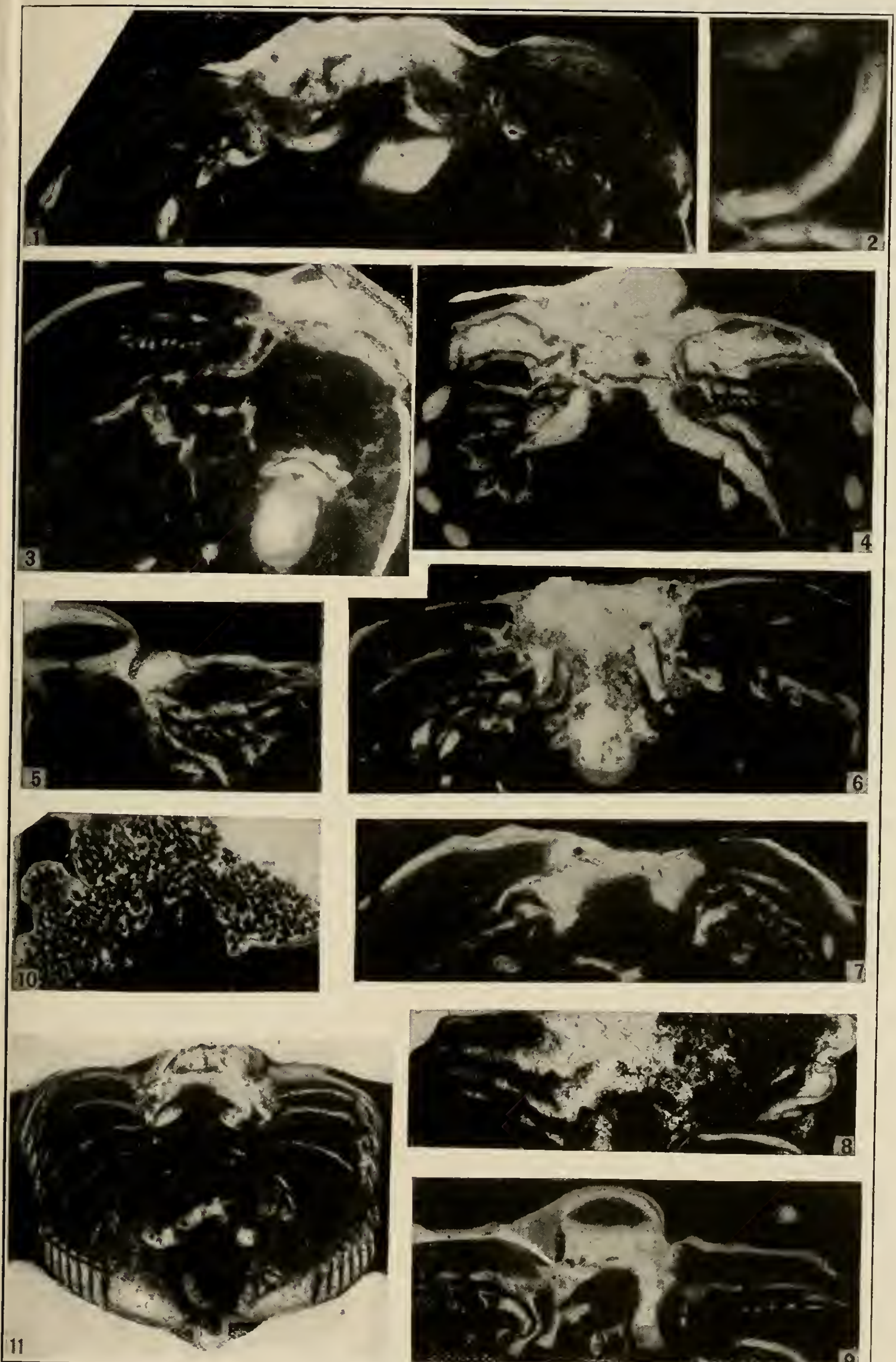

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FIG. 9. (× 6.) Transverse thoracic section showing section of distorted alimentary canal; section of a coxopodite on left side; distorted coxopodite on right side, and several slender appendages on each side apparently belonging with the coxopodites; also below sections of the arm of the exopodite. (Slide No. 13, M. C. Z.) This slide was illustrated by Walcott, 1881, pl. 1, fig. 3, and 1918, pl. 26, fig. 14.

10. (× 10.) Ova-like bodies imbedded in the calcite filling the anterior end of a partially enrolled specimen. (Slide No. 33, M. C. Z.)

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FIG. 11. (× 6.) Transverse section of an enrolled specimen cutting across the thorax and pygidium. The oblique sections of the ends of the six posterior thoracic pleuræ are interesting. This section shows faint outlines of four or five slender elongate appendages on each side beneath the pleural lobes and in the pygidium on the right side sections of four limbs, and on the left side what may be the supporting arm of an exopodite with five spiral-like segments attached to it. See fig. 7, pl. 100. (Slide No. 56 M. C. Z.)

All of the sections illustrated on this plate are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

The specimens illustrated are from the Ordovician; upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.

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Fig. 1. (× 4.) Transverse section of a partially enrolled specimen crossing the cephalon on the line of the eye and the thorax at about the first segment. The detailed description of this section is given in the text. (Slide No. 22, M. C. Z.) A drawing of this slide was published by Walcott in 1881, pl. 3, fig. 2, and again in 1918, pl. 27, fig. 12. (See figs. 1 and 2, pl. 100.)

3. (× 6.) Transverse section of the thorax of an enrolled specimen showing section of alimentary canal, with section of the articular extension of the stergite of the axial lobe, also on right side a triangular section of the arm of an epipodite with numerous filaments. (Slide No. 27, M. C. Z.) A drawing of this slide was published by Walcott in 1881, pl. 3, fig. 7. (See fig. 5, pl. 100.)

6. (× 4.) Transverse section of the thorax of specimen preserving the blade of an epipodite attached to the side of a distorted coxopodite; the outer crenulated margin and a number of the long filaments are shown. (Slide No. 80, M. C. Z.) See fig. 6, pl. 100.

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Fig. 2. (× 6.) Transverse section cutting across the upper posterior margin of the cephalon and the anterior upper side of the thorax in such a manner as to show the filled-in visceral cavity and the basal portion of several filamentous, presumably thoracic appendages, which are interpreted as epipodites. (Slide No. 45, M. C. Z.) See fig. 3, pl. 100.

