New York State Museum

JOHN M. CLARKE, Director

Memoir 14

THE EURYPTERIDA OF NEW YORK

BY

JOHN M. CLARKE

AND

RUDOLF RUEDEMANN

VOLUME I

TEXT

ALBANY

New York State Education Department
Science Division, June 6, 1910

Hon. Andrew S. Draper LL.D.
Commissioner of Education

My DEAR SIR: I have the honor to communicate herewith and to submit to your approval for publication as a memoir of the State Museum, a manuscript constituting a monograph on *The Eurypterida of New York*, to be accompanied by adequate illustrative plates.
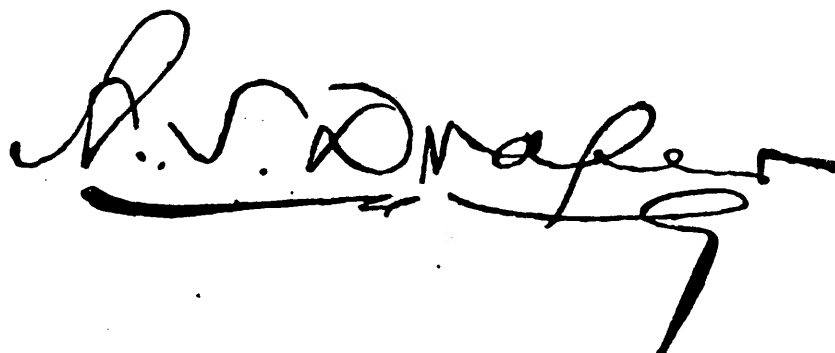
Very respectfully

JOHN M. CLARKE
Director

STATE OF NEW YORK
EDUCATION DEPARTMENT
COMMISSIONER'S ROOM

Approved for publication this 6th day of June 1910

Commissioner of Education

EURYPTERID GENERA OF NEW YORK

Restored and Reduced to the Natural Size

EUSARCUS

EURYPTERUS

STYLONURUS

DOLICHOPTERUS

PTERYGOTUS

HUGHMILLERIA

New York State Museum

JOHN M. CLARKE, Director

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PREFACE

While the senior author of this work was engaged in the preparation of the monograph of the American Devonic Crustacea which constituted volume 7 of the *Palaeontology of New York* [1888], the forms of the Eurypterida there presented for consideration, led to the impression that it would be a service to paleontology to restate in detail the structure of this unique group of extinct creatures. The Siluric rocks of New York had proven so profuse in these remains that the material was not wanting for such analysis; the late Professor James Hall, who in 1859 had given the most intimate account of the eurypterids developed up to that time, concurred in the belief that the 30 years which had then passed would, with the aid of accumulated data and in the light of the contributions made by other writers, afford new facts worth recording. Not long after this Gerhard Holm published his very remarkable analysis of the structure of Eurypterus based on specimens from the Baltic Siluric and on the appearance of this exhaustive memoir it seemed that the anatomy of the group could hardly be supplemented except by the estimation

of specific and generic differences, and the study of the habitudes of these animals. Notwithstanding, as early as 1895, I began the assemblage of materials looking specially to a revision of the New York and American eurypterid faunas. The collections of the State Museum were already pretty well supplied with representatives from the well known localities at Buffalo and in Herkimer county and now these collections have been vastly amplified, first by repeated acquisitions from the Herkimer county localities during the past 15 years, again by the close study of all outcrops of the Eurypterus beds along the line between Herkimer county and Buffalo which has progressed in connection with the field work in areal geology, then by the courtesy of the trustees of the Buffalo Society of Natural Sciences who in 1898, by special vote, placed at my disposal the extraordinary assemblage of specimens from the Buffalo cement quarries which is known, from the name of its principal contributor, as the Lewis J. Bennett Collection. Soon thereafter followed the discovery of the Eurypterus-bearing black shales at Pittsford, Monroe co., which were brought to light by the work of enlargement of the Erie canal in 1895, the species of which were described in our reports by Mr Clifton J. Sarle from material now in possession of the State Museum. To this notable addition to our knowledge has been added in years still more recent the new fauna in the dark shales of the Shawangunk grit at Otisville, Orange co., an assemblage of eurypterids remarkable for its profusion of immature growth stages; this fauna lying far to the east of all previously known occurrences of these creatures, was described in a preliminary way by the writer. Still more recently, indeed since the preparation of this book was believed to be completed, the field investigations of Dr Ruedemann have brought to light a large and new fauna in the Lower Siluric (Frankfort) shale rather widely disseminated in the lower Mohawk valley and this constitutes the very earliest assemblage of these merostomes in conditions which indicate that they formed a colony of long local duration.

The collections which have thus been brought together from the productive localities mentioned for the preparation of the present treatise have been

really great; indeed they represent some thousands of specimens and it is quite within reason to say that no series of the Eurypterida of equal size and variety has ever before been assembled. It is quite as true that no equal area in the world has proved as fruitful in the quantity and diversity of these organisms as the State of New York. And through the courtesy of many correspondents and museums much material from outside of New York has been placed at the demands of this work: the species of the Kokomo waterlimes of Indiana; of the Cambric Strabops of Missouri; the Siluric Megalograptus of Ohio and the Carbonic Hastimima of Brazil and New Brunswick; in all, I believe, an unexampled array of these extinct arachnids.

The work of elaborating these earlier studies and expanding them into this fuller form has very largely depended on the aid of Dr Rudolf Ruedemann who has brought to the work keen analytical powers, a broad grasp of its problems and an enthusiastic assiduity. I fully realize and gladly express my obligation to this assistance and desire that the interested reader accord to my coworker adequate acknowledgment of his efficient part in this work.

The treatise itself seems to carry its own justification; aside from the close analysis of structural details, there are chapters on ontogeny, phylogeny, on life habits and conditions as well as on organization which, though probably not beyond criticism, are at least informing and constitute an advance of knowledge.

To the following individuals and institutions the authors have been indebted for aid:

> The Buffalo Society of Natural Sciences, through its board of trustees and its superintendent, Mr Henry R. Howland
>
> The American Museum of Natural History, through Dr E. O. Hovey and the late Prof. R. P. Whitfield
>
> The United States National Museum, through Drs R. S. Bassler, E. O. Ulrich and David White
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> The Smithsonian Institution, through Secretary Charles D. Walcott

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Dr E. M. Kindle, Washington

Prof. Stuart Weller, Chicago

Prof. Gilbert van Ingen, Princeton

Dr Mark E. Reed, Buffalo

Mr Irving P. Bishop, Buffalo

Dr August F. Foerste, Dayton, Ohio

Mr Fred Braun, Brooklyn

The illustrations in the work are from drawings skilfully rendered by George S. Barkentin, many of them, especially the restorations and stages of immature growth, based on Dr Ruedemann's sketches and camera drawings.

*   *   *

The eurypterid colonies of the New York Siluric are very distinctly localized and of them we know two at the bottom of the Salina series or beneath the salt beds and two at the top of the series. These colonies were doubtless in part breeding pools in brackish waters, partly more open basins, restricted in extent by the limitations of favorable physical conditions.

Colony O, or the Otisville basin lying far eastward of the rest and on the borders of the Appalachian region, is embedded in an almost unlimited repetition of thin black shale between layers of heavy sandstone of the Shawangunk formation (Salina stage). In the construction of railroad improvements the rock wall here was broken down for ballast and while this work was in progress the eurypterid remains were detected by Dr Ruedemann. From this time on until the completion of the construction work referred to, Mr H. C. Wardell was almost continuously

engaged in acquiring these fossils and when the work was done the rock exposure was left with a vertical face, so that no further product is now available. In this eastern region of New York State the Salina formation is without salt deposits but the Otisville basin doubtless antedated those deposits in central New York and is assignable to an early part of the Salina stage.

Colony P, or the Pittsford pool, is embedded in a black shale formation which has never been exposed in any natural outcrops. As we have observed, the rock was first brought to light by excavations made in the deepening of the Erie canal in 1895 and the outcrops were soon after covered by the riprap construction of the canal lining and so remain. Extensive collections of material were made by Mr Clifton Sarle and these were subsequently increased by the work of Messrs D. D. Luther, H. C. Wardell and Fred. Braun. The opportunity of further acquisitions from this fauna rests with the future and depends on possible new excavations in the progress of public improvements.

Colony H, or the Herkimer pool, has been long exploited. It lies above the horizon of the salt and its localities are in the vicinity of Jerusalem Hill, Clayville, Sauquoit and Waterville. The most productive parts of the region have been the Wheelock and Schooley farms near Jerusalem Hill, though here as elsewhere actual outcrops of the waterlime are few. Experience has shown that the exploitation of the fresh rock does not afford eurypterids in satisfactory preservation, because of its blue gray character. Exposure not only reduces this to a light gray but aids the fissility of the rock and the broad, flat surfaces of the fossils also help to induce cleavage planes in the matrix. Exposure of a few years to the weather aids but little. The experiment was made of taking from the outcrop a good many cords of fresh rock which were left exposed for a period of five years but the result in the particulars referred to was wholly unsatisfactory. Therefore the supply of these fossils has come from weathered slabs distributed over this region. Miles of stone fences have been inspected and many rods of them taken down and rebuilt. Some of

the most productive material has been found in the foundations and cellar walls of buildings and in one instance the foundation wall of a large barn has been removed without disturbing the building, the abstracted rock being replaced with concrete as the work proceeded. Many hands have helped in the acquisition of this material: Messrs D. D. Luther, R. Ruedemann, C. A. Hartnagel, Jacob Van Deloo, H. C. Wardell, Fred Braun and the writer, and while it may be difficult at the present to greatly enlarge these extensive collections, still they are only an index of the profusion of these forms of life in this pool.

Colony B, or the Buffalo pool, appears to have been quite closely confined to the quarry beds of the Buffalo Cement Company in the northern part of the city of Buffalo. It is from these quarries that the majority of the specimens widespread now through the museums of the world, has come. Formerly such specimens were available to any collector, but a few years ago the president of the company determined to place all specimens uncovered in the progress of quarry work in the possession of the Buffalo Society of Natural Sciences and by virtue of this laudable act that society possesses in the " Bennett Collection " a very remarkable array of these remains, which are specially noteworthy for the prevailing large size attained by the individuals. At the present time few Eurypterida are obtained from this historic locality and there is reason to believe that the boundaries of the pool have been approached, though remains of these creatures are found scattered at this geological horizon as far west as Bertie, in Ontario, the locality from which this waterlime formation takes its name. Like the Herkimer pool, that at Buffalo lies in the Bertie waterlime above the salt.

Colony S, or the Schenectady basin. This recent discovery (1910) of eurypterids in the Frankfort shale (Lower Siluric) is comparable to their occurrence at Otisville. These remains, usually in fragmentary condition, abound most freely in fine grained black shale intercalated between thick calcareous sandstone beds locally known as " Schenectady bluestone," but they also occur in the sandy passage beds between the two.

These sandy shales are full of organic remains, partly of the supposed seaweed S p h e n o t h a l l u s   l a t i f o l i u m Hall and partly of what appear to be large undefined patches of eurypterid integument. In the black shales the eurypterid remains are rarer but their surface sculpture is excellently retained, and here their organic associates are C l i m a - c o g r a p t u s   t y p i c a l i s and T r i a r t h r u s   b e c k i . As a result of imperfect retention of these eurypterids in the rocks where they most abound and their sparseness in the shales which have best preserved them, we are still left in ignorance of the full composition of this assemblage, but it is safe to say genera, species and individuals were abundant at this early period, and the evolution of distinctive characters which we have heretofore recognized only in a later period had progressed to so sharp a differentiation, that we are compelled to carry back further in history, some of the commoner generic designations. These remains in the Frankfort shale are distributed through fully 1500 feet of strata deposited off a northeast-southwest coast line in an area of maximum deposition, and it is difficult to conceive that the physical conditions of the habitat of these merostomes were those of an inshore pool—rather those of a purely marine basin where sedimentation went on rapidly in an appalachian depression. Hence this occurrence is without parallel among our assemblages of these creatures in respect to long endurance.

All other occurrences of Siluric eurypterids in New York have been desultory and indicate no intercommunication between the pools or colonies mentioned.

<div align="right">JOHN M. CLARKE</div>

INTRODUCTION

HISTORY OF INVESTIGATIONS UPON THE EURYPTERIDS OF NEW YORK AND ADJOINING TERRITORY

The Siluric rocks of New York are, of all countries of the world, the richest in eurypterids. The first example ever described was obtained here. The specimen was found in Westmoreland, Oneida co., and was regarded by Dr S. L. Mitchill [1818] as a fossil fish of the genus Silurus, an error obviously induced by the peculiar catfishlike aspect of the carapace. In 1825, James E. DeKay, afterward the distinguished zoologist of the Natural History Survey, recognized the arthropod nature of this fossil. He erected for it the genus EURYPTERUS, and termed the species E. remipes, considering it as a crustacean of the order Branchiopoda, naming Apus, among others, as a recent form probably of near relation to it and suggesting that Eurypterus may

Figure 1   DeKay's figure of Eurypterus remipes

be a connecting link between the trilobites and recent Branchiopoda.

In 1835, Dr Richard Harlan described the Eurypterus lacustris, the predominant species in the Siluric waterlime at Buffalo, and next in abundance to E. remipes.

These descriptions preceded those of European species by a considerable interval; hence they were frequently copied into early text-

books and the Baltic species now known as E . f i s c h e r i long passed
current as E . r e m i p e s .

From 1835 until 1858–59, little was added to our knowledge of
the eurypterids except through brief descriptions of a few fragmentary
remains from the rocks of Scotland and Russia; then almost simul-
taneously three fundamental publications appeared, representing the three
areas that still today furnish the principal eurypterid faunas. These
were Nieszkowski's *De Euryptero Remipede* [1858], describing elabo-
rately the Baltic species now known as E . f i s c h e r i ; Huxley and Salter's
classic monograph *On the Genus Pterygotus*; and James Hall's exhaustive
description and beautiful illustration of the eurypterid fauna of the water-
limes of New York, in volume 3, of the *Palaeontology of New York* [1859].
Nieszkowski's and Hall's papers supplement each other very fully; both
described for the first time the whole organization of a eurypterid; they
recognized the full number and character of the cephalothoracic appendages
exclusive of the chelicerae whose existence was even at this early date
intimated by Hall [*op. cit.* p. 396, footnote]; they established the number
of preabdominal and postabdominal segments. They failed, however, in
making out the correct number of sternites, Hall recognizing but one (the
operculum) and considering the others as ringlike segments, while Nieszkowski
(under the guidance of Dr Fr. Schmidt) found out the true platelike
character of the sternites, but assumed their number to be six. Huxley
and Salter at the same time restored with approximate accuracy the
organization of Pterygotus. Both Nieszkowski and Hall recognized the
close relationship of the eurypterids with Limulus,[1] while Huxley and
Salter adduced other crustaceans for comparison.

Hall described the appendages of the cephalothorax and that of
the female operculum in great detail and with his usual accuracy. He

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[1] Hall submitted his collection to Professor Agassiz who gave " his opinion most
unequivocally that the Eurypteri are closely related to Limulus, belonging even to
the same order."

added to the longer known species of eurypterids (E. remipes and E. lacustris) the following new types, all from the rocks of New York:

Eurypterus microphthalmus   E. pachychirus

E. lacustris *var.* robustus   E. pustulosus

E. dekayi

He erected the new subgenus Dolichopterus (now given full generic standing), for the species D. macrochirus and also recorded the presence of the genus Pterygotus (theretofore known only from Scotland) in the Salina waterlime, describing three species, viz, P. cobbi, P. macrophthalmus and P. osborni.

It is obvious that Hall, with his accustomed thoroughness, had availed himself of all New York collections extant, from the fact that for a decade and a half not a line was added to his investigations on American species, notwithstanding the intense activity in other branches of paleontology, and the further fact that Henry Woodward was meanwhile [1866–78] publishing his excellent *Monograph of the British Crustacea of the Order Merostomata*. During this period the large cement quarries at Buffalo were gradually producing a great number of striking specimens and these became somewhat widespread through the museums until, in later years and with keen and intelligent interest the proprietor of the quarry took measures to see that they were carefully safeguarded and donated to the Museum of the Buffalo Society of Natural Sciences. Some of the early collectors in Buffalo undertook to describe the supposed new material that at first found its way into that museum but, being trained in branches of science remote from paleontology, they succeeded only in creating for the most part a burdensome mass of synonyms. Thus Grote and Pitt [1875–78] described the following:

Eusarcus scorpionis, representing a new and important genus

E. grandis (= E. scorpionis)

Pterygotus cummingsi (not properly defined)

Pohlman [1881, 1882, 1886] published descriptions of the following eurypterids from these rocks at Buffalo:

Pterygotus buffaloensis
Ceratiocaris grandis (=Pterygotus grandis (*Pohlman*) C. & R.)
Eurypterus giganteus (=E. pustulosus *Hall*)
Pterygotus globicaudatus (=E. pustulosus *Hall*)
P. acuticaudatus (=P. buffaloensis)
P. quadraticaudatus (=P. buffaloensis)
P. bilobus *Huxley & Salter* (=P. buffaloensis)
Eurypterus scorpionis *Grote & Pitt* (=Dolichopterus macrochirus *Hall*)

While the splendid collection at Buffalo was being brought together and some part of its treasures made known by the publications referred to, other rocks of this State as well as of adjoining regions were giving evidence of the presence of very remarkable eurypterid remains.

In 1882 Whitfield recorded the occurrence of an Eurypterus in the Siluric waterlime of Ohio, which was fully described as E. eriensis in the *Report of the Geological Survey of Ohio*, volume 7, 1893, and Walcott announced the discovery of a multispinose eurypterid leg in the Utica slate near Holland Patent, Oneida co., N. Y. The genus Echinognathus was proposed for this new type and the species described as E. clevelandi.

In the same year Prof. D. S. Martin at a meeting of the New York Academy of Sciences reported that he had seen in the State Museum a head shield nearly a foot in length and breadth from the Catskill beds at Andes in Delaware co., N. Y. This was described and figured by Hall the following year as Stylonurus excelsior, a gigantic representative of a genus already known from the Ludlow beds of Scotland. Another carapace of this species from the Catskill beds of Pennsylvania was described the same year by Claypole as Dolichocephala lacoana.

The next year [1884] James Hall described for the Second Geological Survey of Pennsylvania an interesting fauna of eurypterids found in the Productive Coal Measures. The first announcement of a eurypterid of

Carbonic age from the American continent had been made in 1868 by Meek and Worthen who described E u r y p t e r u s   m a z o n e n s i s from the Coal Measures of Illinois, erecting for it the subgenus Anthraconectes, and in 1877 C. E. Hall described two species (E .   p e n n - s y l v a n i c u s   and   E .   m a n s f i e l d i) from the Coal Measures of Pennsylvania. James Hall noted four species from the Carbonic of that State, adding two types to those before known, and he described besides a new form from the Chemung group of Warren, Pa. (E .   b e e c h e r i) which Beecher later determined to be a Stylonurus.

Considerable progress in the understanding of the organization of the eurypterids and especially of the genera Eurypterus and Pterygotus, was made by Fr. Schmidt's admirable investigations entitled *Die Crustaceenfauna der Eurypterenschichten von Rootziküll auf Oesel* published in 1883. Nieszkowski's work had already been done under Dr Schmidt's supervision and Schmidt now carried out a very detailed examination of the remains of E u r y p t e r u s   f i s c h e r i   and   P t e r y g o t u s o s i l i e n s i s . He was thereby enabled to correct many details of Hall's and Nieszkowski's descriptions of the appendages; to show the existence of five " Blattfüsse " or sternites open on the ventral side, as in Limulus; to recognize sexual differences in the opercular appendages; to establish the correct number of walking legs in Pterygotus (8, while Woodward assumed 6), and the form and position of the epistoma.

In 1884 Whiteaves made known an Eurypterus (E .   b o y l e i) from the Guelph limestone of Canada, and in 1888 Matthew described as E u r y p t e r e l l a   o r n a t a , a peculiar Devonic organism that is referred by him to this group.

In this year, 1888, also appeared volume 7 of the *Palaeontology of New York* by Hall and Clarke. This volume supplements the description of the Siluric eurypterids in volume 3, by bringing together the remaining merostomes from the State of New York and the adjoining regions. It contains a full size drawing of Hall's type of the famous carapace of S t y l o n u r u s   e x c e l s i o r   and gives an

account of the chelicera and first endognathite, as well as the coxae
of other legs of this Stylonurus, which were discovered and worked out
by the junior author of that volume from the underside of the fragmentary
carapace that served for Claypole's description of the species.   There
was further described a species of Eurypterus (E . p r o m i n e n s)
from the Clinton beds of New York, one from the Waverly beds
near the boundary of Pennsylvania and New York (E . a p p r o x i -
m a t u s); and a tubular body from the Portage beds of Yates county,
which Dawson had described as E q u i s e t i d e s w r i g h t i a n u s ,
and Jones & Woodward regarded as probably a phyllocarid (Echino-
caris), was provisionally referred to Stylonurus.

Two years later (1890) Claypole announced the occurrence of euryp-
terids in the waterlime of Kokomo, Indiana, and he described therefrom
a large Eusarcus, for which he first proposed the generic name Eurysoma
and later Carcinosoma.   A species of Eurypterus from the same locality
was described in 1896 by Miller and Gurley.

While thus in the last decades of the preceding century on this side
of the Atlantic, the fragments of the eurypterids scattered in the forma-
tions of New York, Ohio and Illinois were brought together and published,
important work on the organization of the eurypterids was donè in Europe.
We refer here to Laurie's paper on the *Anatomy and Relations of the
Eurypterida* [1893] and to Holm's new investigation of E u r y p t e r u s
f i s c h e r i [1896].   Laurie had already added considerably to our knowl-
edge of the Scottish species by descriptions of new forms from the Pentland
Hills [1892], among them the new genera Drepanopterus and Bemby-
cosoma, and had discovered the epicoxite and gillplates in Slimonia;
he now took up the discussion of the anatomy of the genera Slimonia,
Pterygotus, Eurypterus and Stylonurus, the relations of the eurypterids
among themselves, to the trilobites and crustaceans, to Limulus, the scorpion
and other arachnids.[1]   We have given full appreciation of this work in

[1] The arachnidan affinities of Limulus had been for some time the subject of dis-
cussion among zoologists, especially in Lankester's paper: *Limulus an Arachnid ?* [1881].

the chapters on the phylogeny and taxonomic position of the eurypterids. Holm had for the subject of his investigations the same E u r y p t e r u s f i s c h e r i from Oesel that had already been studied by Nieszkowski and Schmidt, and he succeeded by most clever manipulation in isolating the chitinous test of the animal which at Oesel is not metamorphosed into a carbonaceous film as in other localities, and was able to elaborate its organization in such detail that E . f i s c h e r i has really become the most completely known of all extinct animals, and our exact knowledge of it is quite comparable with that of its recent relatives. By comparison with Limulus the differences in the appendages of the first and second sternites were referred to their proper sexes. Many details of structure were discovered, such as the minute chelicerae, the epicoxite of certain coxal segments, the endostoma of the posterior margin of the mouth, the connection of the metastoma with the gnathobase, the clasping organ of the second endognathite of the male, the originally composite nature of the metastoma, corresponding to the chilaria of Limulus and the interior tubular processes of the female opercular appendage. This work served to bring out with still greater force the numerous homologies and consequent close relationship of the eurypterids to Limulus.

A comprehensive review of the more important of these discoveries with the status of the classification of the merostomes, was given in 1900 by Clarke in the chapter Eurypterida, Eastman's English edition of Zittel's *Textbook of Palaeontology*, where note was also taken of the ontogeny of Eurypterus.

In 1900 also there appeared C. E. Beecher's reconstruction of the giant S t y l o n u r u s e x c e l s i o r Hall (which he preferred to call S . l a c o a n u s) from the Catskill beds and in the next year the same author announced the discovery of a true eurypterid (S t r a b o p s t h a c h e r i) from the Cambric of Missouri, the only eurypterid from that fauna thus far known.

At this date, aside from the few scattered individuals discovered in the Clinton and Manlius (Siluric), Portage and Catskill (Devonic) beds

there was only one large and typical eurypterid fauna, that of the Bertie waterlime, known from the rocks of this State, and except the small fauna of the waterlime of Kokomo, from the entire continent. Of so much greater interest therefore is the discovery within a few years of three new and larger faunas. The first is that of the Pittsford shale at the base of the Salina beds in Monroe county, found by Clifton Sarle. Its most striking and common member is the representative of a new genus, termed by its discoverer Hughmilleria. This is a form which has a very interesting bearing on the phylogeny of Pterygotus and Slimonia. The eurypterid portion of the remarkable arthropod fauna of Pittsford has been elaborately described and figured by Mr Sarle in the Report of the State Paleontologist for 1902. It consists of the following species:

Hughmilleria socialis   Pterygotus monroensis
H. socialis *var.* robusta   Stylonurus (multispinosus C. & R.)
Eurypterus pittsfordensis

The associated forms (crustacean species of Ceratiocaris, Pseudoniscus, Emmelezoe, Bunodes, mostly described by Clarke), the peculiar lithologic surroundings of this fauna, and the fact that through this discovery the salt and gypsum-bearing Salina beds are now known to be both underlain and overlain by Eurypterus beds, all bear on the problem of the physical conditions under which these animals lived.

A second discovery was made in 1906 by the junior author of this book in the shales of the Shawangunk grit formation of southeastern New York. A preliminary description of this fauna was published by the senior author in 1907 [N. Y. State Mus. Bul. 107]. It consists of one species of Eurypterus, one of Eusarcus, one of Dolichopterus, six of Stylonurus, one of Hughmilleria and one of Pterygotus. It has furnished a contribution to the organization of the eurypterids in a specimen of Stylonurus, retaining all four posterior legs of one side, in the light of which previous restorations of that genus are greatly modified. The most novel feature of the Shawangunk grit fauna, is the presence of larval stages of

Eurypterus, Hughmilleria, Stylonurus and Pterygotus from the nepionic, almost microscopic, stage onward. These ontogenetic stages have been carefully described in the present work and their bearing on the much discussed relationship of the eurypterids to Limulus and the scorpions estimated.

The third fauna is, as already noted in the preface, a discovery of quite recent date made by the junior author in 1910 in the Frankfort shale (Upper Lower Siluric) along its outcrops in the counties of Schenectady and Schoharie. This material is not very well preserved and owing to its incomplete character we are for the present forced to form our conception of specific values from the carapaces alone and to unite with them such other parts of the test as are presumably referable to them. For this reason too, the generic references must be regarded as open to question and of provisional value only, there always being the presumption that when the full anatomy of these Lower Siluric creatures becomes really known they will prove to be generically unlike the species of later date. While the morphology of these species is not yet wholly clear, the age of the fauna is a factor of chief interest, for the Lower Siluric has hitherto afforded only a few fragments known under the names E c h i n o g n a - t h u s   c l e v e l a n d i   and   M e g a l o g r a p t u s   w e l c h i . With our present knowledge of this assemblage we are entitled to the inference that in a late stage of the Lower Siluric the eurypterids had attained a diversity and an abundance quite as great as in the Upper Siluric. We estimate this diversity in some measure on the striking differences in test sculpture presented and even though this may be an unsafe guide to either specific or generic distinctions yet these sculptures are in so large measure unlike those of better known species that they must be given full worth. These characters are fully elucidated at the proper place in the descriptive part of this book and there are among them undeniable evidences of ornament which we have come to recognize as indicative of the genera Eurypterus, Eusarcus, Hughmilleria and Pterygotus. Hence these and other outstanding terms have been adopted in the charac-

terization of the assemblage, which consists as far as now known of the
following species:

Eurypterus? (Dolichopterus?) stellatus   D. latifrons
E. pristinus   Hughmilleria magna
E. megalops   Pterygotus nasutus
Eusarcus triangulatus   P. prolificus
E. longiceps   Stylonurus? limbatus
Dolichopterus frankfortensis

THE EURYPTERIDA

I

MORPHOLOGY, ANATOMY AND TERMINOLOGY

General form. The body of the eurypterids, as a rule, is elongated, and often somewhat fishlike in dorsal view, but it may also become distinctly scorpioid. The slender fishlike form is typically expressed by Hughmilleria [*see* restoration, pl. 59] where the body expands but slightly in the anterior third and then tapers very gradually to the caudal spine; the head shield is semiovoid and the body less depressed than in other genera. Pterygotus is similarly built, but the head shield is more rounded in front and some species are broad and plump. In Eurypterus the lateral expansion or flattening of the body becomes manifest in both head shield and abdomen and the contraction of the body to the caudal portion is more abrupt. Stylonurus has a slender body which, however, expands gradually beyond the middle and then contracts more rapidly. In Slimonia a scorpioid appearance is produced by the squarish head shield and the long tubular caudal portion of the abdomen. An extreme differentiation from the slender terete body of Hughmilleria is reached in Eusarcus with its triangular head shield, broad flat body with subcircular outline, from which the long narrow tail is sharply set off.

We shall recur to this variant expression of the body and its bearing on the mode of life of these animals after a consideration of the appendages which are correlated to the form of the body and corroborate the evidence from the latter.

Integument. The body is covered by a chitinous exoskeleton which alone is preserved in the rocks and usually compressed into an extremely tenuous, carbonaceous, more or less wrinkled film. Notwithstanding its thinness it must have been, like the tough leathery integument of Limulus, very strong and able to furnish a stout basis for the powerful muscles of the creatures.
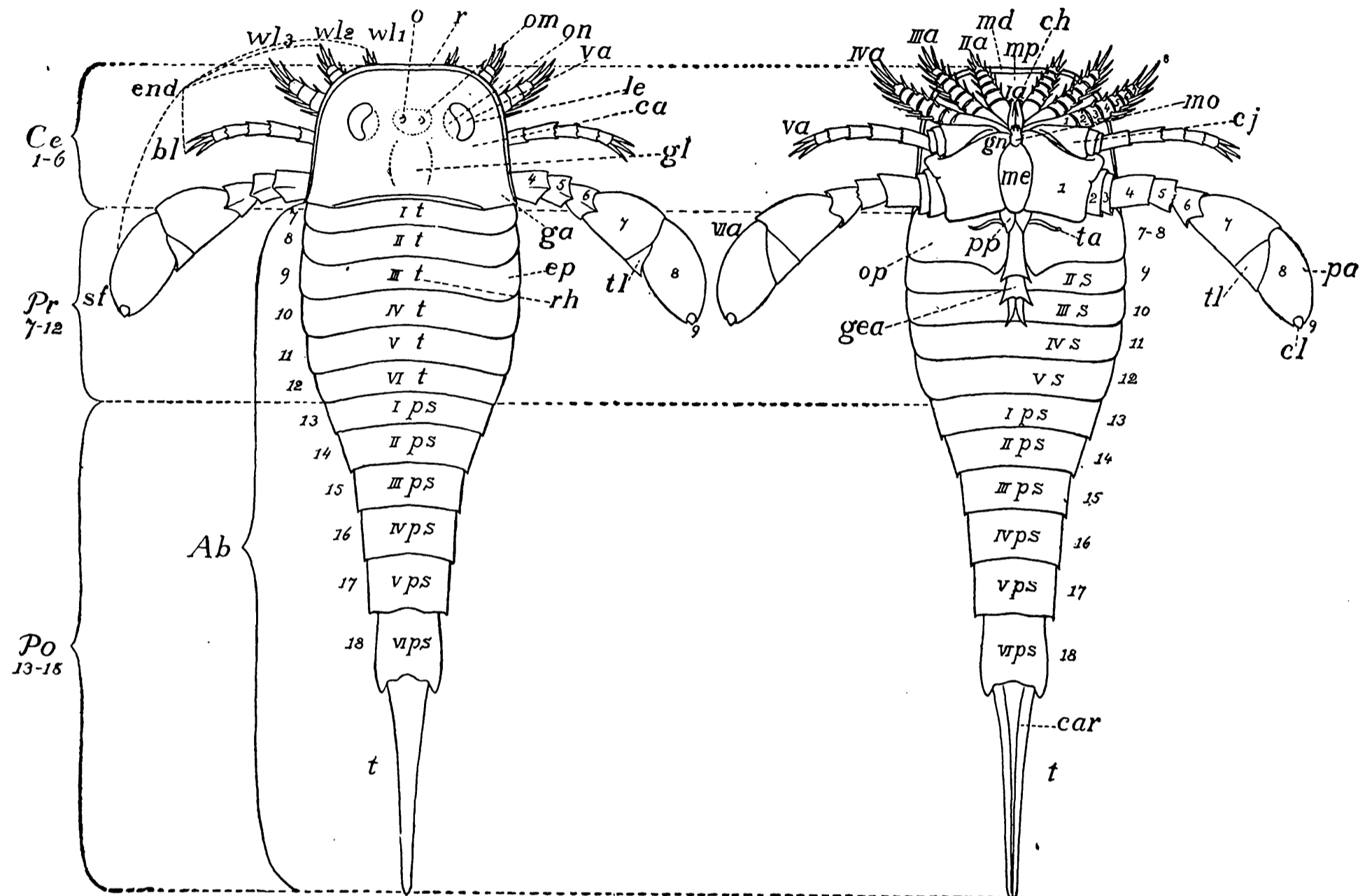
Figure 2   Diagram of an Eurypterid

a; Ia–VIa = appendages or legs
Ab = abdomen
bl = balancing leg
ca = carapace or head shield
car = carina of telson
Ce = cephalothorax or prosoma
ch = chelicerae, *Ia*, preoral appendages or mandibles
cj = coxa
end = postoral appendages or endognathites
ep = epimera or pleura of tergite
ga = genal angle
gea = genital appendage (female)
gl = glabella
gn = gnathobase
le = lateral or compound eyes
md = marginal doublure
me = metastoma or postoral plate
mo = mouth
mp = marginal plate on under side of cephalothorax

o = " larval " median eyes or ocelli
om = ocellar mound
on = ocular node
op = operculum or first sternite
pa = palette
Po = postabdomen or metasoma
pp = pentagonal pieces
Pr = preabdomen or mesosoma
ps, I–VI = caudal or postabdominal segments
r = rim
rh = rhachis
s, II–V = sternites
sf = swimming leg
t = telson
t, I–VI = tergites
ta = tubular organs
tl = triangular lobes
va = visual area
wl 1–3 = walking legs

Probably the majority of the remains found are the cast exuviae from the frequent moltings of growing individuals. The recent Limulus may take as long as eight years to reach maturity when, with the last molt, the clasping organs of the males appear. It is therefore probable that the eurypterids also were relatively slow in growth and it is a fair presumption that the great majority of the specimens found represent immature individuals. They are mostly dismembered and among the fragments of the integument, head shields with the first body segment attached are especially frequent.
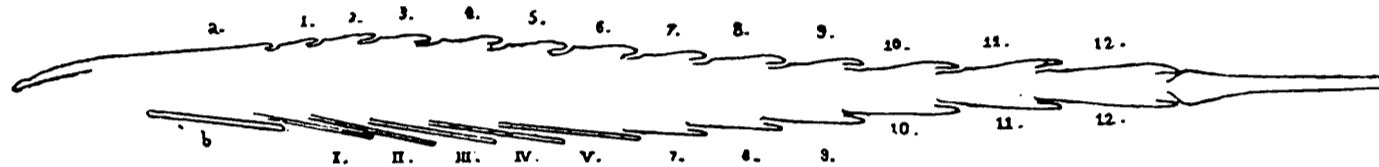
Figure 3 Eurypterus fischeri Eichwald

Diagrammatic longitudinal median section. a, carapace; b, metastoma; 1-6, tergites; I-V, sternites; 7-12, postabdominal segments. (From Schmidt)

We consider it possible, or even probable, that the molting took place as in Limulus through a rent formed back of the frontal doublure of the head shield, through which the animal crawled out. Not only have specimens been found, as the type of plate 6, figure 1, where there is a gaping rent along the front edge of the head shield, but it is also inconceivable that the animal could otherwise have freed its legs so as to pull itself out of its old integument.

The test was thicker on the head shield for that is always less wrinkled and has retained its form better, and it was on the whole, thicker on the dorsal than on the ventral side. The appendages were also clothed with thicker test and the basal segments which attended to the mastication of the food were furnished with an especially thick cover. The postoral plate was likewise thick and is always well preserved.

Scales. The test or exoskeleton is characteristically ornamented by scale markings. On the head shield these consist of tubercles which are mostly simple thickenings of the test, but in some forms, as Eurypterus pustulosus, may grow out into large hollow wart-

like excrescences.   On the abdomen the scales are sometimes disk-shaped but more frequently v-shaped or crescentic, rising in posterior direction.

Nieszkowski [1859, p. 335] has suggested that these scales are the attachment places of muscles, a view which to us seems to explain most peculiarities of their structure and distribution.   The following points seem to support Nieszkowski's assertion:

1   The scales are more distinctly outlined on the inside than on the outside of the test.   In some cases they are well seen on the interior while faint or invisible on the outside, as in the specimens of E u r y p t e r u s   p i t t s f o r d e n s i s .

2   On the abdominal segments they are distributed in distinct transverse zones or belts [see E u s a r c u s   s c o r p i o n i s , pl. 31; Pterygotus, pl. 79] which correspond to the muscle bands that function in moving the segments, and they are entirely absent over the anterior and posterior doublures where no muscles could be placed; on the dorsal side they are arranged in longitudinal rows that follow the course of the intestinal canal and indicate the insertion of muscles with a suspensory function.

3   They are especially strong and distinct on the movable plates of the underside of the abdomen which carried the gill plates and were strongly shifted forward and back in breathing and swimming.

In the mature Limulus the crust is too thick to show any such muscle impressions on the outside, and moreover, the body has become separated into three solid fused regions (the cephalothorax, abdomen and telson) which only are movable upon each other.   The muscles have thus become localized and fastened to strong internal processes or entapophyses.   No such entapophyses have been found in the integument of the eurypterid abdomen, and there is in these structures evidence of the primitive condition of the musculature indicating a state of dissolution into many small muscular fasciculi.   The thin-shelled young Limulus, less removed from the distinct abdominal segmentation of the embryonic stage, still exhibits a like distribution of the muscles and also shows from the outside such

attachment scars as the eurypterids. Even in the mature Limulus, the extensors, or abductors, and the flexors, or adductors, of the gill-bearing ventral plates are still subdivided into many radiating fasciculi, and likewise the extensors and flexors of the tail spine arise from a large number of fasciculi.[1]

The longitudinal zones or series of scales are especially distinct in Eurypterus remipes [pl. 8, fig. 5] and lacustris. They inclose here a distinct smooth, flat median zone, which corresponds to the course of the intestine and there is reason to believe that this double series of scales marks the bases of the muscles and suspensory organs of the intestine. In Pterygotus the distal portion of the intestine

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[1] The muscles of the eurypterid cephalothorax were probably contracted into solid bundles, as in Limulus, following the solidification of the segments. This is indicated by the occurrence of a pair of entapophyses, or chitinous infoldings of the carapace [pl. 6, fig. 6], corresponding in their position to those observed in Limulus, and also by the observation of pairs of circular or oval areas arranged along the median line. At least three such pairs of areas have been seen in Eurypterus remipes. The foremost of them is shown in plate 5, figure 7. They may correspond to the first pair of tergo-proplastrals in Limulus which suspend the anterior horns of the ento-sternon from the dorsal side of the carapace. Gaskell has drawn a hypothetical restoration of the muscle system of the cephalothorax of an Eurypterus [text fig. 4] by inserting in the carapace of E. scouleri the segmental dorso-ventral muscles as met with in the living scorpion. In a general way this

Figure 4   Dorso-ventral muscles on carapace of Eurypterus

le, lateral eyes; ce, ocelli; 62, median dorso-preoral-entosclerite muscle; 63, anterior dorso-plastron muscles; 64, median dorso-plastron muscle. (From Gaskell)

is corroborated by our observations, with the exception that the muscles do not appear to be arranged so closely around the center of the carapace, at least in Eurypterus remipes. From evidence presented subsequently it would seem preferable to use Limulus as the basis of such restoration.

was sharply bent and the angulation has produced a distinct protrusion on the dorsal side of the last segment [pl. 75].

4 The scales are not found on the telson spine, except the anterior swollen portion where the extensors and flexors were attached, nor on the broad, solid oarplates of the swimming legs, while they are present on the leg segments, frequently in distinct longitudinal rows which in some cases develop into regular continuous entapophyses on the inside of the integument, as in the powerful arms of Dolichopterus [pl. 43].

5 On the postoral lip (metastoma) the scars are most strongly developed on the side that is turned toward the body and held by muscles.

6 The prevailing form of the scales is that of a V or a crescent pointing backward, and this shape, together with the fact that the integument is distinctly thicker and darker along the edges of the scales, is indicative of their function, since the muscle scars here, as among mollusk shells, are marked by their thickened edges. Forms with thicker integument, as E u r y p t e r u s   m i c r o p h t h a l m u s , do not exhibit any scaly sculpturing on the outside.

7 The scales are well differentiated from the tubercles which are scattered among them [see test of Eusarcus, pl. 35, fig. 4] and on those parts where the thickness of the integument prevents the appearance of scales over the surface, as on the carapace, these tubercles alone are observed. Similarly the serrations of the edges of the rudder plate of the swimming legs, of the epimera of the abdominal segments and of the telson are independent of scales. But it appears that the spinules on the dorsal crust originate from scales, we surmise from a lengthening of the point of the angle of the V. In E u r y p t e r u s   r e m i p e s ,   l a c u s t r i s and p i t t s f o r d e n s i s , as well as f i s c h e r i , but a single transverse row of such spines is developed on each segment. In E .   r e m i p e s the longitudinal series of scales on the postabdomen over the intestine show a strong tendency to develop into overlapping spinules and in the Carbonic subgenus Anthraconectes all scales possess this tendency.

Besides the scales and spines the integument of the eurypterids was also in many parts covered with fine hairs as in Limulus, especially on the lips and legs. These have been observed and photographed by Holm in E . f i s c h e r i .

Pores of doublures. Schmidt [*loc. cit.* p. 67] has observed that in Pterygotus the posterior third of the dorsal thoracic segments is provided with a separate interior lamella or doublure (" Umschlag ") perforated by numerous fine tubes especially abundant toward the posterior and lateral margins. In Eurypterus this doublure is present but imperforate.

A slightly weathered specimen of P t e r y g o t u s b u f f a l o e n s i s very beautifully exhibits this interesting feature not only verifying Schmidt's observations but also allowing some amplification of them. In this specimen, the pores are distributed over the whole lamella, but are most closely arranged and most distinct in a belt occupying the posterior third of the lamella except for the hindmost millimeter which is entirely imperforate. Where fully exposed, they appear as sharp black lines, about $1\frac{1}{2}$ millimeters long, passing from below and posteriorly, obliquely upward and forward. At the posterior margin of the belt they stand more vertical but they rapidly bend forward and increase in obliquity of direction toward the anterior margin of the belt. They are most distinct on the tergites, but have been seen on the sternites in a similarly situated, though narrower belt, corresponding to the smaller width of the doublure. Similar belts of pores are visible on the posterior thirds of the broad doublures of both the dorsal and ventral sides of the abdominal segments, and on the narrow doublure of the posterior margin of the head.

The weathered head of the same specimen also exhibits anastomosing lines near the center and a ring of several rows of black points and lines which seem to indicate either the presence of similar pores or of a system of pits.

Another row of pits which seem to have been pores, is also seen just inside the flexure of the head shield into the doublure. These would seem to correspond to the row of "Punkte" observed by Holm in E u r y p t e r u s

f i s c h e r i . Such minute pores or canals may have given passage to sense organs (sensory setae or bristles) or to tegumentary glands.

Serrations and spines. The edges of the integumental plates are frequently furnished with sharp serrations, like those of the abdomen of Limulus. These serrations are especially frequent on the anterior edge of the palette of the swimming leg, on the epimera of the postabdominal segments and on the lateral edges of the tail spine. In Eurypterus the distal edges of the segments of the swimming legs are also distinctly serrate. Frequently an alternating series of larger and smaller serrae is found. A good example of this is the telson of P t e r y g o t u s b u f f a l o e n s i s .

. The spines on the legs and those on the manducatory edges of the coxal segments have originated from fine hairs, which grew first into strong bristles and finally into spines. These spines become powerful spurs in some genera, as Eusarcus and Stylonurus. In Ctenopterus, the subgenus of Stylonurus, they are sometimes broadened and may have assisted in swimming. Like the hairs, the spines are inserted and fixed by ringlike swellings of the integument at their bases· and frequently broken out, leaving distinct scars.

Cephalothorax. The body of the Eurypterida consists of 18 segments and is functionally divided into two sharply distinct regions, the *cephalothorax* or *prosoma*, consisting of six fused segments and the *abdomen* consisting of 12 segments. The cephalothorax with its appendages is specialized for locomotion and prehension, while the abdomen is essentially a vegetative sac. The six segments of the cephalothorax find their expression in the six pairs of appendages. The cephalothorax consists of the *carapace* or *head shield* and the organs of the underside.

The *carapace* is of small size, one fifth of the body (exclusive of the telson) or less in length. This small size is a feature that gives the eurypterids a greatly different aspect from Limulus with its immense semicircular carapace, but it well corresponds to the relative dimensions in the scorpions. In Limulus it is expanded so much both laterally and frontally

that it entirely covers the legs and is the result of extreme adaptation to a mud-groveling habit, but in the eurypterids it never covers more than the basal segments of most legs. It nevertheless shows considerable variation in relative size, which is roughly correlated to the size and weight of the legs. Thus Dolichopterus with its very stout walking legs and extremely long swimming legs has a relatively very large carapace, while Pterygotus with thin walking and short swimming legs has, in spite of the enormously extended chelicerae, a remarkably small carapace.

The carapace is typically subrectangular in Eurypterus, Dolichopterus, Slimonia and Stylonurus, semiovoid to semicircular in Strabops and Hughmilleria, and subtriangular in Eusarcus.[1] The broadly semielliptic or semicircular form is manifestly original and primitive, as indicated both by the larval stages of the eurypterids and the carapace of the Cambric Strabops, while the subrectangular and subtriangular forms are the extremes of different lines of development.

The carapace culminates at the middle or the posterior third in the median ocellar tubercle. Along the margin it is more or less flattened and the border is frequently thickened and beveled, forming a shoveling edge. This is notably the case in Eurypterus but not in the Pterygotus branch of the subclass.

In the great majority of specimens the surface of the carapace is flattened by compression. Nieszkowski figured in Eurypterus a short ridge extending backward from the middle of the frontal margin and two crescentlike lateral ridges on which the compound eyes are situated. Schmidt says that Nieszkowski exaggerated these ridges. He himself describes a narrow pointedly triangular prominence reaching from the posterior margin forward to the ocellar tubercle, whence two broad sector-like elevations extend forward and inclose a median depression extending to the frontal margin. Holm has considered the ridges as accidental and

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[1] The form of the carapace varies with the position of the eyes, the form of the legs and the mode of life of the animals. We shall note these relations more fully in another chapter.

represented the carapace of Eurypterus as evenly rounded with the exception of the frontal elevated areas.

The usual waterlime material does not give any evidence of the original form of the carapace of Eurypterus, the integument having been completely flattened out in the fine mud. A sandy dolomite bed of the Bertie waterlime at Morganville, Genesee co., has however furnished a few specimens of E u r y p t e r u s r e m i p e s that are uncompressed. These [pl. 6, fig. 6] have glabellalike posterior median ridges well defined by two subparallel furrows deepest half way between the posterior
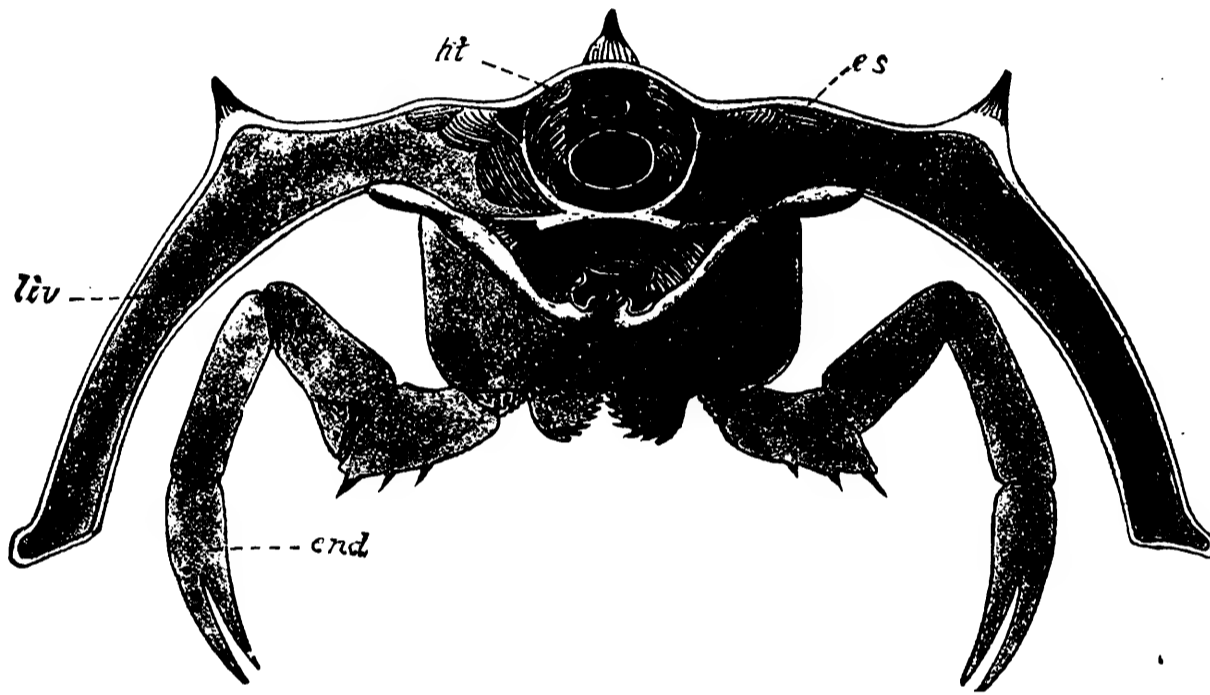
Figure 5   Transverse section through the head of Limulus

ht, heart; *liv*, liver; *es*, entosternon; *end*, endognathite.   (From Packard)

margin and the ocellar tubercle, which, by the way, the glabella does not quite reach. They also show a crest extending from the lateral eyes to the posterior margin and separating the elevated apical area from the steeply outward sloping lateral areas. This sculpturing is so remarkably like that of Limulus that we have no doubt it represents a general feature of the eurypterids. The dorsal furrows bounding the glabella correspond to entapophyses, serving for the attachment of muscles. The appended sections of Limulus [text fig. 5, 6] show the relation of the glabella to the position and extension of the heart and the relation of the glabellar furrows to the muscles holding in place an internal cartilaginous

plate, termed the *endocranium, plastron* or *entosternon*,[1] which in its turn forms the fulcrum for other important muscles. Owen has shown that the glabellar furrows, or rather the entapophyses or infoldings to which the furrows correspond, are the bases of the powerful levators of the preabdomen and also of the muscles which serve to steady the entosternon while the latter furnishes the fixed points for the flexors or depressors of the preabdomen and the important muscles that hold and move the coxal joints of the legs.
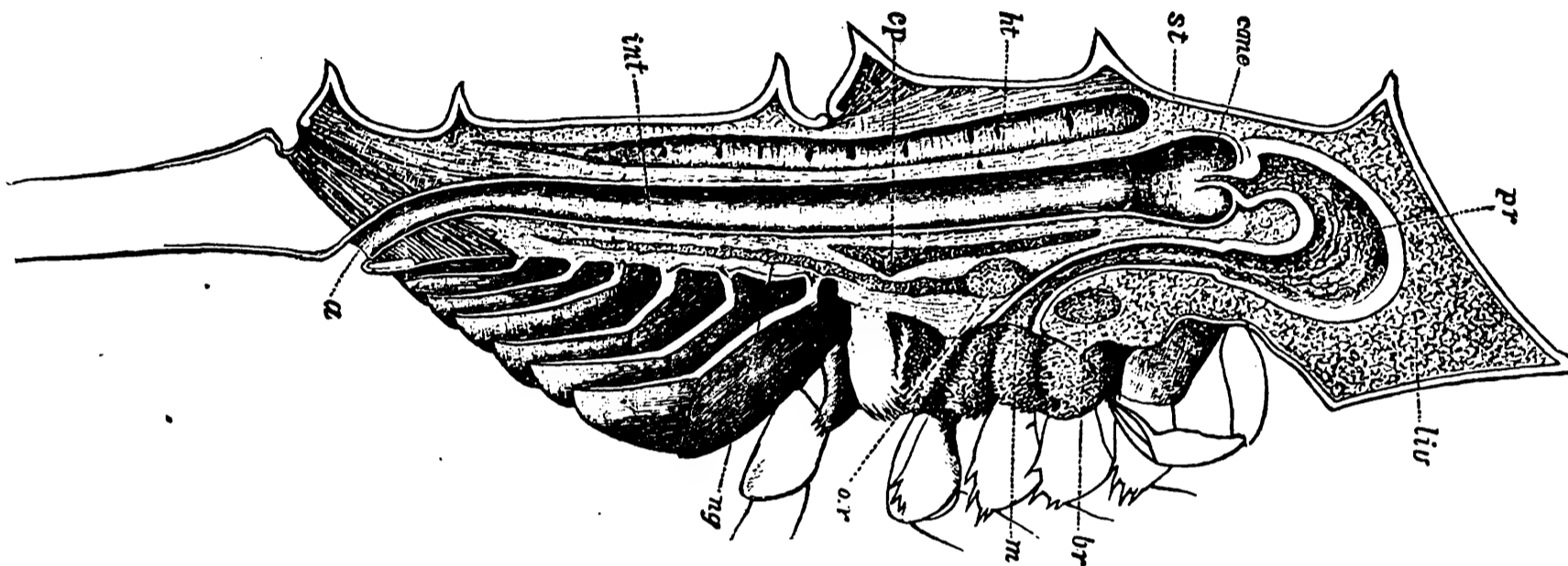
Figure 6 Longitudinal section of Limulus

liv, liver; *pr,* proventriculus; *st,* stomach; *ht,* heart; *cp,* cartilaginous plate, entosternon; *int,* intestine; *a,* anus; *br,* brain. (From Packard)

The glabellar furrows of Eurypterus thus correspond quite precisely in position and extension to those of Limulus and the appendages on the ventral side are entirely homologous and of like position and structure; hence it is to be inferred that the same system of muscles existed in Eurypterus as in Limulus, that also Eurypterus may have possessed a cartilaginous entosternon and that the glabellar furrows served as bases for the levators of the preabdomen and the lateral levators of the entosternon. These furrows are also well developed in species of Stylonurus, as S. cestrotus.

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[1] The importance of this internal skeleton to the muscular system of Limulus is fully described by Owen [Palaeontographical Society 1878. 32 : 187].

This glabellar ridge with its bounding furrows is most distinctly marked in the embryonic Limulus [text fig. 24] where it bears the ocelli at its anterior point. It there continues over the abdomen and gives this stage its well known trilobitic appearance. It is still more prominent in the fossil Limuli (e. g. L . w a l c h i), than in the recent species and is therefore apparently an old character possibly inherited from the common ancestor of the merostomes.

The elevated area of the glabella manifestly served, as in Limulus, to receive the anterior portion of the heart, while the space between the carapace and the ventral membrane in front of the ocelli contained the liver. We find that the interior surface of the carapace sometimes exhibits in this region, in E . l a c u s t r i s and r e m i p e s , anastomosing radiating lines similar to those seen in many trilobites (Conocephalites, Harpides, etc.), and which have been interpreted by Jaekel as liver impressions.

The edge of the carapace is bent under, forming a *doublure*. This is usually narrow as in Eurypterus and runs out toward the genal angles. In Stylonurus, however, and notably S . m y o p s [pl. 52, fig. 10] it becomes very broad and concentrically striated. In Limulus the doublure broadens in the median part of the anterior portion into a concave triangular shield that is said to serve as an inlet to the water for respiration when the broad carapace is resting on the mud. A triangular area of like relation and relative dimensions is set off in some species of Stylonurus [pl. 46, fig. 11] and may have had a like function.

To the doublure are attached by an open suture two plates, figured by Hall [1859. v. 3, pl. 80A, fig. 12], meeting in the median line along a suture and together forming a horseshoe-shaped organ, which toward the mouth passes gradually and by an irregular contact into the very thin membrane that surrounds the coxal segments of the legs. One of these *marginal plates* is shown in place in plate 5, figure 6, where the carapace is partly removed. Frequently in specimens of E u r y p t e r u s r e m i p e s not completely flattened, they have prevented the marginal portion

of the carapace from further sinking in and therefore appear on the compressed carapace as a very marked smooth, flat marginal zone [pl. 6, fig. 5]. In Pterygotus a third plate is intercalated between the two marginal plates in front of the mouth, forming an *epistoma* that occupies the same position as the hypostoma of the trilobites.

Limulus possesses in front of the chelicerae a wartlike node on the ventral membrane which has been shown by Patten [1894] to contain an olfactory organ. While Holm's photographs demonstrate the absence of anything similar in E u r y p t e r u s   f i s c h e r i , it seems to us that nodes observed in specimens of Eusarcus and Stylonurus in the corresponding place may possibly indicate the presence of a like organ in these genera.

The *connection of the carapace with the abdomen* is accomplished by articulations near the postlateral angles, well seen in plate 6, figure 5. It is indicated by an abrupt change in the direction of the posterior margin where the truncation of the genal angle begins. Between the articulations the margin of the carapace is curved forward, so that an open slitlike space remains between the carapace and the abdomen which is occupied by a thin membrane connecting the doublures of the carapace and first abdominal segment. As Holm has pointed out, the open space indicates that the movability of the articulation between the carapace and the abdomen must have been very considerable.

Eyes. The carapace bears two pairs of eyes, the large *lateral* or *compound eyes* and the *median eyes* or *ocelli*. The lateral eyes distinctly fall into two groups by virtue of structure and position.

The first of these groups exhibits a smooth *visual area* which is more or less crescent-shaped and borne on an elevated *ocular node* between the glabella and the lateral margins. This type of eye is exemplified by Eurypterus and is also found in Dolichopterus, Drepanopterus and Stylonurus. Probably Strabops also possessed eyes of this type; Eusarcus, in regard to its eyes as well as its whole body form, is an aberrant type, for while it possesses apparently smooth bean-shaped eyes these are marginal as in those of

the second group, being borne near the anterior angle of the subtriangular carapace.

The second group of eyes is typically represented by Pterygotus, and found also in the genera Slimonia and Hughmilleria. In these the visual area occupies the whole node, is marginal and faceted. In Pterygotus the immense eyes [pl. 73] occupy the antelateral angles. The side of the somewhat globose carapace is impendent in the antelateral region so that in flattened individuals part of the lateral eyes is pressed over on the underside (particularly well seen in P . b i l o b u s); similarly in Slimonia, where the lateral eyes lie at the anterior angles of the rectangular carapace, half of the eye is on the underside [see Woodward's restoration, 1872, pl. 20]. The connection between the Pterygotus and Eurypterus eyes is afforded by that of Hughmilleria as we show in the generic discussion of that genus. While it is marginal in H. s o c i - a l i s , the genotype, it is still submarginal in H . s h a w a n g u n k and while it is smooth on the outside, it shows delicate facettae on the inside.

Homology of lateral eye in Pterygotus and ·Limulus. No observers have recorded the presence of corneal facets in the eyes of Euryp-terus and Holm states that even in excellent microscopic preparations he has been unable to notice anything but an apparently smooth, uni-formly thick cornea; the faceted eyes of Pterygotus, however, have been known to the earliest writers on this group of fossils. Beyond the fact that the lateral eyes of Pterygotus possess faceted corneae, nothing can be gleaned from the literature, and the figures given are equally inconclu-sive showing either projecting round lenses in a square meshed interstitial test or sclera [cf. Huxley & Salter Monogr. I, pl. 3, fig. 1b] or len-ticular depressions with a hexagonal scleral test [Woodward, pt 2, p. 56]. More frequently it is stated that the facets are not discernible, a fact attri-buted to their extremely small size.

Several carapaces of P t e r y g o t u s m a c r o p h t h a l m u s and P . b u f f a l o e n s i s, their visual surfaces excellently retained, permit us to elaborate the anatomy of this type of eye with a fair degree of pre-

cision, and to demonstrate the *entire homology in structure of the eyes of Pterygotus and Limulus.* The visual surfaces of the specimens in question exhibit five distinct states of preservation, here illustrated by diagrams.

In states I and II the visual surface is perfectly smooth without a trace of reticulation or lenticular depressions or prominences even under condensed light and under water. Two specimens show this state in the exterior view, two more as intaglios of the exterior of the head. Among the former is one of the best preserved carapaces [pl. 69, fig. 7] which

distinctly shows the fine granulation of the surface and hence might be expected to retain also the finest details of the visual surface. The other specimens with smooth eyes are so well preserved that the corneal facets should be visible. Where the smooth surface is seen in an exterior view, the presence of the carbonaceous film indicates that the exterior of the test is actually under observation while in case II where the smooth visual surface is seen in a cast, the absence of the test proves likewise that we do not have before us an interior view of that surface.

Figure 7 Compound eye of Pterygotus;
diagrams of preservation states

The second group comprises preservation states III and IV. In case III the visual surface in an exterior view exhibits lenticular depressions in a network of squarish meshes. This is well shown in the large head [pl. 73, fig. 1]. In case IV the visual surface is seen in a cast and provided with a system of low papillae corresponding to the depressions seen in case III. Here the test is reduced to a mere carbonaceous film.

The relation between these two states of preservation, the absolutely smooth and the papillate, is indicated in the condition V exhibited by the fine head shield in the Buffalo collection. Here is a smooth visual

surface showing whitish circles in a dark reticulate mass and resting on this surface patches of a smooth carbonaceous test which in this case shows but the faintest shadow of the underlying lenticular structure.

On plate 72, figure 1, we illustrate an internal mold of P . b u f - f a l o e n s i s from the collections of the National Museum and the external mold of the same specimen from the Museum of the Buffalo Society of Natural Sciences is shown on plate 72, figure 2. In this external mold the test of the lateral eye is radially wrinkled and lacks all traces of facets, while in the internal cast the eyes are finely faceted but without radiating wrinkles. In this case, there must have taken place before the entombment of the specimen a partial separation and a wrinkling of an outer smooth cornea.

We may hence conclude with entire safety that *this Pterygotus* at least *possessed a smooth, relatively and uniformly thick cornea* and *below this a system of lenses*.

In accordance with this conclusion the lenses were either separate from the overlying cornea or they were only papillary prolongations of its underside. If the former they have a structure like that of the holochroal eye of the trilobites; if the latter then the structure is in entire accordance with that of the eye of Limulus [*see* text figures 8 and 9].

The choice of the alternatives seems to be indicated by states IV and V; for both can only be explained by assuming that the lenses have been lifted out as a whole or system, leaving the sclera forming the sockets. In case III the epidermal layer into which the lenses projected is still preserved; in case IV this is lost and only the impression left. In the latter case the cornea and the attached lenses must have been lost before burial by the sediment as otherwise the papillate cast should not have been produced. It is obvious that if the lenses had been distinct and separate from the cornea, we would find, after the loss of the cornea, the majority of the lenses still embedded in the epidermal layer, while in fact in these two cases none at all are thus preserved.

The sole case which might be taken to exhibit separate lenses is the last (V), where a smooth faceted surface is seen. As stated before, the lenses appear as light circular spots in the brown carbonaceous test. Close examination shows that they consist of semilenticular dolomite fillings of depressions that correspond with those observed in case III. They could be taken either as demonstrating that the cornea with the papillae was lifted out of the sclera before the burial of the specimen in the sediment and thereafter the depressions filled with mud, except where patches of the cornea adhered to the eye; or as representing the filling of corneal cavities which function as lenses and are homologous to the anterior corneal cavity observed by Clarke [1888, p. 258] in the schizochroal eye of P h a c o p s r a n a . It is obvious that the former explanation is, in view of the preservation states III and IV, by far the more plausible, especially since the presence of a continuous smooth cornea precludes the comparison with the schizochroal trilobite eye.[1] There are besides these direct arguments for the limuloid structure of the Pterygotus eye, other facts which point, though less directly, to the same conclusion. These are the distinct continuity and at the same time strange tenuity of the large cornea of Pterygotus in contrast with the solid holochroal eye of such a trilobite as Asaphus. These characters show themselves in its wrinkling (often distinctly radiate, as in plate 72, fig. 2, more often concentric) or bursting in other specimens. That this cornea is continuous with the integument of the head is indicated by the fact that it is not divided from it by any distinct line and in macerated heads does not separate from it.

This evidence may be supplemented by two *a priori* reasons for similarity of eye structure in the eurypterids and Limulus: *a*) in all other organs these organisms have been found to agree with that ancient genus, *b*) the eyes of Limulus are of a remarkably primitive type such as would actually be expected in these archaic arthropods.

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[1] It may be noted in this place that a specimen in Buffalo exhibits indications of a faint apical depression of the papillae.

In view of this inferred structural identity in the lateral eyes of Ptery-
gotus and Limulus, the stage of development which the latter has attained
becomes a matter of interest to us here.

Packard [Am. Nat. 1880, 14:212] describes the eye of Limulus as
follows:

> The structure of the eye is very unlike that of any other arthropod
> eye. The cornea is simply a smooth convex portion of the integument,
> which is much thinner than the adjoining part of the chitinous skin. There
> are no facets, the cornea externally being structureless, simply laminated
> like the rest of the integument. In the internal side of the cornea are a
> series of solid chitinous conical bodies, separated from one another by a
> slight interspace and in form resembling so many minié-rifle balls; the
> conical ends of these solid cones project free into the interior of the body,
> and are enveloped in a dense layer of black pigment. Within the base of
> these cones are secondary shallow cuplike bodies or shallow secondary
> cones. It is these primary cones which, seen through the smooth convex
> translucent cornea, give the appearance of a faceted surface to the
> external eye.
> All the parts thus far described except the pigment layer, are molted
> with the rest of the crust, and the large slender cones can be easily seen
> by viewing a piece of the cast-off eye; the solid cones being seen projecting
> from the inner surface of the cast-off cornea.

The author adds: " So far as we can ascertain, no arthropod eye is
so simple as that of Limulus."

Watase [Biol. Studies, Johns Hopkins Univ. 1880, 4:287] in conse-
quence of his investigation of the compound eyes of arthropods considers
the ommatidium of the lateral eye of Limulus as making the nearest
approach to the primitive condition. " It is nothing more and nothing
less," he states, " than a depression in the skin, with the thickened chiti-
nous cuticle fitting in the open cavity and acting as a lens to condense
the light." We have copied two of Watase's excellent figures to illustrate
this structure [text figs. 8, 9].

In view of the close relationship clearly uniting Pterygotus with the
other eurypterids, notably Eurypterus and Eusarcus, we have little reason
to doubt that the lateral eyes in all were of like structure. Nevertheless,

there may here exist a difference from that of Pterygotus, for in the other eurypterids no facets have been observed. It is obvious that both Eurypterus and Eusarcus possessed an exteriorly smooth cornea just as Pterygotus; as to the interior of their compound eye, however, several possibilities present themselves: either the lenses were separate from the cornea and thereby lost in fossilization, not being united by the sclera as in the holochroal eyes of the trilobites; or the facets were so feebly
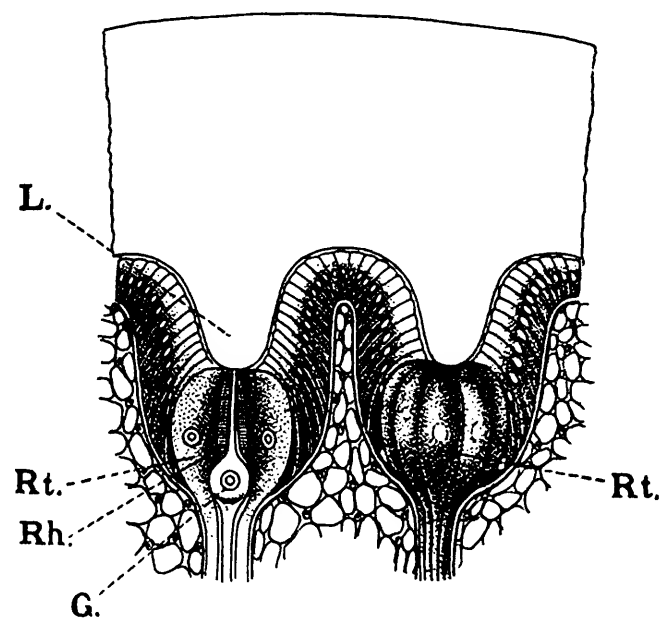
Figure 8 Limulus. Two ommatidia shown side by side, partly schematic. The thick unshaded body is the chitinous covering of the eye. *L*. lens cone, fitting into the depression of the skin. *Rt*. retinula. *G*. ganglion cell. (From Watase)
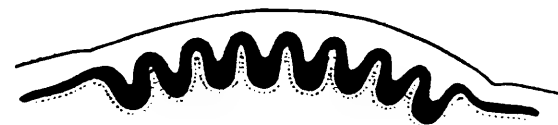
Figure 9 Diagram of the compound eye of *Limulus*, the black, heavy line representing the ectoderm and each depression in this layer corresponding to an ommatidium. (From Watase)

developed as to escape observation. There are no records as far as we are aware, either among living forms, or among the fossil merostomes, to support the former hypothesis. Numerous recent crustaceans, among them the venerable Apus, either lack the facets entirely or have them so poorly developed that they are hardly noticeable,[1] and this fact seems well suited to shed light on the failure to detect the facets in Eurypterus and Eusarcus.

In some arthropods the crystalline cone assumes a transparent semiliquid state [*see* Watase, 1890, p. 147], and it may perhaps be assumed

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[1] *See* Parker, G. H., The Compound Eyes in Crustaceans. Mus. Comp. Zool. Bul 1891. v. 21.

that the eye of Eurypterus had advanced one step beyond that of Pterygotus leading to the separation of the lens cone into an independent crystalline cone, and that this crystalline cone had failed to become hardened. In other arthropods, as in such insects as form Grenacher's "aconous type" of the compound eye, the whole ommatidial cell may remain as a clear transparent body [Watase, *ibid*].

The bearing of the position of the compound and simple eyes on the habits of life of the eurypterids will be noted in another chapter.

The *median eyes* or *ocelli*, which are also frequently termed the *larval* or *simple eyes*, consist of two single, transparent spots of the integument in round pits with ringlike walls situated on a small mound or tubercle. In Eurypterus and Eusarcus the transparent spots are distinctly thickened into lenslike bodies. The ocellar tubercle is always situated on the median line of the carapace and it wanders forward and backward with the lateral eyes so that as a rule it is on a cross line connecting the posterior extremities of the lateral eyes. Exceptions are made by the genera Eusarcus, Pterygotus and Slimonia where the lateral eyes have become marginal at the front of the carapace while the ocelli remain on the middle of the carapace, thus retaining the advantage of their position at the apex of the shield. In Limulus, on the contrary, the lateral eyes have remained in the posterior half and the ocelli have wandered to the front.

As to the *function of the ocelli and compound eyes*, observations on other classes of arthropods which possess both groups have led to the conclusion that the two sets are complementary to each other, the compound eyes being adapted to distant sight while the ocelli are myopic, as indicated by their highly convex lenses. This specialization has been necessitated by the slight adaptability of the stiff compound lenses to different distances. The most primitive ocelli lack lenses entirely and are mere pigment spots sensitive only to intensity of light.

Appendages of cephalothorax. The *cephalothorax* or *prosoma* bears six pairs of limbs which are homologous with those of Limulus. It is this close homology and the detailed comparison which is possible between

the limbs of Limulus and the eurypterids that are among the strongest proofs of their intimate relationship.

The six pairs of limbs are currently divided into the *preoral* (the first) and *postoral* (the following five pairs). The preoral limbs are the *chelicerae* or *mandibles*, the postoral the walking, and burrowing or swimming legs. Besides these the mouth is surrounded by platelike appendages, functioning as lips. These are the *epistoma*, *endostoma* and *metastoma*.

a The **chelicerae** in Limulus are small [*see* text fig. 10] and consist of three segments, the much compressed but relatively long basal segment and the two forming the pincers or chelae. The basal joint articulates, as Holm has pointed out, with an unpaired, lanceolate plate placed between the coxal segments of the first pair of walking legs.

The preoral appendages of the eurypterids exhibit great differentiation. They are smallest in Eurypterus, where they have been described in detail by Holm and have proved to have almost the exact structure of those in Limulus. We figure here the chelicerae of E . r e m i p e s and E . l a c u s t r i s [plate 7, figure 1, and plate 12, figure 1] which verify Holm's observations. Those of Stylonurus have a like structure and similar relative size as shown by Hall and Clarke [*see* under S . e x c e l s i o r]. Eusarcus had similar chelicerae which, how-
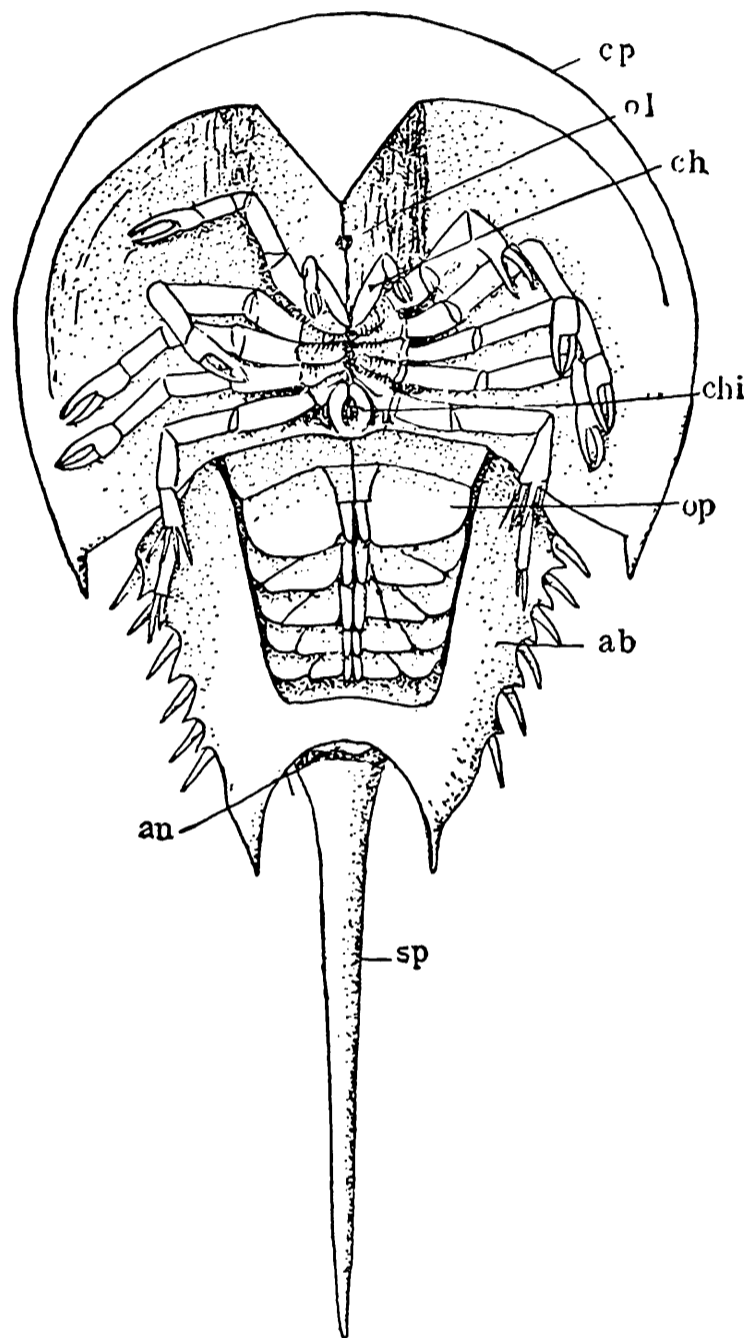
Figure 10 Limulus polyphemus; female, from ventral surface

ab, abdomen; *an*, anus; *ch*, chelicera; *chi*, chilarium; *cp*, cephalothorax; *ol*, olfactory organ; *op*, operculum; *sp*, spine. (From McMurrich)

ever, were relatively large and had stronger chelae. The specimen of E. scorpionis reproduced on plate 32, retains them in their natural position. Woodward figured them, as pointed out by Laurie, in Eurypterus scorpioides, which is an Eusarcus. In Dolichopterus and Drepanopterus they are not known. In general it may, however, be said that they were extremely similar in the genera of the Eurypterus group, viz, Eurypterus, Eusarcus and Stylonurus.

On the other hand they show extreme variation in the genera of the Pterygotus group, viz, Hughmilleria, Slimonia and Pterygotus. In Slimonia they were discovered by Laurie [1893, p. 511, pl. 1, fig. 3] and found to be very small and with strong curved pincers, but otherwise as in Limulus. Those of Hughmilleria have been fully described by Sarle. They are larger [pl. 61, fig. 6] than in any other genus except Pterygotus, projecting beyond the margin of the carapace when extended and thus forming a transition to their condition in the latter genus. In Pterygotus they have been developed into the gigantic pincers which give that genus its fantastic aspect. Notwithstanding their great size in Pterygotus, there still prevails much doubt as to their structure. The current restoration [Zittel-Eastman's Textbook, fig. 1423] is one that would indicate a structure greatly different from that of the chelicerae of the other eurypterids. Our material fortunately sheds light on this problem and we have for this reason inserted here the following note.

The morphology and formation of the chelicerae in Pterygotus. In several specimens of P. macrophthalmus and P. buffaloensis at our disposal, the chelicerae are so excellently preserved as to remove all doubt regarding their morphology and function. In one [pl. 74, fig.1] the chelicera of a large individual is perfectly preserved from the distal extremity of the chelae or pincers to the base of attachment. This shows distinctly that the organ consisted only of one unjointed long arm carrying the terminal pincers. In the second specimen the arms of both chelicerae lie side by side, while the pincers of both have swung back, one until it is subparallel with the arm. These latter chel-

icerae serve to suggest the ready reversibility of the pincers. On comparing the length of the pincers with that of the arm [specimen pl. 77, fig. 3] one finds that the pincers are as long as the uncontracted part of the arm. The contracted basal portion, which amounts to about one fifth of the length of the arm is, as our material and the drawings of the British specimens indicate, nearly always missing. In another specimen, this part contrasts by its thinness with the thicker test of the arm, which terminates abruptly at a convex line along the contracted part. One might at first glance infer the presence of an articulation at this point, but the continuance of the test and the contrast in thickness of it on the arm and of the basal contracted part show that this latter was rather of the nature of a membrane and probably a part of the epistoma, Its basal edge is ragged and obviously torn.

The corresponding lengths of the pincers and arms and the actual occurrence of pincers thrown back, demonstrate, we believe, the functional possibility and competency of the pincers to grasp food and carry it to the mouth. The crustaceans afford several instructive examples of analogous prehensile organs. One of these is the giant spider crab from Japan (M a c - r o c h i r u s k ä m p f e r i) seen now in many of the larger museums. It possesses a pair of immensely long prehensile chelate limbs which consist of two long segments and the chelae, besides a small proximal segment. In the articulation it can be doubled in the exact middle between the two equally long segments, thus serving to bring the prey readily within reach of the masticating edges of the other limbs surrounding the mouth.

In the restorations of Pterygotus, a varying number of segments has been assigned to the chelicerae. Salter and Huxley [op. cit. pl. 15, fig. 6] gave four segments (the supposed additional basal ones not visible in the dorsal view), but Woodward doubled this number in his figure [op. cit. pl. 8, fig. 1]; and the latter is retained by Schmidt [op. cit. p. 73, fig. 1B] and has long since entered the textbooks. While Salter and Huxley figure the chelicerae as rigidly straight, as they are indeed seen in our specimens,

Woodward gave them a graceful backward curvature. Schmidt again drew them nearly straight.

A perusal of the literature suggests that this conception of the many-jointed composition of the chelicerae is based on doubtful evidence. Woodward, for example, says of P . a n g l i c u s [p. 37] that " three joints at least may be observed " and of P . b i l o b u s [p. 57] " there appear to be five joints in the antennae of this species, but it is seldom that their true line of articulation can be readily distinguished. Five are clearly to be seen in one of the antennae figured in the accompanying woodcut, figure 10." Schmidt states [p. 74] " Von den Scheerenfühlern sind in meinem Material nur die letzten beiden eigentlichen Scheeren-glieder vorhanden, die ersten Glieder, von denen 3–5 angenommen werden, fehlen uns bisher." Laurie [p. 516] concluded that the question of the number of segments is still unsettled, and that the markings resembling articulations on the proximal portion may be due to crumplings of the undoubtedly thin cuticle, adding: " I believe them to have consisted of three segments—a long straight proximal one, and the two distal ones which possess the toothed pincers."

Laurie's contention is corroborated by our examples of P . m a c r o p h t h a l m u s and b u f f a l o e n s i s and its correctness is suggested by the rigidly straight direction of the chelicerae in both the European and American species which can only mean the lack of articulation in the long arms. Finally we have also been able to convince ourselves of the presence of but three articulations in a fine specimen of one of the principal English species, P . b i l o b u s , in the possession of the American Museum of Natural History. In this specimen both chelicerae show long straight well preserved basal segments without any trace of articulation in them, the whole chelicera being distinctly composed of but three segments.

Another problem in regard to the chelicerae of Pterygotus not yet solved by direct observation is their point and mode of attachment to the cephalothorax. A glance at the restorations of P . a n g l i c u s by Woodward, and P . o s i l i e n s i s by Schmidt, both reproduced in

Zittel's Handbook and in textbooks, will make this point clear. In the former they are represented as attached to the foremost point of the underside of the cephalothorax; in the latter they appear as inserted just in front of the mouth at the base of the epistoma. Schmidt says regarding this point [p. 73]: " Um auf die Scheerenfühler zurück zu kommen, so hätte ich ihren Ansatzpunkt gern, wie meine Vorgänger, nach vorn an der Unterseite des Kopfes verlegt, aber die eben besprochene 3-theilige Umschlagsplatte liess eine andre Auffassung nicht zu, als ich sie oben auseinandergesetzt. An ihrer Oberfläche ist nirgend ein Platz für den Ansatz der Scheerenfühler und zugleich war für diese Umschlagsplatte selbst keine andre Deutung möglich." Laurie has not critically discussed this question in his study of the eurypterids, but only suggests that there was perhaps no properly developed articulation between them and the epistoma because they are always found torn off.

While we are not in a position to offer direct evidence on this problem, or at least only such as is inconclusive, we believe in the correctness of Schmidt's inference for the following reasons. One of our specimens shows that the six appendages of one side radiate from one point, which would mean that the chelicerae were inserted directly in front of the first pair of walking legs. But aside from this observation, the fact that the attachment of the chelicerae, in Slimonia, Eurypterus and Hughmilleria, has since been fully established to be directly in front of the mouth as in Limulus, leaves little doubt that the large pincers of Pterygotus, if they are at all homologous to the minute chelicerae of those three genera, must have had the same place of insertion, viz, at the posterior end of the epistoma. We may add that the homology of the large pincers of Pterygotus with the chelicerae of Limulus, Eurypterus etc. would also suggest as an a priori conclusion, their composition of but three segments and the lack of a distinct articulation with the epistoma.

The general conclusion from the foregoing observations is that the chelicerae exhibit a remarkable identity of structure in all genera despite their great differences in relative size.

b **Postoral appendages.** Of the five pairs of postoral limbs which are frequently designated as *endognaths* or *endognathites*, the first and fifth show the greatest amount of differentiation, while the intervening three pairs, as a rule, are very much alike and are functionally uniform, mostly serving as walking legs. We find the same condition in both Limulus and the scorpions and may therefore infer that the intermediate legs retain the original condition and that differentiation most easily affected the most exposed pairs, the first and last.

Generally all legs increase in length regularly from in front backward. This condition is typically shown in the more primitive genera Drepanopterus, Eurypterus and Hughmilleria.

The legs of Drepanopterus [pl. 54] exhibit the least differentiation of all genera, whose legs are known. All five pairs form a series of limbs which increase in length backward and are very much alike. One distinction, however, is that the first three are provided with a pair of fairly large spines on each segment, the posterior being longer than the anterior, an arrangement which was obviously of great assistance in pushing the body forward. The spines become gradually reduced backward in the series of legs; in the third pair posterior spines only are still well seen, the anterior ones being reduced to mucros. On the last pair they are all reduced to mucros. From the legs of Drepanopterus those of Stylonurus can be directly derived.

In Hughmilleria the first four pairs form continuous series of walking legs, all four being equally spiniferous and undifferentiated.

In Eurypterus the structure of the legs has been most minutely described by Schmidt and Holm in E . f i s c h e r i , and our large collection of E . r e m i p e s and l a c u s t r i s corroborates their excellent work. The first three pairs are thick and heavy and increase in length regularly backward. The first leg consists of seven, the second and third of eight segments each, the terminal claw included. They are convex on the upper and flat on the underside and so articulated that they can be bent only downward. The principal spines are articulated and paired, the

posterior one of each pair much longer than the anterior, an arrangement that also aided in pushing the body forward. The fourth pair shows a different form; it is comparatively slender, its segments are flat and lack the long spines, except the penultimate segment whose two spines, together with the terminal spine (forming a ninth segment), make a flat extension of the leg in the plane of the greatest length. Holm pointed out that this leg had its principal articulation between the basal and second segments. This fact and the form indicate that it aided in swimming, but probably had as its principal function the balancing of the animal in swimming.[1] This differentiation of the fourth pair of legs for another function than that of walking is most distinct in the genus Eurypterus.

Dolichopterus [pl. 40] is most nearly like Eurypterus in the character of the first four pairs of postoral appendages. They form a similar series, with the difference, however, that the fourth pair is considerably longer than the third. The first to third pairs are stouter than in Eurypterus, the spines much longer and the spines of each pair of subequal size. The fourth pair is still better adapted to its swimming and balancing function through the greater length of the leg, the greater breadth of the segments, and especially the lobelike character of the spines of the eighth segment which clearly exhibit the tendency of the leg to enlarge its lateral surface.

Stylonurus represents the extreme end of a branch that has developed through Drepanopterus. Its legs are hence to be regarded as derived from those of that genus. As restored by Woodward and by Beecher [see under Stylonurus] the first three pairs were conceived as short and spiniferous, while the fourth and fifth pairs were enormously extended, of subequal length and without spines. From the observations of the writers on the species from Otisville (S . c e s t r o t u s) which exhibits the last four pairs of legs, these formed a continuously increasing series of long

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[1] Our common crab (C a l l i n e c t e s   h a s t a t u s) also appears to use the fourth pair of legs, that in front of the paddle-shaped swimming legs, as a kind of balancer in swimming.

legs, giving the specimen very much the aspect of a spider crab.   The
first two of these were, however, furnished with a great number of paired
spines or leaflike appendages of the underside.   It is therefore concluded
that in this group, for which the term *Ctenopterus* is here proposed, a dis-
tinct differentiation of the legs has taken place into three spiniferous
anterior and two nonspiniferous posterior pairs.   Laurie's S t y l o n u r u s
e l e g a n s is a form in which a like series of at least four pairs of long
legs is shown, the two foremost of which bear many long spines [*see* text
fig. 62].   In Stylonurus proper, as represented by S . l o g a n i , the first
three pairs of legs appear to have retained more of their original character,
in being relatively shorter and bearing only one pair of spines on each
segment.   Still another type of differentiation, not represented in our rocks,
is shown in S . s c o t i c u s Woodward.

Eusarcus [pl. 27] represents a distinctly aberrant line of leg develop-
ment corresponding to the entirely peculiar structure of the animal.   The
first pair of legs is of the length and character of that of Eurypterus;
the second to fourth, however, form a series that decreases in size back-
ward, the second being the longest of the walking legs.   Correlated with
this marked difference from Eurypterus is the greater length of the anterior
spines on each leg.   It is manifest that this creature in walking carried
the pointed frontal part of its head shield, on which also the lateral eyes
are found, raised high above the ground.[1]

In Pterygotus the four pairs of walking legs are simpler than in any
other genus.   They are of equal length, thin and nonspiniferous and were
clearly for walking only, the prehensile function having been entirely
transferred to the chelicerae.

It is manifest that in the genera in which the chelicerae are very small,
especially in Eurypterus, the walking legs with their long curved spines
were, as in Limulus, also actively engaged in grasping prey and trans-
ferring it to the chelicerae which transmitted it for mastication to the basal

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[1] We have described more fully in the generic discussion the peculiar character
of the genus as expressed in its appendages.

segments of the legs. There is other evidence of their prehensile function. In Limulus the first pair of walking legs of the male becomes transformed at maturity into a hooklike grasping organ and in E u r y p t e r u s f i s c h e r i , the second pair of legs also develops in the mature male a hooked clasping organ.

The first pair of postoral appendages probably also served in most genera as a tactile organ. This is very clearly indicated in Slimonia where it is directly developed into an antenniform appendage.[1] Its small size in Eusarcus and Stylonurus which contrasts with that of the following legs, is also evidence that it could have aided little, if at all, in walking or swimming.

The fifth pair of postoral appendages have been termed the *ectognaths*, *ectognathites* or *swimming legs*, because in most genera (Eurypterus, Dolichopterus, Eusarcus, Hughmilleria, Slimonia, Pterygotus) the terminal segments are flattened into a paddle-shaped organ that is currently considered as having functioned in swimming. Hall figured the swimming legs of the crab P l a t y o n i c h u s o c e l l a t u s [1861, pl. 84A, fig. 6, 7] to point out the remarkable analogy in its structure with that of the last leg of Eurypterus; and Holm has carefully worked out the characters which so excellently adapted this organ for a swimming function [1899, p. 27]. The most important of these are the sharp, knifelike edge of the anterior margins of the fourth to sixth segments, the thin blade of the seventh and eighth segments and their articulation, by which they were enabled to form a continuous oar blade at the time of the backward stroke, while in the forward stroke, the eighth segment could be turned backward on the seventh like the blade of a shears to diminish the resistance of the water. The oar blade form of the extended seventh and eighth segments is well shown on plate 4, figure 3; the reflexing of the eighth segment is

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[1] The following pairs of walking legs also show a peculiar development in Slimonia in being equally as long as in Pterygotus, but having a fringe of long spines on the distal edges of the segments, evidently developed from the serrations seen in Eurypterus and other genera, while the paired spines are absent.

observable in many other specimens [as pl. 7, fig. 7]. The oar blade is entirely smooth, without scales or hairs. The turning of this oar into a vertical position in the backward stroke probably took place mainly between the sixth and seventh segments.[1]

The material before us is competent to throw some very interesting light on the development of this swimming leg. Where typically developed, as in Eurypterus, it consists of the large basal segment, which. is
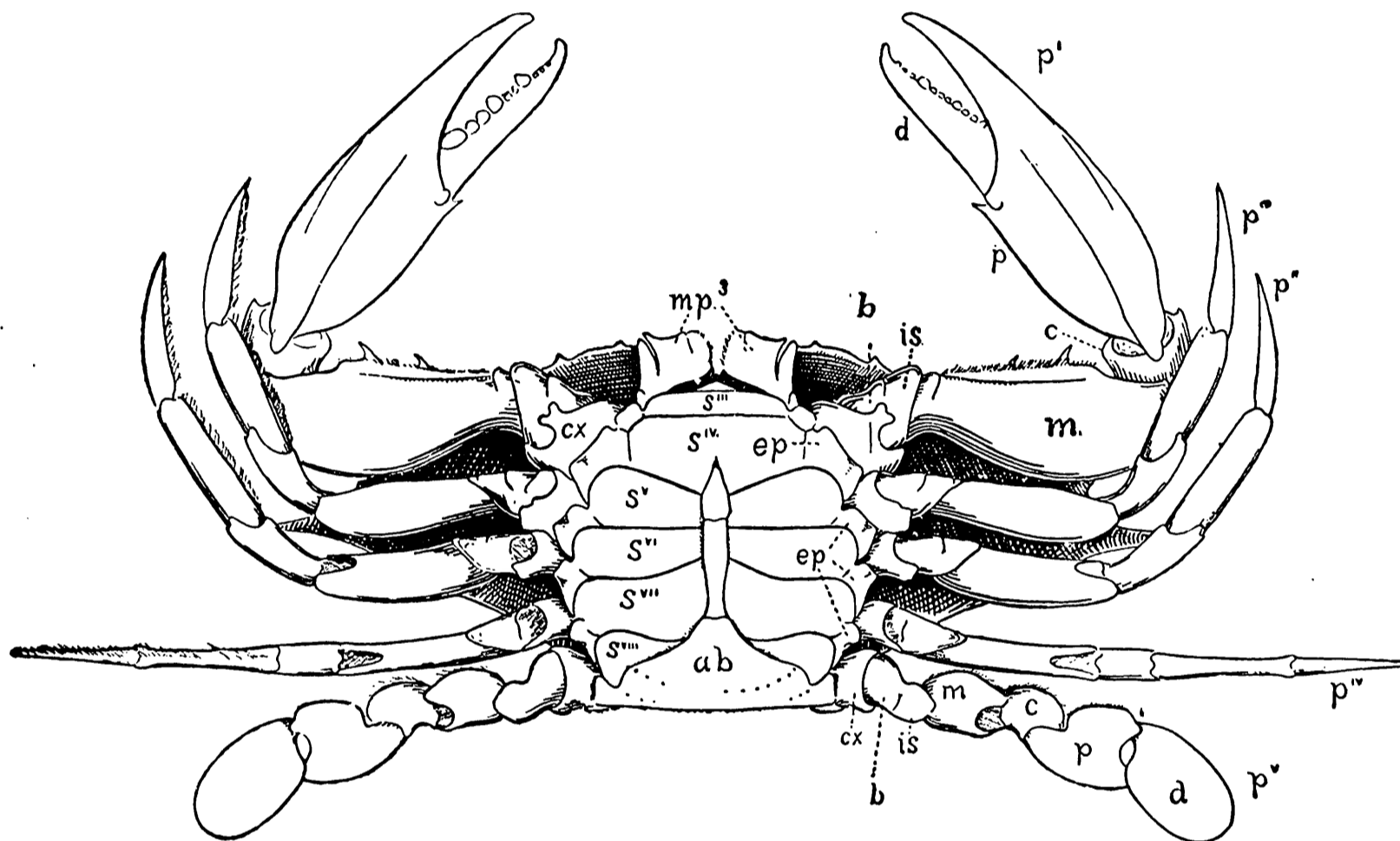
Figure 11   Ventral surface of male specimen of Callinectes hastatus

ab, abdomen; *p* I–*p*V, the five pairs of legs (pereiopods); S III–VIII, sterna of thorax. (From Brooks)

followed by two ringlike segments, a longer subtubular segment (the fourth), and two shorter segments with triangular section, flat underside, sharply keeled anterior edge and expanded distally. These segments

[1] Laurie [1893, p. 124] has suggested that " it seems more probable, that the foot was used for anchoring the animal firmly in the soft mud of the sea bottom, and possibly also for shoveling up the sand and mud when the beast wished to conceal itself." We shall recur to the question of the use of the last pair of legs in our further discussion.

were especially active in aiding the movement of the following seventh and eighth segments which form the oar blade. The seventh segment is a flat trapezoidal plate possessing on the posterior side a triangular lobe, that served as a guard to the eighth. The latter is oval and has a terminal notch, in which a minute claw is inserted that represents a ninth segment and was termed the *palette* by Hall, while later authors have more properly applied the term *palette* to the entire eighth segment.

The species which seem to us of especial interest in the explanation of the strange structure of the swimming leg are E u r y p t e r u s (O n y c h - o p t e r u s) k o k o m o e n s i s and D o l i c h o p t e r u s m a c r o - c h i r u s. The former [pl. 26, fig. 2] shows the most primitive shape of the swimming leg known to us. This primitive character manifests itself most distinctly in the following features. Beginning at the distal end, the ninth segment is a well developed terminal claw, such as is found on the other legs, indicating that the minute ninth segment of Eurypterus is a reduced terminal claw. The seventh and eighth segments do not yet so exactly fit together into a single oar blade, the seventh being still narrower and the eighth more expanded. The triangular guard lobe of the seventh segment in Eurypterus is here represented by a long relatively narrow lobe, indicating that it originated from a broadened and flattened spine of the seventh segment. A glance at figure 26, plate 2, will show that the preceding joints also are still much more uniform in character and like those of the walking legs in Eurypterus. In D o l i c h o p t e r u s m a c r o c h i r u s [*see* restoration, pl. 40] on the other hand, the ninth segment has been developed into a third element of the oar blade which thereby has become still more powerful. Here we find triangular guard plates on both the preceding, the seventh and eighth segments, which by their form still distinctly indicate their origin from spines. The lobelike projecting anterior portions of the distal edges of the seventh and eighth segments also suggest a similar origin, especially if we compare them with the lobe-like spines of the fourth pair of postoral limbs, already noted.

The postoral limbs performed a still further function, viz, mastica-

tion which rests in the basal segments termed *coxae*. In correspondence with this activity these are narrow, elongate, subtriangular, armed with rows of teeth borne on the narrow end (*gnathobase* or *mandible*) and form a manducatory edge. They increase in length with each successive pair and overlap like the tiles of a roof from the front backward seen in ventral view, and thus the coxae of the last pair of legs are not covered. Their sides are furnished with smooth gliding faces. In Eurypterus and Hughmilleria the fourth coxa possesses a circular perforation covered by a thin membrane and this is also present in Limulus. Holm first observed this, suggesting from its structure and position near the inner margin of the coxa which is exposed to the outside, that it was an auditory organ. This perforation is here figured in E u r y p t e r u s   r e m i p e s [pl. 7, fig. 6] and   H u g h m i l l e r i a   s o c i a l i s [pl. 62, fig. 5].

Patten [1894] has indicated that the spines on the anterior portion of the gnathobase of Limulus serve as gustatory organs. The inference is proper that the thick, blunt, hollow spines observable in like position in E u r y p t e r u s   f i s c h e r i [*see* Holm, *op. cit.* pl. 2, fig. 5-8] and other eurypterids [pl. 16, fig. 1] had a like function.

The coxae of the second to fourth pairs of limbs of 'Limulus bear a small, movable appendage behind the inner end of the manducatory
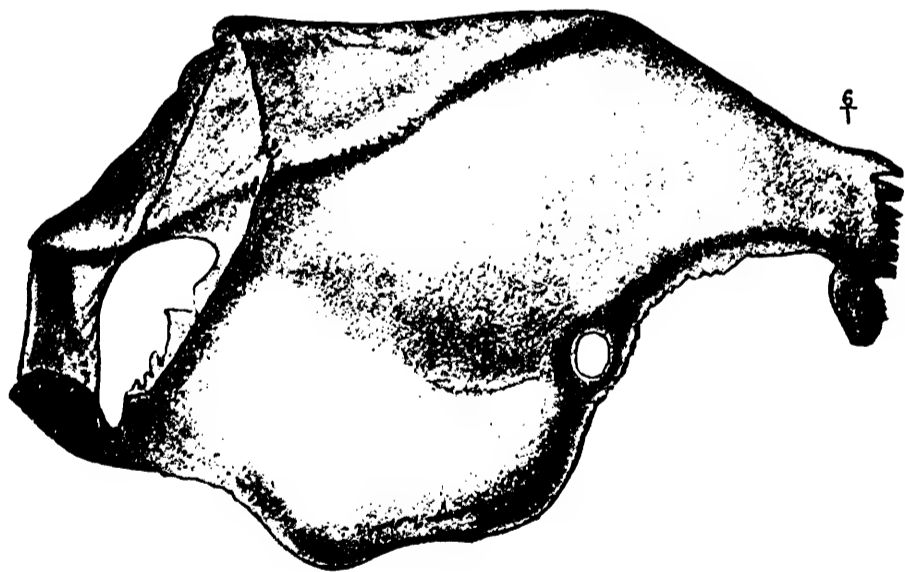
Figure 12 E u r y p t e r u s   f i s c h e r i Eichwald. Coxa of fourth left endognathite, seen from below (outside), showing epicoxite at right and circular perforation. (From Holm)

edge, which is also found in the scorpion. This is known as the *epicoxite*. It is furnished with fine bristles and small brushes and has a tactile function. Laurie discovered this articulated process in Slimonia [1893, p. 511] but was unable to determine how many and which pairs of legs bear it. Holm found epicoxites on the first to fourth pairs of the

walking legs of Eurypterus, but those of the first pair of somewhat dif-
erent appearance and therefore possibly belonging to a different category
of structure. We have also observed this appendage [*see* text fig. 12;
pl. 57, fig. 3].

The coxa of the fifth pair differs in structure and size from those
of the preceding legs. It corresponds in its large size to that of the entire
leg which surpasses all other limbs in dimensions. It is of rhom-
boidal form, with a large neck on the anterior inner angle forming the
gnathobase. The manducatory edge [pl. 72, fig. 2] is made up
of an upper sharp cutting portion and a lower crushing portion con-
sisting of a row of teeth which as a rule become finer posteriorly. The
neck often becomes so lengthened as to give the coxa a retortlike appear-
ance, as in Hughmilleria and Pterygotus and especially so in Dolichopterus
and Eusarcus, where the necklike extension becomes as long as or longer
than the rhomboidal base. This great extension of the gnathobase in
the latter two genera is clearly correlated to the great longitudinal exten-
sion of the cephalothorax and the forward position of the mouth. In Hugh-
milleria, Pterygotus and especially Slimonia, the similarity to a retort is
still much increased by the rounding outline of the body of the coxa. In
Dolichopterus and Eusarcus the immense last coxae cover more than
half of the ventral side of the cephalothorax [pl. 44]. Their form is
quite characteristic in the different genera and the generic relations of
detached coxae are readily recognized. While the large last coxa covers
the preceding coxal segment as well as the anterior portion of the first ventral
abdominal segment or operculum, the inner portion, except the chewing
edge, is in turn covered by the underlip or metastoma.

The mouth, which is situated at about the middle of the ventral side
of the carapace, is surrounded not only with the coxae but also by
several covering liplike plates. One of these is the *epistoma* of Ptery-
gotus. This was first described and figured by Huxley and Salter [Monogr.
pl. 1, fig. 1]. They were, however, misled, probably by the direction
of the sculpture on it, and figured it with the straight margin toward

the front. Schmidt [1883, p. 71] described it as a subquadrangular plate with convex anterior and concave posterior margin, lying directly in front of the mouth and a part of the doublure of the carapace, separated from the remainder by two sutures. Laurie [1893, p. 516] has shown that the scale markings on the epistoma have their convex side directed forward contrary to the almost universal rule among eurypterids and that this fact would seem to indicate that we have here a portion of the carapace bent over. At the same time he remarks that some of his specimens are fractured along quite different lines than those Schmidt observed. One of these he reproduces on plate 2, figure 10. On another [his pl. 1, fig. 4] the " epistoma " of Slimonia is reproduced. This, however, is but the ventral marginal plate of the cephalothorax that occupies the space between the doublure of the carapace and the thin membrane surrounding the coxae and which is termed the " Randschild " by Holm. This plate in Eurypterus had been figured by Hall [pl. 80A, fig. 12] as " the lower surface of one side of the cephalic shield " and has been more fully described above. We reproduce in plate 74, figure 3 a well preserved upper lip or epistoma of P . m a c r o p h t h a l m u s .

The term *endostoma* has been applied by Holm [*op. cit.* p. 28] to a small plate that bounds the posterior portion of the mouth. It is here figured from P t e r y g o t u s   b u f f a l o e n s i s [plate 81, figure 4.]

It corresponds to the promesosternite of Limulus or of the scorpion group. To its anterior edge a thinner membrane is attached which passes inward in the direction of the throat and forms, therefore, the lower lip.

The *metastoma* or *postoral plate* is a highly characteristic organ of the eurypterids. It is large, somewhat variable in form but all its variations are derivable from the oval form seen in Eurypterus. Its size corresponds to the longitudinal extension of the last pair of coxae since it covers their inner margins and the interspace between them. Its frontal margin is always more or less emarginate, its margin bent under into a broad doublure connected with the membrane covering the interspaces of the ventral side. Holm has shown that there are traces still present of a

bisegmented structure in the metastoma, indicating that it originated from a paired organ. He considers it homologous to the chilaria of Limulus, a pair of movable sclerites set behind the coxal segments of the last pair of legs [text fig. 10] and remarks that the metastoma of the eurypterids certainly represents a much higher development of the organ than the chilaria of Limulus. Pocock [1901, p. 302] considers the metastoma as the homologue of the sternum of the scorpion but the observations of Kishinouye [1891] upon the embryo of L i m u l u s   l o n g i - s p i n a   and those of Brauer [1895] on the embryo of the scorpion demon-
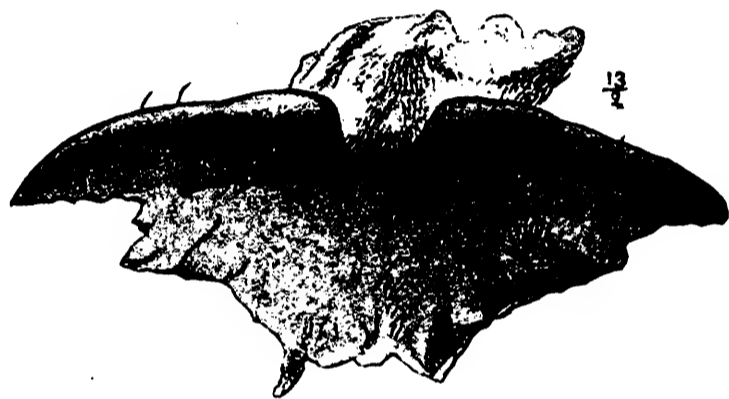
Figure 13   Eurypterus fischeri Eichwald.   Endostoma, seen from below (outside).   (From Holm)
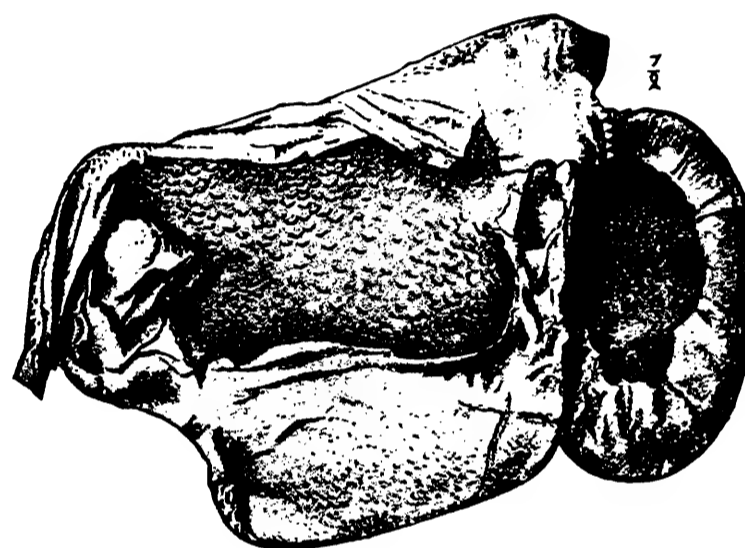
Figure 14   Eurypterus fischeri Eichwald. On the left the right coxa, seen from the interior and showing the doublure, the large cutting tooth and the smaller teeth; and its connection with the metastoma (on the right), which also shows its interior doublure.   (From Holm)

strate that it represents the appendages of a distinct suppressed segment. For practical reasons we have not counted this abortive first segment of the preabdomen [see diagram p. 24].

Gaskell, in his lately published *The Origin of Vertebrates*, in order to derive a vertebrate prosomatic or oral chamber fully separated from the gill chambers, has assumed that the metastoma and the operculum of Eurypterus became fused [op. cit. p. 242 and our text fig. 16]. It is safe for us to say that we have no evidence in the eurypterids of any tendency toward the fusion of these organs and that it seems to us such a procedure

would at once have seriously interfered with the movements of the crea-
tures in several ways; one, because the line of fusion would be directly
under the important articulation between the carapace and preabdomen,
and another, it could not have failed to disturb the mutual independence
of two organs of entirely distinct character and rhythm of movement,
namely, the coxae of the swimming legs which the metastoma closely
adjoins, and the operculum with its respiratory and sexual functions.

The form of the metastoma has been found by us to be highly char-
acteristic of the genera of the eurypterids and to be a good indicator of
their phylogenetic relations. That of Eurypterus is typically oval in
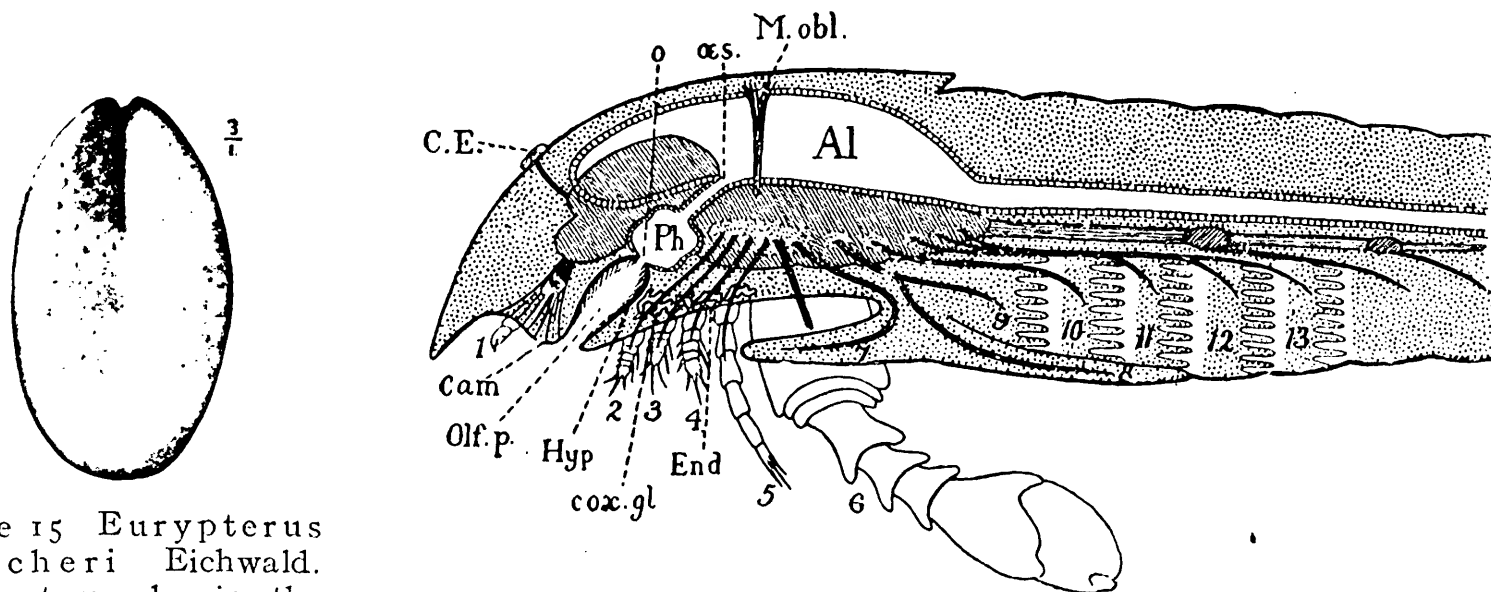
Figure 15 Eurypterus
fischeri Eichwald.
Metastoma, showing the
deep furrow of the an-
terior portion. (From
Holm)

Figure 16 Diagram of sagittal median section through Eurypterus:
7, metastoma; 8, operculum; 2, 3, 4, 5, endognathites. (Gaskell's
reconstruction)

outline, while those of Hughmilleria and Pterygotus show a strong tendency
to become wider in the anterior half and narrower in the posterior, and
at the same time more deeply emarginate in front. In Slimonia this
tendency is carried to an extreme, the metastoma having become very
elongate-cordate with a narrow posterior half and a deeply emarginate
anterior one. In Dolichopterus and the Stylonurus branch in general,
again a different tendency is developed. Here the base of the metas-
toma becomes rectangular, the lateral margins subparallel and the plate
approaches a long rectangle, with the short front side deeply emarginate
(Stylonurus) or it becomes lyrate (Dolichopterus). Finally, in Eusarcus

the metastoma has become subtriangular or cordate in outline, the anterior portion being greatly widened and emarginate and the posterior tapering to a blunt point.

We have thus at least four distinct lines of development of the metastoma, which fully correspond to the four principal branches of the eurypterids here distinguished [see chapter on *Phylogeny*, p. 124] namely, that of Eurypterus, of Pterygotus, of Eusarcus and of Stylonurus.
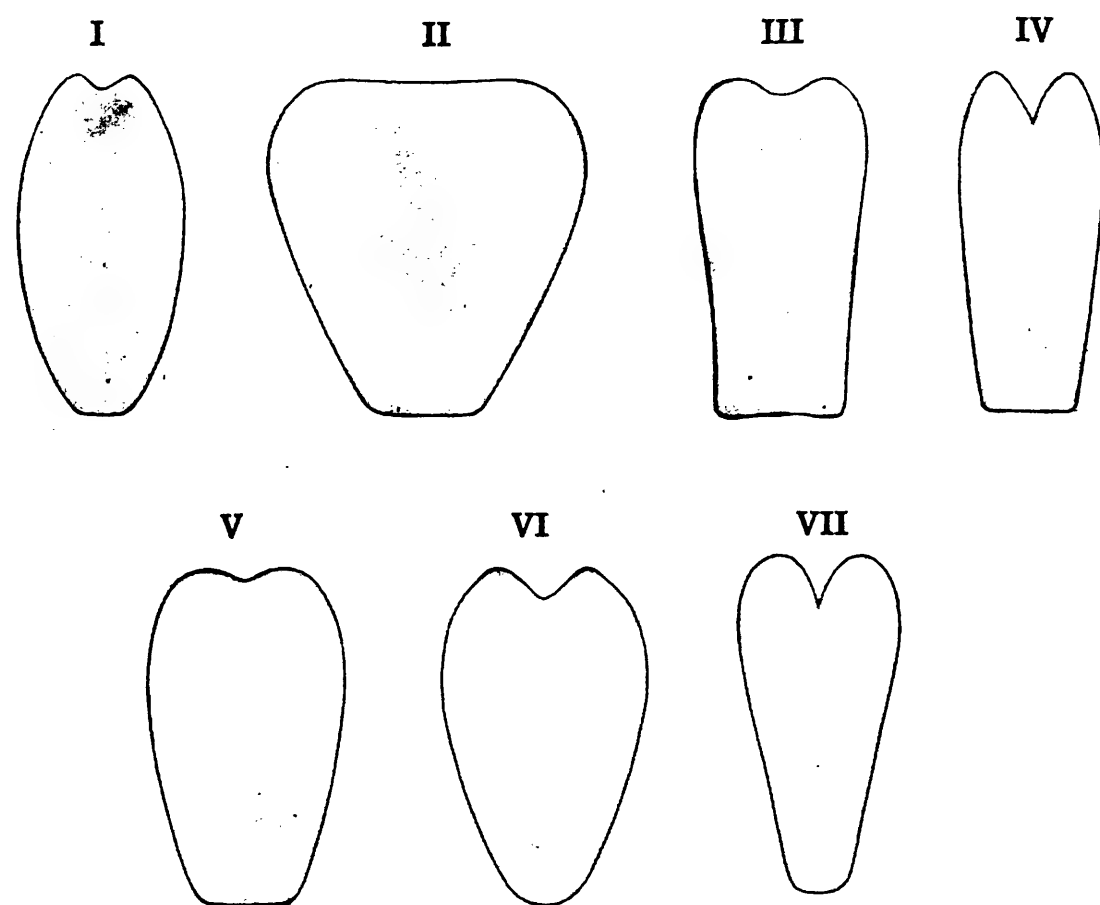
Figure 17 Metastomas. I, of Eurypterus; II, of Eusarcus; III, of Dolichopterus; IV, of Stylonurus; V, of Hughmilleria; VI, of Pterygotus; VII, of Slimonia

Abdomen. The abdomen consists of 12 segments or somites. The anterior six of these are divided into separate dorsal and ventral pieces. They form the *preabdomen* or *mesosoma* which is also sometimes termed the *thorax;* the six posterior ones are annular and form the *postabdomen* or *metasoma*, the *abdomen* or *tail* of earlier writers. The dorsal plates of the preabdominal or mesosomatic segments are termed the *tergites*, the ventral pieces the *sternites* or *Blattfüsse*. Those of the postabdomen are known as *caudal, postabdominal* or *metasomatic segments* or *somites*.

The *preabdomen* is widest at the fourth or fifth tergite whence it usually contracts more rapidly.   It formed a unit in the movements of the body, the easier articulation taking place between it and the cephalothorax on one side and at the boundary of preabdomen and postabdomen on the other.   The first tergite is a narrow plate curved backward and with rounded ends.   The other tergites are transverse bandlike plates, with convex anterior and concave posterior margins in the middle and the lateral ends curved slightly forward.   Corresponding to this outline of the plates the middle portion of the preabdomen is elevated forming the *rhachis*, while the wings are often depressed or concave.   This lateral portion of the segment is frequently termed the *epimeral portion, epimera* or *pleura* [pl. 5, fig. 3].   The epimera are produced at the antelateral angle into lobes, or *ears*, especially distinct in Pterygotus.   These "ears" have been considered as serving for the attachment of muscles but according to Schmidt they only correspond to the rounding of the postlateral angles and served merely to protect the outside of the body.   The lateral and posterior margins are furnished with more or less broad doublures to which the connecting membrane is attached.   The anterior margin of the tergites which is overlapped by the preceding one (except that of the first tergite) is smooth or bears only very fine ornamentation and is depressed, thus forming an articulation with the doublure of the preceding segment.   In some genera, as Eurypterus, this articulation extends the whole width of the tergite; in others, as Pterygotus, only the rhachis is provided with a distinct articulation; this difference probably indicating different degrees of mobility of the preabdomen.

The posterior margin of the gliding or articulating face of the tergite is mostly bounded by a continuous transverse line of scales [pl. 8, fig. 2].

Corresponding to the six tergites are only five ventral plates or *sternites*. This is due to the fact that the first two ventral segments lack the ventral sclerites, their place being taken by the large genital plate or *operculum*, homologous to the operculum of Limulus which bears the generative organs. The operculum of the eurypterids consists of a pair of plates meeting in

the median line and having a median lobe attached to them. The plates have a straight anterior margin and frequently well rounded ante-lateral angles. The scales form a continuous transverse line across the plates which has been erroneously considered as the suture resulting from the fusion of the two sternites. In front of the median lobe two trian-gular—or sometimes pentagonal—areas are marked off [pl. 11, fig. 3] by sutures from the opercular plates in Eurypterus and Slimonia but rarely in Pterygotus. Laurie suggests that these areas may represent the paired sternite of the first abdominal segment, the remaining portions of the plates representing the appendages.

The middle lobe shows two different forms not known to Hall but which were recorded by Woodward in P t e r y g o t u s   b i l o b u s   and S l i m o n i a   a c u m i n a t a   [1863, p. 61; 1872, p. 114, f.] and attributed to sexual differences. Schmidt likewise recognized two forms of oper-cular appendages of sexual significance in E u r y p t e r u s   f i s c h e r i , and Holm, by reference to Limulus, agreed with Woodward in assigning the more primitive appendage to the male and the more elaborate to the female, thus bringing out the fact that the mature males, at least in Euryp-terus, are smaller than the females, as is true of Limulus. Gaskell, how-ever, asserts [1908, p. 191] that the operculum of the eurypterids belonged to the type of Thelyphonus rather than to that of Limulus or Scorpio and as appears from his diagram [see text fig. 18] he would, on the strength of this claim, reverse the reference of the appendages to the sexes.[1] While it may be that the elaborate opercular appendages of the eurypterids exhibit less similarity to the extremely primitive exterior genital apparatus

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[1] In this connection Gaskell has introduced [op. cit. fig. 78, p. 191] a figure which is stated to " be a picture from Schmidt of the ventral aspect of Eurypterus," but in fact is a monstrous mixture of the characters of Eurypterus and Pterygotus, such as Friedr. Schmidt could not possibly have perpetrated even in a nightmare. This is a good example of the careless treatment of fossils in zoological textbooks and treatises, exemplified again by the figure of a P t e r y g o t u s   a n g l i c u s   labeled as " Euryp-terus remipes " in the Text-book of Invertebrate Morphology, by J. P. McMurrich.

of Limulus than to that of Thelyphonus, we must not forget that Holm
has found important corroborative evidence for his sex determination of
the male in the clasping organs of the second endognathites.

Accepting the determinations of Woodward, Schmidt and Holm, the
female appendage consists of two single lobes and two paired terminal
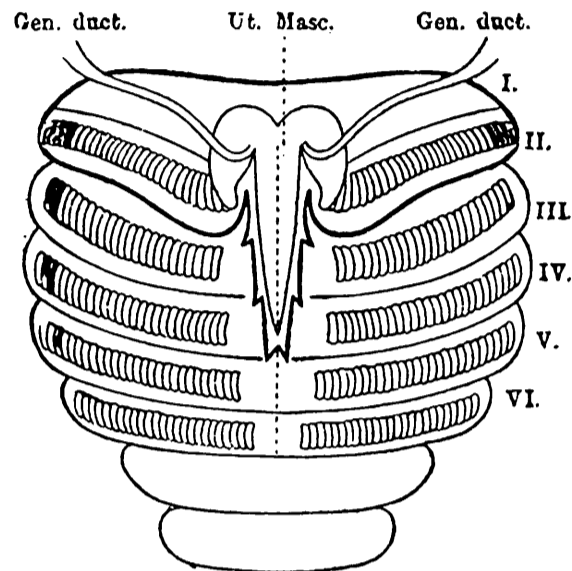
Figure 18 Diagram to indicate the
probable nature of the mesoso-
matic segments of Eurypterus.
Ut. masc., Uterus masculinus;
gen. duct, genital ducts. (From
Gaskell)
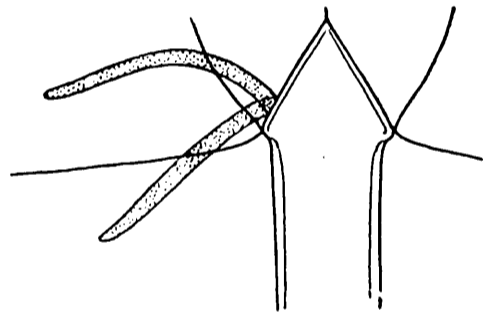
Figure 20 Eurypterus lacustris
Harlan. Specimen showing the
paired genital appendages turned
to one side. Natural size
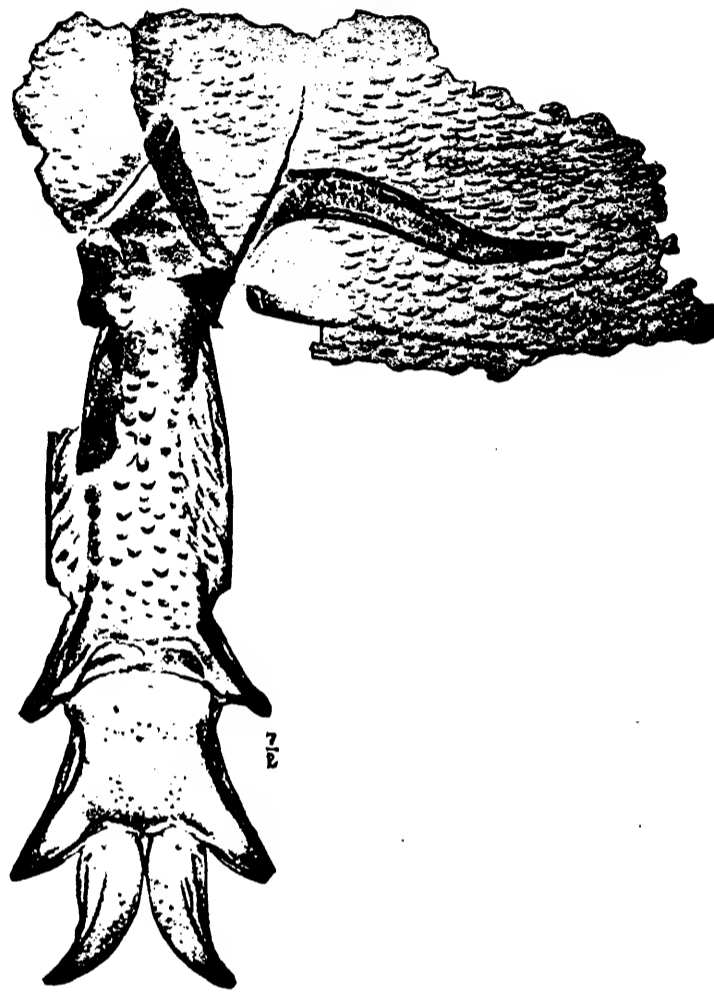
Figure 19 Eurypterus fischeri Eich-
wald. Female genital appendage of oper-
culum. At the right the tubular append-
age. (From Holm)

pieces.[1] The first of the single lobes is the largest; it is pointed in front,
where it extends between the pentagonal basal pieces, with which it is
connected by sutures. The middle portion is found occupying the space
between the lateral opercular plates which here do not meet in the median

[1] Holm also counts the two pentagonal anterior areas [see above] as belonging
to the genital appendage.

line. The distal end is produced into two short pointed pieces. The second single piece underlies or is telescopically pushed into the first and is of the same or very similar form as the first. Connected with the female genital apparatus were paired internal tubular appendages first correctly recognized in E. f i s c h e r i . These are also well seen in specimens of E. r e m i p e s [pl. 8, fig. 1] and E. l a c u s t r i s [pl. 12, fig. 2]. In one of the representatives of the latter species [Buffalo Society of Natural Sciences] both tubes lie to one side of the median lobe [*see* text fig. 20] thereby indicating that they extended free into the interior of the body.

In the male the two lateral opercular plates are more regularly rectangular in outline and come into contact along the median line. The genital appendage is very small and composed only of two single pieces. No pentagonal areas are set off by sutures. The principal single appendage consists of a median piece with parallel sides exposed to the outside and two larger wings underlying the opercular plates; the second appendage is very small, triangular and adjoins the first.

In other genera, as Hughmilleria and Pterygotus, the genital appendages are clearly much simpler. In Hughmilleria only one sagittate-based lobe is found on the female operculum [pl. 62, fig. 9, 10] and in the male a convex, broadly lanceolate lobe [pl. 62, fig. 11].

In Pterygotus these sexual appendages are not yet clearly distinguished, but they seem to be little advanced beyond those of Hughmilleria. The female appendage in its simplest form [P . b i l o b u s, *see* Woodward, 1869, p. 61, pl. 12, fig. 1c; Laurie, 1893, pl. 2, fig. 14] is a straight, narrow, very slightly expanding plate with a ridge down the middle and ending in a bluntly triangular point, while, where more highly developed, as in P . o s i l i e n s i s, it possesses a rhombic sagittate base, connected by sutures with the lateral opercular plates, and continued into the free club-shaped principal part with rounded extremity. In some cases, as in P . a n g l i c u s, [*see* Huxley and Salter, pl. 3] and in an unidentified form from Otisville [pl. 78, fig. 3] the extremity was expanded into a disklike body, the whole appendage

there resembling a pendulum. Another, supposedly the male, appendage has been figured by Woodward [1869, p. 61] and by Laurie [1893, pl. 2, fig. 13]. This is hastate at its proximal end, and sharply pointed at its distal extremity in Woodward's figure while Laurie represents it as a short, blunt process, but Laurie's figure suggests that it was taken from a fragmentary specimen. Woodward and Laurie also figure the pair of triangular areas in front of the process. Schmidt mentions only faint traces of the sutures in P . o s i l i e n s i s [op. cit. p. 78] and our material has not shown them at all. As they are also absent in Hughmilleria, they are probably a new acquisition in some species of Pterygotus.

In Slimonia the appendages have retained fundamentally the same structure as in Pterygotus, but they show greater elaboration. The frontal
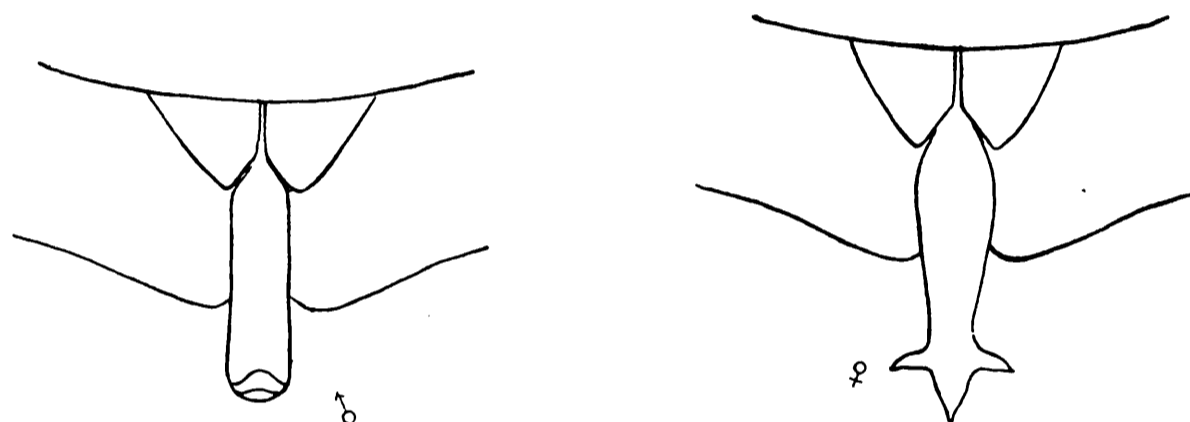
Figure 21   Slimonia acuminata (Salter).   Opercular appendages.
(From Woodward)

paired triangular areas are distinctly set off. That form of the median lobe which is considered as belonging to the female [see Woodward, 1872, p. 116, fig. 35; Laurie, 1893, p. 513] terminates in three sharp points at its free end, while the other or male form terminates in a more or less truncated cone. This shows two or three deep transverse furrows, which Laurie thinks due to its having been eversible [op. cit. pl. 2, fig. 8].

In Eusarcus the genital appendages are still incompletely known. We have seen only fragments of the female appendage [pl. 33, fig. 3; text fig. 55] which exhibit the triangular areas, the hastate basal portion of the first lobe, and a faint impression of the second lobe. Indications of the interior tubular appendages have also been seen. According to this evidence the whole organ is a simpler expression of that in Eurypterus.

A fairly well preserved genital appendage of a female D o l i c h o p - t e r u s m a c r o c h i r u s [pl. 44] has been observed by us. It is clearly built on the type of that of Eurypterus in showing the two invaginated median lobes with their bifid extremities. The organ was also, as in Eurypterus, of relatively large size.

The genital appendages of Stylonurus are not known.

The second sternite has also been found to bear a genital appendage in the females of Eurypterus, Hughmilleria and Dolichopterus. In Eurypterus it consists of one short unpaired proximal and two long awl-shaped distal pieces, the whole being covered by the opercular appendage. In Dolichopterus we have seen the impression of two similar slender terminal pieces between the shorter hornlike terminal pieces of the opercular appendage, and therefore feel sure that it possessed an appendage of the second sternite like that of Eurypterus. In Hughmilleria the appendage of the second sternite has been fully described and figured by Sarle [op. cit. pl. 62, fig. 9, 10]. It is small and attenuate with a triangular base.

Probably the second sternite of the female was also furnished with a small appendage in some of the other genera where it has thus far escaped observation.

From present evidence it may be stated as a general proposition that there are two lines of development of the genital appendages of the operculum in the eurypterids, those of the Pterygotus group and those of the Eurypterus group. In the first, the appendage is composed of but one unpaired lobe, which may become more or less elaborated, as in Slimonia. In the second group two unpaired and two paired lobes are developed.

There is little known as to the *genital openings* in the eurypterids. Woodward has figured [1872, p. 117, fig. 36] small openings on round tubercles on the basal triangular areas of the opercular appendages in Slimonia, which he considers as ovarian openings. Laurie, however, has not mentioned or figured these openings in his investigation of Slimonia [1893] and their presence seems open to doubt, especially since no homologous apertures have been seen in the other genera. Neither have

other authors taken up this problem as far as we are aware. In several species we have found distinct openings in the corners where the posterior points of the triangular areas of the opercular plates meet the lateral points of the hastate basal portion in the unpaired lobe of the female genital appendage. These lateral points are as a rule extended into earlike or scroll-like lobes that cover the openings. Since the paired interior tubular appendages observed in Eurypterus end at these lateral points, it is certain that they emptied here, as suggested by Holm, who considers them as auxiliary generative organs.

The large opercular appendage of the female is but a median tongue and not a tube, and it is probable that it concealed the complicated terminal portions of the genital organs, as the median part of the operculum still does today in the arachnids Phrynus and Thelyphonus. Gaskell [p. 192] has drawn a restoration, representing these genital organs " in accordance with our knowledge of the nature of these organs in the present-day scorpions, as a median elongated uterus, bilaterally formed, from which the genital ducts passed, probably as in Limulus, towards a mass of generative glands in the cephalic region, and not as in Scorpio or Thelyphonus, tailwards to the abdominal region." We surmise that the female eurypterid thrust this chitinous opercular appendage, together with the opercular plate, into the sand during oviposition, just as Limulus does today.

It is possible that the paired tubular organs mentioned above are not auxiliary generative organs, as surmised by Holm, but are the genital ducts and that the openings observed by the writers are the apertures of these ducts leading into the median uterus.

The sternal plates of the third to the sixth mesosomatic somites are well developed, forming the four *sternites* following the operculum. These plates are always slightly arched forward, the anterior margin being slightly convex, the posterior concave. The antelateral angles are produced into rounded lobes and the median line is marked by a suture, along which they readily separated. The sternites were often more arched than the

tergites, as shown by uncompressed specimens [pl. 20, fig. 8] and by the common observation that in compressed specimens the sternites protrude on both sides from under the tergites [pl. 4, fig. 4]. Although there are but five sternites including the operculum corresponding to the six tergites of the preabdomen the former are relatively so much longer that they overlap each other with fully half their length.

The sternites, the operculum included, bore the *branchiae*. Woodward was the first to observe platelike appendages of the sternites in Pterygotus which he described as lamellae, and Laurie observed appendages of the sternites in Slimonia which he designated as " branchial lamellae." Holm found organs in Eurypterus corresponding to those described by Laurie, but considers them only as " Kiemenplatten " instead of " Kiemenblätter," or as oval spongy thickenings of the outside of the thin, soft membrane on the upper side of the sternite, which probably served as attachment places to the branchial lamellae.
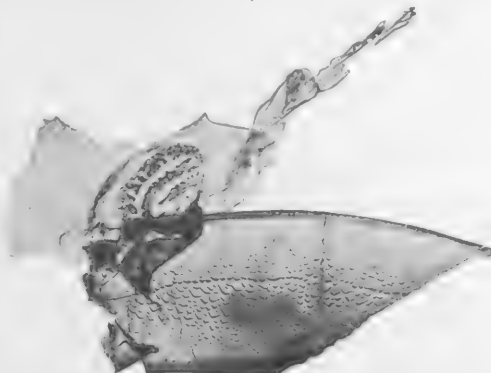
Figure 22 **Eurypterus fischeri Eichwald.** Portion of one of the posterior sternites, showing anteriorly the very delicate membrane of the interior side torn off and pushed forward and exhibiting the oval attachment area of the gills. x3. (From Holm)

He has also observed detached bundles of two or three extremely thin superjacent leaves which he considers with doubt as possible branchial lamellae. The " Kiemenplatte " or " branchial plate " exhibits a very characteristic structure consisting of one or two trunk veins running parallel to the longitudinal extension of the plate and from which smaller branches proceed [*see* text fig. 22].

In our material we have frequently been able to see the impression of the " branchial plates " from the dorsal side, as in the fine specimen of Eusarcus [pl. 29]. Detached branchial plates have also been observed

and in the remarkable specimen of E u r y p t e r u s   k o k o m o e n s i s, reproduced in plate 26, figure 2, the branchial plates are distinctly set off from a very tenuous brownish film, the integument of the individual, as thick, jet-black oval plates with a coarsely granular surface.[1] These gill plates were here very much smaller than those of the following sternites, those of the third and fourth sternites being the largest and those of the last pair of sternites again considerably smaller. On the plates of the operculum and of the next sternite, projecting thick-walled tubes can be seen that perhaps correspond to the trunk veins observed by Holm.

Metasoma, postabdomen or tail. The tail of the eurypterids consists of six ringlike segments, which decrease in width and correspondingly increase in length in posterior direction. In the primitive genus Strabops they merely decrease in width; and in all more primitive forms, as Strabops and Hughmilleria, and the simpler species of Eurypterus, the decrease in width is very gradual. In others it is abrupt in the first and second postabdominal segments. The first postabdominal segment in most species is a strongly contracted conical ring. In forms where the preabdomen has been excessively broad, the contraction takes place mainly in the last two tergites and the first postabdominal segment. In Eusarcus, where the contrast between the broad preabdomen and the narrow tail-like postabdomen has become extreme, the first caudal segment contracts by more than one half, while the following segments have nearly uniform width, forming a cylindrical tail.

The segments fit into each other like the joints of a telescope, the posterior one always reaching, with its anterior articulating edge, as far as the posterior doublure of the anterior segment. They consequently articulate in all directions and are therefore found either extended straight or curved to either side. An exception to this rule seems to be presented by Eusarcus in which the tail is nearly always curved to one side— although specimens with straight tails have been observed in the short-

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[1] The plates are much more distinct on the specimen than the photograph was able to bring out, owing to a thin whitish film over them.

tailed E . n e w l i n i; and moreover is so twisted that while the first caudal segments show the dorsal or ventral side, the last and the telson are seen in profile. This fact, together with the presence of an emargination in the posterior upper margin of the segments and the downward curvature, seems to indicate that the tail was capable of bending upward and forward as in the scorpion.

The section of the postabdomen usually was lenticular at the anterior end, remaining so throughout in some forms, as some species of Eurypterus, while in many species it became circular toward the other end. Circular sections of the caudal segments of species of Eurypterus and Hughmilleria are frequently found [pl. 63, fig. 12].

The lateral angles of the posterior margins are nearly always produced into pointed lobes. Those of the ultimate segments are usually much larger than those of the preceding segments, as e. g. in E . d e k a y i . In some species these lobes, together with the lateral edges of the segments, grow out into prominent flat winglike appendages, representing the "epimeral pieces" of the caudal segments. These are notably developed in D o l i c h o p t e r u s   m a c r o c h i r u s ,   in the subgenus Anthraconectes and in some species of Stylonurus.

The ultimate and penultimate segments of Pterygotus carry on the dorsal side a crest or ridge that begins at about the middle and continues to the posterior end. It is doubtless caused by the intestinal canal.

The *telson* is an appendage of the 12th segment, as indicated by the position of the anus in relation to it. Strabops and our larval stages seem to indicate that the primitive form of this spine was short, thick and four-sided with dorsal, ventral and two lateral edges. This view is supported by the consideration that from this pyramidal form we can most easily derive the two different lines of development of the telson, which culminated on one hand in the styliform telson of Stylonurus and on the other in the bilobed telson of Erettopterus. The more primitive genera, such as Eurypterus and Hughmilleria, retain the general character of the primitive telson and at the same time exhibit in an incipient stage

the new features that lead to Stylonurus and Erettopterus. In Euryp-
terus also the telson has still the original four-sided form, but the two upper
sides have already become so reduced that they are united in either a flat
or a concave broad dorsal side, while the ventral edge is developed into
a flat-topped carina.[1] In Hughmilleria the development is reversed, the
dorsal side bearing a carina, and the ventral side being smooth and either
flat or but slightly convex, the telson having thus the subtriangular section
and dorsal carina of that in Limulus. The essential characters of the telson
of Eurypterus are retained in Dolichopterus. In Anthraconectes, however,
it becomes extremely long and styliform, thus assuming the characters in
Drepanopterus and Stylonurus. In the extreme forms of the latter genera
the telson becomes contracted in the proximal portion and expanded
clublike in the distal portion, sometimes with development of flat lateral
carinae or flanges, as in S t y l o n u r u s s c o t i c u s .

The telson of Eusarcus was apparently still four-keeled; but it was
bent downward toward the end, so that when the scorpionlike tail was
thrown forward over the body, its sharp point would be directed upward.
This is an aberrant development of the telson not found in other genera,
but clearly connected with that of Eurypterus.

From the telson of Hughmilleria first that of Slimonia, and through
the latter, those of Pterygotus and Erettopterus can be derived. Slimonia
possesses a long tail spine with dorsal carination. The anterior portions
of the lateral carinae of this spine, however, are developed into two broad
flanges which together form an oval, leaflike expansion with coarsely serrate
posterior margin, the median keel being continuous with the long spine
[see text fig. 25]. In Pterygotus the projecting spine of the Slimonia
stage has been reduced to the size of the serrations of the flanges, and
in Erettopterus the reduction of the median spine that has become the
axis of the broad leaflike telson has been carried still further so that a
bilobed telson has resulted.

The keeled lateral and ventral edges of the tail spine in Eurypterus
and the lateral edges of the broad telson in Pterygotus and Erettopterus

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[1] It is possible that this section is but the result of compression and desiccation
and that the living specimens had a trapezoidal section.

are, as a rule, furnished with serrations, which become more prominent in posterior direction.

The articulation of the telson is quite like that of Limulus, consisting of a broad transverse lower and a small upper segment and is mainly adapted to movement in a vertical plane.

II
MODE OF LIFE

The mode of life of the eurypterids has thus far been touched upon incidentally in the description of the "swimming feet"; the earlier writers have generally assumed that the eurypterids were active swimmers on account of the structure of these legs which Hall very properly compared with the quite similar swimming organs of the common "lady crab" (P l a t - y o n i c h u s   o c e l l a t u s) of our eastern Atlantic coast. Woodward pointed out that the position of the eyes of Pterygotus, half above and half below the margin, indicates that it can not have been a mud grubber and he has also said of P .   a n g l i c u s that its large eyes, its powerful natatory appendages and the general form of its body suggest that it was a very active animal. Laurie [1893, p. 511; 1893, p. 124], on the other hand, has repeatedly advanced the view that the eurypterids were bottom crawlers and diggers in the mud. He says of the swimming leg of Slimonia [op. cit. p. 511]:

This appendage is always described as a swimming organ, but I am inclined to doubt the correctness of this interpretation of its function. The Eurypteridae appear to me, from their general build, more fitted for crawling than swimming, and I am inclined to explain this appendage as having been used by the animal to get a firm hold on the bottom, and probably also for digging out sand and covering itself, in much the same way that Portunus uses its very similar pair of appendages.

Holm concluded from his study of E u r y p t e r u s   f i s c h e r i that the last pair of legs of that species was principally adapted to swimming. He says:

Die Hauptbewegung des achten Gliedes im Verhältniss zum siebenten scheint von vorn nach hinten gewesen zu sein, indem sich, wie schon von Fr. Schmidt hervorgehoben ist, das achte Glied bei der Bewegung über die dreieckige Platte wie ein Scheerenblatt über das andere schiebt. Die beiden Glieder müssen daher beim Schwimmen wie ein einziges Ruder-

blatt fungiert haben und die mehr oder weniger vertikale Stellung des- selben beim Schwimmen durch die Gelenkverbindungen der übrigen Glieder, besonders diejenigen zwischen dem fünften und sechsten Gliede stattgefunden haben.   Das bedeutende Zurückbiegungsvermögen des acht- en Gliedes hat gewiss zur Verminderung des Widerstandes des Wassers bei der Zurückführung des Ruderfusses, um einen neuen Schwimmangriff machen zu können, gedient.   Hiermit hängt auch die, wie wir schon oben gesehen haben, scharfe, schneideartige Form des Vorderrandes des vierten bis sechsten Gliedes zusammen.   Hall hat einen Schwimmfuss eines jetzt lebenden Krustenthieres Platyonichus oculosus [ocellatus], welcher in seinem Baue eine grosse und interessante Aehnlichkeit mit dem Ruderfusse von einem *Eurypterus* zeigt, abgebildet. [1898, p. 27]

We have to gather our evidence by analogy from the habits of the living relatives of the eurypterids and of similarly built marine animals, comparing the structures in which their habit finds its most distinct ex- pression with the supposedly analogous structural features of the euryp- terids.   With a view to this end, we may briefly consider the habits of Limulus, the common king crab, and those of crabs with swimming legs as in the eurypterids.

An early and excellent account of the habits of the king crab was given by the Rev. S. Lockwood (cited by Owen [1872]) who says:

It is emphatically a burrowing animal, living literally in the mud, into which it scoops or gouges its way with great facility by means of the anterior edge of its enormous cephalic shield. In the burrowing operation the forward edge of the anterior shield is pressed downwards and shoved for- wards, the two shields being inflected, and the sharp point of the tail providing the fulcrum as it pierces the mud, while underneath the feet are incessantly active, scratching up and pushing out the earth on both sides.   There is a singular economy of force in this excavating action, for the alternating doubling up or inflecting and straightening out of the two carapaces with the pushing purchase exerted by the tail spine, accomplish both digging and a subterranean progression.   Hence the king crab is worthy to be called the " marine mole."

As to the use of the last pair of legs in burrowing and the use of the tail spine in locomotion, Owen also cites the interesting observations of W. A. Lloyd on living Limuli in the aquarium at Hamburg.

At Hamburg, specimens of *Limuli* were kept alive from the year 1865 to 1870.   From his observations of these Mr Lloyd informs me, "the ulterior

pair of limbs" are not employed for walking, but exclusively for burrowing. These limbs are terminated by four long, stiff, oval, or leaf-shaped lobes, jointed at their base to the leg, and capable of being opened and closed in a four-radiate manner. When it wishes to burrow these two limbs are sometimes alternately and sometimes simultaneously thrust backwards below the carapace quite beyond the hinder edge of the shell, and in the act of thrusting the lobes or plates on each leg encounter the sand, the resistance or pressure of which causes them to open and fill with sand, a load of which at every thrusting operation is pushed away from under the crab and deposited outside the carapace. The four plates then close, and are withdrawn closed, previously to being opened and charged with another load of sand, and at the deposit of every load the whole animal sinks deeper in its bed, till it is hidden all except the eyes. The great overarching shield of the carapace again prevents one from seeing whether this excavating work is being aided by the fanning motion of the branchial false feet, but I *think* such a fanning is going on, as I have seen signs of sand being driven out as if urged by a current of water.

Mr Lloyd thus describes the use of the tail spine in locomotion:

The animal having climbed up a rock in the aquarium till it has got near the top of the tank (which in Hamburg contained a depth of 30 inches of water), and having assumed a vertical position, it leaves go its hold on the rock and allows itself to fall back into the water; but its downward fall is instantly checked, and the creature propelled upwards by the powerful flapping of its false branchial feet, and when the impetus given by these appendages ceases the animal again sinks down, but is prevented from falling prone on the floor of the tank by alighting on the tip of its tail spine. The moment this happens, and before the creature has lost its balance on the spine, the false feet make another flap and give another impulse upwards and forwards; all this time the position of the carapace is slanting, the top inclining downwards at an angle of about 45°, the hinder shell being at another angle, and the tail spine hanging down vertically, and so it progresses by a combination of flapping and hopping till it reaches the limits of its tank and sinks to the ground. The *Limulus* was fond of thus going about at night, generally remaining on the sand all day.

Another use made of the tail spine was as a lever by means of which it righted itself when it fell off a rock on its back. The spine is then bent, its point is planted in the sand so that it makes an acute angle with the carapace, which is then so far raised that some of the feet are enabled to grasp a projecting surface, and the crab then turns over.

Another more recent brief account is given by H. W. Fowler[1] which reads in effect as follows:

The king crabs prefer such conditions as are afforded in Delaware Bay, where there are muddy or sandy bottoms, and it is seldom that they are found along the ocean beach. They also prefer more or less tranquil water where there is little or no surf and burrow in these places just under the sand or mud where they find an abundance of food in the many small animals; they are said to feed principally on worms. Although without any means of offense to such animals as fishes, they are amply protected from most enemies by their hard covering. The strong tail spine is used to right themselves when overturned. They progress through the sand by crawling, and when burying themselves are assisted by means of the hinged back, and also the spine. They are good swimmers, though they may frequently be seen crawling about over the bottom. When in shoal water they may easily be discovered by the two rows of small bubbles constantly appearing at the surface of the water.

From these notes on the habits of the American king crab it may be inferred that though a good swimmer, it mostly frequents the bottom and is a crawler, but feeds by digging in the mud and sand. In an aquarium such as that in Castle Garden, New York, it can be seen to swim easily by flapping the powerful sternites which thus function as breathing and swimming organs.[2] It crawls by the use of the four pairs of endognathites, and digs by the combined use of the shovel-shaped head shield, the pushing spine, the activity of the legs, especially of the last pair, which are adapted to this function and probably even by the aid of the flapping sternites.

The features of Limulus which appear to be of importance in ascertaining the habits of the eurypterids, being also observed in one or the other of their genera, are: the broad carapace, its beveled edge, the triangular concave shield in the middle of the doublure of the underside, the subapical position of the lateral eyes, the large, platelike sternites,

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[1] Fowler, H. W. The King Crab Fisheries in Delaware Bay. N. J. State Mus. An. Rep't. 1907. p. 116.

[2] We may remark that in the accounts of the embryology of Limulus the great swimming ability and the swimming habit of the young are emphasized.

the articulation between the carapace and abdomen and that between abdomen and telson, and the spiniform telson.

The other marine animals that have been repeatedly referred to as indicating the habits of the eurypterids by their similar swimming feet are the crabs of the family Portunidae, notably Matuta and Portunus (Huxley and Salter), P l a t y o n i c h u s   o c e l l a t u s   (Hall), and Portunus (Laurie). Our most common forms with swimming legs are the edible or blue crab (C a l l i n e c t e s. h a s t a t u s) and the lady crab (P l a t y o n i c h u s   o c e l l a t u s). Here the question arises as to whether their last pair of limbs which so strongly resemble the swimming legs of many eurypterids, are better adapted to swimming or to digging. A full account of the habits of C a l l i n e c t e s   h a s t a t u s has been given by Mary J. Rathbun,[1] and a shorter account of the habits of the edible, lady and green (C a r c i n u s   m o e n u s) crabs by Paulmier.[2] We learn from these descriptions that the edible crab usually wanders about crawling or hides under stones and logs and in seaweeds, but when pursued and finding speed ineffective, will rapidly bury itself in the sand to escape observation. As October draws to a close the crab moves into deep water and at this season may frequently be seen paddling near the surface as he works himself down stream with the tide. Paulmier states that " as may be supposed from the finlike posterior legs, it is a good swimmer and may often be found at the surface." On the other hand, he says of the lady crab, which has quite similar swimming legs: " Its usual habitat is the sandy beaches, even the most exposed, when at low water mark it buries itself all but the eyes and antennae and is on the watch for enemies and prey. If disturbed when feeding or if dug out, it disappears with great rapidity, burrowing backward into the sand."

We thus infer, and have verified this inference by actual observation, that they use their last legs with great ease for both digging and swimming, but are more given to a crawling and a burrowing than to a swimming habit.

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[1] U. S. Nat. Mus. Proc. 1895. 18: 368.

[2] N. Y. State Mus. Bul. 91, 1905, p. 142.

On comparison of the characters similar to the eurypterids, the king crab and the brachyuran crabs here mentioned, we may first remark that both Limulus and the crabs are highly specialized in comparison with the eurypterids. This is evinced in Limulus by the extreme broadening of the carapace, the adaptation of the last pair of legs to burrowing and the fusion of the abdominal somites; in the crabs by the excessive broadening of the cephalothorax and the reduction of the abdomen. In both cases the specialization is mainly a distinct adaptation to the crawling and burrowing habit. No such far-reaching specialization is found among the eurypterids.

In surveying the genera of the eurypterids in regard to the characters bearing on their habits, we find that they readily fall into four groups which show the following differentials:

1   Compound eyes *marginal*, body *slender*, *fishlike*, last pair of limbs *swimming legs*, telson *mostly broad and finlike:* Hughmilleria, Pterygotus, Erettopterus, Slimonia

2   Compound eyes *marginal and frontal*, body *scorpioid*, last pair of limbs *swimming legs*, telson *spiniform:* Eusarcus

3   Compound eyes *dorsal*, *subapical*, body *slender to broad*, last pair of limbs *swimming legs*, telson *spiniform:* Eurypterus, Dolichopterus

4   Compound eyes *dorsal*, *subapical to apical*, body *slender*, last pair of limbs *exceedingly long and slender jointed*, telson *styliform:* Drepanopterus, Stylonurus

We are disposed to believe that these four groups of genera represent four different modes of life habit.

In regard to Pterygotus and Erettopterus, the typical representatives of the first group, it has been remarked by Woodward that the marginal eyes which are half on the underside, prove that the animals could not have been mud grubbers and that the spatulate and bilobed telson was obviously adapted to swimming. Laurie [1893, p. 521] has also conceded that " the only advantage which occurs to one as possibly appertaining to

the bilobed form of telson is its greater efficiency as a swimming organ." The general form of the body, notably the relatively small carapace which lacks the shoveling rim of other eurypterids, the slender body with relatively narrow preabdomen that gradually tapers into the postabdomen, are clearly adapted to greater agility, and the long slender prehensile pincers in front, show that Pterygotus was highly predaceous and not a burrower after worms as Limulus or a carrion eater as most of the crabs, which use their stout claws largely as organs of defense and for tearing pieces off their food. The poorly developed walking legs of Pterygotus attest that it was a bad walker or crawler. There, then, seems to remain by exclusion the single inference that Pterygotus was essentially a swimming creature, probably slow and therefore in need of the long prehensile pincers. The large size attained by some species (5 feet and more) would also indicate that they could hardly have been of burrowing habit.

Hughmilleria, in both its species, has a distinctly fishlike appearance in dorsal aspect, which is evidence of its agility; this is effected by the relatively long, convex, anteriorly angular carapace and the very slender form of the body, which gradually tapers to the stout tail spine. It also lacks the distinct shoveling edge of the carapace. Hughmilleria has much better developed walking legs than Pterygotus and lacks the broadening of the telson. As it is clearly a more primitive and less specialized form than Pterygotus, it is equally adapted to a crawling and swimming habit. Its telson was probably used as an organ of defense.[1]

Slimonia, specialized in the position of its compound eyes at the anterior angles of the carapace, the broadened telson and slender form of body, seems adapted to swimming and by its well developed walking legs also to crawling.

All these three genera, in comparison with Eusarcus and Eurypterus, have relatively small and narrow swimming legs, which is the more sur-

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[1] The authors above cited with regard to the habits of Limulus, have not emphasized the use made by that animal of the telson in defending itself. When buried in the shore sand, at low tide, in spawning time, the erected spine protrudes through the sand, and thereby causes much annoyance to waders.

prising as for the rest of their organization they appear to be better adapted to swimming than the others. Quite likely the more slender body required less effort and smaller organs to paddle it.

In the group represented by *Eusarcus*, the carapace is subtriangular, raised in front, where it bears the marginal compound eyes, the walking legs are powerful and provided with long spines, the preabdomen is very broad and flat, the tail long and scorpionlike, with a curved spine that could be raised above the body as an organ of defense. This is a quite aberrant and highly specialized genus and doubtless its habits were different from those of the other genera. On account of its general form it is highly improbable that it was a good swimmer, in spite of the marginal, frontal eyes, and its scorpioid form indicates that it was given principally to crawling, scorpionlike, on the bottom and, as we have little doubt, to burying itself in the mud, with the eyes on the raised frontal end and the scorpioid tail projecting from the mud. It is a singular character of Eusarcus that the second pair of walking legs is longer than the rest, and the series decreases in posterior direction. This arrangement not only served to raise the eye-bearing frontal end of the carapace above the mud, but the long spiniferous legs in front undoubtedly aided also in seizing and holding the prey, the chelicerae being relatively small.

The swimming legs of Eusarcus are relatively large and heavy, the segments carrying the blade being short and stout. The legs were therefore more strong than agile and quite surely adapted to digging and anchoring the creature in the mud.

The group represented by *Eurypterus* and *Dolichopterus* is characterized by the prevailing broad carapace with dorsal eyes, broad to slender body, relatively strong swimming legs and a spiniform telson. The stout walking legs in all members of this group leave no doubt that they were able crawlers on the bottom, but there is considerable evidence to show that they burrowed in the mud and were also well able to swim; some species more given to one, some to the other habit. The evidence of a burrowing habit is seen in the relatively broad carapace with a distinct

shoveling edge, the dorsal or subapical position of the lateral eyes, as in Limulus, which would allow them to project above the mud, the peculiarly long, mobile and yet strong articulation of the carapace and first body segment, and the spiniform telson.

It has been particularly pointed out by Holm [*op. cit.* p. 9] that in E u r y p t e r u s   f i s c h e r i the articulation between the carapace and the preabdomen must have been one of great mobility, as indicated by the broad slit, closed only by a membrane between the lateral fulcra. This connection was nevertheless so strong that the first preabdominal segment is most frequently found attached to the carapace in dismembered specimens. These facts suggest that Eurypterus may have been able to use the articulation between the carapace and the abdomen somewhat like Limulus in pushing itself through the mud, a process which would be aided by the tail spine.

On the other hand, there is good evidence that the species of Eurypterus were able swimmers. We have elsewhere cited Holm's description of the adaptation of the swimming legs in E .   f i s c h e r i , evident in the sharp anterior keel of the organ and the arrangement of the articulation allowing the turning of the oar blade into a vertical position. Still more conclusive is the preceding pair of spineless slender legs, which would seem to have no other function than to serve as balancers and aid in swimming.

The combined evidence of the characters of Eurypterus is that it was a still little specialized, primitive genus, not yet wholly adapted to either crawling, digging or swimming, but could perform all these functions and was on the whole a sluggish animal. As it is not provided with strong organs of offense, it probably lived on worms or carrion.

There are certain species of this genus, such as E .   m a r i a , which are distinguished by a remarkably slender form. As a rule these also have the eyes far forward on the small carapace. Their form indicates that they were more inclined to a swimming habit. Others have the broad head of a catfish and seem well adapted to resting on the mud and there

awaiting their prey or digging for it as Limulus does. A good instance of such a species is E . p i t t s f o r d e n s i s .

We consider the genus *Dolichopterus* well adapted to a swimming habit. This is indicated by the notably forward position of the compound eyes and the remarkable lengthening and broadening of the swimming legs. The lengthening has been produced not only by the great lengthening of the segments, but also by the development of the ninth segment (only a minute claw in Eurypterus), into a palettelike plate. We have also shown [*see* generic description p. 264] that the spines on the swimming legs are transformed into expanded leaflike appendages, which serve to broaden the limb. If these appendages were arranged in whorls, as in Limulus, the claim could be made that they served in digging as in the latter genus, but it is difficult to conceive that these appendages, arranged in a series on the posterior side of the limb, could have well served that purpose, since they would fail to push the mud outward as does the leg of Limulus, but would move it backward and inward. Nor is the great length of the swimming legs favorable to the digging function, for digging organs are always short and stout; and as for serving only as anchors in the mud it would not seem necessary to lengthen the limbs to such extent.

The last group, represented by *Drepanopterus* and *Stylonurus*, shows again a different adaptation. Here the legs exhibit a distinct tendency to become greatly lengthened without being broadened. It is obvious that these forms were not mud dwellers, and if we consider Drepanopterus as the ancestor of Stylonurus, they were originally crawlers.

Drepanopterus [*see* restoration pl. 54] possesses five pairs of walking legs which increase regularly in length backward and exhibit no differentiation, except that the frontal legs have longer spines and the last pair is spineless. The very broad shovellike carapace with its elevated eyes and the long styliform telson are, however, quite suggestive of a mud-grubbing mode of feeding.

In *Stylonurus* the tendency of Drepanopterus to lengthen the last pairs of legs has reached its extreme. While all its species exhibit these

strikingly long last two pairs, different groups have developed differently in regard to the preceding legs. In some these have remained relatively short and shaped as in Dolichopterus, in others they have grown in correspondence with the last pairs, are highly spiniferous, the spines becoming very long and increasing greatly in number [pl. 49, fig. 6] and in others again the spines of the first three pairs show a tendency to become flat and broad.

In Woodward's well known restoration of Stylonurus the animal is given three short pairs of anterior legs and two very long, subequal pairs of posterior legs, the latter being regarded as for swimming, and the former for walking. Laurie, who recognized the probable derivation of Stylonurus from Eurypterus through Drepanopterus, considered the sixth pair as being reduced " from the typical digging foot to a purely crawling one," adding: " This may indicate more purely littoral habits, or a more active predatory existence, demanding rapid locomotion rather than firm anchorage." Beecher's life size restoration of S . e x c e l s i o r accepted Woodward's conception of the posterior legs, adding only the bladelike appendages of the short first three pairs of legs observed by Hall and Clarke in the first and second endognathites of S . e x c e l s i o r and suggested that these legs " served partly as swimming organs."

From the somewhat different restoration of Stylonurus, at which we have arrived in this paper and which is fully set forth in another place we infer that the animal was comparable to the existing gigantic Japanese spider crab, which some of its species rivaled in size. Like that grotesque creature it probably used its long hind legs to shove itself forward over the muddy bottom, while its short front legs indicate that the head lay near the bottom, the front legs being used for walking and grasping, and perhaps also, where the spines are broadened, as swimming organs. The extremely long styliform telson frequently with a blunt extremity, may have served less as a protecting than as a supporting organ of the long abdomen, and have aided in righting the awkward creature when it was overturned.

In summing up the evidence regarding the life mode of the eurypterids, and in view of the variety of forms with incipient adaptations, it would be a legitimate inference that the whole group was not so highly specialized as the recent merostomes and was still able to use different methods of locomotion though no one of them with great proficiency. Some were best adapted to swimming, others to crawling and many to finding their food by grubbing in the mud.[1]

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[1] In connection with the locomotion of the merostomes, the question suggests itself whether they may not have been in the habit of swimming on their backs; this swimming attitude being assumed by the young of Limulus, and directly asserted for the merostomes by Patten [1890].

The peculiar attitude of the young Limulus has been described by Alex. Agassiz [1878, p. 75] in support of Walcott's claim that the trilobites swam on their backs, as follows:

"An additional point to be brought forward to show that the trilobites probably pass the greater part of their life on their back, and died in that attitude, is that the young Limulus generally feed while turned on their back; moving at an angle with the bottom, the hind extremity raised, they throw out their feet beyond the anterior edge of the carapace, browsing, as it were, upon what they find in their road, and washing away what they do not want by means of a powerful current produced by their abdominal appendages."

Patten [Origin of Vertebrates from Arachnids, p. 363] in the endeavor to correlate the neural (dorsal) surface of Pterichthys or of the fishes in general with the neural (ventral) surface of the merostomes assumes that the position of the eyes depends largely on the position of the animal in swimming, adding: " In Pterygotus, for example, where locomotion was probably largely effected by swimming on the haemal (dorsal) surface, the eyes have already become lateral—a position very unusual in Arachnids. This change is readily explained, since the original position in the embryo of all arthropods is neural; moreover, the history of arthropod eyes shows conclusively that they can assume any position the method of locomotion may demand." In citing further evidence for his claim of important resemblances between the cephalothorax of arachnids and the head of vertebrates, the same author says [p. 365]: " The trilobites probably swam, if at all, on their backs; and it is still more probable that the Merostomata, from their shape and the position of their oarlike appendages, swam in the same way. The larvae of Limulus, according to my own observations, always swim on their backs. Thus the way is prepared for the manner of locomotion in fishes."

In view of the great contrast in the shape of their bodies, we doubt the propriety of comparing the swimming mode of the young Limulus with that of such eurypterids

Some light seems also to be shed on their probable mode of life by a consideration of the separate faunules to which they pertain. Thus the Otisville fauna is composed of notably slender forms, such as H u g h - m i l l e r i a   s h a w a n g u n k and E u r y p t e r u s   m a r i a , which indicate that a large element of the fauna consisted of agile, swimming

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as Pterygotus and Hughmilleria. We have, however, been impressed from another consideration with the possibility of their having been able to swim on their backs. In casting about for living water animals of a shape similar to the general expression of the eurypterids, we could find no better analogy than the well known " water-boat-men " or " boat-flies " (Notonecta) of our ponds with their elongate elliptic bodies, anteriorly rounded carapace with large marginal eyes, and long natatorial feet in the middle of the body. We have again and again been struck with this analogy in looking over the young specimens of E u r y p t e r u s   r e m i p e s with their outstretched swimming feet, or in wondering at the long and powerful oarlike feet of Dolichopterus. The species of Notonecta swim on their backs, but those of Corisa, a closely related genus of associated waterbugs (the " oar-feet bugs ") of like outline as seen from above, swim like all other water insects on their ventral surface. It appears that the peculiar attitude of Notonecta is principally adapted to the easy accumulation and storage of air in the hairy covering of the upper (ventral) side and that the body is distinctly boat-shaped, the dorsal side being keeled, to facilitate the inverted mode of locomotion, while in Corisa as in the other swimming waterbugs the body is distinctly flat.

From analogy with Notonecta and Corisa we consider it possible that Pterygotus and other types of eurypterids could have assumed an inverted position in swimming, but there are several reasons why it is unlikely. The most important of these is that the inverted attitude is not the normal one for nektonic organisms, but distinctly an adaptation to special conditions. It is not apparent that any of these conditions existed in the adult eurypterids, and the marginal eyes of the Hughmilleria and Pterygotus group would permit, by analogy with Notonecta and Corisa, either attitude in swimming.

In regard to the probable swimming attitude of the long-legged eurypterid types, Drepanopterus and Stylonurus, we know no better analogy than the water spider of the middle European ponds (A r g y r o n e t a   a q u a t i c a). Any one who has watched the ease with which this interesting arachnid swims by means of its long spider legs and even overtakes its prey of water insects, can not fail to appreciate the swimming possibilities of even the awkward looking Stylonurus. This water spider also differs from other spiders by having the median eyes raised on a round mound, and the lateral ones on oblique nodes, just as in the eurypterids and especially in Stylonurus. The water spider swims with its right (dorsal) side up, and by analogy we infer that the similar Stylonurus group did the same.

species.   The presence here of heavy beds of conglomerate with very thin shale seams between corroborates the view that these forms were but little adapted to digging in the mud.   The prevalence of Stylonurus in the fauna would seem to support Laurie's suggestion that Stylonurus possessed purely littoral habits.

The sedimentary facies in which the Otisville and Schenectady faunas are involved is not a usual accompaniment of the eurypterids, as fine mud rocks constitute the prevailing sediment and relatively broad-headed forms the expression of the body.

If one tries to picture the group as a whole, the typical habit would appear to be that of the mud grubber, and the broad carapace, relatively broad preabdomen, the flippers and the tail spine will be the most important elements in producing this picture.

It is very interesting to note in this connection that a subclass of an entirely different phylum, viz, the Ostracophora (Cephalaspis, Pteraspis [Old Red Sandstone of Scotland]), among the fishes, lived at the same time with the eurypterids, is frequently associated with them in the rocks, had acquired the same mud groveling habit and a similar general form.   The theory that these earliest fishlike vertebrates are derived from the arthropod stem, and have features in common with the merostomes (eurypterids) and arachnids (scorpions etc.) is still seriously defended by some competent investigators.   Eastman, in an excellent essay[1] on the evolutionary history of the fishes, has emphasized the fact that the merostomes and arachnids at this early date had already diverged too widely along certain directions from the primal trilobitic type of organism, to be the possible ancestors of backboned animals, and such resemblances as are shared by merostomes and early fishlike vertebrates are explained as "due to mimicry, or to adaptation of creatures of different grades to a similar environment."

We are here not so much interested in the problem of the possible derivation of the vertebrates from the merostomes, as in the fact of the

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[1] C. R. Eastman.   Iowa. Geol. Sur. Rep't 1908.   18:51f.
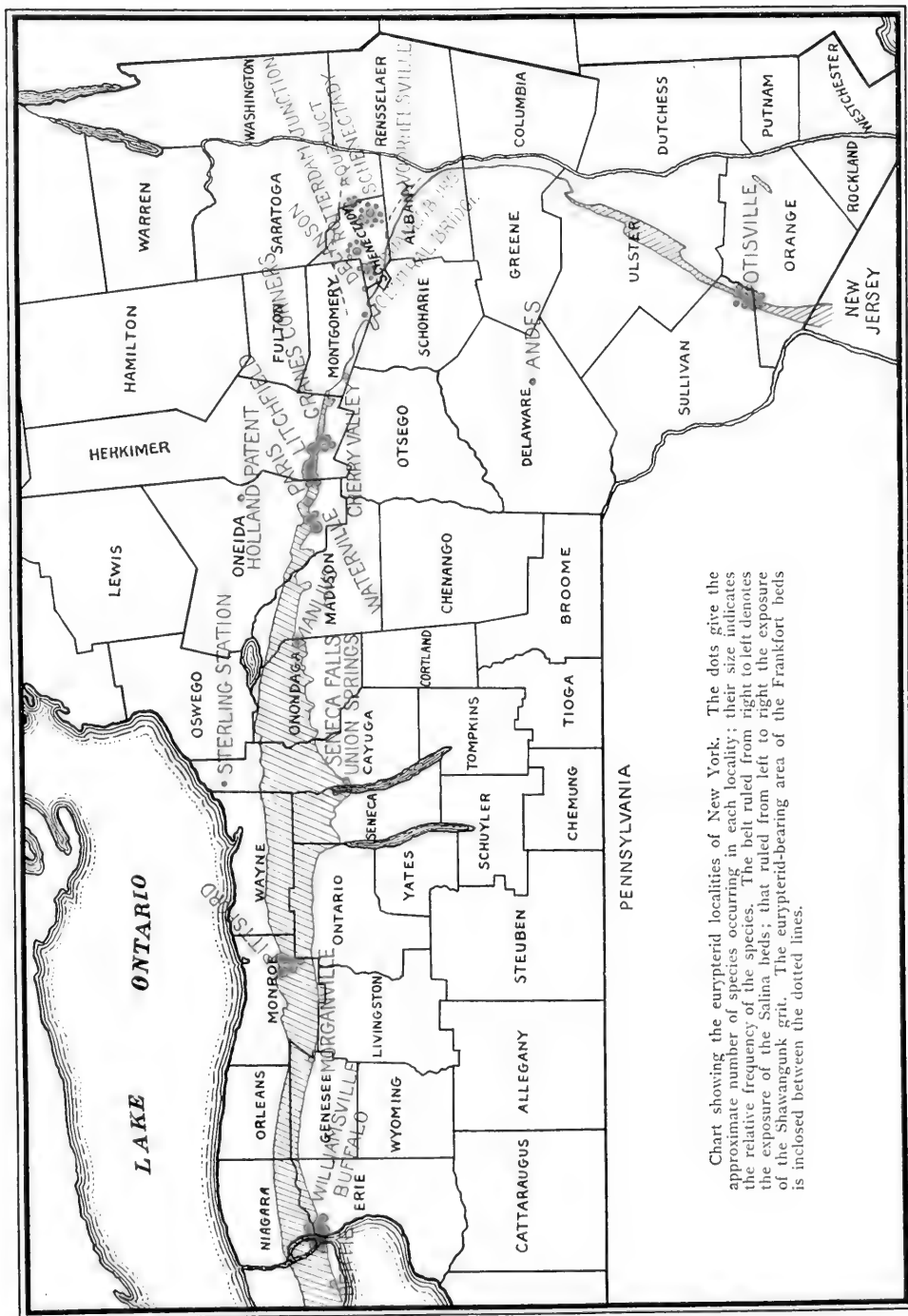
Chart showing the eurypterid localities of New York. The dots give the approximate number of species occurring in each locality; their size indicates the relative frequency of the species. The belt ruled from right to left denotes the exposure of the Salina beds; that ruled from left to right the exposure of the Shawangunk grit. The eurypterid-bearing area of the Frankfort beds is inclosed between the dotted lines.

great exterior similarity of the eurypterids and ostracophores and the explanation of this phenomenon as resulting from adaptation to like conditions. The ostracophores have been generally regarded by paleontologists. as owing their peculiar form to their mud-grubbing habit, and it may be inferred that the eurypterids, being of similar form, were of like habit and perhaps of like form because of similar habit.

III
GEOLOGICAL DISTRIBUTION AND BIONOMIC RELATIONS

In this chapter we shall first survey the geological distribution of the eurypterids in North America as indicated by the following conspectus, compare this distribution with that in Europe, and finally attempt a conclusion as to the physical conditions under which these strange creatures lived.

A Conspectus of American species arranged according to their geological occurrence

Algonkian

Beltina danai *Walcott*.   Greyson shales, Montana

Cambric[1]

Strabops thacheri *Beecher*.   Potosi limestone, St François county, Missouri

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[1] There occur gigantic tracks in the Potsdam rocks of New York which, have been considered by good authorities as suggesting the presence of merostomes at that age. These tracks known as Climactichnites, were first described by Logan [Can. Nat. & Geol. 1860. v. 5] and later recorded by Hall [N. Y. State Mus. 42d Rep't. 1889. p. 25] from Port Henry, Essex co., N. Y., and by Woodworth [N. Y. State Mus. Bul. 69. 1903. p. 959] from the town of Mooers, Clinton co., N. Y. In the latter locality they assume gigantic proportions, being 6 inches wide and 15 or more feet long, terminating in an oval impression 16 inches long.

Various explanations have been suggested for these tracks. Besides having been referred to trilobites, burrowing crustaceans, plants, gastropods and annelids, they have been compared with those of the horseshoe crab, first by Dawson and recently again by Hitchcock and Patten. Sir William Dawson [Can. Nat. & Geol. 1862. 7 : 271], who studied the American Limulus on the seashore, pointed out that when Limulus creeps on quicksand, or on sand just covered with water it uses its ordinary walking legs and produces a track strikingly like that described as Protichnites from the Potsdam sandstone, but in shallow water just covering the body, it uses its abdominal gill plates and produces a ladderlike track the exact counterpart of the

Lower Siluric (Champlainic)

UTICA SHALE

Echinognathus clevelandi *Walcott.*   Oneida county, N. Y.

FRANKFORT SHALE

Schenectady and Schoharie counties, N. Y.

Eurypterus megalops *nov.*

E. pristinus *nov.*

E. ? (Dolichopterus ?) stellatus *nov.*

Eusarcus triangulatus *nov.*

E. ? longiceps *nov.*

Dolichopterus frankfortensis *nov.*

D. latifrons *nov.*

Hughmilleria magna *nov.*

Pterygotus nasutus *nov.*

P. prolificus *nov.*

Stylonurus ? limbatus *nov.*

Climactichnites except that in the track of Limulus the lateral and medial lines are furrows instead of ridges.   Patten [Science. n.s. 1908.   28: 382] " described the movements of a modern Limulus in advancing up a sandy beach with the tide and the action of the abdominal gill plates making rhythmic ridges in the sand.   He compared these with the tracks of Climactichnites which he ascribed to forms related to the eurypterids rather than the trilobites.   The tracks showed a beginning in a hollow in the sand and where continued on the specimen to the further end there became fainter, as if the animal rose from the bottom.   This would correspond with the habit of the Limulus, which remains buried on recession of the tide and upon its first return crawls and then swims away.   Beside one track were seen two symmetrically placed impressions attributed to the longer arms of a Eurypteroid form."

In favor of this view is the fact that Strabops is a Cambric eurypterid that would appear competent to produce such tracks; but Woodworth has brought forward arguments to the effect that the trail was made by a mollusk and the sedentary impression is the end of the trail [*op. cit.* p. 961, 964] instead of its beginning. The direction of the obliquely transverse marks of Climactichnites is always toward the oval impressions and comparison with those of the Limulus tracks [Dawson, fig. 1-3, and also fig. 157 in Cambridge Nat. Hist. v. 4] would indicate that the animal, if an eurypterid, moved toward the sedentary impression and not away from it.

RICHMOND GROUP

Megalograptus welchi *Miller*.   Liberty beds, Warren county, Ohio

Upper Siluric (Ontaric)

CLINTON BEDS

Eurypterus prominens *Hall & Clarke*. Clinton sandstone, Cayuga county, N.Y.
E. *sp*.   Arisaig, Nova Scotia

LOCKPORT LIMESTONE (Noblesville dolomite)

Kokomo, Indiana

Eurypterus ranilarva *nov.*
E. (Onychopterus) kokomoensis *Miller & Gurley*
Eusarcus newlini *(Claypole)*
Drepanopterus longicaudatus *nov.*

GUELPH DOLOMITE

Eurypterus (Tylopterus) boylei *Whiteaves*.   Elora, Ontario

PITTSFORD SHALE

Pittsford, Monroe co., N. Y.

Eurypterus pittsfordensis *Sarle*
Stylonurus (Ctenopterus) multispinosus *nov.*
Hughmilleria socialis *Sarle*
H. socialis *var.* robusta *Sarle*
Pterygotus monroensis *Sarle*

SHAWANGUNK GRIT[1]

Otisville, Orange co., N. Y.

Eurypterus maria *Clarke*
Eusarcus? cicerops *Clarke*

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[1] Since this memoir went to press information has been received of new occurrences of eurypterids in the Upper Siluric of Pennsylvania and Maryland which we have been able to investigate by the favor of Dr Ulrich and Mr Jesse E. Hyde.

One specimen, collected by Mr Billingsley at the Delaware Water Gap, is a slab

Dolichopterus otisius *Clarke*

D. stylonuroides *nov.*

Stylonurus (Ctenopterus) cestrotus *Clarke*

S. (Ctenopterus) *sp. α, sp. β, sp. γ*

S. myops *Clarke*

S. *sp.*

Hughmilleria shawangunk *Clarke*

Pterygotus globiceps *nov.*

of black shale of the Shawangunk grit with indeterminable patches suggestive but not demonstrative of eurypterid integument. (*See* Appendix).

From the National Museum are three lots. The first, two split pieces of one slab of waterlime, is from the Salina of Selinsgrove Junction, Pa., and exhibits segments which suggest an Eurypterus, like E. remipes. This occurrence was recorded by Schuchert in 1903 [Lower Devonic and Ontaric Formations of Maryland, p. 416]. In character of the rock and the association of these remains with large Leperditias this slab is very like the Bertie waterlime.

The second lot consists of " black shale interbedded in the Keefer sandstone member of the McKenzie formation (basal Cayugan), Lock 53, 4 or 5 miles above Hancock, Md." The shale and the mode of preservation of the fossils here are as at Otisville. The material contains some recognizable parts of the integument; two carapaces, some tergites, small patches with ornamentation, and a telson. All these, save the carapaces, have the characteristics of a Pterygotus, especially in the sculpture which consists of large, semicircular, posteriorly rising scales and the telson. The smaller of the two carapaces is either a distorted Dolichopterus comparable to D. otisius, or a Pterygotus, approaching a Slimonia in outline. The larger is too incomplete for determination; what there is of it also points to the Hughmilleria-Pterygotus group. There is also a small fragment that suggests a badly crumpled carapace of Hughmilleria. On account of the interest attaching to this new locality, we have figured the carapaces and telson [pl. 70, fig. 6-8].

The third lot consists of thin slabs of waterlime, collected, according to the label, from the upper part of the McKenzie formation. In this the remains of the integument are so comminuted, that but a small tergite and several pieces with Pterygotus sculpture are recognizable.

It appears from these small lots of fossils that the peculiar eurypterid facies, both of the waterlime and of the shale extended in Cayugan time into the narrow bay reaching southward from New York into the Appalachian basin. Favorable conditions, such as for a time existed at Otisville through extensive quarrying, will undoubtedly some day bring these faunas more fully to light.

BERTIE WATERLIME

Eurypterus remipes *Dekay*. Herkimer, Oneida, Madison, Cayuga and Erie counties, N. Y.

E. lacustris *Hall*. Erie and Cayuga counties, N. Y.; Bertie, Ontario

E. lacustris *var*. pachychirus *Hall*. Erie county, N. Y.

E. dekayi *Hall*. Erie county, N. Y.

E. pustulosus *Hall*. Erie county, N. Y.

Eusarcus scorpionis *Grote & Pitt*. Erie county, N. Y.

Dolichopterus macrochirus *Hall*. Herkimer and Erie counties, N. Y.

D. siluriceps *nov*. Erie county, N. Y.

D. testudineus *nov*. Herkimer county, N. Y.

Pterygotus macrophthalmus *Hall*. Herkimer county, N. Y.

P. buffaloensis *Pohlman*. Erie county, N. Y.

P. cobbi *Hall*. Herkimer and Erie counties, N. Y.

P. grandis (*Pohlman*). Erie county, N. Y.

RONDOUT WATERLIME

Eurypterus remipes *Dekay*. Seneca and Genesee counties, N. Y.

MANLIUS LIMESTONE

Eurypterus microphthalmus *Hall*. Herkimer, Onondaga and Otsego counties, N. Y.; Monroe limestone, Put-in-Bay, Lake Erie, Ohio

Devonic

Pterygotus atlanticus, *nov*. Campbellton, New Brunswick

P. *sp*. Gaspé, Prov. Quebec; Dalhousie, New Brunswick

? Eurypterus pulicaris *Salter*. New Brunswick

? Eurypterella ornata *Matthew*. Lancaster, New Brunswick

PORTAGE SANDSTONE

Stylonurus (?) wrightianus (*Dawson*). Yates county, N. Y.

CHEMUNG — CATSKILL BEDS

Stylonurus (Ctenopterus) excelsior *Hall*. Delaware county, N. Y.; Wyoming county, Pennsylvania

S. beecheri (*Hall*). Warren, Warren co., Pennsylvania

Carbonic (Mississippian)

WAVERLY BEDS

Eurypterus approximatus *Hall & Clarke*.   Warren, Warren co., Pennsylvania

PRODUCTIVE COAL MEASURES

Eurypterus (Anthraconectes) mazonensis *Meek & Worthen*.   Mazon creek, Indiana

E. (A.) mansfieldi *C. E. Hall*.   Beaver county, Pennsylvania

E. (A.) pennsylvanicus *C. E. Hall*.   Venango county, Pennsylvania

E. ? potens *J. Hall*.   Pennsylvania

E. (A.) stylus *J. Hall*.   Beaver county, Pennsylvania

B Biologic facies of the eurypterid faunas

It is not necessary for us to discuss here the Algonkian[1] and Cambric occurrences, further than to mention that the Cambric species which is a true eurypterid, conclusively demonstrates the great age of the merostomes and their early existence in truly marine beds.[2]

The earliest appearance of the eurypterids in profusion is in the Lower Siluric Frankfort shale of Schenectady and Schoharie counties, N. Y., lately discovered.   Here at least 11 species, at present referred to the genera Eurypterus, Dolichopterus, Stylonurus, Eusarcus, Hughmilleria and Pterygotus, have been found to range through the eastern littoral marine development of the formation.

The earliest appearance of the characteristic biologic facies of the Eurypterida in America is that in the waterlime of Kokomo, Indiana which contains four species of the order.   Kindle [1904] has distinguished two stratigraphic horizons in the Niagaran of Indiana, which correspond to the Lockport and Guelph formations of New York respectively, and

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[1] The Algonkian Beltina is referred to in the Appendix.

[2] The Potosi limestone which has furnished this eurypterid contains, according to Beecher, an abundant and characteristic marine Cambric fauna   [Amer. Jour. Sci. 1901: 362].

Schuchert [1904] is of the opinion that, judging from the associated brachiopods, the Kokomo cement beds are probably of Noblesville, i.e. essentially Lockport age, and surely not of the age of the Bertie waterlime of New York, since no beds younger than the Guelph are known from northern Indiana. The aspect of the Kokomo fauna is in full accordance with this correlation since at least two of the species (O n y c h o p t e r u s k o k o m o e n s i s and D r e p a n o p t e r u s l o n g i c a u d a t u s) may be considered as older types than the species of the Bertie waterlime and following faunas.

The Guelph dolomite, like the Clinton, has afforded only a single straggler, the eurypterid facies of the horizon not yet having been observed; but the directly following age, that of the basal Salina, is represented by two faunas in New York State, viz, those of the Pittsford and Shawangunk shales. While these two have no species in common, they are characterized as probably belonging to approximate horizons by the presence of the genus Hughmilleria in both and by the similarity of their sedimentary and faunal aspects in general.

The Pittsford Eurypterus bed has been found by Sarle to be but 20 feet from the base of the Salina group; while the Shawangunk grit rests unconformably on the upturned edges of the Lower Siluric shale and, before the discovery of its eurypterid fauna, had been referred to the Salina by Hartnagel [1903, p. 1175; 1907, p. 50] on purely stratigraphical evidence, the latter consisting in the fact that the Shawangunk grit is conformably overlain by a series of formations of upper Salina age.

The Pittsford shale is separated by the main body of the Salina formation (Vernon and Camillus shales) from the principal eurypterid-bearing horizon of the State, the Bertie waterlime. In the exposures of the latter about Jerusalem hill in Herkimer county and in the quarries at Buffalo it has afforded the fauna described by Hall in the *Palaeontology of New York* and later exploited by Grote, Pitt and Pohlman. It is a fauna in which the genera Eurypterus and Pterygotus prevail in number of species (Eurypterus with five, Pterygotus with three) and in the size of the creatures,

which are there obviously near the climax of their development.   It is also the horizon where individual development is greatest.[1]

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[1] Though we have been discussing the eurypterids of the Bertie waterlime as if they constituted a single congeries, there is actually a very marked geographic distinction in their distribution.   At the two productive localities, Erie county and Herkimer county, there are noteworthy distinctions in respect to species.   The two faunules are as follows:

HERKIMER COUNTY	ERIE COUNTY
Eurypterus remipes	Eurypterus lacustris
Dolichopterus macrochirus	E. lacustris *var.* pachychirus
D. testudineus	E. pustulosus
Pterygotus macrophthalmus	Eusarcus scorpionis
P. cobbi	Dolichopterus macrochirus
	D. siluriceps
	Pterygotus buffaloensis
	P. cobbi
	P. grandis

The species common to both are D o l i c h o p t e r u s   m a c r o c h i r u s and P t e r y g o t u s   c o b b i , both of which are quite rare, while the predominant species in both places are unlike.   It is not believed that these differences necessarily express distinct stratigraphic horizons, as both congeries lie near the top of the waterlime succession, but rather indicate original regional separation into distinct lagoons or pools, so that we may without impropriety speak of these regions as the *Buffalo pool* and the *Herkimer pool*, which we may assume to have been synchronous.   There is, in the face of the differences suggested, a certain degree of approximation in the two expressed by such vicarious species as E.   r e m i p e s   and   l a c u s t r i s ,   P. m a c r o p h t h a l m u s and b u f f a l o e n s i s , which may well   mean   distinctions due to geographic isolation.   The Herkimer pool is well restricted and its faunule can not be traced very far toward the west; the Buffalo E. l a c u s t r i s , however, appears alone as far east as Union Springs, Cayuga co., and as far west as Bertie, Ontario. Another difference in these faunas is the preponderating great size of' all the species in the Buffalo pool and, by contrast, the small size of and abundant young among the Herkimer county species; a distinction which may be due to differences in depth.   That the smaller creatures lived in conditions of shallower water is evinced by the sun-dried and cracked rock surfaces of their matrix, while such evidences are wanting in the Buffalo pool; and indeed it would be quite in accordance with our acquaintance with

One or two stragglers, notably E u r y p t e r u s   r e m i p e s , return in the Rondout waterlime in greatly diminished number, and a new peculiar type of Eurypterus (E .   m i c r o p h t h a l m u s) appears in waterlime intercalations of the Manlius limestone above.[1]

The North American Devonic has furnished but scanty remains of Pterygotus in the Dalhousie formation of New Brunswick,[2] the Gaspé

the limulids to find the smaller and younger forms in the shallower shore waters, where there might be laid down with their remains the drifted fragments of larger individuals such as are indicated by the great Pterygotus segment and the large carapace of E. r e m i p e s , elsewhere figured.   While E. r e m i p e s seems to have strayed farthest beyond the bounds of its lagoon, yet both pools were really quite restricted and today the most productive part of the Buffalo pool seems to have been removed by the quarrying operations of the Buffalo Cement Company.

[1] To show the more exact position of the Eurypterus-bearing beds in the entire succession of the Siluric, this briefer tabulation is appended, in which a descending order is followed.   The productive beds are in italics.

DEVONIC

Helderbergian

Upper Siluric	Salina		*Manlius*
			Rondout
			Cobleskill
			Bertie
			Camillus
			Salt
			Vernon
			Pittsford-Shawangunk
	Niagaran		*Guelph*
			Lockport-*Noblesville*
			Rochester
			Clinton
			Medina-*Richmond*
Lower Siluric			*Frankfort*
			Utica
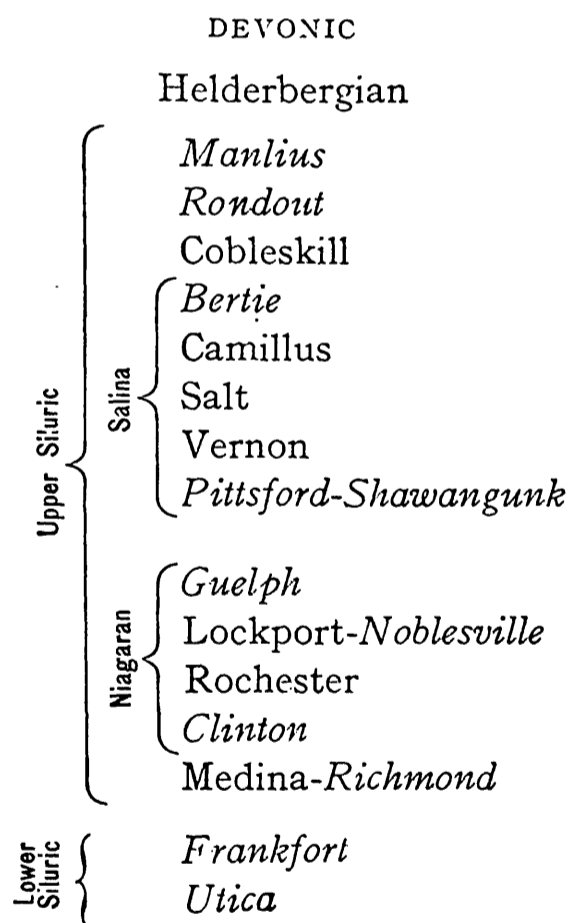
[2] Clarke, N. Y. State Mus. Mem. 9,2: 18, 1909.   The diminutive E u r y p t e r u s ? p u l i c a r i s Salter and E u r y p t e r e l l a   o r n a t a Matthew from the Devonic rocks of New Brunswick are so little known and their eurypterid nature so doubtful that they are here left out of consideration.

sandstone of lower Quebec,[1] the fish beds at Campbellton, N. B.,[2] the S t y l o n u r u s ? w r i g h t i a n u s of the Portage sandstone, the gigantic S. e x c e l s i o r of the Catskill beds of New York and S. b e e c h e r i from the Chemung of Pennsylvania.

The Waverly beds of Pennsylvania, near the New York boundary, have furnished a single straggler in E . a p p r o x i m a t u s but the Productive Coal Measures of Pennsylvania frequently contain remains of the peculiar phylogerontic group of the genus Eurypterus, distinguished as Anthraconectes.

C   Geological distribution in other countries

In Scotland and on the shores of the Baltic occur beds comparable in wealth of merostomes with those of New York, and there the eurypterid horizons exhibit a remarkable parallelism with our series and are approximately homotaxial.

The lowest distinct eurypterid horizon in Scotland is the lower one in Lanarkshire and the Pentland hills, characterized by species of Eurypterus and Stylonurus and especially by the genus Slimonia and is now correlated with the Wenlock.[3]   It hence corresponds in age to our lowest American eurypterid horizon, that of the Kokomo waterlime. It has in common with the latter the primitive stylonuroid genus Drepan-opterus.

The upper horizon of the Lanarkshire eurypterids is in beds that protrude, islandlike, from the Old Red sandstone and for this reason were formerly confused with the latter but are now correlated with the Ludlow and the " Passage " beds.   Their fauna corresponds in age to our Salina faunas.   The presence of species properly referred to Eusarcus (E u r y p t e r u s   s c o r p i o i d e s   Woodward) and Hughmilleria

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[1] Clarke. *op. cit.* 1 : 84.

Whiteaves. Canadian Naturalist. 1883. 10:100. Clarke *op. cit.* 1: 90.