A drawing based on this section was published by me in 1881 in which the right side was restored (fig. 1, pl. 3, Bull. Museum Comp. Zool., Harvard Coll., Vol. 8); also by a photograph in 1918, pl. 27, fig. 11.

4. (× 8.) (See pl. 91, fig. 3.) Transverse thoracic section cutting across coxopodites; six slender jointed appendages on the left side and four on the right side. Midway of the large coxopodite on the left side there is a rounded depression with a downward extension of the contents of the axial lobe extending into it. This slide is the one from which Raymond drew his diagrammatic outline (p. 53, fig. 15) illustrating the "ball-and-socket" joint. (Slide No. 63, M. C. Z.)

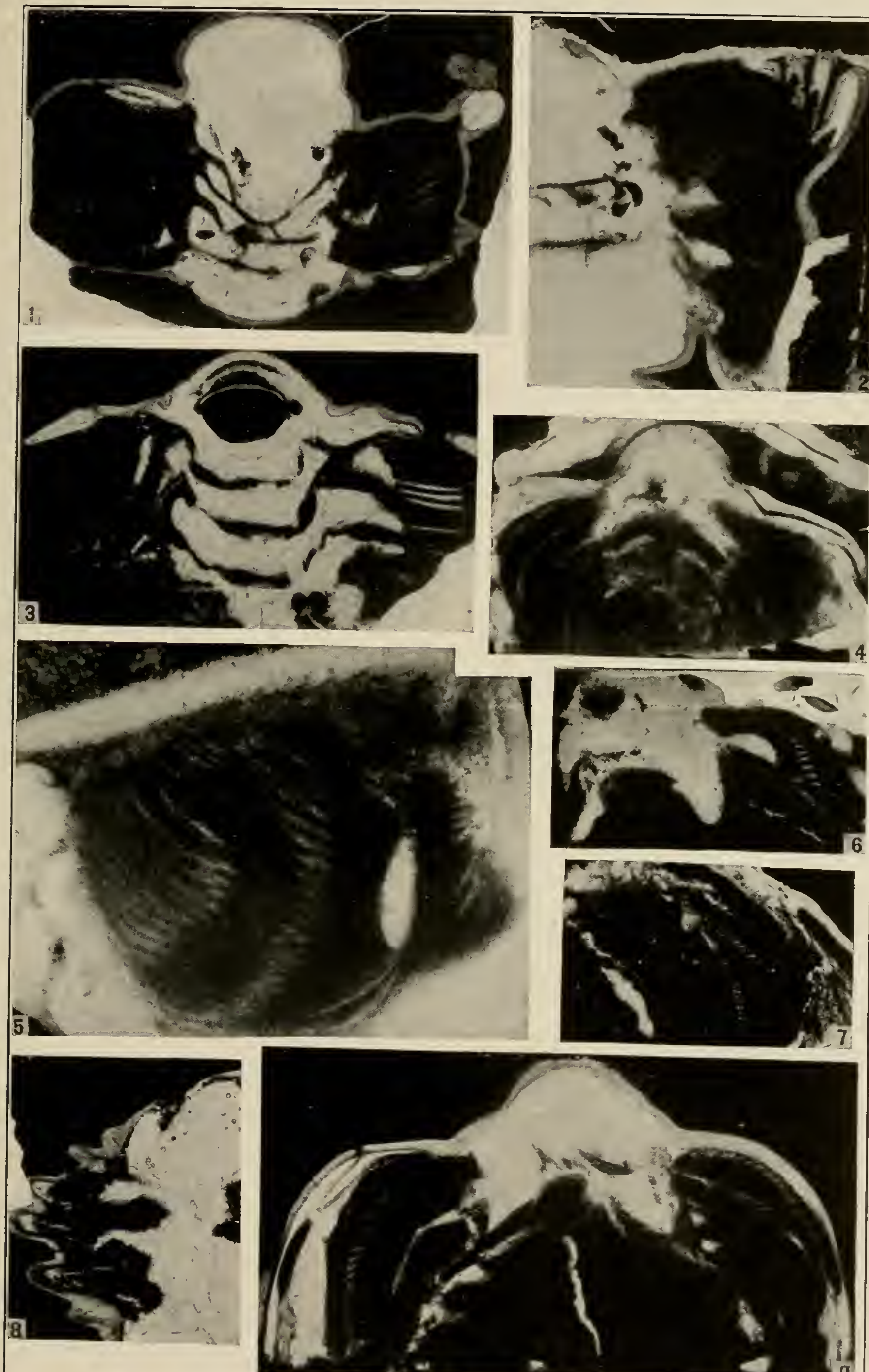
5. (× 10.) Obliquely transverse section of an enrolled specimen passing through the posterior portion of the pleural lobe of the cephalon and pleural lobes of four thoracic segments, and cutting obliquely across the filaments of several exopodites. (Slide No. 28, M. C. Z.)

A drawing from a photograph of this slide was published by Walcott in 1881, pl. 3, fig. 8, and a photograph of it in 1918, pl. 27, fig. 13. The exopodites were referred to as epipodites in the description of the figure.

7. (× 6.) Transverse thoracic section cutting lengthwise across two spiral arms of the exopodites. See fig. 10, pl. 97. Text description. (Slide No. 31, M. C. Z.)

A drawing from a photograph of this slide was published by Walcott in 1881, pl. 4, fig. 3, and a photograph of it in 1918, pl. 27, fig. 5.

8. (× 6.) Transversely oblique section of an enrolled specimen cutting across the filling of the thoracic visceral axial cavity and the bases of two irregular appendages with long, slender filaments attached to their outer edges. (Slide No. 112, M. C. Z.) See fig. 4, pl. 100.



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9. (× 6.) Transverse thoracic section showing ridges on ventral integument, sections of coxopodites, and exopodites. See detailed description in text. (Slide No. 29, M. C. Z.) A drawing from a photograph of this slide was published by Walcott in 1881, pl. 3, fig. 9, and a photograph in 1918, pl. 27, fig. 4. (See figs. 8 and 9, pl. 97.)

All of the sections illustrated on this plate are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

The specimens illustrated are from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.