[3] *See* Laurie, M., 1899, p. 575, and Kayser, Lehrb. der geol. Formationskunde, 1908, p. 90.

(E u r y p t e r u s l a n c e o l a t u s Salter) is faunistic evidence of this homotaxy.

Still closer is the faunistic and stratigraphic agreement of the Bertie waterlime with the eurypterid beds of Oesel. The upper Oesel zone contains in E u r y p t e r u s f i s c h e r i a species which is conceded by Schmidt and Holm to be but a vicarious form of the E . r e m i p e s ; and as both the Bertie waterlime and the upper Oesel are situated close to the top of the Siluric, there is little doubt that they are homotaxial [Schmidt, 1892].

The Devonic of Great Britain contains one eurypterid horizon, that of the Old Red sandstone, characterized by the giant P t e r y g o t u s a n g l i c u s , the "seraphim" of the Scottish quarrymen. To this monster of the great lakes and estuaries of the Old Red sandstone continent, Eria, the S t y l o n u r u s e x c e l s i o r of the Catskill beds is a parallel; it lived at the same time, under like physical conditions, in the same continental waters and is found in a similar association of ganoids (Holoptychius), placoderms and land plants. In a similar association these remains are found in the Upper Devonic of Belgium and of New Brunswick.

Minor occurrences are also known from Podolia, Galicia, and Bohemia [Barrande, 1872; Semper, 1898; Seeman, 1906]. Those of Podolia and Galicia are essentially a continuation of the Oesel horizon [v. Alth, 1874; v. Siemiradzki, 1906]. Australia has furnished a single fragment of Pterygotus from the Upper Siluric [McCoy, 1899].

The last outburst occurs both in Great Britain and North America in the Productive Coal Measures where a number of species of Eurypterus appear which bear the distinct marks of the approaching extinction of the race, and because of their phylogerontic characters these have been united under the subgenus Anthraconectes. In North America the Coal Measures of Pennsylvania and the iron stone nodules of Mazon Creek, Illinois, have furnished about half a dozen species of this peculiar group.[1]

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[1] The Coal Measures of the Joggins, Nova Scotia, contain eurypterid remains [Salter, 1863, p. 78], and the Lower Gondwana areas of South Africa and South America have lately furnished eurypterids [see supplement on Hastimima p. 401].

The Permic of Portugal has furnished the final straggler of the race
in a small Eurypterus [de Lima, 1890].

D Bionomy of the eurypterid faunas

A very interesting problem in the study of the eurypterids is that
of their bionomic relations and geologic facies. A philosophic contri-
bution to the discussion of this problem has been given by Professor
Chamberlin in his paper *On the Habitat of the Early Vertebrates* [1900,
p. 400].

Chamberlin's hypothesis is to the effect that "the fish and the
eurypterids descended from the rivers to the sea in the mid-Paleozoic,
though their remote ancestors may have ascended from it," and the
principal argument in its support is found in the claim that "there is
only one conspicuous type that is facilely suited to free life, independent of
the bottom, in swift streams, and that is the fish form"; it is further
urged that " this could have developed only in water that possesses a per-
sistent and usually rather rapid motion in a fixed direction, i. e., in
rivers."

In support of this hypothesis it is pointed out that the Paleozoic fish
and the similarly built eurypterids are always associated and it is suggested
that the two possessed a parallel development due to the same physical
influence.   This view of the fresh-water origin of the eurypterids is directly
contradictory to the current view among paleontologists of their originally
marine habitat and later adoption of first a brackish and finally a fresh-
water life. Zittel-Eastman's Textbook of Paleontology expresses this
prevailing view as follows [1896, p. 673]:

> They are found associated with graptolites, cephalopods, and trilobites
> in the Ordovician of Bohemia and North America; with marine Crustacea
> (Phyllocarids and Ostracods) in the Silurian; with Ostracoderms and Arth-
> rodires in the Devonian; and with land plants, scorpions, insects, fishes
> and fresh-water amphibians in the Productive Coal Measures.   It is ap-
> parent, therefore, that from being originally marine forms, they became
> gradually adapted to brackish, and possibly even fresh-water conditions.

In describing the geologic occurrence of the fish and eurypterids, Chamberlin lays special stress on the abrupt appearance of both groups of fossils in the Siluric, heralded by very scanty remains in the preceding formations, and gives the following account of the phenomena of their distribution in the rocks.

In the Ludlow " bone bed " of England, where they first make their appearance in abundance, the fish remains are associated with eurypterids, probably the most gigantic crustaceans that have ever lived, some of them attaining two meters in length. There is the same association on the continent, notably in the island of Oesel in the Russian Baltic and in Podolia and Galicia, and so again in the waterlime group of America in which the P t e r a s p i s [P a l a e a s p i s] a m e r i c a n a of Claypole occurs. The physical conditions in all these cases seem to have been peculiar, and in the case of the waterlime group they were singularly so, for they permitted a host of these larger eurypterids and other crustaceans to flourish in seeming luxuriance, while only a meager and pauperate marine fauna found an occasional entrance into the series. The conditions seem to have been congenial to the fish and eurypterids but not to a typical marine fauna.

In the Old Red sandstone of the Devonian both in Europe and America a similar association obtained. A most extraordinary group of fishes and a family of most gigantic crustaceans flourished where marine life found only an occasional and meager presence. These few marine forms, here and there in a massive deposit, no more imply prevalent salt water than the present marine species in the bay of San Francisco imply that the gravels, sands and silts of the valley of California and of the Great Basin, which seem to be analogues of the Old Red sandstone, are prevailingly marine. The further association of the fishes and eurypterids with land plants and fresh-water mollusks, together with a total absence of marine relics from the same beds, leaves no solid ground for hesitating to accept the dominant view of English and other geologists that the typical Old Red sandstone and its homologues are the deposits of fresh waters and that both the fishes and the eurypterids found congenial conditions of life in them. As fishes and eurypterids were found both earlier and later in marine deposits the question arises: *Were the fishes and eurypterids primarily marine and later became adapted to fresh water, or were they primarily fresh-water forms which were occasionally carried out to sea, and which later became adapted to salt water?* The two cases do not necessarily

require an identical answer, but the singular association of the two in unusual display under peculiar conditions and on both continents strongly implies a community of habit, at least at the stages in question. The association is one of the most unique [!] faunal and physical combinations of geologic history.

The earlier occurrence of the eurypterids in marine deposits is almost as limited as that of the fishes, and yet they were well adapted to fossilization and were actually fossilized as far back as Precambrian times, as Walcott has recently shown by their discovery in the Belt Mountain terrane of Montana. Of about a dozen known genera of eurypterids, only two or three of those least well known are without associations with formations regarded as fresh water. The relics found in marine sediments may be attributed to transportation from the land just as is done in the case of the terrestrial plants and land insects not infrequently found in marine beds; but transportation in the opposite direction can not be assigned . . . From the occurrence of eurypterids first in marine beds apparently and later in fresh-water deposits it has been inferred that they were originally sea dwellers and later became adapted to land waters, but the meagerness of their marine record on the one hand, and their abundance and fine preservation in the fresh-water deposits on the other give point to the question whether their early marine record is anything more than the chance deposit of river forms borne out to sea.

In view of the contrasting opinions which have been thus expressed as to the original habitat of the eurypterids, it will be well to analyze closely here the evidence from the rocks which contain the eurypterids, and from the associated species.

In regard to the Cambric S t r a b o p s t h a c h e r i , the Lower Siluric E c h i n o g n a t h u s c l e v e l a n d i and M e g a l o g r a p t u s w e l c h i , the Clinton E u r y p t e r u s p r o m i n e n s and the Guelph E. b o y l e i , we might concede, in view of the fact that all these remains have been found in only a single individual each, that they are remains carried out to sea from terrestrial waters, yet their combined evidence inclines to the side of the marine habitat.

The profuse Lower Siluric (Frankfort) fauna is associated with seaweeds, graptolites, trilobites, cephalopods and brachiopods, and inhabited the pools of a littoral region with abundant detrital sediments. All

the Lower Siluric eurypterids thus far known were hence still purely marine.[1]

The rich faunas of the Kokomo and Salina beds (the latter containing these creatures by thousands) are all intercalated in distinctly marine deposits; the Kokomo beds carry such brachiopods as C o n c h i d i u m c o l l e t t i and W i l s o n i a k o k o m o e n s i s , and the Salina eurypterid shales Leperditias, Pterineas (P . s u b p l a n a), cephalopods (Orthoceras, Gomphoceras), marine gastropods, Conularias, Lingulas and Orbiculoideas.   The same is true of the European eurypterid horizons intercalated in the Wenlock and Ludlow beds of Great Britain, and of the Oesel beds of Russia.   The latter horizon lies between the lower Oesel zone with heavy coral banks, numerous trilobites (as C a l y m - m e n e b l u m e n b a c h i , E n c r i n u r u s p u n c t a t u s , etc.) and

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[1] The investigation of this Frankfort shale fauna proves it to be restricted geographically to the exposures of the formation in the lower Mohawk valley, where it seems to pass with equal profusion through a thickness of several thousand feet. Specimens have been obtained in the Dettbarn quarry at Schenectady, the bluestone quarries at Aqueduct and Rexford Flats, on both sides of the Mohawk river; and a profuse association of Sphenothallus and the eurypterids was found in the upper part of the section described by Cumings [N. Y. State Mus. Bul. 34, p. 451] from Rotterdam Junction, west of Schenectady. In much higher beds of the Frankfort shale the same fauna was obtained in abundance at quarries at Duanesburg and Delanson, on the Schenectady branch of the Delaware & Hudson Railroad, and still farther southwest in the reëntrant of the Helderberg escarpment, caused by the Schoharie creek, in exposures along that creek above Schoharie Junction. In a ravine of a small stream which joins the Cobleskill between Central Bridge and Howes Cave (mentioned by Grabau [N. Y. State Mus. Bul. 92, p. 102] on account of its fine exposure of the Brayman shale), the eurypterid fauna could be traced quite up to the Brayman shale. Thus in the western part of its range it occupies the whole thickness of the Frankfort shale, unless it is absent in the lowermost part of the formation, not yet found in good exposures in that region. The fauna does not seem to extend to the western localities, for it has not been observed in the Frankfort shale sections at Frankfort and Ilion, where the fossils have been very thoroughly studied by the junior author.

Toward the southeast the last traces of the eurypterids are found in the sandy shales exposed along the Vly, below Voorheesville. Here the eurypterid beds are fol-

brachiopods (O r t h i s   e l e g a n t u l a , etc.) and the so called Oster-
garn beds which still contain Eurypterus, but also L u c i n a   (I l i o n i a)
p r i s c a ,   M e r i s t i n a   d i d y m a , Leperditia and in their upper-
most layers species of Chonetes, Spirifer, Beyrichia, etc.

Thus the Eurypterus beds of the Salina formation in which the
fauna reaches its climacteric development, are clearly stamped with their
marine origin, and the. profusion and perfection of preservation of the
eurypterid remains precludes the possibility of their transportation into
the basin by land waters; it is also apparent that the beds were not formed
under normal marine conditions.   The eurypterid horizons of Kokomo, of
the Salina and of Oesel, as well as of Great Britain, exhibit as clearly
all the characteristics of a particular and peculiar marine facies, as do the
graptolites or the corals.   These facies are indicated partly by the unusual
nature of the rocks and partly by the peculiar aspect of the associated

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lowed after an interval by several hundred feet of shales and sandstones that form
the top of the Frankfort formation and contain a distinct fauna without eurypterids.
These rocks, elsewhere designated the *Indian Ladder beds*, are typically exposed in a
high bluff below the Indian Ladder at the Helderberg escarpment.

The peculiar restriction of the eurypterids to the easternmost exposures of the
Frankfort shale would seem at first to be explicable, as in the case of the Salina faunas,
by assuming their occurrence in " pools."   But the Frankfort shale exhibits
notable differences from the Salina in total thickness, faunal association and
lithological character as between the eastern and western occurrences, evidence which
tends to indicate that the eastern beds were deposited close to the shore line, and the
more western beds farther offshore.   The Frankfort eurypterids were thus inhabitants
of the shallow littoral waters with their mud flats and lagoons, and if the shore line of
the late Utica-Frankfort period extended in northeast-southwest direction, just east
of the lower Mohawk region, as conceived by Schuchert [Paleogeography of North
America, pl. 60] the exposures along the lower Mohawk valley happen to intersect only
their former narrow habitat.   The range of the eurypterids extends in this limited area
through a thickness of from 1500 to 2000 feet which is due to the fact that this region
was apparently involved in the Appalachian folding then going on, and thereby suffered
depression while large quantities of material were swept down from the rising land
in the east.

animals. The most characteristic of eurypterid rocks is the water-lime.[1] It is in this that the faunas of Kokomo and of the Bertie waterlime of New York are contained. How close is this association of eurypterids and waterlime, is shown by the fact that with the recurrence of waterlime formation (Rondout) in the Salina section after the close of the salt deposition and the Cobleskill dolomitic limestone stage, Eurypterus reappears, though much diminished in number, and later again, after the introduction of the Manlius fauna the upper waterlime bed of the Manlius brings back a single species (E . m i c r o p h t h a l m u s). The section at Manlius given by Hartnagel[2] [1903, p. 1165] illustrates well the intimate connection of waterlimes with eurypterids on one hand and the intercalation of limestones with Stromatopora and brachiopods on the other.

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[1] The appended analysis of the Buffalo waterlime or cement rock, kindly furnished by Mr Lewis J. Bennett of Buffalo, shows the peculiar composition of this strongly magnesian limestone:

Silica...	11.48
Iron..	.90
Alumina...'...	17.50
Carbonate of lime...................................	42.75
Magnesia (carbonate)	20.35
Potassium...	1.00
Sodium..	.80
Combined water and loss.............................	5.22

[2]GENERAL SECTION AT MANLIUS, ONONDAGA COUNTY

Top			Feet
1	Oriskany.	Fossiliferous sandstone....................................	.5—2
2	Helderbergian.	Gray, compact fossiliferous limestone....................	6
3	Helderbergian.	Blue limestone beds....................................	14
4	Helderbergian.	Stromatopora beds, upper portion much broken..........	12
5	Helderbergian.	Blue limestone, fossils rare.............................	14
6	Manlius.	*Upper waterlime bed. Eurypterus at Split Rock*...............	4
7	Manlius.	Blue limestone with S p i r i f e r v a n u x e m i and L e p e r d i t i a a l t a...	4
8	Manlius.	Lower waterlime bed....................................	4
9	Manlius.	Stromatopora bed at top. Blue layers below containing typical Manlius fauna..	65

The peculiar yellow plattenkalke and marls of Oesel which contain the well known Baltic eurypterid fauna are of similar character with the Salina eurypterid beds.

A different rock facies containing eurypterids is represented in the Pittsford shale and the Shawangunk grit shale beds. In the former the fossils occur in a rather fissile, very dark olive-green to black shale. Its relations to the Salina section have been recorded by Sarle [1903, p. 1082].[1]

Top		Feet
10	Rondout. Upper portion, light weathering impure limestone; lower portion, a cement rock with cavities (*see* p. 170)..............................	45
11	Cobleskill. Fossiliferous limestone gradually grading into the Rondout...	6
12	Salina. *Waterlime with Eurypterus*....................................	6
13	Salina. Soft, greenish shales.......................................	10
14	Salina. Gypsum beds, with intercalations of shale.....................	65
		255

[1]SECTION IN OLD ERIE CANAL AT PITTSFORD

Salina

Top		Feet	Inches
1	Red shale...	6	
2	Light gray, compact, fine grained, dolomite, with imperfect conchoidal fracture, weathering light brown to cream color..		10
3	Soft, gritty mudrock, purple with bright red mottlings........	1	3
4	Dolomite like no. 2.......................................		4
5	Purple shale with red mottlings............................	1	11
6	Green shale..	1	2
7	Thin layer dolomite like no. 2.............................		4
8	*Black shale*, very compact, the base splitting unevenly; grading to olive-green shale in the upper part.....................		10
9	Dolomite like no. 2.......................................		10
10	*Black shale*, with leaf of dolomite ½ inch thick 4 inches from its base..	1	2
11	Dolomite like no. 2.......................................		2
12	Soft, green, arenaceous mudrock, occasionally becoming shaly; the lowest exposed rock of the cut.........................	1	8

These sections show that the Eurypterus-bearing black shales are intercalated in red and green shales with thinner beds of dolomites and mudrocks. The waterlime and shale occurrences of Eurypteri in these Salina beds are hence not expressions of different biologic facies.

The eurypterid fauna occurs in the black shale, nos. 8 and 10 in the foregoing table.

From wells of the neighborhood of the preceding locality the following section has been obtained by Sarle:

Salina

Top		Feet	Inches
1	Red shale or marlite..	10	
2	Hard, fine grained, yellowish dolomite, having an imperfect conchoidal fracture.......................................	2	
3	Red shale...	1	
4	Break estimated at..	3	
5	Dolomite like no. 2..	3	
6	Green shale or marlite...	4	
7	Red shale...	1	8
8	Break estimated at about..	2	
9	Green shale..	2	5
10	*Black shale*, very fine textured, fissile and with 1 inch dolomite parting (eurypterid horizon).............................	1	6
11	Green shale..	1	
12	Dolomite like no. 2...	2	
13	Green shale or marlite...	6	
	From west branch of Allen creek:		
14	Light colored waterlime, some pyrites and sun cracks,.........	5	
15	Pea-green shaly marlite..	7	
		51	7

Niagaran

16	An impure yellowish porous limestone		
17	Succeeded by an impure bituminous limestone made up of imbricating, shell-like domes, etc.		

It is very different with the Eurypterus horizon in the Shawangunk grit. There the eurypterids occur in thin shale intercalations that are found in endless repetition between heavy beds of conglomerate and grit.[1]

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[1] The following section has been measured at Otisville [Clarke, 1907, p. 299]:

Section of the Shawangunk series in ascending order

Erie Railroad cut ⅓ mile west of Otisville

129 ft of " Hudson River " shale with interbedded thin layers of sandstone

Unconformity

SHAWANGUNK SERIES

12′ conglomerate	6″ *shale, thinning out rapidly*
2″ *shale*	13′ 5″ grit
8′ conglomerate	2″ *shale*
2″ *shale*	5′ grit
1′ conglomerate	4′ *shale*
2″ *shale*	7′ grit
16′ 8″ conglomerate	1′ *shale becoming thicker at top of cut*
2″ *shale*	41′ grit
6′ 10″ grit	50′ (estimated) of grit not exposed
6″ *shale*	between top of railroad cut sec-
2′ 10″ grit	tion and base of quarry section

Erie Railroad quarry ⅓ mile west of Otisville

101′ grit	3′ grit	
5″ *shale*	1″ *shale*	
3′ 6″ grit	8′ grit	
2″ *shale*	1′ *shale*	
2′ grit	21′ grit	
2″ *shale*	4″ *shale*	
7′ 6″ grit	8′ grit	
2″ *shale*	2″ *shale*	
12′ grit	1′ 9″ grit	
8″ *shale*	2″ *shale*	
3′ grit	1′ 6″ grit	
10″ *shale*	3″ *shale*	
17′ 2″ grit	5′ grit	
4″ *shale* ⎫	2″ *shale* ⎫	Very productive band in
6″ grit ⎪	6′ grit ⎪	section 16′ 8″ begin-
1″ *shale* ⎪	4″ *shale* ⎬	ning at 298′ 5″ above
4″ grit ⎪ Productive band. From	10′ grit ⎪	contact
2″ *shale* ⎬ a vertical section of	2″ *shale* ⎭	
3′ 8″ grit ⎪ 23′ 6″ beginning 198′	22′ grit	
2″ *shale* ⎪ 7″ above contact of	2″ *shale*	
7′ grit ⎪ Shawangunk grit and	6′ grit	
2″ *shale* ⎪ "Hudson River" shale	3″ *shale* ⎫ Productive band; sec-
11′ grit ⎪	1′ 6″ grit ⎬ tion of 1′ 9″, 343′ 3″
1″ *shale* ⎭	2″ *shale* ⎭ above contact

Connected with this difference in rock is that in the aspect of the fauna. While the Eurypterus faunas of Buffalo and Pittsford consist almost entirely of mature and adolescent individuals, the younger growth stages prevail in the Shawangunk grit shales and large individuals are represented only by fragments which indicate that they may have been destroyed by the more turbulent water conditions farther out. On the other hand, the general absence of the earlier growth stages at Buffalo and Pittsford, together with the presence of the finer grained rock, intimate that there we have the habitat of the mature eurypterids which probably, was the somewhat deeper littoral, as in the case of Limulus, while the shale intercalations of the Shawangunk grit are the deposits of the shore pools in which the larvae were hatched and where the earliest stages of the ontogeny were passed, again as in the living Limulus.

An interesting analogy between this breeding place of the eurypterids in Orange county and that of Limulus rests in the fact that the young of Limulus are hatched on sandy tide flats and tide zones and the Shawangunk grit is a coarse sand deposit of this kind. It seems, therefore, a proper conclusion that the Shawangunk grit represents a tidal zone deposit of an encroaching sea or of a delta.

Omitting for the present the peculiar case of the Eurypterus horizons in the Frankfort shale and the Shawangunk grit and returning to the more typical Eurypterus facies represented by the waterlimes and shales of the Salina formation of western New York, we encounter the venerable and still current view that these beds were formed under conditions of much abnormal salinity. This view is based on the presence of the salt and gypsum

2′ 2″ grit	10′ grit
2″ shale	3″ shale
1′ 2″ grit	7′ grit
2″ shale	4″ shale
8′ grit	60′ grit (estimated) with occasional
5″ shale	very thin layers of shale. As these
9′ grit	60′ have not been quarried, shale layers
2″ shale	have been weathered away at ex-
4′ grit	posures.
10″ shale	

deposits of the Salina formation and the absence of fossils in the middle Salina beds (Vernon, Camillus shale) which were early ascribed to "salt pan" conditions in the Salina sea. The authors have pointed out in Memoir 5 [Guelph Fauna of New York, p. 117] that the preceding Guelph was a distinct phase in the development of the vast Niagara coral sea into the desiccating, more or less inclosed sea of the Salina stage, the fauna of the Guelph already exhibiting characters suggestive of the increased salinity of the sea. The cycle of events leading to the culmination and decline of the Salina sea has been expressed by Hartnagel in the appended diagram and described as follows:

DECREASING SALINITY	A B	Niagara–Guelph fauna	Cobleskill
	C	Waterlime with Eurypterus	Salina
	D	Gypseous shales	
		Beds of rock salt	
INCREASING SALINITY	D	Gypseous shales	
	C	Pittsford shale with Eurypterus	
	B	Guelph fauna	Niagaran
	A	Niagara fauna	

With the ever increasing salinity of the waters the Guelph fauna retreats, and next in the black Pittsford shale at the base of the Salina there occur Eurypteri, and with them constantly associated a species of Lingula. With the retreat of this fauna we find, as physical changes went on, deposits of gypseous shale and later the salt beds. The deposition of these great beds of rock salt marks the turning point in this cycle, . . . beds of gypsum were again deposited, but never again were the conditions favorable for the deposition of extensive beds of rock salt. Following the gypsum beds, we have the Salina waterlime with its splendid Eurypterus fauna, and associated with the Eurypterus is a species of Lingula simi-

lar to the one at the base of the Salina. Above the Eurypterus beds follows the Cobleskill limestone, and here again are representatives of the Niagara-Guelph fauna.

If the cycle just described is considered as produced by the desiccation of a closed basin, in which extreme salt pan conditions prevailed at its climax when the thick beds of rock salt were deposited, it follows as a manifest corollary that the eurypterids of Salina age had their biologic optimum in a sea of greater salinity than the typical mollusks and trilobites of the Upper Siluric could endure.

In view of the hypotheses before us and the evidence that the eurypterids flourished in brackish and fresh water in the Devonic and Carbonic this corollary requires a closer study.

The English geologists, notably Hugh Miller and Lyell, in the middle of the last century, explained the origin of salt deposits by the evaporation of sea water in basins so separated from the ocean by shallow bars that the evaporated water could be replaced by new marine water while the corresponding more saline water could not flow out on the bottom. This bar theory has been based on safe physical and chemical data by Ochsenius,[1] while von Koenen[2] and others have shown that this theory on the whole explains the complex composition of the German salt deposits.

A close analysis of the Salina sections and of the character of the Salina rocks also suggests this conception as fully competent to explain the conditions surrounding their deposition.

The facts which we consider as of especial importance to a correct view of the physical conditions of the Salina sea are: (1) the continuous alternations of gypseous and dolomite beds, (2) the great thickness of the salt beds.

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[1] Zeitschrift für Praktische Geologie, Mai und Juni 1893; *see also* Kemp, Handbook of Rocks, 1904, p. 106.

[2] von Koenen, A., Zur Entstehung der Salzlager Nordwest-Deutschlands. Excerpt aus Nachr. der k. Gesellsch. der Wissensch. zu Göttingen, 1905.

The oft repeated alternation of gypseous beds with shales or limestone is illustrated by the section at Buffalo[1], where five to six repetitions of gypsum and shale are exposed. A like repetition of gypsum beds, the gypsum mostly in thin seams and nodular layers, is shown in the section of the Livonia salt shaft,[2] Livingston county, N. Y. This alternation of the gypseous beds with the dolomites and shales indicates a constant change of conditions which is difficult of explanation in a slowly and regularly desiccating basin, but denotes a periodic interruption of the drying process, either by inflow over the bar, or, perhaps, by seasonal freshets.

Another feature of the Salina beds favoring the bar theory is the great thickness of the salt beds. In the Retsof salt shaft at York, Livingston co., [Luther, *op. cit.* p. 118] the drill passed successively through 22 feet of salt, 30 feet of shale and limestone and again through 58 feet of

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[1] *Section by Julius Pohlman* [Buffalo Soc. Nat. Sci. Bul. 5:97] from the base of the Eurypterus beds (Bertie waterlime) of Buffalo down to near the base of the Salina formation

Feet	
1–25	Shale and cement rock in thin streaks
25–30	Tolerably pure cement rock
30–43	Shale and cement rock in thin streaks
43–47	Pure white gypsum
47–49	Shale
49–61	White gypsum
61–62	Shale
62–66	White gypsum
66–73	Shale and gypsum, mottled
73–131	Drab colored shale with several layers of white gypsum, measuring 18 feet in all
131–133	Dark colored limestone
133–137	Shale and limestone
137–140	Dark colored compact shale
140–720	Gypsum and shale, mottled and in streaks
720–725	Limestone
725–760	Soft red shale
760–785	White solid quartzose sandstone, very hard
785–1305	Soft red shale

[2] Luther. N. Y. State Geol. Rep't, 1893, 1: 90 *et seq.*

salt.[1] Recent writers[2] have held that such thicknesses of salt can not be explained by the desiccation of a sea enclosed by land barriers in distinction from bars.   The salt of the Retsof mine would require the desiccation of a sea 1750 feet deep, and this is irreconcilable with the shallow water conditions of the Salina beds evidenced by the frequent sun cracks in the dolomites and waterlimes of the formation.

There is no doubt that the culminant salt pan condition of the Salina period with its heavy precipitation of salt, implies an arid climate.   There is also evidence indicating the persistence of these desert conditions throughout the Salina period and at the time when the eurypterid-bearing sediments were deposited.   This evidence is found in (1) the scarcity of carbonaceous matter in the Salina beds, (2) the prevalence of dolomites and waterlimes.

The Salina beds are notably free from carbonaceous matter when compared with the underlying Niagaran and overlying Helderbergian beds. This may be partly due to the absence of such decaying marine organisms as furnished the bitumen with which part of the underlying Guelph dolomite is saturated, but it is also an indication of the absence of vegetation on the adjoining land.   This becomes especially manifest if it is considered that the Salina sea was almost entirely surrounded by land, and that, as the frequent sun cracks in the waterlimes of central New York demonstrate, the shore was nowhere very distant.   Several authors, as

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[1] The section is as follows:

. Feet
   6 *Onondaga*
     Oriskany
  68 Limestone (*Lower Helderberg* + *Manlius*)
  47 Gypsum
  63 Limestone
 140 Shale and limestone
  89 Shale
  12 Limestone
  32 Shale
  22 Salt
  30 Shale and limestone
  58 Salt
     Shale

[2] Kemp, Handbook of Rocks, 1904, p. 106.

Joh. Walther [1900], Joseph Barrell [Geol. Jour., 1908] have, in recent years, pointed out the absence of carbonaceous matter in littoral and delta deposits as characteristic of an arid climate.

While thus the salt and gypsum-bearing deposits serve to demonstrate the increase of land-locking and salinity of the lagoon and the subarid to arid climatic conditions, the black and green Pittsford shales indicate that · then the aridity had not reached its climax and that the lagoon or estuary still received at certain seasons both clastic sediments and fresh water.

It is therefore hardly necessary to infer that the eurypterids of the Salina period lived in a brine. It is quite possible that, when the lagoon became too saline, they withdrew into the brackish water zone of estuaries or deltas. This inference agrees well with the meagerness of the marine brachiopod and mollusk fauna with which they are associated, the brackish water being still today the least inhabited zone of the hydrosphere on account of its frequent changes in salinity; and it is also in full accord with the occurrence of the eurypterids in the Devonic rocks. There is no longer any doubt that the Stylonurus of the Catskill beds inhabited an estuary with brackish water conditions; and in regard to the Old Red sandstones which are currently considered by the British geologists as fresh-water deposits, Kayser in his excellent textbook has noted [p. 168] that the presence of whole layers of brachiopods and other genuine marine shells in the Old Red sandstone of St Petersburg proves the prevalence, at least temporarily, of brackish water lagoon conditions, and Clarke[1] has described the lagoons indicated by the Upper Devonic deposits of eastern New York, comparing these with the conditions prevailing now in the bar-locked lagoons of the Prussian Baltic with their shifting of fresh-water and brackish faunas. The eurypterid beds of Lanarkshire and the Pentland hills, of Ludlow age, are regarded by British geologists as brackish water deposits, for the reason that they contain eurypterids, phyllocarids limulids, scorpions and myriapods together with fish and land plants. It therefore seems proper to conclude that the eurypterids in Siluric time

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[1] Naples Fauna in Western New York. N. Y. State Mus. Mem. 6, 1904, p. 206.

were prevailingly inhabitants of the brackish water zone, and in Devonic time they were wholly so.

In the Carbonic era on this continent the eurypterids are mainly perpetuated by the peculiar subgenus Anthraconectes, in the Productive Coal Measures. These are found in Pennsylvania on slabs densely covered with fern leaves and other plant remains which can not fail to suggest near land and probable fresh-water conditions. Yet even in this case, the fragmentary condition of many of the fern leaves which would, according to the criteria of the "Allochthonie" of the coal measures, advanced by Potonié[1] indicate the transported condition of the material; even more the profuse presence of the small spiral tubes of the marine Spirorbis on the plant remains, as shown by Simpson's excellent figure [Hall, 1884, pl. 6] afford a caution against an unqualified conclusion as to the fresh-water habit of these Carbonic eurypterids. In a recent exhaustive discussion, Girty[2] has reached the conclusion that it seems most reasonable to regard the fauna of the Carbonic of Pennsylvania " as a natural assemblage of species selected and modified by a habitat, if not in strictly marine, at least not in strictly fresh waters."

There is, however, clear evidence at hand of the fresh-water habitat of the Carbonic eurypterids in other regions. One of these is the occurrence of E u r y p t e r u s (A d e l o p h t h a l m u s) g r a n o s u s Jordan in the coal measures of Saarbrücken. That basin was formed in the interior of a continent and never reached by the sea.[3] In other coal basins, notably those of England[4] the gradual freshening of the lagoons and the disappearance of such marine types as Lingula and Orbiculoidea, which are frequent in the lower coal measures, has been clearly recognized. It is only in the upper measures that the eurypterids occur, there in association with ostracods, phyllopods and schizopod crustaceans. Woodward [1879,

[1] Frech. Lethaea Geognostica. 1899, pt 1, v. 2, no. 2, p. 270.

[2] Jour. Geol. 1909. 17:309.

[3] Frech. op. cit. p. 270.

[4] Geikie, Text-book of Geology. 2:1031.

p. 198] makes a positive statement that the Carbonic E u r y p t e r u s
s c o u l e r i is a fresh-water form, basing his conclusion on the character
of the rocks and the associated flora and fauna.

There seems hence little doubt that the eurypterids of the Carbonic
finally abandoned the sea and entered the fresh water. Directly thereafter,
in the Permic they became extinct, the last of the race being the E u r y p -
t e r u s   d o u v i l l e i   de Lima, found in the Rotliegende of Portugal
associated with W a l c h i a   p i n n i f o r m i s and S p h e n o p h y l -
l u m   t h o r n i .

Summarizing these data we conclude that the eurypterids lived in the
sea from Cambric to Siluric time. They had then become less sensitive
to changes, positive and negative, in the salinity of the water. In fact
they seem to have thrived best under conditions of life that exclude most
other marine groups of animals, that is, in the marginal, more or less
inclosed marine lagoons, accompanied by estuaries receiving delta-forming
terrestrial drainage, with prevailing arid or subarid climate, the waters
being in some places more than normally briny, in others having less than
normal salinity. In other words they were *euryhaline* or able to live in
both salt and brackish water.

Their adaptation to such conditions is paralleled today by such crus-
taceans as Apus and Artemia which not only thrive under rapid diminution
of normal salinity but, by means of strongly protected eggs, even survive
salt pan conditions which end in complete desiccation, as shown by their
well known occurrence in desert lakes. The usual associates of the Siluric
eurypterids are peculiar crustaceans whose nature emphasizes the reference
above made. They are phyllocarids and ostracods and members of the
strange family Hemiaspidae (Neolimulus, Bunodes, Hemiaspis, Pseudonis-
cus). This congeries of peculiar crustaceans seems to constitute a fauna
especially adapted to, and therefore highly characteristic of, lagoon and
estuary conditions.

Thus while the earlier eurypterids were marine and their climacteric
fauna euryhaline; their later habit throughout the Devonic and Carbonic
led them finally into the fresh water.

The succession of habitats is hence, according to our evidence, the reverse of that suggested by Chamberlin's hypothesis noted at the beginning of this discussion.[1]

The cause of the withdrawal from the sea of these well armed and often gigantic eurypterids into the brackish and fresh water is a problem of much interest. Perhaps the development of the more agile and more advanced fishes put these slow and archaic merostomes on the defensive and finally forced them altogether out of the sea. Their association with clumsy and heavily armed, equally archaic Old Red fishes which clearly suffered a like fate from their own more advanced relatives, would seem to be very suggestive in this connection.

It may be mentioned that even the gigantism of these arachnids, as typified by Stylonurus excelsior, is probably an indication of race degeneracy, as gigantism is generally, and as such is also suggestive of their increasing failure to cope with the conditions of marine life.

IV

ONTOGENY

The collections from the shale beds of the Shawangunk grit at Otisville have furnished an unrivaled series of larval stages of one species each of the genera Eurypterus, Pterygotus, Stylonurus and Hughmilleria. Many of the growth stages measure but 2 millimeters or even less in length and hence so little surpass in size the eggs[2] of Limulus and probably

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[1] Another consideration which antagonizes that hypothesis is the fact that the brackish fauna, small as it is, as a rule is composed of species which entered the brackish zone from the sea and not by such as descended from the fresh-water lakes and the rivers. This has been shown by Walther [Einleitung in die Geologie als historische Wissenschaft. 1894. 1 Theil. Bionomie des Meeres] to be especially true of the mollusks and crustaceans.

[2] Henry Woodward described and figured [1872, p. 79, pl. 16, fig. 10, 11] as egg packets (Parka decipiens) of Pterygotus ludensis, masses of small, oval carbonaceous bodies of frequent occurrence in the basal Old Red sandstone. Dawson and Penhallow [1891] after a careful study of these bodies, concluded that they are sporocarps, filled with sporangia, of an aquatic plant. The Bertie waterlime and the shale layers of the Shawangunk grit have both furnished circular to oval carbonaceous bodies that suggest or are comparable to the eggs of Limulus.

those of E u r y p t e r u s   l a c u s t r i s and Pterygotus that they may be safely considered as representing the first larval or nepionic stage.   Our large amount of material has allowed us to connect these larval stages with the adult forms by a fairly continuous series.   There have also been obtained at Buffalo and Jerusalem hill youthful stages of E u r y p t e r u s   r e m i p e s , E . l a c u s t r i s , P t e r y g o t u s   m a c r o p h t h a l m u s and E u s a r c u s   s c o r p i o n i s which present characters indicating their neanic condition.

All these young individuals have a number of characters in common which distinguish them from the adults and for this reason may be considered as ontogenetic characters of larger scope.   We here briefly summarize these general ontogenetic features from lists of specific ontogenetic characters taken from the detailed descriptions of the development given under the respective species.

Eurypterus remipes [pl. 4, fig. 1-4; pl. 5,   fig. 1, 2]

The neanic stage is distinguished from the mature by

1   Larger, less quadratic carapace
2   Larger, more anteriorly situated compound eyes
3   Larger and more prominent ocellar mound
4   Larger swimming feet
5   Possibly a more compact, more rapidly contracting preabdomen

E. lacustris

Neanic stage [pl. 11, fig. 1]

1   Larger size of compound eyes
2   Possibly more compact form of preabdomen

E. maria

Nepionic and neanic stages [pl. 21, fig. 1-11]

1   Excessively short and wide, subtriangular carapace
2   Very large, anteriorly situated diverging compound eyes
3   Rapid contraction of abdomen
4   Short, wide preabdominal segments
5   Larger swimming feet

Eusarcus scorpionis

Neanic stage [pl. 36, fig. 1]

  1 Wider preabdomen
  2 Wider postabdomen

Eusarcus (?) cicerops

Nepionic stage [pl. 36, fig. 9]

  1 Carapace triangular with

      a Spinelike prolongations of frontal and genal angles
      b Immense, diverging eyes
      c High median crest or glabella
      d Broad, thick border

Pterygotus macrophthalmus

Neanic stage [pl. 69, fig. 3, 5]

  1 Larger compound eyes
  2 Larger ocelli and more prominent ocellar mound
  3 More rapid contraction of preabdomen
  4 Larger swimming feet
  5 More spatulate telson

Pterygotus globiceps

Nepionic and neanic stages [pl. 81, fig. 1-5]

  1 Very large carapace and very small abdomen
  2 Smaller number of abdominal segments

    The larval eyes are in this form relatively not larger than in the adult, but provided with a prominent ring (orbital ridge)

Hughmilleria shawangunk

Nepionic and neanic stages [pl. 64, fig. 1-13]

  1 Larger (longer and broader) carapace
  2 Much larger compound eyes
  3 Larger and more prominent ocellar mound
  4 More slender abdomen
  5 Smaller number of (preabdominal) segments

Stylonurus myops

Nepionic and neanic stages [pl. 51, fig. 1-13]

1 Larger carapace
2 Broad, flat border of carapace
3 Distinct glabella
4 Larger eyes (very large ocular nodes)
5 Eyes nearer to margin
6 Segments not differentiated
7 Smaller number of segments
8 Smaller telson
9 No distinct ornamentation

These lists of ontogenetic characters permit the following general inferences:

1 *The carapace is relatively larger in the larval stages; often very much so.* This is especially marked in the representatives of Pterygotus, Hughmilleria and Stylonurus. It is also recognizable in the young of E . r e m i p e s ; the few young specimens of E . l a c u s t r i s are also suggestive of a larger size of the carapace but not conclusively so, since the preabdomen of the specimens·is probably accidentally contracted. In E . m a r i a the carapace is distinctly shorter and wider than in the mature stage. This is in accordance with the entire character of this larval stage which in its broad carapace and broad short preabdomen, anterior divergent eyes and rapid contraction of the preabdomen distinctly exhibits the characters of the genus Eusarcus. The young carapace of E . s c o r - p i o n i s indicates no relatively larger size although the single individual available may be already too far advanced to still exhibit this difference in size.

The shieldlike character of the carapace is sometimes still emphasized by a broad flat margin, as in Stylonurus and E u s a r c u s (?) c i c e r o p s .

2 *The compound eyes are relatively much larger than in the mature stage;* and sometimes borne on more prominent ocular nodes. The larger

size of the compound eyes is a prominent feature of all very young stages here investigated and seems to be a general ontogenetic character. In one species, P t e r y g o t u s   g l o b i c e p s , the eyes are not notably larger than in the ephebic individual, but in this case they are very large at maturity and obviously a retained larval character. In E u r y p t e r u s   m a r i a ,   P t e r y g o t u s   m a c r o p h t h a l m u s   and   H u g h m i l - l e r i a   s h a w a n g u n k   the difference in size is especially notable. In S t y l o n u r u s   m y o p s   the visual area exhibits little difference in relative size, but the ocular nodes are so extended that they occupy nearly the entire dorsal side of the carapace within the flat border.

3 *The compound eyes are nearer to the margin;* either the anterior margin (Eurypterus), or the lateral (S t y l o n u r u s   m y o p s). In Pterygotus and Hughmilleria they are already marginal in the nepionic stage and remain so to the ephebic stage.

4 *The ocellar mound or tumescence exhibits a distinct tendency to both larger size and greater prominence in the earlier growth stages than in the adult.* This ontogenetic feature has been especially noted in E u r y p t e r u s   r e m i p e s ,   E .   m a r i a ,   P t e r y g o t u s   m a c r o p h t h a l m u s   and   H u g h m i l l e r i a   s h a w a n g u n k . There is also evidence that the ocelli themselves are relatively larger.

5 *The swimming legs are, as a rule, larger.* This has been noted in E u r y p t e r u s   r e m i p e s ,   E .   m a r i a   and   P t e r y g o t u s   b u f - f a l o e n s i s . The great majority of all larval individuals have lost the appendages. The specimen reproduced on plate 21, figure 5, shows the relative great size and width of the swimming legs in E .   m a r i a .

Of much interest in this connection is a larval specimen of S t y l o - n u r u s   m y o p s   exhibiting the metastoma in fine preservation [pl. 51, fig. 6]. The latter is of immense size, almost equaling the carapace in length. As the metastoma is correlated in size to the coxae of the swimming legs it would follow that the latter must have been enormously developed in this species and the larvae highly agile. The probable activity of the larvae is further suggested by the enormously bulging eyes.

6 *The abdomen lacks distinct differentiation into pre- and postabdomen.* This condition is made clear by the nearly uniform length of all segments. In width there prevails considerable difference, most early growth stages appearing to contract more rapidly than the mature individuals, while in Hughmilleria the body is distinctly more slender [pl. 64, fig. 1]. In E u r y p t e r u s   r e m i p e s ,   E .   l a c u s t r i s   and especially in E.   m a r i a ,   as well as in   P t e r y g o t u s   b u f f a l o e n s i s   there is evidence of a relatively broader and shorter preabdomen, although the more compact appearance of the preabdomen may be partly due to casual contraction after death.

7 *The number of segments is less in the nepionic stage than in the following stages.* In some nepionic individuals there are not more than six segments or half the number normal to the adult [*see*   S t y l o n u r u s   m y o p s ,   pl. 51, fig. 1]. On account of the smallness of the earliest growth stages and the lack of differentiation of the segments we have not been able to satisfy ourselves as to whether the preabdomen or the postabdomen is first completed. The larva of   H u g h m i l l e r i a   s h a w a n -   g u n k   [pl. 64, fig. 1] where a distinct preabdomen with four segments and a postabdomen of six segments are noticeable, and some other specimens, suggest that the latter was first completed.

8 The telson spine may have been less developed than in adults; at least such a condition is indicated by several specimens. Unfortunately and singularly the telson is nearly always missing in young specimens. In the embryo of Limulus there is no tail spine and in the larval stage the telson is small.

It is now interesting to inquire which of these ontogenetic characters are purely larval acquisitions, and which are palingenetic, or of phylogenetic significance as representing the recapitulation of ancestral characters. Comparison with the larval stages of Limulus has been of much assistance in discerning between these coenogenetic and palingenetic structures.

The larger size of the carapace we consider as a merely larval character, for the following reasons: This larger size is principally due to the

lack of development of the abdomen in the earlier stages and corresponds to a like antecedence in development of the cephalothorax in Limulus especially manifest in the embryological stages. From geological evidence and theoretical reasons, just the reverse is to be postulated in the phylogeny of the eurypterids, i.e. an earlier weaker development of the cephalothorax. The greater size of the carapace in such trilobites as Harpes is considered as a larval character retained to maturity, but this is no evidence of the primitive character of the genus. Likewise eurypterids with large carapaces, as certain species of Eurypterus, are not at all to be considered as primitive. The philosophy and phylogeny of the arthropods agree in postulating a gradual growth and consolidation of a greater number of segments into the cephalothorax. The smaller cephalothorax is therefore to be considered as the more primitive and the evidence from such euryp-terids as the Cambric Strabops and the simpler species of Eurypterus, is not contradictory to this conclusion. Altogether the remarkably small size of the cephalothorax of the eurypterids in comparison with the abdomen is to be considered as one of their most striking primitive characters.

The larger size of the larval eyes is regarded by us as a larval char-acter without phylogenetic significance. It finds its striking analogy in the megalops stage of the crustaceans, well shown in the common crab Callinectes [see text fig. 23]. In this stage the eyes are not only of excessive size, but also situated at the ends of very movable stalks. In the larvae of the euryp-terids the lateral eyes were not only of large size but also borne on very high and large ocular nodes (particularly well shown in Stylonurus myops), giving them a like prominence. None of these features is observable in either the larvae of Limulus or of the scorpion and we have probably to regard them as larval features peculiar to the young of the eurypterids.
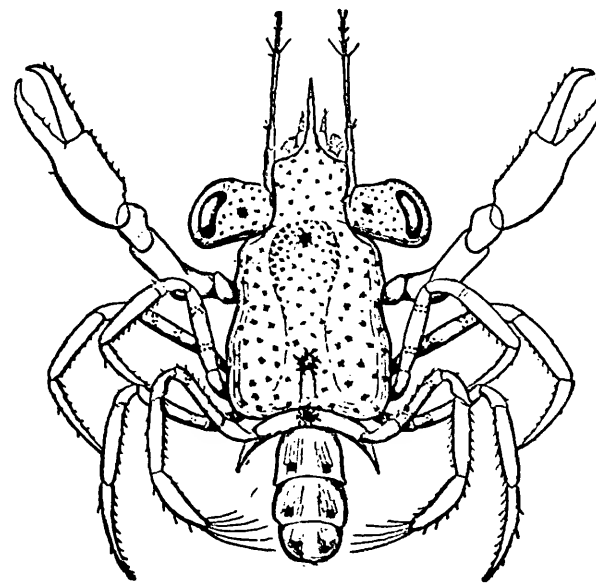

Figure 23   Megalops-stage of the common crab (Callinectes hastatus). (From Brooks)

The closer approximation of the lateral eyes to the margins in the young than in the adult eurypterids is a feature shared to some extent by young Limuli and still more distinctly shown by the embryo of the scorpion [Laurie, 1890, pl. 17, fig. 45]. In Limulus the lateral eyes and ocelli are placed on distinct ridges, termed by Packard [1870, p. 168] the ophthalmic ridges, which separate the cardio-ophthalmic region from the lateral regions of the carapace. These ridges are most prominent in the larva and become obscured in the adult. They are faintly seen in the later embryonic stages and are there distinctly farther away from the median line of the carapace. The ocelli appear first on the under side of the head [Packard, p. 168] just in advance of the chelicerae and in later embryonic life wander to the upper side.

Strabops of the Cambric has the lateral eyes in about the position where they are seen in nearly all our larval eurypterids; E. m e g a l o p s (Frankfort) and the Clinton E . p r o m i n e n s as well as the primitive Hughmilleria also have submarginal eyes, and we see in this approximation of the eyes to the margin a palingenetic feature which probably points to ancestors with submarginal eyes. In the Frankfort Lower Siluric fauna taken as a whole, the eyes are nearer the margin, a noteworthy fact in this connection. The genera Pterygotus, Slimonia and Eusarcus make a nearer approach to the primitive condition in this respect than Stylonurus and those species of Eurypterus with approximate eyes high up on the carapace. A comparison in point is afforded by the trilobites, in which, according to Beecher's excellent investigations, the eyes appear on the under side in both the ontogenetic and phylogenetic development.

The prominence and great size of the ocellar mound in the larvae of the eurypterids are fully in consonance in function with the early appearance and relative great size of the ocelli or " larval eyes " in the embryo and larva of Limulus and the great size of the central eye in the scorpion. There is no direct evidence to indicate that the prominence of the ocellar mound is of any other than larval or coenogenetic character.

In the primitive trilobite Harpes the ocelli remain functional through life and no compound eyes are developed; we may infer that the early appearance and strong development of the ocelli in the larvae of both Limulus and the scorpion are, in view of their retention in later life, with diminished force, rather suggestive of their having been the first eyes of the ancestral forms.

As the swimming legs are clearly a secondary acquirement their larger size and probably that of the other legs also, is a purely larval feature in
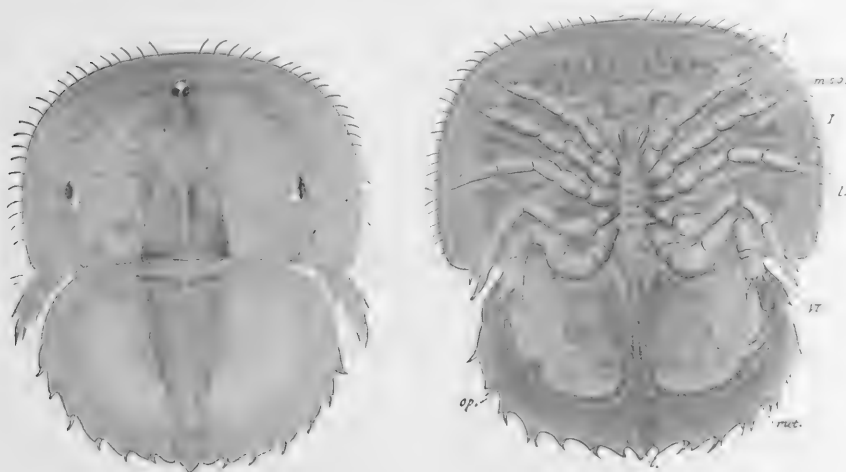
Figure 24 Dorsal and ventral views of last larval stage of Limulus before the appearance of the telson. *l*, liver tubule; *I*, chelicera; *op*, operculum. (From Kingsley)

line with the greater size of the lateral eyes, both of these being coenogenetic larval characters developed in connection with the greater agility of the larva. The larvae of Limulus [*see* text fig. 24] possess relatively longer legs than the adults, and this is especially notable in the last pair that projects considerably beyond the carapace. A still better analogy is found in the lively megalops stage of the crab [*see* text fig. 23] where immense eyes and long legs are correlated features.

The lack of differentiation of the preabdominal and postabdominal segments is likewise shown in the embryo and larva of Limulus, while in that of the scorpion the two regions are distinguishable almost as soon as segmentation sets in, obviously owing to the very pronounced differentiation between the broad preabdomen and the narrow taillike postabdomen in the adult. In the Cambric Strabops there is less differentiation· observable between the two abdominal regions than in any later eurypterid and the more primitive of these later forms distinguish themselves by a more uniform and gradual contraction of the abdomen. It is a wholly proper assumption that the undifferentiated condition is the more primitive. The lack of differentiation of the abdomen in the larvae is hence to be interpreted as an inherited palingenetic feature.

The smaller number of segments in the nepionic stage is, for theoretical and observational reasons, to be considered as a purely larval feature incidental to the growth of the organism. The Cambric Strabops possesses the same number of segments as the Upper Siluric or Carbonic eurypterids and if any change in the number of segments in the development of the higher Arthropoda has taken place, it has generally been a reduction. The trilobites with the smaller number of segments in the immature stages and the greater number of segments in mature conditions of the earlier and more primitive species such as Paradoxides and Harpes, furnish an excellent analogy.

The smaller size of the telson is in accordance with the ontogeny of Limulus and is manifestly a palingenetic character indicating the primitive condition. This view is supported by the short, blunt telson of Strabops and the primitive later eurypterids, such as Hughmilleria.

In summing up the larval characters observed in these immature eurypterids we consider as coenogenetic or purely larval the relatively larger size of the carapace, of the compound eyes and of the swimming legs, and the smaller number of the abdominal segments; as palingenetic and phylogenetic, the approximation of the compound eyes to the margin, the prominence of the ocelli and their tumescences, the lack of differ-

entiation of the abdomen and the smaller size of the telson. In these palingenetic characters the nepionic stage resembles so much the Cambric Strabops, that we shall designate this as the *Strabops stage*. We shall use these characters in the reconstruction of the primitive ancestor of the eurypterids in the next chapter and the discussion of their taxonomic position.

In reference to this taxonomic position it may be stated here that the ontogeny of the eurypterids fully corresponds to that of Limulus in lacking any indication of a nauplius or zoea stage; that the larvae of the eurypterids (nepionic stage) have in common with that of Limulus:

1 The large size of the carapace

2 The broad border of the latter (in S t y l o n u r u s m y o p s)

3 The prominent cardiac region of the carapace, giving it a trilobate character (in S t y l o n u r u s m y o p s, E u s a r - c u s (?) c i c e r o p s, P t e r y g o t u s g l o b i c e p s)

4 The lack of differentiation of the abdominal segments

5 The undeveloped telson.

They differ from it in:

1 The terete abdomen

2 Megaloptic development of the lateral eyes, and

3 Their nearer approach to the margin

4 Having but nine abdominal segments, while Limulus is hatched with the full number of segments.

The meaning of these agreements and differences in the development of the eurypterids is discussed more advantageously in the chapter on the taxonomic relations of the eurypterids where also the ontogeny of the eurypterids is compared with that of the scorpion.

V

PHYLOGENY

Since the date of Laurie's commentary on the relations of the eurypterids among themselves [1893, p. 520], two important lines of evidence have been obtained bearing on the genetic relationships of the genera.   One is afforded by the growth stages of the principal genera, collected at Otis-·ville, the other by Strabops of the Cambric.   In the preceding chapter we have analyzed the ontogenetic characters and have fixed upon a small number of these that may, with a fair degree of certainty, be considered as recapitulations from eurypterid ancestry.   As these characters are actually expressed in Strabops, it seems safe to use the two sets of facts for a conception of the prototype of the eurypterids, and to proceed from this prototype in tracing genetic relationships.   Aside from our knowledge of the one Cambric genus, the geologic succession of the genera is of little aid in the problems before us, since nearly all genera seem to be present in the Lower Siluric.

In the preceding chapter we have recognized as palingenetic characters of the larval eurypterids the approximation of the compound eyes to the margin, the prominence of the ocelli and their tumescences, the lack of differentiation of the abdominal segments and the smaller size of the telson.   All of these characters, save the prominence of the ocelli, are typically shown in S t r a b o p s t h a c h e r i , or the Strabops stage.

While the characteristics of this stage will be the basis of our reconstruction of the prototype, others may be safely inferred from a comparison of Strabops with the general characters of the Siluric eurypterids and from theories of the development of the arthropods in general.

In Strabops the carapace [pl. 1] is short, and a little less wide. than the greatest width of the body.   It is so in most of the later eurypterids, notably in Eurypterus, Hughmilleria and Pterygotus.   The eurypterid carapace has been formed by the consolidation of six segments, and a priori it should not be longer than six of them.   As a matter of fact it approximately corresponds, as a rule, to the five first tergites in length, suggesting a condensation.   This it does also in Strabops and since the segments in that form are all remarkably short, the carapace is much
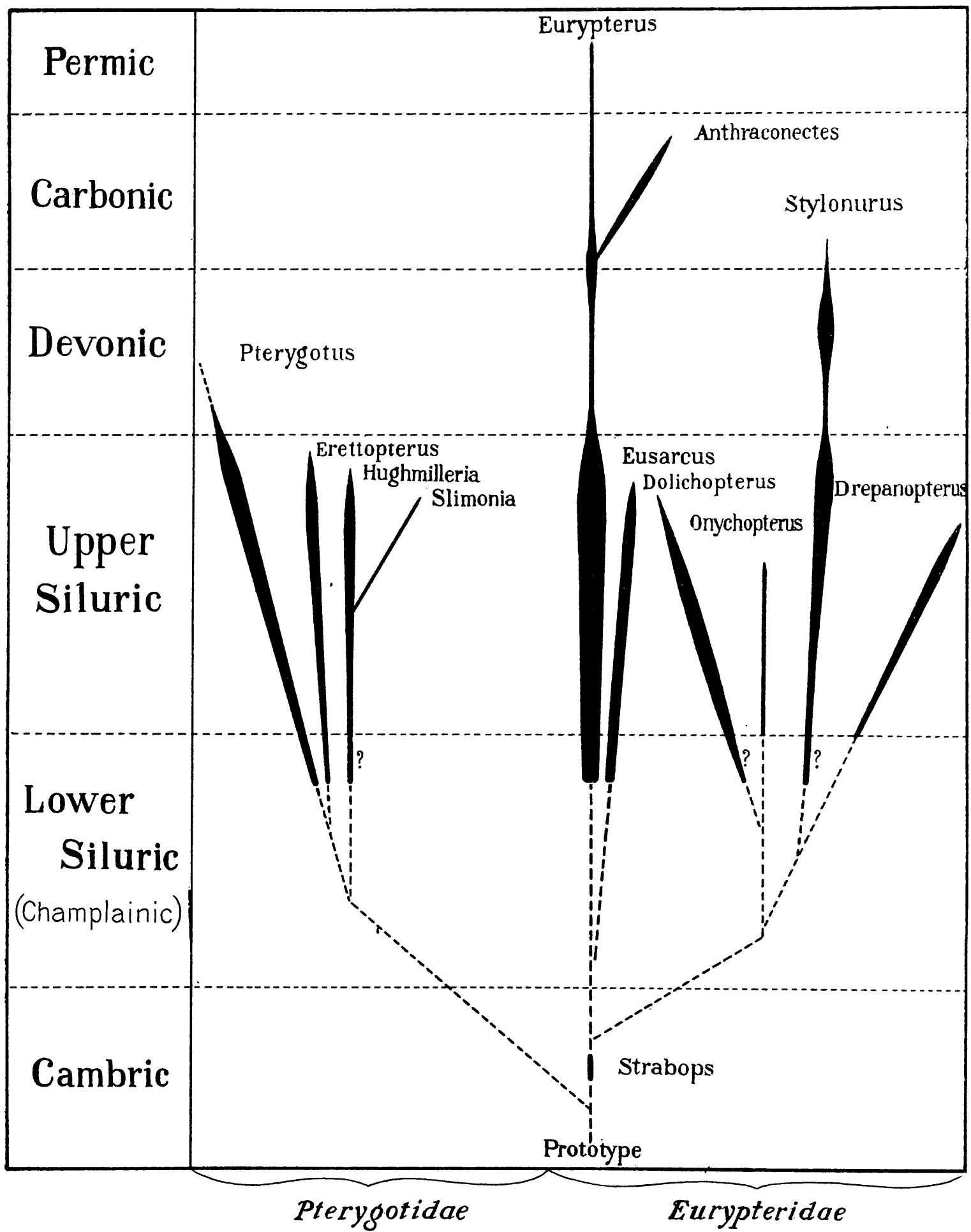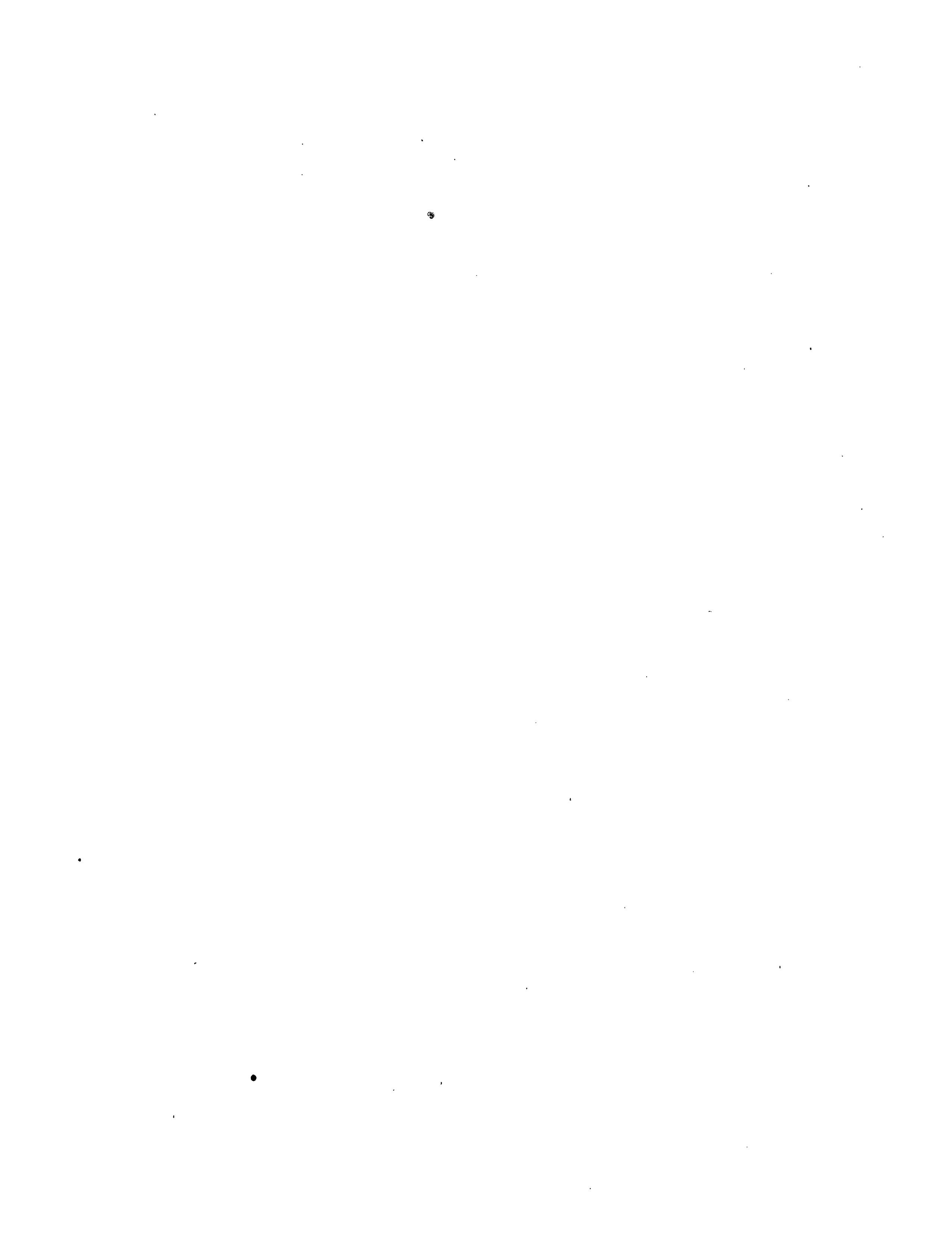
Diagram of the phylogeny and geological distribution of the genera of eurypterids

shorter than wide. In all eurypterids the preabdominal segments are greatly wider than long and it is hence safe to infer that the carapace also was originally wider than long, and to assume for the prototype a small, short carapace of the width of the preabdomen.

In one section of the eurypterids the lateral eyes are marginal and faceted, and in the other situated on the dorsal surface and smooth. It is important to determine which of the two forms of eyes is the more primitive. Laurie has argued in favor of the eyes of Pterygotus, representing the first group, basing his view on a comparison with the trilobites (on the assumption that the eurypterids are derived from the trilobites), the Scorpionidae and Thelyphonidae, "which must be derived from some way down the eurypterid stem." The Lower Siluric fauna is constituted of species with submarginal eyes and this fact seems to favor Laurie's view.

It is a proper assumption that the appendages of the prototype were undifferentiated. Those of Strabops are unknown with the exception of two segments of the last pair which indicate a primitive form of appendage, and eurypterid larvae have also failed to afford any conclusive evidence bearing on this point. The Siluric genera all exhibit far-reaching differentiation in the legs; this manifests itself especially in the last pair which has been variously transformed either into broad and strong paddles or excessively lengthened; the preoral appendages have been developed into enormous pincers in at least one genus, Pterygotus, but the four pairs of walking legs which lie between these extremes have remained relatively simple in construction, especially so in Pterygotus where all four are alike, rather slender and without spines. Laurie has regarded the simple character of the Pterygotus legs as an argument in favor of the primitive character of the genus. While we do not share this view we agree as to the manifest primitiveness of these four pairs of legs and therefore assign such appendages to the prototype.[1] In Eurypterus the fourth pair has also

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[1] Laurie has also advanced as a point in favor of the primitive condition of Pterygotus "the apparently much greater development of the epicoxite—a structure common to the eurypterids, Limulus and Scorpion, and therefore probably primitive—in Pterygotus than in the other genera" [*op cit* p. 521]. The evidence in regard to Eurypterus since obtained by Holm shows that the epicoxite is as strongly developed as in Pterygotus.

retained its primitive character; and while the legs are of uniform length in Pterygotus, in all other eurypterids, mature and adolescent [E. r e m i p e s, pl. 2], they form a series that is longer backward.[1] It is therefore to be concluded that, even if the legs were originally of uniform length, a differentiation in length took place very early. The relatively great length of the few segments observed in Strabops indicates that the last pair of legs, had attained considerable length and that the differentiation had already commenced in the Cambric. We have accordingly restored Strabops with a series of gradually lengthening slender, nearly spineless legs and would provide the prototype with a similar only more uniformly long series of legs.[2]

The chelicerae, or preoral appendages, are of identical structure in all—only excessively enlarged in Pterygotus—and therefore not available for inferences as to the prototype except that it had them as seen in the majority of the forms.

The opercular appendages have not been observed in either the larvae or in Strabops and are therefore useless for the present inquiry. Laurie has suggested that the median lobe of the genital operculum in Pterygotus shows a less degree of development than in Slimonia and Eurypterus, but

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[1] Eusarcus makes a partial exception, inasmuch as the second pair is the longest and the following legs are successively shorter; but as the first pair of legs is the shortest, it is obvious that this reversal is a secondary modification.

[2] In order to get a transitional form from the eurypterids to the larval Ammocoetes, Gaskell [*Origin of Vertebrates*, p. 242] has " made the four endognaths small, mere tentacles in recognition of the character of these appendages in Eurypterus " [*see* text fig. 16]. While it is admissible to assume the possibility of such reduction of the endognaths for purposes of a hypothetical phylogeny, the fact should not be lost sight of that we have no evidence whatever of any tendency among the eurypterids toward a suppression of these appendages to mere tentacles, but on the contrary it is very clear that in all branches there is a progressive lengthening and development of the legs, with the exception of Pterygotus where 4 pairs remain primitive, but without reduction. The growth in relative size is most notable in the Stylonurus branch, but is observable in the central Eurypterus stock as late as Carbonic time. Gaskell's figure and description must then have reference to a divergent, early branch of the eurypterids, whose existence is quite unknown.

qualifies his suggestion by admitting that the details of this structure are hardly sufficiently known to admit of our attaching very much morphological value to it. Hughmilleria exhibits the same type of opercular appendage as Pterygotus but is in all other respects a more primitive form than the latter. The evidence from both Hughmilleria and the appendages of such forms as P . a n g l i c u s indicates that the development of the organ in question has taken a different course in the Pterygotus and Eurypterus branches.

We have observed no facts in either ontogeny or in Strabops that would seem to indicate the date of the development of the genital operculum. Laurie [*op. cit.* p. 525] has argued that both Limulus and the scorpions came off from the eurypterid stem before the great development of the genital operculum, because in Limulus an appendage of the second abdominal segment is present which has become reduced in the eurypterids and in the scorpions the second segment is well developed. The scorpions have, however, not been traced farther back than the Siluric, and Limulus not even so far. Thus they leave us in doubt as to the date of the suppression of the second body segment in the eurypterids, but it is obviously safe to assume that it had already taken place in Strabops in view of the typical development of all other eurypterid characteristics in that early genus.

The abdomen of the prototype of the eurypterids was more or less terete, contracting gradually and thereby lacking the distinct differentiation on dorsal view into preabdominal and postabdominal regions by any abrupt constriction at the posterior end of the preabdomen. This is evidenced by both the adult Strabops and the larvae of the Siluric genera. The segments were of nearly equal length, lacking the marked lengthening of the caudal part of the body which finds its extreme in Eusarcus. The number of the segments was already fixed in the Cambric progenitors, Strabops having six tergites and six postabdominal segments. The larvae of the Siluric genera have less in the nepionic stage but soon reach the full complement, thus attesting in their ontogeny the early fixation of the number of segments in their phylogeny.

The telson exhibits two very distinct lines of development. It is lanceolate in most genera, notably Eurypterus, Dolichopterus, Eusarcus and Hughmilleria, becoming in extreme cases styliform, as in the Stylonuri and some of the earlier Eurypteri and the later Anthraconectes; then again it is broad and bilobed in the subgenus Erettopterus. Laurie leaves the question open as to which style of telson is the more primitive, the geological succession having given him no clue. He suggests, however, that as the pointed telson is characteristic of the earlier trilobites, it also is of the eurypterids. Our investigation supports this suggestion. Strabops possesses a short and blunt pointed telson which fully corresponds with the telson of the Siluric larvae, indicating that this is the primitive form of that organ. The primitive Hughmilleria possesses a similar telson, though it already exhibits a tendency to a broadening and flattening of the proximal portion. Slimonia has this tendency still more developed, so that the telson appears as lanceolate with winglike lateral extensions of the anterior half. A reduction of the posterior spine may then be conceived to produce the telson of Pterygotus, and a further suppression of the axial lanceolate portion would lead to the bilobed telson of Erettopterus. The telson of Hughmilleria, Slimonia, Pterygotus and Erettopterus thus seems to present a continuous series of developmental stages, and the pointed or bluntly lanceolate-triangular form to be that of the prototype of the eurypterids.[1]

Genealogy. In the preceding reconstruction of the prototype we have indicated our views of the genetic relationships of some of the genera,

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[1] The remarkable observations of Walcott on the trilobites of the Mesonacidae [Smithsonian Miscell. Coll. 1910, v. 53, no. 6] show that the telson of Olenellus is not a true pygidium but originates from a median spine of an earlier segment by the suppression of posterior segments which are still present in the genera Mesonacis and Paedeumias. The fact that the telson of Olenellus resembles that of Limulus has suggested to Walcott the view [p. 246] that while this resemblance does not necessarily indicate that Olenellus was the ancestor of Limulus, " its origin does indicate the manner in which the telson of Limulus may have originated."

The possibility of such origin for the telson of Limulus and the eurypterids is

and will now proceed to trace the development of the different branches of eurypterids upward from this prototype as expressed in the appended genealogical tree.

Strabops is such a generalized type that it is eminently fitted to serve as prototype; since it is the earliest eurypterid known it may be an actual progenitor of most Siluric forms. Its relatively great width will be disregarded here as not characteristic of the prototype. It suggests that Strabops is already nearer to the Eurypterus than to the Pterygotus stock.

The Siluric and later genera of the eurypterids distinctly fall into two groups or stocks, namely, that of Pterygotus and that of Eurypterus. The former group (Hughmilleria, Slimonia, Pterygotus, Erettopterus) is principally distinguished by the marginal, faceted eyes; the latter, containing the genera Eurypterus, Dolichopterus, Echinognathus(?), Eusarcus, Drepanopterus and Stylonurus, by the smooth, intramarginal or dorsal eyes. There are many differences in the two which indicate that they separated early and developed as independent stocks. We have, therefore, here separated the Pterygotidae from the Eurypteridae.

First in regard to the *Pterygotidae:* We have elsewhere analyzed the genetic relationship of Hughmilleria to Pterygotus and Slimonia as shown by the position and character of the lateral eyes, the larger chelicerae, the genital appendage and the telson, and have intimated that in the characters of these organs Hughmilleria clearly evinces a more primitive structure than the other two genera. This view is further supported by the more slender form of the abdomen and the shape of the carapace; the latter while more elongate than that of Pterygotus exhibits a distinct

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extremely interesting but we have thus far not become aware of facts, in either the ontogeny of the eurypterids or of Limulus and the scorpions, that would suggest such mode of origin of the eurypterid telson spine; indeed the absence of median spines on the dorsal segments of any eurypterids as well as the very early fixation of the number of segments in the Eurypterida, contrast to the variability of these features in the trilobites and militate against the probability of the origin suggested.

approximation to it in outline. The close relationship of Hughmilleria to Pterygotus is further evinced by the small size of the swimming legs and the form of the metastoma. The endognathites of the two differ, those of Hughmilleria and of the Eurypteridae being spinous, stout and increasing in length backward. The endognathites of Slimonia, except the antenniform first pair, differ similarly from those of Pterygotus, and both Hughmilleria and Slimonia lack the immense development of the chelicerae of Pterygotus, and we believe that the endognathites of these two genera have assumed these characters in order to perform a part of the functions of the chelicerae of Pterygotus and so served as organs of offense and defense, while those of Pterygotus remained undeveloped, being overshadowed by the great chelicerae. As a corollary we may assume that the earlier Hughmilleriae approached Pterygotus in the character of their endognathites.

The genetic relationship between the three genera of the Pterygotidae we conceive as shown in the genealogical tree. An unknown series of forms branched off from the prototype in Cambric time and led in late Lower Siluric time to Hughmilleria. From this was developed on one side Pterygotus proper which again produced the subgenus Erettopterus with bilobed telson, and on the other side Slimonia, which retained the small chelicerae but specialized in developing the second pair of appendages for a tactile function, in the greater development of the opercular or genital appendage, the peculiar exaggerated spinosity of the other endognathites, the lobed and lanceolate telson and other features. Slimonia, represented by but a single species, has all the features of a local and aberrant type.

The *Eurypteridae* are represented by the far larger stock. Strabops points the course the development of that stock took from the prototype through the Lower Siluric. From the latter era we have only the endognathites on which the genera Echinognathus and Megalograptus are based. These clearly represent another aberrant branch which, judging from the character of the multispinous endognathite, ends here, is independent or may lead to Stylonurus (Ctenopterus).
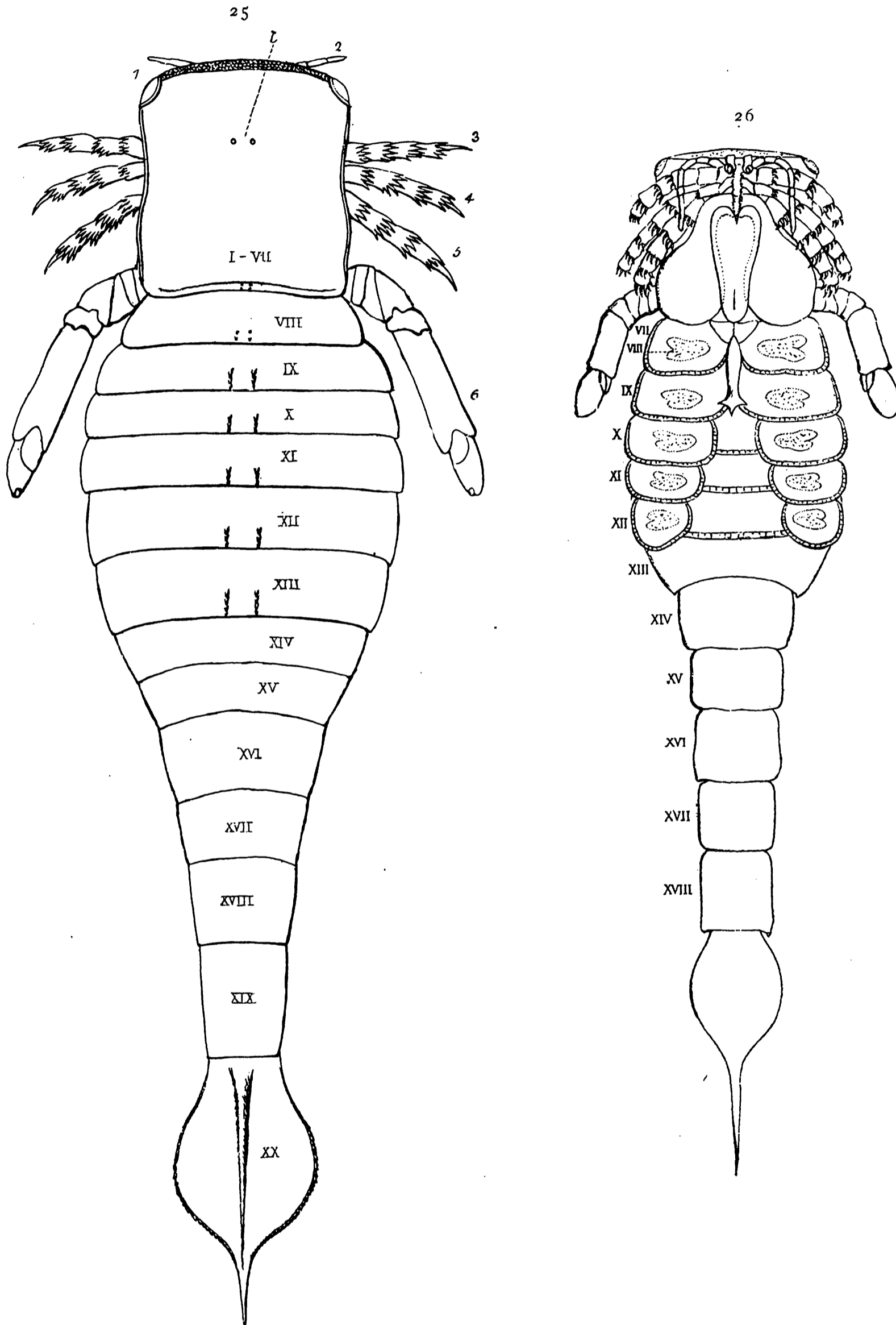
Figures 25, 26 Slimonia acuminata (Salter)

Figure 25 Dorsal view. (From Woodward)   Figure 26 Ventral view. (From Laurie)

The main stem of the family Eurypteridae is formed by the genus Eurypterus, whose earliest form seems to appear in the Lower Siluric (Frankfort shale) and it persists into the Permic without materially changing. Corresponding to the vigor shown by its longevity is the great preponderance of its individuals and the number of species it has produced. Among the latter very different stages of progress are found. Some have clearly progressed but little, as shown by their terete, undifferentiated abdomen, short blunt telson and short swimming legs. Such forms are E. maria Clarke, E. pygmaeus Woodward and E. minor Laurie. The form and small size of all these suggest an immature condition or an arrested development. This is emphatically true of the peculiar type for which Laurie [1899, p. 588] has proposed the genus Bembycosoma which has a semicircular carapace and a short, conical body, stout, short telson and apparently but nine abdominal segments. This form, represented by a single species, resembles nothing more than our eurypterid larvae from Otisville and it is very possible that these and some other primitive-looking small species of Eurypterus are cases analogous to those occurring among the recent crustaceans where development has been arrested by parasites which prevent molting and result in dwarfed adults retaining larval characters.

One species of Eurypterus, viz, E. kokomoensis [pl. 25, fig. 1] is of special phylogenetic interest as pointing the way which has led from Eurypterus to Dolichopterus, Drepanopterus and Stylonurus. These genera form a group by themselves, well defined by a number of peculiar characters, the most important of which are the great lengthening of the legs, especially of the last pair; the slender body without distinct differentiation of preabdomen and postabdomen and the slender, styliform telson. Connected with the enlargement of the cephalothoracic appendages is that of the carapace which is relatively longer than in all other eurypterids, shows a distinct tendency to become squarish, and develops a broad border. Likewise the greater development of the legs affects the metastoma which in all these genera is very long and subrectangular with deep

frontal emargination. The ninth segment of the fifth pair is not rudimentary as in Eurypterus but fully developed. The epimeral pieces of the post-abdominal segments are more prominent than in the other groups of genera.

Eurypterus kokomoensis possesses all these characters in an initial condition. While it still has the swimming legs of an Euryp-terus, they are longer and slenderer than in other Eurypteri and the ninth segment has grown out into a spur like that of the feet of Drepanopterus and Stylonurus. All the other endognathites are also longer than in typical species of Eurypterus and the fourth pair is not distinguished from the others by its lack of spines and its slenderness. The carapace already exhibits the characteristic large size, squarish outline and broad border (doublure?) and the telson is distinctly styliform. We have for this reason deemed this species worthy of subgeneric distinction and erected the sub-genus *Onychopterus* for its reception.

From this prototype of the Stylonurus branch two genera, Dolichop-terus and Drepanopterus, are clearly derived. Dolichopterus [*see* restora-tion, plates 40, 41] is principally distinguished by the development of the ninth segment of the sixth appendage which here forms a broad suboval lobe, instead of the claw of Onychopterus, exactly corresponding to the palette of Eurypterus. The same tendency to the broadening of the spines into lobes or plates is displayed on the fourth endognathite [pl. 45, fig. 2], giving this leg an aspect strikingly different from that of all other forms. All legs in the genotype are powerful organs with large coxae and the cephalothorax is of corresponding size; the gnathobase is especially large and the metastoma long, as in the whole Stylonurus branch. The genital appendage, however, resembles most that of Eurypterus. We may consider Dolichopterus as a more specialized genus derived from Onychopterus.

Like Dolichopterus the genus Drepanopterus is also derived from Onychopterus or from forms most nearly represented by that genus. The fifth pair of legs has become still more lengthened and its segments are

round or tubular instead of flattened into a paddle; and the ninth segment forms a strong claw corresponding to the size of the whole leg. The legs form together a series that increases regularly in length backward, and the first four pairs are spinous. The carapace is large, the body slender and the telson distinctly styliform.

Laurie [1899, p. 582] has shown that his genus Drepanopterus differs from Stylonurus only by a negative point of chief generic importance, namely, the fact that its last pair of appendages are not excessively elongated, and he states that Stylonurus developed from Eurypterus by way of forms most nearly represented by Drepanopterus, in which there was greater specialization of the fifth appendage, and reduction of the sixth appendage from the typical digging leg to a purely crawling one. The Otisville material and some of Laurie's drawings indicate that in Stylonurus the second and third pairs of legs are also much elongated and specialized by the multiplication of the spines and by their development into broad lobes in species such as S. e x c e l s i o r [see restoration plate 47]. The body has become still more slender and the slender form of the telson has given the genus its name.

Stylonurus alone of the whole branch has lived into the Devonic era, attaining there immense proportions. It represents an extreme of specialization that is strongly contrasted to that of the Pterygotus branch.

The main stem represented by Eurypterus has persisted with little change into the Carbonic and even into the Permic. The prevailing expression of Eurypterus in the Carbonic is, however, that represented by the subgenus Anthraconectes. We have elsewhere fully shown that the species referred to this group exhibit distinct phylogerontic characters in the excessive spinosity of the body due to the development of the "scales" into spines, in the elongation of the epimeral pieces and in the excessive length of the telson.

A small independent branch that came off from Eurypterus is represented by Eusarcus. In its triangular carapace, anterior eyes, broadly

oval preabdomen and narrow taillike postabdomen, anteriorly longest series of endognathites, curved telson and other features, this genus bears marks of a peculiar aberrant type that apparently left no successors.

VI

TAXONOMIC RELATIONS

Any inquiry into the zoological position of the eurypterids must be based on that of Limulus since there is little doubt in the minds of paleontologists of the close relationship between the eurypterids and the king crab. In fact, all recent investigations and discoveries of eurypterids have only served to bring out new homologies of structure between the two groups. Nieszkowski, Hall and Woodward among the earlier writers on eurypterids clearly recognized and distinctly pointed out the numerous homologies and united the eurypterids and xiphosurans. They were especially successful in correlating the segments and the appendages of the cephalothorax. Later Schmidt and Laurie established the fact that the Eurypterida had four pairs of platelike abdominal appendages that bear the branchiae on their posterior surfaces and constitute another important homology with Limulus. Finally Laurie and Holm indicated as a further common structure the existence of preoral appendages in the eurypterids. Holm especially demonstrated this close relationship with the limulids, by the description of a number of finer details of organization: the occurrence of epicoxae in the second to fourth endognathites, the presence of a circular hole spanned by a thin membrane in the coxa of the fourth endognathite. We believe we have added to this array of evidence some further important details in identity of structure of the compound eye of Pterygotus and that of Limulus, and of the general parallelism in the ontogeny of the eurypterids and Limulus. The former argument is considered of especial significance as the eye of Limulus has been shown by Watase and others to be of a type of structure entirely peculiar. In the chapter on ontogeny we have not expressly pointed out the similarities and differences in the individual development of the eurypterids and

limulids, and may here briefly enumerate them. The nepionic stages of both have in common:

    1 The large size of the carapace
    2 Its broad border
    3 Its distinct median, glabellalike ridge (best seen in S t y l o n u-
         r u s   m y o p s)
    4 The smaller number of body segments (nine or less, seen also in
         S.   m y o p s)
    5 The lack of differentiation of the segments
    6 The undeveloped telson

As differences appear:

    1 The terete or conical abdomen in the young eurypterids in
         contrast with the broadened abdomen of Limulus, and
    2 Large larval eyes in the eurypterids

We consider both these differential characters as due to purely adaptive changes. The broader abdomen of the larvae of Limulus results from the earlier appearance of the broad abdomen of the mature type through acceleration, and the adaptive nature of the large larval eyes has been fully discussed on page 119. For the reasons here given we find ourselves in agreement with those authors who have united the eurypterids and limulids under Dana's subclass Merostomata.

If the relationship of the eurypterids with the king crabs is so close that it places them in one subclass, the eurypterids will have to follow the Limulidae in their wanderings in the zoological system.

The limulids were, as is well known, classed with the crustaceans, chiefly on account of their aquatic habit and branchial respiration, since the Arthropod phylum was by common consent divided into two subphyla, the Branchiata and Tracheata. Opposition arose to this classification through the recognition of the affinities of Limulus with the arachnids, first suggested by Strauss-Dürkheim, and especially elaborated by Van Beneden, Lankester, Kingsley and Laurie, though not without opposition from such authorities as Packard, Woodward, Thorell and Lindström,

Bernard and others. Some, as Kingsley, have placed the Merostomata next to the Arachnida and united the two in one class. The scheme proposed by Kingsley [1894, p. 122] is as follows:

Phylum, Arthropoda
Subphylum I, Branchiata
Class I, Crustacea
    Subclass 1, Trilobitae
    Subclass 2, Eucrustaceae
Class II, Acerata
    Subclass 1, Gigantostraca (Merostomata)
    Subclass 2, Arachnida
Subphylum II, Insecta

Lankester, in his paper " Limulus an Arachnid?" and his followers have gone farther and placed the Merostomata under the class Arachnida. They propose the following classification [*see* Shipley, 1909, p. 258]:

Class, Arachnida
Subclass 1, Delobranchiata (Merostomata)
  Order (I), Xiphosura
  Order (II), Eurypterida
Subclass 2, Embolobranchiata
  Order (I), Scorpionidae
  Order (II), Pedipalpi
    etc.

The Delobranchiata, which term is equivalent to Dana's Merostomata, are characterized by their gills which are patent and exposed; the Embolobranchiata have lungbooks or tracheae. We prefer to retain the term Merostomata, there being no apparent need for a new word.

As there is a burning interest attaching to the question whether we should regard the merostomes of the Siluric as giant marine arachnids or archaic crustaceans, we here briefly review the arguments for the relationship of the merostomes with the scorpions; and since, the larval

stages of the eurypterids are described in detail now for the first time, it appears very appropriate to test the hypothesis of this arachnidan relationship by the ontogenetic evidence now available. Kingsley [1893, p. 228] cites, in his full discussion of the agreements and differences between Limulus and the crustaceans on one hand and the arachnids on the other, these six points of agreement:

1   A branchial respiration
2   The possession of biramous appendages
3   The absence of malpighian tubes
4   The absence of salivary glands
5   The absence of embryonic envelops
6   The presence of compound eyes

and 28 points in which Limulus and the arachnids agree, and in which both differ from the other " Tracheates " (Hexapoda and Myriapoda). The following of these points are considered as of special importance for the association of Merostomata and Arachnida:

(1) The numerical homologies of segments and appendages; (2) the exact homologies existing in the respiratory organs; (3) the fact that the cephalothoracic appendages are pediform, the basal joints serving as jaws; (4) the presence of true nephridia opening in the base of the third or fifth pair of appendages or in both; (5) genital openings in the seventh (or more probably eighth) segment of the body; (6) extreme length of the midgut; (7) presence of an internal structure, the entosternite; (8) inclusion of the ventral nerve cord and its nerves in the external artery and its branches; (9) the close similarities in the central nervous system.

The last chapter of Thorell's paper on *A Silurian Scorpion from Gotland* is entitled: Are the Merostomes Arachnids ? Here the author gives a critical discussion of these points of resemblance and concludes that the characters on the basis of which the merostomes have been considered as nearly related to the scorpions are " fully counterbalanced by the differences exhibited in the structure of the organs of respiration and by the fact that the scorpions and all the higher Arachnida are provided with

malpighian vessels, whereas the merostomes (Limulus) and all unques-
tionable Crustacea are devoid of these vessels." He suggests that the
arachnids also form an ancient type, and that the common origin of the
merostomes and the arachnids must be sought for far down in the pedigree
of the arthropods. " The agreement between scorpions and eurypterids
would then be derived from causes quite independent of close relationship,
and perhaps from a *convergence* in some branches of the two stems which
are formed by the merostomes and the arachnids."

Opposed to this, Lankester and his followers hold that the presence
of gills and the absence of malpighian tubules are features associated
with aquatic life, and hence of no critical classificatory value, and Laurie
and Claus assert that the morphological value of the gills has been
greatly overestimated. Laurie notes that the branchiae of eurypterids,
like those of Limulus, are constructed on a type unknown amongst
the Crustacea, and further, that structures such as these, which are the
product of a physiological necessity, are not of much value in indicating
close relationship. He cites as arguments against the crustacean relation-
ship " the segmentation of the body and position of the genital aperture—
which does not agree with that of any known crustacean, the absence
of anything representing the first antennae, the chelate structure of the
one pair of preoral appendages and the fact that there is no trace of the
typical crustacean biramous structure of the appendages." Admitting the
relationship of the eurypterids to the arachnids, Laurie thinks that " the
eurypterids must be considered as intermediate between Crustacea and
Arachnida, in the sense that they are among the most primitive arachnids,
and therefore nearer the junction point of the two terms." Agreeing with
the other authors as to the close relationship of the eurypterids with Limulus,
Laurie sees a point of great morphological importance " in the fact that
Limulus has a pair of platelike appendages on the second abdominal seg-
ment," and takes this to indicate that " Limulus branched off from the
eurypterid stem before the genital operculum was so highly specialized as it
is in the eurypterids, and, consequently, before the appendage of the second

abdominal segment had become reduced." From this fact, and the absence in Limulus of anything comparable to the central lobe of the genital operculum, the higher state of development of the metastoma in eurypterids, and the higher specialization of the last pair of legs, it is inferred, that " Limulus represents a more primitive type in almost every respect except the fusion of the abdominal segments, and is to be related to the euryp-terids not by direct descent, but through a comparatively unspecialized ancestor."

Our evidence is fully accordant with Laurie's view of the early separation of the eurypterids and Limulus. Of especial importance in this regard is the occurrence of a typical eurypterid in the Cambric era (Strabops). The ventral side of this form is still unknown and in view of its important bearing on the phylogenetic relations of the eurypterids with the limulids and scorpions, the elucidation of the character of its genital operculum is especially desirable. At any rate, none of the eurypterids now known from the Cambric to the Permic even suggest any fusion of the abdominal segments such as distinguishes Limulus, while in the Devonic Protolimulus eriensis Williams, the abdominal segments are apparently already fused and the characteristic Limulus structure developed.

Figure 27 Protolimulus eriensis Williams. Chemung group, Erie county, Pennsylvania. (From Hall and Clarke)

With the conclusion that the limulids and eurypterids were probably separate in Precambric time, the question arises as to the date of separation of the Scorpionidae from the eurypterids. The relationship of Scorpio to Limulus has been fully discussed, especially by Lankester, and is no longer doubted. That of Scorpio to the eurypterids has been more fully
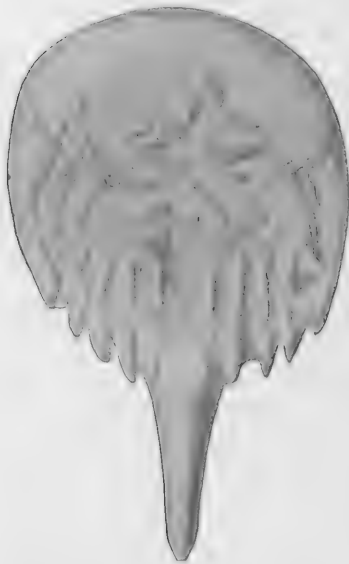
dealt with by Laurie. Lankester had already indicated the close homologies existing in the number of body segments of the cephalothoracic appendages [*see* especially *op. cit.* tabular statements p. 536].[1] From these it would follow that Limulus on the one hand, Scorpio and the eurypterids on the other, separated before the consolidation of the body segments observable in Limulus; but Laurie states that the second abdominal segment in Scorpio is well developed and shows no sign of ever having been suppressed by the genital operculum as in the eurypterids. From this argument only it might seem that the scorpions came off the eurypterid stem before the great development of the genital operculum. Laurie considers this development of the genital operculum at the expense of the second free segment as a point of considerable morphological importance and has therefore [*op. cit.* 526, *see also* Recent additions, etc. p. 127] considered it probable that the Pedipalpi (Thelyphonus) are more nearly allied to the eurypterids than are the scorpions, for in the former a similar suppression of the second ventral segment has taken place in favor of the genital plate. The four scorpions known from the Siluric all exhibit char-

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[1] A brief summary of the resemblance of the eurypterids with the scorpion has been lately given by Woods [1909, p. 283]. It reads as follows:

The eurypterids present a striking resemblance to scorpions. In both groups the segments in the three regions of the body are the same in number, and the appendages of the prosoma also agree in number and position. The preoral appendages are chelate in both, but the second pair of appendages are chelate in the scorpions only. In eurypterids the coxae of the five pairs of legs are toothed and meet in the middle line, but in the scorpions the coxae of the last two pairs do not meet; this difference, however, appears to be bridged over in the earliest known scorpion—Palaeophonus, from the Silurian rocks. The eurypterids are distinguished from the scorpions by the much greater development of the last pair of legs. The large metastoma of the former is homologous with the sternum of the scorpion. The genital operculum is much smaller in scorpions than in eurypterids, and in this respect the latter agree with Thelyphonus (one of the Pedipalpi) more than with the scorpions. The pectines are absent in the eurypterids except in Glyptoscorpius. Instead of the lung books of the scorpions the eurypterids possess branchial lamellae on the platelike appendages; but this difference between the two groups appears to be bridged over by Palaeophonus, which was marine, and may have possessed branchial lamellae since stigmata seem to be absent.

acteristic features of their order. Recently a fossil Thelyphonus from the Bohemian Carbonic, P r o t h e l y p h o n u s b o h e m i c u s (Kusta), has been fully made known by Fritsch [1904]. Unfortunately the specimen shows the ventral aspect only, more or less involved with the dorsal side. But if we read the figures 5, 6 and 7 of his plate 6 aright, the ventral segments in Carbonic time still possessed a like development with the dorsal ones and the agreement of the Pedipalpi with the eurypterids in the greater development of the genital plate would have manifested itself only after the disappearance of the eurypterids and so lack phylogenetic significance.
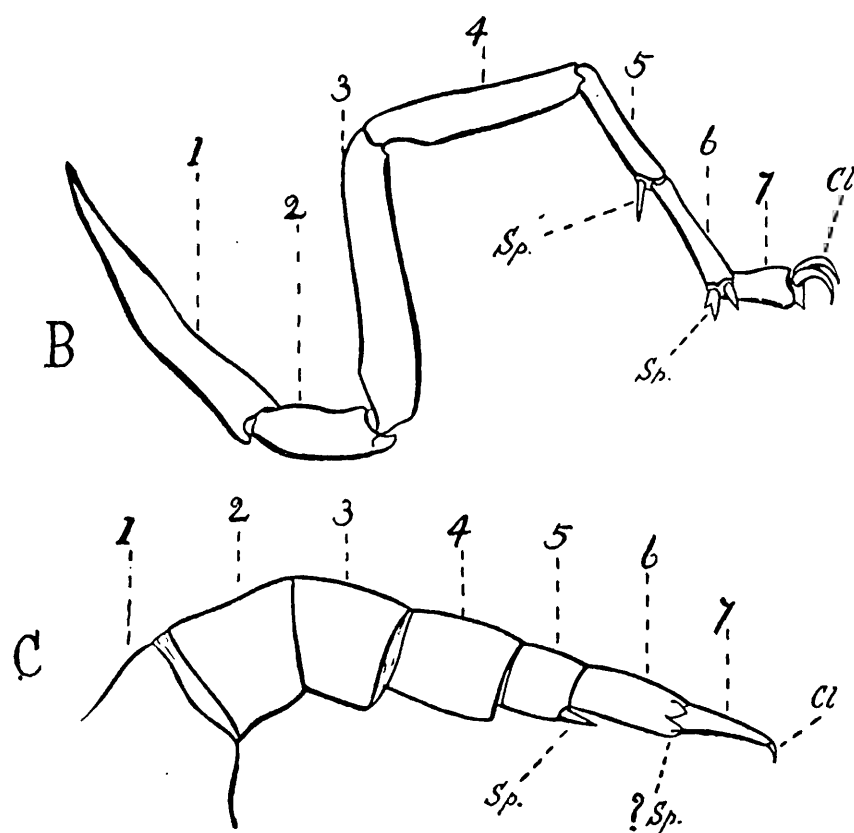
Figure 28 B, fourth leg of a recent scorpion (B u t h u s a u s t r a l i s); C, third leg of Siluric scorpion (P a l a e o p h o n u s n u n c i u s). (From Pocock)

Some very significant points regarding the relationship of the eurypterids and scorpions have been brought out by Pocock's investigations [1901] of the Scottish Siluric scorpion, P a l a e o p h o n u s h u n t e r i . We briefly note the more important of these. Pocock points out that the walking legs of Palaeophonus differ from those of all other scorpions, living or fossil, in their primitive character [text fig. 28]. They consist of the primitive number of segments (seven), show the simplicity of segmentation by the subequality of the individual segments and possess a sharply pointed, practically clawless terminal segment, strikingly resembling those of some eurypterids (Pterygotus) and differing greatly from those of the recent scorpions. Further, in distinction from the later scorpions, the basal or coxal segments of all the appendages were in contact or capable of meeting in the middle line, although the coxae of the fourth were small and functionless [text fig. 85]. In this feature the archaic Palaeophonus

presents a condition intermediate between that of the typical scorpions and of Limulus or Eurypterus. Likewise, it is shown that the comb is structurally intermediate between a typical scorpion comb and the outer branch of one of the metasomatic appendages of Limulus. Finally Pocock doubts that Palaeophonus possessed spiracles or was an air breather but suggests that it was still aquatic and may have possessed branchial lamellae attached to sternites.[1]

We have above pointed out the features which the larvae of Limulus and the eurypterids have in common. The supposed close relationship of the eurypterids to Scorpio, makes it desirable to compare the larval stages of the two.