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Ceraurus pleurexanthemus 394-412

FIG. 1. (× 20.) Section of a fimbriated epipodite in which the attachment of the fimbriæ to the blade is not well shown. Sections of somewhat similar specimens are shown by figs, 2-6, 8. The position of the section in this slide is shown by fig. 1, pl. 99, lower left side. (Slide No. 22, M. C. Z.)

2. (× 20.) Section of a fimbriated epipodite in which the fimbriæ are in contact with the blade, situated on the opposite side of the axial lobe in the same slide as fig. 1 (see pl. 99, fig. 1.)

6. (× 16.) A blade or arm of the epipodite cut across so as to show the fluted outer margin and a series of seven fimbriæ that appear to have been cut across close to their base, and a second series further out that were attached to a base either in advance of or behind the one preserved in the section. (Slide No. 80, M. C. Z.)

9. (× 30.) A section of the calcite replacing the contents of the body of the trilobite. The crystallization of the calcite has usually destroyed all traces of the ventral integument, the test of the limbs, and the membrane of the alimentary canal, etc. (Slide No. 120, M. C. Z.)

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FIG. 3. (× 20.) Sections of two fimbriated epipodites. Their position in relation to the axial lobe of the trilobite is shown by fig. 11, pl. 27, Smithsonian Miscellaneous Collections, Vol. 67, 1918. This slide was the basis of the drawing of Walcott, 1881, pl. 3, fig. 1, in which the right side was restored from the data furnished by the left side of the slide. (Slide No. 45, M. C. Z.)

4. (× 20.) Sections of two fimbriated epipodites. Their position in relation to the axial lobe of the trilobite is shown by fig. 8, pl. 99. (Slide No. 112, M. C. Z.)

5. (× 18.) Sections of two fimbriated epipodites showing the fluted margin of the upper one and the strong fimbriæ. The position of the triangular shaped outline of the base or blade and its position in the slide is shown by fig. 3, pl. 99. A drawing of this section was published by Walcott in 1881, pl. 3, fig. 7. (Slide No. 27, M. C. Z.)

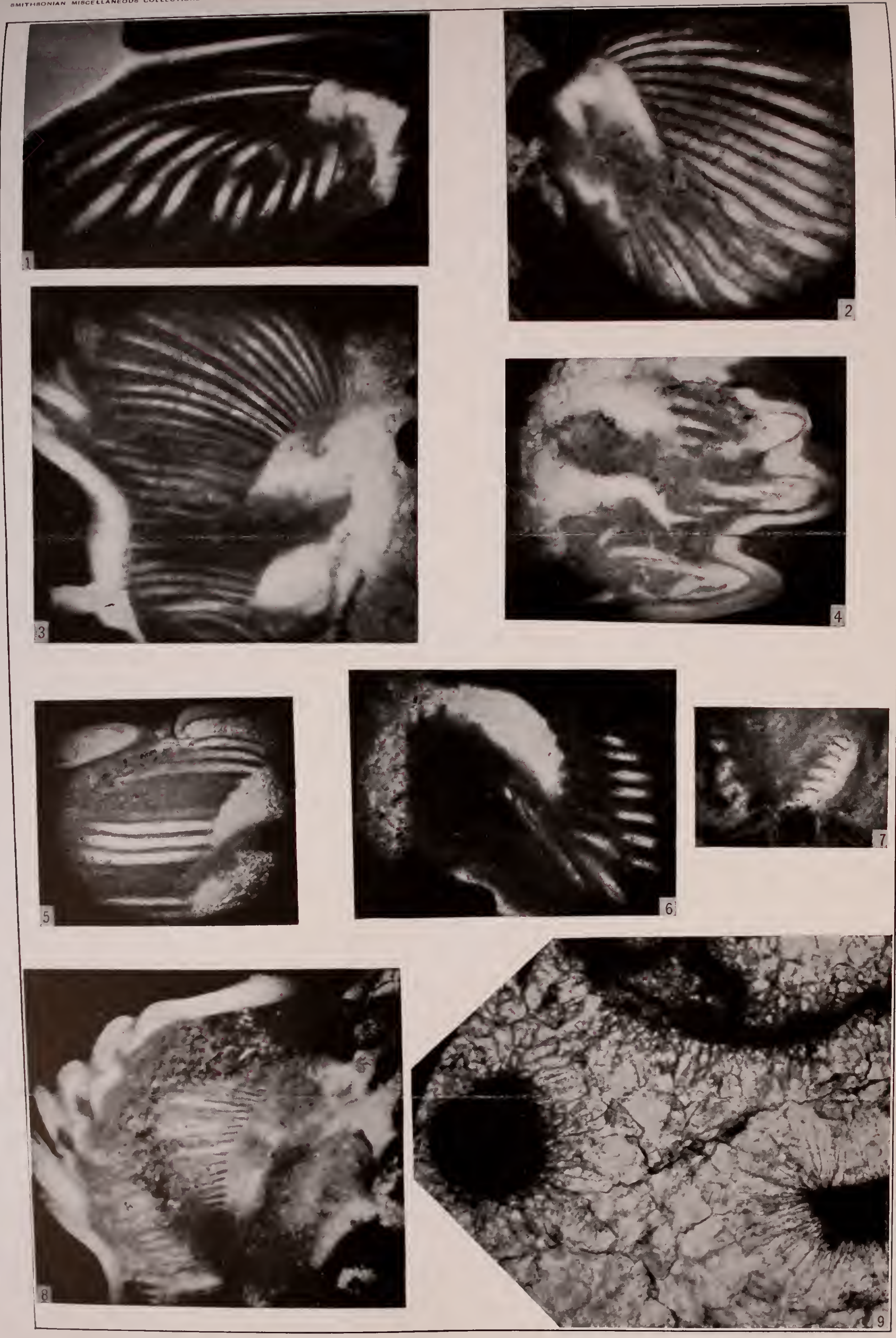
7. (× 18.) Section of a fimbriated arm that occurs beneath the posterior portion of the pygidium. See fig. 11, pl. 98. This may be the arm of an exopodite with the spiral attached to it as in fig. 7, pl. 97. (Slide No. 56, M. C. Z.)

8. (× 15.) Section of a fimbriated epipodite the position of which in relation to the coxopodite of the ventral limb is shown by fig. 3, pl. 3, Walcott 1881, also same figure on pl. 26, fig. 2, 1918.

This section of this slide also cuts across the filaments and spiral arm of two or three exopodites that have been displaced and pushed out against the pleural lobe of several thoracic segments. (Slide No. 23, M. C. Z.)

The slides represented by figures 1-9 were made by me and are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

The sections illustrated are of trilobites from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.



SECTIONS OF TRILOBITES

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FIG. 1. (× 6.) Longitudinal section of a partially enrolled specimen, a detailed description of which is given in the text, ante p. 397. Two other sections cut from this trilobite are illustrated by figs. 1 and 2, pl. 105. (Slide No. 35, M. C. Z.) A drawing from a photograph of this slide was published by Walcott in 1881, pl. 5, fig. 3.

FIGS. 2 and 3. (× 3.) Longitudinal sections of the side of the axial lobe cutting through the cephalon, hypostoma, several thoracic segments, and the basal portions of the ventral limbs. (Slides No. 15 and 17, M. C. Z.) Drawings from photographs of these slides were published by Walcott in 1881, pl. 2, figs. 5 and 7.

4. (× 6.) Section crossing the axial lobe obliquely so as to cut the anterior coxopodites, then the thickened sternites of the thoracic segments, and back of these the coxopodites. (Slide No. 36, M. C. Z.) A drawing of this slide was published by Walcott in 1881, pl. 5, fig. 4.

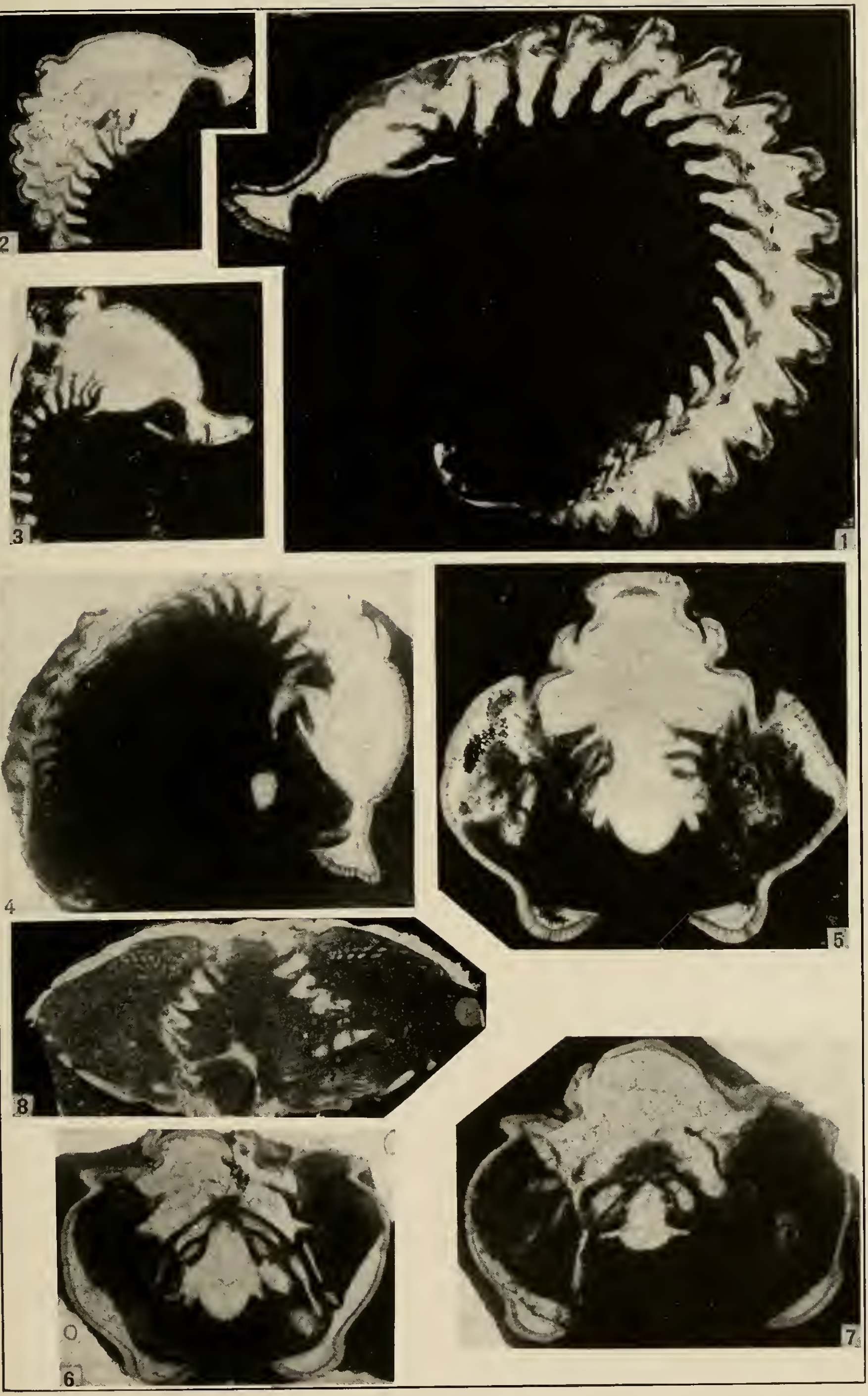
5. (× 6.) Transverse section cutting obliquely from the first thoracic segment down through the cephalon, hypostoma and cephalic limbs. For detailed description see text. (Slide No. 9, M. C. Z.) A drawing from a photograph of this slide was published by Walcott in 1881, pl. 1, fig. 9.

6. (× 6.) Transverse section cutting obliquely down across the cephalon, hypostoma and cephalic limbs. For detailed description see text. (Slide No. 6, M. C. Z.) A drawing from a photograph of this slide was published by Walcott in 1881, pl. 1, fig. 6, and a photograph in 1918, pl. 26, fig. 11.

7. (× 6.) Transverse section cutting obliquely down through from the first thoracic segment across the cephalon, hypostoma and cephalic limbs. For detailed description see text. (Slide No. 38, M. C. Z.) A drawing from a photograph of this slide was published by Walcott in 1881, pl. 1, fig. 8, and a photograph in 1918, pl. 26, fig. 9.

Ceraurus pleurexanthemus Green...

FIG. 8. (× 4.) Transverse section of an enrolled specimen cutting across the thoracic coxopodites and the spiral arms of several exopodites. (Slide No. 147, M. C. Z.)