The embryology of the scorpions has been investigated by Metschnikoff and more recently by Laurie [1890] and Brauer [1895]. We copy here for comparison one of Metschnikoff's [from Balfour's *Treatise on Comparative*

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[1] His arguments are that the Scottish P a l a e o p h o n u s   h u n t e r i does not show the stigmata, which Peach believed he saw, and that the single stigma seen by Thorell and Lindström in P .   n u n c i u s is a fortuitous crack. He therefore holds that Palaeophonus had no stigmata and spiracles and that on account of the excellent preservation of the Siluric scorpions in undoubted marine beds, they can not have been land animals, and that the strong sharply pointed legs were admirably fitted, like those of a crab, for maintaining a secure hold amongst the seaweed.

In regard to the supposed absence of stigmata in P .   h u n t e r i , notwithstanding the fact that the ventral side is exposed, it may be mentioned that Fritsch [1904, p. 64] has pointed out that the relation of the chelicerae to the frontal margin of the carapace shows that the specimen (of P .   h u n t e r i) lies with the dorsal side up and with the ventral organs of the cephalothorax pressed through the mutilated carapace. In that case it can not be expected that the fine slitlike stigmata should be observable, and in all Siluric scorpions which happen to have only the dorsal sides exposed, the question of the presence or absence of stigmata is obviously still an open one. Nevertheless Pocock's view of the aquatic habit of Palaeophonus is of interest in connection with the New York P r o s c o r p i u s   o s b o r n i in view of the absence of all other remains of land animals or plants in the waterlime; and especially in view of Brauer's discovery [1895, p. 351] that the ontogeny of Scorpio shows that the lungbooks are derived from gills borne on mesosomatic appendages.

Embryology] and one of Brauer's figures. Study of these shows that the carapaces of the larval eurypterids have a closer agreement with Limulus than with the scorpions. In the scorpion embryo and larvae the carapace is relatively of larger size than in the eurypterids, being nearly half the length of the embryo, but it is long and slender, instead of short and broad or semicircular as in the merostomes; the procephalic region early exhibits a deep frontal emargination and, according to Metschnikoff, a distinct bilobation, features that are found in neither Limulus nor the eurypterids, but which are characters of the adult scorpion. Likewise the development of the cephalothoracic appendages, while homologous in number and original position as to the stomodaeum (embryonic mouth) to that of the merostomes, differs from that of the eurypterids and Limulus in the early development of the pedipalps of the second segment, corresponding to their prominence in the adult scorpion. They are even recognizable earlier than the chelicerae of the first segment, while the following four pairs of walking legs are of uniform size and character.
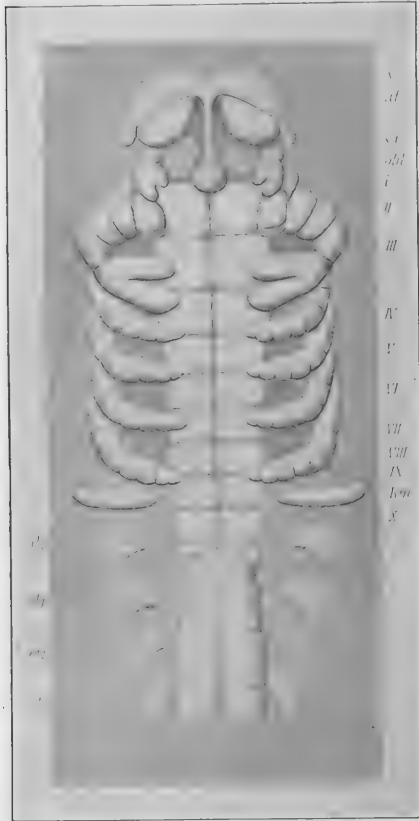
Figure 29   Early stage in development of scorpion. Ventral view of embryo. *af*, eye fold; *sa*, lateral eyes; *obl*, upper lip; *Km*, comb (pecten); *abp*, abdominal legs (gills). (From Brauer)

The homology of the appendages of the cephalothorax repeats itself in the abdomen; here again the number is absolutely in agreement

with that of the merostomes, but there appears to exist from the beginning a striking difference in the strong differentiation of the preabdomen and the postabdomen early in the embryonic life of the scorpion, while in the eurypterids that difference between the two parts of the abdomen is still obscure in the larva, as it is in Limulus. In the scorpion the preabdomen is broad and bulky while the postabdomen or tail is abruptly set off, very narrow and flexed upon the ventral surface [see text fig. 30].

The abdominal appendages of the embryo of the scorpion [see text fig. 29] atrophy except for the first pair which form the " combs." In the places of the others the lungbooks appear, resulting from paired invaginations, the walls of which subsequently become plicated. In the merostomes, on the other hand, the preabdominal appendages remain throughout life and bear the branchial lamellae. It is the current opinion of zoologists that the lungbooks of the scorpion are derived from such branchiate abdominal appendages as those of Limulus, the conversion of one set of organs into the other being supposed to have been effected by the formation, behind each pair of abdominal appendages, of an invagination which, deepening, has carried in with it the branchial lamellae. Brauer [1895, p. 373] has recognized the origin of the lungbooks from gills.

Figure 30 Later embryonic stage in development of scorpion. Ventral view. *ch*, chelicerae; p^1-p^4, walking legs; *pe*, pecten; *st*, stigmata; *ab*, postabdomen. (From Balfour)

In summing up the comparison between the embryonic and larval stages of the scorpion and the larvae of the eurypterids we may say that, (1) the general homologies of the two are very apparent in the composition of the carapace and abdomen of an equal number of segments, but that, (2) while in the scorpion the segmentation is completed long before the hatching, in the eurypterids the larvae in the nepionic stage still lack the full complement of segments, recalling the trilobites in this feature and clearly representing a more primitive condition; (3) there are a number of distinct differences in the larvae of the eurypterids and of the scorpions,

some of which lie in the form of the carapace, the early embryonic differ-
entiation of the pedipalps from the other appendages, the strong prelarval
differentiation of preabdomen and postabdomen and the disappearance
of the abdominal appendages in the scorpions and their persistence in
the eurypterids.

It is yet to be determined whether these differences are of phylo-.
genetic significance or only due to the pushing back, by acceleration, of
later adaptations of the scorpions into the embryonic and larval stages.
The latter is undoubtedly the case in the embryonic development of the
pedipalps and of the narrow, distinctly defined, scorpionic tail. The early
appearance and later atrophy of the abdominal appendages is, however,
clearly a feature that points to a common ancestor for the scorpion and
the eurypterids having such appendages, and we believe that the cepha-
lothorax in the embryo of the scorpion, retains ancestral features from
the facts that its length corresponds to about six abdominal segments
and it equals the latter in width [text fig. 29]; that, however, the strong
development of the procephalic region is tachygenetic.

A comparison of the larvae of all three, the eurypterids, Limulus
and the scorpion, shows both the latter to have lost the primitive form
of the abdomen by acceleration, that of Limulus being much broadened,
that of the scorpion abruptly contracted to the tail or postabdomen while
the eurypterids have best preserved the original gradual and uniform
contraction. The carapaces of the eurypterids and the scorpion have most
nearly retained the original proportions and form of the common ancestor.
Of the cephalothoracic appendages the chelicerae are alike in all three
groups and obviously ancestral in their form; the remaining legs have
taken quite different courses of adaptation, the scorpions having developed
the powerful chelate pedipalps, the eurypterids the swimming legs, while
those of Limulus have remained relatively undifferentiated, and show no
tachygenetic features in the embryos except the chelae. The embryo of
the scorpion shows simple walking legs, like those of the eurypterids, and
lacks the two movable claws. This simple form of the walking leg is also

exhibited in a very remarkable manner by the Siluric Palaeophonus. It is quite safe to infer that this is the form of the cephalothoracic appendages inherited from the common ancestor.

A corollary of these inferences is that neither Limulus nor the scorpions is derivable from the eurypterids, but that all three, while related, have early separated; and that the eurypterids are still nearest in their general aspect to this common ancestor. The early authors in pointing to the "larval aspect" of the eurypterids, showed therefore, a very clear insight into the phylogenetic status of this subclass. The appearance of the eurypterids in the Cambric with the essential characters of the group is in accordance with this larval aspect while the early separation of the scorpions from the stock is evinced by the occurrence of typical scorpions in the Siluric, and by the fact that in the Carbonic they show a greater diversity of form than they do today. On the other hand the similarity of the P a l a e o p h o n u s   n u n c i u s to recent forms is conclusive evidence that the scorpions have been very "persistent types" and have carried their typical characters well back of the Siluric. There is no reason to doubt that, as there are eurypterids in the Cambric, the scorpions also reach back to that era and the diversion from the common ancestor must have already been inaugurated in early Cambric time.

As to what this common ancestor was we have no clue. The trilobites were commonly adduced as competent to furnish it, they, the Xiphosura and eurypterids, having been united as "Poecilopoda," until the phyllopodiform structure of the trilobite limbs was demonstrated by Beecher and they were recognized as true, primitive Crustacea. While the trilobites are separated by a series of features that effectively characterize them as primitive Crustacea (as the protonauplius, the hypostoma, the slender jointed antennules, the biramous character of all other limbs, the compound eyes on free cheek pieces, etc.) and that disprove any assumption of their ancestral relations to the Merostomata, phylogenists still assert that the resemblances between the crustaceans and the Acerata (Merostomata and Arachnida) are much closer than those between either

and any of the other groups of arthropods and they would derive the Arachnida through the Merostomata from primitive crustaceans. Laurie [*Recent Additions*, etc. p. 117] however, has pointed out that the relationship of the eurypterids to the Crustacea is not so evident, as they show no special points of affinity with any one group. " The absence of that special modification of three pairs of appendages to serve as mouth organs, which is characteristic of all Crustacea except the Ostracoda, indicates that their point of union must have been very low down the crustacean stem, and the very definite number of segments and arrangements of appendages in the Eurypteridae indicates on the other hand that they are removed a considerable distance from any such primitive type." The fixation of the number of segments in the Cambric eurypterid Strabops is significant as indicating that at this early date they were already far removed from the common ancestor with an indefinite number of segments.

As the most primitive and earliest crustaceans, the trilobites, are clearly not ancestrally or otherwise closely related to the eurypterids and the latter even in the Cambric are far removed from any possible synthetic ancestors, it is a fair question whether it is not proper to look for more primitive arthropods than the crustaceans as ancestors of the eurypterids. We have in mind now the investigations of Bernard [1896] who disputes the relationship of the merostomes to the crustaceans on one hand and to the arachnids on the other, and states that "As arthropods, no relation whatever exists between them; as segmented animals, however, they are both derivatives from the chaetopod annelids, but along different and opposite lines of specialization." Bernard derives the Crustacea from a bent carnivorous annelid, a view which Beecher regards as partly verified by his discoveries concerning the ventral anatomy of the trilobites, and it is therefore worthy of consideration in this place. If we consider the absence of anything in the ontogeny of the eurypterids that would suggest a crustacean nauplius stage, the admitted absence of all crustacean features in the adult forms, and the equal absence of all crus-

tacean features in the ontogenies of Limulus and the scorpion, it becomes manifest that the inference of the derivation of these classes from arthropods more primitive than the Crustaceans, seems well founded.

Through the suggestive investigations of Professor Patten, published in his paper *On the Origin of Vertebrates from Arachnids* and the ingenious speculations of Dr Gaskell as to the origin of the vertebrates from some Limuluslike ancestor, the eurypterids have gained increased interest and some notoriety as possible ancestors of the earliest vertebrates.

VII

SYNOPTIC TABLE OF THE NORTH AMERICAN EURYPTERIDA

Those marked by an asterisk are found in New York State.

Class ARACHNIDA

Subclass MEROSTOMATA (Dana) Woodward

Order EURYPTERIDA Burmeister

Family EURYPTERIDAE Burmeister

Genus DOLICHOPTERUS Hall

Type: *Dolichopterus macrochirus *Hall*

*D. frankfortensis *nov.*

*D. latifrons *nov.*

*D. otisius *Clarke*

*D. siluriceps *nov.*

*D. stylonuroides *nov.*

*D. testudineus *nov.*

Genus ECHINOGNATHUS Walcott

Type: *Echinognathus clevelandi *Walcott*

Genus EURYPTERUS DeKay

Type: *Eurypterus remipes *DeKay*

*E. approximatus *Hall & Clarke*

*E. dekayi *Hall*

*E. lacustris *Hall*

*E. lacustris *var.* pachychirus *Hall*

*E. maria *Clarke*

*E. megalops *nov.*

*E. microphthalmus *Hall*

*E. pittsfordensis *Sarle*

*E. pristinus *nov.*

*E. prominens *Hall & Clarke*

*E. pustulosus *Hall*

  E. ranilarva *nov.*

*E. ? (Dolichopterus?) stellatus *nov.*

Subgenus ONYCHOPTERUS

E. kokomoensis *Miller & Gurley*

Subgenus TYLOPTERUS

E. boylei *Whiteaves*

Subgenus ANTHRACONECTES

Type: E. mansfieldi *C. E. Hall*

E. mazonensis *Meek & Worthen*

E. pennsylvanicus *C. E. Hall*

E. stylus *Hall*

Doubtful species

E. ? potens *Hall*

E. ? pulicaris *Salter*

? Genus EURYPTERELLA Matthew

? E. ornata *Matthew*

Genus EUSARCUS Grote & Pitt

Type: *E. scorpionis *Grote & Pitt*

*E. ? cicerops *Clarke*

*E. ? longiceps *nov.*

E. newlini (*Claypole*)

*E. triangulatus *nov.*

Genus MEGALOGRAPTUS Miller

Megalograptus welchi *Miller*

Genus STRABOPS Beecher

Strabops thacheri *Beecher*

Genus STYLONURUS Page

Subgenus CTENOPTERUS nov.

Type: *S. cestrotus *Clarke*
*S. multispinosus *nov.*
* ? S. excelsior *Hall*
*S. sp. α
*S. sp. β
*S. sp. γ

Subgenus DREPANOPTERUS Laurie

Drepanopterus longicaudatus *nov.*

Indeterminate species

S. beecheri *Hall*
*S. ? limbatus *nov.*
*S. myops *Clarke*
*S. sp. δ

Family PTERYGOTIDAE nov.

Genus HUGHMILLERIA Sarle

Type: *H. socialis *Sarle*
*H. socialis *var.* robusta *Sarle*
*H. magna *nov.*
*H. shawangunk *Clarke*

Genus PTERYGOTUS Agassiz

Pterygotus atlanticus *nov.*
*P. buffaloensis (*Pohlman*)
*P. cobbi *Hall*
*P. globiceps *nov.*
*P. grandis (*Pohlman*)

*P. macrophthalmus *Hall*

*P. monroensis *Sarle*

*P. nasutus *nov.*

*P. prolificus *nov.*

VIII

SYSTEMATIC ACCOUNT OF THE E U R Y P T E R I D A

Class **ARACHNIDA**

Subclass **MEROSTOMATA** (Dana) Woodward

Order **E U R Y P T E R I D A** Burmeister

Family **EURYPTERIDAE** Burmeister

Genus STRABOPS Beecher 1901

Strabops thacheri Beecher

Plate 1; plate 4, figure 5; plate 13, figure 2

Strabops thacheri Beecher. American Journal of Science, n. s. 12:365, 1901

An eurypterid of extraordinary interest because of its age and completeness is a specimen obtained in the Cambric Potosi limestone of St François county, Missouri, which was studied by Prof. C. E. Beecher, and made by him the type of the genus and species: S t r a b o p s t h a c h e r i . Professor Beecher, evidently without his own knowledge had the use only of the relievo of this specimen and the counterpart has been found by the authors in the collections of Columbia University. The specimen is so preserved that the interior view of the dorsal side is shown in both cast and mold, and the latter is obviously the more distinct. Had it been at the disposal of the describer it would probably have prevented some evident misconceptions of structural details. The intaglio, cleaned with potash [pl. 4, fig. 5] and sharply cast [pl. 13, fig. 2], exhibits quite distinctly all true structure lines.

The specimen was correctly recognized by Dr Beecher as suggesting the genus Eurypterus. Its differences from the latter genus which, as such, constitute the generic characters were set forth by him as follows:

The cephalothorax is comparatively shorter and wider than in Eurypterus, the eyes are further forward, nearer together, and more oblique, and besides the telson but 11 abdominal somites can be determined on the dorsal side, instead of 12, as in Eurypterus. These differences are con-

sidered as indicative of a new genus and it is proposed to recognize this type under the name Strabops *nov. gen.*, with S t r a b o p s t h a c h e r i n. sp. as the type species. The generic name is in allusion to the inward turning or squinting of the eyes.

Two of the differential characters here cited, viz, the anterior position of the eyes and the absence of one somite, are not verified by the counter-part. The supposed eyes, which were represented as oblique ovate cavities with the visual surfaces apparently broken out [*see* original figure, copied here in text fig. 31], are small lumps of the underlying rock held in place by the overlapping fold which has formed near the frontal mar-gin by a shoving of the specimen. These have been chiseled out on the counterpart and the surface of the folded part of the carapace exposed. The real eyes are seen in our specimen half way between the anterior and posterior edges, near the lateral margin. They are small and circular.

The other difference concerns the number of abdominal somites on the dorsal side, for the intaglio and the plaster cast therefrom seem to leave no doubt that Strabops agreed with the later eurypterids in having 12 segments.

Figure 31 S t r a b o p s t h a c h e r i Beecher. Outline of original drawing

The 1st segment is for the greater part pushed under the carapace, and the next, the 1st in Beecher's figure, is shown only on the right side of the bent specimen; on the other side the bending of the abdomen has forced it back over the 3d tergite.

With these corrections of structure, Strabops stands still closer to the Siluric Eurypterus than it appeared to Beecher; in fact it is obvious that all the principal parts of eurypterid structure are already fully fixed in

this Cambric progenitor; the carapace, preabdomen, postabdomen and telson exhibiting the same general characters and number of component parts. Notwithstanding this conformity in structure Strabops presents a number of distinctly primitive characters which indicate its closeness to the archetype of the eurypterids. We see the most important of these in the lack of differentiation in width and length between the preabdominal and postabdominal segments, the contraction of the postabdomen taking place so uniformly that the conventional division between body and tail, so evident in all later eurypterids, is here still entirely undeveloped. The postabdomen, always a slender part of the body with much lengthened posterior segments in later forms, is here short and broad, the segments not at all increasing in length backward. Altogether, all abdominal segments retain a highly primitive and simple aspect in their appearance as uniformly narrow straight bands that hardly bend forward at the lateral extremities. The first tergite, however, has progressed in development beyond the others, and, as in the Siluric genera, is more closely connected with the carapace than with the abdomen, and is distinctly bent forward at the extremities.

The carapace is distinguished from that of the Siluric descendants by its remarkable shortness, or relatively very small size which may also constitute a primitive feature.[1]   On the other hand the doublure or rim of the underside is very broad, suggesting the genus Stylonurus. The eyes are especially notable for their small size and circular outline.

The telson spine is short and plump, and thus in correspondence to the short compact body.

Of the limbs but a single fragment is shown, and this is too small to indicate their character. Doubtless they correspond in lack of differentiation with the dorsal test and were probably all of simple and similar form, slightly increasing in length posteriorly. Strabops has served in our effort to reconstruct the archetype of the Eurypterida.

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[1] This shortness may be partly due to a fore and aft foreshortening, as indicated by the pushing of the first tergite under the carapace and by the fold at the frontal margin.

To sum up the foregoing distinctive features in Strabops, we find that the lack of differentiation of the parts of the abdomen and the general primitive aspect of the form, together with the high geologic age of the genus warrant its recognition as distinct from Eurypterus, though it is manifest that the form is very similar thereto.

Genus EURYPTERUS DeKay 1825

The genus Eurypterus embraces not only those representatives of the order Eurypterida longest known and most completely understood, but it also surpasses all other genera in the number of species and in geological and geographical range; it represents the most vigorous and the most typical genus of the order, although it does not contain the giants of the group. It is therefore very proper that it should have given its name to this remarkable order of the class Arachnida.

The genus was erected by James E. DeKay in 1825 for the most common of the New York species, viz, E u r y p t e r u s   r e m i p e s . The organization of the body of Eurypterus was first elucidated and elaborately described by Nieszkowski [1858] and James Hall [1859]; the former basing his observations on the finely preserved material from the island of Oesel in the bay of Riga, Russia, the other on that from the waterlimes of New York. Hall described seven supposed species from the New York rocks, viz, E . r e m i p e s , m i c r o p h t h a l m u s , l a c u s t r i s , r o b u s - t u s , p a c h y c h i r u s , d e k a y i , p u s t u l o s u s , to which a few have been added since from the rocks of this State, viz, E . (?) p r o m i n e n s Hall and Clarke [1888], E . p i t t s f o r d e n s i s Sarle [1902] and E . m a r i a Clarke [1907]. A form from the Guelph dolomite of Canada (E . b o y l e i Whiteaves), two from the waterlime of the same horizon at Kokomo, Indiana (E . k o k o m o e n s i s Miller & Gurley and E . r a n i l a r v a nov.) a small number of species from the Carbonic of Illinois and Pennsylvania (E . m a z o n e n s i s , E . m a n s f i e l d i , E . p e n n s y l v a n i c u s , E . p o t e n s , E . s t y l u s and E . a p - p r o x i m a t u s); and the species E .? m e g a l o p s , E . p r i s t i n u s

and E. ? (D o l i c h o p t e r u s) s t e l l a t u s from the Frankfort shales
complete the list of North American representatives of the genus.[1]

In Europe a considerable number of species were described by Salter
and Woodward but the principal advance in the knowledge of the genus
and its structural details has been made by F. Schmidt [1883] and Holm
[1898]. Both of these authors described the E . f i s c h e r i from Oesel,
which had already served as the subject of Nieszkowski's investigations
and was at that time identified with E . r e m i p e s DeKay. Schmidt
corrected and supplemented in many ways Hall's and Nieszkowski's de-
scriptions of the endognathites, demonstrated the presence of five separate
sternites (Hall knew but one, the operculum, and Nieszkowski assumed
six) and showed that they are open on the ventral side. He further pointed
out differences in the appendages of the first and second sternites in indi-
viduals otherwise alike and attributed these to sexual differences. In the
dolomite marls of Oesel these merostomes are not preserved as in the
waterlimes of New York where the integument is fully carbonized. By
most skilful manipulation Holm succeeded in removing from the matrix
the integumental film of E . f i s c h e r i and was thus enabled to study
these parts by transmitted light, and to describe the structure of the
integument with a completeness that could be equaled only from the
living organisms themselves. We shall not here enter upon a detailed
review of the results of his investigations, but shall point out the more
important of the determinations, since there is no reason to doubt that
entirely similar structures existed in the closely related species E . r e m i -
p e s and E . l a c u s t r i s . Indeed, our material verifies several of
his detailed discoveries referred to below.

The absence of facets in the compound eyes was conclusively shown
by transmitted light. On the underside of the cephalothorax the presence

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[1] E . p u l i c a r i s Salter [1863] from the Devonic plant beds of St John, New
Brunswick, is based on two minute postabdomina that are insufficient for generic de-
termination and probably do not belong to the eurypterids.

of preoral chelicerae in place of antennae, already inferred by Schmidt, was demonstrated,[1] [see restoration pl. 3, fig. 1]. The fifth segment of the second endognathite in the male carries a long, curved, tubular process [text fig. 32] which, by analogy with Limulus, Holm considered as a clasping organ employed during copulation. The epicoxite of the coxal segments before observed by Laurie in Slimonia and Pterygotus, was found in its proper position in Eurypterus and a circular perforation with very thin covering membrane has been observed close to the inner margin of the coxa of the fourth endognathite [see text fig. 12; pl. 7, fig. 6]. A corresponding organ in the living L i m u l u s p o l y p h e m u s was discovered by Holm on the coxae of the third and fourth endognathites near the epicoxite. On account of the structure of this organ and its position on that side of the coxa which is turned toward the outside, it was suggested that it has an auditory function. This structure has also been observed by Sarle in H u g h m i l l e r i a   s o c i a l i s [pl. 62, fig. 5] and by the writers in E . r e m i p e s [pl. 7, fig. 6].

Figure 32   Second endognathite of E . f i s c h e r i with clasping organ of male; the long reflexed hornlike appendage of underside. (From Holm)

A new organ was discovered, the endostoma. This consists of a small, thin, deeply emarginate shield, not clearly bounded on the sides, which formed the inner posterior margin of the mouth [text fig. 13].[2] Further, the connection of the metastoma with the ventral integument of the cephalothorax by a doublure [text fig. 14] was shown. The distinction between male and female genital appendages was clearly elaborated and the presence demonstrated of an interior paired, curved, tubular organ connected with the

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[1] E u r y p t e r u s   s c o r p i o i d e s , in which the chelicerae had been found before by Laurie, is in our view generically distinct and an Eusarcus although on the strength of the presence of equal chelicerae in both, Holm argues for their congeneric character.

[2] We describe and figure here the endostoma of Pterygotus, hitherto unobserved [pl. 71, fig. 3].

female genital appendage [text fig. 19]. A like pair of tubes has been found by the writers in E. remipes and lacustris [pl. 12, fig. 2]. Finally, the delicate membranes of the interior of the ventral side and the oval attachment areas of the gill plates were described and reproduced by photographs.

It so happens that E. fischeri, which thus has become known down to the least details of its integumental structure, differs very little from the genotype of Eurypterus, E. remipes; and both Schmidt and Holm have suggested that these with E. lacustris may be only geographical varieties of the same species, inasmuch as they appear at the same geological horizon. But the question remains open whether E. remipes, the genotype by right of priority, is a faithful expression of the structure displayed by the genus Eurypterus. To determine this point we may briefly survey the phylogenetic relations of the species of Eurypterus.

The American species of Eurypterus readily fall into three subdivisions, viz, (a) those that group themselves around E. remipes; (b) those that vary in different directions from this group but are approximately contemporary; and (c) the later Carbonic species. Group (a) is represented by E. remipes, E. lacustris and its var. pachychirus, E. pittsfordensis, and possibly also E. maria. It is Eurypterus *sensu stricto*. Group (b) is a diffuse association comprising aberrant species E. dekayi, E. microphthalmus, E. pustulosus, E. kokomoensis, E. prominens and E. boylei. Eurypterus microphthalmus is representative of a small group, also present in England (E. brewsteri), characterized by its small compound eyes and broad, short cephalothorax. Eurypterus dekayi is probably a branch from E. lacustris with a number of characters already suggestive of approach to a phylogerontic condition. Eurypterus pustulosus, although attaining immense size, is aberrant in the exaggerated development of the tuberculation. Eurypterus kokomoensis stands apart in a number of char-

acters, especially in the clawlike development of the ninth or terminal segment of the swimming leg, and it is made the type of the subgenus Onychopterus. Eurypterus prominens has a long carapace with eyes well forward, characters that are also present in the young of E. remipes. Eurypterus boylei, from the Guelph formation, also exhibits proof of aberrant development in the large median tubercles of the tergites. Group (c) shows distinct phylogerontic characters in the strong development of the spines, surface scales and other excrescences, as well as in the large epimeral pieces of the postabdominal segments, and these are comprised under the subgeneric term Anthraconectes.

The group Eurypterus *sensu stricto*, or as represented by division (a), embraces not only the relatively simplest expression of the genus around which the other forms quite naturally group themselves, but also the most vigorous and that which dominates the stage (Salina) where the genus clearly reaches its climacteric development. The Eurypteri of the Bertie waterlime, notably E. remipes and E. lacustris, are therefore properly considered as representing the typical expression of the genus.

The genus thus defined is characterized by an elongate, slender body, widest in the middle of the preabdomen and distinctly differentiated into preabdominal and postabdominal regions. The carapace is subquadrate to subrectangular in outline, with rounded anterior angles, relatively small, one fifth to one seventh the total length of the body. The compound eyes are reniform, without distinct facets; situated on the dorsal side of carapace. The ocelli are situated between the compound eyes. The chelicerae are small, not extended beyond the edge of the carapace. The endognathites increase in length from the first backward; the first three pairs relatively robust, short and spinous; the fourth pair slender and bearing only a terminal spine with two spines on the penultimate segment. The fifth pair is developed into swimming legs with bladelike and extended seventh and eighth segments. Its ninth segment is rudimentary. The ventral membrane of the cephalothorax is separated by a distinct suture

from the doublure of the carapace, but no epistoma is formed. The metastoma is oval in outline, but slightly emarginate in front. The tergites and sternites are more or less bandlike and plain as in other genera; the male opercular appendage is small, with simple median lobe; that of the female long, extending to the third sternite and beyond, consisting of two paired and two single members, the paired members forming two pentagonal basal pieces, and two clawlike terminal pieces. The single imbricating lobes form the long median part. They are produced into lateral points at their posterior extremities. Two curved, interior tubes are connected with the female organ. The postabdominal segments are bandlike rings. The telson is long, spinelike, flat on the dorsal side and carinate on the ventral side.

Several species which have currently been brought under Eurypterus are here shown to belong to Eusarcus and to differ in a number of characters of generic value, viz, the form of the carapace which is triangular, the marginal position of the compound eyes, the decrease backward of the endognathites and the spinosity of all legs, the form of the metastoma, which is subtriangular and the broad· and flat preabdomen. The differences of Eurypterus from the other genera are well known and for the most part manifest. They consist principally in the position of the lateral eyes, the absence of distinct facets, the different development of the chelicerae and endognathites, the form of the metastoma, of the opercular appendages and of the telson.

The North American species are given in the following list, those found in New York being distinguished by an asterisk. The list is in ascending order.

Lower Siluric
    FRANKFORT SHALE
*E. megalops *nov.*
*E. pristinus *nov.*
*E. ? (Dolichopterus?) stellatus
        nov.

Upper Siluric
    CLINTON BEDS
*E. prominens *Hall*
    KOKOMO WATERLIME—(=Lockport)
E. kokomoensis *Miller & Gurley*
E. ranilarva *nov.*

Upper Siluric

GUELPH DOLOMITE

E. (Tylopterus) boylei *Whiteaves*

PITTSFORD SHALE

*E. pittsfordensis *Sarle*

SHAWANGUNK GRIT

*E. maria *Clarke*

BERTIE WATERLIME

*E. remipes *DeKay*

, *E. lacustris *Harlan*

*E. lacustris *var.* pachychirus
   Hall

*E. dekayi *Hall*

*E. pustulosus *Hall*

MANLIUS LIMESTONE

*E. microphthalmus *Hall*

Carbonic

WAVERLY BEDS

E. approximatus *Hall & Clarke*

COAL MEASURES

E. mazonensis *Meek & Worthen*

E. mansfieldi *C. E. Hall*

E. pennsylvanicus *C. E. Hall*

E. potens *Hall*

E. stylus *Hall*

Eurypterus remipes DeKay

Plates 2–8

E u r y p t e r u s r e m i p e s DeKay. Ann. N. Y. Lyc. Nat. Hist. 1825. 1: 375, pl. 29

E . r e m i p e s DeKay. *Ibid.* 1828. 2:273

E . r e m i p e s Harlan. Geol. Soc. Penn. Trans. 1832. 1: 96, pl. 5

E . r e m i p e s Bronn. Lethaea Geognostica. 1: 109, v. 9, fig. 1

E . r e m i p e s Hall. Palaeontology of New York. 1859. 3: 404*, pl. 80, fig. 1-12;
   pl. 80A, fig. 1-6; pl. 83B, fig. 2

E . r e m i p e s Clarke. Zittel's Text-book of Palaeontology, Eastman Translation.
   1900. v. 1, pt II, p. 676, fig. 1420, 1421

and of numerous authors.

Not

E . r e m i p e s Eichwald. Soc. Imp. des Naturalistes de Moscou. Bul. 1854. 1: 49,
   100, pl. 1

E . r e m i p e s Nieszkowski. Arch. für Liv-, Est- u. Kurland. 1859. Ser. 1, Bd. 2,
   p. 299-344, T. 1, 2

E . r e m i p e s Logan. Geology of Canada. 1863. p. 354, fig. 464

E . r e m i p e s F. Roemer. Lethaea Palaeozoica. 1876. pl. 18, fig. 4

E . r e m i p e s Gerstäcker. Klassen und Ordnungen des Thierreichs. pl. 35, fig. 13-16;
   pl. 43, fig. 1, 2

E . r e m i p e s McMurrich. Text-book of Invertebrate Morphology. 1894. p. 433,
   fig. 198

Description. Body of small size, ovate-lanceolate in form, four times as long as wide, relatively wide in front and broadest at one third of its length; moderately convex.

Cephalothorax relatively small. The carapace occupies one sixth or less of the total length of the body, is typically trapezoidal in outline, length to width as 3 : 4 or more frequently as 4 : 5; its lateral margins nearly straight, slightly converging forward, forming an obtuse, slightly rounded angle, with the nearly straight frontal margin. The posterior margin is broadly concave, the postlateral angles truncated, the truncated portion forming a distinct angle with the extremities of the concave part. The surface is moderately convex, highest in the middle near the posterior margin, where it is about one fourth as high as long. The carapace is bordered by a steeply inclined smooth marginal rim, broadest in front and narrowing toward the postlateral angles. The outer edge of the carapace is sharp; its underside is formed by the narrow doublure to which the connecting membrane is attached. The latter is frequently cleft along the anterior median line. Its width and natural position are shown in plates 5 and 6, figure 2. The *compound eyes* are situated a little in front of the middle, twice as far apart as distant from the lateral margin, one fifth, or less, as long as the carapace, bean-shaped, prominent, the kidney-shaped visual area entirely smooth. The two *ocelli* are situated on separate tubercles in a line connecting the centers of the compound eyes. Along the posterior half of the middle line a broad flat ridge (glabella) is delimited by two parallel furrows. Another pair of broader and deeper furrows passes in front and outside of the lateral eyes. These can be traced to the posterior margin, toward which they converge and become fainter. The part of the carapace outside of this furrow is very smooth. Frequently a small triangular area or a median furrow is observed on the mediofrontal part of the carapace.

The *preabdomen* occupies one fourth of the length of the body, and is a little wider than long. It attains its greatest width at about the fourth tergite. In the best preserved specimens it is almost evenly convex

[pl. 5, fig. 5], the marginal portions but slightly flatter than the rest; in many partly compressed specimens [pl. 4, fig. 4] the axial part remains prominent, as in the axis of the trilobites, while the lateral parts assume an aspect similar to that of the pleura. They are depressed and slightly raised toward the margin and bent specimens show on the inner side folds that are slightly curved and pass obliquely forward. The first tergite is narrower than the others and its postlateral angles truncated like those of the carapace. Its length is about seven and one half times the width. The middle portion of the tergites is broadly arched forward, while the lateral portions are normal to the axis of the body or again curve forward. The antelateral angles are produced into articulating lobes. The tergites overlap along their anterior margins about one sixth their length. The posterior doublure is about one fifth the length of the segment. The ventral side of the preabdomen appears to have been more convex than the dorsal, for in compressed specimens the edges of the ventral plates project on both sides beyond the dorsal plates [pl. 4, fig. 4]. Probably the ventral median line was somewhat depressed, as in E. microphthalmus. The five sternites are longer than the tergites, medially cleft, bounded by straight transverse anterior and posterior margins and, with the exception of the operculum, are furnished with large rounded antelateral lobes. The operculum is longer than the other sternites, its antelateral angles are rounded off, while the anterior edge is produced into a broad median lobe. A like lobe is observed on the second sternite in the female. The postmedian angles of the two opercular plates are also produced into lobes, while those of the following sternites are well rounded.

The *postabdomen* is one third as long as the whole body. From the first to the sixth segment the width decreases by three fifths of the width of the first segment, while the length of the last is double that of the first. The first differs in appearance from the others in having the lateral margins strongly convergent backward, thus resembling the preceding tergites, while the others have subparallel lateral margins. Likewise the first segment has broadly convex anterior and equally concave posterior

margins, while the succeeding segments have approximately straight transverse margins. The segments possess faintly outlined pleural areas denoted by a flattening of the lateral region, and a small spine on the postlateral angles. The spines of the last segment are distinguished from the others by their size, but do not grow into the long lobes which flank the telson in other species of Eurypterus. The posterior doublures are short, not one fourth as long as the segments.

The *telson* is short, having one fourth the length of the body, contracts rapidly from the articulation to one half its width and then continues slender to the bluntly triangular point. The margins are marked by oblique fine incisions that increase in size posteriorly and form a tuft of spines surrounding the point. The upper side is flat or slightly concave, the underside furnished with a rather narrow, flat-topped carina.

Appendages. The appendages of the cephalothorax with exception of the chelicerae were well known to Hall. They agree in all features with those of the closely related E . f i s c h e r i . The preoral appendages have been found more or less entangled with the endognathites; a single detached chelicera, lacking only the basal segment has however been observed [pl. 7, fig. 1]. The pair of pincers is broadest at the base, about twice as long as broad; the blades occupy only about one third of the length of the pincers; they are broadest at the base, taper rapidly, are edentulous, and with very acute tips. The tip of the movable blade is bent inward and is needlelike. The *endognathites* are relatively short and robust; of the first pair only the terminal spines or claws project beyond the shield border, while the members of the second pair extend for about one half their length beyond it, and those of the third pair clear it by fully three fourths their length. The fourth pair reaches beyond the third by the length of its last three segments. The first three pairs are of equal width, and in the first, the segments are twice as wide as long. The spines are long, slender, curved, paired and of subequal length, each segment bearing one pair [pl. 7, fig. 3]. The hooklike long, reflexed evagination of the fifth segment of the second endognathite in the male which has been

described by Holm [text fig. 32] has not been seen in our material, probably because, as in Limulus, only the mature individuals after the last molt possessed it. Besides the long paired spines, each segment was furnished with one or more short, blunt spines [pl. 7, fig. 2], located at the anterior margin. The clawlike terminal segment and the spines of the penultimate segments are shorter than the others. As in most Eurypteri, the fourth endognathite lacks the spines, except those of the last two segments, and is relatively longer and more slender. As none of the coxal segments of the first three pairs of endognathites have been found detached, we are unable to describe them beyond stating that they are short and broad and bear at the inner upper angles, dentate manducatory faces with short conical teeth. They apparently show the progressive changes in form posteriorly as described by Holm. The coxa of the fourth endognathite is seen on plate 7, figure 6. Its length and width are nearly equal, while in the preceding coxae the width surpasses the length. The manducatory edge is borne on a marked prolongation. The circular foramen of the posterior margin, to which an auditory function has been ascribed, is well shown. Plate 4, figure 2, shows the mode in which the coxae of the endognathites are arranged like the tiles of a roof, exposing in ventral view only the upper margin and the prolongation bearing the manducatory edges, while plate 4, figures 2, 3, show the relative length and thickness of the endognathites.

The swimming legs are strongly developed in this type. When reflexed, they reached to the sixth tergite, and are correspondingly stout. The coxa is usually well exposed [pl. 6, fig. 8; pl. 7, fig. 7, 8]. It is subquadrate, broader in front than behind; the manducatory face is about one third the length of the inner margin and borne on a well defined neck. The face consists of a beveled chisel-like upper half followed by a more prominent row of six to seven denticles that are shorter than those of the other legs [pl. 7, fig. 6]. The second and third joints are short and ringlike. The stemlike process by which the second joint articulates with the coxa is distinctly seen in plate 7, figures 7, 8. The fourth segment is about one

third longer than wide, distinctly convex forward and furnished with a small spine at the posterior end of the gently concave distal margin. The fifth segment is subquadrate, deeply emarginate at the under side of the distal extremity [pl. 7, fig. 8] and furnished with a triangular process on the upper side. The sixth segment is semioval, rapidly expanding distally and bearing an acute articulating process on the distal extremity. The seventh and eighth segments are much expanded; the seventh subrectangular, its anterior side very convex, the posterior nearly straight. The triangular guard plate is of relatively large size, its distal margin finely serrate. The eighth segment is oval in outline, about as long as the seventh, but only half as wide. Its anterior margin is very finely serrate, the serrae becoming longer and narrower toward the extremity and grouped into larger serrae, alternating with about six small ones [pl. 7, fig. 11]. The latter segment bears the small, oval, rudimentary ninth segment.

The *epicoxite* has not been seen in position; a detached epicoxite, found in association with this species and presumably belonging to it, is reproduced on plate 7, figure 5.

The *endostoma* has not been seen.

The *metastoma* is oval, not quite twice as long as wide, widest in the middle, or a little in front of the middle. The anterior extremity is gently emarginate and the posterior truncate.

The *genital appendages* of the species have been found well developed in but very few specimens, obviously owing to the fact that the great majority of individuals in the Litchfield region are immature. A mature female operculum with appendages, except for the terminal pair, is shown in plate 8, figure 1. The most important features of this specimen are the two pentagonal anterior pieces separated by sutures from the two halves of the operculum, and the two imbricating unpaired lobes, each of which expands slightly at the posterior extremity and terminates with two diverging, acute lateral lobes. The two tubular organs which were first recognized by Holm in E. fischeri, are here seen as two black

curved appendages of the anterior part of the large median lobe. According to Holm they are tubular, thick skinned organs on the inside of the operculum. The tubes, in this specimen an internal view of the operculum, terminate exactly in the posterior corners of the pentagonal pieces, thus seeming to verify Holm's inference that they emptied there. This operculum also distinctly shows the transverse median line, which here is not simply constituted of a row of scales but begins as a sharp continuous linear depression along which the anterior part projects above the posterior, dying out toward the lateral edges. The posterior paired hornlike appendages are as in other members of the genus.

The appendage of the second sternite has not been seen separately, but its two long and slender terminal pieces are sometimes noticed below the appendage of the operculum in an interior view of the ventral side. Plate 8, figure 4, is a separate second sternite with the basal portion of its genital appendage preserved. .

The male appendage has been observed in several individuals. It is best seen in the two detached half opercula [pl. 6, fig. 7] as a small median lobe with sagittate anterior and straight transverse posterior ends.

Ornamentation. The carapace exhibits a fine granulation along the lateral and frontal margins [pl. 6, fig. 3, 4] in a belt that is narrowest on the sides and widens in front so that it reaches back to the compound eyes; and a short transverse row of small spines along the posterior edge. The tergites possess a zone of small subcircular scales along the middle portion of the frontal margin and a transverse row of six longer spinelike scales along the posterior margin, which [pl. 8, fig. 2] are seen to be the posterior terminations of longitudinal rows of smaller scales of the general character. On the postabdominal segments [pl. 8, fig. 5] these terminal spines die out, but the six longitudinal rows of scales become reduced to two, which are very prominent, diverge backward, are circular at the beginning, lengthen posteriorly and finally overlap. A transverse row of small semicircular scales delimits the exposed portion of the tergites and postabdominal segments from the frontal overlapped portion. The ven-

tral side [pl. 8, fig. 3] is ornamented with closely arranged semicircular to semilunar scales, largest and most prominent in the middle anterior region of the operculum, otherwise rather faint.

Ontogeny. E u r y p t e r u s r e m i p e s has not yet afforded any growth stages as young as those of species from Otisville. The smallest specimens are already of neanic age. Hall figured an example [1859. v. 1, pl. 80, fig. 1] which without the telson spine, measures but 18 mm. An outline drawing [text fig. 33] and photograph [pl. 4, fig. 1] of this specimen are here reproduced, and also the drawing of another small indi-
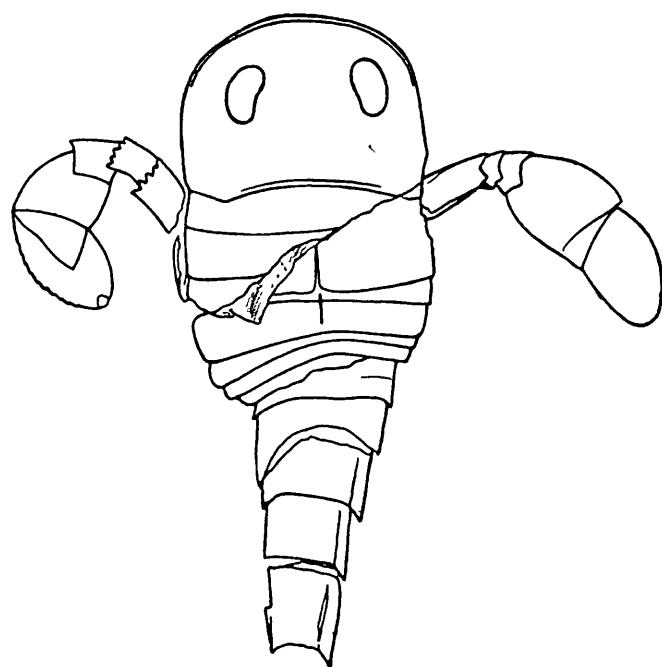
Figure 33 Outline camera drawing of young of E u r y p t e r u s r e m i p e s. x3. The same specimen is reproduced on plate 4, figure 1
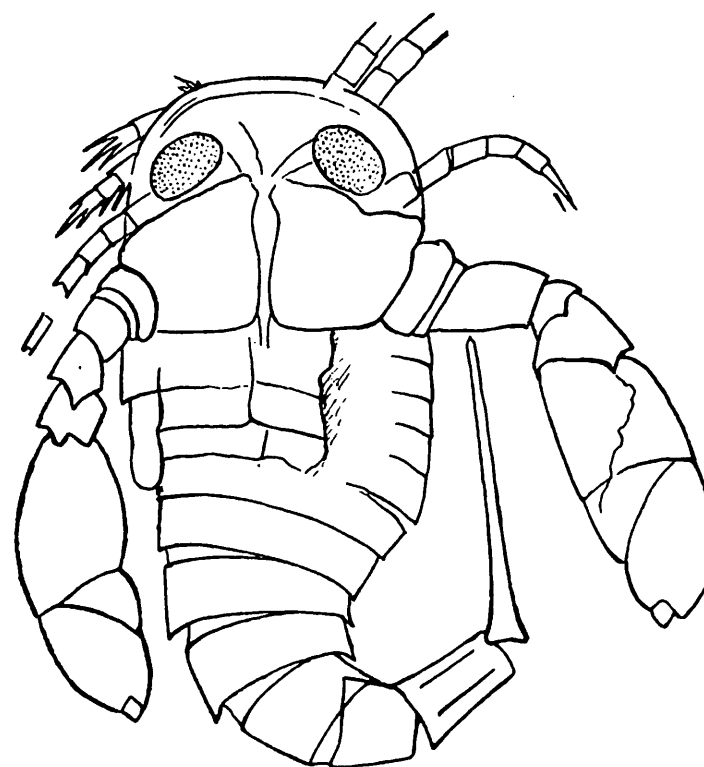
Figure 34 Another very young specimen of the same species. x3

vidual [text fig. 34] given by Clarke in Zittel-Eastman, *Text-book of Palaeontology*, 1896, figure 1420. In the explanation of these figures Clarke pointed out the strongly anterior position of the eyes, relatively large size and length of the swimming legs and abrupt posterior contraction of the abdomen. The paucity of abdominal segments in figure 33 proves on investigation to be only apparent and due to the forcing of the posterior abdominal segments under the anterior. This secondary contraction of the body, apparently but accidental, or incidental to the process of molting, is also observed in some other young individuals. It is the principal cause of the contracted appearance of the abdomen.

We add here several more photographs of parts of very young individuals, among them a carapace [pl. 5, fig. 1] that is much smaller than any others before mentioned (2.5 mm long). This is especially remarkable for the great size and prominence of the compound eyes, as well as of the ocellar mound, a feature that was uniformly observed in the nepionic eurypterids from Otisville. The eyes are here 1 mm long, or four tenths the length of the carapace as against one fourth or 2.5 in the mature individual. This relatively great size of the eyes in youth is still apparent in larger individuals, as that figured in plate 4, figure 4. While these eyes of the young are relatively larger than those of the adult, they still remain entirely in the anterior half of the carapace, thereby producing an appearance of more anterior position which, however, in the figure cited from Zittel-Eastman is somewhat exaggerated.

The outline of the carapace in the youngest specimen is still rounded at the antelateral corner, but soon becomes squarish as in the older ones [pl. 5, fig. 1, 2]. The carapace itself is distinctly larger in comparison to the whole body than in the ephebic stage, although on account of the distortion of one or another part of the body in every observed individual it is difficult to demonstrate this fact by measurements. In specimen plate 4, figure 1, the smallest whole individual observed, the carapace occupies fully one fourth of the whole body, while in the larger specimens it is less than one fifth the length of the body.

The swimming leg when reflexed will reach to the tenth segment or farther in young individuals [pl. 4, fig. 1–3], while in the ephebic stage it reaches only to the seventh segment. The posterior endognathites appear also to be slightly longer.

It is questionable whether the preabdomen is relatively shorter in the young at our disposal than in the adult although the Otisville material indicates that in the nepionic stage the preabdomen may well have been shorter and more abruptly contracted toward the postabdomen. In the specimens before us, however [pl. 4, fig. 1–3], the relatively greater size of the carapace produces the impression of a relatively smaller and shorter

preabdomen, since the latter is here only as long as the carapace, while in the resulting adult it is longer by one fourth.

The postabdomen in the young exhibits its usual proportions.

The ornamentation of the dorsal side shows a difference between the neanic and ephebic forms in the recognizable number of longitudinal series of scales, the former possessing but four on the anterior preabdominal and two on the following segments as against six and two in the ephebic stage.

Measurements. A well preserved and normal specimen, plate 5, figure 5, gives the following figures: length and width of carapace, 18.7 mm and 24.5 mm; length and width of preabdomen, 27.3 mm and 27 mm; length of postabdomen, 40.4 mm; its anterior and posterior widths, 20 and 7 mm. The telson measures 28 mm and is 5 mm wide at its beginning. The lateral eyes of this specimen are 5 mm long and 5.5 mm from the frontal margin. The first tergite is 3.6 mm long and 25.5 mm wide, the third about 6 mm long and 27.4 mm wide. The first postabdominal segment is 6 mm long and 19 mm wide in the middle, the last measures 10.5 mm by 8.5 mm.

The largest carapace observed is 50 mm in length and 67 mm in width; the one figured on plate 6, figure 3 is 45 x 60 mm.

Horizon and localities. DeKay's type of this species came from Waterville, town of Westmoreland, Oneida co., N. Y. Hall's numerous originals were partly from the same locality and in still greater number from Jerusalem or Wheelock's hill, Litchfield, Herkimer co., N. Y. which, with its neighborhood, has to this day furnished the principal supply of this species. In late years it also has been obtained in great numbers a few miles northeast (near Cedarville) and west (Paris Hill) of Jerusalem hill. It occurs near Oriskany; at Cayuga junction, Cayuga co. and possibly at Buffalo. In all these localities it has been found in the uppermost part of the Bertie waterlime, near the overlying Cobleskill limestone. But we have also from Seneca Falls, Seneca co., typical specimens from the Rondout waterlime above the Cobleskill limestone.

Remarks. As E . r e m i p e s was the first described representative of the genus and is a very close relative of the Baltic form, it is not surprising that the latter was for a long time identified with our species, until Eichwald [1860, p. 1355] pointed out the differences. Schmidt has more fully stated the relations of the two. He writes [*op. cit.* p. 62]:

Die amerikanischen Arten E . r e m i p e s DeK. und l a c u s t r i s Harl. stehen dagegen unsrer Art ganz besonders nahe und es ist kein Wunder, dass man sie lange mit ihr identificirt hat. Sie kommen genau in dem nämlichen geologischen Niveau vor und könnten ganz gut als lokale geographische Varietäten unsrer Art angesehn werden. Der Kopfform nach steht unsre Art ziemlich in der Mitte zwischen den beiden amerikanischen, doch ist bei letztern die bei uns gewöhnliche trapezoidale Form selten so ausgeprägt. Auch das Metastoma weist einen kleinen Unterschied auf, indem seine grösste Breite bei unsrer Art in die Mitte, bei den amerikanischen etwas vor dieselbe kommt. Die grössere Zahl der Schuppenreihen auf der Oberseite bei unsrer Art, auf die Eichwald aufmerksam macht, scheint mir kein ganz genügendes Kennzeichen zu sein. Am meisten scheint sich der Schwanzstachel von dem der amerikanischen Arten zu entfernen, da er bei keiner derselben so schlank wird; ebenso ist auch das letzte Leibesglied bei den amerikanischen Arten am Grunde nie so tief eingeschnitten wie bei unsrer, bei der in dieser Beziehung allerdings auch Variationen vorkommen.

We may add a further difference, readily noticed with good material, namely, that the spines of the endognathites do not differ on the anterior and posterior sides so greatly in length as in E . f i s c h e r i , where the posterior spines are much longer than the anterior ones. Also the surface sculpture differs, as pointed out by Eichwald, but doubted by Schmidt, in that in E . r e m i p e s and l a c u s t r i s there are seen distinct rows of scales in single file on the postabdominal segments while in E . f i s c h e r i only longitudinal patches of scales appear.

Other differences are seen in the form of the segments of the legs. Thus the fifth segment of the swimming leg is deeply concave on the underside in our species, but not so in E . f i s c h e r i , and the seventh segment is straight on the posterior side and very convex on the other, while it is equally concave on both sides in E . f i s c h e r i . A very

suggestive distinctive character appears to us to be the great difference in the relative sizes of the compound eyes. In E . f i s c h e r i they reach about one third the length of the carapace, but in both E . r e m i p e s and E . l a c u s t r i s they are but one fifth or less of the length of the carapace. For this reason E . f i s c h e r i makes a rather youthful impression when compared with our forms. Altogether, the differences are so small that Schmidt's suggestion that they are but geographical varieties, is fully supported.

The relations of E . r e m i p e s and E . l a c u s t r i s are described under the latter species. It may be here stated that the two are more closely related to each other, than either of them to E . f i s c h e r i , indicating that they had but lately separated. Their differences rest mainly in the shape of the carapace and they are duplicated by those between E . f i s c h e r i and E . l a t i c e p s , two forms associated in the same (Baltic) rocks.

The E . p i t t s f o r d e n s i s described by Sarle from the Pittsford shale, is also very closely related to E . r e m i p e s and l a c u s t r i s , indeed is hardly more than a mutation and therefore undoubtedly a direct ancestor of the two later Bertie waterlime species.

Several of our specimens of E . r e m i p e s are so favorably preserved that they present features not observed before. The most important of these is that represented in plate 6, figure 6, which comes from a porous bed of coarse dolomite at Morganville, N. Y., in which the integuments are but little or not at all flattened. It shows a distinct glabella, corresponding in form and extension to that of Limulus and obviously due to the same causes. The same specimen also exhibits a deep furrow surrounding the lateral eyes and an obscure broad ridge connecting the latter and bearing the ocelli. The frontal slope is even and uniform and a narrow flat or slightly depressed border is found inside the beveled edge. Another partially compressed specimen [pl. 6, fig. 5] exhibits the glabella and a broad smooth border, corresponding in extent to the underlying frontal membrane of the underside of the carapace.

Another interesting specimen is that reproduced on plate 5, figure 7 which shows two circular, transversely wrinkled patches behind the frontal margin.

Specimens plate 5, figures 3–5, show a trilobation of the abdomen on account of the distinct depression of the epimera. It will be noticed that the spines on the posterior margins of the tergites are restricted to the axis. Where the body is slightly bent, as in specimens figures 3 and 4, peculiar oblique folds appear, which indicate the relative thinness of this part of the integument and may correspond to folds that formed during the life of the animal. This condition gives the test a peculiar trilobite-like appearance.

We have already mentioned among the differential characters of E. remipes and E. fischeri the double series of scales on the dorsal side of the postabdomen. In specimens where the inside of this integument is exposed, it is seen that between these rows the carbonaceous film appears lighter, suggesting a somewhat thinner test, which at the same time projects a little. This fact indicates that the interspace marks the position of the alimentary canal, the scales being the attachment places of the suspensory muscle strands. The interspace would then correspond to the projecting preanal ridge on the last segment in Pterygotus, which is also attributed to the pressure of the intestine.

Another specimen worthy of notice is one in which the test of the carapace is partially weathered, leaving the cast of the interior surface of the frontal part exposed and exhibiting a faint radiating structure that is restricted to the region where, from analogy with Limulus, the liver must have been located. It resembles strikingly the supposed liver impressions seen in some trilobites.

Eurypterus lacustris Harlan

Plates 9–12; plate 13, figure 3

Eurypterus lacustris Harlan. Geol. Soc. Pennsylvania Trans. 1834. 1:98, pl.5
E. lacustris Hibbert. Roy. Soc. Edinburgh, Trans. v. 13, pl. 12
E. remipes Bronn & Roemer. Lethaea, 3d ed. 1854. 2:666, pl. 9³, fig. 1

E . l a c u s t r i s Hall.   Palaeontology of New York.   1859.   3: 407*, pl. 81, fig. 1-11;
      pl. 81A, fig. 1; pl. 81B, fig. 1-5; pl. 83B, fig. 3
Not
E. l a c u s t r i s Salter. Geol. Soc. London.   Quart. Jour.   1859.   15: 235
E. r e m i p e s Logan.   Geology of Canada.   1863.   p. 354, fig. 464.

Description. *Body* medium sized, ovate-lanceolate in form, robust, not quite four times as long as wide.

Cephalothorax broad and short. *Carapace* trapezoidal, about two thirds as long as wide (length: width as 6 : 9–10), occupying between one fifth and one sixth of the whole length; broadest at the base. Its lateral margins are nearly straight, slightly converging forward; anterior margins gently convex forward; antelateral angles well rounded; posterior margin slightly concave, bent forward near the genal angles. Profile of carapace not observed. The lateral eyes are small, only one fifth as long as the carapace or less; situated in front of the middle, twice as far apart as distant from the lateral margin, bean shaped, prominent; ocelli situated midway between them.

The *preabdomen* occupies about one fourth the length of the body. It is slightly wider (about one eighth to one ninth) than long, widening gradually to the fourth tergite and then decreasing again as gradually. The first tergite is seven and one half times as wide as long, the fourth only about six times. The outline of the tergites is the same as in E . f i s c h e r i . The sternites are also like those of that species, about four times as wide as long.

The *postabdomen* occupies one third of the length of the whole body. The first two segments contract at the same rate as the posterior preabdomen, the rest more gradually to nearly one third its anterior width. The telson corresponds in its relative size and character to that of E . r e m i p e s .

Appendages. The cephalothoracic appendages, including the chelicerae, are well shown in several specimens. They differ but slightly from those of E . r e m i p e s .

The chelicerae are seen in position in one specimen. The pincers are partly lost and partly obscure, but the full length of the basal joints is shown. A well preserved chelicera exhibiting a broader free blade with slightly curved tips and a narrower straight finer blade is shown in another example. The basal joint is twice as long as the blades and rather slender. This chelicera measures about three sevenths the length of the metastoma. A third detached chelicera, finely exhibiting the blades, is reproduced in plate 12, figure 1. Here the basal joint is broad and relatively short.

The four pairs of endognathites do not differ from those of E . remipes. The first three pairs are relatively short and stout; they increase in length from the first to the third pair at such a rate, that in their usual position their extremities form a straight line nearly tangent to the front of the carapace [pl. 10], the third being about twice as long as the first. The middle segments of the first endognathite are about one third wider than long, those of the third as long as wide. The spines of these endognathites are long and slightly curved and those of the posterior sides slightly longer than those of the anterior. The fourth pair of legs is longer than the preceding pair by one half and slightly more slender. The last clawlike segment is very strongly developed. The coxa of none of these endognathites has been seen fully exposed; nor has the epicoxite been observed.

The swimming legs are broad and powerful organs, though subject to some variation [see var. pachychirus]. They reach to the sixth tergite when reflexed. The coxa [pl. 11, fig. 5] is correspondingly large and strong. In form it does not differ from that of E . remipes. The second to the sixth segments are also like those of that species. The seventh segment which with the eighth forms the paddle is much widened and trapezoidal in outline; its length and width about equal; the posterior side straight or slightly convex, the anterior highly convex, the distal margin straight, with a large subtriangular guide plate for the eighth segment attached to it. The eighth and ninth segments are as in the preceding species.

The metastoma is very similar to that of E . r e m i p e s , but subject to some variation and frequently somewhat contracted in the posterior portion [pl. 11, fig. 5], giving it a more slender appearance.

The female genital appendage was very correctly figured by Hall [*loc. cit.* pl. 81B, fig. 4]. Several well preserved specimens before us show the great size attained by this organ in mature individuals. It reaches with the long paired, hornlike terminal appendages, to the posterior edge of the third sternite. The interior tubular appendages of this organ are finely seen in the original of plate 12, figure 2, where the integument has broken away. They have the precise form and relative proportions of that of E . r e m i p e s . The appendage of the second sternite has not been seen unobscured by the overlying appendage of the operculum. It is, however, well shown in the interior view, reproduced in plate 11, figure 4 [Hall's type of pl. 81, fig. 6]. It is extremely slender and pointed and reaches nearly as far back as that of the operculum. The male appendage does not differ from that of the preceding species.

Figure 35 Euryp- terus lacustris Harlan. Cast of in- terior of proximal por- tion of female oper- cular appendage

Figure 36 Euryp- terus lacustris Harlan. Young indi- vidual. Reproduced on plate 11, figure 1. Natural size

Ornamentation. As far as our observation goes, the ornamentation is quite like. that of E . r e m i p e s . This is especially notable in regard to the series of scales on the dorsal side, already correctly figured by Hall [pl. 81B, fig. 1]. The smaller scales which are rarely seen, are crescent-shaped to subtriangular and nowhere densely crowded. Those of the longitudinal series were larger and circular in the anterior portion, becoming elongate in the pos- terior part of each row.

Ontogeny. But little is known of the ontogeny of this species as but very few young individuals have been obtained and these are too far developed to afford much information. Hall's figure, [plate 81, figure 1],

represents about the youngest stage known as yet in an entire specimen. This is here reproduced by photograph on plate 11, figure 1 [text fig. 36]. This specimen exhibits the somewhat larger size of the eyes and the more compact form of the body. It must, however, be remarked that the body shows evidence of compression axially.

Measurements. In a well preserved adult the carapace measures 44 x 63 mm; the preabdomen (slightly shortened) 51 x 72 mm; the first segment measures 8.8 x 65 mm; the fourth 11 x 70 mm; the postabdominal segments measure respectively 8 x 51 mm; 12.7 x 42 mm; 14.5 x 37 mm; 15 x 33 mm; 17.5 x 27.5 mm; 20.5 x 22 mm. The eyes are 4.7 mm long. The telson spine is 64 mm long and 12.5 mm wide at its anterior extremity. The fourth endognathite projects 41.5 mm beyond the edge of the carapace, the swimming leg 70 mm. In another specimen the carapace is 49.5 x 71 mm; the preabdomen 60.5 x 80.5 mm; the postabdomen is 88 mm long and measures 56.5 mm at its anterior extremity and 20 mm at the posterior one. The telson is incomplete. The eyes are 8.5 mm long; the first endognathite projects 8.5 mm; the second 13 mm; the third 21.5 mm; the fourth 35.5 mm; the swimming leg is 75.5 mm long.

Horizon and localities. E . l a c u s t r i s occurs typically only in the Bertie waterlime quarries at Williamsville and Buffalo, N. Y. and Bertie, Ontario. A few smaller specimens also have been obtained at Black Rock, Erie co. and Union Springs, Cayuga co.

Remarks. In regard to the differences between E . r e m i p e s and E . l a c u s t r i s, Hall makes this statement: " This species differs from E . r e m i p e s in its greater size, and less abrupt attenuation toward the tail, while the carapace is proportionately broader and shorter. There are likewise differences in the anterior feet, and in the form of the postoral plate; the entire form of this latter appendage not having been fully determined." We see the principal distinctive character in the greater width of the carapace, the proportion of length to width in E. r e m i p e s being as 6 : 7 (with 8.5 as maximum) and E. l a c u s -

t r i s as 6:9 (8.5 – 10); and in the different outline; the former having a squarish carapace with subparallel sides and straight frontal margin and subrectangular anterior angles, while in the latter species the sides are more convergent and the anterior angles more rounded. Specimens are, however, common which it is difficult to assign to either species, partly on account of their original intermediate form and partly because of secondary changes through lateral compression. The average representatives of E . l a c u s t r i s are considerably larger than those of E . r e m i p e s although a few carapaces of the latter species indicate that it did not fall much short of the other type in size attained. Nevertheless the great majority of the specimens of E . r e m i p e s obtained in the central New York region are very much smaller. No differences have been observed in the proportions of the abdomen and the appendages (including the metastoma), save perhaps the swimming legs, in which a tendency to greater broadening is observable in E . l a c u s t r i s , and this has led to the variety p a c h y c h i r u s .

A variety r o b u s t u s of the present species has been distinguished by Hall, in regard to which it is stated that: " The form of the anterior feet and the swimming feet are essentially the same, while the joints of the body are proportionately longer and stronger, furnishing sufficient ground for a variety, but not satisfactory evidence of specific difference." In the explanation of his figures [plate 81C] a note is added saying that further examination with other species has shown that the form has the characters of a distinct species. The difference supposed to rest in the greater length and strength of the abdominal segments is due to the postmortem separation of the segments as far as the stretching of the connecting membranes permitted, while on the other hand, Hall's types of E . l a c u s- t r i s are all somewhat contracted through sliding of the segments over each other. We have been unable to find other differences and therefore consider r o b u s t u s as only a preservation state.

Eurypterus lacustris Hall var. pachychirus Hall

Plate 12, figure 3; plate 19, figure 1

Eurypterus pachycheirus Hall. Palaeontology of New York. 1859. 1: 412*, pl. 82, fig. 1-3

This variety which Hall separated from E. lacustris is based on an abdomen, a group consisting of two swimming legs, several endognathites with operculum; and a separate swimming leg. The types of the abdomen and the swimming leg are in the State Museum; the group of swimming legs and operculum in the American Museum of Natural History. The species is diagnosed as follows: " Carapace unknown. Body robust: crust thick; articulations strong, those of the abdomen extended in strong salient angles at the lateral edges. Bases of the anterior feet strong and broad. Swimming feet strong and large; the seventh (sixth) joint very large and long, inflated and much curved on the anterior side; the free eighth joint is thick and strong, somewhat oval, and narrowing gently toward the point of articulation; the terminal palette is small. The last joints (and perhaps the others) of the swimming feet are serrated on the margins."

In the notes it is added that " the peculiar arching of the seventh (sixth) joint, and the thickened or inflated character of the swimming foot in this species, appear to be sufficiently characteristic to rely upon for specific distinction," and as further distinctive characters are mentioned, that the scaly surface marking of the body is more strongly developed than in any other species observed, and that the anterior margin of each segment is raised in a little elevated band, more prominent and more strongly serrate on its anterior edge than in any of the other species, and finally that the surface is marked by strong longitudinal wrinkles somewhat irregularly disposed.

The great width of the distal portion of the swimming leg and especially that of the seventh segment appear as good distinctive characters, when compared with the narrower appendages of the typi-

cal l a c u s t r i s , but a survey of the larger collection of specimens since gathered from the Bertie waterlime of Buffalo leaves no doubt that there are numerous examples with equally broad swimming legs which are not otherwise distinguishable from E . l a c u s t r i s and that furthermore there occur transitional forms between the two in this regard.

The additional characters, the stronger sculpturing. etc., are taken from the type specimen [*op. cit.* pl. 82, fig. 1] which also retains a swimming leg not shown in the figure. This specimen differs markedly in state of preservation from the great majority of the Buffalo specimens, in not being preserved in a black, perfectly attenuated film, but in bas-relief and with a light brown film, upon which the scales distinctly show. This different preservation is due to the conservation of the fossil, not in the mud rock of the typical waterlime, but in a lighter, dolomitic, slightly coarser grained, somewhat uneven bedded rock that contains L e p e r d i t i a s c a l a r i s and O r t h o t h e t e s i n t e r s t r i a t a. This forms the top stratum of the Bertie, at Buffalo, directly underlying the Cobleskill. There are two other specimens from this bed in the Museum of the Buffalo Society of Natural Sciences and one in the State Museum, all of which retain the surface ornamentation in like distinctness and one of which possesses the broad swimming legs of p a c h y c h i r u s ; but in all other characters they are indistinguishable from E . l a c u s t r i s , especially in regard to the carapace.

We have for these reasons here placed p a c h y c h i r u s with E . l a c u s t r i s as a variety distinguished by its tendency to a broadening of the swimming legs, and consider the other distinctive characters cited by the author of the species as due to the preservation of the material. It may be added that the exposure of the elevated anterior band of the segments and of the line of scales at its posterior margin is due to a pulling of the integument before entombment.

Eurypterus dekayi Hall

Plate 19, figure 2; plate 20, figure 1

Eurypterus dekayi Hall. Palaeontology of New York. 1859. 3: 411*, pl. 82, fig. 1

This species was based on a single specimen, now in the State Museum [pl. 20, fig. 1]. Its distinguishing characters are thus given in the original description: " The entire body is proportionally shorter, the carapace shorter and broader than in E. remipes. The swimming feet are shorter, and the terminal palette a little more developed than in E. remipes or E. lacustris, and the upper abdominal joints differ less from the thoracic joints in length, while the last one is alate on the two lateral edges, a feature not observed in any other species."

The aspect of the type is that of a specimen which has distinctly suffered contraction by a shoving together of the segments and, mindful of the strange changes in aspect resulting from a pushing or pulling of the segments, especially in cast-off integuments, one might reasonably infer that all the above cited differences, save the alate lateral edges of the last segment, were largely of casual origin. The other specimen figured on plate 19 which is more favorably preserved, exhibits the same and additional distinctive characters while it is clearly but partially contracted in the preabdominal region and distended in the postabdominal. The most striking new character in this specimen is the presence of four to five long spines on each segment of the endognathites, instead of but one or two in all other members of the genus. The combined evidence of the two specimens leaves no doubt that we have to regard E. dekayi a peculiar aberrant type of Eurypterus. The following are the characters of this species:

Description. Body of small size, short but broad and compact. The carapace is about one sixth the length of the body, the latter a little more than three times as long as wide.

Carapace relatively very broad and short, its length to width as 6 : 10–11; the character of the margins as in E . l a c u s t r i s ; the lateral eyes relatively small (one fifth of length of carapace), in front of center, far apart, halfway between median line and lateral margin. Ocelli not seen.

Abdomen. The *preabdomen* is contracted in both specimens, in the second less than in the type. Its length is to its width as 2 : 3+. It probably contracted more rapidly at the last tergites than the associated species of Eurypterus, but not so much as the two specimens, in which the last sternites are somewhat shoved together would indicate. The tergites have not been seen, except the first in the hypotype, specimen 2, where it is a narrow band, 11 times as wide as long. The operculum and other sternites apparently do not differ from those of E . l a c u s t r i s except in being relatively somewhat wider.

In the type specimen the postabdomen occupies four ninths of the length of the body without the telson; it is about one fifth longer than wide at its beginning and its total length surpasses its anterior width by about one fifth. At the posterior extremity it has decreased to one third of its anterior width. The first segment is about four times as wide as long, the last is one seventh longer than wide. Its most striking feature is the long alae, resembling those of E . f i s c h e r i in relative size and form. Like the latter they were probably somewhat variable.

The telson spine occupies in the type but little less than one third of the length of the body, as against more than one fourth in the other species. Although the abdomen is contracted, it is manifest that the spine is relatively long. Otherwise it does not differ from that of E . l a c u s t r i s . It is five times as long as its anterior width.

Appendages. But one (the third) endognathite has been seen, its last four segments projecting beyond the head shield. In the type the basal portions of all endognathites are withdrawn under the carapace and have been artificially exposed. The endognathite exhibits four spines on its fifth, five on its sixth and four on its seventh segment, all of which seem

to be of uniform length and slender when compared with those of other species of Eurypterus. It seems hence, that in this species, not only the two usual spines at the distal edge are present, but also that the rudimentary spines at their bases, seen in other species and one or more accessory spines have grown out to the full size of the first pair.

The swimming legs are equally distinct from those of the associated Eurypteri in several features. The coxa is distinctly broader, corresponding to the great basal width of the carapace. Its length and width are subequal. The second and third segments are annular.[1] The fourth, fifth and sixth are notably stronger and wider than in E . f i s c h e r i and r e m i p e s , though not differing otherwise, while the seventh is remarkably short and wide, having the general form of the corresponding segment of E . l a c u s - t r i s var. p a c h y c h i r u s , but being much smaller relatively to the whole leg. The eighth segment also, forming with the seventh, the oar blade, is notably smaller than in other species. The terminal, rudimentary segment, as already remarked by Hall is a little larger than in E . l a c u s t r i s .

The metastoma is like that of E . l a c u s t r i s . The female and male appendages, seen in these specimens, do not appear to differ from those of either E . l a c u s t r i s or E . r e m i p e s except that the terminal paired lobes in the female appendage are shorter than in E . l a c u s t r i s and correspond to those of E . f i s c h e r i or r e m i p e s .

Ornamentation. Only interior views of the integument have been obtained and hence the character of the ornamentation has remained unobserved, except for the two converging rows of spines on the post-abdominal segments and a few traces of subtriangular scales, indicating a sculpturing very much like in E . f i s c h e r i .

Measurements. The carapace of the type is 31 mm long and about 58 mm wide; that of the hypotype measures 33 x 55 mm; the eyes of the latter are 6.8 mm long. The preabdomen of the type measures 40.4 x 71 mm, both measurements being but approximate on account of

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[1] The third was overlooked by the draftsman of the original drawing.

contraction and imperfect preservation.   In the hypotype the dimensions of the preabdomen are 42 x 63 mm.   The postabdomen of the type is 50 mm wide at the proximal end, 56 mm long and 17 mm wide at the distal end. That of the other specimen is too long by distention, its proximal width being 50 mm, its distal 17.5 mm and its length 73 mm (probable normal length about 65 mm).   The telson of the type is 53 mm long and 10 mm wide at its proximal end.

Horizon and localities.   The two known specimens are from the Bertie waterlime of the neighborhood of Buffalo.

Eurypterus maria Clarke

Plates 21, 22

E u r y p t e r u s   m a r i a Clarke.   N. Y. State Mus. Bul. 107.   1907.   p. 305, pl. 1, fig. 1, 2, 4; pl. 2, fig. 2, 4, 7; pl. 3, fig. 1-5, 7

The preliminary description of this form in Bulletin 107 is as follows:

The general form of the largest observed individuals of this species is elongate and slender with very little abdominal expansion and no lobation of the segments.   In these ephebic conditions the head is somewhat elongate, regularly rounded in front and with subparallel lateral margins. The eyes are crescentic, subcentral, as far asunder as the inner margin of each is from the margin of the shield.

The ocellar lobe is well defined at an early stage.   A specimen 63 mm long without the telson, apparently mature, has 11 segments, but a break across the body leaves room enough for a 12th.   The width of the base of the head is 15 mm and this is but very slightly less than the greatest expansion of the abdomen.   Little trace of surface sculpture is visible on any of the parts.

Description.   *Body.* The body is terete or subconical, with subcircular sections in all parts save the carapace.   It is about five times as long as wide, and tapers very gradually from the base of the carapace.

Cephalothorax. The cephalothorax is broadly semielliptic to semicircular in outline, about one third wider than long, widest at the base and evenly rounded.   While it is as broad as, or broader than, the widest part of the abdomen, it attains but one sixth to one seventh the length

of the body. Its surface was evenly and highly convex, culminating near the center at the ocellar mound. It is surrounded by a narrow thickened filiform border. The posterior margin is straight transverse with a faint indication of fulcra near the acute genal angles.

The compound eyes are subcentral in position, situated as stated in the preliminary description; the visual surface is crescentic and only prominent in compressed specimens, while the entire ocular node, which has the form of a sector, being rounded at the outside and angular on the inner side, is distinct only in young individuals. The eyes occupy about one third the length of the carapace.[1] The ocelli are situated on a line connecting the centers of the compound eyes and located on a large, prominent mound.

Abdomen. The abdomen is slender, widening so little from the base of the carapace to the third segment that in many specimens it tapers with apparent regularity toward the telson. The length is three times the greatest width.

The *preabdomen* is widest at the third and fourth tergites. Its length is to its width as 5 : 4. The tergites are narrow bands with straight or but slightly curved transverse margins and parallel lateral margins. The anterior and posterior margins diverge near the lateral extremities where the segments widen somewhat. Their antelateral angles are produced into broad blunt lobes, while the postlateral angles are either rectangular or furnished with short acute lobes, that are directed posteriorly and increase somewhat in size in the posterior segments. The segments were originally highly arched with a narrow flat strip, representing the epimera, along the lateral margins. Each tergite was not only strongly bent from one side to the other but also from forward backward and highest in the anterior third, with a steep decline forward and a more gradual one backward, finally grading into a narrow flat border.

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[1] The extreme variation in size and location of the compound eyes is due to different direction of compression and has been more fully described under " Remarks."

The first tergite is considerably shorter than the others. It is six to seven times as wide as long; the following ones are about four times as wide as long.

The sternites are less straight bands than the tergites, their middle portion curving forward more distinctly. Their antelateral angles are produced into broad rounded ears or lobes, while the postlateral angles are well rounded. The operculum has not been observed.

The *postabdomen* tapers uniformly to the posterior extremity which is but one third as wide as the anterior. The segments are all circular in section, and they gradually become longer while they diminish in width, the first segment being four times as wide as long, while in the last the width is to the length as 3 : 4. The segmental rings are very simple with but very inconspicuous lateral flanges in the first segments and none in the last.

The telson is bluntly lanceolate; at the base it is three times as wide as long. Its dorsal side is convex and raised into a median keel; the underside flat and the lateral margins are furnished with sharp, blade-like edges.

Appendages. In spite of the great number of heads found only the swimming legs have been observed In mature specimens [pl. 21, fig. 11] these are remarkably short and protrude but little more than half the basal width of the carapace. The eighth segment (the palette) is long, elliptical, the ninth forming a small terminal claw. Of the seventh segment but a portion has been seen protruding from below the carapace and this indicates that it was considerably narrower than the following ones.

Ornamentation. No scales or tubercles have been made out on either the carapace or abdomen. The only traces of ornament observed are a median transverse line on both the sternites and tergites, with traces of more lines n the latter, especially near the anterior margin.

Ontogeny. In its ontogeny Eurypterus maria includes a larval stage that is not only strikingly different from the mature but also highly suggestive phylogenetically by its great similarity to Strabops.

This we have identified with the *nepionic* stage since it can not be much older than embryonic. It is represented by the two specimens plate 21, figures 1, 2.

Herein the most striking differences from the ephebic stage are:

1 The great width and small length of the body and the resulting rapid contraction from the preabdomen to the postabdomen.

2 The excessive width and small length of the subtriangular carapace.

3 The great size of the compound eyes.

4 The shortness and great width of the segments.

5 The relatively greater size of the swimming legs.

In these nepionic specimens the width of the body is to its length as 3:8, and in the ephebic stage as 3:15, hence the former stage is about twice as stout as the latter and conversely the contraction of the body is twice as rapid in the nepionic stage.

The carapace of the mature E u r y p t e r u s m a r i a is one third wider than long (3:2), while that of the youngest nepionic specimen is twice as wide as long (4 : 2) and in the other much larger nepionic specimen the proportion is still 3½ : 2. The antelateral angles are so strongly truncated that the carapace approaches a triangular outline.

In this nepionic stage the compound eyes may reach one half the length of the carapace [pl. 21, fig. 3], while in the ephebic form they occupy only one third that length. They also lie farther forward and converge strongly on their longitudinal axes, while in mature individuals they either converge slightly or are subparallel. This strong convergence in the nepionic stage is continued into the neanic stage [pl. 21, fig. 9] and is in harmony with the convergence of the lateral margins. It is further to be noted that the outline of the ocular node is broadly elliptical in this stage and that the crescentic visual surface is not to be distinguished from the ocular node. It is therefore possible that the visual surface extended over the whole node and not until later became restricted to the crescent band or anterior side of this node. The appearance of these nodes as represented in figures 9 and 3 would seem to support this view. In the

former specimen the eyes are not only circular, at least that on the left side which is fully exposed, but this left eye is also distinctly surrounded by a thickened border, and as this border in the adult only surrounds the visual surface, the inference is suggested by this specimen that the whole node was covered by the visual area. The second specimen suggests that here the visual surface still occupied the greater portion of the node, leaving only a narrow crescent on the inner side of the node unoccupied.

The shortness of the segments, compared with their width, is a striking feature of these nepionic individuals. The preabdominal segments are from 6–9 times as wide as long, while in the ephebic stage they are but 4 times as wide as long with the exception of the first tergite which retains the nepionic dimensions. The first tergite in the first nepionic stage, shows no difference in length from the others, while in the next stage [pl. 21, fig. 8], it is well distinguished. A specimen [pl. 21, fig. 1] with a length of 5.25 mm has but 8 segments. One [pl. 21, fig. 2] which measures 8 mm has already the full complement of 12. In the latter the shortness of the segments is still more striking than in the former and it appears that the insertion of the new segments took place rapidly in successive molts at the expense of their longitudinal growth. It is impossible in these young specimens to discern the boundary between the pre- and postabdomen.

The swimming legs are relatively longer and wider in the larval forms, as a comparison of figures, plate 21, figures 1 and 2; plate 21, figure 5, with plate 21, figure 11 will readily show. In the ephebic specimen the swimming leg when reflexed hardly reached beyond the third segment; in the first nepionic specimen it extends to the posterior margin of the fourth; in the second even to that of the fifth. The specimen, figure 5, also furnishes evidence of the greater size of this leg in the neanic or following stage.

The telson in the nepionic stage does not materially differ in shape and relative size from the mature condition.

Neanic growth stage. This stage is represented by a considerable number of specimens from which the originals of figures 3–11 have been

selected. These specimens differ from the mature stage in the following characters:

1 The carapace is still relatively wider though not as wide as in the preceding stage and already approaches a semicircular shape.

2 The compound eyes are still relatively large, holding a median position in proportions between the nepionic and ephebic stages. In plate 21, figure 9 the length of the eyes to the length of the carapace is as 3 : 7, while in the nepionic stage they are as 3 : 6 and those of the ephebic stage as 3 : 9. They are also distinctly nearer to the frontal margin than in the mature specimens and the ocular nodes are more prominent than in later stages. They still show a distinct tendency to converge forward. The crescent visual surface is now distinctly seen, but it appears still broader than in the mature stage.

In many examples of this stage the ocellar mound is so large and distinct that its greater size and prominence in more youthful stages may be legitimately inferred [figs. 3, 4, 8, 10].

The abdomen in these neanic specimens is already as slender as in the adults [fig. 8]. One exception is the fine specimen [pl. 22, fig. 7], which is a little broader than the others. The presence of the lobes of the post-lateral angles, however, indicates that this individual was flattened out before burial.

Measurements. Length of smallest nepionic individual, 5.25 mm; its width, 2 mm; width and length of carapace, 2 mm and 1.1 mm; length of compound eye, .45 mm; length of swimming foot, 1.6 mm.

An average specimen [pl. 21, fig. 12] measures in length (with the telson gone) 63 mm; its greatest width, 16 mm; the length of its carapace is 12 mm; that of the first segment 1.5 mm and that of the third 3.5 mm. The last segment is 6.5 mm long and 6 mm wide.

The largest carapace observed measures but 16 x 11 mm, so that this form is one of the small species of the genus.

Position and localities. Abundant in the fossiliferous shale of the Shawangunk grit at Otisville, N. Y.

Remarks. In aspect, E u r y p t e r u s   m a r i a is greatly different from all its American congeners. This is largely due to the terete form of the body that apparently is without preabdominal expansion. A few specimens [pl. 22, fig. 8] indicate that there was a slight expansion, but it seems to have found its expression mostly in an increased vertical convexity of the body. This convexity both of the dorsal and ventral sides producing the subcircular section of both preabdomen and postabdomen, is shown by several specimens which are but slightly compressed. A species quite similar to our type in both form of body and size is E . p y g m a e u s Salter from the Downtonian (uppermost Ludlow) of Great Britain. Its carapace, however, seems to have been a little longer

I   II   III   IV   V
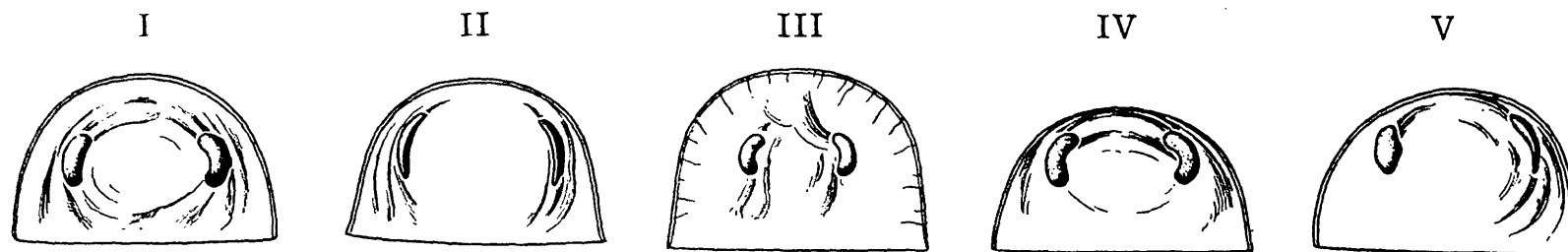
Figure 37   E u r y p t e r u s   m a r i a   Clarke

I–V   States of preservation affecting the outline of the carapace and the size and position of the compound eyes

and the eyes a little more forward in position. From the other species of Eurypterus these two forms differ in their long, gradually tapering, terete body and the small size of the swimming legs.

The variability in the size and position of the eyes is commented upon in the preliminary description. Note might also be taken of the confusing variability in the outlines of the carapace. A survey of a great number of carapaces shows that the variability of features which in other species exhibit considerable stability, is for the most part due to the great convexity of the carapace of this species and the resulting various modifications under the influence of differing directions of compression. The accompanying text figures are inserted to illustrate this fact. In figure I the carapace has been vertically and gradually compressed so that the eyes are projected on the horizontal plane directly below their original position. The uninterrupted concentric wrinkles and the normal size of

the eyes characterize this frequent mode of preservation. In figure II the vertical pressure has acted with a slight centrifugal component, the eyes have wandered outward and become long, narrow and slitlike while the wrinkles are only found parallel to the lateral margins. In the specimen figure III the reverse has taken place; a component acted in a centripetal direction and moved the eyes inward. In this case the latter always appear reduced in size, the whole change producing a strangely different aspect of the head, which is also frequently somewhat squarish in outline [pl. 22, fig. 1]. In this state of preservation the margin of the head is frequently cut by many radiating marks indicative of the intensive flattening out of the outer portion of the carapace. In figure IV the pressure acted from behind and the head is folded over forward and nearly always shortened. In figure V, the pressure acted obliquely, so that the left eye is completely flattened out and the other reduced to a narrow crescent. The possibility of so many different expressions of form under pressure must be taken into account in construing specific values.

Eurypterus megalops nov.

Plate 83, figure 7

Description. Carapace semicircular (width of type, 45 mm, length, 30 mm), both frontal and lateral margins forming a continuous curve; posterior margin well preserved in the middle portion only, which is rather strongly concave; genal angles not clearly seen; eyes submarginal, of large size, occupying one fourth the length of the lateral margin, situated behind the middle line of the carapace; visual surface crescent-shaped (in compressed condition); eye surrounded on the outside by a distinct dumbbell shaped depression; ocelli well defined, large and lying between the anterior portions of the lateral eyes.

The ornamentation is obscured by the compression of the specimen; patches of the surface exhibit a shagreenlike sculpture which suggests that the better preserved fragments of integument with similar ornamentation, found in the same beds, belong to this species.

Horizon and locality. Frankfort shale (Schenectady beds) near Rotter-
dam Junction, Schenectady co., N. Y.

Remarks. This species is remarkable in several regards; mainly in
the extraordinary size of the eyes, which in relative proportion are com-
parable to the eyes in larval stages. Their submarginal position and the
round shape of the carapace give the form a distinct pterygotoid aspect,
but the eye node and the visual surface are those of an Eurypterus. This
species with its larval eyes and other features indicating the traits of a
synthetic type promises, when better known, interesting data relating to
the phylogeny of the eurypterids.

Eurypterus microphthalmus Hall

Plate 20, figures 2–10

Eurypterus microphthalmus Hall. Palaeontology of New York. 1859.
    3: 407*, pl. 80A, fig. 7
Eurypterus eriensis Whitfield. N. Y. Acad. Sci. Ann. 1882. 2: 196
Eurypterus eriensis Whitfield. Geol. Sur. of Ohio. 1893. 7: 416, pl. 1, fig. 31, 32

Description. The entire animal is small, but robustly built. The
cephalothorax is relatively large, its length equal to that of the preabdo-
men. The body is sharply divided into the broad, short preabdomen and
the narrow, cylindrical postabdomen. While the carapace was slightly
elevated, the segments of the preabdomen were strongly arched, increasing
in hight posteriorly and the last four segments were circular in section. The
carapace and the preabdomen together form a compact oval, at the
narrow end of which the taillike postabdomen is inserted, the whole body
much resembling a tadpole in its last stage. The integument of this form
seems to have been relatively strong.

The carapace is semielliptic, approaching the semicircular form and
outline; its length to width approximately as 2 : 3 and in older individuals
approximately as 3 : 4. Its outline is evenly rounded. It is slightly promi-
nent, reaching its apex between the lateral eyes, whence it rapidly declines
forward and gradually backward.

A longitudinal triangular depression at the middle of the frontal margin indicates sometimes, in compressed specimens, the location of the frontal shield of the doublure. The lateral eyes are very small, kidney-shaped, and prominent, with vertical, semicircular visual surface and placed so much within the margins that the distance between them is not greater than that from the eye to the margin of the carapace, as pointed out in the brief original description. They are also placed relatively far forward, their posterior ends lying in front of the transverse middle line of the carapace. The ocelli are separate, very distinct, and placed on a line connecting the posterior angles of the lateral eyes. The doublure of the carapace is narrow, widening slightly near the postlateral angles.

No limbs are shown in our specimens.

Only the first tergite of the dorsal side is shown in the type specimen. This is relatively narrow. Another example retains the ventral integument of the abdomen. The operculum and the first sternite are deeply cleft, depressed and distinctly sutured along the middle line. The transverse lines are very distinct.

The telson has not been observed.

The carapace was smooth but on the sternites and postabdominal segments are traces of small tubercles. Whitfield has observed " minute spinelike pustules or pointed granules . . . . arranged in irregular transverse lines across the body." Along the posterior margin of the dorsal side of the last segments appear four or five longitudinal folds, originally probably spine bases.

Measurements. The carapace of the type specimen measures 15.5 mm in length and 22 mm in width. The eyes are but 2.5 mm long. Wrinkles and the direction of the eyes show that it has suffered a slight oblique compression. The best preserved carapace is from Litchfield. It measures 17.5 x 27.4 mm. Its lateral eyes are 3 mm long and 6.3 mm apart. A carapace from Cherry Valley measures 25.3 x 35 mm. The largest obtained in the state is 30 mm long and 45 mm wide. The type of the carapace of E. e r i e n s i s preserved in the Columbia University Museum

measures 27 x 36.8 mm and a smaller cotype in the same collection, 24.5 x 32.4 mm. The proportions of the carapace hence lie between 2 : 3 and 3 : 4.

The tergite of the type is but 1.8 mm long. A nearly entire specimen from Onondaga Valley possesses a carapace 20.6 mm long; its preabdomen (perhaps somewhat pushed together) measures 26.5 mm and the remaining. five postabdominal segments about 30 mm. It is widest at the second sternite (30.5 mm). The abdomen figured by Whitfield is complete to the telson, which is lacking. The specimen is probably slightly reduced in the figure, judging from the size of the accompanying carapace, and we have not the original at hand. The preabdomen in the figure is 31.5 mm long and about 33.8 mm wide. The postabdomen is 35.8 mm long and shrinks from a width of about 24 mm to 10 mm in the last segment.

Horizon and localities. The type came from a loose boulder near Cazenovia, Madison co., N. Y., which by its lithologic character and the associated fragments of S p i r i f e r v a n u x e m i shows its derivation from the Manlius beds. Besides this rather poorly preserved specimen the State Museum possesses a series of carapaces and a nearly complete specimen of this extremely rare form. This entire specimen was found loose in Onondaga Valley by Prof. Philip F. Schneider and appears also to have come from the Manlius limestone. Of the carapaces, one was collected by the authors in the town of Litchfield in Manlius limestone, not less than 100 feet above the Eurypterus horizon in the Bertie waterlime; another was found loose on Jerusalem hill (probably also from Manlius limestone, according to the lithologic aspect of the slab); still another was obtained at Cherry Valley falls. A series of carapaces, some of relatively large size, were obtained in the layers of the Manlius formation at the Kolb farm, Crane's Corners, near Jerusalem hill, Herkimer co., and some segments in the waterlime of the Manlius at Manlius village. From this it appears that there is a continuous waterlime bed near the top of the Manlius formation, extending from Onondaga county to Albany county and the species seems to be confined to this layer. Professor Whitfield's

types of E. eriensis came from the hydraulic limestones (Monroe formation) of Beach Point, Put-in-Bay Island, Lake Erie.

Remarks. E. microphthalmus is well characterized by a number of peculiarities, the most notable of which are the round outline of the head, the small size and subcentral position of the lateral eyes and the short compact form of the preabdomen, from which the cylindrical postabdomen is well set off. The slight compression of both the carapace and the abdomen shows that the integument must have been relatively very strong. To this fact may be also due the absence of the scales on the surface.

While the differences between the carapaces of E. microphthalmus and E. eriensis, cited by the author of the latter species, seemed well founded as long as the poorly preserved type of the former species or the not quite successful representation of the same were solely available, the specimens which have lately been collected in the Manlius limestone, leave no doubt of the identity of the Ohio specimens with E. microphthalmus. The proportions of the carapaces are the same, within the small variation due to different compression and to the developmental changes.

E. microphthalmus is, stratigraphically considered, an isolated form, since it is the sole eurypterid hitherto known from the Manlius limestone. It is likewise isolated from the preceding eurypterids by the series of peculiar features cited above as characteristic of this form, and though the form is in general outline near enough to the preceding E. remipes so that its derivation from that common species could be conceived, the fact remains that it is more closely related to later species, like E. brewsteri Woodward, from the British Old Red sandstone, with which it has in common the round outline of the carapace, the small size, forward and approximate position of the eyes—that is, all the features which give it its characteristic aspect. The Old Red species is also without ornamentation of the carapace. A third species exhibiting the same characters, except the lack of ornamentation, is E. approx-

i m a t u s Hall & Clarke, from the Waverly beds of Pennsylvania. These species form a well defined group that is distinctly foreshadowed by one of the eurypterids of the Shawangunk grit, viz, E . m a r i a .

Eurypterus pittsfordensis Sarle

Plate 13, figures 4–6; plates 14–16; plate 17, figures 1–6; plate 18, figures 3–8

E u r y p t e r u s p i t t s f o r d e n s i s Sarle. N. Y. State Paleontologist Rep't.
     1902. p. 1098, pl. 10, fig. 7; pl. 15, fig. 1-3; pl. 16-23; pl. 24, fig. 2-5; pl. 25,
     fig. 2, 5, 6

E u r y p t e r u s p i t t s f o r d e n s i s was very fully described by its author.   We have secured little additional material since the Sarle collections were added to the museum and therefore reproduce the original description with our observations appended:

This species is comparatively rare and is not represented in the collection by any entire individuals. There is, however, sufficient material to enable its main features to be correctly determined.

The entire animal is large and robust, and broadest at about the third segment. The cephalothorax is two thirds as long as broad, eyes of medium size, appendages heavy. The preabdominal and postabdominal portions are not strongly differentiated; the telson long, probably equal in length to the five preceding segments.

The cephalothorax is broad, rounded in front, the sides curving out near the genal angles, and the base straight, or very gently curving over the middle portion, and extending a little forward near the sides. The margin is beveled in for a distance, in the average sized individual, not exceeding 2 mm in the widest part or in front, narrowing and fading out at the genal angles. The extreme edge is slightly upturned. The compound eyes are separated by one half the breadth of the shield, with their bases in line with its center. They are prominent, reniform, broader at the anterior ends, and one fifth as long as the shield. The ocelli are situated on a faint tumescence between the centers of the compound eyes. They are rather large and separated by about their own diameter. Near the basal edge of the shield is a pair of sharp, raised, triangular scales, one on either side of the axial line. In some cases there is a row of shallow, flat-bottomed pits on the beveled margin.

The abdomen increases slightly in breadth from the base of the cephalothorax to the third segment, then tapers to the telson, there being no apparent constriction between the preabdomen and postabdomen. The tergites

are comparatively short, the length averaging a little less than one fifth the breadth. They are broadly concave along the middle of their posterior edges, and each carries, bordering this curve, four raised, triangular scales like the two on the posterior border of the cephalothorax and the middle two in line with them. The five sternites are medially cleft and marked by transverse sutures, which give to each the appearance of having been formed by the fusion of two plates. With the exception of the first or operculum, they have the antelateral angles projected forward into small lobes. In the operculum these angles are noticeably rounded away, and the anterior edge is projected into a broad median lobe. In the female the second sternite has a similar lobe. The annulate segments, or sclerites, comprising the postabdomen increase in length and decrease in breadth from the first, which is very broad and short, to the last in which the length exceeds the width of the anterior or wider end. They are depressed and have faintly defined pleural areas or flattenings at the sides. Each is prolonged on either side, at the posterior angle, into a short, striated spur, which grows longer with each succeeding segment, those on the last forming conspicuous pointed lobes. The first two segments each carry on the dorsal side four triangular scales like those of the preabdomen, the third, fourth and probably the fifth, each two, the last none. This segment has a shallow notch in the middle of the dorsal, posterior edge, marked on either side by a small denticle, succeeded toward the sides by very minute ones. The series of striations of the lobes continue up the sides of the segment to its articulation with the preceding. On the ventral portion of each ring segment is a shallow posterior emargination fringed with lobelike teeth. Extending forward from near either end is a curved rent, a pair sometimes almost inclosing an irregular, oval area.

The telson is very long, nearly equaling in length the rest of the postabdomen. For a short distance from the anterior end it contracts rapidly, then continues slender to the abruptly rounded point. The edges are sharp and, from near the anterior end, are marked by short, oblique incisions. The dorsal surface is smoothly convex, the ventral has a flat topped carina which begins near the proximal end and extends to the tip. On the carina is a double row of pits like those bordering the cephalothorax.

The doublure, at its dehiscence in the axial line, equals in width about one fourth the length of the cephalothoracic shield. From this point it narrows toward the genal angles.

The preoral appendages have not been observed. The endognathites are robust and vary greatly in length, the first pair being barely long enough to reach the shield border, while the members of the third clear it by fully three fourths their length. The fourth pair is known only by a coxal joint and a basal portion consisting of three joints. The first legs consist of seven joints; the second and third each, of eight. In the first

three, each joint from the third to the penultimate is provided with two long, curved, striated spines. The terminal joints are comparatively long and clawlike. The coxal joints are large. The first three are short and broad, the length being a little less than two thirds the breadth. They have narrow, curved, postlateral prolongations equal in length to the second joint. The lower, inner angles are rounded and crenulated. The dentate faces at the inner, upper angles are on slight prolongations, which grow longer with each succeeding coxa. All three begin with two or three isolated, anteriorly directed, lobelike teeth, followed by slender conic ones, which become finer toward the posterior end. The fourth coxal joint is comparatively long. The inner lower angle is gently rounded away, and the neck supporting the narrow dentate face, long. The teeth appear to be comparatively few and coarse. The epicoxite of the third left coxa is shown on plate 16, figure 1.

The swimming arms are stout and moderately long, extending back nearly to the fifth tergite, and consist of nine joints. The gnathobases are subquadrate and large, and are provided with seven or eight short, bevel-edged denticles, the two anterior being large and prominent. The length of the gnathobase was 33 mm, its breadth 30 mm, the length of the dentate face 8 mm. The middle joints have the anterior and posterior angles sharp, in the fifth the anterior forming a blunt, striated spine, much like those at the sides of the postabdomen. The seventh and eighth joints are broadly expanded, and their margins, particularly in the latter, are marked by sparse, shallow serrations. Inserted on the inner side and near the end of the eighth joint, is a small, oval, rudimentary ninth joint.

The metastoma is elongate ovate, widest in the middle, with ends truncated. The anterior or narrower end is notched and minutely dentate.

The genital appendages of this species, so far as they are preserved in the material of the collection, are, with the exception of the part carried by the second sternite in the female, essentially like those of E . f i s c h -e r i Eichw., as described by Holm. That of the female is the more complex and is carried partly by the operculum and partly by the second sternite. The part carried by the operculum follows two subtriangular areas formed by a pair of sutures extending posteriorly from either side the median lobe to meet the cleft, and extends considerably beyond the posterior edge of the plate. It consists of a short sagittate base and a slender portion divided transversely into two imbricating sections, each terminating in a short bifid expansion. In E . f i s c h e r i there is a third part consisting of two, short, flat, diverging crura. As this appears to be a general feature in Eurypterus, it is probable that it exists in this species also. The part of the appendage carried by the second sternite is covered by that of the operculum. It lies in the median cleft which extends through the posterior two thirds of the sternite, the anterior third

of the two halves of this plate being fused.   It is slender, being about one fourth as wide as long and does not quite reach the posterior edge of the sternite.   The anterior end is slightly constricted where it fuses with the sternite, and the distal is tapering.   The male appendage is confined to the operculum.   In the material of the collection is a single specimen showing the exterior, the others showing the internal form only.   It was evidently small, about one fifth the length of the operculum by which it is surrounded.

The body is covered with comparatively coarse, imbricating crescentic scales, most distinct on the sternites and swimming arms.   When the integument of the metastoma and paired appendages are scaled away, there remains a punctate surface.   The specimens found show that the size of these animals averages from 20 centimeters to 30 centimeters.   A fragment of the third joint of a swimming arm was found, however, which appears to have been part of an individual over 60 centimeters in length.

In the outline, size and proportions of carapace (length : width as 2 : 3) this species resembles E . l a c u s t r i s more than any other form.   Moreover, the abdomen and the legs appear not to have been very different, but the telson is notably longer and more slender than in E . l a c u s t r i s or in any other of our species of Eurypterus.

Before us are carapaces showing that this species grew still larger than the type specimens indicate.   One of these measures 54 x 89 mm, another is 58 mm x circa 98 mm.

One of the original figures [*op. cit.* pl. 10, fig. 7] shows three ends of appendages with thick, clawlike terminal segments.   On the left side, however, two endognathites are shown with thin spinelike terminal segments. As other specimens show that the endognathites did not possess such clawlike segments at their extremities, it is probable that Sarle's interpretation of the specimen is not correct.   An inspection of the original shows that the supposed terminal segment on the middle line of the figure is one of the chelicerae, but the two others on the right hand side are oval prominences with a median sulcus but without separation of the test. We surmise, therefore, that they are the upper views of the first segments of endognathites which are displaced.   A corrected figure is here given on plate 13, figure 6.

Horizon and locality.   Pittsford shale, Pittsford, Monroe co., N. Y.

Eurypterus (?) (Dolichopterus?) prominens Hall

Eurypterus prominens Hall. Am. Ass'n Adv. Sci. Proc. 1884. 33: 420
Eurypterus prominens Hall & Clarke. Palaeontology of New York. 1888,
    7: 157, pl. 27, fig. 3, 4

This species, the single eurypterid representative from the Clinton group, is based upon a carapace that was fully described by Hall and Clarke. These authors also point out the characters by which this species is distinctly different from any other species of Eurypterus. The most important of these is the anterior position of the eyes, which coupled with their submarginal position and the great length of the carapace (length to width as 27 : 30 or 9:10) gives the latter an aspect very like that of Dolichopterus, so that it would not be surprising if later discoveries prove this species closely allied to that genus. In Dolichopterus the specialization has gone a step farther and the carapace, which there is still well rounded at the anterior corners, has become subquadrate.
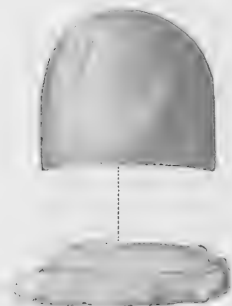
Figure 38 Eurypterus? prominens Hall. Original figures. (From Hall and Clarke)

It may be also mentioned that the youngest stage of E. remipes observed has the same long carapace and anterior eyes and that, for this reason, E. prominens may represent a phylogenetically youthful type of Eurypterus, an inference that is supported by the geologic position of the species.

The ocelli have, as usual, followed the compound eyes and are situated well forward on a line connecting the posterior extremities of the lateral eyes. They mark the apex of the carapace. The uncompressed type specimen shows this head shield to have been relatively high, but its summit flattened and culminating in a broad ridge connecting the compound eyes.

The oblique linear depressions on the postlateral areas are rather faint and somewhat exaggerated in the drawing. Similar depressions

occur in other species, as in E. m a r i a . They appear to mark the location of a strong muscle or muscle-bearing interior process.

The specimen is supposed to have been derived from the greenish Clinton sandstones in the northern part of Cayuga county, N. Y. and is now in the collection of Cornell University.

Eurypterus pustulosus Hall

Plates 23 and 24

E u r y p t e r u s p u s t u l o s u s Hall.   Palaeontology of New York.   1859.   3: 413,*
pl. 83B, fig. 1

E u r y p t e r u s g i g a n t e u s Pohlman.   Buffalo Soc. Nat. Sci. Bul.   1883.   4: 41,
pl. 2, fig. 1

P t e r y g o t u s g l o b i c a u d a t u s Pohlman.   *Ibid*. p. 42, pl. 2, fig. 2

P t e r y g o t u s g l o b i c a u d a t u s Laurie.   Roy. Soc. Edinburgh Trans.   1893.
v. 37, pt 2, p. 515

Hall based his species upon a single fragmentary and rather poorly preserved carapace, now in the American Museum of Natural History. This, however, is fully competent to show the most characteristic features; the form of the carapace, the position of the lateral eyes and peculiar ornamentation.

More than a score of years later, Pohlman found in the Museum of the Buffalo Society of Natural Sciences another much
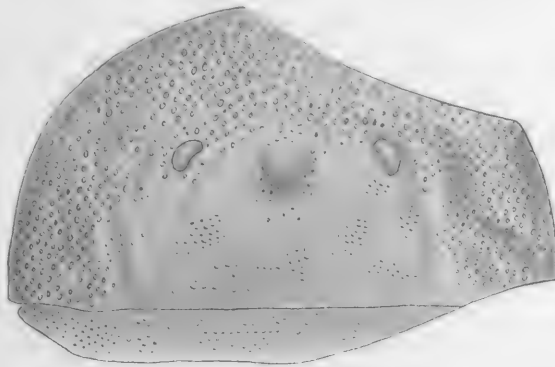
Figure 39   Copy of original figure of E u r y p t e r u s g i g a n -
t e u s Pohlman. (From Pohlman)

better preserved carapace [here reproduced in pl. 23, fig. 1] and he recklessly denoted it as E . g i g a n t e u s , stating that his species had

markings like those of E . p u s t u l o s u s but that "the shape of the carapace and the position of the eyes are so totally different that the two species can be distinguished very readily." As a matter of fact, the proportions of the carapace and the positions of the eyes are quite the same in both specimens [*see* under *Measurements*].

In the same publication Pohlman added several "new species" of Pterygotus to those before described from the Buffalo waterlimes by Grote & Pitt, increasing the number to a half dozen, all of which are synonyms of P . b u f f a l o e n s i s save one. This latter was described by Pohlman as P . g l o b i c a u d a t u s . It is based on a single postabdomen, in relief and counterpart, now in the Museum of the Buffalo Society. The two were combined in one figure, here copied [text fig. 40]. This figure illustrates the three principal characters of the specimen, viz, the bladelike extensions of the postlateral angles of the segments, the apparent globosity of the "telson" which gave the species its name and the coarsely pustulate sculpturing.

Figure 40 Copy of original figure of P t e r y - g o t u s   g l o b i c a u d a t u s   Pohlman. (From Pohlman)

This "telson" [pl. 24, fig. 1] has, at first glance, the features ascribed to it by Pohlman. It appears to have a round outline; the upper and lower plates have separated and a thick mass of matrix lies between them, suggesting the globose character attributed to it. But such a "telson" would have compelled this unfortunate creature to drag, like a member of an old-time chain gang, a cannon ball after him all his life. This structure

Figure 41   Counterpart of original of P t e r y g o t u s g l o b i c a u d a t u s Pohlman.
Natural size

would be so abnormal for that very reason as to invite close scrutiny. It is evident that like the type of "P. q u a d r a t i c a u d a t u s ," this supposed telson is in reality the ultimate postabdominal segment, which is indeed preserved in a very deceptive manner. On the right margin the serration ends abruptly at the postlateral corner, where there is a small offset in the edge. The same feature is less distinctly shown on the opposite side. The posterior margin is smooth. In true telsons of Pterygotus, however, the serrations always increase in posterior direction. The offset, the smooth posterior margin and the wrinkling of the test, as well as the presence of crowded small scales along the edge, all indicate that this is the posterior margin of a postabdominal segment. In P. b u f f a l o e n s i s , the ultimate postabdominal segment is described as expanded laterally and serrated just like the telson, while the posterior margin is smooth. Furthermore, the scales are present on the telson only near the anterior margin, but here they are distributed in undiminished size and in the same arrangement as on the preceding segments. One side of this segment has been dragged backward until its posterior edge forms an apparent continuous circular outline with the lateral margins. The curvature and direction of the wrinkles on the right side show distinctly that this dragging took place.

The telson of g l o b i c a u d a t u s is hence unknown and the term undoubtedly a misnomer.

The postlateral extensions of the segments are faintly indicated in P t e r y g o t u s a n g l i c u s but absent in other members of that genus. Some species of Eurypterus, however, as E . p i t t s f o r d e n s i s , have them equally well developed and they also appear to represent an ontogenetic feature of the young of other members of this genus.

The third peculiar character of this species is the " scales." They differ indeed from the surface sculpture of most eurypterids and consist of relatively large [1 mm], circular disks, many of which are flat-topped while in most the center is slightly sunken or the margin raised. Under enlargement [pl. 24, fig. 4] most of the scales have the anterior margin less

rounded and in many the disk is distinctly heart-shaped. About the center are two darker spots which represent a pair of pitlike depressions. The scales are largest and most crowded on the anterior half of the segment. The over-lapped anterior fifth of the segment is sharply set off from the remainder by a line of oval disklike scars and the overlapped part itself is densely crowded with smaller scales which in front consist of crescents and behind change gradually into the disks, thereby evincing the morphologic and functional identity of these peculiar disklike scales with the crescentic scale of other eurypterids.

A brief study of the ornamentation of Pohlman's type of E. gigan - teus (= E. pustulosus Hall) figured on the same plate as his Pterygotus globicaudatus, shows it to be of quite the same character and relative dimensions as the latter, the fact being taken into account that the sculpture pustules of the eurypterids are always of smaller size and at the same time more prominent on the carapace than on the body. The enlargements of the ornamentation of the type of E. gigan - teus [pl. 24, fig. 2, 3] show that the carapace was covered with large wartlike pustules in front of the eyes, which are flat on top or slightly sunken in. They are now filled with rock and were hence originally hollow and probably rounded on top. Between them are found many smaller ones, scalelike, with thicker test, which exhibit the disk shape of those of P. globicaudatus, as seen on the anterior portions of the segments [pl. 24, fig. 4]. Like scales are observed on the first tergite of the type of E. giganteus and since the sculpturing as a rule increases in coarse-ness from the first tergites posteriorly, there is no doubt that this ornamentation fully corresponds to that seen on the postabdomen of P. globicaudatus.

It is hence, manifest that P. globicaudatus and E. gigan - teus are of the same species and as E. giganteus is identical with E. pustulosus the original P. globicaudatus represents the postabdomen of E. pustulosus. The species characters are then the following:

Description. Body medium-sized to large. Carapace semicircular, nearly twice as wide at base as long (length : width as 6 : 11), probably originally quite high (as indicated by concentric wrinkles); lateral and frontal margins forming a continuous circular curve, when the carapace is flattened; the thickened edge scalloped; posterior margin straight and transverse, genal angles nearly rectangular; compound eyes relatively small (one seventh the length of carapace), consisting of a bean-shaped, very prominent ocular node and narrow reniform visual surface, situated halfway between the frontal and basal margins, far apart (three fourths as far from lateral margin as apart); the ocellar node prominent, in exact middle of carapace.

First tergite one fifth as long as the carapace, nine times as wide as long. Postlateral angles truncate. Postabdomen at its anterior end about three fourths as wide as long and tapering to about one third of its anterior width. The segments possess distinct epimera which become increasingly winglike posteriorly, on the last segments possessing sigmoidal margins.

Ornamentation. The ornamentation of the carapace and postabdominal segments has been described above. From an exfoliated portion of one specimen [pl. 23, fig. 1] it is seen that the test of the marginal shield of the cephalothorax was furnished with wartlike, round pustules.

Measurements. Carapace of type, 67 x 120 mm (as 6 : 10.7); that of Pohlman's type of E. giganteus 50 x 93 mm (as 6 : 11). Eyes in type 41 mm apart and 30 mm from lateral margin; in other specimen 7 mm long, 31 mm apart and 24 mm from margins. First tergite of this specimen 9.5 mm long. Postabdomen about 150 mm wide at anterior end, 210 mm long and about 50 mm at posterior end.

Horizon and locality. Bertie waterlime at Buffalo.

Remarks. A third carapace (with attached first tergite) of like dimensions with the type of the species is in the Buffalo Museum. It is noteworthy for the distinctness of the ornamentation of the first tergite, consisting of a narrow anterior zone of very closely arranged tubercles and the characteristic disklike scales which here are larger, more numerous, and

more prominent than in the other two specimens. This specimen also demonstrates that the scalloping of the edge of the carapace is due to the presence of scales.

The National Museum contains a fragment [pl. 23, fig. 2] of a very large carapace of this species from the waterlime at Buffalo which indicates that the species must have attained much larger proportions than any other known Eurypterus. This carapace was approximately 250 mm wide in front of the eyes, to which a basal width of about 300 mm and a length of the carapace of about 160 mm would correspond. The whole body must have measured fully one meter.

There is no species of Eurypterus which this form closely resembles, and it must represent an aberrant branch of the genus, if, indeed, it actually belongs in the genus at all. Only the carapace and the postabdomen of the animal are known and the appendages may prove to be quite different from those of Eurypterus. In this connection it is suggestive that the Scottish representatives of Laurie's genus Drepanopterus possess some of the features in which E . pustulosus differs from typical Eurypterus [Laurie. 1892, pl. 3, fig. 16; 1899, pl. 3, fig. 17; pl. 4, fig. 22]. Drepanopterus pentlandicus exhibits strong "granular markings " which, judging from his figure [pl. 4, fig. 22], may well resemble those of E . pustulosus in size and distribution, while in D . lobatus the posterior angles of the postabdominal segments are produced into like processes. On the other hand, E . pustulosus does not possess the characteristic form of the carapace of the Drepanopterus-Stylonurus group and in the lobation of the postabdominal segments and its strong ornamentation, it suggests the last Carbonic representatives of the race, notably E . mansfieldi Hall and E . (Anthraconectes) mazonensis.

Eurypterus pristinus nov.

Plate 83, figures 5, 6

Description. Carapace broadly subrectangular, about one half longer than wide (width, 20.5 mm, length, 13.5 mm). Anterior margin slightly

convex, antelateral angles well rounded, lateral margins nearly parallel, slightly concave in the middle and curving outward toward the genal angles which are slightly produced sideways; posterior margin nearly straight transversely; eye nodes subcircular, small (about one seventh the length of the carapace), situated just forward of the center and twice their diameter from the lateral margin; the form and size of the visual surface have not been made out.

The surface of the type specimen exhibits, especially on the posterior portion, low, rather broad nodes, so closely arranged as to be in contact at their bases. A body segment lying close to the carapace possesses a similar ornamentation.

Patches of integument are found associated with the eurypterids at Schenectady which present the aspect of a shagreen, their surface being covered with low, flat nodes which in many places become so crowded that they assume polygonal outlines. We consider it probable that these patches belong to this species.

Horizon and locality. Frankfort shale. Dettbarn quarry, Schenectady, N. Y.

Eurypterus ranilarva nov.

Plate 17, figure 7; plate 18, figure 2

Description. *Body* of small size, very plump in general appearance, the carapace and preabdomen forming a broad oval from which the post-abdomen is set off rather abruptly.

The *carapace* is strikingly broad (length : width as 5 : 7) and nearly as wide as the broad preabdomen; subrectangular in outline; anterior margin straight to slightly emarginate in the middle and rounded at the anterior corners; lateral margins gently convex, slightly contracted toward the posterior angles; its doublure remarkably broad, forming a wide rim (4 mm) that gradually narrows along the sides; it bears a deep broad furrow in the middle that ends somewhat abruptly just behind the anterior corner, and fine parallel striae on the flat portion outside of the furrow; along the inner edge of the furrow runs a narrow crest. The rim seems to have been

produced into a relatively large triangle in the middle line. The eyes were large (between one third and one fourth the length of the carapace), reniform in outline and situated on the anterior half of the carapace, separated by about their own length from the outer margin. The preabdomen is so broad that its length is to its width almost as 2 : 3. The broadest part is in the region of the fourth tergite or third sternite. On account of the complete flattening of the specimens, both the tergites and sternites appear only as ill defined bands, the overlap, and consequently the true length, of which can not be determined. So much, however, is certain that they were rather short and wide, about seven times as wide as long. Their doublures can not be satisfactorily seen. The postabdominal segments are better shown and their broad posterior doublures well observed in all specimens. The postabdomen is relatively short and broad, it reaches not more than one third the length of the body while in the typical species of Eurypterus it amounts to one half of that length. It tapers gradually to not quite one third its anterior width. The postabdominal segments are short, the length of the penultimate segment to its width having the proportion of 2 : 3. The ultimate postabdominal segment is furnished with two short blunt lobes of the postlateral angles. The telson, corresponding to the rest of the body, is short and strong, rapidly tapering to the distal extremity. Its length was apparently only about one fourth or one fifth of the whole body.

Appendages. The limbs indicate that this species was a better walker than swimmer, for while the walking legs were strong and well developed, the swimming legs are rather slender and furnished with but small paddles. These paddles also seem to have ended in a spine although the evidence on this point is not conclusive, only a single indication of the spine having been seen. The details of the walking legs are not very distinct. The last pair, which typically in Eurypterus is comparatively slender, is here short when compared to the great width of the carapace, but somewhat broad jointed. The swimming legs are long in comparison with the short body. When turned back they reach to the posterior edge of the preabdomen.

The coxae of the swimming legs are apparently large, occupying in length one half that of the carapace and of the usual trapezoidal outline. The following segments of the swimming legs are short and stout but not as short as in the typical forms. Likewise the next two segments (nos. 4 and 5) are long and tubular like those of the walking legs. The sixth segment is shorter, and the seventh and eighth are broadened to about double the width of the other segments to form the paddle. They were of subequal size; the eighth segment formed a broad oval approaching a circle.

The metastoma appears to have been broadly elliptic (length to width as 3 : 2), not half as long as the carapace.

The genital appendages have been seen only as faint shadows, too indistinct to describe.

The ornamentation of the surface is also obscured to such an extent by secondary roughening and wrinkling of the integument that nothing reliable can be ascertained.

Measurements. The largest specimen (no. 12905, University of Chicago collection) measures 160.5 mm in length and 53.5 mm in greatest width. Its carapace measures 35 x 49 mm. The rim is 4 mm wide, the eyes are 10 mm long, the metastoma 14.5 mm. The swimming leg projects 41 mm beyond the margin of the carapace. The preabdomen is 40 mm long and 53.5 mm wide; the postabdomen is 50 mm long, 43 mm wide at its proximal end and 14 mm at its distal extremity. The telson measures 35+ mm. In another well preserved specimen (no. 12907, University of Chicago collection), which is 154+ mm long, the dimensions of the carapace are 33 x 48 mm; those of the preabdomen 43.5 x 52.5 mm, of the postabdomen 41.5 mm, of the telson 36+ mm.

Horizon and locality. Kokomo waterlime, Kokomo, Indiana.

Remarks. This is probably the species cited by Claypole [1890, p. 259] as E . l a c u s t r i s from Kokomo, for in its broad carapace it is most likely to suggest that form. It resembles still more, however, the E . d e k a y i of the Buffalo waterlime, which is built on like proportions,

possessing a similar broad carapace and preabdomen and a still shorter postabdomen. The slender swimming legs of r a n i l a r v a serve at once to distinguish it from this Buffalo species. Its nearest relative is obviously the E . k o k o m o e n s i s of the same locality with which it has many characters in common, notably the broad plump form of the body, the broad doublure and the weak development of the swimming legs. Its principal distinguishing character from the latter is the greater width of the carapace, as a comparison of figure 7, plate 17, and figure 1 on plate 25 will readily show. In E . k o k o m o e n s i s the width surpasses the length by one fifth and in E . r a n i l a r v a by one third. It is possible that these differences are only those of sex, a point that at present can not be determined since the opercular appendages of E . r a n i l a r v a are not distinctly shown.

A younger specimen (no. 12906, University of Chicago collection) [pl. 18, fig. 2] is interesting in showing a relatively broader carapace and preabdomen, a shorter body, and more abrupt contraction to the postabdomen, which is much more slender than the rest of the body. It thus displays distinctly immature features, corresponding well to those observed in other eurypterids.

Eurypterus ? (Dolichopterus ?) stellatus nov.

Plate 83, figures 1-4

Description. Carapace subtrapezoidal, width (22 mm) a little less than twice the length (13.5 mm). Posterior margin slightly arched forward in the middle third, lateral margins curved, flatly sigmoidal, slightly converging forward; frontal margin not clearly seen, but apparently gently convex.

The compound eye is elongate elliptical in outline, very large, one third of the length of the carapace (4 mm in type specimen), situated near the antelateral angle; the visual surface is long and curves far inward at both ends. The ocelli seem to be situated behind the center of the carapace.

The ornamentation of the carapace consists of sharply elevated, hollow tubercles, densely arranged and evenly distributed (absent, however, on the eye nodes) and frequently with a stellate form or provided with a few radiating ridges or wrinkles. A fine granulation occupies the interspaces between the tubercles.

Horizon and locality. Frankfort shale (Schenectady facies) in Dettbarn quarry at Schenectady, N. Y.

Remarks. The forward position and form of the eyes suggest that the species may belong to Dolichopterus, but the carapace is markedly shorter than that of other members of the genus.

Besides the carapace a number of patches of integument have been found which still better display the peculiar stellate ornamentation and the finer granules.

Subgenus ONYCHOPTERUS nov.

This subgenus is proposed for E u r y p t e r u s   k o k o m o e n s i s to give expression to the phylogenetic importance of the species as indicating the path of development of Dolichopterus, Drepanopterus and Stylonurus from Eurypterus. Its distinctive characters are the large, squarish carapace, the lack of differentiation of the fourth pair of endognathites, the spurlike form of the ninth segment of the swimming legs and the styliform telson.

Eurypterus (Onychopterus) kokomoensis Miller & Gurley

Plate 25, figures 1, 2; plate 26, figure 2

E u r y p t e r u s   k o k o m o e n s,i s   Miller & Gurley.   Illinois State Mus. Bul. 10. ,1896.   p. 90, pl. 5, fig. 1

Description. Body of small size, relatively broad, about three and a half times as long as wide, attaining its greatest width in the region of the fourth tergite, thence tapering gradually to the telson.

The carapace is decidedly squarish in outline, its anterior angles are rounded and it is little wider than long. The anterior margin is slightly convex and emarginate, the lateral margins subparallel and nearly straight.

The lateral eyes are apparently reniform and not very large, about one fourth to one fifth the length of the head shield. They lie on the anterior half of the carapace, just in front of the bisecting transverse line. The ocelli have not been seen. The doublure of the carapace is very broad in front, about one ninth the length of the head, narrowing somewhat posteriorly, distinctly produced in the median line to form a small triangular shield.

The abdomen is little wider than the carapace, the preabdomen as wide as long, and the postabdomen relatively short and compact, longer by one third than the preabdomen. The tergites are short, the length about one sixth of the width, with broadly concave posterior margins in the middle half. The sternites are longer (length : width as 1 : 4.5), the operculum apparently but little different from the other sternites in size and outline. In compressed specimens their anterior margins are almost straight. The doublure is apparently narrow. The posterior margins are deeply concave in the middle portion and project into broad, rounded lobes at the lateral angles. The doublure widens under these lobes so that its anterior margin is approximately transverse. All sternites bear transverse oval gill plates whose major diameter is twice the minor. Those of the operculum are but half the size of the others and those on the last pair of sternites are smaller. The postabdominal segments gradually increase in length posteriorly, the last being twice as long as the first, but only one third as wide. The posterior doublure is narrow (1.5 mm). The last segment is produced at the postlateral angles into two short broad lobes with blunt extremities. The telson is short and thick, a little more than one fifth the length of the body. It contracts very rapidly in its first third, then more gradually to its blunt extremity.

Appendages. Only four pairs of limbs have been observed, viz, the three last pairs of walking legs and the swimming legs. The walking legs, notably the last pair, are relatively a little stronger than those of most other members of the genus, while the swimming legs are slender and bear a long terminal spine in place of the " claw," thereby indicating their

primitive condition as natatory organs and their functional adaptation to walking organs. The coxae of the swimming legs are distinctly seen in the type specimen. They are relatively small, considerably less than one half the length of the carapace, long at their inner margin and subrhomboidal in general outline, the anterior and posterior margins being rather oblique and long. The fourth, fifth and sixth segments are longer than in the later species of Eurypterus and distinctly tubular, while the seventh and eighth are not nearly of the relative size and width in E. remipes or E. fischeri. Both are about equal in length, not longer than the preceding ones. The seventh segment is as wide as long and the eighth subcircular. The terminal spine is more than half as long as the preceding segment, slightly curved. The metastoma is small, measuring little more than one third the length of the carapace, oval in form; the anterior portion slightly narrower than the posterior one.

The genital appendages have been clearly seen in only one specimen, a female [pl. 26, fig. 2]. They are here so long that they reach to the posterior margin of the third sternite. The paired basal plates are visible only in faint outline. They were apparently of the usual shape. The first median lobe distinctly spreads in posterior direction and its paired extremities are produced into relatively long laterally curved alae that extend to the posterior margin of the second sternite. The second median lobe is but little shorter than the first and of less, though uniform, width. The terminal paired appendages are long (as long as the second median lobe) and slender, slightly curved outward.

Ornamentation. The type specimen shows on the last postabdominal segments where patches of the surface are preserved, very small, evenly distributed, sharply angular or pointed scales.

Measurements. The type specimen is 136 mm long. Its carapace measures 28 mm in length and 34.7 mm in width; the preabdomen is 32.3 mm long and 39.4 mm wide; the postabdomen 42.2 mm long, 31 mm wide at its beginning and 12.5 mm at its posterior end. The telson is 30.4 mm. The metastoma is 9.5 mm long, the swimming legs are

about 52 mm long each. Judging from the size of the genital appendages (in specimen 12909 University of Chicago) all specimens before us are of mature age and the species probably did not reach a much larger size than that exhibited by the largest specimen before us. This attained a length of 125 mm to the base of the telson (which is but partly preserved), to which may be added at least 34 mm for the telson, giving a total length of 159 + mm, to which corresponds a greatest width of 50.5 mm, a figure clearly exaggerated by the strong flattening of the specimen. The carapace measures 33.7 x 40 mm. The eyes were about 7.6 mm long and the amount of their length distant from the margin. The limbs appear very small in this specimen; the swimming legs extending but 44 mm beyond the lateral margin of the carapace.

Horizon and locality. Noblesville waterlime at Kokomo, Indiana.

Remarks. The material before us consists of four specimens, three from the museum of Chicago University, among these the type, and one from the collections of the State Museum. The type specimen is exceptionally preserved for Kokomo eurypterids. It exhibits all details of structure but the original figure does not do it justice as the specimen had not then been worked out nor the extremities of the limbs, among them the curious spines of the paddles, exposed. For these reasons this specimen has been refigured [pl. 25, fig. 1] and a drawing added of one of the other specimens [pl. 25, fig. 2] which shows the faint outlines of the eyes, and is remarkable for its size and exhibits well the terminal spines of the paddles. The third specimen is entirely unique in its preservation [pl. 26, fig. 2]. As shown in the reproduction, the gill plates are preserved as thick, black, roughly surfaced blotches, while the whole specimen appears as hardly more than a color stain. We have more fully referred to this specimen in the general remarks on Eurypterus. The doublures of the segments also come out with remarkable distinctness as dark bands and the female opercular appendage is distinctly set off from the darker background. The sutures of the basal plates of this appendage are barely discernible.

The fourth specimen is very fragmentary, poorly preserved and recognizable as belonging here only by the presence of the terminal spines of the paddles.

E . k o k o m o e n s i s bears some similarity to E . r e m i p e s in the squarish outline of its carapace and the proportions of the carapaces and preabdomina. It was not so well adapted to swimming as is shown by the less developed and more slender swimming legs and the presence of a terminal spine, obviously used in walking, and also by the shorter and stouter postabdomen. While the species may have been a less active swimmer, the extremely broad doublure of the carapace may indicate an adaptation of the front edge to shoveling or digging.

Subgenus TYLOPTERUS [1] nov.

This subgenus is proposed for the species, E u r y p t e r u s b o y l e i , described by Whiteaves from the Guelph formation of Ontario; a form which exhibits a number of characters that show it to be an aberrant type distinctly adapted to the peculiar conditions of the Guelph sea. These special traits are found in the thick integument of carapace and abdomen which apparently was not only chitinous but calcareo-chitinous; the highly raised lateral margins of the carapace and the presence of elevated and divided knots on the second to fifth tergites.

The extraordinary thickness of the test is shown not alone in the wholly uncompressed condition of the carapace but more in the fact that, though the abdomen has been shoved forward so that the segments are pushed into each other like joints of a telescope, they have not suffered from crumbling or folding as they always do in the other eurypterids and their greatly thickened posterior edges stand out freely. The front margin of the carapace forms a broad beveled shoveling edge, while the lateral margins are much thickened and elevated into prominent ridges. The abdomen seems to have been very compact and short, as shown by the relatively short last two postabdominal segments. The telson spine is

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[1] τύλη, knot; πτερόν, wing.

also short and thick. The surface of the carapace exhibits in front an unusual sculpture consisting of intricately mingled short, coarse, curved ridges of confluent tubercles. On the posterior part of the carapace the tubercles are mostly separated. The axial knots on the segments were solid bodies. All these features combined demonstrate that the integument of this subgenus was not merely chitinous as in the typical Eurypterus, but much strengthened by calcareous deposits which became most prominent in the sculpture of the carapace and in the knots of the tergites.

This thickening of the carapace is entirely in accord with the character of the Guelph fauna described by the authors from New York, where the fact of the peculiar thickening of the shells in all classes, notably the brachiopods and mollusks, has been emphasized and been ascribed to the strongly saline water and in part to the life of the organisms on wave-beaten coral reefs. Tylopterus boylei seems to be an adaptation to the
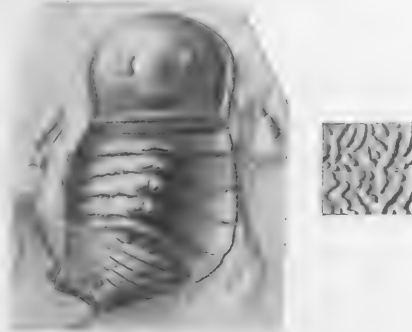
Figure 42 Tylopterus boylei (Whiteaves). Holotype refigured in natural size, and enlargement of sculpture of carapace

same peculiar conditions which are also indicated by the character of the matrix of the fossil, a porous, coarse-grained dolomite.

It would suggest itself to compare this species with the Carbonic eurypterids described by Etheridge (E.? stevensoni, see text fig. 48) and Woodward (E. scabrosus) in which the integument has become greatly thickened by deposition of globular calcite (" calculi "). We have in another place considered these features as phylogerontic in the Carbonic subgenus Anthraconectes and as due to the waning vitality of the race. It is hardly to be assumed that the characters of the Siluric T. boylei are due to the same gerontic conditions and that the latter is an ancestor of the Carbonic Anthraconectes. It would

for this reason be unwarranted to unite it with the latter subgenus, especially since both lived under unlike abnormal marine conditions, that is, Tylopterus in very saline water, Anthraconectes in brackish or fresh water.

Tylopterus boylei (Whiteaves)

Eurypterus boylei Whiteaves. Paleozoic Fossils, v. 3, pt 1. 1884. p. 42, pl. 7, fig. 3

The species was very carefully described by Whiteaves as follows:

Carapace moderately convex, broader than long, greatest breadth a little above the middle; semiovate, broadly rounded in front and squarely truncated behind; sides somewhat convex at their margin above, but straighter below; front and sides bordered by an elevated, narrow ridge, which is highest and most strongly marked on the posterior half of the sides. Eyes reniform, prominent, about 4 mm in the greatest diameter; 9 mm apart (as measured from the center of their inner margins) and placed at a distance of 6 mm from the anterior, and of 7 mm from the lateral margin. Ocelli not clearly indicated, but probably placed on or near a small rounded prominence or elevation, which is situated exactly in the middle of the space between the two eyes. Surface of the carapace apparently finely granulose, and ornamented with minute rounded tubercles, some of which are isolated and others confluent in sets of two or three.

Thoracic and caudal portions together consisting of 12 segments, exclusive of the telson or caudal spine; the first, second, third and fourth thoracic segment each bearing on the median line a single, large and prominent, transversely elongated tubercle, which is arcuate or reniform at its base and somewhat bilobate at its summit. The lateral diameter of each of these tubercles greatly exceeds the longitudinal, and measuring at their base, the proportions of each tubercle may be thus approximately estimated; that on the first thoracic segment, lat. diam. 4 mm, long diam. not quite 1 mm; that on the third, lat. diam. nearly 5 mm, long diam. rather more than 1 mm; that on the third, lat. diam. 5 mm, long. diam., 2 mm; and that on the fourth, lat. diam. 5½ mm, long diam., 3 mm.

Telson produced into a gradually narrowing, slightly curved, and rather obtusely pointed linear spine, which seems to be triangular in transverse section.

Antennae, endognaths and ectognaths unknown, as is also the nature of the surface markings of the test of the thoracic and caudal segments.

Entire length, including the telson, about 75 mm (or 3 in.); length of carapace, 20 mm, greatest breadth of the same, 27 mm; length of telson, 15 mm.

Tylopterus boylei is known in only a single specimen preserved as a mold of the dorsal surface. Guttapercha squeezes of this show that the knots are not located on the first to fourth segments as stated in the original description but on the second to fifth. The squeezes also show distinctly the ocelli on the prominence between the lateral eyes. On the right side also two segments of the fourth ectognathite (balancing leg) are seen and on the opposite side the edges of two flat segments, apparently the oar plate of the swimming leg. The legs seem, therefore, to have agreed with those of Eurypterus.

Subgenus ANTHRACONECTES Meek & Worthen[1]

Meek and Worthen suspected that their species Eurypterus mazonensis from the Lower Coal Measures (Pennsylvanian) represented a distinct subgenus, if not a genus, for which they proposed the name *Anthraconectes*. They state. that this fossil " differs from the typical forms of Eurypterus particularly in the great length and single extremity of the mesial appendage of its operculum, as well as in the possession of two little spatulate supplementary pieces." Hence they "strongly suspect that other characters will be found, when better specimens can be studied, showing it to belong to a distinct subgenus, if not indeed to an entirely distinct genus from Eurypterus proper."

Hall suggested that these differences may not be of great importance [*op. cit.* p. 26] and emphasized the fact that the species from the Pennsylvania Carbonic are typical Eurypteri [p. 27].

While we agree with Meek and Worthen that the peculiar character of the opercular appendage would warrant a separation of the species from typical Eurypterus, we believe that the preservation of this organ is not so distinct that its characters are beyond doubt. On the other hand, we have no doubt that Anthraconectes mazonensis has a number of characters in common with the Pennsylvania and also with British Carbonic species which distinctly indicate a phylogerontic condition

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[1]*See* Appendix.
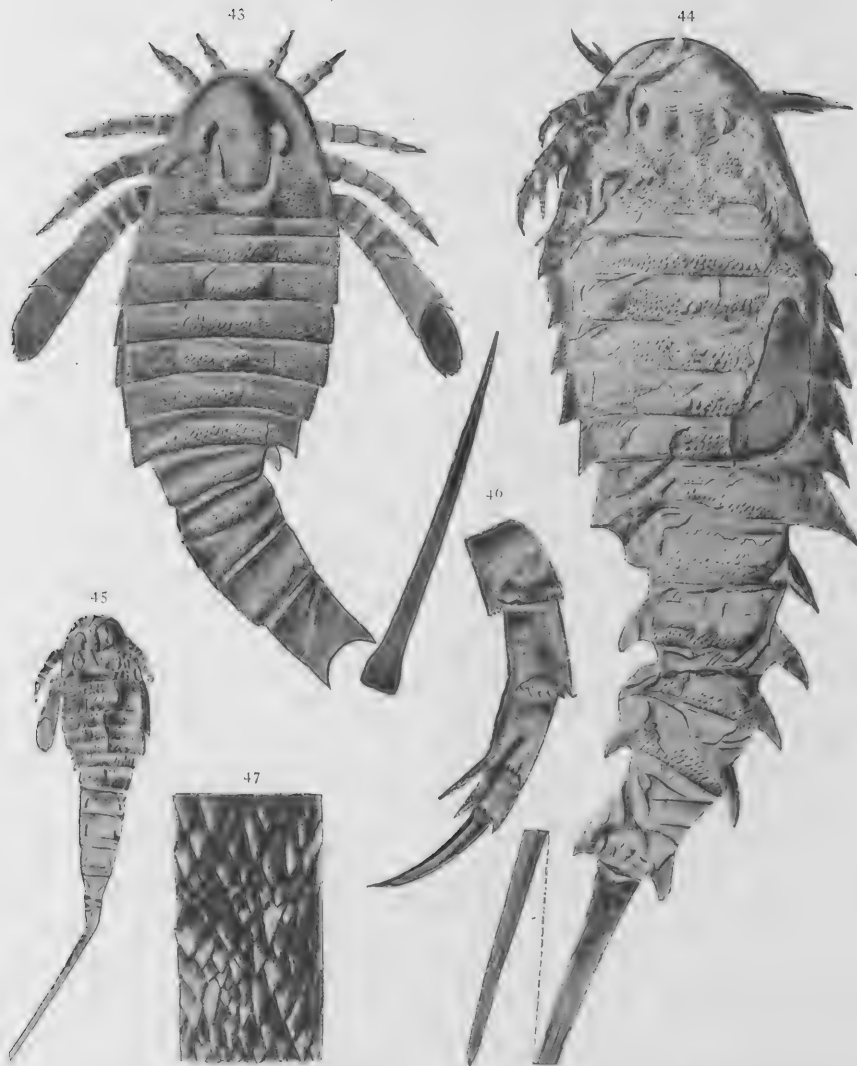
Figures 43–47 Eurypterus (Anthraconectes) mansfieldi C. E. Hall. Figure 43, a small, fairly perfect specimen, x3; figure 44, large specimen, natural size, showing the long epimera; figure 45, a nearly entire small individual, showing the extremely slender telson and the doublures of the postabdominal segments; figure 46, the fourth endognathite, x2; figure 47, enlargement of test with narrow, triangular scales.   (From James Hall)

of the genus and in this evidence of waning racial characters it invites special recognition.   The Pennsylvania species to which we have referred are E . mansfieldi C. E. Hall, E . pennsylvanicus C. E. Hall, E . stylus J. Hall and E . approximatus Hall & Clarke.[1] These species, together with E . (Anthraconectes) mazonensis are distinguished from Eurypterus proper by the following features: (1) the character of the spines of the endognathites,[2] seen in E . mansfieldi, in E . mazonensis and E . stylus,[3] (2) the development of the scales into mucros, giving the greater portion of the surface a spinous appearance.   This tendency to spinosity, especially of the posterior margins of the abdominal somites is also present in British Carbonic forms, as is amply evidenced by E . scouleri Woodward[4] with its long pointed scales, E . (?) stevensoni R. Etheridge jr [Geol. Soc. Lond. Quar. Jour. 1877. 33:223] in which the surface is covered with long blunt spines and scales, giving it the appearance of a mass of congealed drops, while in E . scabrosus H. Woodward[5] the scales have become prominent wartlike tubercles, interspersed with disklike bodies which proved to be

Figure 48   Eurypterus (?) stevensoni Etheridge. Spines and scales. (From Etheridge)

"calculi" or bodies of globular calcite formed inside the integument.   All these excrescences are distinctly phylogerontic and seem to indicate that

[1] The first two are described in the Proceedings of American Philosophical Society, volume 7, 1877, and Second Geological Survey of Pennsylvania, Report of Progress, PPP, 1884, page 31 et seq.   E . stylus is described in the last named publication and E . approximatus in the Palaeontology of New York, volume 7, 1888, explanation of plate 27, figure 6.   E . potens Hall is not described and the figures [Penn. Rep't, pl. 4, fig. 9, 10] indicate that it is based on unrecognizable fragments.

[2] See Appendix.

[3] In E . pennsylvanicus and E . approximatus the endognathites are not preserved.   The former species is based on a single carapace.

[4] Pal. Soc. 1872. v. 26, pl. 25-27.

[5] Geol. Mag. n. s. 1887. dec. 3, 4: 481.

the eurypterids which in the Upper Siluric were the lords of the sea, were now put largely on the defensive. Fritsch has contended [1904, p. 77] that Glyptoscorpius is but an eurypterid and that the supposed combs are merely long fringes at the posterior margins of abdominal segments, and if this is correct then this genus may represent an extreme development of Anthraconectes.

The third feature which the Carbonic species have in common is the exaggeration of the development of the epimeral pieces of the abdominal segments, well seen in the figure of E. mazonensis on the left side [text fig. 50]. E. mansfieldi shows the same features very clearly

[text fig. 44] and E. approximatus possessed long and recurving epimera on the preabdominal segments (the postabdominal segments are not satisfactorily preserved in the single type). These epimeral pieces are produced into strong recurving spines [text fig. 49] and the character is hence entirely in line with the spinosity of the surface, increasing the gerontic aspect of these species.

Another important distinctive character is the lack of differentiation between the first three pairs of endognathites and the last pair. This is especially distinct in E. mansfieldi [text fig. 43]. Finally these species of Anthraconectes were fresh or brackish-water animals while the true Eurypteri were marine.

Even if the characters of the opercular appendage noted by Meek and Worthen should not warrant the recognition of this subgenus, the features mentioned which are common to the majority of the Carbonic Eurypteri are fully competent to verify their suspicion that "other characters will be found showing it to belong to a distinct subgenus—if not indeed to an entirely distinct genus from Eurypterus proper." It is on the sum of these characters that we would base the subgenus Anthraconectes.

Eurypterus (Anthraconectes) mazonensis Meek & Worthen

Plate 26, figure 1

Eurypterus (Anthraconectes) mazonensis Meek & Worthen. Am. Jour. Sci. & Arts. 1868. 46: 21, figure

Eurypterus (Anthraconectes) mazonensis Meek & Worthen. Geol. Sur. Illinois. 1868. 3: 544, figure

Eurypterus (Anthraconectes) mazonensis Hall. Pennsylvania 2d Geol. Sur. Rep't of Progress, PPP. 1884. p. 25, fig. 2, 3

Meek and Worthen have elaborately described and illustrated by an outline sketch this species from the iron stone concretions of the Carbonic of Mazon creek, Illinois. Their material consisted of but one specimen which exhibits the ventral side. Professor Whitfield kindly pointed out to us that the counterpart of this type is in the American Museum of Natural History and this has been made accessible for our study. The latter is a well preserved intaglio which happily complements the type. We therefore embrace this opportunity to add such data to the knowledge of this curious species as are furnished by this specimen. The most remarkable of these is the strong contraction of the postabdomen.

The excellent photograph[1] reproduced on plate 26, figure 1 shows the condition of the specimen and all essential features observable in it. Some structures, as the position of the eyes, the outline of the impression of the opercular appendage, are only observable with favorable illumination. It has been possible to demonstrate the outlines of the carapace and first tergites a little better than shown in the photograph. These features as well as the outlines of the doublures of the tergites are illustrated by a text figure. For the sake of completeness we have also copied the outline drawing of the ventral side, given by Meek and Worthen.

Description. Body long, elliptical in outline, with the posterior third truncated by the abrupt contraction of the postabdomen. It is widest in the region of the fourth tergite, increasing gradually from the

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[1] A drawing of this counterpart was given by Hall *loc. cit.*

front of the head shield to that segment and then decreasing as gradually to the second postabdominal segment where a contraction to half the width takes place.

The carapace appears to have been subrectangular, rather short and broad; length to width in the approximate proportion of 3 : 5. The lateral
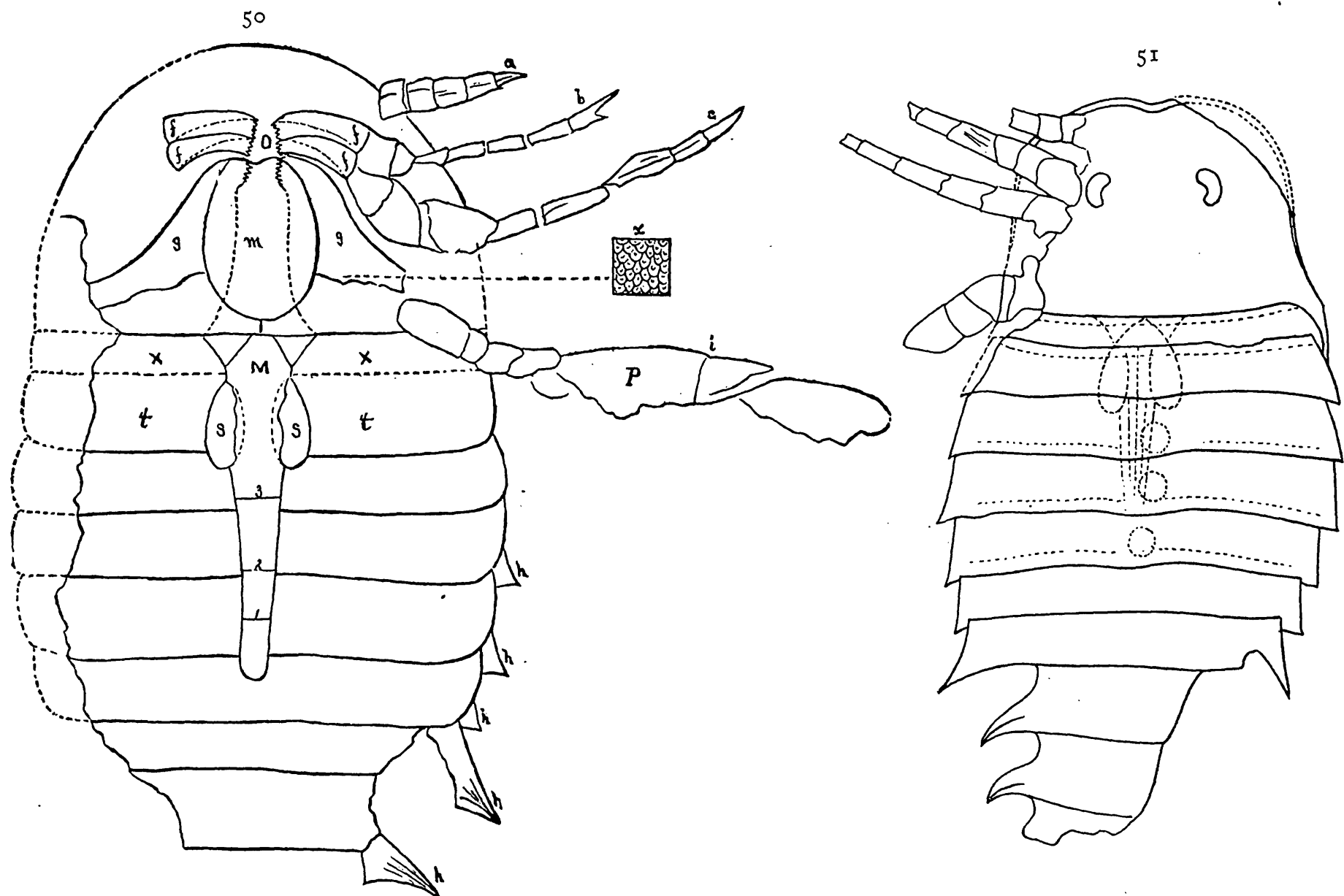
Figures 50, 51 Eurypterus (Anthraconectes) mazonensis Meek & Worthen. Figure 50, copy of original figure; figure 51, outline sketch of counterpart of original, slightly reduced [see pl. 26, fig. 1]

margins are slightly convergent, at least in the middle portion where they can be traced. The antelateral angles are somewhat abruptly rounded, the frontal margin transverse, slightly emarginate in the middle. At the postlateral angles the carapace is a little more broadened. The posterior margin is overlapped by the first tergite and not exposed. The eyes are seen as rather small and slight kidney-shaped depressions; the right eye

in the specimen is distinctly outlined by its chitinous section. Their length is but one sixth that of the carapace. They lie a little in front of the middle of the carapace and about four times their width from the lateral margin.

The preabdomen is the broadest part of the body, broader by one fourth than it is long. Its sides are subparallel, as it increases but little in breadth to the fourth tergite, and then decreases again. The lateral margins of each tergite converge anteriorly so that the postlateral angles project along the sides. The first tergite is only half as long as the others. Its lateral portions are produced forward into flat lobes, as they are also in the next tergite, while in the following two the anterior margins are nearly straight and in the last two they are gently convex forward. The first tergite is entirely flat and smooth, the following are slightly raised in the middle portions of the posterior belt and culminate in a round median node highest on the third tergite and obscure on the last.

Of the postabdomen three segments and a portion of the fourth are shown. The first is of similar width and shape as the last tergite but furnished with long, striated spines at the postlateral angles, as are also the following postabdominal segments. The second segment is but half as wide as the first, but longer by one third. Its epimera are drawn out into long, slightly curved, oblique, posteriorly directed spurs. The last segment fully exposed is again longer and carries a still longer spur on the side.

The third postoral appendage is preserved nearly entire. It was short and stout. Impressions of spines appear on one of the segments. Of the fourth limb five slender segments are shown, so that this is probably also entire. Of the last limb, the five short basal segments, following the coxa are exposed. The other side also retained portions of the last two segments which were long and formed a paddle as in Eurypterus and Pterygotus. The specimen also retains the second limb which is a short stout walking leg ending in a spine.

The impressions of the coxae of the swimming legs, figured by Meek and Worthen, are also faintly seen in this specimen. So also are im-

pressions of the opercular appendage; especially distinct is that of the anterior hastate part.

The ornamentation of the dorsal side is very striking. The carapace is for the most part smooth, but on the middle posterior region there appear small prominent tubercles most of which are semilunar and project backward. They are irregularly crowded around a median smooth depression. Along the posterior margin the semilunar scales are abruptly changed into two rows of larger, sharply angular scales. The first tergite is smooth; the following tergites as well as the postabdominal segments show a dense mass of extremely small semilunar to linear scales on the anterior half (mostly of so small size that these parts appear smooth), while the middle posterior halves bear prominent angular scales that are largest upon the median nodes. Toward the sides the angles of the scales become smaller until linear scars are formed, making a system of parallel oblique lines on the epimera (not well shown in the figures).

Measurements. The carapace is 32 mm long and approximately 53 mm wide at the base. The eyes were 5.5 mm long and 16 mm apart. The preabdomen measures 46 x 62.5 +mm. The first tergite is 4 mm long; the second 7.5 mm long and 59 mm wide; the third is 9.5 mm long and 61 + mm wide. The first postabdominal segment measures 9 x 52 mm, the next 11.5 x 26 + mm. The limbs are only fragmentary.

Horizon and locality. Lower Coal Measures of Mazon Creek, Grundy co., Illinois. Counterpart in American Museum of Natural History (no. 8532).

Genus EUSARCUS Grote & Pitt

The most striking and interesting eurypterid of the waterlimes of Buffalo is undoubtedly a large animal which, when discovered in 1875, was made the type of a new genus and species by Grote and Pitt under the designation of E u s a r c u s s c o r p i o n i s . The authors of the genus gave no generic diagnosis but the following description of the species suggests what they considered as its distinctive characters:

The cephalothoracic portion appears to be separate from the body, and to be considerably narrower in proportion than in allied forms. The

legs are in the same number as in Eurypterus. The swimming feet appear to differ by the straighter, less rounded outer margins. In the specimen the rhomboidal plates are not given. From the impressions of the joints of the swimming feet their relative dimension does not seem to accord with Eurypterus. The four pair of anterior feet proceed from two elongate oral plates of which the impression is very distinct. The spines of the anterior feet appear to be long, curved, and to have an anterior direction. The absence of chelate appendages to the posterior margin of the feet is particularly noticeable. The first seven broad segments of the abdomen form a large ellipse. There is an evident and remarkable narrowing of the succeeding caudal segments. Of these six appear to be made out on the specimen. The surface of the cast is punctate with scattered triangular impressions. The cast shows a widening of the terminal segment and no traces of a spiniform process are exhibited.[1]

Of the differentials indicated in the passage quoted, the following have stood the test of larger collections: the much " narrower " cephalothoracic portion, the broad large ellipse of the abdomen and the " remarkable narrowing " of the postabdomen (" caudal segments "). At least three, possibly four species, exhibiting quite similar characters of general form, are known from the British Siluric rocks and these have been referred to Eurypterus by Woodward, the differences in outline not being considered of generic importance by that eminent authority. It is not surprising therefore that authors generally have shown little inclination to recognize this genus Eusarcus.

Grote's successor as curator of the Buffalo Society's museum, Mr Pohlman, was apparently the first to assail the proposed genus, stating [1886, p. 29] that the discovery of several new specimens had shown that the form has " the leading characteristics of the genus [Eurypterus], as given by DeKay," viz, " a terminal joint prolonged into a sublinear or lanceolate triangular spine with serrated edges," and " eyes reniform or oval, placed within the margin of the carapace." Pohlman's observations in regard to the telson, which is as in Eurypterus, are correct, but the original of the supposed carapace of Eusarcus which he figures [op. cit.

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[1] In the original description the specimen is erroneously described as presenting a ventral surface.

pl. 3, fig. 3] and which is now in the collection of Columbia University, proves to be a carapace of D o l i c h o p t e r u s s i l u r i c e p s [pl. 26, fig. 3], in which the eyes are normally intramarginal. We have however specimens of E u s a r c u s s c o r p i o n i s which leave no doubt of the marginal position of the eyes in that species, and thus afford an important differential of the genus. In none of the British species with typically Eusarcuslike outlines (viz, E u r y p t e r u s s c o r p i o i d e s and· E. p u n c t a t u s) was the position of the eyes known to Woodward, and one species, of which only the triangular carapace and subcircular abdomen have been found, was referred by him to Pterygotus (P . r a n i - c e p s) on the strength of its marginal eyes.

Grote and Pitt based their new genus on mere differences in outline and though Woodward did not regard these as generic characters, and Miller [N. A. Geol. & Pal. 1889, p. 548], obviously for like reasons, refused to recognize the genus, while Zittel cites it as doubtful, it is entirely evident from our present knowledge that the group, typically represented by E u s a r c u s s c o r p i o n i s, is generically distinct from all its allies.

On this continent there is another locality, Kokomo, Indiana, which has afforded representatives of Eusarcus sometimes in gigantic examples. The first specimens were described by Claypole as E u r y s o m a n e w - l i n i [1890, p. 259]. The term Eurysoma was soon after withdrawn by its author as preoccupied and was replaced by Carcinosoma. In 1894 another species (C . i n g e n s) from the same locality was added and Eusarcus indicated as the nearest ally of the new genus, with the following qualification: " But the description of that genus [Eusarcus] mentions that the cephalothoracic portion is considerably narrower than in allied forms and that the terminal segment shows a widening and no trace of spiniform process. There are also several other minor points of difference." None of the differences here suggested by Claypole really exist, for our working material, which probably comprises nearly all Kokomo specimens ever collected, shows this carapace to have quite the same subtriangular form as in the Buffalo specimens, while both possess an ensiform

telson. There are only minor differences between the Buffalo and Kokomo specimens; the latter are undoubtedly congeneric and the term Carcinosoma has to yield to Eusarcus.

From the study of the large collection of material representing the genotype we consider the genus as characterized by (1) the triangular carapace, (2) the marginal and forward position of the eyes, (3) the decrease in length of the walking legs backward, (4) the spinosity of *all* walking legs, (5) the broad elliptic to subcircular preabdomen, (6) the sharply defined, greatly lengthened, cylindrical postabdomen, (7) the broad and short, subtriangular metastoma, (8) the distinctive proportions of the segments of the swimming legs.

These characters, we believe, are correlated and shared by a number of species which thus constitute a well defined group. We have been able to satisfy ourselves as to their presence in Carcinosoma newlini Claypole (including C. ingens Claypole), save the form of the metastoma which has not been clearly seen. Woodward's elaborate description and excellent figures of Eurypterus scorpioides bring out all of these characters save the position of the eyes which were not observed. The inversely triangular form of the metastoma is particularly well established in that species. A like shield-shaped metastoma is assigned by Woodward to Eurypterus punctatus, known only by disjointed parts and regarded by him as closely related to E. scorpioides. Eurypterus obesus H. Woodward may be the young of E. scorpioides, a possibility suggested by the author of the species; at any rate, it strikingly exhibits the characters of Eusarcus, the last drawing published [1872, pl. 30, fig. 8] also showing the characteristic triangular carapace thus leaving only the supposed intramarginal eyes as a discordant feature to which we will return in another chapter. The Pterygotus raniceps H. Woodward, referred by its author to that genus on account of its marginal eyes, leaves no doubt in our mind as to the propriety of its reference to Eusarcus, on account of the triangular form of its carapace, the forward and marginal position

of the eyes, and the subcircular outline of the preabdomen. Laurie properly compares his E u r y p t e r u s   s c o t i c u s with E u s a r c u s   s c o r - p i o n i s Grote & Pitt. It has the outline of body and the limbs of an Eusarcus. Further, the imperfectly known E u r y p t e r u s   a c r o - c e p h a l u s Semper (1898), a Bohemian form, belongs here. Its subtri- angular carapace which gave the species its name and the broad, abruptly contracted preabdomen warrant this reference and Semper has correctly

Figure 52 Metastoma of E u s a r c u s   p u n c - t a t u s Salter. Nat- ural size. (From Wood- ward)

Figure 53 E u s a r c u s   o b e s u s (H. Woodward). Natural size. (From Woodward)

pointed out the similarity of its species to E .   s c o r p i o n i s and E .   s c o r p i o i d e s . Finally the S t y l o n u r u s   (?)   s i m o n - s o n i Schmidt is distinctly an Eusarcus, as we have set forth in the appended footnote.[1]

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[1] This species was originally described as E u r y p t e r u s   s i m o n s o n i and later referred with doubt to Stylonurus, the author stating that he believes the form to represent a new genus closely related to Stylonurus. The latter reference is based on the surface sculpture and the similarity of a detached part to the long last leg of Styl- onurus. The specimen shows the metastoma which, as Schmidt remarks, differs from all other metastomas. In its triangular, pear-shaped outline it agrees completely with that of Eusarcus. The sculpture, also, consisting of disklike prominences with raised

The presence of the genus Eusarcus in the Frankfort fauna is demonstrated by various characteristic parts of the integument, viz, two forms of carapaces, cordiform metastomas so typical of Eusarcus, extremely broad and short tergites, the long conical postabdominal segments, a telson, and fragments with the characteristic ornamentation. The metastomas are probably the most conclusive of these, no other genus having furnished singularly broad and short subtriangular plates.

The two species here described are for the present entirely based on the carapaces and the other parts of the integument are noted below.[1]

The genus hence comprises the following species:

Eusarcus scorpionis *Grote & Pitt*	E. raniceps (*H. Woodward*)
[*incl.* E. giganteus *Grote & Pitt*]	E. scoticus (*Laurie*)
E. newlini (*Claypole*)	E. acrocephalus (*Semper*)
[*incl.* E. ingens (*Claypole*)]	E. simonsoni (*Schmidt*)
E. punctatus (*Salter*)	E. longiceps *nov.*
E. scorpioides (*H. Woodward*)	E. triangulatus *nov.*
? E. obesus (*H. Woodward*)	

margins making horseshoe-shaped impressions, is characteristic of Eusarcus as fully stated in the generic description. The clear photographs of the type of the Russian species show that the general outline and the form of the attached last leg possess the characteristics of Eusarcus. The detached part is not a leg as surmised by Schmidt but the scorpioid slender postabdomen of Eusarcus, and furnishes another character typical of that genus. As to the " Dorsalfurchen " we have the impression that they are accidental. Less pronounced furrows have been noticed by us in various specimens of E u r y p t e r u s r e m i p e s and other species.

The abdomen appears relatively a little longer than in our species of Eusarcus, possibly through a pulling apart of the segments in anteroposterior direction.

[1] *Other appendages referable to Eusarcus in the Frankfort shale.* We reproduce three metastomas which, by their cordiform outline indicate that they probably belong to a type that is either identical or closely related with Eusarcus. The smallest of the three [pl. 84, fig. 10] is covered with flat, round tubercles that agree with those of the integument of E . s c o r p i o n i s . Another possesses small, granular tubercles [pl. 84, fig. 11].

Our collection also contains the characteristic long conical tail segments and in one case a segment with attached curved telson spine; this and a few tergites suggest the preabdomen of a Eusarcus.

As minor characters which, however, also contribute to give Eusarcus its peculiar or even odd appearance and which seem to be present in all the species before cited, may be mentioned the strong development of the spines of the walking legs, the relatively great length of the seventh segment of the swimming legs and the peculiar surface sculpture, which in all representatives shows a strong tendency to become tuberculate instead of triangular-scaly as in the others, i.e. the scales are much smaller, more crowded and more or less circular in outline.

Three of the generic characters are closely correlated and combined. They indicate an attitude of the animal wholly different from that of Eurypterus. These are the triangular carapace, the frontal position of the compound eyes and the predominant size of the anterior walking legs. These characters demonstrate that Eusarcus raised the eyebearing front end of its carapace highest above the ground while Eurypterus brought its broad shovel-shaped frontal part down to the ground in walking.

Another peculiarity is intimately connected with this style of bearing the carapace. Though at first glance it is apparently of minor importance, it gives species of Eusarcus a very different aspect from those of Eurypterus and indicates a difference of habit in the two genera. In Eurypterus the walking legs are invariably bent backward in the fossil state, while in Eusarcus they are as invariably bent forward.[1] In the living animals their direction was downward in Eurypterus as well as in Eusarcus but while in the former the posterior spines are the longer, in Eusarcus the anterior ones were either longer or at least of equal length with the posterior. The greater length of the posterior row of spines in Eurypterus must have emphasized the effect of the greater length of the posterior legs in bringing the front of the carapace down and, likewise, the greater length of the anterior row in Eusarcus would have increased the effect of the greater length of the anterior legs and assisted in lifting up the front

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[1] With the exception of the small E u s a r c u s o b e s u s (probably a young form) while in the British E u s a r c u s s c o r p i o i d e s they are as strongly bent forward as in our two species.

of the carapace. The position of the longer row of spines, however, will determine the side on which the walking legs come to rest when limply sinking to the bottom.

The difference in the walking legs finds its strongest expression in the fourth pair. In Eurypterus the fourth is not only longer and thinner than the others, but also lacks the spines, while in Eusarcus, it is the shortest leg of the last three pairs, though equally strong and, like the others, provided with spines on all segments.

Another difference consists in the form of the swimming legs. Corresponding to the plumper, heavier form of Eusarcus, these legs are more powerfully developed. The paddles are much longer and broader, while the preceding segments, connecting with the coxae, are much shortened and thickened, so that the eighth segment in Eusarcus is fully as long or even longer (in old individuals) than the 2–6 segments together. The latter segments are consequently, in their proportions and even in their form, entirely different from those of Eurypterus. In these characters the swimming leg of Eusarcus has become closely like that of larger species of Pterygotus such as P. b u f f a l o e n s i s .

Eusarcus scorpionis Grote & Pitt

Plates 2 7–3 4; plate 3 5, figures 2–5; plate 3 6, figure 1

E u s a r c u s s c o r p i o n i s Grote & Pitt. Buffalo Soc. Nat. Sci. Bul. 1875. 3: 1,
pl. 1

E u s a r c u s g r a n d i s Grote & Pitt. *Ibid.* p. 17

E u s a r c u s s c o r p i o n i s Pohlman. *Ibid.* 1881. 4: 21

E u r y p t e r u s s c o r p i o n i s Semper. Beitr. z. Pal. u. Geol. Oesterr.-Ung. u. d.
Orients. 1898. 11: 86 *et seq.*

E u r y p t e r u s s c o r p i o n i s Seeman. *id.* 1906. 19: 57

Not E u r y p t e r u s s c o r p i o n i s Pohlman. *op. cit.* 1886. 5: 29-30, pl. 3,
fig. 3

Our description of this hitherto very imperfectly known species is based on the remains of 20 specimens, apparently all that have been thus far secured. Seven of these are entire, or nearly entire, specimens and one

of them is a young individual. Among the fragments are some that prove that this inelegant squatty eurypterid attained to similar gigantic proportions as the associated Pterygotus. The material at hand permits us to give a fairly complete description of both the dorsal and ventral aspects and of the various appendages.

Description. The outline of the body is a very broad oval, acute anteriorly and broadly rounded posteriorly, where a tubular tail (post-abdomen) of equal length is affixed, ending in a long, curved telson, of again half the length of the tail.

Cephalothorax. The cephalothorax is about as broad as long, its outline is bluntly subtriangular, the two lateral margins converging at an angle of about 50° toward the anterior end which is truncated. The base is but little longer than the lateral margin (about one thirteenth). The anterior margin is about one third as long as the lateral margin. The posterior margin bends gently forward in the middle and is well rounded and projects slightly at the postlateral angles. The lateral margins were moderately convex; the frontal line slightly emarginate. There is evidence that the carapace was relatively convex along the middle axis and that it remained so to the anterior margin or even culminated there, where the compound eyes were borne on the sides of this frontal snoutlike prominence. The compound eyes are kidney-shaped, apparently smooth, without recognizable facets, about one tenth the length of the carapace and situated at the antelateral corners of the latter. The ocelli, well shown in one specimen, lie a little behind the center of the carapace [pl. 29], and probably occupied the apex of the head shield. The doublure is narrow at the sides; along the posterior margin it is 2 mm wide in medium sized specimens.

Abdomen. The abdomen is broad and depressed in the anterior portion and narrow and tubular in the posterior portion, the two parts contrasting in a most striking manner. The dorsal side of the anterior preabdomen appears to have been entirely flat, but the middle third of the posterior part projects above the flat or slightly concave pleural portions

and this median convexity grades into the round postabdomen. The ventral side of the preabdomen was more strongly and uniformly convex than the dorsal. In outline the abdomen widens so rapidly that at the third and fourth dorsal segments, where it is broadest, it is already more than twice as wide as the head shield at its base. With the next two segments it contracts abruptly to the postabdomen.

Preabdomen. The tergites are broad, short plates; those in the middle are five times as broad as long. First tergite much shorter than the others, its posterior margin parallel to the posterior margin of the carapace; anterior margin uniformly and deeply concave, the segment having a shape approaching a crescent; antelateral angles produced into blunt ears. In most specimens this plate is pushed under the cephalothorax, sometimes, as in the type, so much that only its posterior margin remains visible. Second tergite also very concave in front, its antelateral angles projected forward. Posterior margin with a low broad concavity in the middle. This and the following tergites are much longer in the lateral than in the middle portions.

The five sternites or ventral segments are strongly curved forward and convex, of relatively great length, the latter amounting to one fourth of the width in the typical middle plates of the series.

Operculum differing from the following plates in outline but little if any longer. Anterior margin not seen in perfect preservation, but the evidence at hand indicates that the antelateral angles were truncated and well rounded and the remainder of the margin straight transverse. Posterior margin notably less curved backward near the sides than the following sternites, but produced into two prominent blunt lobes at either side of the median cleft.

The other sternites possess a double curvature. They are strongly curved forward in the middle half. The anterior margin becomes so deeply concave on either side that a middle transverse line passing through the center of the last sternite will touch the interior edge of these sinuses. The antelateral angles are produced into prominent ears. Corresponding to the anterior margin the posterior margin shows two

broad, well rounded lobes on either side of the broad median sinus. Post-lateral angles obliquely truncated and rounded. The second sternite has also the posterior angles of the median cleft well rounded off, while in the succeeding plates the posterior margin is continuous.

As the specimen reproduced in plate 35, figure 5 shows, the sternites were not only very convex in outline, but also highly arched, forming a high ventral vault.

The *postabdomen* forms a slender tail that sharply contrasts with that of the extremely broad preabdomen. The curved telson spine combines with the long tubular postabdomen to produce the singularly scorpioid aspect of the tail.

The first postabdominal segment which closes the interval between the broad preabdominal and the following narrow segments resembles the former in the dorsal and ventral aspects, as in other eurypterids. It is a short ring, about three times as wide as long, contracting posteriorly by one third of its width. The other segments are practically tubular. Their relative length increases so strongly backward that while the second segment is not quite half as long as wide, the last is six times as long as wide. The numerous marginal wrinkles and the form of the median portion of some less compressed segments indicate that the section of the last segments was nearly or quite circular.

The *telson* is a curved, stout spine, half as long as the postabdomen or equal in length to the last two segments. Its first two thirds are gently, and the last third strongly curved downward. Its basal portion is swollen globularly on the ventral side and hollowed out on the dorsal, thus forming an articulation specially adapted to a strong up and down movement in the vertical plane. The compressed condition of the telsons in our material has not permitted a clear view of the section but the keellike projections which appear on the lateral view indicate that the spine was probably four-sided. The edges of the keels are serrate.

Appendages. The chelicerae have been seen in position in two specimens [pl. 32] and one well preserved chelicera has been found detached

[pl. 31]. These preoral appendages were the only prehensile organs of the animal; they are, therefore, of relatively large size. If the separate chelicera belongs to the specimen alongside which it lies—of which there is
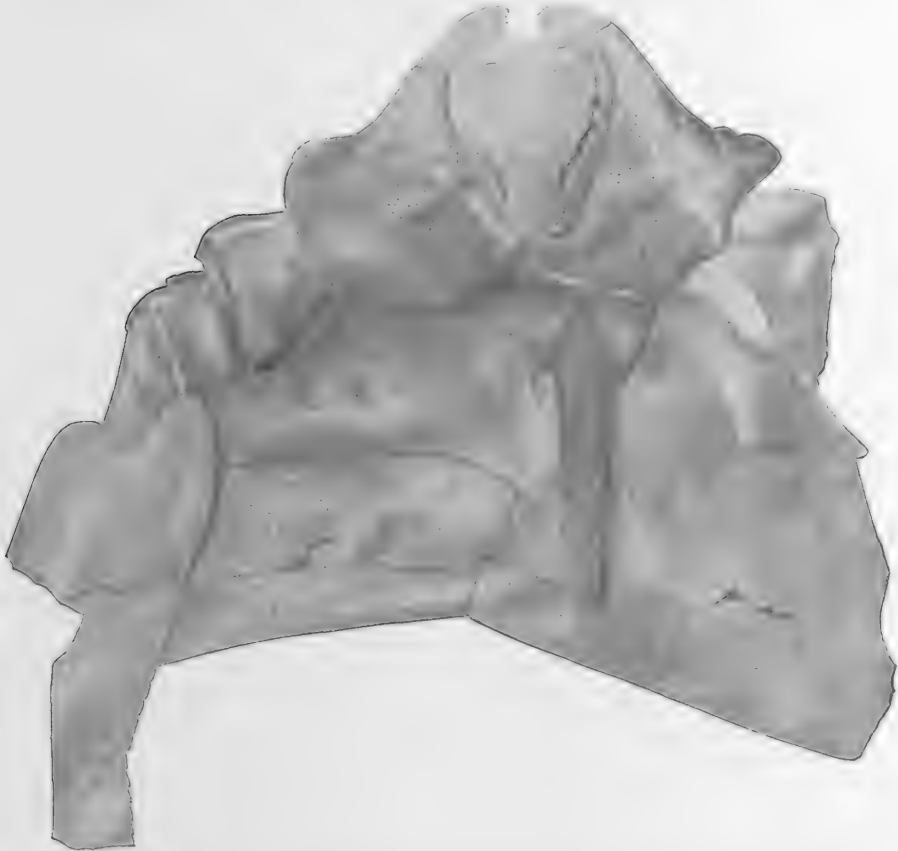
Figure 54 Eusarcus scorpionis Grote & Pitt. Ventral view of swimming leg of right side, and the coxa of that of the left side; the metastoma; operculum and the two following sternites. The female opercular appendage is partly preserved [see diagram, text fig. 55]. Text figure 57 is a diagram from the swimming leg here shown. Natural size. The original in the State Museum

little doubt—then it attained three fourths the length of the carapace. The basal segment is broad and massive, three times as long as wide, contracting slightly at the distal end. The two segments forming the pincers are but half as long as the basal segment, broad at the base and furnished with very acute, slightly curved tips. In the type of the species [pl. 31] the basal segments alone are seen, turned back to their full length; in plate 32 the pincers and a part of the basal segments are folded backward.

The walking legs are all relatively short but massive and are provided throughout with very long, stout, curved spines. The first pair is very short and project a little at the tips beyond the margin of the carapace; the second is the longest of the series and the following two pairs again decrease in size, the third being but little shorter than the second, while the fourth is shorter by about one third. In old individuals [pl. 33, fig. 2]

Figure 55 Outline sketch of the incomplete female opercular appendage of the preceding figure, with the sutures of the pentagonal pieces and of the sternites

the spines on the first leg attain one third the length of the whole member.

The coxa has been seen only in the leg referred to. It is here elongate, widens toward the base and is about as long as the following segment. The distal part is drawn out into a curved neck bearing the manducatory edge on its inner side. The teeth, which form a decreasing series, are long and sharp. Just above the first is a large round scar which may be the base of a much larger tooth at the head of the series, such as is found in other eurypterids. At the end of the series is a small round node

which may correspond to the finely haired cushion which Holm observed on the coxa of the first walking leg and which he considers as possibly corresponding to the epicoxite of the following legs. The posterior portion of the coxa is partly lost as shown by the broken edge. The next segment is short and broad, about as wide as long, while the third, the longest of the series, is twice as long as wide. The following segments decrease rapidly in length and at a lesser rate in width. The terminal segment is spiniform. The spines, two of which are borne on each segment, save the first two and the last, increase in size regularly to the distal spines which are the longest.
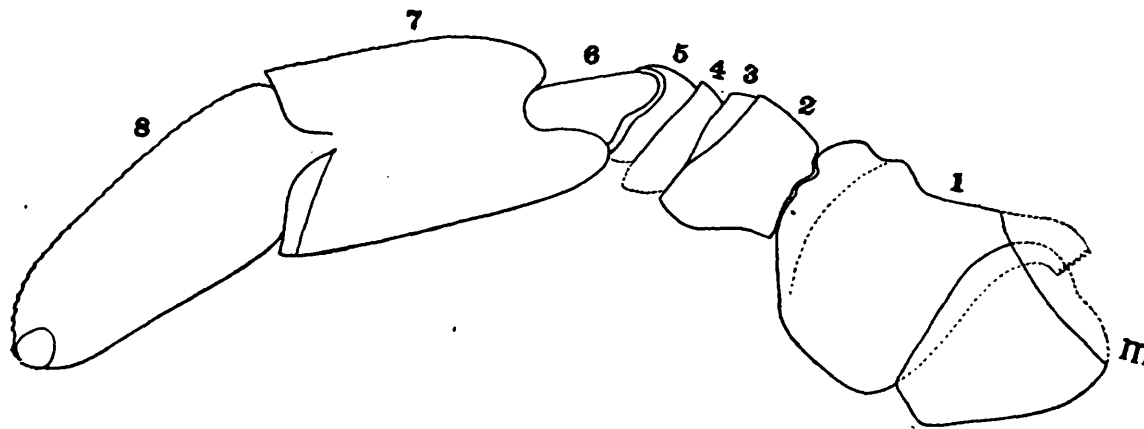
Figure 56 Diagram of ventral view of right swimming leg of Eusarcus. *m*, metastoma; the figures indicate the segments

The detached walking leg consists of seven segments. Its short and thick form and the composition of seven segments indicate that it was one of the first pair of walking legs. None of the following legs have been seen entirely free, but the combined evidence of our specimens leads to the inference that they consisted of eight segments each, as in Eurypterus.

The swimming leg, corresponding to the plump form of the animal, is of massive proportions and furnished with a large paddle. The seventh and eighth segments forming the latter, are greatly lengthened and broadened and the segments connecting this paddle with the coxa are shortened and swollen for the reception of powerful muscles, held together by strongly interlocking articulations and, as their frequent plastic preservation shows, were covered by a thick periderm. Compared with the swimming leg of the species of Eurypterus this leg makes the impression of a much stronger,

but less active and movable organ. The coxa has not been seen entirely free. Enough, however, is shown to indicate that it is of a rhomboidal outline, like that of Eurypterus, differing in that it is relatively higher and shorter [pl. 32]. The gnathobase is not preserved in the specimen cited. The second segment is not short and ringlike as in Eurypterus, but cup-shaped, widening rapidly distally. It is connected by the narrow ringlike or wedge-shaped third segment to the ringlike fourth segment. In an old

Figure 57   E u s a r c u s   s c o r p i o n i s   Grote & Pitt.   Portion of dorsal view of left swimming leg.   Natural size.   Original in State Museum

individual [text fig. 57] the three segments mentioned form a powerful spherical part of the leg. The fifth segment is ringlike on the under-side of the limb, widens out and is extended anteriorly on the upper side. Near the center of the flaring upper portion of this segment the next, sixth, segment is inserted. This appears from both sides as a tri-angular, or originally rather conical body, the distal basal surface of which is deeply emarginate on the posterior side and extended on the anterior, so as to fit into the deeply emarginate basal portion of the seventh joint. The latter is by far the broadest segment of the limb and nearly as long as

the following, the palette. It is subrectangular in general outline, its length is one fifth longer than the width, the proximal and distal sides both deeply notched for articulation. The upper angle of the proximal side is evenly rounded, the lower much produced to meet a corresponding notch in the preceding segment. The lower part of the distal side is produced into a triangular plate about one third as long as the segment and separated from it by a transverse suture. The other upper part of the distal margin is nearly straight. The eighth segment is a very long oval, twice as long as wide, the distal end being the more slender. The terminal segment is subcircular in outline and relatively large.

The *metastoma* is heart-shaped in outline and relatively short. The frontal margin is the longest; it seems to be slightly emarginate, but the preservation is not clear enough to determine this point. Length and width of plate nearly equal. The antelateral angles are

Figure 58 Diagram of dorsal view of left swimming leg

well rounded and the sides contract in a gentle curve to the blunt posterior extremity.

Genital appendages. Of these only the female have been seen in two examples. In the older of the two the appendage begins with two triangular (or subpentagonal) basal members, not seen in the younger individual, as the sutures which separate them from the opercular plates are not developed. These plates inclose an elongate sagittate base similar in shape to that of P t e r y g o t u s b u f f a l o e n s i s . At the posterior angles of the latter two semicircular lobes are observable which probably covered the genital openings. From it proceeds the slender middle portion which is convex along the median line and flat along the borders. The distal extremity is seen in the younger specimen. Here it consists of two converging obtuse pieces with parallel inner and converging outer sides. The basal portion which is sagittate in the older individual is rounded or in-

versely heart-shaped in the younger [pl. 33, fig. 3]. The organ was slender and relatively long; in the larger specimen it extends, incomplete as it is, to the third sternite. The appendage of the second sternite has not been observed.

Ornamentation. The ornamentation of this species is characterized by the small size, but immense number and round circular form of the scales and tubercles. The carapace uniformly bears small tubercles, giving it a shagreen surface. The coxa, the metastoma and the muscular joints of the walking and swimming legs have somewhat larger scales most of which have the form of slightly tilted disks with the anterior segment cut away or submerged in the periderm, the posterior portion being raised. The tergite of a mature individual bears rather widely scattered, larger semi-circular to low triangular scales which terminate rather abruptly or become fewer and smaller over the posterior doublures but continue on their overlapped anterior parts. On the sternites the scales are arranged in distinct bands, the anterior halves of the plates being covered with such a densely crowded mass of small semicircular scars that the naked eye fails to discern them. These increase in size to the middle of the sternite where they form a zone of larger semi-circular to crescentic scars which are less densely arranged and become farther separated posteriorly until they almost entirely disappear above the doublure. Between these larger scales numerous small ones, often of microscopic size, are interspersed. The opercular plates differed from the other sternites in being almost entirely covered with the larger scales which are much more densely arranged than on the following plates, but are also lacking along the posterior border. The pentagonal and sagittate basal portions of the female genital appendage are ornamented like the opercular plate.

The postabdomen, as a whole, bears scales of the size and distribution of those on the tergites. They lengthen, however, posteriorly, approximately in proportion to the remarkable lengthening of these postabdominal segments until on the last segment they have become acutely pointed.

The telson is furnished with small circular scales on the swollen basal part and with long spinelike scales on the remainder.

TABLE OF MEASUREMENTS OF EUSARCUS SCORPIONIS [IN MILLIMETERS]

	Total length of body	Length of carapace	Width of carapace	Length of compound eye	Length of longest walking leg	Length of swimming leg	Length of seventh joint	Length of eighth joint	Length and width of metastoma	Length and width of preabdomen	Length and width of largest tergite	Length and width of operculum	Length of genital appendage	Length and width of largest sternite	Length of postabdomen	Length and width of first caudal segment	Length and width of last caudal segment	Length and width of telson
Type specimen.....	....	....	71	....	(76)	(120)	(32)	....	......	84:112	(20):112	....	....	....	......	......	....	....
Young specimen....	113	18	22+	....	.....	....	....	....	......	23:35	5:35	....	....	....	48.5	5:18	14:7	23:5
Specimen A........	....	60	66	9	44*	87*	27	37	......	82:106	(19):106	....	....	....	......	......	....	....
Specimen B........	328	(53)	....	....	.....	(102)	(34)	33.5	......	67:88	17:88	....	....	....	(146)	11:(45)	(40):19	(62)
Specimen C........	....	56	59	9	82	(117)	....	(40)	......	76:104	(18):104	....	....	....	......	......	(47):(20)	.....
Specimen D........	....	62†	....	11	.....	....	..;	....	......	99:(123)	22:(123)	....	....	....	205	23:72	61:25	.....
Specimen E........	....	....	....	....	.....	(152+)	63	....	(39):30	......	....	(42):(77)	59+	39:—	....	......	....	....
Largest fragments observed........	....	....	....	....	189+	187+	81	75	.....	......	......	....	....	(49):(211)	....	......	108+:32	151+

* When marked by asterisk only the portion protruding from the carapace is measured. Approximate measurements are in parentheses.
† Length of chelicera 44.5.

Horizon and localities. Remains of this species have been found only in the Bertie waterlime quarries at Williamsville and Buffalo, N. Y.

Observations. The relative size of some of the largest fragments indicates that E . s c o r p i o n i s reached at least a length of four fifths of a meter or 2–3 feet and thus belonged to the larger members of the eurypterid fauna of the waterlimes. It attained at least half the size of the giants of this fauna, the two species of Pterygotus.

Lacking the long and powerful pincers of those dangerous competitors, the principal or sole organ of defense and offense must have been the telson spine. In correspondence with this important function the postabdomen is so much extended that, with the telson, it greatly exceeds

in length the remainder of the body. The curved position of the post-abdomen in several specimens demonstrates the great flexibility of this part, while the downward curvature of the telson would make it a dangerous weapon when the postabdomen is thrown forward over the body, as this action would bring the terminal spine into the position of an upturned sharp pointed scimitar.

There is a striking morphological similarity between the telson of. Eusarcus and the tail of the scorpion and in view of this and the acknowledged close relationship of the merostomes with the scorpions, it becomes a fair question whether the tail spine may not have been equipped with poison glands. The preservation of the telson is not such as to permit the determination of the presence or absence of apical pores for the emission of the venom, or of the poison canal in the compressed spine. The form of the body of the animal does not suggest great agility, either in walking or swimming, but rather a habit of burrowing in mud or lying in wait for prey. In the absence of powerful prehensile organs of long reach, a quick dispatch of the prey must have been a necessity and this could have been well accomplished by an agile and venomous telson.

The table of measurements shows that the young individual exhibits interesting and probably phylogenetically significant differences from the adult in the general proportions of its body. The most notable of these is the relatively greater width of the preabdomen; for while in the young the proportion of length to width here is as 2 : 3, in the older specimens it is as 4 : 5. The postabdomen also is relatively wider or stouter than in the older individuals, while on the other hand, the relative lengths of preabdomen, postabdomen and telson to the total length have remained nearly the same. Still younger individuals would surely show other differences in these ratios. The cephalothorax which in our young and old individuals occupies about one sixth of the length and is a relatively insignificant part of the body, compared with the other eurypterids, has most probably lost in relative proportion during ontogenetic development.

Eusarcus newlini (Claypole)

Plate 36, figure 11; plates 37-39

Eurysoma newlini Claypole. American Geologist 1890. 6: 258
Carcinosoma newlini Claypole. *Ibid.* p. 400
Carcinosoma newlini Claypole. *Ibid.* 1894. 13: 78
Carcinosoma ingens Claypole. *Ibid.* p. 77

The highly bituminous dolomites of Kokomo, Ind., have afforded a species of Eusarcus which was described by Claypole first as Eurysoma then as Carcinosoma newlini. The peculiar character of this rock makes an unfavorable matrix and Claypole was successful only in outlining the body and legs of his species[1] but careful treatment of a series of these specimens has made it possible to elucidate in some measure the essential structures of the creature. The type specimen has not been located by us (cited as belonging to Mr Newlin of Kokomo), but we have before us several specimens brought together by the late Professor James Hall and now belonging to the museum of the University of Chicago, one of which agrees so closely with the figure of the type as to suggest its identity with the latter. Another specimen [pl. 39] in the same collection, both sides of which have been preserved, excels the type in the distinctiveness of several important features.

Besides these specimens we have two large individuals (one from the Hall collection, the other in the State museum) which correspond in size to Claypole's Carcinosoma ingens. This species was erected by Claypole for a specimen received from Mr Charles Smith of Akron, O.

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[1] *Original description.* Animal measuring over all about 10 to 12 inches or even more in length by 4 to 5 inches in greatest breadth. The length may be allotted on the average thus: Head shield, 2 inches; body, 3 inches; abdomen, 4 inches; tail spine, 2 inches; greatest breadth of body somewhat behind the middle.

Of the appendages the foremost pair is the smallest with about 5 spines on each; the second and largest pair have at least 12, the third about 8, and the fourth about 4 spines. From the second the appendages diminish gradually in size to the fourth.

The large fifth pair reach only to the hind segment of the body—about 3 inches—and show merely the details mentioned in the general description.