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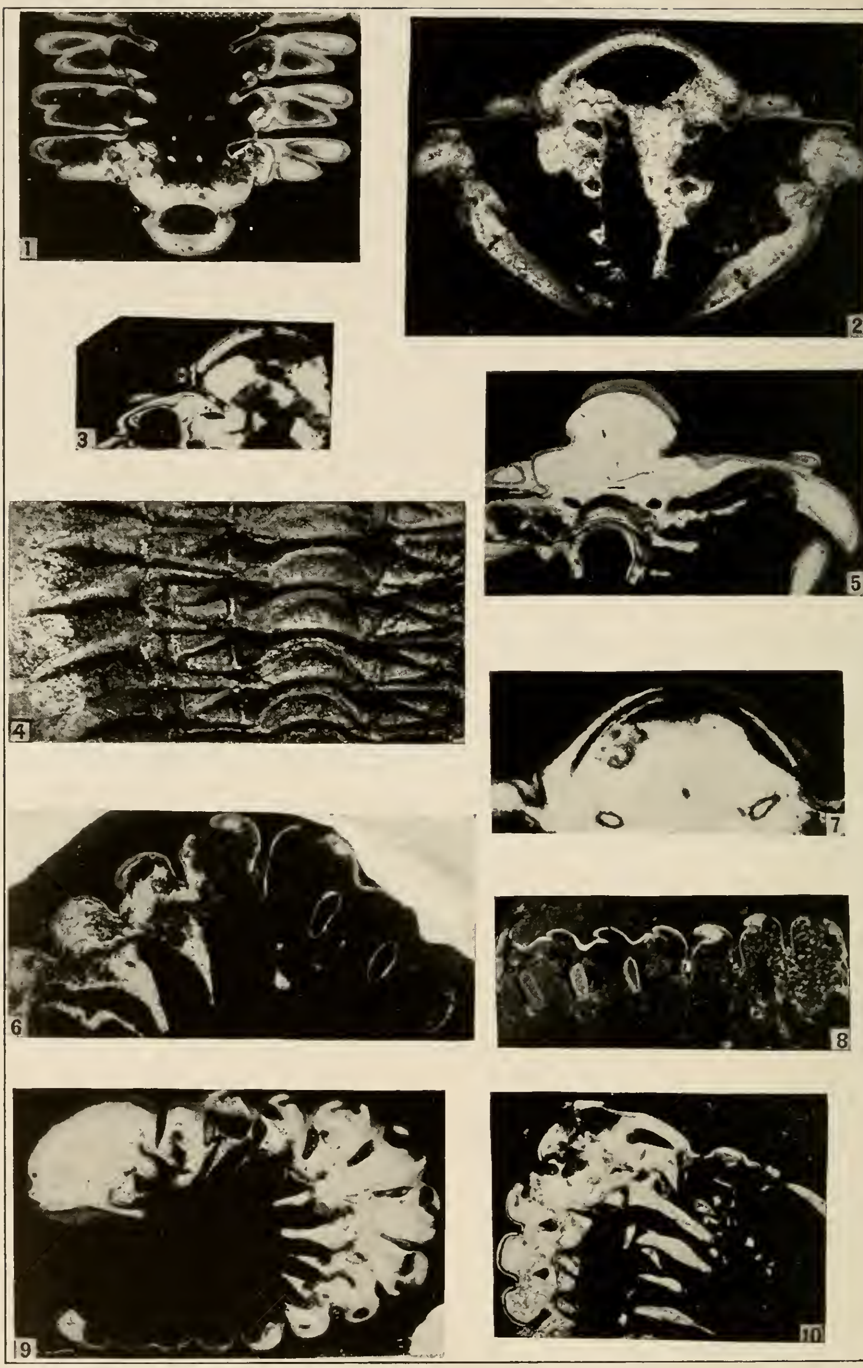

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Ceraurus pleurexanthemus Green................................394-412

FIG. 1. (× 4.) Transverse section cutting four thoracic segments nearly on the plane of the dorsal surface of the pleural lobes and below one axial segment almost vertically so as to cross the alimentary canal. See pl. 95, fig. 4. The details of structure shown are described in the text. (Slide No. 244, M. C. Z.)

2. (× 6.5) Transverse section of an enrolled specimen cutting one thoracic segment almost vertically, and the remainder of the specimen obliquely so as to bisect several articular processes. (Slide 39, M. C. Z.)

3. (× 4.) Transverse thoracic section to illustrate a section of the ridge formed by the folding of the test of the axial lobe of a thoracic segment where the articular extension of the segment unites with the anterior ventral margin of the tergite. (Slide No. 205, M. C. Z.)

4. (× 4.) Ventral surface of four thoracic segments to illustrate the anterior articular extension of the mesotergite beneath the next anterior mesotergite, also where the fold is worn through the inward extension of an axial process as in fig. 1. (U. S. National Museum, Catalogue No. 68388.)

5. (× 6.) Transverse thoracic section showing below the inward extension of the fold of the articular extension of the mesotergite, and laterally a slight downward extension of the test at the dorsal furrows. (Slide No. 123, M. C. Z.)

6. (× 6.) Longitudinal thoracic section cutting across coxopodites of two endopodites and four infoldings of the articular process of the mesotergite. See fig. 8. (Slide No. 169, M. C. Z.)

7. (× 9.) Transverse thoracic section of the axial lobe cutting the ventral extension of the dorsal test at the dorsal furrow, also the anterior articular extension of the mesotergite and below the processes of the fold of the articular extension of the mesotergite. (Slide No. 68380, U. S. N. M.)

8. (× 4.) Oblique longitudinal thoracic section of several mesotergites of the dorsal test illustrating the folding of the articular extension of the mesotergite and the outline of the "processes" formed by them. (Slide No. 231, M. C. Z.)

9. (× 4.) An example somewhat similar to that represented by fig. 10. This section also shows traces of the cephalic appendages and an axial process beneath the cephalon. (Slide No. 193, M. C. Z.)

10. (× 3.) Another example of the cutting across the fold of the articular process as described in the text. This slide also has an interesting section of a coxopodite. (Slide No. 16, M. C. Z.) Illustrated by Walcott 1881, pl. 2, fig. 16.

The sections represented by figures 1-3, 5, 6, 8-10 were made by me and are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts. The specimens represented by figs. 4 and 7 are in the United States National Museum.