Here again the author furnished an outline sketch [reproduced in text fig. 60]
and diagnosed the species by citing its differences from E. newlini.
He says:
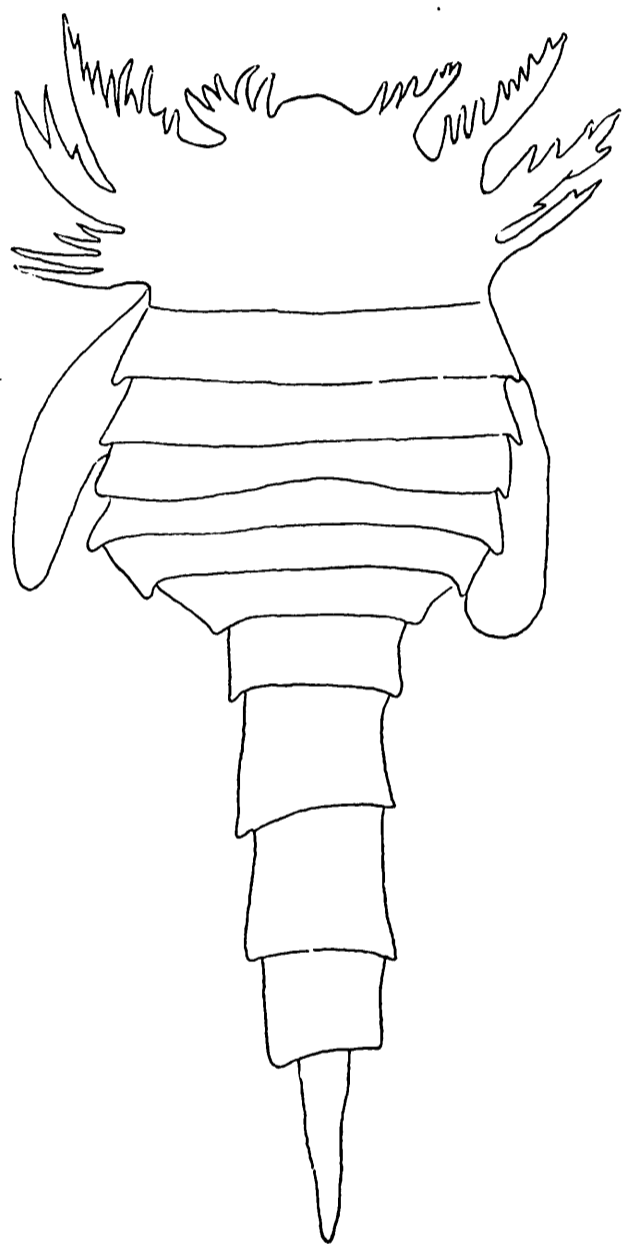
Figure 59   Original figure of Eury-
soma newlini Claypole. (From
Claypole)
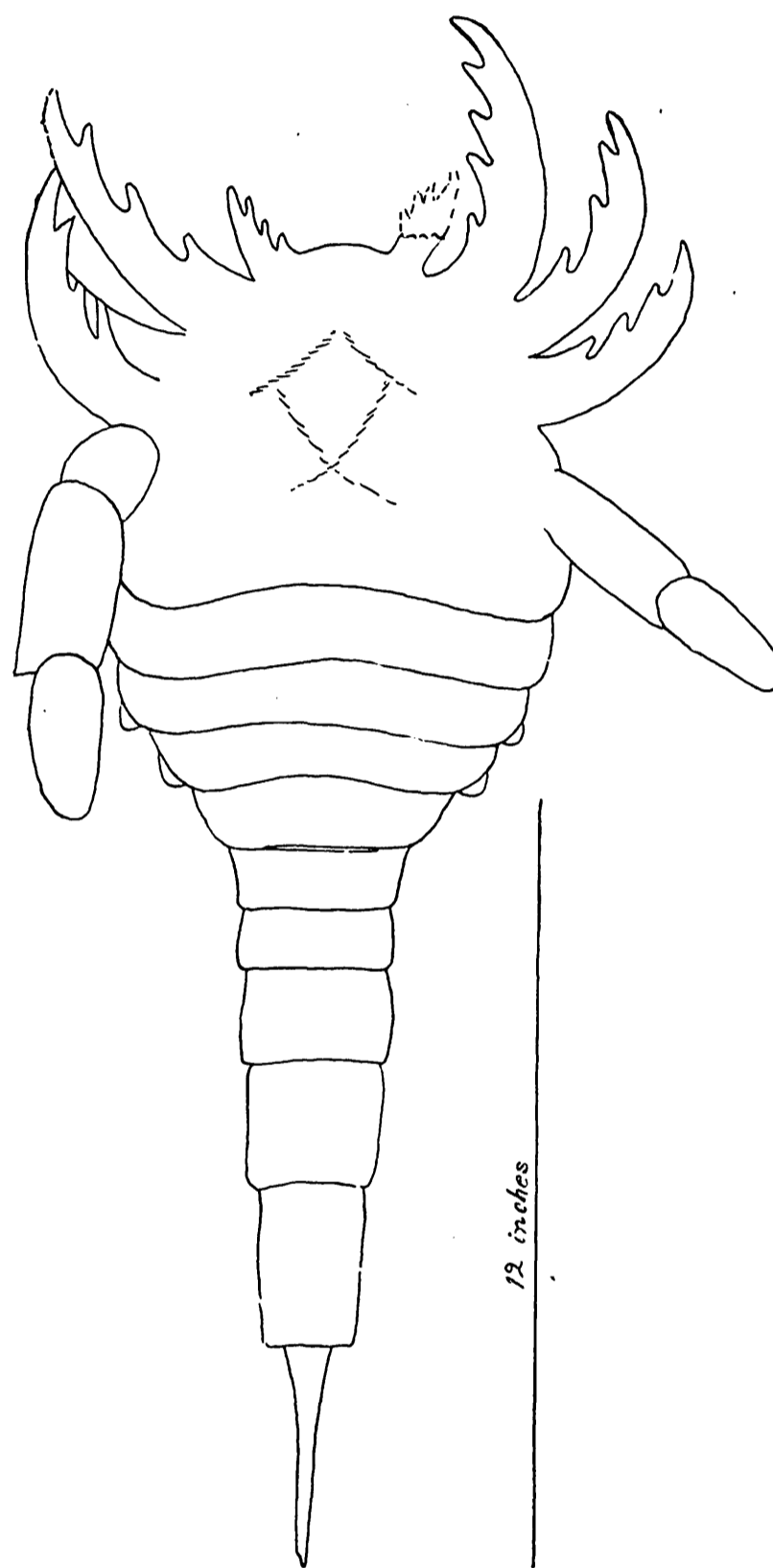
Figure 60   Original figure of Carcinosoma
ingens Claypole. (From Claypole)

In the specific description the leading points of difference and those
on which the definition rests are the greater size of the fossil and the smaller
number of cusps or branches on the four anterior pairs of gnathopods.

The specimen measures 24 inches in length, whereas none of those from which the description of C. n e w l i n i was compiled exceeded 14. There are also only three cusps on the front edge of the first, third and fourth pairs of gnathopods, and four on the second pair. In C. n e w - l i n i these cusps are sometimes 8 to 12 in number, and apparently in some cases project from the back of that organ, though this must be considered uncertain and against analogy.

There is, moreover, on the large paddles, no trace of the fringed or serrated edges which are so conspicuous in the paddles of C. n e w l i n i. They are perfectly even and smooth.

None of the differences cited seem to us to warrant any specific distinction, the different size being clearly due to age, since no important corresponding discrepancies in the proportional lengths of the parts of the body could be found to corroborate the supposed distinction. The cusps are, to our knowledge, of like number in all these Eusarci, all segments, save the first two and the last, bearing two spines each, the last forming a single spine. Both spines were of nearly equal size, as we have already observed in the generic description, but frequently only those of one side are observable, the others being either broken away, leaving their wartlike bases [pl. 33, fig. 1], or imbedded in the rock above or below the bedding plane on which the body rests. Of the two specimens of E u s a r c u s n e w l i n i before us, one [pl. 37] shows the spines of both sides and would hence correspond to E. n e w l i n i s. str., the other only those of one side and would hence have in this regard the character of E. i n g e n s.

The last difference cited is the absence in C. i n g e n s of the fringed or serrated edges "so conspicuous in the paddles of C. n e w l i n i." Much of the serrated appearance of the edges of the paddles in the eurypterids is due to a cracking of the thickened margin of this thin leaflike organ. For this reason one frequently sees in some specimens of this species an apparently very marked serration, while others have a distinctly smooth edge. The same is true of both E. n e w l i n i and E. i n g e n s, E. n e w l i n i possessing, in reality but a very weakly developed serration.

The supposed differences between E. n e w l i n i and E. i n g e n s are doubtless due to slight variations in preservation, but even if of actual

existence, they could be of no more than varietal importance.   We here refer all specimens of Eusarcus from Kokomo to one species which has the following characters.

Description.   *General form* that of a rather short, posteriorly broad oval body (carapace and preabdomen) with abruptly attached tubular tail (postabdomen) of equal length with the body, and a rather short, stout tail spine.

Cephalothorax broader than long (proportion of length to width as 7 : 8 in the youngest specimen), the difference decreasing with increasing age, in the largest example being reduced to but one fourth of its earlier size; outline a regular triangle with truncated angles, the lateral margins moderately convex,[1] the posterior margin gently concave in the middle, almost straight.   Posterior truncating line or postlateral angles very gently convex; frontal margin probably slightly emarginate between the eyes. The lateral eyes have been seen only in the largest specimen; they are located at the antelateral angles, are of bean-shaped outline and about one fifth the length of the lateral margin.   Their structure has not been observed; nor have the ocelli been seen in any of the specimens.

Abdomen.   Preabdomen relatively shorter than in any of the other species ; a little longer than the carapace and nearly twice as wide; broadens in continuation of the lateral margins of the carapace to the fourth tergite, whence it contracts rapidly to the powerful postabdomen which is twice as long as the preabdomen and two fifths as broad.

The outlines of the separate tergites and sternites have not been distinguished with clearness and no separate plates observed; hence no detailed description of their form and relative dimensions can be given, but enough has been seen to prove that they do not differ materially from the corresponding parts of the better known E . s c o r p i o n i s , although it is

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[1] In the smallest specimen they are gently sigmoid in outline, their anterior half being gently concave, a feature that is not observed in the other specimens and quite probably due to differences of preservation, as suggested by a like difference in equal sized specimens of E . s c o r.p i o n i s .

to be inferred from the relative smaller length of the preabdomen that the preabdominal plates were also relatively shorter. The first tergite would, from the evidence of the largest specimen, seem to have been at least eight times as wide as long. The posterior margins (which alone are seen owing to the more abrupt termination) are nearly straight in the anterior tergites but become distinctly concave in the middle of the last two plates; in the sternites they are throughout broadly concave in the middle and well rounded at the postlateral angles.

The gill plates are distinctly outlined in the smallest of the specimens [pl. 37,] and are of elongate, sublanceolate outline, rounded on the inner side and acutely pointed on the outer, slightly diminishing in size posteriorly.

The *postabdomen* appears disproportionately long; it is fully twice as long as the preabdomen. At the same time it is broader (one fourth as wide as long) than in other species and has altogether the appearance of a very powerful organ. The first segment completes the contraction of the oval portion of the abdomen as in the other Eusarci, thence the post-abdomen is of nearly uniform width, contracting but one sixth to the posterior extremity. The first segment is a narrow ring with a strong forward bend, about four and one half times as wide as long. The next is of similar shape and rate of contraction, but four times as wide as long. At the postlateral angles it is slightly produced backward and its lateral margins are concave, indicating that it had the form of a concave truncated cone. The next, like the following, is of tubular form. The last four segments do not lengthen nearly as rapidly in this species as in E u s a r c u s s c o r p i o n i s , the sixth being twice as long as the third and three fifths as wide as long.

The *telson* has been seen in but two specimens. In one of these it agrees with the figures given by Claypole of E . n e w l i n i and E . i n g e n s in being short, stout and straight. Its length is one sixth that of the body and four times as great as its basal width. The basal fourth is slightly expanded or inflated, the remainder tapers regularly to a point. One of the specimens shows at the underside near the base a

fragment of a flat-topped carina such as is found in the other eurypterids, suggesting that the section of the telson does not differ materially from that in other genera. No traces of marginal serrae are observable in our specimens.

Appendages. What appear to be the tips of the chelicerae or preoral appendages are seen in the largest specimen, the chelicerae having there remained in normal position. If this view is correct, these appendages were relatively large and strong.

The ectognathites or walking legs are here developed into stout and long organs which, except for the first pair, protrude far beyond the carapace and by their width give the impression of great strength and importance. This impression is still more emphasized by the great length of their curved spines. The first leg was the shortest, only its last two segments and their spines protruding. The second walking leg which is the longest, is exposed with six segments outside of the carapace; its exposed portion equals the carapace in length. The segments in this pair of appendages are about as long as wide; in the following legs they become increasingly shorter. The spines attain about one fourth the length of the ectognathites, the terminal clawlike spine being the longest and the others decreasing in proximal direction. Each exposed segment bears two spines of apparently somewhat different length which all curve inward. Of the next swimming leg about one segment less protrudes and the segments are also shorter, the exposed part being thereby shorter by one sixth than that of the preceding leg. The fourth pair is shorter than the second by at least one third; its segments, however, are broader than long by about one third, so that again five segments protrude.

The swimming legs are distinguished by great length and width; turned back they reach the beginning of the narrow part of the postabdomen (line of third postabdominal segment). The coxae of the legs have been seen only in outlines too faint and obscure for exact description. One of these is indicated on plate 38. The manducatory edges which are the most resistant parts of the gnathobases are also seen on plate 37,

as rows of fine teeth. The segments forming the arm or pole of the swimming legs are rather short, ringlike and broad with intricate articulations, none of which however is well preserved. The seventh and eighth segments form a much lengthened but little broadened blade; the seventh segment is about one and one half times as long as wide and occupies nearly one third of the length of the arm beyond the coxa. The proximal extremity is deeply notched for the articulation with the preceding segment; the lobelike plate, marked off from the inner distal margin by a suture, is rounded and occupies half the width of the segment. The palette is a long subelliptical body, twice as long as wide; its distal extremity slightly convex, the inner nearly straight. It carries at its distal extremity a nearly circular claw of relatively great size (one fourth the length of the palette) so snugly fitted in a corresponding notch that it is discerned with difficulty. The edges of the blade are furnished all around with small serrae.

The *metastoma* has not been seen.

Genital appendages. The only trace of a genital appendage seen is a small oval area which suggests an immature female appendage.

Ornamentation. The preservation of most of the material is such that the substance of the integument is a finely puckered carbonaceous film obscuring all former surface ornamentation. In the smallest specimen the impression of the postabdomen shows small elongate elliptic scales of the character of those in E . s c o r p i o n i s [pl. 39]. On the sternites and the carapace of the same specimen traces of small circular markings are also observable, suggesting that on the whole, the ornamentation of this form was little different from that of E . s c o r p i o n i s .

Horizon and localities. All representatives of this species have come from the Kokomo waterlime horizon at Kokomo, Indiana.

Remarks. A survey of the specimens figured [1] shows that they form

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[1] A fifth still smaller specimen is in the National Museum. This is so poorly preserved that it is not capable of furnishing positive data. It is, however, of interest in suggesting that the telson was considerably longer than indicated by the other specimens and probably also curved as in the other species of Eusarcus [*see* pl. 36, fig. 11].

a fairly continuous series of later growth stages, the first two of which correspond in size to Claypole's E. n e w l i n i , the last two to his E. i n g e n s . In the introductory remarks we have already given reasons for uniting the two names. These can be briefly restated as consisting in the absence of the distinguishing characters cited by Claypole and in the agreement of the dimensional proportions in the smaller and larger individuals. There appear to exist a few actual differences between the smallest and

TABLE OF MEASUREMENTS OF EUSARCUS NEWLINI

	Total length of body	Length of carapace	Width of carapace	Length of compound eye	Length of longest walking leg	Length of swimming leg	Length of seventh joint	Length of eighth joint	Length and width of preabdomen	Length and width of largest tergite	Length and width of largest sternite	Length of postabdomen	Length and width of last postabdominal segment	Length and width of telson
Original drawing of E. newlini [1]	264	50+	—	—	72+ [2]	110+	—	—	(48:)(94)	—.	—	122	(24:)(27) [3]	44:12
Original drawing of E. ingens [4]	636	—	—	—	164+	(188)	72	80	(148:)(228)	—	—	237	80:4)	108:24
Specimen A (pl. 37)................	—	45	50	—	70	107	28	40	50:89	—	—	—	—	—
Specimen B......................	270	58	68	14	80	116	28	38	(57):96	—	—	112	34:29	43:12
Specimen C (pl. 38)...............	400+	—	—	—	—	(194)	(51)	73	(93):(145)	—	—	—	62:48	—
Specimen D (pl. 39)...............	(304+)	103	108	(18-20)	—	—	—	—	110:190	—	—	—	—	—

Parentheses imply approximate measurements.
[1] Claypole records E . n e w l i n i as measuring 10-12 inches. The original drawing measures 5¼ inches and can therefore be safely considered as being a one half reduction.
[2] The legs are measured to median line of carapace. Measurements too small from figures since full length of spines not drawn.
[3] Drawing obviously not reliable as to this proportion.
[4] Claypole gives as the length of the type 24 inches, but from the scale appended to the original drawing the original would measure considerably less. The drawing measures 6⅛ inches. We assume therefore that it is reduced to one fourth and that the scale is incorrectly drawn.

largest specimens, which can be more plausibly explained as growth differences rather than varietal distinctions. There are the somewhat greater width of the carapace and more convex lateral margin, the greater thickness of the walking legs and swimming legs in the largest specimen, all of which combine to give the latter a more robust and less agile appearance. The same age difference we have observed in other eurypterids, as has been noted more fully in another place.

E . n e w l i n i as here defined unquestionably belonged to the giants of the race and lagged little, if at all, behind E . s c o r p i o n i s in size. Not less than three of the few specimens known indicate individuals of two feet or more in length.

The species differed from E . s c o r p i o n i s in being built still more compact and sturdy. This is shown in the relatively shorter and broader preabdomen, the shorter and especially broader postabdomen and the shorter, stouter and probably straight telson. The posterior contraction of the preabdomen is more abrupt and the outline of the pre‧abdomen and carapace combined more broadly oval posteriorly. The walking legs are stouter and provided with longer spines; the swimming legs reach farther back (principally on account of the greater contraction of the preabdomen) and the postabdomen is notably broader. The cephalothorax has grown somewhat in proportion to the body, probably on account of the greater stoutness of the appendages for which it has to serve as basis of attachment.

Eusarcus (?) cicerops Clarke

Plate 36, figures 2–10

E u r y p t e r u s ? c i c e r o p s Clarke. N. Y. State Mus. Bul. 107. 1907. p. 307, pl. 5, fig. 10; also pl. 5, fig. 7

Description. The original description of this species which was based on a single specimen is:

This diminutive head shield is remarkable for the extraordinary development of the compound eye lobes which are anterior and very prominent and though the shield has a diameter of only 4.5 mm, the ocellar mound is fully developed. So unusual is the aspect of this specimen that it can not be assigned to any of the other species here noted, and though entirely immature, it is given a distinctive designation.

Later collections have furnished a few more specimens of like size exhibiting the same unusual characters as well as somewhat larger specimens which would indicate, if properly referred here, a remarkable change of characters in the ontogeny of this form. We shall first describe the type and then note the later changes.

The type of the original description [pl. 36, fig. 4] is a small broadly triangular carapace so unusually broad that its length to width is as 2 : 3. The lateral margins in their general direction converge to the protruding front of the carapace and possess a gently sigmoidal curvature, the posterior two thirds resembling projecting cheeks while the anterior third is concave. The postlateral angles are acute. The carapace is highest between the eyes, the ocellar mound being on the apex. The posterior portion of the head is strongly depressed in all specimens, rising abruptly to the upturned lateral borders, and gradually from the base forward. A thickened filiform border bounds the lateral margins and a narrow, flat, depressed border the posterior margin. The projecting frontal margin is flat or slightly elevated.

A very striking feature of the carapace is the pearllike projecting eyes placed very far forward and intramarginal, lying in the pit of the concave curve of the lateral margin. The visual surface is distinctly seen in several specimens [pl. 36, figs. 3, 4, 8]. It is crescent shaped and narrow. The ocellar mound which is situated on a line connecting the posterior extremities of the compound eyes is, like the latter, characterized by extreme prominence, and besides by its remarkably large relative size.

Only one specimen has been found that can give a clue to the original form of the abdomen. Corresponding to the diverging lateral margins of the head and its broad basis, this is also broad and widens much toward the posterior portion of the preabdomen, after which it probably contracted rapidly to the telson.

The boundaries of the tergites are but very faintly seen and it is possible that the specimen has suffered contraction by pressure.

The postabdomen and telson have not been seen in place but a curved telson with attached last postabdominal joint [pl. 36, fig. 7] has been referred here provisionally, partly because it could not be placed with any other species and partly because the head and abdomen of E . ? cice - r o p s suggest its reference to Eusarcus and this telson points also to the same genus. Indeed, we consider the presence of this telson good evidence

of the presence of a Eusarcus in the Otisville fauna, and therefore as supporting the reference of the species here described to that genus.

The carapace of E . ? c i c e r o p s , as exemplified by the holotype, corresponds to that of Eusarcus in the following characters: its typically subtriangular outline with slightly projecting cheeks, the oval form and highly anterior marginal position of the compound eyes. The great width of the preabdomen is also a feature comparable only to Eusarcus.

The immature aspect of the holotype has been mentioned in the preliminary description. It finds its most distinct expression in the relatively large, oval eyes, their forward position and the prominence of the ocelli. It is shown in this paper that the earliest growth stage of E u r y p - t e r u s m a r i a , and to some extent also of members of other genera, is distinguished by its broad carapace, and thus the form of the head of E . ? c i c e r o p s also emphasizes this impression of immaturity. It is, however, to be noted that while the specimens are quite probably not mature forms, their size excludes them from the larval or nepionic stage, of which the immature features mentioned here are characteristic. Moreover we have a specimen of larval dimensions and features [pl. 36, fig. 9] whose size indicates that the other specimens are at least of neanic age. If this be correct, they allow a fair conclusion as to the mature form which, as the largest of the specimens [pl. 36, fig. 2] indicates, retained the outline of the head and the position of the eyes, but lost the pearllike prominence of the eyes and the sigmoidal curvature of the lateral margins. The scarcity of the young individuals in the Shawangunk grit at Otisville allows the inference that the species was very rare in that fauna and adults have therefore not yet been obtained.

The carapace of the nepionic specimen [pl. 36, fig. 9], measuring but 1.2 millimeters, is of striking, or rather grotesque appearance by virtue of the following features:

1 The broadly triangular outline
2 The spinelike prolongations of the frontal and genal angles
3 The immense, diverging eyes
4 The strong median crest
5 The broad margin

In this nepionic individual the relative width of carapace is much greater than in the type. The impression of excessive width is, however, hightened by the lengthening of the genal angles parallel to the base of the head. These horizontal genal spines, together with the equally produced third frontal angle of the triangle, serve to strongly emphasize the triangular aspect of the head. The frontal projection is the forward continuation of a strong median crest extending forward from the base. The lateral margins exhibit the sigmoidal curvature and the cheeklike convexity of the posterior portion as in the following stage.

The compound eyes are oval in form, of great size (about one third the total length of the head), strongly divergent and placed in the middle of the head instead of forward and farther inward from the margin than in the older individuals. The fact that they are surrounded by a deep depression seems to indicate that they were originally quite prominent, thereby drawing the surrounding test downward with them in becoming depressed to the level of the carapace. The ocelli have not been discerned. Finally the carapace exhibits a broad thick margin on all three sides, possibly a broad doublure on the under side.

It is easily seen that this larval form, notwithstanding its own peculiar characters, shares its most important features with the larval stages of other eurypterids. This is especially true of the large size of the eyes, the great width of the head and the presence of a median crest. The acute lobes of the angles are a character peculiar to this larval form and perhaps in line with the spinose processes of the larval forms of many crustaceans. The position of the compound eyes in the middle of the head may be of phylogenetic significance and indicate the secondary acquirement of the frontal position of these eyes in Eusarcus. It should be also noted that the convergence of the eyes in the mature form is directly reverse to that in the larval stage, obviously a consequence of the later adjustment in position of the compound eye to the converging frontal margins.

Measurements. The length of the type (carapace) is 3.2 mm; its width 4.8 mm; the width of the carapace of the original of plate 36, figure 5

is 4.5 mm; the greatest width of the abdomen is 6.1 mm. The largest carapace referred to here [pl. 36, fig. 2] measures 7.4 mm in length and 10.6 mm in width. The telson figured in connection with this species measures about 27 mm in length and 5 mm in basal width.

Horizon and locality. Very rare in the dark shales of the Shawangunk grit at Otisville, N. Y.

Eusarcus (?) longiceps nov.

Plate 84, figures 1-6

Description. Carapace semielliptical in outline, about as wide at the base as long, the lateral margins nearly straight and slightly converging forward to the antelateral angles. Frontal margin well rounded; posterior margin straight transverse and genal angles acute, apparently produced a little sidewise Eyes marginal, small, about one fifth the length of the carapace, situated at the antelateral angles, the visual surface occupying the whole eye node; the latter apparently without facets. Ocelli large, situated between the lateral eyes. The carapace was either smooth or the original ornamentation is obscured.

Horizon and locality. Frankfort shale (Schenectady beds) at Schenectady.

Remarks. We have comprised under this species a number of carapaces of strange aspect, which in outline do not agree exactly with any of the Siluric genera. The eyes, in form and position, suggest the genus Eusarcus, but the position of the ocelli near the frontal margin between the compound eyes is a feature not observed in any genus. It would seem that this form had gone even beyond Eusarcus in the concentration of the sense organs at the front, in adaptation to its habit of covering itself with mud. The type specimen [pl. 84, fig. 5] measures 18 x 15 mm, its lateral eyes are about 4 mm long, the largest specimen observed is 31 + mm long; its width is indeterminable, the sides being folded under; the eyes measure 7 mm.

Eusarcus triangulatus nov.

Plate 84, figures 7-9

Nine carapaces which have in common the broad, short, subtriangular form and the forward position of the marginal lateral eyes, bear a close resemblance to the carapace of E . s c o r p i o n i s from the Bertie waterlime. The largest of these [pl. 84, fig. 7], which is also the most distinct, has been selected as the type of the species E . t r i a n g u l a t u s .

Description. Carapace broadly subtriangular in outline, twice as broad as long (length of type, 20 mm, width, 43 mm), the lateral margins gently convex in the anterior third, forming a blunt frontal angle. Posterior margin straight transverse or broadly convex forward; genal angles acute. The lateral eyes are marginal, situated one third of the length of the lateral margin from the frontal apex, small (one seventh to one eighth the length of the side), bean-shaped, the visual surface apparently occupying the entire node. No facets seen. Ocelli situated in the middle of the carapace.

In several specimens the first tergite is found attached to the carapace. This is broad and short, about seven times as wide as long. In another specimen [pl. 84, fig. 9] the preabdomen and the proximal portion of a swimming leg are also preserved.

The carapace and first tergite were smooth or have only small, scattered tubercles.

Horizon and localities. The Frankfort shale (Schenectady beds) at Schenectady (Dettbarn quarry), Duanesburg and Rotterdam Junction.

Genus DOLICHOPTERUS Hall

Hall erected Dolichopterus as a subgenus of Eurypterus, citing as its distinguishing characters: the development of the "palette" (ninth segment), the less dilatation of the natatory feet, the form of the metastoma, and of the "central footlike organ" (genital appendage). It has been accorded full generic rank by later authors, with perfect propriety, we feel

sure, although it remained monotypic until Holm referred two metastomas from the dolomitic shale of Rootziküll, Island of Oesel,[1] to this genus. The Bertie waterlime of Williamsville, near Buffalo, which has furnished the genotype, has afforded the carapace of a second species, here described as D . s i l u r i c e p s , and the shale of the Shawangunk grit at Otisville has furnished a third species which sheds much interesting light on this rare and little known genus. We have named this last species D . s t y l o n u r o i d e s because the carapace has all the characteristics of that of Stylonurus [pl. 46, fig. 13] in its subrectangular outline, broad doublure with frontal triangular plate on the underside and broad rim of the dorsal side, position, relative size and form of the lateral eyes. Its most peculiar features are, however, its swimming feet which appear beset with leaflike plates, the last segment being tripartite and consisting of three lanceolate plates. It is not difficult to recognize in its structure a further development of the peculiar lobelike lengthening of the segments of the last pair of legs noticed in D . m a c r o c h i r u s and to see in the tripartite extremity of the leg the result of the strong development of the ninth segment characteristic of Dolichopterus, the middle lobe representing the ninth, the lateral ones the preceding eighth segment. The same development of lobes is shown on the preceding pair of legs in the genotype and the leg retained in D . s t y l o n u r o i d e s still further resembles that balancing leg as the last segment is developed into a spine, flanked by two lobes.

This interesting combination of a Stylonurus carapace and Dolichopterus leg in the same specimen suggests the question of the relationship of these two genera. A comparison of the two shows that Dolichopterus is more closely related to Stylonurus than to Eurypterus as a subgenus of which it was regarded by Hall and with which it has been associated by later authors. The similarity in the outlines of the carapace is manifest; they also have in common the distinctness and great width of rim,

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[1] As we shall presently show, the metastomes of Stylonurus and Dolichopterus are alike or very similar and the two genera closely related. It is therefore possible that more complete material of the Oesel species will show them to belong to Stylonurus.

while the doublure in D . m a c r o c h i r u s is much narrower than in the typical Stylonurus. The eyes differ in both genera from those of Eurypterus in being relatively much larger, placed as a rule further forward and having their visual surfaces so extended that the extremities of each edge approach each other [pl. 45, fig. 1 and S . m y o p s]. The relationship of the two is strikingly brought out in the form of the metastoma. The elongate subrectangular outline in D . m a c r o - c h i r u s is well shown in plate 45, figure 3. It obviously corresponds in length to the much elongated carapace and the long coxa of the swimming leg. The two metastomas figured by Holm are of like shape. Laurie has succeeded in tracing the outlines of the metastomas of two species of Stylonurus [text fig. 64] and they exhibit the same form as that of D . m a c r o c h i r u s . Similar metastomas are quite common in the Otisville beds, where two species of Stylonurus and one of Dolichopterus occur. The form of this organ appears to furnish an excellent criterion of generic unity, as here demonstrated among the species of Eusarcus and Pterygotus, and it is inferred that like metastomas in different genera are strong evidence of close relationship.

Further, we have here shown that at least one subgenus of Stylonurus, viz, Ctenopterus, is characterized by long, straight, relatively thin, closely arranged spines. The same feature is repeated in D . m a c r o c h i r u s [see drawing of type, Hall, pl. 83A, fig. 1 and, here, pl. 45, fig. 3].

This similarity of the legs continues in the last two pairs, and shows itself in the great lengths of the fourth and fifth segments.

Finally the slender, gradually tapering abdomen of Dolichopterus with its winglike epimera [pl. 43] is also more suggestive of Stylonurus than of Eurypterus or any other of the genera of the eurypterids. We suspect that the telson will prove to be styliform in Dolichopterus as in Stylonurus.

The main difference between Dolichopterus and Stylonurus is in the development of the distal parts of the last pair of legs; in Dolichopterus these are broadened and beset with leaflike lobes, while in Stylonurus they are narrow and greatly lengthened. The preceding pair of legs is also furnished with lobelike appendages in Dolichopterus and is free of such in Stylonurus.

The question of the phylogenetic relation of Dolichopterus to Stylonurus, Drepanopterus and Eurypterus has been fully dealt with in the introductory chapter to which we here refer.

Besides the three species of Dolichopterus from the New York rocks thus far mentioned, the Bertie waterlime at Litchfield and the Shawangunk grit at Otisville have each furnished a type represented only by the carapace; D . t e s t u d i n e u s and D . o t i s i u s ; and the Frankfort shale has afforded the fragmentary remains designated D . f r a n k f o r t - e n s i s and D . l a t i f r o n s .

From the waterlime beds of Litchfield we have a swimming leg, which possesses in general the characters of Dolichopterus but has a greatly differing palette or terminal segment. The latter is elongate oval and strikingly resembles the palette of Pterygotus. As the palette in Pterygotus is the eighth segment, while that of Dolichopterus is the ninth, this similarity can hardly be more than the result of convergence. This limb is as far different from that of the genotype, D . m a c r o c h i r u s , in one direction, as that of D . s t y l o n u r o i d e s is in another. In this the relative compactness and strength of the swimming leg of D . m a c r o c h i r u s is carried to extreme, in the other the tendency of D . m a c r o c h i r u s to the development of broad lobelike appendages.

These few species together indicate a greater variability in the characters of this genus than is shown by other genera.

The genus is at present represented by seven American and two European species, viz:

D. macrochirus *Hall*	D. stylonuroides *nov.*
D. frankfortensis *nov.*	D. testudineus *nov.*
D. latifrons *nov.*	D. laticeps (*Schmidt*)
D. siluriceps *nov.*	D. sp. *Holm* [1]
D. otisius *Clarke*	

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[1] As before stated, Holm recognized the probable occurrence of this genus in the Baltic provinces by the observation of two metastomes, one of which he has referred to E u r y p t e r u s   l a t i c e p s Schmidt. This species is known only by its carapace which in outline, broad rim, large eyes and ornamentation is very suggestive of the Stylonurus-Dolichopterus group. He also referred an operculum with female

Dolichopterus macrochirus Hall

Plate 35, figure 1; plates 40-45

Dolichopterus macrocheirus Hall.   Palaeontology of New York.   1859.
    3:414, pl. 83, fig. 1; pl. 83A, fig. 1

Professor Hall based his description of this genus Dolichopterus
and of its genotype D. macrochirus upon a single specimen from
the waterlime at Williamsville.   This is now in the American Museum of
Natural History and is unique in its state of preservation, for it can be
lifted bodily out of the matrix and exhibits both sides; these were so
accurately figured by Whitfield that new figures can add only im-
material features.   Unfortunately, however, this type lacks the greater
part of the postabdomen and telson and retains only the proximal
portions of the limbs, save the last pair, besides being incomplete in
such other important points as the posterior portion of the metastoma,
the opercular appendages and the operculum itself.   It is therefore ex-
tremely gratifying that later collections in this State have afforded three
more specimens of this extremely rare species which happily supply the
desired information.   The most important of these is a specimen from
the famous locality of Wheelock's hill, Litchfield [pl. 43].   This retains the
postabdomen and telson and furnishes important information as to the limbs

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genital appendages to Dolichopterus, pointing out its similarity to the cor-
responding part of D. macrochirus.   The opercular appendages of Stylonurus
however are not yet known and hence this similarity is not conclusive of identity
with Dolichopterus.

Schmidt figured [*op. cit* pl. 7, fig. 9] a very interesting leg, referred by him with
doubt to Pterygotus osiliensis, and which possesses broad, leaflike spines
like those on the last legs of species of Dolichopterus.   Holm [p. 56] indicated the simi-
larity of this leg to that of Dolichopterus but suggested that the broad spines are only
wrinkles since the limb is very poorly preserved.   From our observations of like
appendages on the legs of at least two species of Dolichopterus, we consider it probable
that Schmidt's figure is correct and that this leg indeed demonstrates the presence
of the genus Dolichopterus in the fauna of Rootziküll.

and the metastoma. Another specimen, from Forge Hollow near Waterville, N. Y., now in the American Museum, exhibits beautifully the second, third and fourth postoral limbs with their spines and lobes, showing novel characters especially as to the structure of the fourth limbs. Finally, the museum of the Buffalo Society of Natural Sciences contains a specimen with well preserved appendages. With the help of this material the following description of the species can be given:

Description. *Body* medium sized, relatively slender, with long appendages. Carapace and preabdomen of about equal length, postabdomen larger by one half than preabdomen, and telson as long as carapace.

Carapace of quadrangular outline, relatively long (length to width as 6 : 7); the frontal margin broadly emarginate, the rounded anterior angles slightly projecting, the lateral margins parallel and nearly straight for more than half their length from the base. Doublure narrow. Lateral eyes large, about one fifth the length of the carapace, situated close to the anterior angles, less than their length distant from the anterior margin, and about that distance from the lateral margin. The protuberance is oval, and apparently surrounded halfway by the visual surface.

The *preabdomen* is little shorter than wide (length to width as 5 : 6) attaining its greatest width at the third tergite and contracting thence gradually to the postabdomen. Judging from the specimens reproduced on plates 42-44, the segments of the preabdomen were highly arched. In the flattened condition, they are about six or seven times as wide as long. Their posterior margin is broadly concave in the middle.

The *operculum* is a very long plate; it is hardly more than three times as wide as long. The other sternites seem to have overlapped to more than half their length and were hence also relatively long plates.

The *postabdomen* is the longest division of the body. It surpasses by one half the preabdomen, decreases gradually in width to nearly one half, while at the same time the length of the segments is doubled, in the first segment the width surpassing the length five and one half times, and in the last not even one half times (actual proportion 10 : 54; 20 : 28). The

postabdominal segments are furnished with distinct epimera that increase in width with each succeeding member, and are prolonged into short spurs, except on the last segment where they are produced into long, rounded lobes. The posterior doublure is wide, amounting to nearly one half the width of the first segment.

The *telson* is narrow and long, apparently little shorter than the postabdomen. It contracts rapidly for a short distance from the anterior end, then it continues slender, or increases again slightly to the point which is abruptly rounded. The section is triangular. The dorsal surface is flat or slightly convex, the ventral produced into a flat-topped carina. The edges are sharp and marked by oblique incisions which, toward the extremity, grow into sharp teeth.

The *preoral appendages* of the cephalothorax have not been seen. The first three pairs of *postoral appendages* form a series of remarkably stout walking legs that increase in length posteriorly and decrease very little in width distally. They consist of short, ringlike segments, all of which, except the three basal ones, bear a pair of extremely long, curved spines [pl. 45, fig. 3]. The terminal spine or claw also is distinguished by its great length. It is flanked by the almost equally long spines of the last segment. The fourth limb, which has been known hitherto by its basal portion only, displays quite as peculiar characters as the last limb. In length it is intermediate between the third walking leg and the much elongated swimming leg, begins rather slender and becomes gradually wider distally. Though it terminates in a very long and strong claw, thus having the appearance of a walking leg, this claw is not flanked by the two like spines on the last segment as in other eurypterids, but by two broad bractlike lobes. Tracing these legs proximally, the impressions of further bractlike appendages are seen on the inner side [pl. 45, fig. 2, 3], in the places where in the preceding legs the long paired spines are found. Since the opposite sides of the same leg show these bractlike lobes, it is apparent that they represent a modification of the spines of the preceding limbs.

Hall fully recognized that the last postoral limb differs from the corresponding organ of all other eurypterids in the development of the ninth segment into a broad expansion like an oar blade. These last limbs are not only very long, for when fully turned back they would have nearly reached the penultimate postabdominal segment, but also rather flexible and expanded in all segments, most markedly however in the last four. The coxa of this leg, which is fairly well shown in the type and still better in the specimen from Litchfield, differs in outline from those of other eurypterids being much longer in anteroposterior direction.[1]

The coxa is subrhomboidal in shape (its short posterior side only half as long as the long inner edge), with a long curved neck leading to the manducatory edge. The second and third segments are short, ringlike, especially so the third, while the fourth is distinguished from all others by its length, it being twice as long as each of the two following segments and four times as long as the preceding one. It is twice as long as wide. The fifth and sixth segments are of subequal dimensions, each nearly one fourth longer than wide. The seventh and eighth segments are broad and relatively short, their longitudinal and transverse diameters being about equal. Their outer edges are obscurely serrate. The lobe of the seventh segment which is narrowly triangular in Eurypterus, is here produced into a leaflike process, which in length equals the segment. The eighth segment, which is the palette in Eurypterus and Pterygotus, is in this genus of similar form as the preceding segment. The ninth segment, the small " claw " in other eurypterids, has here assumed the bladelike shape of the eighth segments in Eurypterus and Pterygotus. It is oval in shape, with its extremity somewhat drawn out, longer than the preceding segments, one and one half times longer than wide. Its outer margin is coarsely serrate, the serrations directed obliquely forward and convex on the outer side. The metastoma has been described by Hall as "lyrate, with the anterior margin

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[1] This elongation is of course shared by the metastoma and obviously induced by the relatively great length of the carapace. But the mouth is further forward in this species than in other genera.

cordiform." Its length is more than half that of the carapace, its greatest width (in the anterior fourth) one half of its length. It decreases slightly in width posteriorly. Its lateral margins are nearly straight or but slightly concave. Its posterior end is transversely truncate, slightly emarginate in the middle.
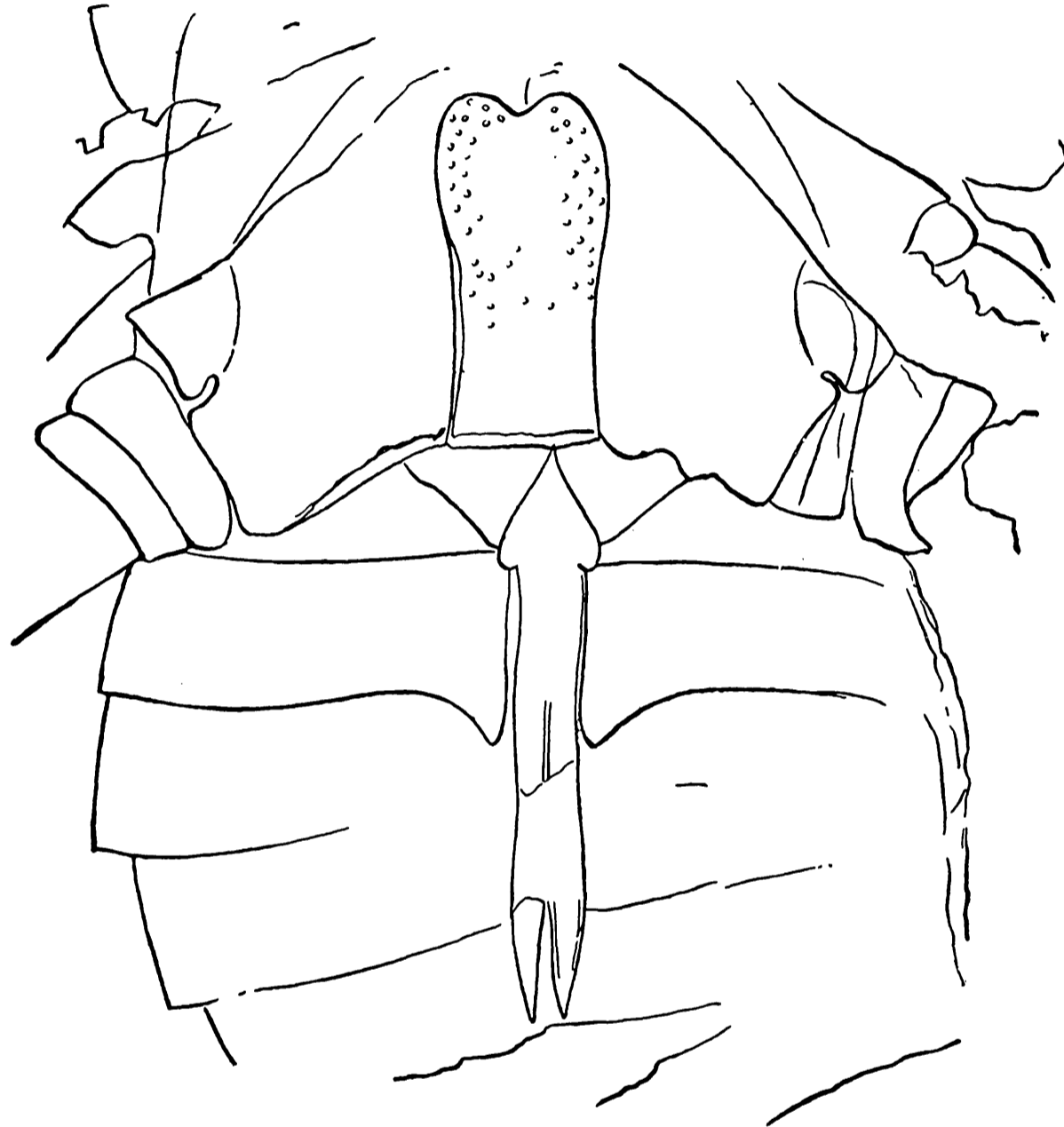
Figure 61 Dolichopterus macrochirus Hall. Outline sketch of the ventral appendages of the type specimen. Natural size

The opercular appendage of the female is seen very imperfectly in Hall's type. It is better shown in the specimen in the museum of the Buffalo Society of Natural Sciences [pl. 44]. It is similar to that of Eurypterus, differing mainly in the greater length and less curvature of the paired terminal pieces. The proximal portion has not been distinctly seen. Traces of the pentagonal areas and the inclosed hastate proximal

extremity of the first unpaired lobe are observable. The appendage extends beyond the middle of the second sternite, but the specimen is probably stretched. In Hall's type, which is clearly contracted in the preabdomen, it extends to the middle of the fourth sternite.

No surface ornamentation has been observed except linear rows of high, circular scales on the proximal segments of the last two pairs of limbs.

Measurements of type: millimeters

Length of carapace....................................	57.5
Width of carapace......................................	70
Length of eyes...	13
Length of metastoma...................................	32 +
Anteroposterior length of coxa of last leg...............	43
Length of swimming leg beyond carapace................	125
Length of preabdomen................................	68 +
Width of preabdomen.....·...........	74
Length of tergite......................................	15 +
Length of operculum about............................	25
Length of opercular appendage about...................	52
Length of first postabdominal segment unknown; width of same about..	52.5

Some measurements complementary to the preceding are afforded by the Litchfield specimen.

The metastoma is 30.4 mm long; 16.5 mm wide *ad maximum* and 11 mm at the posterior end.

The coxa of the last limb is 35.7 mm long on the inner side and 22.4 on the posterior. The swimming leg measures 128.7 mm; its eighth segment is so much contracted that the original length was about 130 mm.

The preabdomen is 53 mm long and 54 mm wide. The postabdomen measures 90 mm in length; it is 53 mm wide at its anterior end and 28 mm at its posterior end. The first sternite is 12.5 mm long, the last 19.5 mm. Of the telson 44 mm are preserved; its initial width is 15.5 mm.

Horizon and localities.   The four known specimens of this rare species, from Williamsville, Litchfield and Waterville, were obtained from the Bertie waterlime.

Remarks.   Hall clearly set forth the peculiar characters of this species in the original description.   He says "this species is distinguished by its robust, elongate body, the long straight-sided carapace, very anterior eyes, strong and thick jointed anterior feet, and extremely long swimming feet, with the great development of the terminal palette and the little dilation of the two preceding joints.   The form of the postoral plate is very remarkable, though its posterior termination is unknown; the appendage is more prolonged and of a different form, and the adjacent articulation is very peculiar; and there are distinctive features in the maxillary plates."

The exceedingly long spines of the first three pairs of legs, the bractlike appendages of the fourth pair, and the great anteroposterior extension of the coxae of the last legs may be mentioned as further peculiar characters.

The powerful, long spined first legs indicate that D . m a c r o - c h i r u s was an able walker and the bract-covered next pair of limbs, as well as the great elongation of the last pair, serve to demonstrate that it was likewise a powerful swimmer.

In consequence of the active use it made of its swimming legs, the species appears to have developed strong internal keels [pl. 43] within some of the segments corresponding to the entapophyses or internal keels and bars in recent arthropods, serving as attachment bases for powerful muscles.

Dolichopterus frankfortensis nov.

Plate 83, figures 9-14

The presence in the Frankfort shale fauna of at least one species with the characteristics of a Dolichopterus is demonstrated by a considerable number of carapaces and several metastomes.   We refer these all for the present time to one species.

Description.   Carapace subquadrate; length and width about equal; frontal margin very bluntly angular in the middle; lateral margins nearly

straight; slightly bulging in the posterior half; posterior margin broadly concave. Antelateral angles very prominent, a little larger than a right angle; genal angles well rounded in the type, rectangular in other specimens. A distinct flat or beveled border follows the lateral margin, and a narrower one the frontal margin. The lateral eyes are situated at the antelateral corners, relatively small (about one fifth the length of the carapace), semicircular to semielliptical in form, the straight diameter forming the inner margin. The visual surface was apparently crescent-shaped. The ocelli were situated on a line with the posterior extremities of the lateral eyes. The ornamentation [*see* pl. 83, fig. 10] consists of closely arranged, low flat nodes.

Horizon and localities. Frankfort shale at Schenectady (Dettbarn quarry), Aqueduct, Rotterdam Junction and Duanesburg, whence the type and some of the best specimens came.

Remarks. We have about a dozen carapaces, mostly from Schenectady, which agree in general outline and position of the lateral eyes, but show slight variations in the character of the frontal margin which in some exhibits a rather sharply protuding middle projection while in others it is somewhat emarginate. It is, however, quite probable that these latter variations from the form of the frontal margin of the type, are due to lateral and oblique compression and folding of the thin integuments.

This species must have attained considerable size, for one carapace [pl. 83, fig. 14] was about 69 mm long and 62 mm wide at the frontal angles. The type specimen measures 8 mm by 8 mm.

A metastoma has been found which recalls that of D . m a c r o - c h i r u s .

Dolichopterus latifrons nov.

Plate 83, figures 15-16

Description. Carapace of small size, spade-shaped in outline, broader by one half in front than at the base, its greatest width equal to its length; the frontal margin marked by a flat or beveled border, most produced in the middle, and posteriorly bounded by a straight transverse projecting

edge; antelateral angles rounded; lateral margins divergent forward and gently convex; posterior margin slightly concave, the edge slightly raised; genal angles obtuse; lateral eyes large, about one third the length of the carapace, situated in the antelateral angles and submarginal, with semi-circular eye nodes and crescent-shaped (when compressed) visual surfaces; ocelli situated between the posterior portions of the lateral eyes. No ornamentation has been observed.

Horizon and locality. Two specimens have been found in the Frankfort shale at Schenectady, N. Y.

Remarks. The carapace described here differs from the preceding species mainly in the posterior contraction. In this feature it agrees closely with D . o t i s i u s , a species from Otisville. The eyes in position and form are typically those of Dolichopterus.

The type specimen measures 14 mm in length, 14 mm in frontal width and 9 mm in basal width. The eyes are 4.5 mm long.

Dolichopterus otisius Clarke

Plate 46, figures 1-8

P t e r y g o t u s ? o t i s i u s Clarke. N. Y. State Mus. Bul. 107. 1907. p. 308, pl. 6, fig. 6, 7

Description. The original description of this species is:

An elongate subquadrate head with eyes anterior, far apart and just within the margins; ocellar mound well back between the posterior horns of the eye crescent; surface quite smooth. The specimen figured and one other of similar character are all that is known of this species.

Although later collections have afforded us upward of 30 specimens of this odd species, none of them retains more than the carapace and two body segments. The generic determination is therefore dependent as before on the character of the carapace and suffers the resulting lack of positiveness. The better and varied preservation of the new material which ranges considerably in size, permits however a greater elaboration of the description.

The carapace is subquadrate in outline, narrowing slightly toward the base. The frontal margin is the most convex, increasing in prominence with advancing age and in the largest specimens becoming distinctly angular. The antelateral angles project but are well rounded; behind them the carapace contracts somewhat rapidly and widens again in the posterior half forming low cheeklike projections of the lateral margins. The posterior angles are subrectangular and but little rounded. The posterior margin is gently concave or straight. A fine thickened filiform rim surrounds the lateral and anterior sides. The produced frontal part of the carapace is flat or depressed and continuous with a flat border on the sides. The remaining part appears to have been moderately elevated and to have culminated behind the ocellar mound. The doublure of the underside is broadest in front, corresponding in extension to the flat frontal border and is narrower on the sides. It possesses one to two deep wrinkles that cross the frontal portion transversely. The lateral eyes are situated in the anterior corners, near the margin, separated from the latter by about twice the width of the flat border. They are very large (one third the length of the carapace), prominent, semielliptic in outline, the outer side convex, the inner straight. The visual surface is crescent-shaped, situated on the outer slope. The supporting ridges are apparently very strong, especially so along the convex outer margin. In one specimen the surface exposed is ornamented with low, small, very closely arranged circular tubercles.

The first tergite is a very short band of subequal length, nearly eight times as wide as long. The second tergite is twice as long and considerably wider.

Measurements

Type: millimeters

Length of carapace.......................................   15.2
Width of carapace.......................................   15
Length of eyes...   4.6

Smallest specimen observed: millimeters

    Length of carapace..   5.1

    Width of carapace.......................................   5.1

    Length of eyes...   1.9

The largest specimen observed is but slightly larger than the type.

Horizon and locality.   Shawangunk grit at Otisville, N. Y.

Observations.   The carapace of this species does not bear the typical expression of any genus; its aspect is rather suggestive of several; viz, Pterygotus, Slimonia and Dolichopterus.   The type specimen in which the outline is more rounded than in the rest may be well compared with Pterygotus, while the approach of the eyes to the anterior corners, the quadrangular outline of the carapace and the frontal rim are quite likely to suggest Slimonia.   The lateral eyes, however, although possessing an elliptic outline as those of Pterygotus and Slimonia, are quite obviously not furnished with a visual surface extending over the whole prominence as in those genera, but with one that is crescent-shaped as in the genera more closely allied to Eurypterus.   This, taken in connection with the fact that the eyes are distinctly within the margins, necessitates a reference to the latter group of genera.   This granted, the identification of the species with Dolichopterus becomes imperative, for the squarish outline, the position of the eyes in the corners, their relatively large size and the broad border of the carapace are features which are combined only in the genotype of Dolichopterus.   We may add that the semielliptic outline of the eyes, also a very characteristic feature in all well preserved specimens of the present species, are repeated in D . m a c r o c h i r u s .

The youngest specimens are of special interest in this connection; for they lack the frontal angular extension which constitutes a difference from D . m a c r o c h i r u s although it is only a further development of the broad frontal rim common to the young of D . o t i s i u s and to the genotype.   The young [pl. 46, fig. 4] is hence still more like Dolichopterus: in fact it has the typical expression of that genus in every particular.

Dolichopterus siluriceps[1] nov.

Plate 26, figure 3

Eusarcus scorpionis Pohlman. Buffalo Soc. Nat. Sci. Bul. 1886. v. 5, no. 1. p. 30, pl. 3, fig. 3

Description. In 1886, as above cited, Pohlman figured and described as belonging to Eusarcus scorpionis, a carapace that subsequently came into the possession of Prof. J. S. Newberry and this specimen is now in the museum of Columbia University (no. 3078).

Eusarcus scorpionis has a subtriangular carapace and it is apparent that this specimen, both in outline and the position of the eyes, belongs to Dolichopterus; at the same time it differs in its proportions specifically from the genotype D. macrochirus. In the carapace of the former the proportion of length and width is as 6 : 7, but here it is as 6 : 8.5, as a result of which the carapace of D. macrochirus looks squarish in outline, while this is broadly quadrangular. The relation of these carapaces is similar to those of Eurypterus remipes and E. lacustris. A further obvious difference consists in the marked contraction of the carapace in the anterior half and the resulting strongly converging anterior lateral margins in E. siluriceps.

The carapace of this species furnishes the following description:

Hexagonal, basal side the longest, curving broadly forward in the middle third; the lateral margins are very slightly divergent behind and more strongly convergent in front; the greatest width of the carapace being at the point of change of direction in the lateral margins. The postlateral angles are nearly right angles, very slightly rounding, while the very obtuse antelateral angles are broadly rounded, and are connected in front by a nearly straight or slightly concave anterior margin. The eye tumescences are broken out. Their cavities occupy nearly one

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[1] Silurus a catfish; in allusion to the form of the carapace.

fourth the length of the carapace, are broadly oval in shape and only 4 mm distant from the margin, at the antelateral angles. The ocelli have not been seen. An obscure tumescence which may have borne them is noticeable midway between the posterior portions of the lateral eyes. The doublure of the carapace does not seem to have been very broad on either the front or the sides. The surface is smooth.

Measurements. The carapace measures 81 mm in length along the median line and 85 mm where it is longest. It is 77 mm just in front of the eyes, 108.5 mm in its widest part and about 99 mm at the base.

Horizon and locality. Rare in the Bertie limestone at Williamsville, N.Y.

Observations. There is no other species in our faunas, save a small form from Otisville, with both similar outline of carapace and like anterior position of the eyes. Nor are we aware of European forms that invite comparison.

Dolichopterus (?) testudineus[1] nov.

Plate 57, figure 2

Description. A single uncompressed carapace from the Bertie beds is of small size, obovate in outline; the greatest width, which surpasses the length by one tenth, forward of the middle, just behind the eyes; thence the well rounded margins converge to a point in front; and they also converge rather strongly toward the base of the head shield, so that the latter is but three fourths as wide as the widest part of the carapace. As the lateral and frontal margins form an evenly rounded curve, no indications of antelateral angles are present, but a slightly projecting anteromedian or frontal angle is produced. The posterior margin is broadly concave in the middle and gently curved forward at the genal angles, so that the latter are obtuse and rounded.

By breaking away parts of the head shield a broad doublure is exposed. It passes all around to the genal angles, where it is abruptly cut off; the posterior margin being lined by a very narrow doublure. The

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[1] In allusion to the turtlelike head.

surface of the carapace appears to have been uniformly convex, but just behind the frontal angle a rather sharp transverse ridge is observed.

As in the other species of Dolichopterus, the compound or lateral eyes are situated within the margin where the frontal and lateral margins unite. They are of great size (one fourth the length of the head shield) and separated by a distance equal to their own length. The ocular node is semicircular in outline; the inner margin straight, the outer a semicircle; its top flat or slightly depressed; the visual surface is crescent-shaped. The ocellar node is situated between the lateral eyes; ocelli not seen.

Measurements   millimeters

    Length of carapace.....................................   27
    Width of carapace.....................................   30
    Width of base...   22.5
    Length of lateral eyes................................   7

Horizon and locality. Bertie waterlime; Schooley's farm, east of Crane's Corners, town of Litchfield, Herkimer co., N. Y.

Remarks. This species, as represented by the single carapace, is quite similar to D . o t i s i u s [comp. pl. 46, fig. 2]. It differs from the latter mainly by the greater extension of the frontal portion and by the more pronounced posterior contraction of the carapace. The frontal transverse ridge or fold observed in the species is also seen in D . o t i s i u s .

The same locality has also furnished a swimming leg [pl. 57, fig. 1] which while distinctly belonging to a Dolichopterus, is greatly different from that of D . m a c r o c h i r u s , the only fully known congener occurring at Litchfield. We consider it therefore probable that it belongs to D . t e s t u d i n e u s . Its most striking character is the development of the palette or ninth segment, which is very elongate elliptic, with an obliquely truncate base and which much resembles the palette (or eighth segment) of Pterygotus. The preceding segments are very broad, indicating a powerful organ, but lack the distinct development of lobelike appendages seen in D . m a c r o c h i r u s and still more striking in D . s t y l o n u r o i d e s .

The fourth and fifth segments are well shown, the latter with the typical elongate development seen in Dolichopterus. The sixth and seventh are pushed so into each other that it is impossible to clearly separate them; the eighth is of cup-shaped outline and shorter than the corresponding segment in the genotype, but, as indicated by wrinkles, probably much compressed longitudinally.

Dolichopterus stylonuroides nov.

Plate 46, figure 9-14

A rare and interesting species from Otisville is represented in the collections by three carapaces and one more complete specimen retaining besides the carapace one entire swimming leg and three tergites. From these specimens the following description is derived.

Description. *Body* small, probably slender. *Carapace* spadelike in outline, as long as wide, widest on anterior fourth and contracting by about one fourth to posterior margin; frontal margin convex, quite uniformly rounded, sometimes slightly produced in the middle; antelateral angles well rounded; lateral margins gently concave; posterior margin slightly concave in the middle. A broad, level rim of approximately uniform width surrounds the frontal and lateral margins, while the underside of the carapace shows a still wider doublure most expanded in the middle of the front where a triangular lobe extends backward; and which also broadens toward the posterior margin. The lateral eyes are large (one fourth length of carapace), kidney-shaped and situated in the antelateral corners, one third the length of the carapace from the frontal margin and half way between the median line and the lateral margin. The visual surface is crescent-shaped. The ocelli are very distinct, and situated on a circular tubercle between the anterior parts of the lateral eyes. A longitudinal ridge seems to extend thence backward.

Abdomen. The first tergite is very short (six times as wide as long), closely parallel to the posterior margin of the carapace. The following tergites are two to three times as long and slightly increase in width.

Appendages. The swimming leg, the only appendage observed, is relatively short, twice as long as the carapace. The coxa and second segment have not been seen. The third is short and ring like, the fourth tubular, long, slender (two and one half times as long as wide) and slightly curved. The next is again shorter (half as long as preceding) and also tubular, slightly widening distally. The sixth is of the same length with the fifth and elongate pentagonal in outline. Like the following segments it bears two broad leaflike spines of greater length than the segment. The seventh and eighth segments are of similar length but broader; apparently of inverted cuplike outline but obscured by the overlying spines, which give the terminal part of the leg the appearance of a bud-bearing twig. The last joint is apparently subdivided into three bractlike lobes, the middle of which is the longest.

No traces of the ornamentation of the test are shown.

Measurements   millimeters

Length of carapace	10.8
Greatest width	10.2
Least width	8.2
Length of eyes	2.4
Length of first tergite	1.0
Width of same	8.4
Length of third tergite	2.2
Width of same	9.4
Exposed length of swimming leg	16.5

The largest carapace observed measures

Length of carapace	17
Greatest width	16.3
Least width	15
Length of eyes	4

Horizon and locality. In the Shawangunk grit of Otisville, N. Y.

Observations. We have already noted the stylonuroid features of the carapace of this species. The spadelike form of the carapace is also

shown by S t y l o n u r u s   s y m o n d s i (Salter) [*see* Woodward, 1872, pl. 21, fig. 4] and S .   m a c r o p h t h a l m u s Laurie. Neither of these two species, however, has as long a carapace as D .   s t y l o - n u r o i d e s .   D.   m a c r o c h i r u s has a shorter carapace and is a much larger species.

Genus STYLONURUS Page

The genus Stylonurus was proposed by Page in 1855 in a paper read before the British Association [*see* Bibliography]. It was based on a single species (S .   p o w r i e i) figured and named the following year in his *Advanced Text-Book of Geology*. Only a single specimen, not very favorably preserved in sandstone, has been recorded and although Page's not very correct figure and explanation have been followed by Woodward's elaborate description and careful illustration, this genotype is still incompletely known. Indeed, when the investigation of a considerable number of species revealed to us the presence of divisions of undoubted subgeneric rank, it remained doubtful with which of these the genotype belongs and which of the divisions therefore represents Stylonurus *sensu stricto*. A conventional conception of the genus has been created by the restorations made by Woodward and by Beecher. Woodward's restoration is based on the species S .   l o g a n i , and Beecher in his restoration of S .   e x c e l - s i o r had to follow Woodward in nearly all important features, only the carapace, the chelicerae and first pair of legs of S .   e x c e l s i o r being known.

It is especially on the character of the limbs that the most important subgeneric differences are to be based; it is therefore necessary to subject the genotype and the restorations mentioned to a critical review in regard to these structures. Woodward's conception of the relative lengths of the legs obviously resulted from a combination of the two specimens of S .   p o w r i e i and S .   l o g a n i . The former furnished the evidence for the conclusion that the last pairs of legs are " about equal both in length and breadth " [1872, p. 123], for it was the only specimen known to him retaining these legs; while the specimen of S .   l o g a n i which

retained the last long leg and several of the anterior limbs scattered about the carapace, furnished the evidence for the two pairs of short limbs in his restoration. Woodward figured in front of these two feeler-like appendages which in Beecher's restoration of S . e x c e l s i o r are replaced by a first pair of short walking legs, the latter together with a chelicera having been successfully prepared by Clarke [1888, pl. 26A].

An example from the dark shales at Otisville has shown by preparation a series of four legs on one side and this species exhibits in the formation of its carapace the typical characters of a Stylonurus. The structure of this species, S . c e s t r o t u s , has suggested a different conception of the limbs of Stylonurus, for, (1) the last two legs are of distinctly different length, (2) the second and third pairs of legs are so long as to form a progressively growing series with the fourth and fifth pairs. The question then arises whether Stylonurus had been incorrectly understood or whether the Otisville form represents a new and different group.

A survey of the 13 species, cited below as falling under the head of Stylonurus by virtue of the characters of their carapaces and abdomina, shows that, besides the original representatives of the genus, S . p o w r i e i and l o g a n i , of only four species are specimens known that retain sufficient fragments of the legs to indicate their structure. These are S . m a c r o p h t h a l m u s and S . e l e g a n s Laurie, S . c e s t r o t u s Clarke and S . s c o t i c u s Woodward. Taken together these demonstrate two important facts; (1) that the legs increased in length quite regularly backward instead of being divided sharply into two different sets as represented by Woodward and Beecher: an anterior one of very short legs and a posterior one of exceedingly long ones, (2) that there are three distinct types of legs among species referred to this genus.

As already stated, Woodward seems to have combined the aspects of his specimens of S . p o w r i e i and S . l o g a n i to effect his restoration of S . l o g a n i ; the former furnishing the two long legs, the other the preceding two short pairs. In considering the question of the two "subequal" long pairs of swimming legs, it may be observed that the

specimen of S. cestrotus
which retains both in full
length, distinctly shows that
there was a considerable dif-
ference in the two pairs, the
fourth being shorter in total
length by about one sixth,
and each of its segments a
little shorter than the cor-
responding one of the fifth
[pl. 49, fig. 6]. In S. ele-
gans Laurie, where the last
two pairs are also shown,
this difference is still greater
[text fig. 62][1] and the same is
suggested by Laurie's draw-
ing of S. macrophthal-
mus [1892, pl. 2, fig. 10].
It would seem then that all
specimens of Stylonurus, ex-
cept the original S. pow-
riei, exhibit a distinct
difference in length between
the last two pairs of legs.
From the two figures of
S. powriei, published
successively by Woodward
[1865, pl. 13, fig. 1; 1872,
pl. 21, fig. 1], it also becomes
obvious that that specimen
must possess the same dif-

Figure 62 Stylonurus elegans Laurie. Second to fourth legs of right side. (From Laurie)

[1] See also Laurie, 1899, pl. 2, fig. 12, 13

ference, for the segments of the fourth pair are throughout shorter than those of the fifth, but as noted above, the single type is poorly preserved, was therefore apt to mislead and is not conclusive in this regard. In view of the fact that Drepanopterus, which clearly leads

Figure 63 Stylonurus logani H. Woodward. Original figure. (From Woodward)

phylogenetically to Stylonurus, exhibits a much greater difference between these two leg pairs, it is a fair deduction that such difference also existed in typical Stylonurus, though less pronounced and perhaps in various gradations.

A further question relating to the legs, suggested by the Otisville specimen of S. cestrotus, is whether the second and third pairs were as short and as nearly equal in size as represented by Woodward and Beecher. Here again all the types which retain these legs; those of S. cestrotus, S. macrophthalmus, S. elegans and S. ornatus, give direct evidence that they also formed a posteriorly increasing series, the last being the longest and that, on the whole, they were much longer than represented in the restorations. The specimen of S. logani [text fig. 63] which served as the basis of the restorations exhibits a fragment of two segments of one of these legs attached to the body and is surrounded by two (three in first figure, 1864) detached anterior legs. The smaller of these undoubtedly represents the first pair of postoral limbs, as clearly indicated by its rapid contraction and the shortness of the segments. As the first pair Woodward introduced antennae and constituted as the second pair what we believe to be obviously the first, while the other, which has about twice the length of the former, to us represents the second pair. The third pair is only represented by the small fragment still attached. It is quite clear that there is considerable difference in length between the first and second legs and a still greater difference between the second and third legs. The relative lengths of the first and second legs are well shown in Laurie's type of S. macrophthalmus [text fig. 64] and the relative great length of the third pair is evident in S. elegans [text fig. 62] where it nearly equals the fourth pair and surpasses it in width. Looking back again, in relation to these legs, to Drepanopterus, the ancestor of Stylonurus, we find that there the first three pairs also form a series increasing in length backward.

The combined evidence, then, of the material at present available is that the legs formed an approximately continuous series, the anterior members being longer than hitherto supposed and the last two not so greatly surpassing the others in length and not of so nearly equal length. On the basis of these facts we have drawn a new reconstruction of S. excelsior, although only the first pair of legs of that species are known, using mainly our specimen of S. cestrotus for this reconstruction.

Figure 64 Stylonurus macrophthalmus Laurie. Original figure, showing four legs and metastoma. (From Laurie)

It is proper to say here that the restorations of S . l o g a n i and S . e x c e l s i o r have always looked unnatural to us in leg construction, because it is not apparent how the two very different sets of legs could have been used harmoniously. Woodward and Beecher were not in accord in their opinions as to the use of these legs; the former considered the long legs as the swimming feet [see his description of S . l o g a n i] and the short ones as the walking feet, while Beecher per contra considered the long legs as the crawling feet [see 1900, p. 149]. As to the latter conception, it is unintelligible to us how the creature could have balanced itself on these four legs or could have taken up its food without correspondingly long prehensile organs, much like the chelae of Pterygotus and those of the recent sea spiders. The short anterior legs of the restoration would seem to have been hardly competent to propel the huge body in swimming and their position at the front of the carapace would have scarcely allowed their effective use for walking without the assistance of the other legs.

The gradually lengthening series of legs suggests to us that they, all combined, were functional in crawling, the long hinder pairs, on account of their stronger curvature and backward direction, reaching the same level as the shorter forward pairs with their terminal claws, thereby carrying the body as it is carried in nearly all crustaceans and arachnoids, on four or more pairs of legs.

There is a difference of opinion as to whether the last pair or pairs were the more active in swimming, as in the other eurypterids, or the first three pairs, as suggested by Beecher. On one hand analogy with the other eurypterids would indicate the use of the last pair of legs as swimming organs, and it would constitute a wide departure if this group reversed the functions of the fore and hind limbs. On the other hand, these hind legs show none of those characters which naturally accompany a swimming function, such as a widening of the joints and an intricate articulation insuring rigidity of the legs, while the preceding legs, in some species as S . c e s t r o t u s , are provided with a dense fringe of contiguous

spines or bristles well adapted to broaden the swimming surface of the limbs. To the first leg of S . e x c e l s i o r which is the only one observed, paired flat spines are attached whose form suggests their adaptation to swimming. We are disposed to regard all legs as adapted for crawling. Though in some species the forelegs served as swimming organs, the long posterior ones were mainly active in pushing the animal forward.

In another group of species again the forelegs do not differ in relative length and character from the walking legs of Eurypterus. The typical representative of this group is S . l o g a n i . This leads us to the discussion of the subdivisions of Stylonurus, distinguishable on the basis of leg structure. On comparing the figures of S . l o g a n i and S . m a c - r o p h t h a l m u s [text fig. 65] with those of S . c e s t r o t u s and S . e l e g a n s , it is at once evident that in the former the forelegs are not only relatively smaller and narrower than in the other but are also provided with only one pair of spines each, as in Eurypterus, while in the latter group these legs are relatively much longer, more powerful and furnished with a contiguous series of long spines, each segment carrying a greater number of spines than two, a character apparently not repeated in other genera.[1] A third group is represented by S . s c o t i c u s Woodward. In this, the single limb known (obviously one of the last pair) is greatly broadened from the beginning and is distinctly a swimming leg. The similarity of this swimming leg to that of Eurypterus would suggest a reference to the latter genus if the other characters of the animal were not so manifestly stylonuroid. Still the species is not a typical Stylonurus but distinctly a later and more specialized form. This is shown not only by the swimming leg but also by the large hooked, winglike epimera of the postabdomen and the sculpture of the tergites. It demands recognition as representing a subdivision of Stylonurus.

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[1] Laurie's figure of E u r y p t e r u s s c o t i c u s [1899, pl. 39, fig. 26] shows on the fourth segment three spines, which would suggest a like feature, but since the succeeding segments clearly possess only two spines it would seem that this appearance of a close series of spines is accidental.

The genotype is not sufficiently known to establish its relationship to any of the three subdivisions here proposed.

Subgenus A is typically represented by S . l o g a n i and S . m a c - r o p h t h a l m u s . Its first three pairs of legs retain the characters of those of Drepanopterus and are like those of Eurypterus, i. e. relatively short and stout and furnished with two curved, strong spines on each segment. S . o r n a t u s Laurie also belongs in this group.

We suspect that also E u r y p t e r u s s c a b r o s u s , a curious form described by Woodward [1887, p. 481] from the Lower Carbonic shales of Eskdale, belongs here, although the specimen does not retain the fifth pair of legs, which are of critical importance in the distinction of Eurypterus from Stylonurus.[1] The great length and slenderness of the preceding legs, however, are a character only found in Stylonurus, but not in any of the species of Eurypterus known to us. Likewise the coarse, roundish, tuberculate sculpture of the posterior margins of the tergites is more suggestive of Stylonurus than of Eurypterus.

Subgenus B. This is typically represented by S . e l e g a n s Laurie and S . c e s t r o t u s Clarke. Its second and third pairs of legs are relatively much longer and furnished with more than two pairs of long, less curved spines which are vertical on the lower side of the segments. Besides the species mentioned, another form from the Pittsford shale, S . m u l t i s p i n o s u s , only known from two of its legs, clearly belongs here; and we surmise that S. e x c e l s i o r also, from the character of its first legs which alone are known, should be brought under this group. In case this structure should not be found in Stylonurus proper, the

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[1] Woodward refers this form unhesitatingly to Eurypterus, stating in regard to the fifth pair of legs [p. 483]: " The fifth pair of broad spatulate swimming feet answering to the maxillae, or to the maxillipeds of the higher Crustacea, are not preserved in this fossil; but as they have been found with nearly all the species of Eurypterus hitherto described, there is little doubt that this form also possessed them when entire. Certainly the other appendages reproduce with only slight modification in their style of ornamentation those of the Russian, the American and the Lanarkshire Eurypteri already described and figured by Hall, Schmidt and myself."

term *Ctenopterus* may be applied to this group. The leg from the Utica shale figured by Walcott as E c h i n o g n a t h u s   c l e v e l a n d i, shows a like structure in exaggerated form and may prove to represent the group, in which case the term Echinognathus would take precedence. At present the employment of the latter term would be unwarranted as the body of the Utica form may be entirely different from that of Stylonurus.

Subgenus C. This is represented alone by S. s c o t i c u s. Its differential characters are the flat broad last pair of legs, the greatly enlarged winglike epimera of the postabdomen and the emphasized sculpture of the posterior margin of the tergites. The short club-shaped telson is also notable. The carapace and the form of the abdomen are as in Stylonurus. We propose for this group the term *Tarsopterus*.

Subgenus D. Finally Drepanopterus is, in our opinion, not more differentiated from the typical Stylonurus than S. s c o t i c u s, though it stands quite at the other end of the phylogenetic line. D r e p a n o p t e r u s   l o n g i c a u d a t u s nov. is a form distinctly intermediate between Stylonurus and the type of Drepanopterus. On account of its phylogenetic importance in the development of Stylonurus we have treated this division as a separate genus.

The majority of the species can not at present be definitely referred to any of these groups as only their carapaces are known. The following is a provisional synoptic table of the species:

Subgenus A. (Stylonurus *s. st.*)

S. logani *H. Woodward*   S. powriei *Page*
S. macrophthalmus *Laurie*   Stylonurus (?) scabrosus (*H. Woodward*)
S. ornatus *Laurie*

Subgenus B. (Ctenopterus)

S. cestrotus *Clarke*   S. multispinosus *nov.*
S. elegans (*Laurie*)   (?) S. excelsior *Hall,*

Subgenus C. (Tarsopterus)

S. scoticus H. Woodward

Subgenus D. (Drepanopterus)

S. lobatus *Laurie*   S. bembycoides *Laurie*

S. pentlandicus *Laurie*   S. longicaudatus *nov.*

Indeterminate species

S. megalops *Salter*   S. beecheri *Hall*

S. ensiformis *H. Woodward*   S. ? limbatus *nov.*

S. symondsi (*Salter*)   S. myops *Clarke*

Among the American species only group B (Ctenopterus) and group D (Drepanopterus) have thus far been recognized, the former with one, the latter with two species. The subgeneric relations of the four other American species: S. e x c e l s i o r, S. b e e c h e r i, S. ? l i m b a t u s and S. m y o p s remain undetermined.

Stylonurus (Ctenopterus) cestrotus Clarke

Plate 49; plate 50, figures 1-7

E u r y p t e r u s ? c e s t r o t u s Clarke. N. Y. State Mus. Bul. 107. 1907. p. 307, pl. 3, fig. 8-10

The original description of this species reads: " Of this species we have only enough to satisfactorily establish its difference from other forms— the two specimens here illustrated. Both show the peculiarly ornamented frontal border of the cephalon which carries a row of denticulations. One of these specimens conveys a satisfactory idea of the form of the body, and presents the ventral aspect but there is some uncertainty in regard to the number of segments and though evidences of four pairs of legs are present the structure of these is not apparent. The head shown in figure 10 indicates that the compound eyes are large and very far forward. It is entirely probable that when this species becomes better known it will have to be excluded from the genus Eurypterus."

The larger collections acquired since this date and the development of the counterpart of the first of the two specimens figured in the preliminary paper, have afforded sufficient data to form a fairly accurate conception of this most peculiar type.

Description. *Body* of small size, slender and terete, all parts being noticeably elongate.

Carapace elongate oval in outline, broadest in the posterior fourth, whence it contracts to half the width at the frontal margin. Its length and greatest width are but slightly different. The lateral margin is most convex at the broadest portion of the carapace which is frequently somewhat expanded into a kind of cheek. It becomes gently convex more anteriorly and passes rather abruptly at the antelateral angles into the more or less projecting frontal margin. The postlateral angles are well rounded and the posterior margin is deeply concave in the middle. The frontal border is furnished with a row of 8-16 acute denticulations which are longest in the middle and decrease in size toward the lateral ends. The serrae are directed obliquely upward. The lateral margins are bordered by a thickened rim.

The upper side of the carapace is highly sculptured. Its most prominent parts are the big bulging compound eyes. The portion of the carapace in front of these is flat but rises in the middle to a large subcircular mound, bearing tubercles of greater size than those forming the ornamentation of the rest of the carapace. Oval, sharply set-off cheeklike ridges extend backward from the lateral eyes to near the posterior margin, and from the intervening depression, midway between the lateral eyes, rises the very prominent small mound bearing the ocelli. The underside of the carapace bears a broad and thick doublure which is widest along the frontal margin and there exhibits a deep concentric furrow.

The lateral eyes are very large (one third the length of the carapace), forming projecting elliptical bodies that lie near the lateral margin and parallel to the latter in their major axis, thus converging strongly forward. Their posterior extremities lie approximately on the transverse bisecting line. The visual surface is crescent-shaped and narrow; its horns approach each other on the inner side. The eye mound overtops the visual surface considerably and forms apparently an overhanging ridge on the inner side of the visual surface so that the latter frequently disappears entirely in compressed specimens.

The ornamentation of the carapace consists of small tubercles which

reach their largest size on the frontal mound and cheeks and extend over the whole carapace, including the eye mounds, in uniform density.

The *abdomen* is slender. It expands gradually to the fourth segment whence it contracts again as gradually to the long and slender postabdomen. The greatest width is probably about one fourth greater than that of the carapace. The preabdomen is longer by one third than the carapace, and the postabdomen is but little longer than the preabdomen. The tergites are short plates with nearly straight anterior and posterior margins, while the sternites exhibit strongly curved posterior margins, the middle being strongly concave and the postlateral angles well rounded and produced backward. Traces of a marginal line of tubercles on the tergites have been observed and it is possible that the whole surface was tuberculate.

The telson has not been observed in position, but it is quite probable that a slender spine, found in association with these remains, belongs to this species since it fully corresponds to the form of the postabdomen.

Appendages. The chelicerae and first pair of legs have not been seen. Of the second pair but four segments of the specimen could be exposed without destroying the following legs, and of the third pair also a portion of a fifth segment. These exposed portions show that the legs were long and slender, the third still somewhat surpassing the second in length; thus the second to fourth legs continuously increase in length backward. The fourth and fifth segments, and presumably the following ones, are furnished with a series of straight, slender paired spines, about 6–9 pairs on each segment. The fourth and fifth pairs of long legs were not of equal size, but the fourth shorter by one eighth. The latter, fully reflexed, would reach the last postabdominal segment and the fifth leg the telson. The coxae of these legs are not exposed; the first and second segments, however, are partly seen and can be recognized as consisting of short rings; the third is somewhat longer, while the fourth is the longest and broadest of all. It is two and one half times as long as the third. The sixth is again shorter by one third while the seventh and eighth are distinguished by again increasing in length and decreasing notably in width. The

terminal spine is short and stout with incurved point. All the segments, including the terminal spine, carry sharply elevated longitudinal ridges.

On account of the obvious distortions of all specimens we refrain from giving measurements of the parts of the animal beyond the relative dimensions cited above.

The metastoma and genital appendages have not been observed in place.

Horizon and locality. One of the rarer forms in the Shawangunk grit at Otisville, N. Y.

Remarks. S . (Ctenopterus) cestrotus stands apart from all its allies in a number of characters that show it to be an aberrant form. The most notable of these are the frontal prolongation of the carapace, the frontal row of denticulations, the strongly tuberculate mound behind the latter and the submarginal, forward position of the eyes. It is hardly to be doubted that these characters together with the slender form of the body and the length of the legs indicate that it was an active species and not a mud groveler. The elongate outline of the carapace it has in common with S . excelsior . Both these species probably belong to the same subgenus, Ctenopterus.

Different degrees and directions of compression have produced a strikingly varying series of aspects of the carapace, some of which are here reproduced, since these specimens serve to bring out certain other features. In some we have indicated the direction of compression by pointers. In a few [pl. 50, fig. 4-6] the typical aspect is so completely changed by the preservation that without intermediate stages they would surely be taken for representatives of different species.

There is a distinct similarity by convergence between this form and certain species of the trilobite Dalmanites that finds its most pregnant expression in the frontal row of denticulations duplicated in the subgenera Odontocephalus and Corycephalus, in the bulging frontal mound, recalling the frontal lobe of the glabella, and the large, widely separated crescent-shaped eyes. We can hardly go amiss in attributing this similarity less to an accidental coincidence in fugitive characters than to an adaptation to like conditions or similar habits.

Stylonurus (Ctenopterus) excelsior Hall

Plates 47, 48

Stylonurus excelsior (Stylomurus in error) Hall (Martin). N. Y. Acad. Sci.
Trans. 1882. 2: 2

Stylonurus excelsior Hall. N. Y. State Mus. 36th An. Rep't. 1883. p. 77,
pl. 5, fig. 1

Dolichocephala lacoana Claypole. American Philosophical Soc. Proc.
1883 21: 236, pl. 3

Stylonurus excelsior Hall. American Assn. Adv. Sci. Proc. 1884. 33: 421

Stylonurus excelsior Hall & Clarke. Palaeontology of New York. 1888.
7: 158, 221, pl. 26, 26A

Stylonurus lacoanus Beecher. American Jour. Sci. 1900. 10: 145, pl. 1

Only two specimens of this species are yet known. One a natural external mould of the complete carapace from the Catskill beds at Andes, Delaware co., N. Y., is in the possession of Rutgers College and is the type of Hall's original description. Another fragmentary carapace from the same formation in Pennsylvania, the original of Claypole's description, is now in the National Museum. Clarke succeeded in developing on the underside of the latter, a chelicera, one of the first pair of legs and the coxae of two legs of the succeeding pairs.

Both these specimens and the discovered appendages have been fully described by Hall and Clarke in Palaeontology of New York, volume 7, pages 158, 221, to which the reader is here referred for the details.

Professor Beecher subsequently selected S . excelsior for restoration on account of its gigantic dimensions, supplying the missing parts from the British species S . logani and S . powriei , and the American S . beecheri . The discovery by the authors of a specimen of S . cestrotus at Otisville retaining all save the first pair of legs, and the fact that S . excelsior is, according to the form and character of its carapace, manifestly more nearly related to that species than to any other, have suggested to us some corrections in this careful restoration which have already been dealt with in the preceding generic discussion. The

Figure 65   Ventral appendages of S t y l o n u r u s   e x c e l s i o r   Hall.   C, chelicera; B, one of first pair of endognathites;
D, G, coxae of legs of second and third pair.   Natural size.   (From Hall & Clarke)

close relationship existing between S. e x c e l s i o r and S. c e s t r o ·
t u s is also indicated by the presence of paired spinous appendages on
the first pair of legs of the former which correspond to those on the second
and third pairs of legs in S. c e s t r o t u s. We have above proposed
the subgenus Ctenopterus for this well defined group of species.

Another alteration of the restoration of S. e x c e l s i o r, suggested
by evidence afforded by S. c e s t r o t u s, relates to the structure of
the eyes. The carapace of Beecher's restoration is a cast from the
Rutgers College specimen. In this the eye regions
exhibit an inner circular depression described by Hall
and Clarke as the eye. This is encircled on its outer
edge by a conspicuous subsemicircular orbital ridge,
but separated from the latter by a concentric level
area bearing the same sculpture as the rest of the
carapace. In much compressed or collapsed carapaces
of S. c e s t r o t u s the eye presents an aspect very
like that of this specimen of S. e x c e l s i o r. In a
few better preserved examples however [pl. 49, fig. 1,]
the eye is highly prominent, looking like a bean lying
on the carapace and the large semilunate visual sur-
face surrounds a small, subcircular top area [pl. 50,
fig. 1]. The logical inference hence is that the visual

Figure 66 The terminal
portion of the median
dorsal ridge of S t y -
l o n u r u s e x c e l s i o r,
showing the ocelli. Nat-
ural size. (From Hall &
Clarke)

node of S. e x c e l s i o r bulged in the same way and we have repre-
sented it thus in our restoration. The intense concentric wrinkling of the
area within the orbital ridge in the specimen in the National Museum is
direct evidence of the collapse of the visual node.

By analogy it would be necessary to infer that the central circular
broken area in the eye of S. e x c e l s i o r is the outer end of the palpebral
lobe and the entire surrounding concentric area the visual surface. The
latter part of this inference is at once invalidated by the fact of the ex-
tension of the surface sculpture upon the concentric area. The first part
of the inference that the broken down inner circular areas were parts of the
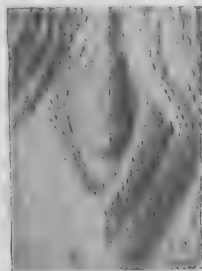
palpebral lobes is supported by the fact that in the National Museum specimen this part projects prominently; further in all other species of Stylonurus the visual surface is a more or less narrow crescent on a circular base [*see* S . m e g a l o p s , S. m y o p s and S. s c o t i c u s], and it therefore should not be assumed to be circular in S . e x c e l s i o r .

Some closer study of the eye region in the two carapaces of S . e x c e l s i o r has furnished the solution of these apparently contradictory facts in the finding of distinct, narrow crescentic, visual areas on the outside of the broken, circular, palpebral area. They are particularly well seen in the Rutgers College specimen, where they are clearly outlined although somewhat obscured by having become infolded at the collapse of the visual node.

We picture, then, the original aspect of the eye of S t y l o n u r u s e x c e l s i o r as a bulging subhemispheric, visual node, supported on the outside by the strong orbital ridge, on the inside by the median ridge of the carapace and the transverse palpebral lobes. At the apex of this node and at the outer end of the palpebral lobe the relatively small crescentic visual surface was situated.

It is obvious that the visual area did not keep step with the growth of the carapace and of the visual node and thus became finally a relatively small band around the apex of a high node. This giant merostome would thus seem to have possessed very small eyes in comparison with smaller eurypterids, a feature common in the giants of other groups, as in the whales and elephants among the mammals.

Stylonurus? limbatus nov.

Plate 85, figures 1-3, 5

The collections from Schenectady and Duanesburg contain half a dozen specimens that are strikingly different from the associated eurypterids in greater relative length of carapace, broad, flat margin and subcentral position of the rather close-set large circular eyes, or eye nodes. All these characteristics suggest the generic reference of this interesting

species to Stylonurus. The presence of this genus, or rather of that branch of the eurypterids which leads to the late Siluric and Devonic Stylonurus, is further indicated by body segments (tergites) [pl. 85, fig. 6] which have the form and ornamentation of the Otisville species S t y l o n u r u s m y o p s .

Description. Carapace elongate semielliptic, a little longer than wide, widest at the base and contracting uniformly to the front which is evenly rounded. The posterior margin is straight transverse. The carapace is surrounded on all sides by a distinct border which is broadest in front where it attains one eighth the length of the carapace, and narrowest along the posterior margin. On the upperside this border slopes outward and is smooth, on the underside it was flat and concentrically grooved. The eye nodes are large, about one fifth the length of the body, circular, situated just in front of the transverse middle line of the carapace, close-set, about their own diameter apart. The visual surface has not been clearly distinguished from the node and it may have occupied the entire node. The ocelli have not been seen. The ornamentation is not visible on the carapace, but tergites probably belonging to the same species show circular to elliptic, relatively large nodes.

The tergites are strongly curved, convex forward in the middle and concave toward the sides, with very prominent " ears " at the antelateral angles and much rounded postlateral angles. They were very convex in the middle and surrounded by a depressed border.

Long slender tubular leg segments [pl. 85, fig. 9] and broad flat leg spines also occur in the Frankfort shale, such as among the later eurypterids are only known from the Stylonurus group.

Horizon and localities. Frankfort shale (Schenectady facies) at Schenectady and Duanesburg.

Remarks. Besides these elongate carapaces, a broad short carapace with the eyes far apart has been found at Schenectady [pl. 85, fig. 4]. This closely resembles the S . m y o p s from Otisville. Like the latter, it has a very broad, concentrically striated or grooved border. This cara-

pace quite probably represents a distinct species; on account of the rather unsatisfactory preservation of the single carapace representing it, we have refrained from naming it.

S . l i m b a t u s was of fairly large size. The carapace selected as type is 38 mm wide and 39 mm long.

Stylonurus (Ctenopterus) multispinosus nov.

Plate 50, figures 9, 10

Unknown Eurypterid (genus?) Sarle. N. Y. State Palaeontologist Rep't. 1902. p. 1105, pl. 26, fig. 2-4

Mr Sarle collected from the Pittsford shale a group of endognathites that present characters quite different from those of the associated species. He gave an elaborate description of the fragments but was unable to refer them to any of the genera of eurypterids and therefore suggested that " with more perfect material the forms will be found to represent a new genus."

Our entire specimen of S t y l o n u r u s c e s t r o t u s from Otisville furnishes the clue to these organs, in showing that the longest endognathite of the group corresponds to the third pair in Stylonurus, subgenus Ctenopterus. The general form and the relative dimensions of the parts of this endognathite are quite precisely those of Stylonurus. We infer from these facts that the fragments indicate the presence of a fairly large species of Stylonurus in the Pittsford shale. As this form is recognizable from the figured parts, we venture to name it.

Sarle's description of the fragments is as follows:

An eurypterid differing very materially from anything described from the Bertie waterlime, is represented in the collection by a group of four incomplete arms and a body segment, and by another of two incomplete arms.

In the first group [pl. 50, fig. 10] the longest of the arms has the coxal and succeeding five joints preserved. These are long, measuring altogether 110 mm in length. The three distal bear a series of long, curved spines. The form of the coxal joint is subtrapezoidal, the anterior side being

considerably the longer. The breadth and the mean length are each about 18 mm. The dentate border is slightly produced and in length is equal to about one half the breadth of the joint. The dentation begins at the front end with an isolated, blunt tooth pointing forward, followed by sharp, curved teeth of small size which grade posteriorly into fine, hairlike bristles. The anterior side of each joint from the second to the sixth inclusive, is arcuate. The posterior sides of the second and third joints are straight, of the fourth, fifth and sixth, concave. The distal end of each is at right angles to the long axis. The second joint is narrower (14.5 mm) than long (23 mm); the third just twice as long (28 mm) as wide (14 mm); the fourth a little longer than the preceding (30 mm) and less than half as wide (7 mm). Along the concave, posterior side of the fourth are articulated five, long, curved, striated spines, nearly perpendicular to the joint. At the distal end of the series there is an indication of another. The most complete of these spines is 16 mm in length. The fifth joint is 16 mm long and 6 mm wide. Near the anterior end of the posterior edge it carries the stump of a large spine followed by the sockets of four more. The sixth joint bears the basal portion of three spines, but is so crushed and foreshortened that neither the original number of spines nor the length of the joint can be determined. Judging by the taper of this arm, there may have been two more joints.

The remnant of another appendage appears to be part of the proximal four joints, and measures 32 mm in length. From its robustness, it seems to have belonged just in front of the last mentioned. The peculiarities of these joints are their shortness and their thickening at the articulations. The joint, which on the tablet lies nearest to the large arm, is a little inflated and, though very imperfect, has the appearance of being the coxal joint.

The two other appendages of this group are robust and short. One is tolerably complete, apparently lacking only the dentate border of the coxal joint. It is 38 mm long and consists of seven joints. The coxa is large and globose. Each joint from the second to the fifth carries on the posterior edge a pair of short, stout, distally directed, lanceolate spines, averaging 2.5 mm long and nearly half as wide. Joint two is broad and very short. Joints three, four and five are subquadrate and successively smaller. Joint six is nearly one and one half times as long as broad and at the end bears two distally directed spines, one anterior, the other posterior. The seventh is long and clawlike, slightly inflated at the base. The other appendage is so crushed and folded that little can be determined by it. However, from the larger size of the coxal joint, it is probable that its position on the body was behind the more complete. The spines preserved on it, like those of the smaller appendage, are short and lanceolate.

The body plate in this group is very narrow (76 mm) as compared to its length (23 mm). Its division into right and left halves by a suture, the arching of each half and the produced antelateral angles indicate it to have been a paired sternite.

In the second group one of the imperfect arms consists of the four distal joints, the other of two imperfect proximal joints. The joints of the former are short and expanded at the articulations. The first and second are each provided on the posterior side with a pair of distally directed spines. These are long, curved and sharp like those of the large arm of the other group. The second has also, on the opposite side of the distal angle, a single, large one extending parallel with the axis of the arm. The penultimate is long and shows no sign of having been spiniferous. The terminal is about equal in length to the spines and, like the terminal appendage in the other group, is clawlike. This arm, judging from the shortness of the joints and the broadening at the articulations, probably corresponds to the second described from the other group. The joints of the other arm appear to correspond to part of joints two and three of the first of that group.

Associated with this last, and lying partially beneath its larger end, is a fragment of test which is ornamented by sharp, triangular scales differing from anything found on the other eurypterids herein described. However, it is not certain that this had any connection with this arm. Aside from this possibility, neither the appendages nor the sternite show any signs of ornamentation.

The most noticeable features revealed by these specimens are: the robustness and the great difference in size of the several pairs of endognathites; on the anterior three of these the arrangement in pairs of the posterior spines, which, on the first two, are noticeable for their shortness and lanceolate form, and on the third for their length and curvature; the high degree of specialization of the fourth pair of endognathites, shown by the great length of the joints and the number and large size of the spines; the narrowness and proportionately great length of the compound sternite; and the probability of there being several compound sternites. It is evident that the animal had a long, slender body with long, very strong limbs.

From a comparison of these parts with those of the various genera of eurypterids, it appears that they do not agree very closely with any. To show this, it is necessary only to point out certain of the more evident differences. In Eurypterus proper the fourth endognathite, to which I consider the longer of these arms to correspond, consists of nine joints, probably a greater number than is possessed by the other; besides, it bears no spines except the two formed by the prolongation of the eighth or penultimate joint. On the three anterior pairs of endognathites the spines are more uniform in shape and size. The body is proportionately broader

and shorter than that indicated by the sternite described above.   In euryp-
terids of the type of E u s a r c u s   s c o r p i o n i s   Grote and Pitt,
C a r c i n o s o m a   n e w l i n i Claypole, E c h i n o g n a t h u s   c l e v e-
l a n d i   Walcott, E u r y p t e r u s   p u n c t a t u s   Salter, E . s c o r-
p i o i d e s Woodward, É . s c o t i c u s Laurie, etc., so far as material
shows, the preabdomen is obese, the second pair of endognathites is the
longest, and all four pairs with their spines are curved forward.   In
Stylonurus and the related genus, Drepanopterus, the fourth endognathites
are without any elaborate development of spines, and in the former are ·
greatly elongated.   In Slimonia the first pair of endognathites is tactile,
the succeeding three pairs are short, vary little in size and are all pro-
vided with small spines at the distal ends of the joints.   In the Pterygotus
the four pairs of endognathites are filiform, of nearly equal size and
probably in all cases, spineless.

A metastoma of peculiar form, figured by Sarle [*op. cit.* pl. 12, fig. 5;
here pl. 46, fig. 15] and referred to in the explanation of his plate as " Doli-
chopterus?? metastoma of an undetermined form," approaches in shape
more closely the metastoma of Stylonurus than that of any other genus.
It seems to us very probable that it also belongs to this species.

Stylonurus myops Clarke

Plates 51, 52, 53, figures 1–5, 7

E u r y p t e r u s   m y o p s Clarke.   N. Y. State Mus. Bul. 107.   1907.   p. 306, pl. 6,
   fig. 1–5

E u r y p t e r u s   m a r i a Clarke. *Ibid.* pl. 3, fig. 6

E u r y p t e r u s   or   P t e r y g o t u s . *Ibid.* pl. 6, fig. 8

Segments and joints of Eurypterus, Hughmilleria, etc. *Ibid.* pl. 8, fig. 4

In the preliminary note on the Otisville fauna this species was con-
sidered as being " in many respects a diminutive expression of E u r y p-
t e r u s   p i t t s f o r d e n s i s Sarle, the head (all that is now known of
it) being subquadrate, almost as much squared in front as behind, the eyes
large, semicircular, subcentral and approximate and the ocellar mound
developed in mature forms."   The greatly enlarged collections from the
same locality secured by the State Museum since the date of the preliminary
paper, throw a different light on the generic relations of this species, and
furnish the data for the following description.