The sections are of trilobites from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.

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Isotelus gigas DeKay.. 452

FIG. 1. (× 4.5) Transverse thoracic section cutting across the coxopodite of a ventral limb. (Slide No. 19, M. C. Z.)

2. (× 4.5) Section cutting across the coxopodites and the anterior limbs beneath the pygidium. (Slide No. 226, M. C. Z.)

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FIG. 3. (× 4.2.) Transverse section of the cephalon on the line of the eyes. (Slide No. 94, M. C. Z.)

4. (× 12.) Transverse section cutting across the articular extension of the mesotergite of a thoracic segment. See fig. 1, pl. 95. (Slide No. 27, M. C. Z.)

5. (× 6.2) Median longitudinal section of cephalon and hypostoma. (Slide No. 102, M. C. Z.)

6. (× 5.) Longitudinal section cutting a little obliquely through the cephalon and hypostoma. (Slide No. 174, M. C. Z.)

7. (× 4.2) Four ventral thoracic limbs cut across so as to show the attachment of the shaft of the exopodite to the coxopodites. There is also a suggestion that the parts about the mouth have been pushed forward above the hypostoma. (Slide No. 168, M. C. Z.)

8. (× 3.5) Longitudinal section through the limbs beneath the cephalon and anterior portion of the thorax. (Slide No. 198, M. C. Z.)

9. (× 3.5) Longitudinal section cutting the outer part of the axial lobe of the pygidium and posterior portion of the thorax so as to show a section of the proximal joints of the limbs beneath the pygidium. This section was figured by Walcott in 1881, pl. 2, fig. 8. (Slide No. 18, M. C. Z.)

11. (× 16.) Longitudinal section of the proximal portion of the endopodite shown in fig. 4, pl. 98, which cuts across the fine spines along the ventral margin. Compare these with spines of the endopodites of *Neolenus*, pl. 93, fig. 2. (Slide No. 120, M. C. Z.)

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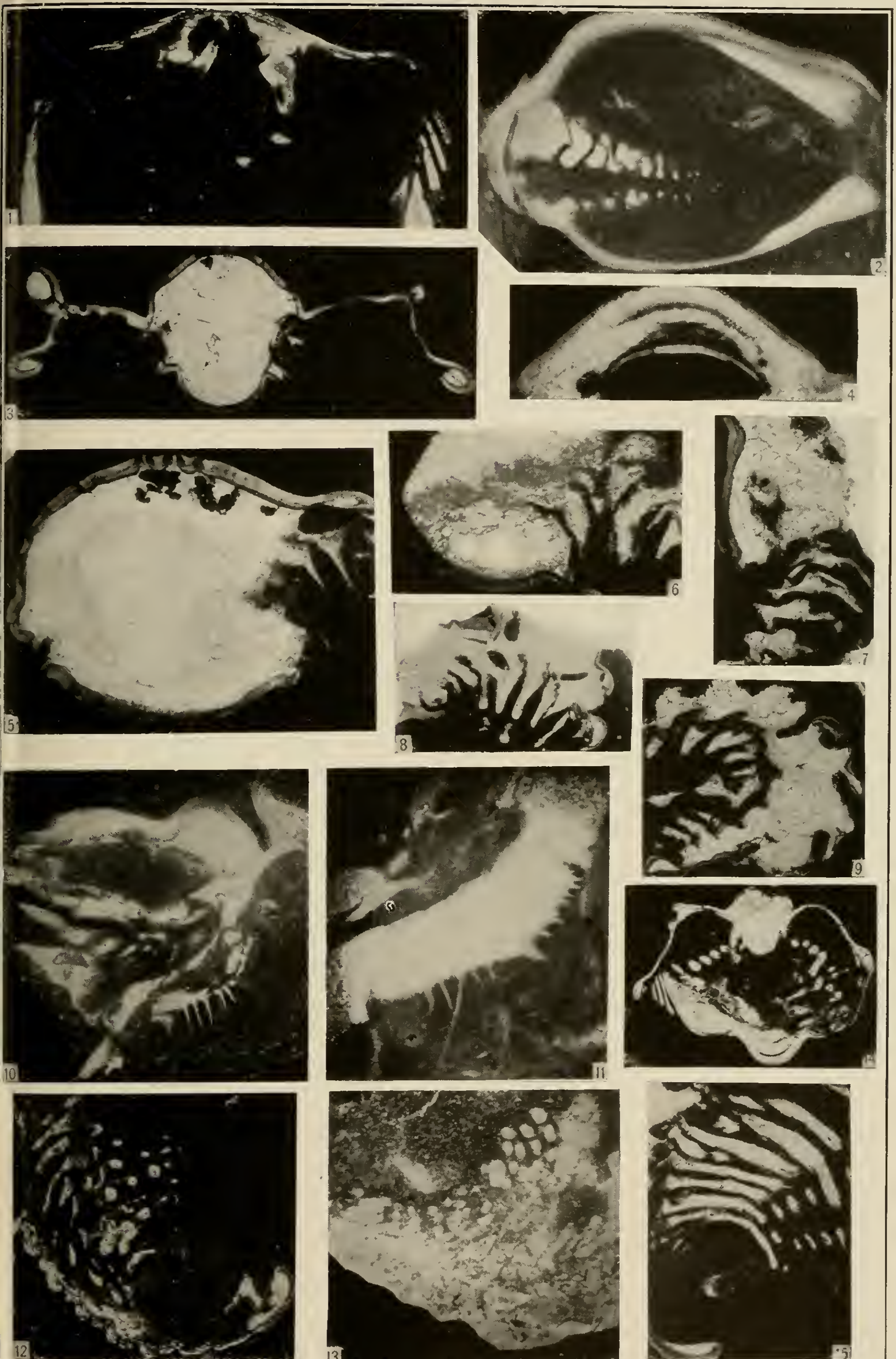
FIG. 10. (× 16.) Longitudinal section of a thoracic limb with endopodite and fragments of exopodites. The spines on the ventral margin of the proximal joint are of interest for comparing with those of *Ceraurus*, fig. 11. A diagrammatic drawing of this section is given by Raymond, p. 79, to illustrate the alimentary canal and the infolding of the dorsal test at the dorsal furrow which he identifies as an appendifer. (Slide No. 153, M. C. Z.) See fig. 5, pl. 98.