Description. Carapace subrectangular, its length and width approximately as 2 : 3; both the anterior and posterior angles approaching right angles in older specimens; anterior angles, however, more rounded than the posterior ones. Frontal margin varying in different specimens from slightly convex to gently emarginate; lateral margins moderately convex, posterior margin broadly concave. The greatest width is found in the middle between the anterior and posterior margins. The upper test carries but a very narrow thickened rim on the anterior and lateral margins; it is continued, however, into a very broad, concentrically furrowed doublure on the underside, which in front attains one sixth the length of the carapace and becomes reduced to one half that width toward the genal angles. The eyes are very large (one third of length of carapace); much elevated, furnished with a semicircular, narrow visual area; approximate, about their own length apart, situated a little forward of the bisecting line. The ocelli are situated on a prominent, heart-shaped mound between the posterior extremities of the lateral eyes. The surface is covered with closely arranged prominent tubercles which along the frontal margin are arranged in concentric rows.

The first tergite is short and wide and like the following furnished with a row of large tubercles along the posterior margin.

Measurements of type [first specimen figured, 1907, pl. 6, fig. 1]. millimeters

Length of carapace	12.3
Width	16.5
Width of doublure	1.5 +
Length of lateral eye	2.5
Distance between visual surfaces	9.
Exposed length of first tergite	1.2
Width	12.4

The smallest carapace observed measured

Length of carapace	3.5
Width	5.5
Length of lateral eye	.9
Distance between visual surfaces	4.

The largest carapace observed measured   millimeters

  Length of carapace................................... 19.

  Width... 27.

  Length of lateral eye...............................   6.9

  Distance between visual surfaces................... 12.8

Horizon and locality. One of the rarer forms in the Shawangunk grit at Otisville, N. Y.

Remarks. The principal features which characterize this species as belonging to Stylonurus are the broad, furrowed doublure, the large size of the eyes, the semicircular outline of the visual surfaces and their approximate position and the rows of tubercles along the posterior margins of the tergites. In the general outline of the carapace and its relative dimensions S. m y o p s may be compared to S. p o w r i e i , m e g a l o p s and s c o t i c u s . The great size of its eyes recalls S . m e g a l o p s and, as in that little known Scottish form, the visual surface extends over more than a semicircle. Its prominent ornamentation distinguishes it from all of these species.

The later collections from Otisville have afforded some carapaces [pl. 51, figs. 8-12] of very young individuals (width but 5 mm) which differ so much from that of the mature type that they would be easily taken as representing a different species. They are broader and shorter and semicircular to semielliptic in outline. The lateral eyes are close to the margin instead of approximate; and their visual surface is relatively less extensive. The entire surface is so densely covered with tubercles that it has a shagreen aspect. Most of these ontogenetic characters are probably of phylogenetic importance, especially the change in the form of the carapace and in the position of the eyes. These have been noted more fully in another place.

A number of specimens [pl. 51, fig. 14; pl. 52, fig. 9] exhibit a distinct acute process in the middle of the frontal doublure. The same specimens are also relatively a little shorter. For this reason we consider it possible that both these features are due to a slight lateral compression,

which undoubtedly has affected the specimen, figure 9. Larger collections may, however, bring out the fact that we have here to deal with varietal differences.

Besides the carapaces and attached first tergites, fragments of other parts of the test of a Stylonurus occur at Otisville and their prominent rows of tubercles suggest that they belong to this species. Most easily recognized among these are the tergites [pl. 53, fig. 4, 5]. Besides the posterior row of tubercles borne on a high crest, these show a parallel middle row of less distinct tubercles, which also crown a narrow ridge. In some a row of smaller and less distinct tubercles is seen posteriorly of the other and alternating with it. Further, densely tubercled metastomas of the shape of that reproduced on plate 53, figure 1 occur not infrequently. They probably also belong to this species. Portions of legs with longitudinal rows of tubercles [fig. 7] suggesting their reference to this species, have also been observed.

A single entire individual has been observed and, judging from the subrectangular outline of its carapace and the size and position of the eyes this probably represents S . m y o p s [pl. 52, fig. 6]. Unfortunately its test is reduced to a film that retains no sculpturing and shows nothing but the outline. The most characteristic features of the specimen are its relatively compact form and the small length and great width of the abdomen and the long spurlike epimera of the segments, both of the preabdomen and postabdomen. The total length of the specimen is but 55 mm, its greatest width however amounts to 20 mm.

Such spurlike epimera of equal relative size are possessed only by the large S . s c o t i c u s from the Old Red sandstone. Curiously enough that isolated and strange form is like S . m y o p s in outline of carapace, the approximate position of the eyes and the sculpture of the tergites. It seems probable therefore that S . m y o p s , when fully known, will prove a representative of the subgenus Tarsopterus of which S . s c o t i c u s is the type.

Of the telson of the species, but a small proximal portion is preserved.

Ontogeny of Stylonurus myops

Among the early stages of eurypterids obtained at Otisville is a number of very minute individuals, that are noticeable for their owllike appearance due to the very broad, anteriorly emarginate carapace and their immense hemispherical and disklike eyes [pl. 51, figs. 1-6]. Although there is a considerable gap in size in the series of these specimens and of the smallest of the carapaces [pl. 51, figs. 7-9] which undoubtedly belong to S . m y o p s , these small entire individuals seem properly referred here, for the following reasons: The form of the carapace is clearly that of S . m y o p s which is the only one in the Otisville fauna possessing a subrectangular outline; the position of the eyes corresponds to that found in the adult stages of S . m y o p s ; the broad rim of the carapace, a characteristic feature of S . m y o p s and not observed in other members of this fauna, is present in these young individuals.

In surveying this whole series, one distinguishes three ontogenetic groups, the first represented by the small entire individuals on plate 51, figures 1–6; the second by the group plate 51, figures 7–14, and the last by the specimens plate 52, figures 1–4, 10. As the smallest specimens of the first group are but little larger than the eggs of Limulus and are thoroughly larval in their character, we consider them as representing the nepionic· stage. The next group which is intermediate in its character between the first and last may be considered as representing the neanic growth stage, since the last group belongs to specimens of ephebic or mature age, as far as we can judge, although we suspect that these are only the earliest ephebic substage.

The *nepionic* stage is again subdivisible as far as our material is concerned, into two substages. The first of these, illustrated by the figures 1–3, [plate 51] is characterized by (1) the relatively large size of the carapace to the body (proportion as 1 : 3.75 in the former and as 1 : 5 in the latter); (2) the evenly terete or conical form of the body which makes the carapace also the broadest part of the integument; (3) the presence of a distinct border surrounding the whole carapace; (4) the immense size of the

eyes, which occupy the entire space between the border and a median ridge; (5) this distinct median ridge, also a character not observed in later stages, and finally the abdominal segments which are (6) less in number and (7) lack all differentiation between preabdomen and postabdomen as far as the length of the segments is concerned, all being of equal length.

We may now consider some of these larval characters in somewhat greater detail.

The carapace appears to have had more distinctly the nature of a definite shield than at any later stage, for it is here most clearly set off by a flat thickened border of equal width. The same impression is also conveyed by the rounded postlateral angles, well seen in figures 1 and 3.[1]

The large size of the carapace, its distinction from the abdomen and the broad border, are features which this larva has in common with Limulus [text fig. 24], with the difference, however, that in the latter the border is not continuous over the posterior margin. But there are still other features inviting comparison with the larva of Limulus, notably the median ridge, which produces a trilobation of the carapace directly corresponding to that of Limulus in the so called " trilobite stage." It further appears that the number of segments of the abdomen may be the same as that observed in the larva of Limulus shortly after hatching, that is nine including the rudiment of the caudal spine. Eight (including the telson) are distinctly visible in the original of plate 51, figure 4, but it is probable that the first segment is hidden under the carapace. As in the larva of Limulus these segments are not differentiated, at least in their dorsal view and the telson spine is still extremely rudimentary. But herewith all similarities end.

The uniformly terete form of the abdomen of this larva is in strong contrast to the broad, posteriorly widening abdomen of the Limulus larva. There is little doubt that the latter represents a tachygenetic

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[1] In specimen figure 2 the apparent posterior margin of the carapace is probably formed by the first segment underlying it.

character of later acquisition and that S . m y o p s exhibits the more primitive condition.

Another striking feature of this nepionic form not seen in the larva of Limulus is the great size of the lateral eyes which suggests very strongly the megalops stage in the zoea of many crustaceans. The large eyes appear in most specimens as disks bearing a central node [pl. 51, figs. 1, 5]; in some as globose projections with an apical depression [pl. 51, fig. 2]. By tracing these parts through later stages to the adult form, it becomes apparent that the disks or semiglobes are the large visual nodes with an outer orbital ridge and that the apical nodes are composed of the crescentic visual surface [1] and the included apical area as in the mature S . e x - c e l s i o r . With this conception of the parts of the eye, it follows that the visual node was protruded enormously as in the megalops stages of the crustacean larvae. This protrusion disappears entirely, as figures 7–13 show, and only the small visual node surrounded by the visual surface on the outer side remains. In figure 5 the outer orbital ridge is still very well seen; in figure 6 it seems to have merged into the semilunar ridge that runs parallel to the anterior and lateral margins of the carapace.

The original position of the visual surfaces, or eyes proper, in the earliest larvae seems to have been about halfway between the anterior and posterior margins and nearer to the lateral margin or border than to the median ridge. This position is retained throughout the neanic stages. It is identical with that observed in the larval Limulus. With the beginning of the ephebic stage the compound eyes wander inward and become

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[1] The visual surface itself has not been observed in the individuals of nepionic age, we presume on account of the extremely small size of the specimens and the usual compression of the visual area into a narrow crescentlike band or slit which is very frequently obscure even in the mature specimens. On account of this failure to see the visual surface itself, we must concede the possibility that in this nepionic stage the whole apical or central node may have constituted the visual surface and the latter been gradually reduced to the crescent-shaped band.

approximate [as in pl. 52 fig. 1-4] and thereby assume the position characteristic to most species of Stylonurus.

The neanic and ephebic stages exhibit a strong tubercular ornamentation of the carapace and segments. No indications of this have been observed in the nepionic stage, a fact that may be attributed either to a failure to observe it on account of the extreme smallness of the specimens or to its absence. We believe the latter to be the case for several reasons. One of these is that the largest specimens of the nepionic stage [figs. 5, 6] could have hardly failed to show traces of this sculpture if it existed, and another, that the smallest carapace of the neanic stage observed [fig. 8] possesses this tubercular sculpture only in an incomplete or but partially developed form. Moreover, the fact of the absence of the ornamentation of the mature forms in the larvae is fully in accordance with the relations of the larvae and mature forms in most other arthropods.

The *neanic* stage, typically represented by figures 7-13, is distinguished from the ephebic stage mainly by two characters, the relatively greater width of the carapace and the submarginal position of the compound eyes. In the carapaces, plate 51, figures 9, 11, 12,[1] the average relation of length to width is as 10 : 16[2] and in plate 52, figures 1-3, as 10 : 14.[3]

Actually the relative length of the carapace increases but little (about one eighth) with advancing age but the fact that in the neanic stage the anterior angles of the carapace are strongly truncated and rounded and in the mature stage subrectangular, assists greatly in increasing the appearance of smaller length and greater width in the neanic specimens. Specimen figure 14 which has almost the size of the mature specimens, still re-

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[1] The carapaces plate 51, figures 10, 13, 14 are obviously affected by lateral compression that shortened the width.

[2] Actual measurements are as 13 : 21.5 or 10 : 16.5; 18 : 28 or 10 : 15.5; and 16.5 : 26 or 10 : 15.8.

[3] Actual measurements as 15.5 : 23 or 10 : 14.7; 19 : 27.5 or 10 : 14.4; and 20.5 : 28 or 10 : 13.6.

tains the neanic position of the eyes and the round anterior angles and stands in the proportion of length to width between the neanic and nepionic stages as 10 : 15.

The submarginal position of the compound eyes in the neanic stage is a feature inherited from the preceding stage and corresponding to the appearance of these eyes in the larva of Limulus at the line of insertion of the rimlike edge of the lateral lobes [text fig. 24]. A peculiar difference, apparently at variance with the enormously enlarged eyes in the larval condition between the neanic and ephebic stages consists in the relatively smaller size of the visual surface and inclosed node in the former [*cf.* fig. 9, 11 with pl. 52, fig. 2, 3][1]. But if, as we have inferred before, the final visual node and visual surface in the nepionic stage are represented by the central or apical node borne on the large larval visual node, then the small size of the eye in the neanic stage is the direct result of the nepionic condition. We have then the peculiar fact, that in the ontogeny of S . m y o p s the actual visual surface of the eye increases relatively with advancing age, while the visual node on which it is borne, greatly decreases.

The ocelli have not been located in the nepionic stage, but their position midway between the lateral eyes in the neanic stage can be clearly made out.

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[1] In former [fig. 9] to length of carapace as 10 : 37; in latter [fig. 2] as 10 : 27.

In tabular form the character of the three stages and the changes are as follows:

	NEPIONIC STAGE	NEANIC STAGE	EPHEBIC STAGE
Carapace........	Large	Decreases in relative size	Continued decrease
	With broad border	Border becomes narrower...........	Border more or less narrow and obscure
Compound eyes...	With immense visual node	Visual node small....	Visual node small
	Position submarginal	Submarginal........	Subcentral
	Visual surface relatively small .	Visual surface relatively small	Visual surface relatively large
Abdomen	Segments 7–8......	Unknown..........	12
	No distinct differentiation	....	Distinct differentiation
Preabdomen.....	Regularly narrowing posteriorly	....	Widest at fourth and fifth segments
Postabdomen....	No epimera........	....	Long epimera
	All segments equally long	....	Last segments much longer
Telson spine.....	Very short and blunt.	....	Long and slender (?)
Sculpture........	None.............	Tubercles..........	Tubercles

Stylonurus beecheri (Hall)

(Text figure 67)

Eurypterus beecheri Hall. 2d Geol. Sur. Penn. Rep't PPP. 1884. p. 30, pl. 3, fig. 1

Eurypterus beecheri Hall & Clarke. Palaeontology of New York. 1888. 7: 157, pl. 27, fig. 5

Stylonurus beecheri Beecher. American Journal of Science. 1900. 10: 148

We have nothing to add to the elaborate original description of this form, since no other specimens than the holotype are known. As the

Figure 67 Stylonurus beecheri (Hall). Figure of original specimen. Natural size. (From Hall & Clarke)

latter lacks the carapace and the first four pairs of legs, its relation to the subgenera distinguished above, can not be determined.

The specimen serves to demonstrate the persistence of the genus Stylonurus into late Devonic time, the type coming from the Chemung sandstones at Warren, Warren co., Penn.

Stylonurus (?) wrightianus (Dawson)

(Text figure 68)

Equisetides wrightiana Dawson. Quar. Jour. Geol. Soc. 1881. 37:301, pl. 12, fig. 10; pl. 13, fig. 20

Equisetides wrightiana Wright. N. Y. State Mus. Nat. Hist. 35th Rep't. 1884. p. 196

Stylonurus(?) wrightiana Hall. *Ibid.* pl. 15, note

Echinocaris wrightiana Jones & Woodward. Geol. Mag. 1884. Dec. 3; 1: 9; p. 393, pl. 13, fig. 1, a, b

Echinocaris wrightiana ·Etheridge, Woodward & Jones. 3d Rep't Committee on Fossil Phyllopoda of the Palaeozoic Rocks. 1885. p. 35

Stylonurus(?) (Echinocaris?)wrightianus Hall & Clarke. Palaeontology of New York. 1888. 7: 160, pl. 27, fig. 7–9

Stylonurus(?) wrightianus Beecher. American Journal of Science. 1900. 10: 148

The foregoing synonymy reveals the interesting history of a two jointed subcylindrical fragment from the lower beds of the Portage sandstones, Italy, Yates co., N. Y. Originally regarded as of vegetable nature, Hall early recognized that its surface sculpture was that of an arthropod and that it probably represents " two of the abdominal segments of a form not unlike Stylonurus." Woodward and Jones then referred the fragment to the Phyllocarida (Echinocaris), evidently basing their opinion on the spinose character of the surface of the fragment. Hall and Clarke later pointed out that no species of that genus possess spines of similar character to those in the specimen and that the latter would be gigantic for Echinocaris but not for a species of Stylonurus. Finally Beecher suggested that the specimen represents two proximal segments of one of

the large crawling legs of a form related to Stylonurus, and not two
somites of the abdomen as indicated by Hall, claiming that " its elliptical
or ovoid sections without any flattening of the epimera, the very consider-
able overlapping of the joints, and the configuration of the suture, are

Figure 68   S t y l o n u r u s ? w r i g h t i a n u s   (Dawson). Dorsal and lateral views of the original
specimen, and enlargement of surface.   (From Hall & Clarke)

more strongly indicative of the nature and requirements of a limb than
of abdominal segments."   The entire specimen of Stylonurus obtained at
Otisville would seem to corroborate the latter view.

Stylonurus sp. α, β, γ, δ.

Besides the fairly complete species of Stylonurus (S . c e s t r o t u s
and S . m y o p s) which the shales of the Shawangunk grit at Otisville

have afforded, fragmentary remains indicate the presence of several other representatives of the same genus, which for the sake of completeness, may be mentioned in this place.

a. Plate 53, figures 8, 10-12. One of these is characterized by its acutely triangular scales, which assume the aspect of short sharp spines and actually seem to have consisted of such in the specimen, figure 10, where the fact that the distal parts of the scales are always broken off, is evidence of their spinose nature. The fragments of segments indicate that these possessed distinct anterior and posterior borders. A single segment of one of the first or second pairs of legs has been obtained. This by its lateral row of spines permits a reference of the species to the subgenus Ctenopterus.

β. Plate 53, figures 14, 15. A second species, quite probably also referable to Ctenopterus, is best represented by the leg segment reproduced in figure 15. This shows a series of teethlike serrations, quite dissimilar to the rows of spines in other species.

γ. Plate 53, figure 19. A third leg segment, also possessing the characteristics of Ctenopterus, shows broad, flat (paired?) spines with longitudinal striae; these features strongly reminding one of the leg spines of S . e x c e l s i o r .

δ. Plate 53, figures 6, 9. Some patches of integument bear a sculpturing which consists of flat, broad, distinctly separated prominences and in part of long ridges, the whole resembling a cobblestone pavement. This is so strikingly different from all other ornamentation observed in the beds at Otisville, that it can not fail to characterize its possessor. It is more suggestive of the ornamentation exhibited by such forms as S. e x c e l s i o r , s c o t i c u s and m y o p s than of members of other genera.

Some other specifically indeterminable fragments deserving mention, may be noted here. One of these is the distal portion of one of the posterior legs [pl. 53, fig. 20] of a Stylonurus, chiefly remarkable for its size, indicating the presence of large individuals of the genus in this Otisville fauna. Another

fragment of a segment [pl. 53, fig. 13] exhibits a curiously serrated posterior margin. This recalls the frontal serrations of the carapace of S . c e s t r o t u s , but the segments of that species have not shown this structure, although on account of their rather poor preservation, this does not yet demonstrate the absence of this fringe. We are not certain that this specimen is referable to Stylonurus.

To a gigantic Stylonurus or Pterygotus probably should also be referred two fragments of plates with marginal rows of slightly curved, rather blunt spines [pl. 53, fig. 16, 17]. These are apparently portions of the manducatory edges of coxal segments. In the smaller specimen the teeth are very thick and solid, in the second they are so much wrinkled and shrunken that they give the impression of having been hollow processes. It is possible that these remains require an entirely different explanation, but the material is at present too fragmentary to permit of positive conclusions. There is a suggestion of similarity between these peculiar fringed bodies and the supposed combs of giant scorpions such as have been described by Peach as Glyptoscorpius, both the fringe and the parallel lines of the base of the fragments indicating the structure seen in the rhachis and the comb of certain recent scorpions. With present knowledge the comparison can be carried no further.

Subgenus DREPANOPTERUS Laurie

In 1892 Laurie created a new genus for a single, then rather incompletely known eurypterid, from the Siluric rocks of the Pentland hills in Scotland. He defines the genus as follows:

Carapace broader than long; widest about two fifths from anterior margin. Body, 1st segment wider than posterior margin of carapace; increases in width to 3d segment, and then tapers rapidly. Limb elongated, subcylindrical, terminating in a very slightly expanded joint, concave on posterior margin.

The subsequent discovery of two other species and of better specimens of the genotype led Laurie [1899, p. 582] to consider the point of chief generic importance to be a negative one: " Last pair of appendages

Figure 69 Drepanopterus pentlandicus Laurie. Original figure. (From Laurie)

neither expanded, as in Eurypterus, etc., nor excessively elongated, as in Stylonurus." The American rocks have furnished a single representative of this genus, here described as D . l o n g i c a u d a t u s , which stands still somewhat apart from its three British allies. In general habit it is a Stylonurus, as evinced by the slender body, broad, somewhat angular carapace with broad rim, the very long and slender legs and the immense telson. At the same time it possesses differential features, some of which clearly denote intermediate stages between the highly specialized limbs of Stylonurus and those of its unknown ancestors. The characters indicative of the incomplete specialization of the legs consist in the smaller size of the last pair; that in Stylonurus reaches to the middle of the telson, but here, notwithstanding the relatively short body, only to the penultimate segment of the postabdomen; and the further fact that the preceding pair of legs is only about half as long (more exactly three fifths) as the last.

Laurie [1893, p. 519] suggests that " the form of the two last pairs of legs [of Stylonurus], which are long and pointed at the end, and are among the most characteristic structures of the genus, is possibly derived from Eurypterus through some form like Drepanopterus, though it is also possible that Stylonurus is descended from an ancestral type in which the last pair of legs were less modified than in Eurypterus." In view of the early appearance of Drepanopterus, and the fact that the young of D . l o n g i c a u d a t u s show no indication of eurypteroid features in their limbs, we are convinced that the last of the alternative hypotheses of Laurie is nearer the truth and that Stylonurus is not derived from Eurypterus but comes through Drepanopterus from a like ancestor with Eurypterus.

Drepanopterus longicaudatus nov.

Plate 25, figure 3; plates 54-56

Description. Body slender, of medium size, clavate in general outline, the carapace being broadest and the body tapering to the long telson.

The *carapace* is subquadrate in a young specimen, but an ephebic individual has the sides so well rounded that it appears subcircular, with the

posterior parts contracted. In the young specimen, the length is to the width as 7 : 8, in the ephebic example, as 8 : 9. It is widest in the middle portion and contracts again by about one seventh of its width toward the base. The doublure is about 3 mm wide in the type specimen and relatively wider in the young. It diminishes in width posteriorly and finally runs out. The margin of the carapace is bounded by a thickened border, behind which several parallel striae are observed. The eyes are somewhat indistinct in the specimens; they appear to have been large and consisted of almost circular visual surfaces surrounding circular prominences. The latter occupied one fifth of the length of the carapace, were situated on the anterior half and not quite twice their width asunder. The ocelli have not been seen. The *preabdomen* is relatively very short (its length amounting to only two thirds that of the carapace) and broad (proportion of length to width as 4 : 5), its greatest width being attained in the region of the fourth tergite whence it contracts rather rapidly. At the widest part of the preabdomen, the tergites seem to be about six and one half times as wide as long. Their general form is but indistinctly discernible in the carbonaceous film, but seems to have been that of straight transverse bands. The operculum is not appreciably wider than the other sternites and the next sternite fully as wide. The details of the outlines of these and the following sternites have not been made out. The third sternite (the widest) is, in its exposed or not overlapping part, eight times as wide as long. The posterior margins are uniformly concave, the curvature increasing in the succeeding segments. The median suture is well seen in a young specimen [pl. 25, fig. 3]. The post-abdomen shows an immense development; it is nearly as long as the carapace and preabdomen together and occupies about one third of the total length of the body. The first postabdominal segment still corresponds in anterior width to the preabdomen, but it contracts so rapidly that its posterior margin is shorter by one fifth and the final width of the post-abdomen is but one third of that at its beginning. While thus the post-abdominal segments diminish greatly in width posteriorly, they increase

in a still more striking manner in length, for the last segment is nearly four times as long as wide; the postabdominal segments thus change from short, wide rings to relatively long, narrow tubes, the last three being the most markedly subconical. The posterior doublures, about 4 mm wide, are well seen on plate 55. There are keels parallel and near to the lateral margins of the postabdominal segments. The telson is enormously developed. It not only occupies nearly one third of the length of the whole body, but is also very strong and thick. In shape it is clavate, contracted at about one fourth of its length and expanding again, and reaches its greatest width at three fourths of its length. Its extremity is blunt.

Appendages. Of the postoral appendages of the cephalothorax, the third to fifth pairs of limbs have been observed in position and one of the preceding limbs has been seen detached [pl. 55]. The latter is of strikingly plump form, its greatest width being nearly one third of its length. Its segments are narrow rings, seven in number, increasing in width to the third and then gradually decreasing to the long, curved terminal claw. The last five segments bear each a pair of short, blunt spines. These, like the terminal spine, are longitudinally striated. This limb contrasts so much in shape with the third limb that we should be inclined to consider it, in view of the regular series which the third to fifth limbs form, as the first postoral appendage. But as Laurie has regarded a similar short, stout appendage as the second leg in S t y l o n u r u s   m a c r o p h t h a l - m u s [1899, pl. 1, fig. 4] and as the first limb of Stylonurus and Drepanopterus are practically unknown, we prefer to leave the question of the number, of this leg open. The third limb is much longer, projecting with four and one half segments as much beyond the margin of the carapace as the base of the carapace is long. It is, however, not slender, its fourth joint being still two thirds as wide as long. The segments are tubular; each is narrower than the preceding, but widens again a little in the distal portion. Those exposed beyond the margin of the carapace bore two spines each at the distal articulation. The limb ends, like the others, in a terminal claw. The fourth limb is built on the same lines as that just described. It pro-

jects twice as far beyond the carapace with five segments exposed and these segments are, as in the preceding limb, of subequal length (except the fifth which is a little longer and the seventh which is much shorter) though greatly differing in width, the fourth being more than twice as wide as the last. The second and third segments can also be seen faintly outlined in specimen, plate 56. They are only about half as long as the following, but wider; the third is still much shorter than the second, as in other euryp-terids, and forms a narrow ring. The undersides of the segments are furnished with two slender spines each. The next, last limb, is again almost twice as long as the fourth in its exposed portion and the slight differences in the lengths of the segments observed in the preceding legs are here greatly exaggerated, the second and third segments being narrow rings, while the fourth segment is greatly lengthened and the fifth again longer by one third. The next two segments (sixth and seventh) are each as long as the fourth, and the eighth is reduced to nearly half that length. The segments of this limb are not furnished with spines on the underside. The coxa of this limb is also outlined on plate 56. It is relatively small, its length amounting to not more than one third of the carapace; distinctly trapezoidal in outline, width and length are subequal, its anterior margin gently convex and larger by one fourth than the posterior. The manducatory edge was apparently short. The terminal claw of the last limb is as long as the last segment and curved inward.

The metastoma has not been seen.

Genital appendages. Specimen plate 56 shows a long elliptic impression, extending over the operculum and first sternite and suggesting a female opercular appendage; and the young specimen on plate 25, figure 3, exhibits a short oval plate in the median line of the operculum.

Ornamentation. The surface sculpture shows a transverse row of sharply angular scales along the posterior margins of the segments on the upperside. Some of these along the median line of the post-abdomen grew into distinct short spines. The remainder of the surface is covered with what look like smaller, more irregular, similar scales,

the appearance of which may, however, be due to secondary changes in the substance of the integument, which gave it partly a scaly, partly a granular character. Some apparently well preserved portions of the integument are quite smooth.

Measurements. The type which is also the largest specimen, measures 295 mm. The carapace is 65 mm long and 73 mm wide at its widest part and 61.5 mm wide at the base. The eye had a longitudinal diameter of 13.5 mm. The preabdomen measures 42.5 mm in length and 61 mm in width; the postabdomen 96.6 mm in length and 53.5 mm at its beginning and 18 mm at its end. The length of the first postabdominal segment is 8 mm, that of the last 29 mm. The telson is 91 mm long and 7 mm wide. The third limb projects about 51 mm beyond the carapace, the fourth about 82 mm, the last about 135 mm. In a young specimen the total length is 93 mm, the carapace measures 21.5 x 24 mm, the preabdomen 18 x 22 mm, the postabdomen 31 x 16.5 mm (31 mm width at beginning and 6 mm width at end); the telson 23 mm. The fourth limb projects 26 mm, the last 44 mm.

Horizon and locality. Kokomo limestone of Kokomo, Indiana. Types (four specimens, nos. 12903 (holotype), 12904, 12908, 12911) in the University of Chicago collection.

Remarks. D r e p a n o p t e r u s   l o n g i c a u d a t u s is a unique form among the American eurypterids being the sole representative thus far found on this continent of this rare and phylogenetically interesting genus. From its Scottish allies, it is readily distinguished by its slender and elongated postabdomen and the long, clavate telson.

Two of the four specimens before us are only one third the size of the others, thus representing much younger stages. Nevertheless, their habitus and relative dimensions do not differ from those of the older as one might expect. This is especially obvious in the comparative lengths of the appendages and the telson to the whole body. In both the old and the young, the length of the last limb to that of the body is as 7 : 15 and that of the preceding limb to the last one as 3 : 5.

Genus ECHINOGNATHUS Walcott

This genus from the Lower Siluric of New York is based on unsatisfactory fragments which indicate relationship to Stylonurus and we associate them provisionally with that genus. Walcott's original diagnosis of Echinognathus follows [1882, p. 213]:

Endognathary limbs (one or more pairs) formed of eight or nine joints, six of which carry long, backward curving spines articulated to their posterior side. Terminal joint slender, elongate, acuminate. Surface of the body and larger joints of the cephalic appendage ornamented with scalelike markings, as in the genus Pterygotus. Type, E . c l e v e - l a n d i .

Two characters are not only the most prominent features of the originals[1] but also of distinct value in determining the taxonomic position of the genus. The first is the great number of paired long, flat spines to each segment of the endognathite. The common genera of eurypterids, as notably Eurypterus and Pterygotus, have but one pair of longer spines to each segment. The greater number of spines occur typically only in the genera Dolichopterus and Stylonurus, and but very exceptionally in other genera—the exceptions being E u r y p t e r u s d e k a y i Hall and probably also E u s a r c u s s c o t i c u s (Laurie).[2] Such continuous series of spines, however, as are exhibited by the endognathite of Echinognathus, are characteristic of the subgenus of Stylonurus here termed Ctenopterus.

It would also seem that the spines of Echinognathus possessed a rather flat, subtriangular section, giving them a bladelike appearance, a character which, coupled with a distinct longitudinal striation, is also repeated in certain species of Ctenopterus.

The second character that we have here in view, is the surface sculpture. This is also of unusual type and consists of very prominent

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[1] These are now in the National Museum, and have been kindly loaned by Secretary Walcott.

[2] Laurie, 1899, pl. 4, fig. 23, pl. 5, fig. 26.

oblong scales that rise rapidly behind and suggest raindrops running down a windowpane [pl. 58, figs. 1, 2], with a row of especially large drops at the bottom, on the posterior margin of the segments. This peculiar ornamentation is also best developed in species of Stylonurus, though it also occurs in some of the later, especially the Carbonic, species of Eurypterus.

Both the extreme spinosity of the endognathite and the surface sculpture indicate that Echinognathus, in comparison to Strabops or Eurypterus, was already a highly specialized genus and was either closely related to Stylonurus or had a convergent development to that genus as far as the two characters mentioned are concerned. There are no other characters observable in the fragments that would appear competent to shed light on its generic relations.

The monotype of this genus is

Echinognathus clevelandi Walcott

Plate 58, figures 1, 2

Eurypterus? clevelandi Walcott. American Journal of Science. 1882. 23: 152. figs. 1, 2

Echinognathus clevelandi Walcott. *Idem.* p. 213

We reproduce the original description as follows:

The only portion of the body discovered is illustrated by figure 1. It appears to be the left side or half of the ventral surface of the anterior thoracic segment. The reference to the ventral surface is from the presence of a thin membranous extension of the anterior margin, a feature observed on the anterior segment of Dolichopterus macrochirus Hall.[1] The test appears to have been thin and firm, and the margins are clearly outlined on the dark, smooth slate, while the surface is ornamented with fine scalelike markings on the anterior portion that increase in size toward the posterior margin (*cc*).

Figure 2 is a sketch, seven tenths of the natural size, of the cephalic appendage as it appears on the surface of the slate and in the matrix. The entire length of the appendage from the point *a a* to the end of the terminal

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[1] Palaeontology of New York, 3:414*.

joint seven, as restored to its natural position, would be 12.5 centimeters, exclusive of the basal joint at *a a*. The long spines of the joints 3 and 4 are 5 centimeters in length.

The joint marked (1) is broad and short with a rounded depression at the center of its inner margin. There is no evidence of the attachment of the long spines that are articulated to the posterior side of the succeeding joints. From the form of the joint and the presence of broken fragments of the test in the matrix at *a a* it is probable that it is the second joint of the appendage and that the first or basal joint is broken up. The joint (2) is large, elongate, rudely subtriangular, the long anterior margin curving around to meet the nearly straight posterior margin at its inner end. The latter margin has nine long curved spines articulated to it while the three following joints (3, 4 and 5) have but three each on their posterior margins. These joints (3, 4, 5), are more or less quadrangular in outline, (3) and (4) being transverse and (5) a little elongate. The spines of (3) and (4) are the longest of any attached to the appendage. Beyond (5) traces of another joint are shown (6), and another is indicated by the position of the three curved spines beyond those of (6). These two latter joints were crushed by the forcing back of the long terminal joint (7), the inner end of which is seen beneath the center of the joint (4). This joint or terminal spine is slender, slightly curved backward, and marked by a slight median ridge and longitudinal striae. The surface of the joint (1) and the anterior portions of (2) and (3) show the scalelike markings observed on the fragment of the thoracic segment. If there were but one joint beyond the transverse joint (1), i. e., the basal, the entire appendage would have had nine joints, if our interpretation of the crushed joints is correct.

The long curved spines (*s, s, s*), are a very curious feature of the appendage and the most marked character of the genus and species. They are articulated to the posterior margin of the joints, as the latter rest flattened out in the slate or shale, and there is no evidence but that they form a single series as shown in the specimen and in the drawing, figure 2. Each spine is constricted a little near its base, forming a rounded end or point of articulation; from this well out toward their pointed termination they retain an average width curving gently backward and inward. They appear to have been flattened when in a natural condition, and formed of a thin test which is rather strongly striated.

Horizon and locality. Utica slate, Holland Patent, Oneida co., N. Y.

Remarks. The great width of the earlier joints of the leg and the very rapid tapering of the limb suggest that it was a first endognathite and that it consisted of eight segments, counting the terminal spine. It is

doubtful whether the spine that now holds a horizontal position, is the terminal spine, pushed far back, or only a lateral spine in an accidental position.

The fragment of a segment indicates by the strong rounding of the antelateral angles and the great length, that it might belong to an operculum, in which case the absence of a median transverse line would be remarkable; or to one of the first sternites. The crowding and the transversely elongate form of the scales in the anterior lateral region indicate that this part has been pushed together in posterior direction and the anterior margin is not complete. It probably extended as far forward as the median portion of the segment.

Mr Walcott has sent with the two types a third fragment which has not been figured hitherto, but which beautifully shows the character of the scales [pl. 58, fig. 2].

All the fragments and the size of the sculpturing indicate that E c h i n - o g n a t h u s   c l e v e l a n d i was a form of large dimensions and robust structure.

Genus MEGALOGRAPTUS Miller

Another eurypterid of the Lower Siluric is from the Richmond group of Ohio and was described by S. A. Miller [1874] as a graptolite under the name of M e g a l o g r a p t u s   w e l c h i . When the junior author was engaged on the monograph of the Graptolites of New York, inquiry was made in regard to this curious fossil and the information obtained[1] through Drs Ulrich and Foerste that the species is based, as the figures at once suggest, on fragments of an eurypterid. Dr Foerste has been engaged for some time in an investigation of the Richmond faunas of the Ohio valley, and as he presumably had secured all the material available of this form, we have asked him to publish in this place that part of his manuscript referring to Megalograptus. To this request he has kindly acceded by sending the appended description. The photographs of Miller's types are here reproduced on plate 58.

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[1] *See* N. Y. State Mus. Mem. 11. 1908. p. 247.

Megalograptus welchi, S. A. Miller

By A. F. Foerste

Plate 58, figures 3-5

The Richmond group of Ohio, Indiana and Kentucky includes, in descending order, the following divisions:

Elkhorn beds	Liberty beds
Whitewater beds	Waynesville beds
Saluda beds	Arnheim beds

In Ohio, most of Indiana, and a part of northeastern Kentucky, the base of the Liberty bed is formed by a stratum in which the brachiopod Hebertella insculpta is very abundant. This stratum is overlain by one in which Plectambonites sericeus abounds, and at a still higher elevation Dinorthis subquadrata makes its first appearance.

The top of the Liberty bed is the horizon at which Gomphoceras cos, Gyroceras baeri, and several species of Cyrtoceras occur. Immediately below these cephalopoda, or associated in the same layers, a large form of Streptelasma rusticum is abundant.

The Liberty beds contain an interesting fauna. Ceraurus miseneri, Dalmanites breviceps, Brachiospongia tuberculata, and various crinoids occur here including Glyptocrinus richardsoni and Glyptocrinus fornshelli. The Liberty beds were a favorite collecting horizon for the crinoid hunters 40 years ago. It was while working out a pocket in which Dendrocrinus casei and Gaurocrinus onealli were abundant, that Megalograptus welchi was found. The locality occurs in the eastern edge of Warren county, Ohio. The road from Clarksville to Fort Ancient crosses Todds Fork half a mile west of Clarksville. A short distance beyond the point at which the road to Morrow turns off, on the left, is the home of Adam Pennington. The Megalograptus specimens were found about 100 yards directly west of the house, along a small stream. A wave-marked layer of limestone, 6 inches thick, overlies a few layers of limestone containing Dinorthis subquadrata. Farther down stream there are no exposures for about 25 feet, but it is evident from the stratigraphy worked out in the surrounding country, that the wave-marked layer here mentioned belongs about 15 feet above the Hebertella insculpta horizon. The Megalograptus occurred in a series of crinoid-bearing clays, 3 feet above the wave-marked limestone.

The specimens were discovered by Dr L. B. Welch, and the largest fragment, a nearly perfect endognathite, remained in his collection. A fragment of a second endognathite, and a large quadrangular fragment, regarded as the dorsal part of a postabdominal ring segment, passed into the possession of Mr S. A. Miller, by whom all three specimens were described and figured as M e g a l o g r a p t u s w e l c h i [Cincinnati Quar. Jour. Sci., 1874, 1:343]. The two specimens acquired by Mr Miller are now in the Walker Museum, at the University of Chicago. Other fragments have been found, but none of these give any additional information. It is probable that if at the time of discovery the fragments at hand had been recognized as that of some large eurypterid, much more could have been obtained. The collectors were after crinoids, and by the time that the black filmy fragments had been recognized as of interest, almost the entire specimen had been irretrievably destroyed.

The large endognathite belonging to the Welch collection was not thoroughly cleaned by Dr Welch, and I have taken great pains to determine its exact outline. In this, there has been fair success except in the case of the basal joint, where a part of the thin chitinous epidermal layer had already scaled off, and where the underlying rock offered no trace of an impression. In the case of the basal joint, therefore, the outline presented is that of the specimen in its present condition, and not of the perfect specimen. The specimen may be described as follows:

If that part of the specimen numbered 1A and 1B in the accompanying figure be the basal joint, then the masticatory edge does not preserve distinct serrulations. The posterior proximal corner is prolonged into a spinose projection. The posterior margin is not well preserved; at the distal end there is a minute denticulate projection. If the large segment here considered as a single basal joint in reality consists of two joints, as the reentrant angle both anteriorly and posteriorly seems to indicate, no trace of jointing could be found on the surface of the specimen.

The line of separation between the first and second joints is distinctly shown, but the distal corner along the posterior edge of the second joint is not well preserved, and its form, therefore, remains in doubt. Along the anterior margin of the second joint there are prominent spines. Of these, the spine nearest the distal margin is 15 mm long; a small spinose projection, 3 mm in length, appears to overlap the proximal end of the base of this spine. Opposite the middle of the second joint there is a pair of spines, apparently united for a short distance above their bases. The proximal edge of this pair overlaps, near the base, the distal edge of another spine, only 9 mm in length; and the latter, in turn overlaps a much greater part of still another spine, at least 6 mm long.

The distal corner of the posterior margin of the third, fourth, fifth

and sixth joints is distinctly and acutely denticulate, and the lines between these joints are directly transverse.

Along the anterior margin of the third joint there are two conspicuous spines. Of these, the one nearest the distal end appears to be 17 mm long. In that case it would be the longest spine shown by the endognathite. At its base the proximal end of this spine slightly overlaps the base of a second spine, only 9 mm long.

Along the anterior margin of the fourth joint there are at least three spines. Of these, the distal spine is 10 mm, and the proximal one, 7 mm in length. The tip of the middle one is imperfectly preserved.

Along the anterior margin of the fifth joint there are at least two spines. Of these, the spine nearest the distal margin is 11 mm long, and the spine opposite the middle of the joint is 6 mm in length.

At the distal end of the anterior margin of the sixth joint, the epidermal skeleton appears prolonged into a spine 7.5 mm long and almost 4 mm wide at the base; the anterior edge of this spine appears to be in line with the anterior edge of the joint, so that the spine points toward the distal end of the endognathite instead of forming a considerable angle with the latter as in case of the spines on the preceding joints. The state of preservation of this spine is not satisfactory for accurate measurement. Possibly a second spine was attached along the line between the sixth and seventh joints near the posterior edge of the spine already described. As a matter of fact, little is known at present of the spines attached to this joint.

The seventh joint has a length of 15 mm and is divided along the middle by a deep notch so as to terminate in two spines 10 mm in length. It is possible that the structure described in the preceding paragraph as forming a spine belonging to the distal end of the sixth joint may in reality belong to the seventh joint, but this is not the interpretation made from the specimen in its present condition of preservation.

The overlapping shown by the bases of some of the spines shows that these were not arranged along a single plane, nor has it been possible to demonstrate a biserial arrangement. For the present, the more exact arrangement of the spines must be regarded as not definitely determined. The endognathite probably was distinctly flattened, as was suitable for an appendage of such large size in case of a swimming animal. As far as may be determined from the specimen at hand, the spines were arranged along the anterior face of the endognathite, and no spines have been found at any distance from this face.

The surface of the endognathite is ornamented by scalelike markings, which, toward the posterior border, become small although distinct. The raised border of these scalelike markings is nearest the distal end of the endognathite. The general distribution of these markings is unknown.

The second specimen, a fragment of an endognathite, which passed from the Miller collection into the Faber collection, and finally into the Walker Museum at Chicago University, probably is another fragment from the same individual. Judging from its size, it may represent the three joints preceding the terminal joint of one of the endognathites. In that case, the presence of the large spine and apparently also of a small spine along the distal margin of this fragment is noteworthy. As a matter of fact, the relative position of this fragment in the endognathite is unknown.

The third specimen, also formerly in the Miller collection, but now in the Faber collection in Walker Museum, is the dorsal side of one of the postabdominal segments. This position is indicated by its considerable length, compared with its width. The surface is ornamented by numerous scalelike markings, the raised border of which is directed toward the posterior extremity of the animal. Most of these markings are oval in form but along certain lines parallel to the length of the animal, they are more nearly oblong or linear in shape. These rows of linear scalelike markings unquestionably were more or less in line with similar rows on preceding and succeeding segments. Along these lines the segments were slightly elevated. These lines of scalelike markings and the slight elevations upon which they are found are at least four in number, and are separated by spaces 14 or 15 mm in width; they extend only along the posterior half of the segment at hand. Near the anterior extremities of these spaces, the surface of the segment is marked by irregular, shallow, anastomosing lines or depressions which may be due in part to compression after the death of the animal.

The endognathite first described bears a considerable resemblance to that figured by Woodward in his *Monograph of the British Fossil Crustacea of the Order Merostomata* as E u r y p t e r u s   p u n c t a t u s . It does not possess the long backward curving spines of E c h i n o g n a t h u s   c l e v e l a n d i Walcott, now in the possession of the National Museum.·

Remarks. As in E c h i n o g n a t h u s   c l e v e l a n d i , the fragments of Megalopterus are not sufficient for a determination of either identity with or differentiation from the Upper Siluric genera, and the generic name is principally the expression of supposed generic distinction based on the Lower Siluric age of the organism. But there stand out a few characters which clearly suggest certain taxonomic relations of the form with the later genera; and these are so similar to those of Echinognathus that they indicate either close relationship or identity in these two Lower Siluric eurypterids. These characters are: the multispinous

segments of the endognathite, the peculiar character of the scales and the longitudinal ridges of the segment.

The multispinosity of the segments is a notable character of the genera Stylonurus and Dolichopterus and of a few rather aberrant species of Eurypterus and Eusarcus. The arrangement of the spines in Megalograptus is rather bunched and in this regard differs from the prevailing serial arrangement in Stylonurus and Dolichopterus, and resembles more that of the apparently aberrant E u r y p t e r u s d e k a y i .

The ornamentation consists of circular to oval rings with deep central pits. The ragged edges of the rings show, however, that they are of secondary origin, and since in some places the original scales are preserved, it is seen that the rings originate where the flat or slightly depressed top of the scales is broken away. The scales, where well preserved, strongly suggest the circular disklike scales so characteristic of Eusarcus. They might result from the compression of such wartlike scales as are present in the aberrant E u r y p t e r u s p u s t u l o s u s , and they may also lead to the droplike suboval scales of Echinognathus and of Stylonurus. The comparison with the latter genus is fortified by the presence of strong longitudinal ribs on the segment which is correctly considered by Mr Foerste as belonging to the postabdomen.

Family PTERYGOTIDAE nov.

Genus HUGHMILLERIA Sarle

The genus Hughmilleria was erected by Sarle in 1902 for the common species of the Pittsford shale which is thought by its author to show close relation to Pterygotus though in many ways suggesting the genus Eurypterus. The following is the original generic diagnosis:

General outline lanceolate. Cephalothorax semielliptic and flatly convex; compound eyes small, subelliptic and marginal; ocelli subcentral. Abdomen divided into distinct anterior and posterior regions. Preabdomen provided dorsally with six plain, transverse, bandlike tergites; ventrally with five sternites, the last three being essentially like the corresponding dorsal plates. First sternite cleft for the reception of a median appendage, which varies in form according to sex. Basing sexual dis-

tinctions on the determinations made by Holm in E u r y p t e r u s
f i s c h e r i , this appendage in the female consists of a narrow, convex,
scalelike, sagittate-based sheath, which appears to be formed by the
fusion of two nearly equal portions, the anterior overlapping, and pro-
jecting posteriorly to cover partially a slightly shorter, simple, lance-linear
appendage in a cleft of the following sternite. In the male the appendage
is confined to the first sternite, the second being entire. It is proportionally
shorter and broader, convex and lanceolate with the posterior free end
slightly produced. Postabdomen composed of six ring segments. The
first is readily distinguished from the segments of the preabdomen by
postlateral prolongations. It appears to be formed by the fusion at their
appressed ends, of a sternal and a tergal portion, the latter of which is
the longer. The following segments are simple, bandlike rings. Telson
long, lanceolate, with dorsal carination. Epistoma convex, peltiform,
dividing in molting or under stress of compression, through the middle,
joined at the sides to a narrow doublure. Preoral appendages attached
at the posterior end of the epistoma; short, stout, composed of three joints,
the two distal a little shorter than the basal, and forming a pair of eden-
tulous, bevel-edged pincers, which normally are folded back so that their
tips converge close to the anterior end of the mouth. Endognathites
increasing in length from the first backward, moderately robust, spiniform,
composed of seven joints, of which the third to the sixth inclusive bear
a pair of spines. Swimming arms narrow, lanceolate paddles, composed
of eight joints and a rudimentary ninth inserted in a notch on the inner
side of the eighth or palette. The proximal joint, or gnathobase, has the
form of an upright retort. The seventh bears on the inner half of the
distal end a subtriangular lobe demarked by a suture. Metastoma elon-
gate, cordate.

Type, H . s o c i a l i s Sarle.

In the elaborate comparison with other genera which Mr Sarle adds
to the generic diagnosis, the characters suggesting Pterygotus, as well as
the resemblances to Eurypterus and Slimonia, are fully discussed. Since
the date of his study the rocks of New York have afforded representations
of this interesting genus in the Shawangunk grit and the Frankfort shale.
These new forms suggest a somewhat different conception of the relation-
ships of Hughmilleria, which is most conveniently set forth by annotating
Sarle's discussion of the relationships of the genus.

As characters suggesting Pterygotus are cited: The rounded trian-
gular or semielliptic outline of the head as seen in P t . b a n k s i i Salter

and P t . r a n i c e p s Salter; the marginal, compound eyes; the slender body with slight constriction between the anterior and posterior abdominal portions; the cordate form of the metastoma; and the simplicity of the opercular plate and its appendage. The two forms of this appendage resemble those of Pterygotus as far as the material of the latter permits of comparison, one form being a slender, sagittate-based scale, the other a shorter, broader, convex body, as in P t . b i l o b u s Salter and P t . o s b o r n i Hall. In the new genus the first form projects posteriorly to protect a shorter lance-linear appendage lying in a cleft of the second sternite, while the second form is followed by an entire sternite without appendage. The sixth pair of cephalothoracic appendages resemble those of Pterygotus in being only slightly expanded distally and consisting of eight joints, with a rudimentary ninth inserted in the end of the palette. The gnathobases have the upright retort form.

The outline of the carapace is very much alike in all species, recalling P t e r y g o t u s b a n k s i i Salter.[1] The latter, however, is by no means a typical Pterygotus, but in various characters, as notably also the form of the carapace, is quite apart from the other Pterygoti. On the other hand, the carapace of H . s o c i a l i s resembles most closely that of a species described by Salter and Woodward as an Eurypterus (E . l a n c e o l a t u s).[2] The latter is, in our opinion, either a true Hughmilleria or a transitional form between Hughmilleria and Eurypterus; at any rate it points to a close relationship of the two genera.

As the second character suggestive of Pterygotus, " the marginal compound eyes " are cited. We see in the structure of these eyes in Hughmilleria strong evidence of the intermediate position of the genus between both Eurypterus and Pterygotus. The facts are the following: It is well known that Pterygotus possesses distinctly faceted compound eyes of elliptic to circular outline, the whole ocular node being occupied by the visual area. In Eurypterus, on the other hand, the facets have

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[1] P t e r y g o t u s r a n i c e p s , also adduced for comparison by Sarle, has a more acutely triangular carapace and is here referred to Eusarcus.

[2] In discussing the resemblances between Eurypterus and Hughmilleria [*ibid.* p. 1090], Sarle correctly indicated the similarity of Hughmilleria to E u r y p t e r u s l a n c e o l a t u s in the form of the carapace and the swimming arm.

never been observed, not even in the transparent specimens studied by Holm, and the visual area occupies only a kidney or crescent shaped space on the outer slope of the eye node.

In Hughmilleria we have found the following condition of the compound eyes. The visual area, in outer view, is always smooth in the hundreds of carapaces we have seen, and without any trace of facets, but an interior view shows unmistakable traces of the facets. These structures are hence present, though very feebly developed.

The compound eye is arcuate on the outer side, but angular on the inner side, as correctly described by Sarle. A laterally compressed specimen [pl. 60, fig. 7] has permitted us to obtain an unforeshortened view of the eye and this shows the kidney-shaped visual area and a triangular palpebral lobe on the inside which is the cause of the angularity.

In H. shawangunk the eyes appear marginal in many specimens, because the marginal portion of the carapace was so impendent that in specimens vertically compressed it becomes folded upon itself and only a portion of the eye is shown [pl. 65, fig. 9]. Wherever the whole carapace is flattened out, the lateral eye is intramarginal by a considerable interspace [pl. 65, figs. 3, 4, 12]. In Pterygotus the lateral eye, at least in the mature stage, is always truly marginal.

Thus we infer that the eyes of Hughmilleria exhibit transitional or intermediate features between Eurypterus and Pterygotus.

The body of Hughmilleria is slenderer than that of the typical Eurypterus, but it falls fully within the limits of the recognized variations of the genus Eurypterus and is much surpassed in slenderness by such forms as E. maria. Similarly the metastoma, while exhibiting a decided tendency to a cordate form, is not nearly so pronounced as in Pterygotus and in general form, stands, about midway between that of Eurypterus and Pterygotus.[1]

The opercular appendages have been considered by Sarle [op. cit. p. 1091] as corresponding in a general way to those of Eurypterus; we see in

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[1] It also seems to be subject to considerable variation as evidenced by figure 4, plate 62, and figures 3, 4, plate 66.

them strong evidence of the closer relationship of Hughmilleria to Ptery-
gotus; for it is obvious that the appendage in P . a n g l i c u s and
P . o s i l i e n s i s is only a more extreme development of that of Hugh-
milleria by the expansion of the distal end.   As a last character suggesting
Pterygotus the small distal expansion of the swimming legs is cited.
Considering the wide variation in this character within the genus Eurypterus
(compare for instance the swimming legs of E u r y p t e r u s r e m i p e s
and E . k o k o m o e n s i s), this similarity with Pterygotus is of but
little import.

As characters distinctive from Pterygotus, Sarle cites the preoral
appendages, the spiniform walking legs and the telson.   The difference in
the preoral appendages is described as follows:

These are stout, three jointed, chelate organs, so short that when
extended they barely equal one half the length of the cephalothoracic
shield.   The pincers are edentulous and bevel-edged and in their normal
position lie folded over the basal joints so that their tips converge close
to the anterior border of the mouth.   Extended, these organs project beyond
the border of the shield for perhaps half their length; when turned straight
back, their tips lap over the end of the metastoma.   In Pterygotus, on
the contrary, these organs are very long, having, at least in P t . b i -
l o b u s Salter and P t . m a c r o p h t h a l m u s Hall a length fully one
third that of the entire animal; and consist of ponderous, dentate pincers
supported on a slender, retrally tapering proximal joint of such a length
as must necessarily have prevented the pincers being used at the mouth,
unless these appendages were somewhat retractile, as suggested by Laurie.

Though the preoral appendages of Hughmilleria are larger than those
of Eurypterus they differ still more widely from the very long appendages
of Pterygotus with their dentate pincers, but they may well be considered
as indicating a tendency to a development of Pterygotuslike chelicerae.

The difference between Pterygotus and Hughmilleria in the character
of the spiniform legs, is clearly set forth by Sarle [1] and the slender lance-
olate telson is distinctly a Eurypteruslike feature.

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[1] The next important difference is in the character of the spiniform walking legs.
As in Pterygotus, these consist of seven joints, but the several pairs present a greater

To Sarle's comprehensive statement: " Regarding its [Hughmilleria] resemblance to Eurypterus, it might be said that, but for the marginal position of the eyes and relatively large chelae, this form would easily be mistaken for a species of that genus " [*op. cit.* p. 1090], we may add from the results of our investigations that the facets of the eyes, the character of the opercular appendage and the cordate metastoma are features indicative of a closer relationship to Pterygotus and that we therefore agree with Sarle that it belongs in one group with the latter genus and Slimonia.

Hughmilleria is a good genus that requires distinction as being of a primitive or generalized character, through which it has points of similarity with a number of other genera. It is certain that, notwithstanding its exterior similarity to Eurypterus, it points, by virtue of its cordate metastoma, the intramarginal to marginal position of the compound eyes, the slightly longer preoral appendages, its slender body, less developed swimming legs and the opercular appendage, to the path of development taken by Pterygotus after separation from its common ancestor with Eurypterus. We consequently find the critical characters of Hughmilleria in the same features as did Sarle and Clarke,[1] notably those evinced in the preoral appendages and marginal eyes, as well as in the other features cited, but with the difference that we take them as denoting a primitive condition. This view is strongly supported by the ontogeny of H . s h a w a n g u n k, for the great similarity of its nepionic and mature growth stages is another proof that Hughmilleria has progressed less beyond the common ancestor of the eurypterids than either Pterygotus or Eurypterus.

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contrast to their respective lengths, are proportionately more robust, and each joint, from the third to the sixth inclusive, carries a pair of ventrally and distally articulated slender, curved spines. It is doubtful if any species of Pterygotus has spines on these appendages; certainly, in several species in which these limbs have been found apparently well preserved, they are lacking.

[1] The senior author follows Sarle in the preliminary description of the Otisville fauna in seeing in the larger preoral appendages and the marginal eyes the critical differences between Hughmilleria and Eurypterus.

Hughmilleria socialis Sarle

Plates 59–63

Hughmilleria socialis Sarle. N. Y. State Palaeontologist Rep't. 1902.
    p. 1091, pl. 6-9; pl. 10, fig. 1-6, 8, 9; pl. 11-14; pl. 15, fig. 4-6; pl. 24, fig. 1; pl. 25,
    fig. 1, 3, 4; pl. 26, fig. 3, 5

This is by far the most common eurypterid in the Pittsford shale and is the genotype and best known species. It has been as elaborately described by Sarle as its novelty, its singular features and the excellence of the material deserve. The original description is as follows:

This type is comparatively small, the length of the average individual not exceeding 15 cm. Viewed from either the dorsal or the ventral side, the outline is slenderly lanceolate. In the natural, undistorted condition, the anterior part of the body is flattened, the dorsal and ventral surfaces being slightly convex, while the caudal portion is nearly cylindric.

Cephalothorax. The cephalothorax is semielliptic or subtriangular in outline, the length equaling the breadth at the base, and comprising about one fifth the length of the entire body. Along the gently curving sides and acutely rounded front is a narrow flattened border, striated on the under surface, and not exceeding a fraction of a millimeter in breadth. The dorsal surface is slightly rounded or arched from the side to the center, so that in an undistorted shield 22 mm long, the elevation is about 2 mm. The posterior edge, except for a slight forward curve at the genal angles, is straight. The compound eyes barely break the outline of the shield; they are small, elongate, widest anterior to the middle, the outer side arcuate, the inner formed by three nearly straight edges—a short basal and a little longer anterior, forming slightly rounded obtuse angles with a long inner side. The anterior end of the eye is acute. The length of these organs on the cephalothorax, the dimensions of which were given above, is 5 mm. However, the usual proportion between the length of the shield and eye is as 1 : 4.5. A line drawn connecting the posterior ends of the eyes passes through the center of the shield. The ocelli are situated on a small tumescence cut by this line; they form two minute, ringlike prominences separated by about the length of their diameter.

Abdomen. The abdomen, at the widest point, or between the third and fourth dorsal segments, is a little wider than the base of the cephalothorax. Thus, in one animal measured, these dimensions were respectively 24 mm and 17.5 mm, in a second 23 mm and 17 mm, and in a

third 33 mm and 26 mm, probably varying somewhat according to the amount of compression and also somewhat with the animal. From this point the abdomen tapers very gradually to the telson; it is divided into anterior and posterior parts, easily distinguished by their structure. The preabdomen consists of six dorsal and five ventral, transverse plates; the postabdomen of six annulate segments and one spiniform.

Preabdomen. The first tergal plate of the preabdomen is very narrow and is overlapped by the posterior margin of the shield. Its posterior edge is slightly convex, and its ends are rounded. The second segment is twice as long as the first, its posterior edge is slightly concave along the middle portion, and the posterior angles are rounded, while the anterior are produced, to make up, as it were, for the rounding away of the preceding tergite. The succeeding tergites are very nearly equal in length, the fifth being perhaps a little the longest, and are about one third longer than the second. The posterior margins are concave as in the preceding, but straighter near the sides, forming almost right angles.

The first ventral plate, or sternite (the operculum), is one third as long as broad, and is divided along the axial line into two equal parts. These are rounded off at the lateral angles, particularly the anterior, and excavated along the median line for the reception of the opercular appendage; the posterior edges are slightly projected on either side of this, while the anterior inner angles are projected forward, forming a compound median lobe. The second sternite, in the female, is nearly as long as the operculum, and is deeply cleft for the reception of an appendage nearly equal to it in length. The sides are cut obliquely forward, making the posterior angles rather acute; the anterior angle forms small lobes, and the middle of the anterior edge is slightly produced. In the male the last four sternites, and in the female the last three, do not differ materially from the last four and three abdominal tergites. The relative position of the several plates of the sternal series to those of the tergal, is as follows: the opercular plate begins a little farther forward than the first tergite, but, owing to its greater breadth, lies beneath the line of overlap of the first and second tergites, while the second sternite lies beneath the overlap of the second and third tergites, and so on, the last sternite underlying the overlap of the fifth and sixth tergites, thus not extending as far back as the posterior edge of the sixth tergite.

Postabdomen. The first postabdominal segment consists of a tergal and a sternal portion united by their appressed pleural ends. The post-lateral angles are prolonged into short, bladelike lobes which extend alongside the following segment for fully half its length. The tergal portion is the longer, and its posterior edge forms a broad lobe; the sternal portion is short, and its posterior edge is straight, while its anterior edge extends forward to meet the last sternite of the preabdomen. The following five

segments are plain, bandlike rings, decreasing in breadth backward. In the first the breadth is considerably greater than the length; in the last, or penultimate body segment the length and breadth, in compressed specimens, are equal. The anterior end of each of these segments is marked by a groove for the attachment of the interarticular membrane.

The telson is very slenderly lanceolate, widest near the anterior end and attenuated at the tip. In length it is equal to the four preceding segments. The dorsal surface is convex, rising from sharp, lateral edges to a median longitudinal carina, which begins in the anterior part as a broad, angular prominence; the ventral surface is nearly flat or faintly convex; a cross section is thus subtriangular. Compression usually flattens the sides and thus heightens the angular appearance. The uncompressed specimen has a length of 31 mm and a greatest breadth of 7 mm.

On the ventral surface of the cephalothorax, in front, is a convex lobe or platform, the *epistoma*, from which extends a flat, tapering doublure ending in a small expansion at the genal angles. In molting and also from compression, the epistoma divided through the middle rather than along the sides.

Appendages. The *preoral* appendages are short, stout, three-jointed, chelate organs attached at the posterior border of the epistoma. The two distal joints of each form a pair of broad based, edentulous, bevel-edge pincers, in the ordinary state of compression having a breadth equal to one half the length. The blades are about equal in length to the basal portion and meet at the very acute, slightly curved tips and again, usually, only near the base. There is considerable variation in the relative form of the pincers, as shown on plate 11. The broad basal joints are about one fourth longer than the pincers, widest near the base and longest on the inner side, and in the natural position extend beyond the anterior margin of the shield for about one third their length. The pincers articulate with this joint in such a way that, when folded backward, they cross it obliquely, and their tips converge a little in front of the mouth; when extended forward, they diverge somewhat. The preoral appendages could also be turned back to their full length over the mouth, the pincer tips then overlapping the metastoma. In an individual having a cephalothorax 22 mm long, the preoral appendages are 10 mm long.

The four pairs of *endognathites*, or crawling legs, do not differ materially from one another except in length. The anterior limbs are somewhat shorter than the extended preoral appendages, and their tips extend but very little beyond the margin of the shield. Each succeeding pair is about one half longer than the preceding, so that the last limbs are probably four times as long as the first. All have seven joints, of which the terminal is spiniform. The third to the sixth joints inclusive carry ventrally and at the distal ends a pair of striated, slightly curved, slender spines. The

inner spine of each pair is the longer, and the length increases for each successive set, from the third to the fifth joints; the spines on the sixth are short. The coxal joints are elongate, slightly curved, widest at the base and equal in length to the succeeding two joints. They increase in length with each successive pair, and bear on the inner end a series of 15 or more, sharp, curved teeth, which decrease in size from the front. On each of the fourth coxal joints is a large perforation of the upper side near the fixed end. No epicoxite has yet been observed. The second joint of the endognathite is divided by constrictions into three transverse sections. It is articulated at the fixed end of the coxal joint and is fully two thirds as wide.

The limbs of the sixth pair are narrow and paddlelike, and consist of eight joints and a rudimentary ninth or claw, the seventh and eighth forming a slightly expanded blade. The seventh carries a large, sub-triangular, lobelike plate, nearly one half as long as the joint proper, marked off from the inner, distal end by a suture. The eighth, or palette, is elongate oval with the margin finely incised, and carries the minute claw inserted in a notch on the inner side near the tip. On the dorsal surface of the seventh and eighth joints, at the proximal end and outer edge of each, is a group of minute, craterlike tumescences, which were probably receptacles for the bases of hairlike bristles. In a swimming arm 29.5 mm long, exclusive of the gnathobase, the narrowest joint or the fourth, measures 5 mm across; from this point the arm gradually enlarges to 6.8 mm on the seventh and eighth joints. When the swimming arms are turned back, they reach the line of the fourth or fifth dorsal segment. The gnathobases have the form of an upright retort. The inner extremity of each is provided with from 18 to 20 sharp, slightly curved teeth, which become finer posteriorly. A gnathobase, accompanying a cephalothoracic shield 22 mm. long, is 16 mm long; the width of the narrow necklike portion 6 mm; the width at the base 13 mm.

The *metastoma* is elongate cordate, the greatest breadth coming anterior to the middle. The smaller, or posterior end, is truncated and has rounded corners. The anterior notch is rather deep and broad. A comparison of the length to the greatest breadth of several metastomas gives the proportion of 2 : 1. In an individual having a cephalothorax 23 mm long the metastoma is 16 mm long.

The *genital appendage* differs noticeably in the two sexes. In the female it consists of two parts, one carried by the operculum, the other by the second sternite. The opercular appendage is a slender, sagittate-based, convex, scalelike sheath projecting for about one fifth its length beyond the posterior edge of the operculum and appearing to be formed by the fusion of two parts. The anterior of these includes the sagittate base and a narrower, more convex portion with a flattened border on

either side. Its distal end is reentrant and fused to the posterior part. This part is a little narrower, slightly tapering and beveled in from either side·for one fourth the breadth, to the sides of a slightly raised platform which is flat-topped for the greater part of its length, but becomes concave posteriorly, forming a shallow groove at the abrupt end. The terminal angles are noticeably truncated. The appendage carried by the second sternite is partially covered by that of the operculum. It is very slender, its greatest breadth not exceeding one sixth the length. The anterior half is sublanceolate with a triangular base; the posterior is attenuate and terminates just within the end of the cleft. In the male the appendage is simpler and confined to the operculum, the following sternite being entire. It is wider and somewhat shorter than that of the female, the average length being only about two and one half times the breadth. It is convex, broadly lanceolate and slightly produced at the posterior free end which just clears the edge of the operculum. A specimen in which a portion of this organ is scaled away gives a cast of the interior showing small elevated lines radiating from near the center backward, and may possibly represent part of the vascular, or duct system of this organ. The two sexes are about equally represented in numbers.

The whole surface of the body is covered with imbricating, crescent-like or angular scales, sometimes carrying smaller ones of the same pattern. These scales are so minute on certain areas as to appear almost obsolete. They are most conspicuous on the ventral side of the preabdomen and appendages. On the cephalothorax and abdomen the scales point backward, on the paired appendages toward the distal end, and on the epistoma, forward.

This singular creature has the appearance of an Eurypterus with the carapace of a Pterygotus. The Pterygotuslike aspect of the carapace is principally due to the marginal position of the compound eyes.

Another character worthy of mention is the ornamentation,[1] which consists of flat, imbricating scales that are crescentlike near the anterior margin and become angular posteriorly. They are evenly distributed over the entire body, carapace [pl. 60, figs. 6, 8], endognathites, metastoma, operculum and its appendages, save the telson where they have not been observed. On the distal segments of the endognathites they appear as small tubercles.

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[1] It is drawn too coarse on the original figures here reproduced and would hardly be noticeable in natural size drawings.

The telson agrees in its slender, spinelike outline with that of Euryp-
terus. But while that of Eurypterus is flat on the dorsal side and bears
a carina on the ventral side, that of H. socialis is flat on the
ventral side and carinate on the dorsal.

Horizon and locality. Pittsford shale at Pittsford, N. Y.

Hughmilleria socialis var. robusta Sarle

Plate 63, figure 16

Hughmilleria socialis var. robusta Sarle. N. Y. State Palaeontologist
    Rep't. 1902. p. 1097, pl. 21, fig. 1, 2

A few fragments have suggested the presence of a larger variety of
socialis in the Pittsford shale on which the following notes were made
by Mr Sarle:

What appears to have been a varietal form of Hughmilleria
socialis is represented by a nearly entire abdomen, two first ring
segments and an imperfect metastoma.

The features which distinguish this form are: its larger size; pro-
portionately much greater breadth; the greater convexity of the dorsal
posterior edge of the first ring segment and, in some cases, the division
of this edge into two, broad smooth lobes; the more noticeable contraction
of the abdomen at the second ring segment; and the more rotund form of
the metastoma.

The abdomen found lies in the shale dorsal side up, showing the
anterior nine segments well preserved. The second and third ring seg-
ments are partially disconnected. The breadth of the preabdomen at the
widest point, or between the third and fourth segments, is 51 mm,
its length 56 mm, the breadth of the first ring segment is 42 mm, of the
second 30 mm. The dorsal posterior edge of the first ring segment is
entire and very noticeably convex. In each of the isolated ring segments
a broad, deep notch produces a bilobation of this edge. A line of pittings
close to this edge shows this feature to be natural. The proportions of the
most perfect of these segments are: breadth 43 mm length of the dorsal
side 22 mm, length of the ventral 11 mm, length of the postlateral lobes 8
mm. The metastoma associated with one of these segments is apparently
of a smaller individual and lacks the anterior notched end. At the widest
part it measures 14 mm, and from there to the posterior end, 14 mm.

It was at first thought that the distinctive features of these specimens
might be merely old age characters of H. socialis, but larger indi-
viduals of that species seem to show the same relative proportions as the

smaller. However, it is considered that the differences shown by the incomplete material of the collection are not, of themselves, sufficient to warrant the founding of a distinct species.

We have not obtained any further material that would qualify the inferences here set forth.

Horizon and locality. Pittsford shale at Pittsford, N. Y.

Hughmilleria magna nov.

Plate 85, figs. 11-19

Description. Carapace semielliptic, length and basal width subequal, lateral margins gently curved, subparallel, frontal margin bluntly angular so as to form a triangular front to the carapace. Posterior margin straight transverse or very slightly concave; genal angles roundish rectangular.

Lateral eyes large (a little more than one third the length of the carapace), submarginal, oval in outline. Ocelli subcentral, their tumescence between the posterior ends of the lateral eyes.

No ornamentation has been observed on the carapace.

Horizon and localities. Frankfort shales. The great majority of the specimens are from the Dettbarn quarry at Schenectady, where in one layer the species is quite common. A few carapaces have also been found at Duanesburg and Rotterdam Junction, Schoharie county.

Remarks. The form of the carapace is subject to much variation in outline, obviously through the stretching and wrinkling of the thin, drifted integuments in various directions. The carapace selected as the type [pl.85, fig. 11] is smooth and but little distorted. When the test is completely flattened out, the lateral eyes are seen to be separated from the margin of the carapace by a narrow strip, half as wide as the eye, contracted forward and broadening backward as in the genotype.

The type measures 17.5 mm in length and 20 mm in width. The eyes are 7 mm long. Several carapaces indicate that this species reached much larger dimensions than its supposed later allies. The original of plate 85, figure 16 is 58 mm wide and 42 mm long. Its lateral margins are completely flattened out and the specimen somewhat compressed in the axial direction.

Besides the carapaces, on which the species is based, a half complete specimen [pl. 85, fig. 13] has been obtained. This exhibits a form of the preabdomen corresponding to that of H . s o c i a l i s , the genotype, if the slight axial contraction of the specimen is taken into account. The swimming leg of the right side can be distinguished in its outline. It is relatively longer than that of H . s o c i a l i s .

Besides the carapaces two detached chelicerae resemble in their strong development and long pointed pincers more those of Hughmilleria than of any other genus [pl. 85, fig. 17, 18] and also detached body rings [pl. 85, fig. 19] exhibit a type of ornamentation, consisting of transverse lines near the anterior margin, known to us only in H . s h a w a n g u n k , the Otisville representative of the genus.

Hughmilleria shawangunk Clarke

Plates 64-66; 69, figure 1

H u g h m i l l e r i a   s h a w a n g u n k   Clarke. N. Y. State Mus. Bul. 107. 1907. p. 308, pl. 4, fig. 1-4; pl. 5, fig. 1-9

Description. H u g h m i l l e r i a   s h a w a n g u n k attains but half the size of the genotype, or about 8 cm and is therefore one of the diminutive species of eurypterids. In outline of body and form of head it closely resembles H . s o c i a l i s ; it is slender and terete, but slightly wider in the middle of the preabdomen than at the base of the carapace, and lacks any marked contraction from preabdomen to postabdomen. With the anteriorly rounded, subtriangular carapace and marginal eyes, the dorsal aspect of the animal is singularly fishlike and suggestive of great agility.

Cephalothorax. The carapace is semielliptic in the mature form, wider than long by one sixth to one fifth, comprises one fifth the length of the body or more; as preserved it is subject to great variations in outline, mostly due to variously directed compression and wrinkling after entombment and to an originally thin test. The lateral margins of the carapace are slightly convex, the frontal part acutely rounded. The

posterior edge is very gently concave forward, nearly straight. The dorsal surface was uniformly and strongly convex, culminating between the lateral eyes and somewhat impending along the sides. A narrow flat border surrounds the lateral and frontal margins. The compound eyes are of medium size (one fourth to one fifth of length of carapace), intramarginal in position, separated from the margin by an interval nearly as wide as the eyes themselves. On account of the position of the eyes on the impending sides of the carapace, however, they appear in most compressed specimens to be marginal [pl. 64, fig. 13; pl. 65, figs. 1, 6, 9]. They are placed so far forward that they are distant only their own length from the foremost point of the carapace. The form of the ocular node resembles that of an elliptic sector, the outer margin being rounded and the inner margin angular or composed of two, frequently unequal radii, the anterior being the longer. The anterior end of the node is acute, the posterior rounded. The node is so slightly prominent that the eyes hardly project beyond the outline of the carapace. The visual surface is crescentlike with somewhat swollen extremities [pl. 65, fig. 10] and situated along the outer edge of the ocular node. The ocelli are distinct, separated by the length of their own diameter, and situated on a flat circular tumescence that lies on a line connecting the inner angles of the compound eyes.

Abdomen. The abdomen is slender, increases slightly in width to the fourth dorsal segment and then tapers very gradually to the telson. Its greatest width is about one fourth the length of the body.

Preabdomen. The tergites [pl. 66, figs. 6, 8, 11] are narrow, subrectangular bands with anterior and posterior margins straight or but slightly bent forward, three to four times as wide as long, save the first which is six and one half times wider than long, or in other words, is a very narrow band. The anterior edge of the latter is straight, the posterior gently concave. The antelateral angles are broadly rounded and produced forward and the postlateral angles slightly extended posteriorly so that both extremities of this segment are widened. In the following

tergites the antelateral lobes are very small [pl. 66, fig. 6] or altogether absent in the last.

The opercular plate has not been observed. The sternites [pl. 66, figs. 7, 10] are longer than the tergites, their anterior and posterior margins similarly subparallel and curve gently forward. The antelateral angles are furnished with blunt triangular lobes while the postlateral angles are well rounded.

Postabdomen. The postabdominal segments [pl. 66, figs. 5, 9] are annular, gradually increase in length and decrease in width posteriorly, so that while the first is three times as wide as long, the last is about as long as it is wide at its proximal articulation. The postabdomen is about one third of the body in length and decreases by one half its width from the first to the sixth segment. The first [fig. 5] postabdominal segment is produced into long bladelike lobes which attain nearly half the length of the segment; the others [pl. 66, fig. 9] possess only small acute postlateral lobes. The posterior doublure is distinct and occupies about one fourth the length of the segment.

The telson is identical with that of H . s o c i a l i s ; it is lanceolate, relatively short (not one fifth the length of the body) and apparently convex on the upper and flat on the under side. It is slightly contracted at the proximal end and widest at about one third of its length. The dorsal surface carries a median carina which begins a little behind the anterior edge of the telson and continues to the point. The lateral edges are sharp and furnished with a thickened, flat border.

Appendages. Our knowledge of the appendages of this species is still very incomplete as but very few entire specimens have been obtained and they show only traces of these organs. The crawling legs appear to have been both short and slender as in H . s o c i a l i s . The swimming legs have been seen in two specimens [pl. 65, figs. 6, 8]. They are small (extending when reflexed to the fourth tergite) and slender. The fourth, fifth and sixth articulations are nearly equal in length, and gradually widen. Their distal edges are lobed or fringed. The seventh and eighth

segments form a slightly expanded oar plate, the seventh being slightly longer than the eighth and bearing a large distal lobe on the inner side. The eighth segment is oval in form, its distal end distinctly acute with a small terminal subcircular ninth segment [pl. 65, fig. 8].

The coxa of the last pair of legs is probably represented by figure 1, plate 66, for these bodies show the outline of the corresponding organ in the genotype and possess a system of fine anastomosing lines characteristic of the sculpturing of H . s h a w a n g u n k . Sarle compares the shape of this coxa in H . s o c i a l i s to that of an upright retort and records the presence of 18–20 sharp, slightly curved teeth on the manducatory edge. The coxa here figured exhibits a stronger neck and longer manducatory edge, but exactly the same number of teeth. Another coxa, reproduced in the preliminary paper [*op. cit.* pl. 8, fig. 10] also possesses a system of fine lines as shown in our figure [pl. 66, fig. 2] but is of more compact form and with shorter neck and smaller number of teeth, the first of which is longer than the rest. This is possibly the coxal joint of an endognathite.

The metastoma has not been seen well preserved in position, but we refer several metastomas to this species [pl. 66, figs. 3, 4] because they possess, on one hand, the form of that in H . s o c i a l i s and on the other exhibit a peculiar striated ornamentation apparently characteristic of H . s h a w a n g u n k . These metastomas are elongate cordate, broadest anteriorly to the middle, with cordate or deeply notched anterior and an evenly rounded posterior extremity in some and a truncated one in other specimens.

The genital appendages have not been seen.

The *ornamentation* is most characteristic. It consists on all segments of a series of fine striae, running parallel to the anterior margin, most crowded near this margin, farther apart and fainter posteriorly, disappearing at about the middle of the segment, save on the postabdominal segments where they can be traced to near the posterior edge. Near the lateral edges of the tergites they bend sharply backward, finally coalescing with the border and gradually disappearing. On the sternites

another characteristic set of striae is added posteriorly of the frontal set. The second set consists of curving striae running obliquely backward and inward from the antelateral angles and lateral margins [pl. 66, fig. 10] and connected by anastomosis with the frontal parallel line. Along the lateral margins they are dissolved into a meshwork of lines. Like systems of lines appear on the metastoma, where they pass transversely across, with a slight forward convexity, and on the coxa where they strongly anastomose. The coxal segments and the metastoma were also furnished with a fine striation.

Ontogeny. The ontogeny of H . s h a w a n g u n k is well shown in the small series of individuals reproduced on plate 64. The most interesting of these specimens is the original of figure 1 which is but 2 mm long and very distinct. This larval form is a clear representative of the nepionic growth stage. It still lacks two, possibly three, segments of the full complement of twelve. Its most important feature is the remarkable general similarity to the mature stage of the species, in the slenderness and form of body, form of carapace and eyes and position of the latter. Its most distinctive larval characters are (1) the relatively greater size of the carapace, (2) the relatively great size of the compound eyes, (3) the smaller number of segments.

The carapace in the nepionic stage attains one fourth the length of the body, while in the ephebic stage it reaches only one fifth. The head is also broader than the rest of the body while in the mature specimens the greatest width is reached in the middle part of the preabdomen. It also seems that in this and the following growth stages the head is relatively somewhat shorter in outline than in mature forms (by about one eighth of the width) and slightly more rounded in front.

The compound eyes do not differ in location from those of the mature individuals, being intramarginal and separated by a small interval from the margin, but they are markedly larger, occupying one half the length of the carapace as compared with one fourth to one fifth in the mature stage. They are likewise distinctly more prominent; at least in the specimens representing the neanic stage.

There are nine distinct segmental division lines in the nepionic spec-imen, indicating the presence of nine segments, with possibly a shorter tenth one directly behind the head. There is a slight break in the outline at the end of the third segment, the fourth setting in a little further. This feature suggests that the postabdomen was already complete and con-sisted of six segments, while the preabdomen possessed thus far only three to four segments. This inference is supported to some extent by the fact that the postabdominal segments already exhibit the proportions of the mature forms in their gradual narrowing and lengthening. It is there-fore probable that the new segments, at least the tergites, are added in successive moltings in the preabdomen, perhaps directly behind the cara-pace, as in the trilobites; or in other words, that the head and tail appear first and the thorax is completed gradually.

The swimming legs are also shown in the nepionic specimen. They are relatively shorter and broader than in the mature age.

The telson spine is of the same form and proportion to the body as in the ephebic stage.

The neanic stage is represented by the originals of the figures 1-11, 13. The first two of these are fair representatives of the earliest neanic (ananeanic) stage. They still retain the nepionic pro-portions of the carapace while the eyes have already been reduced to about one third of the length of the carapace, but are still distinguished from the ephebic eyes by their greater prominence. The large size of the ocellar mound and the distinctiveness of the ocelli themselves are also a characteristic feature of this stage [figures 1-3]. The carapace is surrounded by a thick, flat border in these specimens, possibly the doublure of the underside, exposed by the breaking away of the upper margin. The preabdomen is complete in one of the two specimens and remarkable for its uniform width which is equal to that of the base of the head. As specimen figure 13 shows, this width still remains nearly uniform in individuals a little older, while a somewhat abrupt reduction takes place to the postabdomen at the first postabdominal segment.

This is the first stage in which the fine transverse sculpture lines could be recognized [pl. 64, fig. 5].

Horizon and locality. This species is one of the most common forms in the fauna of the Shawangunk grit at Otisville, N. Y.

Remarks. H. s h a w a n g u n k differs from the genotype in its smaller size, somewhat broader carapace and most distinctly in the surface sculpture which is characterized by parallel, transverse striae, · absent in the other species.

Genus PTERYGOTUS Agassiz

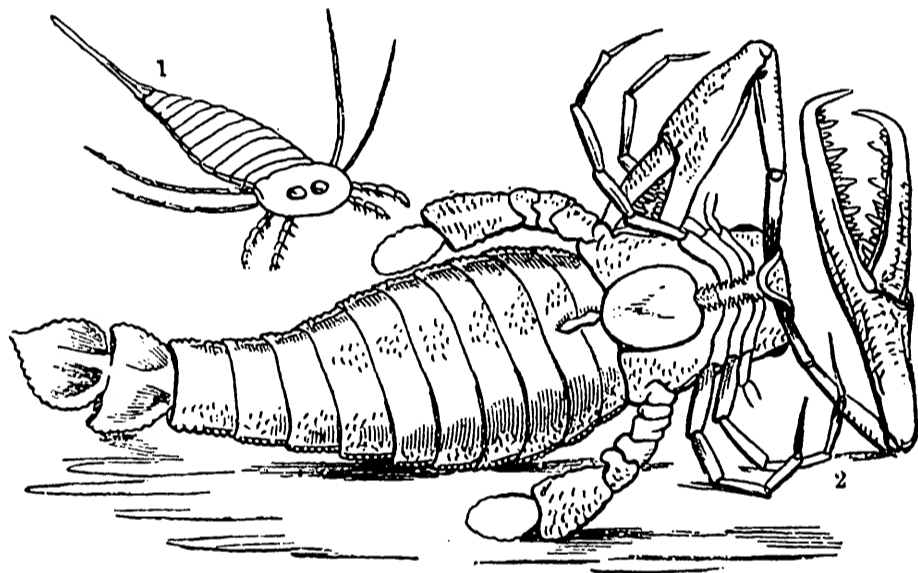Pterygotus will always be historically associated with the rocks of Scotland which carried the " seraphim " of the quarrymen, the type of Agassiz's P. a n g l i c u s, and later afforded the material for the monographs by Huxley and Salter [1859] and by Woodward [1866]. The British rocks have altogether yielded nine species of Pterygotus, two of which, P . a n g l i - c u s and P . b i l o b u s, are known in complete specimens. The fragments of several of these species have left

Figure 70 Restorations of S t y l o n u r u s p o w r i e i (1) and P t e r y g o t u s a n g l i c u s (2) in Page's Introductory Text-book of Geology. ed. 5. 1859. p. 71

no doubt that the individuals attained gigantic proportions and surpassed all other then known Merostomata in size. Schmidt's work [1883] on the merostomes of the Eurypterus beds of Oesel contains a very elaborate description of the Pterygotus, P . o s i l i e n s i s, and corrects several misconceptions of the preceding authors in regard to the structure of the genus. Above all it established the number of walking legs to be four pairs, Woodward having assumed but three, and it recognized the proper position of the epistoma. Ten years after Schmidt's publication

Laurie discovered the epicoxite and the second (female) form of the opercular appendage. The New York rocks furnished to Hall only fragments of the genus on which he based three species, P . c o b b i , P m a c r o p h t h a l m u s and P . o s b o r n i . The waterlime quarries at Buffalo have since afforded somewhat more extensive series of these remains, some of the specimens excellently preserved. Grote and Pitt [1877] and Pohlman [1881–86] made use of some of these, basing thereon descriptions of six alleged species, all of which have proved to belong to two forms, Hall's P . c o b b i and a new type, here recognized as P . b u f f a l o e n s i s (Pohlman). A fossil from the same locality described by Pohlman as a Ceratiocaris, is the telson of a gigantic Pterygotus (P . g r a n d i s). Finally the Pittsford shale, the dark shale of the Shawangunk grit, and the Frankfort shale, have furnished representatives of other species, viz, P . m o n r o e n s i s , P . g l o b i - c e p s , P . p r o l i f i c u s and P . n a s u t u s , all of them as yet very incomplete. As Hall's species P . o s b o r n i has proved to be a synonym of his P . m a c r o p h t h a l m u s , there remain out of the considerable number of proposed species of Pterygotus from the New York rocks, only eight whose differentials can now be regarded as satisfactorily determined, viz:

P. macrophthalmus *Hall*   P. grandis (*Pohlman*)

P. cobbi *Hall*   P. monroensis *Sarle*

P. buffaloensis (Pohlman) *Clarke & Ruedemann*   P. prolificus *nov*.

P. globiceps *nov*.   P. nasutus *nov*.

On this continent no Pterygoti have been found outside of New York and only two of the New York species (P . m a c r o p h t h a l m u s and P . b u f f a l o e n s i s) are known in entire specimens, all the others being based on carapaces, chelae or telsons. The material of these two species, however, is so complete that it has allowed a detailed description of the forms and some additions to our knowledge of the structure of the genus. Among these is the demonstration of the identity of the structure of the " chelate antennae " of Pterygotus with the chelicerae of Eurypterus and their composition of but three segments (as already suggested by Laurie) instead of eight as formerly assumed; the demon-

stration of the identical structure of the compound eye of Pterygotus with that of Limulus and the determination of the endostoma.

The characteristics of this genus consist in the lack of distinct differentiation of the body into preabdomen and postabdomen; the large size of the compound eyes, their marginal position and distinct facets; the presence of a distinct epistoma, the enormous development of the preoral, chelate appendages, the slenderness and lack of spines on the four pairs of walking legs, the heart-shaped, deeply emarginate metastoma and the broad telson.

Huxley and Salter placed P. bilobus in a separate subgenus, Erettopterus, on account of its bilobed telson. While some have recognized this group as a distinct genus, others have not given it even subgeneric rank. Laurie states that the species with such telsons "might fairly be separated from the rest as a subgenus, were it not that the frequent absence of the tail would make such an arrangement highly inconvenient." In our view the recognition of a natural group can not be a matter of convenience, but is of necessity, when the differences are recognized as subgeneric in rank. Erettopterus is represented in our Siluric rocks by P. grandis of the Bertie waterlime, P. globiceps of the Shawangunk grit and certain telsons from the Frankfort shale.

The presence of Pterygotus in the North American Devonic has been shown by Logan, Billings and Clarke, in the Grande Grève limestone (Lower Devonic), by Dawson in the Gaspé sandstone, by Clarke in the Dalhousie formation and by Whiteaves in the Upper (?) Devonic at Campbellton. All these remains from Eastern Canada are fragmentary and only those of Campbellton have justified description (P. atlanticus).

Pterygotus macrophthalmus Hall

Plate 69, figures 2–7; plate 70, figures 1, 2; plate 71

Pterygotus macrophthalmus Hall. Palaeontology of New York. 1859.
3: 418*, pl. 80A, fig. 8, 8a
Undet. crustacean. *Ibid.* pl. 80A, fig. 6
P. osborni Hall. *Ibid.* p. 419*, pl. 80A, fig. 9

Description. *Cephalothorax.* Outline of carapace or cephalothoracic shield semielliptic. In the type of the species, the carapace of a young

individual, the lateral margins converge but slightly forward; the anterior angles formed by the projecting eyes and the anterior margin being well rounded. In mature carapaces the lateral and anterior margins are less rounded and more nearly straight, the lateral margins subparallel. The posterior edge is slightly incurved. The surface is very gently convex, and seems to have been originally rather uniformly, but very moderately, elevated with a slight depression along the medio-anterior margin of the compound eyes. The latter are subelliptic, very prominent, project beyond the margin of the carapace and are located at the antelateral angle of the cephalothorax. Their length is nearly one half that of the lateral margin of the cephalothorax; their distance from each other is distinctly less than the length of the eye. As more fully stated in the generic description, the compound eyes are entirely smooth in their exterior view, the facets becoming visible only when the exterior layer of the cornea has become split off or on an interior view. The facets are small and squarish in shape. The ocelli are borne on a small oblong or rhomboidal tumescence, situated in a line connecting the bases of the marginal eyes, and sometimes prolonged posteriorly in a crest. The ornamentation consists of an extremely fine granulation evenly distributed over the carapace, becoming coarse between the compound eyes.

A relatively narrow doublure surrounds with uniform width the frontal and lateral margins of the cephalothorax. The doublure at the base of this shield is three times as wide; it follows the entire posterior margin, thus making the doublure ring complete.

Abdomen. The abdomen widens to the third or fourth dorsal segments, where, in mature individuals, it seems to have been wider by one fourth than the base of the cephalothorax. From this point it tapers very gradually to the telson.

Preabdomen. The first of the six tergites is shorter by one half than the following ones. It is a narrow band, rather strongly curved forward in the middle portion and rounded at the ends. The following tergites are relatively broad, their length amounting to one third cf their width.

The middle portion forms a broad lobe while the pleurae or epimera are projected forward somewhat more abruptly   The fifth tergite is the widest, while the fourth and sixth tergites are about equally long; the fifth surpassing the other two but very little.

Along the posterior margin extends a broad doublure, amounting to one third the length of the tergite, bending forward at the postlateral angles, thence rapidly narrowing and ending a little behind the ante- lateral angle.   Each anterior tergite overlapped the following one to an amount equal to the width of the doublure.

Such well developed " ears " at the antelateral angles as are figured by Woodward (P . a n g l i c u s) and Schmidt (P . o s i l i e n s i s) have not been observed by us, but our evidence on this point is rather scanty and the following sternites of this species have been seen only in frag- mentary condition.

Postabdomen. The five first postabdominal segments are, on the whole, simple broad rings, indicating that the original form of the post- abdomen approached a conical shape with circular sections.   There existed, however, a slight flattening along the lateral lines, in continuation of the pleurae or epimera of the tergites.   The edge of these alae, at least in the fourth and fifth segments, is thickened and provided with a somewhat coarser sculpture.   The anterior and posterior margins are practically straight with a slight protrusion of the antelateral corners.   The doub- lure of the posterior margin is narrow.

The sixth postabdominal segment differs materially from those pre- ceding both in shape and size.   It is longer by one third to one half than the penultimate segment, possesses more convex lateral margins, which are serrate on their posterior half, and indications of a dorsal median crest extending over the posterior half.

The telson is obovate, one sixth longer than wide in mature speci- mens, and one fourth longer in young ones.   It surpasses the ultimate segment in length by nearly one half but equals it in width.   It is strength- ened by a thick ridge along the middle line which runs out into a blunt

posterior spine. The lateral margins are smooth anteriorly, but bear on the posterior part irregular serrations, which increase in size posteriorly and along the posterior edge consist characteristically of an alternation of one large serra with three or more minute denticulations. The ventral side of the telson was apparently provided with a less prominent keel, though the evidence on this point is not very conclusive.

Appendages. The epistoma, with one of the marginal shields adhering, has been found in one example [pl. 71, fig. 3]. It is a four-sided plate, bounded by a convex anterior, a deeply emarginate posterior, and two broadly concave lateral margins. It is separated by a suture from the triangular marginal shield. Its sculpturing, consisting of crescentic scales with the convexity turned forward, is distinctly seen and verifies by its direction Schmidt's inference that the epistoma, like the marginal shields, originates from extensions of the marginal doublure of the carapace.

The *preoral appendages* or *chelicerae* have been found in only one case in connection with the body [pl. 70, fig. 1]. They are in all particulars identical with the more fully known chelicerae of the closely related P . b u f f a l o e n s i s , with the exception of the less prominence of the distal point of the free ramus, thereby indicating a slight approach to P . c o b b i . Professor Hall figured a fragment of a free ramus of a chelicera on his plate 80A, figure 6, without determining its relations.

The four pairs of *walking legs* or *endognathites* are so thin and slender that they are rarely preserved. They are well seen in Hall's type of P . o s b o r n i [pl. 71, fig. 6]. Another still better preserved leg is reproduced in plate 71, figure 8. This resembles an antenna in its whip-like form and exhibits seven segments, the first two of which are short, the other long and tubular, the middle one being the longest, while of the last only a short fragment is seen. The type of P . o s b o r n i shows also traces of clublike widened coxal segments. The exact number of these we have been unable to establish. They were relatively longer and more slender than those figured in the restoration of the British forms and of P . o s i l i e n s i s .

The *swimming legs* are small as in all Pterygoti; when turned back they do not reach the anterior margin of the fourth tergite.

The gnathobase is like that of P . b u f f a l o e n s i s ; and it probably possessed a like relation in size to the swimming leg and carapace.

In regard to the other joints of the swimming leg, we may also refer to the full description of these parts in the larger species from Buffalo, there being no specific differences apparent in these organs.

The *metastoma* is elongate cordate; its greatest width, which is a little beyond the middle, is about one half the length. The anterior margin is deeply emarginate, the posterior part contracted and the posterior end somewhat acutely rounded.

The *endostoma* has not been observed [*see* P . b u f f a l o e n s i s].

The *opercular appendages* have not been preserved favorably in any of our specimens. The type of P . o s b o r n i [pl. 71, fig. 6] retains only the posterior portion of the operculum, together with the corresponding part of the opercular appendage, which indicates a short subtriangular organ that would correspond to the appendage of the male of other eurypterids. Near the broken edge the margin of an emarginate lobe is exposed and the posterior angle bears two dark spots suggestive of pores. The opercular appendage of the female has not been observed by us in this species.

The *ornamentation* agrees with that here described of P . b u f f a l o - e n s i s .

Measurements. The few fairly complete specimens at our disposal are immature individuals. The specimen on plate 69, figure 2 gives the following measurements:

Length of carapace about 25 mm
Width, about 35 mm
Length of largest tergite, 11.5 mm
Width, 44.5 mm
Length of first postabdominal segment, 11 mm
Width, 39 mm

Length of last postabdominal segment, 16.5 mm

Width, 21.5 mm

Length of telson, 33 mm

Width, 23 mm

Total length of original specimen (not distended as in fossil state), 184 mm

Largest carapace observed:

Length of carapace, 28.5 mm

Width of carapace, 40.5 mm

Length of tergite, 23 mm

Width, 73 mm

A very large tergite [text figure 71] collected at Litchfield and possibly belonging to this species, has a length of 10 cm and a width of about 37 cm.

The largest telson observed measures:

Length, 60.5 mm

Width, 49 mm

This telson, which undoubtedly belongs to P. macrophthalmus, indicates that the species attained at least twice the size of the complete individual represented on plate 69, figure 2 or a length of a foot and a half. If the large tergite from Litchfield belonged to this species, the animal reached a size of about 1.65 m or 5 feet, 5 inches.

Remarks. The species P. macrophthalmus was founded upon the carapace of a young individual from the waterlime at Litchfield, Herkimer co., N. Y. At the same time a specimen lacking the carapace, and showing only four segments of the abdomen and the ventral side of the cephalothorax was made the type of another species, P. osborni. This specimen came from the same horizon, and a locality a few miles distant from Litchfield, viz, Waterville, Oneida co. A separate metastoma [*op. cit.* pl. 80A, p. 16] of the same shape as that shown in the type of P. osborni was also referred to the latter species.