12. (× 5.) Longitudinal section of an enrolled trilobite in which the exopodites have been displaced and cut across at varying angles so as to show the almost round transverse section with a dark spot indicating that the muddy matrix had been forced into some of the joints of the endopodite. (Slide No. 200, M. C. Z.)

14. (× 4.2) Transverse section of an enrolled specimen cutting obliquely through the head, hypostoma and almost vertically through a thoracic segment and the articular extension of a mesotergite of another segment which forms a narrow dark crescent in the axial lobe. The important feature of the section is the series of round and broadly oval sections of the thoracic endopodites. Faint traces of exopodites occur in the lower portion of the figure. (Slide No. 20, M. C. Z.) Illustrated by Walcott 1881, pl. 2, fig. 10.



SECTIONS OF TRILOBITES

The sections represented by figures 1-15 were made by me and are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts, with the exception of fig. 13.

The sections are of trilobites from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York, with the exception of fig. 13 which is from the Cincinnatian rocks, Marysville formation, Cincinnati, Ohio.

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FIG. 1. (× 6.) Transverse section of the thorax. See figs. 2 and 3. (Slide No. 211, M. C. Z.)

2. (× 18.) Left side of fig. 1 enlarged to show elongate epipodite, fragment of coxopodite, and spines on a joint of the endopodite. (Slide No. 211, M. C. Z.)

3. (× 18.) Right side of fig. 1 enlarged to show proximal joints of an epipodite and its position in relation to the coxopodite. See fig. 2, also pl. 97, figs. 1, 3, 6. (Slide No. 211, M. C. Z.)

4. (× 16.) Enlargement of five joints of an endopodite, a fragment of a spiral arm of an exopodite and two elongate epipodites. (Slide No. 111, M. C. Z.)

This slide was figured by Walcott 1881, pl. 11, fig. 2, and in 1918, pl. 27, fig. 1. Two more joints are shown in the endopodite of the latter figure but they are too faint to photograph clearly, and as there is a slight gap betwen the fifth joint of fig. 4 and these faint joints, no attempt is made to show them in fig. 4.

5. (× 6.) Transverse section cutting down through the cephalon and hypostoma. The interesting feature is the two round dark spots just beneath the dorsal test with a projection on the outer upper side that curves inward almost around a dot of white calcite; all around the edges of the dark spots minute short spines appear to project into the calcite; there is a confused cellular structure between the two spots that may represent hepatic cæca, and a small circular ring above may indicate the heart; the dark spots evidently represent a bilateral structure within the head. (Slide No. 68386, U. S. N. M.)

Trinucleus concentricus Eaton 451

FIG. 6. (× 10.) Transverse section of an enrolled specimen cutting the cephalon, hypostoma and some of the ventral appendages. (Slide No. 230, M. C. Z.)

7. (× 25.) Enlargement of right side of fig. 6 to show the outline of endopodites, faint traces of exopodites one of which suggests a spiral structure, and transverse section of several endopodites in the lower right side of the slide. The exopodites are too faint to photograph clearly. (Slide No. 230, M. C. Z.)

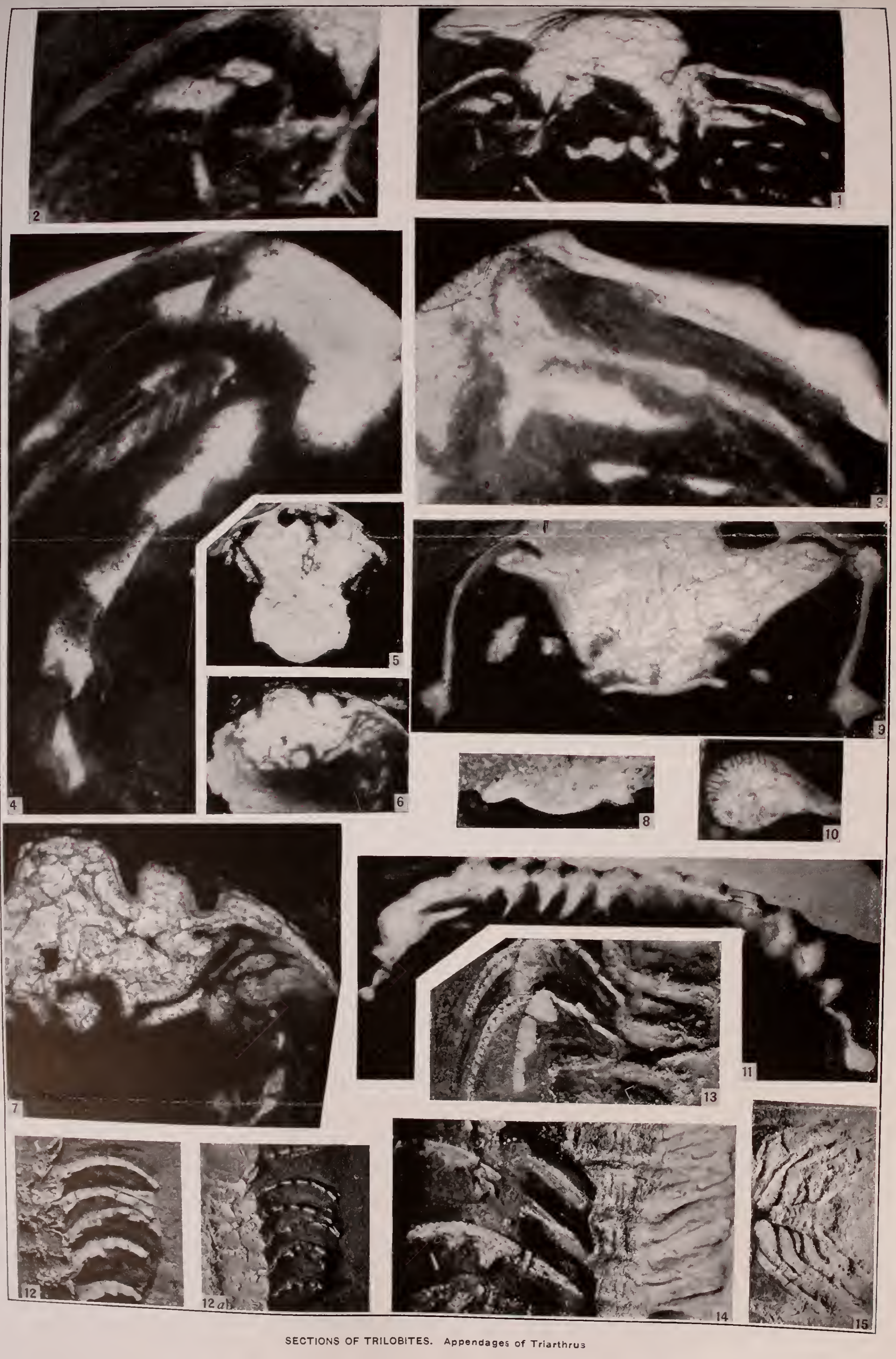
8. (× 15.) Transverse section cutting an hypostoma about midway of its length. (Slide No. 68383, U. S. N. M.)

9. (× 18.) Transverse section cutting the cephalon on the line of the eyes and the hypostoma nearer its posterior end than in fig. 8. There are traces of two cephalic limbs on each side and above the hypostoma. (Slide No. 68384, U. S. N. M.)

10. (× 40.) Enlargement of the section of the eye on the right side of fig. 9. The corneal lenses are finely shown but the outer cornea has been destroyed.

11. (× 18.) Longitudinal section of the axial lobe cutting the cephalon, thorax and pygidium. The traces of the bases of the thoracic limbs are similar to those of *Calymene*. See pl. 101. (Slide No. 68385, U. S. N. M.)

The specimens illustrated by figs. 1-11 are from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.



SECTIONS OF TRILOBITES. Appendages of Triarthrus

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Triarthrus becki Green......................................413-415

Fig. 12. (× 12), 12*a* (× 7). Two photographs of one of the Beecher specimens showing the side view of the broad joints of five thoracic endopodites and a view of the narrow ventral margin of the same. This specimen gives a very clear idea of the form of the joints of some of the thoracic endopodites. (Specimen No. 222, Peabody Museum.) This specimen is illustrated by Raymond, pl. 4, fig. 5.

13. (× 10.) Photograph of ventral view of two endopodites with accompanying exopodites coming from beneath them. The four distal joints of the endopodites are lying with flat side up while the ischiopodite and basipodite and the coxopodite show their narrow ventral edges. (See description of specimen No. 218, Peabody Museum, in the text.)

This specimen is reproduced by Raymond, pl. 6, fig. 3, and a diagrammatic figure p. 157, fig. 43.

14. (× 7.) A photograph of Beecher type specimen showing the "apodemes" of the ventral integument. (Specimen No. 219, Peabody Museum.)

This specimen is reproduced by Raymond, pl. 2, fig. 6.

15. (× 10.) A photograph of Beecher type specimen of cephalic limbs; this is one of the finest illustration of the gnathites worked out by Beecher. (Specimen No. 211, Peabody Museum.)

A photograph of this specimen is reproduced by Raymond, pl. 2, fig. 5.

The specimens illustrated by figs. 12-15 are from locality 373, Ordovician: Utica shale; 3 miles (4.8 km.) north of Rome, Oneida County, New York.

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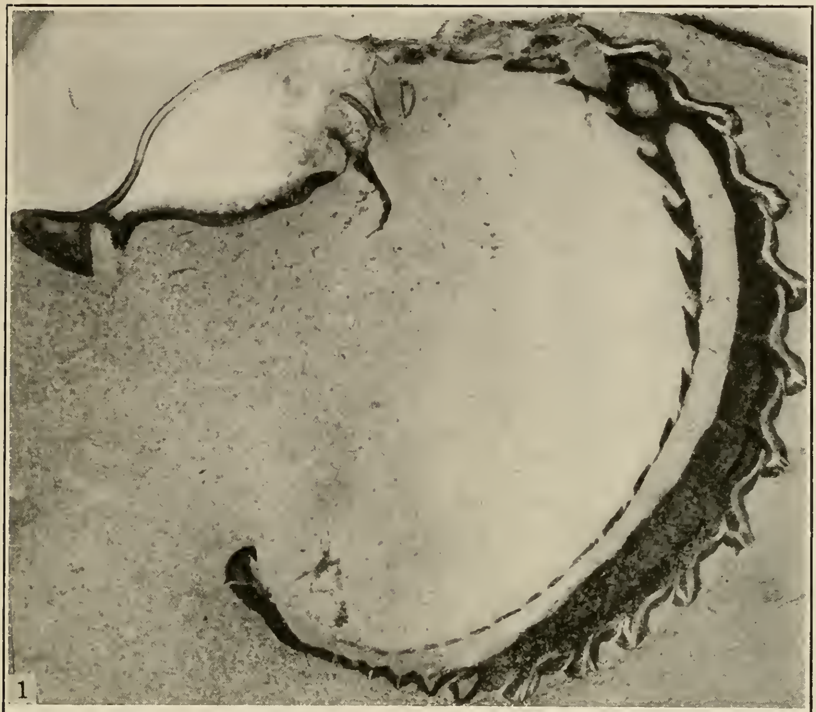
FIG. 1. (× 8.) Longitudinal section of the axial lobe that is slightly oblique to the median line; it cuts across the base of some of the coxopodites of the anterior thoracic limbs, and posteriorly the thickened sternites of the ventral integument. The section is described in detail in the text. (Slide No. 34, M. C. Z. Illustrated by Walcott 1881, pl. 5, fig. 2, and again in 1918, pl. 28, fig. 8.) On fig. 6 of pl. 5, 1881, the line c-c represents the location of this section across the trilobite.

2. (× 8.) Opposite side of the opaque slide of fig. 1. This cuts the axial lobe a short distance from the dorsal furrow of the test and like fig. 1 is slightly oblique to the median line of the lobe, with the result that the proximal joints of the posterior thoracic limbs are difficult to interpret. (Slide No. 34, M. C. Z. Illustrated by Walcott 1881, pl. 5, fig. 1.) On this the line a-a′ of fig. 6 represents the location of this section across the trilobite.

The sections represented by figures 1 and 2 were made by me and are now in the Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

The sections are of trilobites from the Ordovician: upper portion of the Trenton limestone; 1 mile (1.6 km.) east of the middle fall of Trenton Falls, on the West Canada Creek, in the town of Russia, Herkimer County, New York.



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SECTIONS OF TRILOBITES

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