While it was the correct procedure to erect different species for the carapace and the abdomen as long as the parts had not been found con-
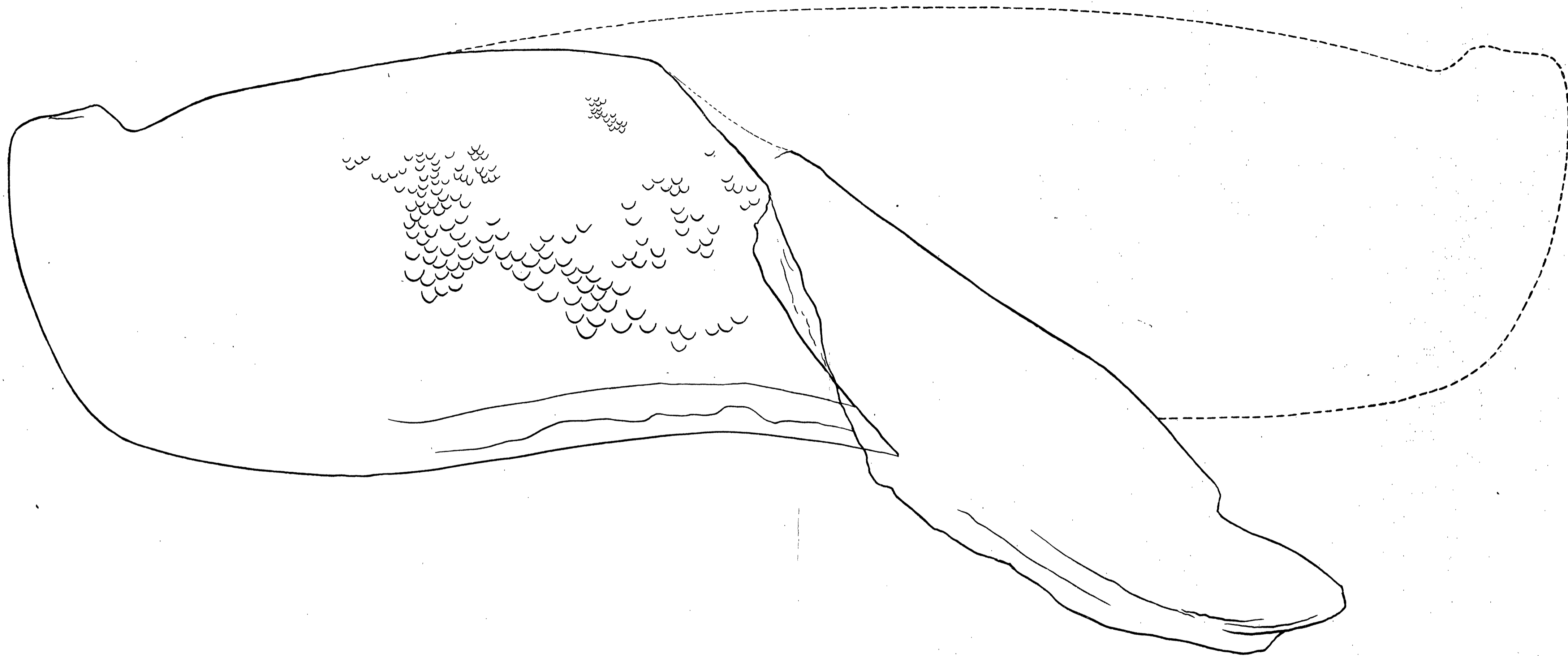
Figure 71 Pterygotus cf. macrophthalmus Hall. Outline of tergite from Litchfield, N. Y. Natural size

nected in the same specimen, our larger collection of individuals in various growth stages and states of preservation leaves no doubt that the types of both belong to one species, which must be named P . m a c r o p h t h a l - m u s , as the latter precedes the other in the original descriptions and is better characterized by being based on a carapace. Professor Whitfield's accurate drawings show all essential features of the type specimens of P . m a c r o p h t h a l m u s . We may add that Hall's figure 6, plate 80A, which is described as " a fragment of a crustacean associated with the E . r e m i p e s at Waterville, the relations of which have not been determined " is the broken fixed ramus of the pincers from a young individual of P . m a c r o p h t h a l m u s .

P t e r y g o t u s m a c r o p h t h a l m u s is quite distinct in its characters from all the European species. It is closely related to P . a n g l i c u s , in the similar form of the telson, but it is readily distinguished from the British type by characters of its own. One of these is the fishhooklike form of the extremities of the chelae and the different direction of their teeth. These features, at least the form of the distal ends of the chelae, are approached by P . o s i l i e n s i s , a species with widely different telson.

Pterygotus atlanticus nov.

Plate 79, figures 3–5

P t e r y g o t u s sp. Whiteaves. Canadian Naturalist. 1883. 10: 100

Remains of Pterygotus recorded from several Devonic horizons of eastern Canada have been briefly referred to on a previous page.

Billings, in Logan's *Geology of Canada*, cited their occurrence at Cape Bon Ami, Gaspé; the single specimen, however, proves to be not from the Bon Ami beds, but from the higher or Grande Grève limestone of the Lower Devonic. This specimen is a fragment of two abdominal segments, together having a length of 75 mm and covered with closely crowded, very coarse scales curved into the arc of a circle. It indicates a species of rather commanding dimensions. Sir William Logan also reported the

presence of Pterygotus remains in the Gaspé sandstone, though these were described by Dawson as plants of the genus Selaginites [*op. cit.* p. 399]. Remains of Pterygotus have also been found in the lower marine Devonic Dalhousie beds of Dalhousie, N. B., in fragments which appear to have been washed seaward of their proper sites. Near Campbellton, N. B., in indurated limestones containing fish remains of probable Upper Devonic age, are also such remains, which were first noted by Whiteaves when describing the fish fauna of this locality.

Fragments, presumably of Pterygotus, have been reported from the Lower Devonic[1] of the Knoydart formation, Arisaig, Nova Scotia, where they are associated with fish remains of the genus Pteraspis and Cephalaspis.[2]

All of the occurrences referred to have been more or less particularly noticed by Clarke in *Early·Devonic History of New York and Eastern North America*, but only that at Campbellton has furnished material adequate for description. This original material consists of a suite of three specimens, now in the Victoria Memorial Museum at Ottawa. These are a free chela, the coxa of a swimming leg and a small portion of a metastoma bearing traces of ornamentation. The chela is of slender form, straight, tapering regularly to the apex which is not preserved. The length is 50 mm, its proximal width, not counting the articulating process, is 9 mm, its distal width, at the point of fracture, about 3 mm. The ramus is but little compressed, its section irregular and convex, the greatest thickness being near the inner edge, whence the ramus abruptly narrows down to the dentate edge, and more gradually to the outer edge. The teeth are in two series, one of more numerous small sharp points, and one of larger distinctly furrowed teeth, the two

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[1] The Knoydart formation, so named by Ami, is regarded by Fletcher as of Upper Devonic age. On the basis of the fish remains Dr Smith Woodward correlated these sandstones with the Lower Devonic Hereford beds. Further investigation will be required to fix their relation to the fish beds of Campbellton, N. B., and Migouasha, Quebec, which are now regarded as of later Devonic age.

[2] *See* Ami. Geolog. Soc. America Bul. 12 : 301-12. 1901; Twenhofel. American Journal of Science, Aug. 1909; Williams, M. Y., Geol. Surv. Canada Rep't, 1911, p. 244.

series, however, not being sharply separated, and the larger series being surpassed by one tooth of much greater dimensions. The coxa indicates a large specimen; its manducatory edge is 38 mm long and bears a series of 13 stout, blunt teeth. The other specimen is probably a fragment of the posterior half of the metastoma, with its counterpart, showing the characteristic semicircular scales of Pterygotus.

These fragments point to a species of considerable dimensions, and all bear a distinct similarity to the corresponding parts of the giant P t e r y g o t u s   a n g l i c u s of the British Old Red sandstone. There is still a differential element present in the regular tapering of the chela and the presence of a greater number of smaller teeth in the American type, both features recalling P .   b i l o b u s . As the Devonic beds at Campbellton are believed to correspond in their facies and age to the Old Red sandstone of Europe, the similarity with P .   a n g l i c u s is quite suggestive. Probably with larger collections this species may prove to be a vicarious form of the British type.

Pterygotus buffaloensis (Pohlman) emend.

Plate 57, figure 3; plates 67, 68, 72–80

? P .   c u m m i n g s i Grote & Pitt. Buffalo Soc. Nat. Sci. Bul. 1877. 3: 18, fig. 1

P .   b u f f a l o e n s i s Pohlman. *Ibid.* 1881. 4: 17, fig. 1-3

P .   s p .   (c u m m i n g s i ?) Pohlman. *Ibid.* p. 18, fig. 4

P .   a c u t i c a u d a t u s Pohlman. *Ibid.* p. 42, pl. 2, fig. 3

P .   q u a d r a t i c a u d a t u s Pohlman. *Ibid.* p. 43, pl. 3, fig. 1

P .   ? s p . Pohlman. *Ibid.* p. 44, pl. 3, fig. 2

P .   m a c r o p h t h a l m u s ? Pohlman. *Ibid.* p. 44

P .   b u f f a l o e n s i s Pohlman. *Ibid.* 1886. 5: 24, pl. 3, fig. 1

P .   b i l o b u s (Huxley & Salter) Pohlman. *Ibid.* p. 27

P .   b u f f a l o e n s i s ,   q u a d r a t i c a u d a t u s ,   c u m m i n g s i Laurie. Roy. Soc. Edinburgh Trans. v. 37, pt 2, 1893, p. 515, 517

P .   b u f f a l o e n s i s Semper. Beitr. z. Pal. u. Geol. Oesterr.-Ung. u. d. Orients. 1898. 11 :74 *et seq.*

P . b u f f a l o e n s i s Clarke. Zittel-Eastman, Textbook of Pal. v. 1, pt 2, 1900,
   p. 678, fig. 1425
P . b u f f a l o e n s i s Seeman. Beitr. z. Pal. u. Geol. Oesterr.-Ung. u. d. Orients.
   1906. 19:51 *et seq.*

The quarrying operations in the cement rocks near Buffalo have
brought to light numerous fragments of large Pterygoti which, as they
were found, were described as new species by the curators of the Buf-
falo Museum. Seven species were thus named. Later years have furnished
more complete specimens and these show that only two species of
Pterygotus can at best be recognized at this locality.[1] One of these is
identical with Hall's P . c o b b i ; the other a form of gigantic propor-
tions, is here discussed.

The history of this species, briefly stated, is as follows:

In 1875 Grote and Pitt described and figured the masticatory edge
of a gigantic coxa [pl. 79, fig. 1], which they termed P . c u m m i n g s i,
stating that " P . m a c r o c e p h a l u s (*sic*) and P . o s b o r n i are
evidently very much smaller species, measuring scarcely as many inches as
P . c u m m i n g s i does feet, and are undoubtedly distinct."

Then Pohlman in 1881 described and figured the swimming leg
here reproduced on plate 78, figure 2, as representing his new species
P . b u f f a l o e n s i s , referring also a fixed ramus of a large chela to the
same species. The latter is identical in form with the same part of a much
smaller individual figured by Hall on his plate 80A, figure 6 as " undeter-
mined crustacean." The following year Pohlman published a further paper
on fossils from the waterlime group of Buffalo in which a telson of a young
individual slightly more slender than the average telson is made the
type of a species, P . a c u t i c a u d a t u s , and a detached ultimate
postabdominal segment that was mistaken for a telson is used as basis
of a species named P . q u a d r a t i c a u d a t u s . In regard to

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[1] One of the " Pterygoti " described from Buffalo (P . g l o b i c a u d a t u s)
proves to be an Eurypterus, and a synonym of Hall's E . p u s t u l o s u s .

this telson we may say that there appears to have existed some variation in form, as there is among our specimens one showing the other extreme, namely, a relatively broad form [pl. 72, fig. 3]; none of these differences seems sufficient for the erection of new species, since the occurrence of transitional stages is obvious. Moreover, a slight lateral compression which clearly has affected some of the specimens, and specially the type of
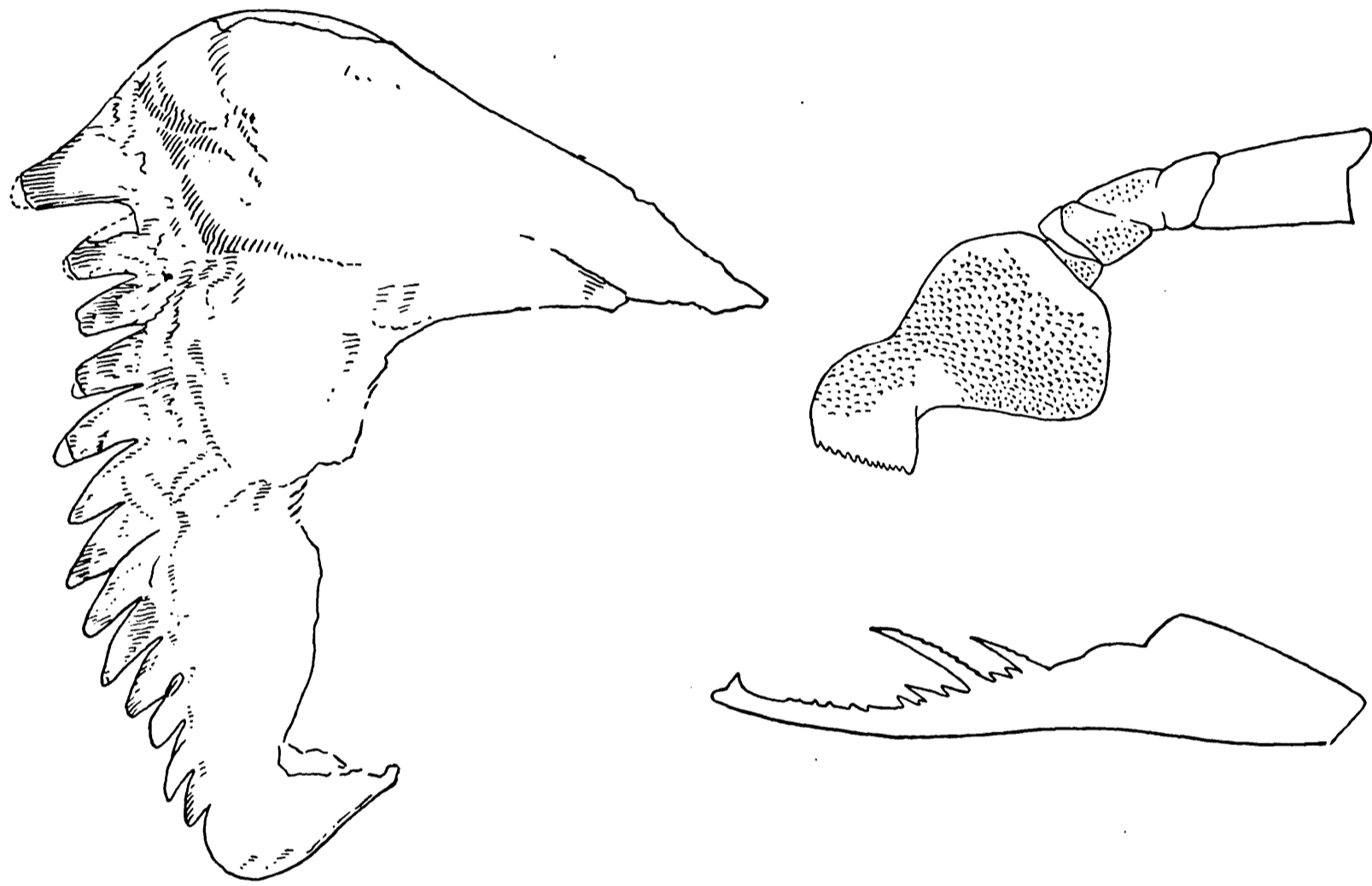

Figure 72 Original figure of Pterygotus
        cummingsi Grote & Pitt

Figure 73 Pterygotus buffaloensis
        Pohlman. The original figures

acuticaudatus, is fully competent to produce a like effect [pl. 77, fig. 5]. Text figure 75 is a reproduction of the type of P. quadrati-caudatus and plate 76 shows the ultimate segment, which in reality it is, in position in a nearly complete postabdomen. Finally Pohlman cited P. bilobus Huxley and Salter, as among the forms of the waterlime at Buffalo, basing his assertion on a fragment consisting of eight posterior segments. This fragment is preserved in the museum of
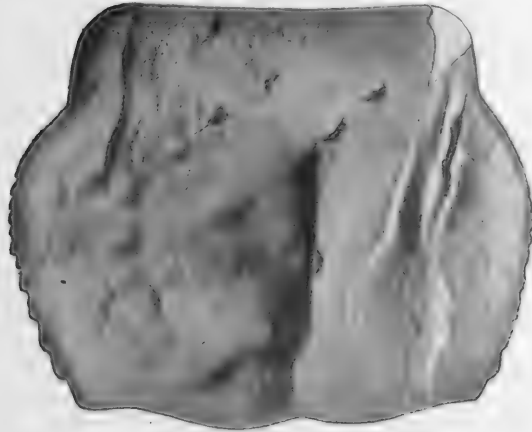
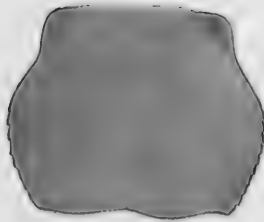Figure 75 The type of P. quadraticaudatus redrawn.
Natural size

Figure 74 Original figure of
Pterygotus quadrati-
caudatus Pohlman

Figure 76 Type of Pterygotus bilo-
bus Pohlman redrawn. Natural size

the Buffalo Society of Natural Sciences and its posterior portion is here reproduced in text figure 76. Closer study of this indicates that again an ultimate abdominal segment has been mistaken for a telson, as the fact of its equal width with the preceding segments readily shows. The misleading bilobed aspect is produced by a strong development of the median dorsal keel which appears in this cast as a deep cleft. In the true British b i l o b u s the telson is nearly twice as long as the ultimate postabdominal segment.

As it would be fatuous to base a species on the manducatory edge of a coxa or even the whole coxa itself,[1] Grote and Pitt's term c u m - m i n g s i is here rejected. This is the more necessary, as these authors afterward referred to their species the free ramus of a chelicera which is clearly identical with P . c o b b i Hall.

Pohlman's P . b u f f a l o e n s i s , a c u t i c a u d a t u s , q u a d - r a t i c a u d a t u s , m a c r o p h t h a l m u s (?) and b i l o b u s all belong to one species. We adopt the first name here used, P . b u f f a l o - e n s i s , emending the species by a fuller description.

Description. Body slender, lanceolate in outline, five times as long as wide.

Cephalothorax. The carapace in mature specimens is trapezoidal, the lateral margins subparallel, slightly convex or angular, forming an obtuse angle with the slightly convex anterior margin. The posterior edge is broadly concave. The surface seems to have been uniformly convex. The compound eyes form the antelateral angles of the carapace, are subelliptic in outline and equal about one half the length of the carapace in younger and four ninths in the largest individuals.

The ocelli and the doublure are as in P . m a c r o p h t h a l m u s .

Abdomen. The abdomen does not differ in either its proportions or characters from that of P . m a c r o p h t h a l m u s . The *operculum* which is not well known in the latter, is here well exposed in several speci-

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[1] Although Grote and Pitt figured only the former, nearly the whole coxa is pre- served in fainter outline [plate 79, fig. 1].

mens. It does not differ materially in form from the same part in the British and Russian species. It is longer than any tergite, its length being one fourth of the width; and its posterior margin has, as pointed out by Woodward, the form of a bracket, while the anterior margin is gently concave and the lateral margins run obliquely forward and inward, the anterior angles being distinctly rounded away.

The transverse line of the operculum, which has hitherto been observed only in Eurypterus, is quite distinctly seen near the margin of the right half of the operculum and can be traced to about one half the distance to the median suture.

The four following sternites are readily distinguished from the tergites by their greater length and the round sweep of their lateral margins. The antelateral angles have not been seen in our specimens on account of the strong overlap of the sternites which must have amounted to fully one half the length of the plates. The doublure of the posterior margin is narrow. The median suture is visible in the operculum and the next sternite. In specimen plate 77, figure 3, the third sternite has split with a straight cleft, thus indicating a line of weakness where the suture might be expected. The doublure of the posterior margin is narrow, amounting to only one fifth of the exposed part of the sternite [pl. 72]; and in the operculum it seems to have been reduced to a narrow band but 1 mm wide in mature specimens. The lateral doublure is well seen on the left side of the specimen; it attains the width of the posterior doublure in its postlateral angle but narrows so rapidly that it does not reach the antelateral angle.

Postabdomen. The postabdomen of this species exhibits the features of that of P . m a c r o p h t h a l m u s with the exception of the ultimate segment which in mature individuals [pl. 76] abruptly flares out, at one fourth its length, into rounded wings that increase the width of the segment by one fourth. The edge of these alae is coarsely serrate.[1] The median

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[1] The form of this edge and the peculiar shape of the entire segment led Pohlman to the erection of a new species, P . q u a d r a t i c a u d a t u s , on the supposition that it represents a telson.

line of the dorsal side is likewise marked, in the middle third of its length, by a keel and covering of massive scales.

The telson is very broadly obovate to circular in outline. It surpasses the ultimate segment in length and in width by one third. The character of the marginal serrations is as in P . m a c r o p h t h a l m u s ; and as in the latter, the telson possessed a median axis or thickening which here is equipped on the dorsal side, with large spines [pl. 73, fig. 2].

Appendages. The form of the epistoma could not be made out in this species.

Some of the preoral appendages or chelicerae are so admirably preserved as to shed light on the structure of these organs and to decide the much disputed number of their segments and the character of the basal attachment. These appendages were long and very powerful, their length equaling fully one half that of the body without the telson. The first segment is subcylindrical, about eight times as long as wide in the compressed state; contracted in the basal seventh of its length, and very gradually expanding toward the distal end. The next segment, which with the third forms the vicious looking pincers or chelae, is of about equal length with the first and easily revolved on it with a rounded basal articulating surface. The basal third of the second segment is inflated, evidently to receive the strong muscles operating the free ramus. Both rami are nearly straight or slightly convex outward, tapering toward the tip and relatively slender. Their distal parts are not roundly curved as in P . c o b b i and the British species, P . a n g l i c u s and b i l o b u s , but end in a sharp distal point and each carries a terminal tooth directed slightly inward, resembling in this structure the jaws of P . o s i l i e n s i s . The fixed ramus carries on the proximal half an irregular series of teeth directed obliquely forward, and on the distal half, smaller teeth that stand vertically. One or several of the oblique teeth surpass all others in length and extend daggerlike into the cavity between the jaws. They are finely barbed on the inner margin, a feature not observed in any congeneric

species. The barbs are quite distinct in specimen, plate 77 figure 3 and still better shown in the fragment reproduced in plate 74, figure 5. They are broad and low near the point of the teeth and become sharp and narrow near its base. Between the larger teeth more numerous and much smaller denticles are everywhere intercalated. The movable ramus carries in its basal part two (in the younger) or three (in the older individuals) stronger teeth directed forward and an irregularly alternating series of mostly smaller teeth on the other parts. The latter all stand vertical in the jaw. One of them surpasses the others in length and is flanked by a group of teeth of about half its length. The edges of these are smooth. All teeth are longitudinally striated. The specimen, plate 77, figure 3, shows apertures near the base of the teeth on the movable ramus.

The *walking legs* or *endognathites* are not very well displayed in our material; and the basal segments fail in all save one specimen [pl. 57, fig. 3]. In the latter the coxae even retain the epicoxites in position, the only case observed in the entire eurypterid material at our disposal. The coxa is slender, with a sigmoidal curvature and the manducatory edge carries a series of about nine teeth. The first two segments appear to be short, ringlike. The legs are slender and relatively longer in this species than in most of its allies, attaining twice the length of the cephalothorax; smooth, cylindrical and tapering regularly toward the blunt spine forming the last joint. The middle segments were longer than both the basal ones and the last. The four pairs do not seem to have differed materially in length.

The *swimming legs* were relatively slender and small extending but little beyond the posterior margin of the third tergite in the older. The coxa is of enormous size in relation to the remainder of the leg. It is half as long as the latter, less the small paddle, and its expansion covers half the underside of the carapace [pl. 78, fig. 2]. Its principal part is rectangular in outline, the interior and posterior sides nearly straight and the others convex, the outer side having a deep sinus in the middle

for the articulation with the next segment. The gnathobase is a strong trapezoidal lobe connected by a contracted neck with the main body of the coxa. On the inner or slightly curved edge, it bears 13 relatively blunt teeth which decrease in size posteriorly with a slight backward direction. The first tooth is distinctly the largest and diverges from the others, and the last teeth at the posterior end (the 14th and 15th of the other species) coalesce into a rounded lobe. The circular opening near the posterior
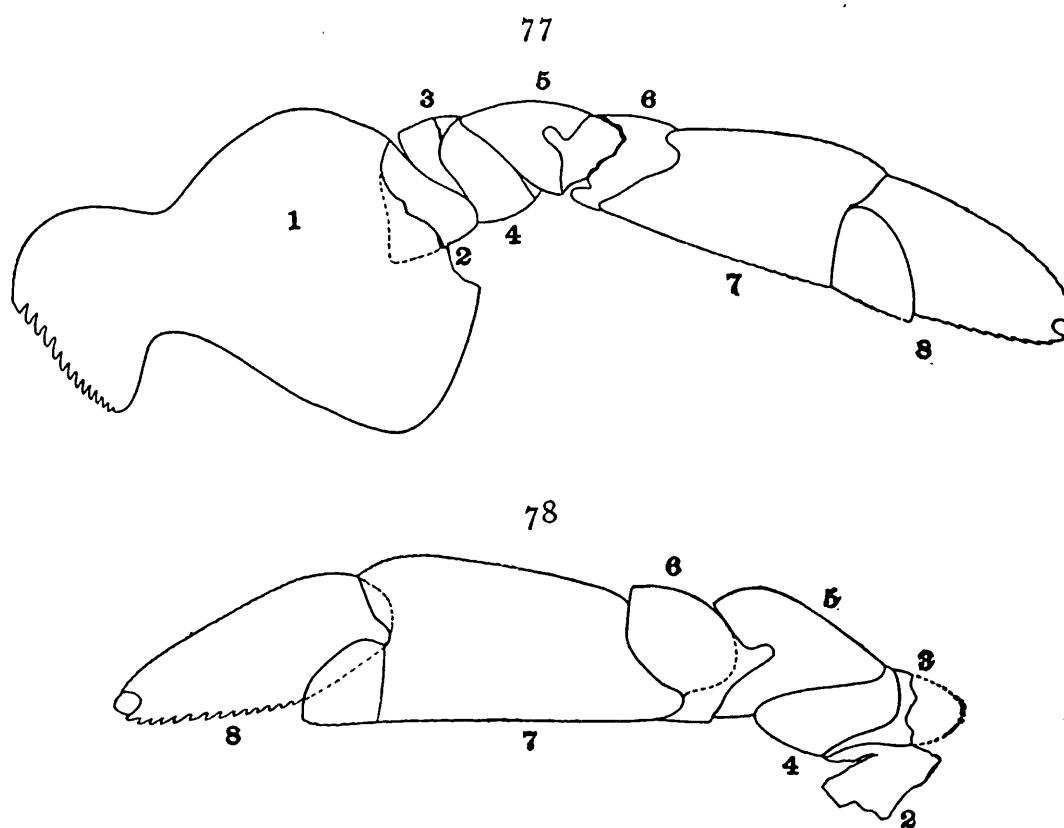
Figures 77, 78 Pterygotus buffaloensis Pohlman.
Outline sketches of swimming legs. Figure 77, ventral view;
figure 78, dorsal view

border of the coxae which occurs in Limulus, Eurypterus and Hughmilleria, has not been seen in Pterygotus.

The second segment is short and ringlike, broadest on the posterior side and provided with a concave outer margin. The third appears wedge-like and is broadest on the anterior side; the fourth is again ringlike, broader than the preceding segment and broadest on the posterior side. The fifth segment is quite like the corresponding part in P . o s i l i e n s i s , triangular semioval in shape, the anterior margin the longest and the distal margin deeply notched; the sixth segment is irregularly rhomboidal

in form, its proximal margin furnished with a strong process that fits into the corresponding notch of segment five, forming a strong articulation, and its distal margin is produced bluntly to articulate with the seventh segment. The latter is the largest one in the swimming leg after the coxa. Its longest edge equals in length the preceding five segments. It is oval in form, as in other species, flat and expands toward the distal end. Its proximal margin is bilobed for articulation with the sixth segment and its distal margin is bluntly indented in the middle for the articulation with the next segment. The outer lateral margin is slightly convex, the inner nearly straight. Both are thickened to strengthen the bladelike expansion. The distal portions of the lateral margin are distinctly serrate. The rather large triangular process of the inner side of the distal margin is, as in the other eurypterids, set off from the rest of the segment by a straight suture. The eighth (paddle) is a little shorter than the seventh, but markedly more slender; it is long, ovate, with lanceolate distal part. Its inner lateral margin is coarsely and its outer margin finely, serrate. The single perfect paddle of our material carries at its distal end a distinct disklike "terminal palette."

The metastoma is elongate cordate; its greatest width about one third the length from the anterior margin. The width equals three fifths of the length. The posterior extremity is well rounded in some specimens and apparently truncated in others. The "Umschlag" or doublure of the inner face, is distinctly seen in one of the specimens [pl. 77, fig. 1] and the wrinkling caused by the compression of the membrane is visible in the figure. In some specimens [pl. 78, fig. 4] a deep median furrow or cleft extended about one third of its length. The inner face was smooth, the outer sculptured as described below.

The epistoma has not been observed. The endostoma was, however, observed lying under a metastoma and accidentally turned backward [pl. 78, fig. 4]. It closely resembles in form the endostoma of Eurypterus fischeri. It is a thin suboval shield with deeply emarginate anterior margin. Its lateral and posterior boundaries are ill defined, as it there

was connected or gradually passed into the thin ventral integument of the cephalothorax. The inner margin of the frontal notch is thickened and a median thickening proceeds from it, posteriorly ending in a thickened semioval plate.

The *opercular appendages* of only two specimens have been observed. These represent the female appendages of young examples. The best preserved and oldest specimen gives two aspects of the appendage, the exterior on the mold of the fossil, and a partially interior one on the cast. Both together show that the appendage was broadly hastate at the anterior end, extending to nearly the anterior margin of the operculum and was produced posteriorly with a clublike process which, in the young individuals at least, did not extend beyond the posterior margin of the operculum. This process was overlapped on both sides by the inner margins of the two opercular plates, which left only the narrow median portion exposed.

In the largest of the specimens, a distinct sigmoid vermiform depression is seen to proceed on one side from the anterior end of the appendage, passing just within the anterior margin of the opercular plate for some distance and finally swinging backward, gradually tapering toward its extremity. This depression corresponds in location and form to one of the paired horn-shaped organs observed by Holm in E . f i s c h e r i on the inside of the operculum on either side of the opercular appendage. It could be well conceived that its presence prevented the filling of the space with mud for a time and its final collapse produced the depression. The opposite opercular plate is bent over and crumpled so that this horn-like organ is not there observable.

Sculpture. The sculpture of the carapace consists only of fine tubercles which are most distinct and closely arranged along the margins and between the eyes; that of the remainder of the integument is composed of linear, crescentlike or angular scales.

The scales of the tergites are small, mostly linear or flat crescentic and distributed on the anterior half of the tergites. The sternites are entirely covered with large, prominent scales except in a belt along the posterior

margin that corresponds to the doublure   The anterior region is covered with small linear or bean-shaped scales which in posterior direction become first crescentlike and then angular, increasing at the same time in size and decreasing in distinctness.

The coxae of the swimming legs bear small, widely distributed crescentic to circular scales that are directed outward.   The other paired limbs show small crescentic scales on the basal segments and longitudinal lines of sharply angular scales on the distal segments.

The metastoma and the hastate part of the female opercular appendage are also provided with crescentlike scales.

On the sternites the scales become smaller, but very densely crowded, more prominent, and show an ever increasing tendency in posterior direction to become circular.   The last tergite is covered on its anterior half with strongly raised, evenly distributed, black, round tubercles. Similar small circular scales are also observed near the anterior margin of the telson which otherwise is smooth.

Measurements.   As we have at our disposal only two complete specimens, and these represent but immature individuals, the measurements of the mature specimens have been obtained by a series of proportions. We give first the measurements of specimen, plate 72, which is the best preserved of the complete individuals.

	Millimeters
Length of carapace	39
Width	52
Length of largest tergite	25
Width	60 +
Length of last postabdominal segment	26
Width	40 ?
Length of telson	39
Width	41
Total length of specimen	290
Length of chelicera on counterpart	115
Length of chela	26
Length of walking leg beyond margin of head	67
Length of swimming leg beyond margin of head	60

Largest carapace observed: Centimeters

 Width........... .... 11.5

 Length... 8.8

 Length of lateral eye..................................... 4

Largest coxa observed:

 Length of anterior edge................................ 20

 Length of manducatory edge........................... 8.2

Largest metastoma:

 Length.. 7

 Width... 4.2

Largest tergite:

 Length... 10

 Width about....................................... 37[1]

Largest telson:

 Length... 11.5

 Width.................... 11

The size of the largest tergite and coxa suggests that this species reached truly gigantic dimensions for merostomes and rivaled the British P . anglicus which Woodward [*loc. cit.* p. 43] felt justified in concluding "attained a length of six feet, and a breadth of nearly two feet, at the widest part of its body." From the relative length and width of the tergites in our specimens we infer that P . buffaloensis was more slender than the British species. The largest tergite leads us to the conclusion that it belonged to an individual 1.65 m or 5 feet, 5 inches long. The very large base from the waterlime at Buffalo [pl. 79, fig. 1] must by comparison of the length of its manducatory edge with that of other specimens, have been the formidable masticating organ of an individual not less than 2 m (2.01 m) or 6 feet, 7 inches long.

The waterlime has furnished the chelae of still another gigantic eurypterid, that of P . cobbi . As the relative dimensions of the chelae to

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[1] Obtained at Litchfield and possibly belonging to P . macrophthalmus .

the other parts of the body are approximately uniform in the other species, we infer from their size (13 cm) that it also attained 5 feet in length.

Pterygotus buffaloensis and P. cobbi vastly surpassed all other arachnids or any organisms of our Upper Siluric era in size and armed with their powerful prehensile pincers, and being evidently active swimmers, as shown by their large swimming legs and telson, they must have been the terrors of the waterlime sea.

Remarks. The principal differences in P. buffaloensis and the closely related P. macrophthalmus are in the form of the carapace, which is less rounded, but more trapezoidal in outline, the frontal margin being less evenly convex; and in the form of the ultimate segment and telson. The telson of the former is not elongate obovate as in P. macrophthalmus, but broadly ovate [pl. 72, fig. 1; pl. 73, fig. 2]. While that of P. macrophthalmus is about one sixth longer than wide, that of P. buffaloensis is as wide as long or sometimes even wider [pl. 72, fig. 3]. Corresponding to this remarkable width of the telson, the preceding, ultimate, segment of the postabdomen is also much wider in P. buffaloensis than in P. macrophthalmus, the widening taking place rather abruptly near the middle of the segment.

Pterygotus cobbi Hall [1]

Plate 77, figure 6

Pterygotus cobbi Hall. Palaeontology of New York. 1859. 3:417*, pl. 83B, fig. 4; pl. 84, fig. 8 ?

Pterygotus cummingsi Grote & Pitt. Am. Ass'n Adv. Sci. Proc. 1878. 26: 300, 301, fig. 1

Pterygotus cobbi (P. cummingsi) Semper. Beitr. z. Pal. u. Geol. Oestr.-Ung. u. d. Orients. 1898. 11: 80

This species is based on the " free ramus of the chelate appendage." The type, a rather poorly preserved specimen, is from the waterlime at Buffalo and now in the American Museum of Natural History. Hall also

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[1] *See* Appendix.

doubtfully referred to this species a postabdominal segment characterized by rather evenly distributed small triangular scales. In form and surface sculpture this is identical with the segment of the postabdomen of E u - s a r c u s ˙ s c o r p i o n i s and quite obviously to be referred to that species. The ramus, however, is distinct from that of the chelae of both P . b u f - f a l o e n s i s and P . m a c r o p h t h a l m u s in the greater relative width of its base and its more regular tapering in distal direction; and most strikingly by the even rounding of the distal end to form a terminal tooth instead of an angular extremity.

By a strange coincidence, this type which Hall says was the " fifth unequivocal fragment of the genus Pterygotus that came under [his] notice from any American locality," seems to represent the rarest of all forms; for so far as we know only one other representative of this species has been thus far found. This is a ramus about twice as large as Hall's type. Grote and Pitt figured it and referred it to their species P . c u m m i n g s i , which had been previously described and based upon a coxa. The latter probably belongs to P . b u f f a l o e n s i s , while the ramus is not refer- able to that species. These writers cited as distinguishing characters from P . c o b b i , the difference in size and the fact that the " apex of the joint is pointed in P . c u m m i n g s i , while in P . c o b b i and P . a n g l i - c u s it is obtuse." By the "apex of the joint" the point of the terminal tooth is meant. The type of P . c o b b i , however, has only obtuse teeth and it is obvious that this is entirely due to weathering. To the same cause and the poor preservation of the type in general may be also attributed the absence of the smaller intercalated teeth in both specimens.

The question suggests itself whether old age could not have produced in P . b u f f a l o e n s i s or P . m a c r o p h t h a l m u s a free ramus like that upon which this species is based; or whether it might not be indicative of a slight variation only. The first suggestion is refuted by the presence in our collection of free rami of b u f f a l o e n s i s of similar size, with typical angular points of the jaws; and perhaps still more by

the fact that the European species P . b i l o b u s , P . a n g l i c u s and P . b a r r a n d e i , which possess similar rounded free rami and have afforded the entire chelicerae, also demonstrate that the fixed ramus is correspondingly formed, and that these characters of the chelicerae appear even in younger individuals. We insert here a sketch of the chelicera of P . b a r r a n d e i, whose free ramus possesses the greatest similarity to that of our type, in order to show the probable form of the entire chelicera of P . c o b b i .
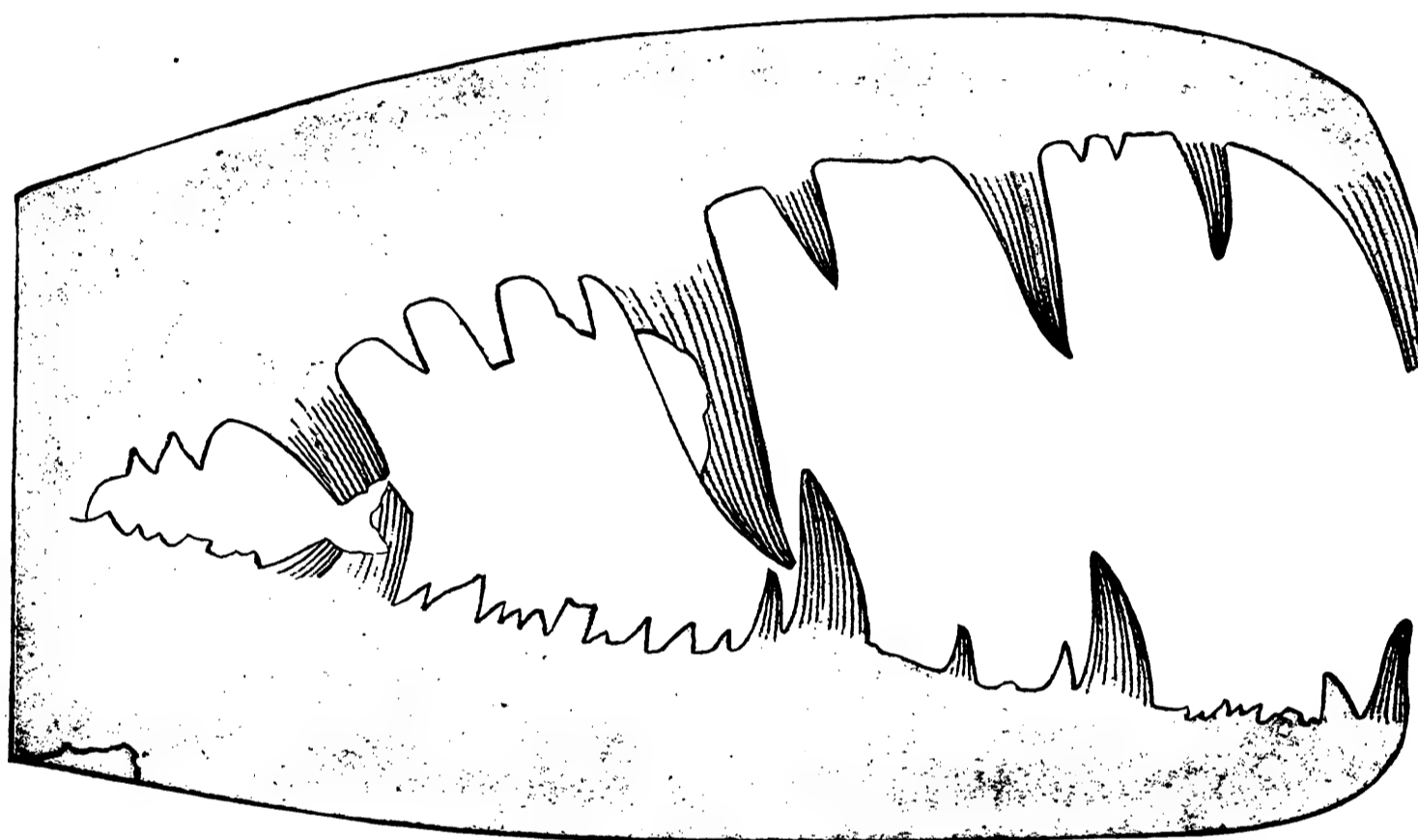

Figure 79 P t e r y g o t u s b a r r a n d e i Semper, here introduced for comparison. Natural size. (From Seeman)

The second suggestion, above advanced, that P . c o b b i may be only a variety, is also refuted by the evidence from the European material, which demonstrates that the chelicerae are very good indicators of specific distinction. The chelicerae of the P . b u f f a l o e n s i s - m a c - r o p h t h a l m u s group are almost identical with those of P . b o h e - m i c u s Barrande, while those of the associated P . c o b b i correspond closely to those of P . b a r r a n d e i Semper, found with b o h e m i c u s in the Bohemian Upper Siluric stage.

We are thus convinced that P . c o b b i , although represented only by a free ramus, deserves recognition as a separate species. Its full characters will have to be established by future discoveries. For the present we base the description on the better preserved second specimen.

The main body of the ramus is nearly straight, its outer edge slightly convex, the inner slightly elevated in the middle in support of the largest tooth. It tapers uniformly, diminishing in width from the articulating extremity to the base of the terminal tooth by one half. It bears three series of teeth, one, consisting of the largest (four in this specimen) and culminating in the second tooth, and another only half as long, intercalated between the large teeth. A few teeth of a third order again half as long as those of the second order are noticeable near the basal part of the ramus.

The teeth possess a very slight forward curvature and stand at right angles on the jaw with the exception of those of the second order near the base, which correspond to the oblique direction of that part, and are directed forward. Fine longitudinal lines are noticeable on the teeth. The distal end of the ramus curves somewhat abruptly into a tooth, longer by one fourth than the culminating tooth of the middle part of the ramus and subparallel to it.

The length of the ramus is 13 cm (5⅛ inches). Its width at the base is 16.8 mm. The culminating tooth measures 19.4 mm.

If we assume that this ramus possessed the same proportional size to the length of the body as in other members of the genus, we derive an individual 6 feet, 7 inches long. Whatever the actual dimensions of this eurypterid may have been, the size and aspect of the jaw are convincing proof of its formidable character.

Pterygotus (Erettopterus) globiceps nov.

Plate 82, figures 1–12

Eurypterus maria (in part) Clarke. N. Y. State Mus. Bul. 107, pl. 2, fig. 3

The presence of a true Pterygotus in the Otisville fauna is shown by several carapaces, a few body segments, a swimming leg and several tel-

sons. As no entire specimen has been obtained, we are not in position to say whether all these parts belong to but one or to several species. We have referred them provisionally to one species since the carapaces do not exhibit differences of sufficient importance to base distinctions upon, though they undoubtedly represent different growth stages. We have selected the largest and most perfect carapace [pl. 82, fig. 6] as the type and derive from this the following description:

Description. Carapace approaching a circle in outline, with a posterior segment cut off, so that the length is one fifth shorter than the width. The greatest width is in the anterior half, just behind the eyes. The frontal margin and the greater portion of the lateral margins form a continuous subcircular curve, the posterior fourth of the lateral margins slightly concave and the posterior margin nearly straight. The postlateral angles are approximately right ones. A narrow flat margin with a thickened rim surrounds the carapace except where the eyes are situated where it is presumably continuous and turned under. This margin widens near the postlateral angles. The posterior margin is also furnished with a narrow flat border. The carapace appears to have been quite convex before compression. The eyes are very large (one half the length of the carapace), of elliptic outline, hardly projecting, and situated at the well-rounded antelateral corners. Traces of the facets are noticeable. The surface is ornamented with contiguous, low broad tubercles. The first tergite is very short (11 times as wide as long), its posterior margin concave in the middle, the lateral margins rapidly diverging and curved. The surface exhibits the same ornamentation as the carapace.

Several tergites have been observed of a Pterygotus exhibiting the same typical Pterygotus-sculpturing as the carapace of this species, though more pronounced. One of these, with much extended lateral " ears " is reproduced on plate 82, figure 8. Some fragments indicate that this species attained the gigantic proportions of the Bertie waterlime species and that the smaller forms are but early growth stages. The relatively very great size of the lateral eyes points to the same conclusion.

The swimming leg [pl. 81, fig. 10] agrees with the corresponding organ of its allies in its smaller elongate paddle and long seventh segment.

Metastomas and telsons, referable to Pterygotus, have also been observed in the Otisville beds. The latter are of bilobed form and indicate Huxley & Salter's genus Erettopterus. The half of one telson, obviously too short, through anteroposterior compression shows a fringe of very minute, acute points such as have, to our knowledge, not been observed before on the telson of a Pterygotus. Smaller specimens (as that reproduced in plate 82, figure 12) are better preserved and consist of elongate bilobate bodies with a central, posteriorly tapering, raised axis. The lobes are broad and well-rounded.

While the carapace of this species strikingly resembles that of P. (Erettopterus) bilobus Huxley & Salter [see especially Woodward, 1869, pl. 10, fig. 3] in its subcircular outline and larger eyes, the telsons from Otisville are much shorter and less bilobed and can be only compared to those of P. (Erettopterus) banksii [Huxley & Salter, Monogr. pl. 12, fig. 23, 36, 37]. Both carapaces and telsons thus show closest relationship to species of the subdivision Erettopterus, a fact that argues for the union of the carapace and telsons.

Ontogeny. By far the most interesting part of this small series of specimens are the four immature individuals [pl. 82, fig. 1–4] which give us the first information on the ontogeny of a Pterygotus. Of these four two are clearly in a larval condition and represent the nepionic stage, while the others have certain characters in common which, together with their size, support the view that they are still immature and belong to the type intermediate between the nepionic and ephebic conditions.

The two *nepionic* specimens are characterized above all by the relatively great size of the carapace, the small size of the abdomen and small number of segments. The carapace occupied nearly one third the length of the whole body while in the mature P. macrophthalmus, the only species of which we have whole individuals, it reached only about one eighth the length of the body. The fourth figure indicates how far in

the neanic stage the body had overtaken the carapace in growth. We judge that in this individual the carapace was not longer than one fifth the entire body. The carapace of the nepionic stage is also wider than any other part of the body, the latter tapering directly from the base of the carapace to the tail.

The imperfection of the body is very apparent in the first individual, which probably had no more than six or seven segments and the next but eight or nine without the telson. The segments are all of equal length, but diminish rapidly in width, while in the mature Pterygotus they gradually widen to the fourth and thence again very gradually contract to the telson.

The compound eyes are, in contrast to the nepionic stages of the other eurypterids, not relatively larger than in the ephebic stage, but rather smaller. This peculiar difference is quite apparently due to the fact that the mature Pterygotus has relatively larger compound eyes than the other genera and we may infer from this relation of the nepionic to the ephebic eyes, that the large eyes of Pterygotus are a further development of a feature larval in the whole class. While the nepionic eyes were not relatively larger than those of the mature individuals they seem to have been somewhat more prominent or bulging. The first of the nepionic specimens [pl. 81, fig. 1] exhibits two very distinct tubercles near the anterior margin which, if ocelli, would have a position corresponding to that in the embryo of L i m u l u s   p o l y p h e m u s .

The telson of the nepionic stage has unfortunately not been seen. We surmise that it would give interesting clues as to the development of the bilobed telson characteristic of Erettopterus.

The specimen figure 2 exhibits a distinct cleft or rupture, slightly more irregular and curved than figured, extending over the posterior part of the carapace and the following segments. This may be the result of molting. Considering the small size (1.5 mm) of the specimen, it is quite possible that this was the first molt after hatching.

The *neanic* stage is represented by the two specimens figures 3, 4.

The specimen figure 3 has suffered strong compression in anteroposterior direction and is therefore not competent to indicate the form of the carapace in this stage, but it corroborates the evidence from the other as to the relatively increased size of the compound eyes and the distinctness and position of the ocelli.

The carapace has lost its position as the broadest part of the body, the preabdomen having been completed and become the widest portion. In other growth-stages of eurypterids obtained at Otisville, the postabdomen is completed before the preabdomen, and it is hence to be inferred that in the specimen figure 3 the number of segments is complete. This is also suggested by the presence of a narrower first preabdominal tergite such as is found in the mature stage.

The compound eyes are relatively larger than in the nepionic stage, occupying fully one half the sides of the carapace, but less prominent. The compound eyes of the first specimen are especially notable for the distinctness with which a thickened ring is seen to surround the inner side of the eye. The same is already visible on the second nepionic specimen figure 2 and partially noticeable on the type. It probably surrounded the whole eye and its function was apparently to support the prominent cornea, corresponding in that to the orbital ridge in Stylonurus excelsior.

Measurements.

  Type, carapace, length, 12.3 mm; width, 15.5 mm

  Length of first tergite, 1.5 mm

  Width of largest tergite observed [pl. 82, fig. 8], 25.5 mm

  Length of same, 9.9 mm

  Largest telson observed [pl. 82, fig. 11], length (incomplete), 35 mm; width (restored), 60.2 mm

  Smaller telson, width, 7.4 mm; length, 7.7 mm

  Smallest specimen, length (incomplete), 1.6 mm; width, .8 mm

Horizon and locality.   Rare in the Shawangunk grit at Otisville, N. Y.

Pterygotus (Erettopterus) grandis (Pohlman) emend.

Plate 81

Ceratiocaris grandis Pohlman. Buffalo Soc. Nat. Hist. Bul. 1883. 4: 19, fig. 5

The waterlime at Buffalo has furnished the broad symmetrical remains of a creature described by Pohlman as the carapace of a gigantic Ceratiocaris on the assumption that the two semicircular valves of this supposed phyllocarid had been spread out on both sides of the dorsal line. This view is clearly erroneous and the fossil is the telson of a Pterygotus. According to Pohlman it was found in the same bed which yielded the Pterygotus. The specimen represents the section with bilobed telson (Erettopterus). Pterygotus banksii, a British Ludlow form, possessed a similar telson [Huxley & Salter, Monogr. pl. 12, fig. 45] although it is considerably surpassed in transverse development by this American species.

As a telson this fossil is characterized by the anterior transverse hinge line where it is connected with the preceding segment, the

Figure 80 Original figure of Ceratiocaris grandis Pohlman

smooth antelateral edge and the scalloped postlateral edge. The anterior half is provided with a median ridge while the posterior part is divided by a median cleft. It is probably the character of this median line which led to the reference of the fossil to Ceratiocaris.

The form of the telson is transversely elliptic with rather acute ends. Its major diameter, 24 cm, is to the minor as 12 : 7. The anterior hinge line is but 69 mm long, thus indicating the broad flaring character of the telson in comparison to the postabdomen. The scallops are broad and shallow; at the termination of the median line is a deeper and broader emargination. The sides of the median cleft are curved outward and overlap considerably. The surface is very finely granulated.

This telson must have been the effective propelling organ of a gigantic merostome, which was undoubtedly 5 feet or more in length. In view of
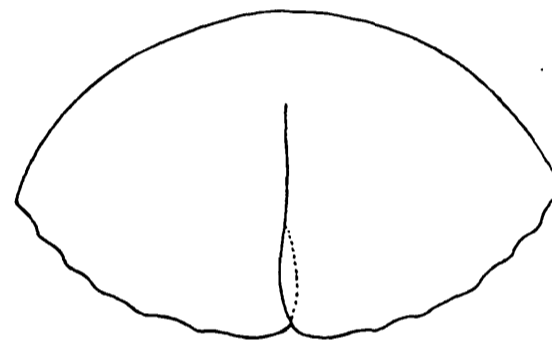
the fact that the known fragments of P t e r y g o t u s c o b b i , from the same locality and formation, also represent a colossal animal, it is possible that the rami of P . c o b b i and the telson of P . g r a n d i s will prove to belong to the same animal.

Pterygotus monroensis Sarle

Plate 70, figures 3–5

P t e r y g o t u s m o n r o e n s i s Sarle. N. Y. State Palaeontologist Rep't. 1902. p. 1102, pl. 24, fig. 7, 9

? P t e r y g o t u s sp. Sarle. *Ibid.* p. 1104, pl. 24, fig. 6, 8

Sarle describes this species as follows:

This species is founded on a single specimen, a cephalothoracic shield. The outline of this shield is semielliptic with the posterior edge noticeably incurved. The surface is moderately convex, and along the sides and front is a threadlike border.. The length of the shield, without the genal angles, is 30 mm, with them 37 mm; the breadth at the base 38 mm. The compound eyes are prominent and project beyond the outline of the shield. They are subelliptic, with a distinct angulation on the inner side of each, produced by an indentation of the inner anterior part. They are 14.5 mm long and 6 mm wide. The facets can be made out with a good magnifying glass. The eyes are located a distance equal to their own length from the front of the shield and 27 mm from each other. A line connecting their bases cuts the axial line a little back of the center of the shield. The ocelli are on a small tumescence just back of this. The ornamentation is almost obliterated, but can be made out at one point, where it consists of minute, short, flat, lobelike scales.

Its differences from P . m a c r o p h t h a l m u s are also indicated by the author as follows:

The cephalothorax of this new species differs from that of P . m a c - r o p h t h a l m u s in that its length is nearly equal to its breadth; the compound eyes are over one third the length of the shield, elongated, angulated on the inner side, situated farther back, and separated by nearly twice their length. In P . m a c r o p h t h a l m u s the length of the shield is three fourths the breadth; the eyes are about one third the length of the shield, anterior, globular and separated by a distance about equal to their length.

The type specimen, which is in the State Museum, possesses some characters quite suggestive of a more proper reference to Hughmilleria. Sarle remarks that the form of the eyes suggests those of " P . b i l o b u s

Salter and P. b a n k s i i Salter and also those of H . s o c i a l i s ."
The reference to Hughmilleria in this connection appears to us especially
significant, since the eyes show the distinct angulation on the inner side,
so characteristic of that genus, and moreover fail to exhibit any
signs of the facets, generally quite distinct in Pterygotus. It is quite
possible that this specimen is a very large carapace of Hughmilleria
partly doubled upon itself in front (of which there is evidence along a
break); although on the other hand it must be conceded that the lateral
eye is relatively larger than that of H . s o c i a l i s .

So far then as concerns this carapace P. m o n r o e n s i s is an un-
certain species, but unmistakable evidence of the presence of a true Ptery-
gotus in the Pittsford shale is afforded by the free ramus of a chela,[1] repro-
duced in plate 70, figure 3. Sarle has separated this and a metastoma[2]
[pl. 70, fig. 4] on the ground that they belong to coarse-scaled fragments
that represent another species. Inasmuch as the carapace as a rule has a
much finer sculpturing than the rest of the body (e. g. in P . m a c r o p h -
t h a l m u s), there seems little ground to assume the presence of more
than one species of Pterygotus in the Pittsford beds.

Judging from the ramus of the chelicera, this type was more closely
related to P . c o b b i than to any other form, the latter species possess-
ing the same rounding of the extremity of the ramus and similar form
and direction of the teeth [pl. 77, fig. 6], the latter being still a little
more rectangular upon the shaft than in P . c o b b i .

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[1] Sarle's description of this reads:

The shaft is nearly parallel sided, 3 mm broad and 12.5 mm long and curves
at the end into a stout, striated, nearly perpendicular mucro 3.5 mm long. Back
of this mucro is a series of 10 erect, subtriangular, striated denticles, very slightly sepa-
rated at their bases. They are of three sizes, the largest or primaries being about one
half the length of the mucro, the secondaries one-half that of the primaries and the
tertiaries about one half that of the secondaries. The first primary is separated from the
mucro by a secondary and from the second primary by two secondaries and two tertiaries
alternating; following the second primary are two secondaries separated by a tertiary.

[2] Described as follows: An ovate metastoma 27 mm long and 16 mm wide, broad-
est just anterior to the middle, with the anterior corners slightly truncated, the lobes
small and the terminal notch very narrow and shallow. It is marked by coarse, rounded,
lobelike scales and is very much more robust than would be expected in Pterygotus
monroensis. Judging by the ornamentation, it should be associated with the coarse-
scaled fragments most frequently found.

Pterygotus (Eusarcus?) nasutus nov.

Plate 86, figures 6–10

Description. Carapace pentagonal; one fourth wider than long, consisting of a greater posterior quadrilateral portion and a smaller triangular frontal portion; the lateral eyes occupying the anterior angles of the quadrilateral portion. The lateral margins are subparallel, gently convex, the frontal margin transverse for a short distance and bluntly angular in the middle; the posterior margin nearly straight transverse. The lateral eyes, about one third the length of the carapace, appear broadly triangular when partly folded under the carapace and compressed, but are normally subcircular and strongly project in the middle. Ocelli forward of center of carapace. Ornamentation small, crescent-shaped scales.

Horizon and localities. Frankfort shale (Schenectady facies) at Schenectady, Aqueduct and Duanesburg.

Remarks. This species is well characterized by the snoutlike frontal projection and the prominent antelateral angles with their large eyes. It does not appear to have reached the dimensions of the preceding species, the largest carapace being only 30 mm wide and 22 mm long. The type specimen is 9.5 mm long and 13 mm wide. Its lateral eyes are about 4.5 mm long.

Pterygotus prolificus nov.

Plate 86, figures 1–5

Description. Carapace semielliptic to roundish quadratic, length to width approximately as 4 : 5; frontal and lateral margins evenly convex, posterior margin straight transverse to gently concave. Lateral eyes large, one third the length of the carapace, elliptic in outline, marginal, situated in the antelateral corners, showing traces of facets. Ocelli subcentral in position. Ornamentation not observed.

Horizon and localities. Frankfort shale (Schenectady facies) at Schenectady, Aqueduct, Rotterdam Junction, Duanesburg, Schoharie Junction and the Vly creek. This is the most common eurypterid of the Frankfort shale; it is, however, possible that more than one species is comprised in this preliminary description.

Remarks. The outline of the carapaces is quite variable, at times being nearly quadrilateral [pl. 86, fig. 3], at others almost semicircular. Much of this diversity of form is obviously due to the compression and wrinkling of the rather flaccid carapaces in different directions, but in the best preserved specimens there is still an element of difference left after allowing for all the secondary influences that suggest the presence of more than the two species of Pterygotus here described and a distinction between the round and the squarish carapaces. This suspicion is strengthened by the evidence from the patches of integument showing patterns of ornamentation which also indicate a greater number of species of Pterygotus. We have selected the squarish specimens as typical of P . p r o l i f i c u s .

Disjecta membra of Pterygotus from the Frankfort shale

Besides the carapaces here used for specific diagnosis, many other fragments are referable to Pterygotus. The most characteristic of these may be briefly noted.

Plate 86, figure 19 represents a fragment of the arm of a pincer.

The distal end of a swimming leg, which in the form of the seventh and eighth segments resembles the leg of a Pterygotus more than that of any other genus, is reproduced in plate 86, figure 16. In the same group belongs plate 86, figure 20. There occur entire large swimming legs which probably belong to O . p r o l i f i c u s . Another very characteristic group of fragments are the female opercular appendages [pl. 87, fig. 1–3]. They resemble those of the giant P . a n g l i c u s and from their dimensions may belong to P . p r o l i f i c u s . Still another form of a large appendage corresponding to a type observed at Otisville, is seen in plate 87, figure 4. The most remarkable of the opercular appendages is one [pl. 86, fig. 11] which beautifully retains the characteristic broad overlapping crescent-shaped scales of the Pterygotus-Slimonia group. This resembles the male opercular appendage of Slimonia.

The metastoma reproduced in plate 86, figure 17, resembles in the anterior half, which alone is preserved, so much the metastomas of several species of Pterygotus and also corresponds in its large size so perfectly to the parts of P . p r o l i f i c u s that there is little doubt of its belonging with the large carapaces of that species.

Plate 87, figure 9 represents a fragment of a large tergite with traces of the Pterygotus ornamentation. This can be referred to P . p r o l i - f i c u s with some certainty.

Characteristic telsons of Pterygotus [pl. 87, fig. 5, 7] are not infrequent at Schenectady and Duanesburg. A very different type is represented by plate 87, figure 8. It exhibits a peculiar ornamentation, consisting of small groups of tubercles on low nodes arranged in subconcentric lines; the other side was smooth. The serration of the margin is very distinct and shows by its direction that the small incision on the longer side is the middle of the posterior margin of the telson and is a faint beginning of the bilobation characteristic of Erettopterus.

Plate 87, figure 6 illustrates a form of fragments met with repeatedly in the beds at Schenectady, and quite obviously a last postabdominal segment best comparable to that of a Pterygotus.

Finally, these black shales also contain small patches of integument which retain the surface sculpture in a preservation surpassing any hitherto observed in our eurypterid-bearing rocks. Some of these patches [*see* pl. 86, fig. 11–15] are clearly referable to Pterygotus.[1]

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[1] Disjecta membra from the Frankfort shale, not referable to any genus.

Besides the few parts of the integument referred in the preceding descriptions to genera known from the Upper Siluric and Devonic, a considerable number of fragments have been found which cannot be placed with any degree of certainty with any of the genera; some are of non-committal character, while others differ so strikingly from all later forms that they undoubtedly represent new types of greater than specific rank and must await future discoveries of more complete material, for description. We merely figure these here to indicate the richness of this new eurypterid fauna.

Plate 86, figure 18, is a coxa, possibly belonging to Pterygotus; plate 84, figure 17, the greater part of a broad, rapidly contracting abdomen, possibly belonging to Eusarcus, and plate 84, figure 19, a long, extremely slender, distinctly striated spine, suggesting Dolichopterus and Stylonurus,

Most indicative of the great diversity of forms occurring in the Frankfort beds are the well preserved patches of integument found in the black shale. Some of these have been mentioned in connection with the genera Eurypterus and Pterygotus. We figure here several patches bearing the ornamentation described of Eusarcus, Echinognathus and Megalograptus and exhibiting some variations [pl. 84, fig. 13-16]. Another style of ornamentation is represented by figure 8 of plate 83. This consists of extremely fine, very closely and evenly arranged tubercles. The patch of integument, reproduced in plate 85, figure 8, shows a mass of densely set, short, sharp spines and that shown in plate 85, figure 7, a profusion of long slender spines.

Plate 85, figure 10, is a part of a supposed leg segment with a strange pattern of parallel raised lines connected by another set of shorter parallel oblique lines.

APPENDIX

Remarks on Beltina danai Walcott

1899. B e l t i n a d a n a i Walcott. Geol. Soc. Am. Bul. 10: 238, pl. 25, 26; pl. 27, fig. 2-6

Ever since the publication of the work cited, these fossils, referred to the Merostomata, have aroused great interest among geologists and paleontologists, principally for the reason that they come from beds considered by Mr Walcott as Precambric (Greyson shales of the Belt terrane in Montana). Merostomata from beds so ancient would be of especial interest to the phylogeny not only of the eurypterids but also of all related subclasses, since it might be postulated that forms of such age were the common ancestors of the Merostomata and Arachnida, and perhaps also of the Crustacea.

Through the liberality of the secretary of the Smithsonian Institution the authors have been able to investigate the principal types and a number of other selected specimens of Beltina. These specimens are in a dark fine grained somewhat micaceous shale which does not, in hand specimens at least, afford much evidence of shearing or distortion. The " Beltina " bodies lying parallel with the bedding of the rock are, it appears from the records, very abundant as the collections of the National Museum contain hundreds of specimens. They are flat films or smooth patches left by organic films, and these only in the rare instances which have been illustrated present suggestions of resemblance to known merostome organs. The fact of their very great age and their presumable primitive form as the possible ancestor of quite diverse classes of organisms should not too rigidly force our expectations of exact resemblance but in such a multitude of fragments the occasional approach to the outline of an eurypterid limb, as for example to the free ramus of a Pterygotus chelicera [op. cit. pl. 25, fig. 13] must be looked upon as favor-

able evidence, if supported by collateral facts, even though such a structure is vastly progressed over what we might deductively expect in these ancient organisms. Speaking broadly however the outlines of all these bodies that we have examined, are indeterminate; we can not avoid the conviction that such resemblances as have been indicated to eurypterid parts are casual and the illustrated specimens represent only a very slender percentage of the total specimens gathered. Aside from these imperfections of outline there should be, so far as experience goes, a crucial test in the matter of integumental sculpture, for everywhere among the fossil merostomes this structure is a guide and index even in inconsiderable fragments. There is no reason to assume the absence of this sculpture even in archaic or ancestral forms of the group, but in all the specimens of Beltina we have scrutinized there is no trace of it; nor is there of body segmentation or arm joints. Many of the Beltina bodies are bandlike fragments or patches which indicate an infolding or overlapping as though they had been floated into the muds as very thin and tenuous films rather than as the rigid parts of an arthropod test. We entertain no doubt that these bodies, or the greater part, are of organic origin and while unable, after careful study, to convince ourselves that they are merostomatous, yet to renewed efforts in the field they do give promise of a recognizable fauna.[1]

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[1] In a quite recent paper (Smithsonian Miscellaneous Collections. Middle Cambrian Merostomata, April 8, 1911) Dr Walcott has given figures of additional specimens referred to B e l t i n a d a n a i, from new horizons regarded as Algonkian, the Altyn limestone, near Altyn, Montana, and a silicious rock in Alberta, Canada. These retain a certain degree of convexity and show a defined merostome sculpture [pl. 7, fig. 2–4], while figures 3 and 4 give clear outlines of merostome segments. It is not quite clear on what basis of structure these very evident merostome remains are identified with the Greyson shale examples of "Beltina" though they intimate the extremely ancient age of the Merostomata and their extraordinary specialization in the earliest fossiliferous rock beds.

Note on **Proscorpius osborni** Whitfield

Plate 88

Palaeophonus osborni Whitfield. 1885. Science, 6: 87, 88, fig.

Proscorpius osborni Whitfield. 1885. Amer. Mus. Nat. Hist. Bul. 1: 187, pl. 20

Proscorpius osborni Scudder. 1885. Zittel's Handbuch der Palaeontologie, 1 Abth., 2 Bd., p. 739, fig. 915a.

Proscorpius osborni Thorell. 1886. American Naturalist, 20: 269

Proscorpius osborni Whitfield. 1886. Science, 7: 216

Proscorpius osborni Scudder. 1886. U. S. Geol. Surv. Bul. 31: 28

Proscorpius osborni Laurie. Royal Soc. Edinburgh Trans. 1899. 39: 557, pl. 3

Proscorpius osborni Pocock. 1901. Quart. Jour. Micr. Sci., ser. 2, 44: 309

Proscorpius osborni Fritsch. Palaeozoische Arachniden, 1904. p. 65, 78, fig. 81

Proscorpius osborni Fritsch. Miscel. Pal. I. Palaeozoica, 1907, p. 6, pl. 3

In addition to its eurypterids the Bertie waterlime of New York has furnished a specimen of a scorpion which represents one of the four species of Siluric scorpions now known. As it is not only associated with the eurypterid fauna, but also related to it structurally, we have thought it well to include the following note on this unique fossil, especially as it has been the object of much debate.

This scorpion was discovered in 1882 by Mr A. O. Osborn in the waterlime of Waterville, Oneida co., N. Y. Although found before the three European species, the discovery was not announced until 1885, shortly after the news of the discoveries of the Swedish and Scottish Siluric scorpions had aroused the interest of paleontologists. Professor Whitfield, to whom the specimen had been sent by Mr Osborn, first gave a brief description and figure of it in *Science* and in the same year produced a more elaborate description with figures in the Bulletin of the American Museum of Natural History.

In the first paper the scorpion was referred to Palaeophonus (the genus to which the other Siluric forms belong), but in the later publication a new genus, Proscorpius, was proposed for it, mainly from the supposed presence of double claws on the walking legs. Scudder [Zittel's Handbuch der

Palaeontologie, p. 739] not only accepted this conception but even created a new subfamily, Proscorpionini, which was not brought under the Siluric Palaeophonidae, but under the Carbonic Eoscorpionidae, chiefly because of the supposed existence of double terminal claws on the walking legs.

A year later there appeared in the *American Naturalist* a critical review by Thorell, of Whitfield's interpretation of certain points in the organization of the scorpion and Whitfield soon after published in *Science* a general denial of all these points.

When describing the Scottish Siluric scorpion, Pocock in 1901, also discussed P r o s c o r p i u s o s b o r n i , obviously unaware of the criticism by Thorell and of Whitfield's rejoinder, and raised some of the identical points as Thorell, especially in regard to the supposed double claws of the walking leg; and subsequently Fritsch published somewhat fuller notes from excellent photographs made by Dr E. O. Hovey. Fritsch, too, was unaware of Thorell's paper, but he fully verifies Thorell's criticisms. As even the best photograph is misleading through the projection of all parts into one plane and the appearance of deceptive shadows, a close investigation of the specimen itself is essential in order to settle the many debated points and by the courtesy of Dr Hovey we have had full opportunity to study the specimen and to compare it with his photograph. In consequence we have added a third figure and a restoration to illustrate our conception of the fossil.

Carapace. This is subquadrate in outline, a little wider than long. Its front margin is straight and faintly emarginate, appearing trilobed through the projection of the eye lobe in the middle and that of the frontal lobes at the antelateral angles. The eyelobe is relatively large, roundish pentagonal. The frontal lobes are well rounded and project slightly beyond the frontal margin. The left lateral margin is distinctly broken and incomplete, and the right one largely covered by the matrix; nevertheless the anterior portion of the right margin can be distinctly seen to bulge out directly behind the eye lobe, and we have no doubt that the carapace was broader in the middle than in front [*see* restoration, text fig. 83]. The posterior margin is slightly concave. The surface of the carapace is rather even and smooth and a great number of bristles

81

82

83
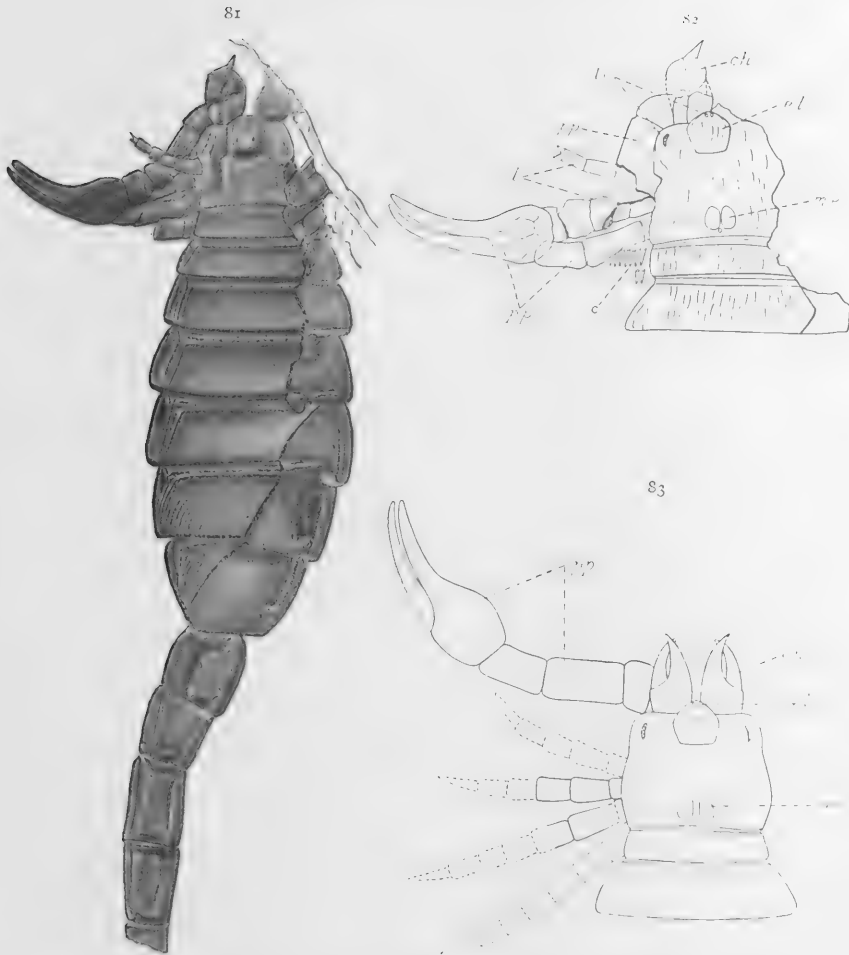
Figures 81–83 Proscorpius osborni Whitfield. Figure 81, original figure; figure 82, diagram of cephalothorax and first segment; figure 83, restoration of same. *ch*, chelicera *pp*, pedipalp; *l*, walking legs; *cl*, eye lobe; *lc*, lateral eyes; *me*, median eyes; *c*, comb

directed backward can be distinctly seen on the carapace.   A faint transverse depression separates the posterior fourth from the rest of the carapace.

Eyes.   Whitfield and later Scudder [1886, p. 28] described the lateral eyes as situated on ridges near the antelateral borders, while Fritsch states that he saw three frontal eyes on the left frontal border of the eye lobe and therefore assumes that there may have been six altogether.   He was the first to discern the contours of the large median eyes near the posterior margin.   A small plain tubercle arising from a shallow depression is situated behind these eyes.

The specimen itself exhibits two distinct ocelli standing out like minute pearls in front of the eye lobe.   There are much more minute tubercles on the left side of the ocelli which are of a distinctly different character. There is further seen on the left antelateral lobe of the carapace a small longitudinal series of four tubercles that, from their position and character, may well represent another group of lateral eyes.

Mesosoma.   The mesosomatic segments forming the preabdomen have been the principal object of doubt.   The upper side of the abdomen is cracked lengthwise; the left side is considered as the dorsal side, the right one as the ventral side by Whitfield and apparently also by Scudder. As a result of this conception of the fossil, it is inferred that the ventral side possessed, in distinction from all other scorpions, six subequal sternites; and as a further corollary, that since these supposed sternites exhibit no stigmata, the species was probably aquatic.   Thorell, Pocock and Fritsch have criticized these inferences, and Thorell and Fritsch agree that only the dorsal plates are seen, the supposed ventral plates on the right-hand side being only the impressions of the dorsal plates that are broken away.   Thorell bases his view mainly on the fact that the articulations of *all* the "ventral plates" are direct continuations of the articulations between the dorsal plates, which is not the case in the scorpions.   The inspection of the specimen leaves no doubt that the ventral side of the preabdomen is not visible.

Fritsch has inferred from his study of the photograph that one sees indications of the organs of respiration on the right side in the 4th–6th seg-

ments. " There are oval bodies," he says, "which correspond to the lung
sacs of the scorpions," adding, "Nothing can be observed of openings of these
sacs, namely stigmata, to the outside." This inference is due to a deceptive
feature of the photograph, in which fragments of the test of the tergites
and slight folds give the appearance of oval depressions in the underside
of the preabdominal segments.

The tergites are of relatively greater width than those of Palaeo-
phonus, especially P . n u n c i u s . The first is the shortest and the tergites
gradually grow in length backward. The anterior and posterior margins
are nearly straight, the lateral margins not well seen, owing to the crumb-
ling of the edges. It is obvious, however, that they did not diverge for-
ward as in Palaeophonus or were entirely rounded off as in Eoscorpius
but diverged backward to the fourth, which is the widest, then again
contracting. The first seems to have been rounded at the posterior angles.
The anterior edge of the tergites possesses a transverse, forward sloping,
smooth, articulating band which is a rather prominent feature though
but faintly seen in the photograph. It does not, however, follow the
lateral edges as figured by Whitfield, nor does it exhibit the raised trans-
verse line appearing in the original figure of the species.

Postabdomen. The first metasomatic or postabdominal segment has
the form of a truncate cone, as in other scorpions. Of the narrow tail
four segments are seen in an impression only. These also have led to some
discussion, as Whitfield, in consequence of his conception of the presence of
ventral preabdominal plates, inferred that the impression is that of the
ventral side of the tail. This side shows only two longitudinal ridges like
the dorsal side in other scorpions, and hence the conclusion was reached
that the " bending of the tail was downward, not upward, over the back."
Against this Thorell has urged that probably the tail, which is detached,
has been turned upside down and that now the inside of the dorsal side
is seen in the impression. The oblique position of the frontal margin of
the tail to the posterior margin of the first postabdominal segment, and
the lateral position of the two carinae of the first tail segment serve to
show that the tail is out of its original position, and that therefore no

inferences as to the character of the dorsal and ventral sides can be drawn from its present position.

Appendages. The appendages present the greatest difficulties to a correct interpretation on account of their unfavorable preservation and small size. We find, accordingly, wide differences in the views held by the authors concerning them.

One of the two chelicerae has been pushed forward and is seen in front of the carapace. Its distal portion is preserved only as an impression and but a portion of one finger is noticeable. The proximal portion of the powerful second joint is preserved as a flattened tubular body, distinctly broken off in front. Fritsch has interpreted this part as the manducatory lamella of the coxa (Kauglied), and states that it shows a short curved claw at the anterior margin. Inspection of the specimen, however, shows readily that the hand of the chelicera is the direct continuation of this proximal part, and that the latter lies upon the coxa of the pedipalp. The short claws are not visible in the specimen and Fritsch's representation is apparently due to shadows produced by irregular depressions between the lost anterior and the preserved posterior portions of the chelicera.

The greatest difficulty is presented by the legs, since these appendages are piled together in one place and badly torn. They have therefore been very differently interpreted and caused much of the controversy about this scorpion The second joint of the left pedipalp (trochanter) is seen as an impression at the left of the base of the chelicera, which it underlies The third joint (humerus or femur) stands, as in other scorpions, at right angles to the trochanter and partly underlies the left side of the carapace. It is broader and longer than represented by both Whitfield and Fritsch. It is partly broken off where one of the walking legs underlies it. Whitfield [*op. cit.* pl. 20, fig. 1, 3] represents this joint as directly connected with the chela or hand of a pedipalp seen in the specimen, by a short fourth joint (brachium or tibia), but Fritsch sees in this connecting broken film " a triangular sternum on which one discerns no further details," and " two oval opercular plates," adding that

both organs agree with those which he has figured from the recent Buthus. We have been unable to notice in the place where Fritsch figures the triangular sternum anything but a faint, irregular discoloration, such as is seen in many places on the slab. This appears too dark in the photograph and is therefore misleading. The opercular plates are more irregular in outline than would appear in the photograph, but the fact that they overlie the legs (hence lay inside of the same in the specimen), and their relative position to the comb which lies nearby, suggest the possibility of their representing the opercular plates.

The hand or chela in the specimen probably does not belong to the left pedipalp, as inferred by Whitfield, for from the crushed character of the " palm " of this hand we infer that it was the strongly bulging inner side, turned upward, and hence is the right chela thrown over on the left side. This inference is supported by the two strong joints which extend from the chela toward the posterior part of the carapace and are too broad and strong to have been joints of walking legs, as represented by Whitfield. The left chela and tibia are probably folded under the body.

The pedipalp of this scorpion was clearly a powerful organ and exactly corresponded in relative size to the pedipalp of recent species.

Of the walking legs but one projects beyond the confused mass of limbs. This has been the subject of much controversy. Both Whitfield and Scudder believed a double claw to be observed at the supposed terminal joint of this leg. Since the other Siluric scorpions, the species of Palaeophonus, are distinguished from all later scorpions by a single, spine-like claw, they rightly saw in this feature an important character connecting Proscorpius with the Carbonic and recent scorpions. For this reason Scudder created the subfamily Proscorpionini, which he placed under the family Eoscorpioidae, the Palaeophonoidae forming the other family of the older Anthracoscorpii. Thorell soon after pointed out that a close inspection of the figures gives the impression that the leg in question is incomplete, " being broken near the base of one—probably the last—of

the joints " and " that the ' bifid ' ending of the leg on the figures does, in fact, not at all give the impression of two claws, but resembles closely the also broken end of the right leg of the last pair in the figure of P a l a e o - p h o n u s   n u n c i u s   Thor. & Lindstr." Other reasons are cited by this eminent authority on the scorpions in favor of the closer relationship of Proscorpius with Palaeophonus, notably the cylindrical character of the joints, while in the later scorpions the tibia is compressed and convex longitudinally on the under side; and, also, the comparatively short joints of the legs. Pocock expressed similar doubts in stating [1901, p. 309] that " the apical segment of the leg is simply bifid at the tip, a feature which may be due to fracture, or may represent a pair of sclerites like those borne at the tip of the distal segments of the fourth leg of Limulus, or may be explained on the supposition that the end segment terminated in a sharp point as in Palaeophonus, and was furnished near the tip with a movable spine or spur." Pocock further points out " that there is no agreement between Scudder and Whitfield as to whether the segment stated to possess these claws is numerically the third or sixth from the base," and that further discussion of the matter is therefore idle. According to Scudder's interpretation the claws would be at the end of the third or fourth segment and are therefore not to be compared with the tarsal claws of other scorpions which were at the seventh joint.

Fritsch has raised the same objections as Thorell to Whitfield's and Scudder's view of the presence of two terminal claws, considering them as due to the wrong interpretation of fragments and pointing out that the tarsal joints which would carry the claws, must be much smaller.

The disagreement between two such trained observers as Scudder and Whitfield as to the number of joints is probably the best proof of the very unfavorable state of preservation of the leg in question, which, in fact, is in its distal portion but a faint impression, precluding positive assertions. Our view is that only the articulations drawn in by Scudder are such, since along them the joints are slightly set off, one of the other lines

being the margin of the palpus pressed through the joint of the leg; and that the " claws " are torn fragments of another joint, the latter being especially suggested by their blunt, unequal, triangular form, in contrast to the hooklike form of the double claws of the later scorpions, and the
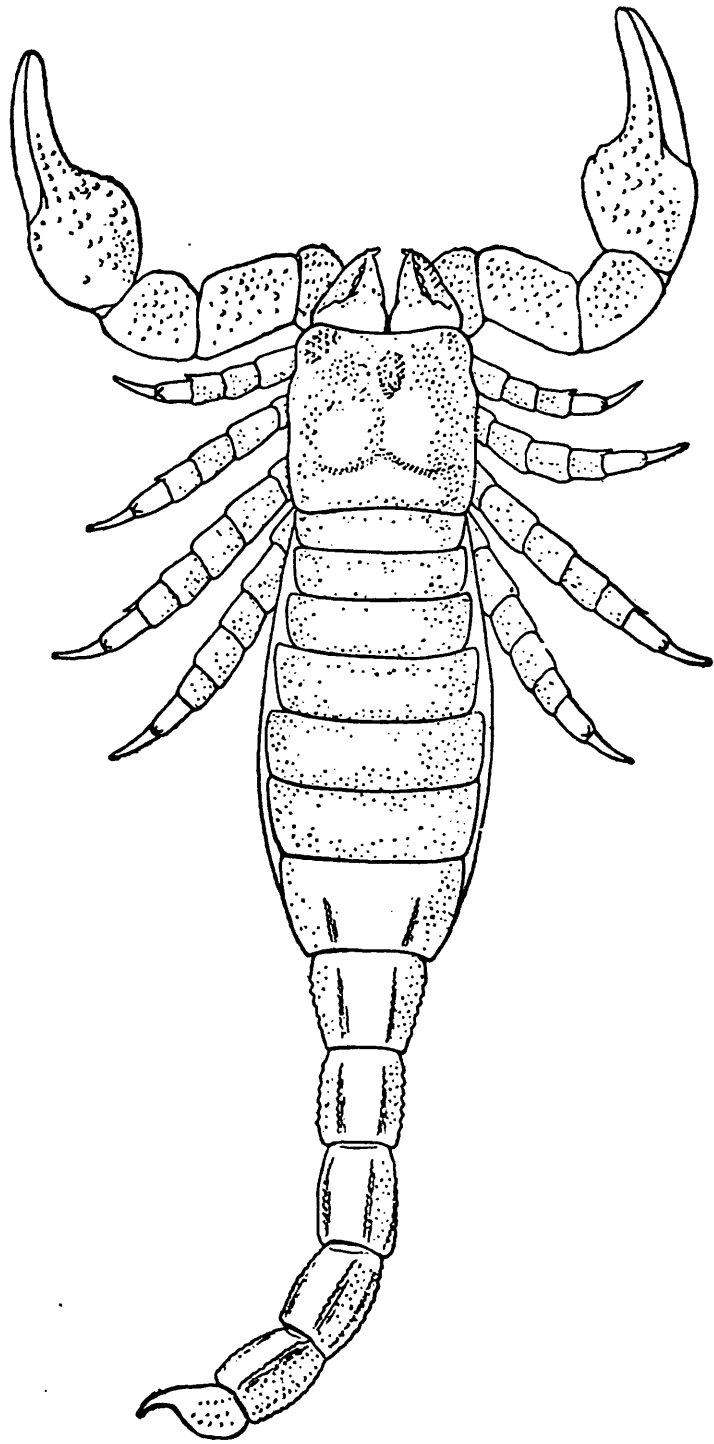
Figure 84 Restoration of dorsal side of P a l -
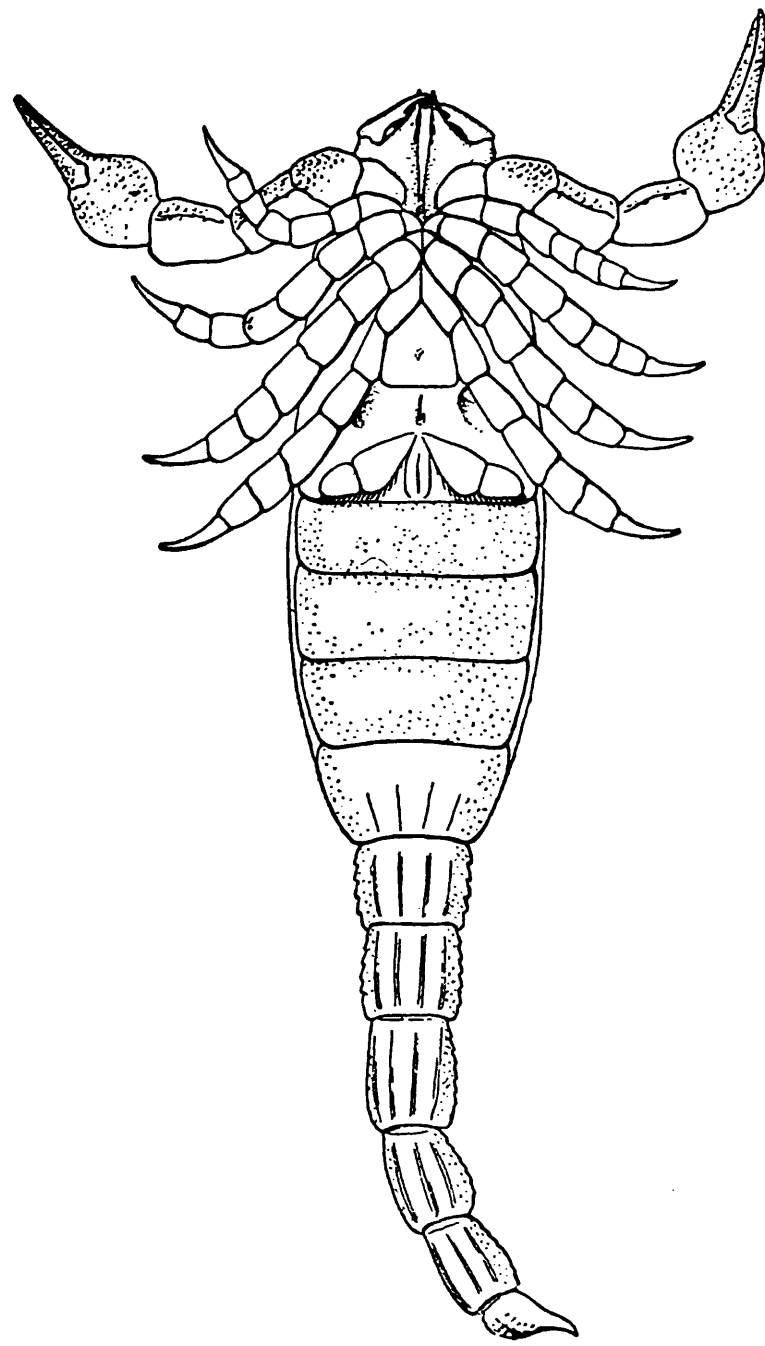aeophonus nuncius Thorell &
Lindström. (From Pocock)

Figure 85 Restoration of ventral side of P a l -
aeophonus hunteri Peach. (From
Pocock)

fact that their outer edges lie in the direction of those of the preceding joint. The leg, if complete, would also be relatively too short.

Scudder has also drawn a small spine at the base of the " penulti- mate " joint, which Whitfield [p. 187, footnote] states he has been

entirely unable to find. We have also failed to find in this place more than a faint, uncolored impression that is probably accidental. Palaeophonus bears a spine in a corresponding position on the second tarsus, and this fact may have induced Scudder's inference.

Although the presence of the two " claws " on which the separation of Proscorpius from Palaeophonus was mainly based [*see* Whitfield, p. 183] may be wholly illusory, Proscorpius is nevertheless a good genus. This is evinced by the marginal position of the eye lobe and the greater width and different lateral margin of the tergites. The general form of the carapace and the character of the legs, as far as perceivable, indicate that its closest relationship is with the other Siluric scorpions.

There are still two joints of another leg distinguishable on the left side. The three legs drawn by Fritsch on the right side of the carapace are due to deceptive shadows on the photograph, produced by irregular organic patches that lie in a higher layer of rock and apparently have nothing to do with the scorpion. It is desirable that this covering matrix be removed and a possibly complete right margin of the carapace exposed.

Fritsch was the first to observe the portion of the comb discernible on the left side. The specimen itself shows the fragments still more distinctly than the photograph, because the surface bearing them slants away from the light. Fritsch recognized fulcra and comb teeth and states that these remains indicate that this organ was of similar structure as in the younger scorpions.

The inspection of the specimen in good light has brought out the interesting fact that the test distinctly retains the bristles with which it was covered. They are most distinctly seen, and also thickest, on the carapace, but also visible on the tergites. The photograph fails to show them.

We may be allowed to touch upon the fascinating question of the original habitat of this waterlime scorpion, even though it can not, in the absence of the ventral side, furnish any direct evidence as to its mode of breathing.

Whitfield inclined to the view that the creature was aquatic mainly because he failed to find the stigmata on the supposed ventral plates. Thorell and Lindström considered P a l a e o p h o n u s   n u n c i u s , in which they observed a possible stigma on the ventral plate, as an undoubted air breather and have acclaimed this as the most important proof of a Siluric terra firma, with an air-breathing fauna. Laurie, in describing P a l a e o p h o n u s   l o u d o n e n s i s says [1899, p. 576] it does not necessarily follow that this scorpion was an air breather, since " the characters which mark it as a scorpion may well have been developed before the terrestrial mode of life and consequent modification of the respiratory organs took place." He adds that " unfortunately these respiratory organs are necessarily so delicate in texture that we know very little of their structure and arrangement in any of the fossil Arthropoda"; and Pocock [1901, p. 305] shortly after Laurie, argued that the Swedish P .   n u n c i u s lacked the stigmata, considering the stigma or spiraculum described by Thorell as a fortuitous crack in the integument, the part of the plate exposed belonging, according to his interpretation, not to the third mesosomatic somite, but to the second, which bears no stigmata in the scorpions. Pocock goes further and claims that the last two plates of the mesosoma of P .   n u n c i u s , considered by Thorell as tergites, are sternites and fail to show the stigmata which constituted Thorell's reasons for considering them as tergites. Pocock also failed to find the stigmata in P .   h u n t e r i , which Peach thought to have seen, and, believing that this Scottish specimen exposes the ventral side,[1] he assumes a sceptical attitude to the presence of stigmata in the Siluric scorpions. The idea that the Siluric scorpions lived on land, he says, is " less easy to reconcile with the facts that both the known specimens are relatively in an admirable state of preservation, and were met with in strata of undoubted marine origin, containing abundance of admittedly marine

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[1] Against this again it is asserted by Fritsch [1904, p. 64] that the specimen exposes the dorsal side and that only some of the ventral organs are pressed through the mutilated carapace and that it hence could not show stigmata.

organisms, than the belief, which I hold, that Palaeophonus lived in the sea, probably in shallow water, its strong sharply pointed legs being admirably fitted, like those of a crab, for maintaining a secure hold amongst the seaweed or on the jagged surface of rocks, and for resisting the force of the rising and falling waves."

We have seen above that Fritsch believed there were indications of lung sacs in P r o s c o r p i u s o s b o r n i , but inspection of the speci-men has failed to reveal any traces of respiratory organs.

Although the discussions of the authors cited demonstrate that the ventral side of the mesosoma is not shown well enough in any of the four Siluric scorpions to settle the question of the presence or absence of stigmata or the life habit of these scorpions, we feel that Whitfield's, Laurie's and Pocock's suggestion of their probable aquatic habitat is well worthy of serious consideration. It is therefore pertinent to summarize here the arguments in favor of this view.

1 All four scorpions have been found in marine beds and in such good preservation that it is difficult to assume they drifted out to sea; especially since the beds containing them do not afford any other remains of land animals or plants. On the other hand, we should note in this connection that they all four occur in association with eurypterids, and these are considered in this publication as having been principally inhabi-tants of estuaries. But this association may, as indicated under 3, have rather a phylogenetic than a physical cause.

2 If the Siluric scorpions agree with the recent ones in respect to the body form and arrangement of the prosomatic appendages, then it does not follow, as pointed out by Laurie [*loc. cit.* p. 577], that they have reached the same point of specialization in respect to their respiratory organs. " The terrestrial mode of life and consequent adaptation to air-breathing may have come later."

3 As Pocock has shown that the arrangement of the parts consti-tuting the ventral side of the prosoma in Palaeophonus indicates that the latter "occupies an intermediate position between Limulus and the

Eurypterida on the one hand, and recent scorpions on the other, standing, if anything, rather nearer to the former than to the latter"; it is probable that Palaeophonus and the closely related Proscorpius still shared an adaptation to water-breathing with their nearer related ancestors and relatives.

4 This suggestion is further strongly supported by the very primitive character of the walking legs of the Siluric scorpions and the fact that they appear better adapted to a marine life than a terrestrial one, as pointed out by Pocock. In fact the legs of Palaeophonus [text fig. 87] are so much like those of the eurypterids that they at once suggest a like use, and a like habitat of the animal; hence a' different one from that of the later scorpions.

5 In view of the latter suggestion, the fact of the association of the Siluric eurypterids becomes significant in indicating that these similar creatures had also a similar mode of life and the same habitat If they were still as nearly related as Pocock asserts, it is proper to assume that the two diverging branches had not yet sought different fields of action.

Figure 86   Fourth leg of a recent scorpion (B u t h u s a u s t r a l i s). (From Pocock)

Figure 87   Third leg of Siluric scorpion, P a l a e - o p h o n u s n u n c i u s . (From Pocock)

sp, spurs and lobate sclerites; ?sp, processes possibly representing the point of attachment of spurs in Palaeophonus; cl, claws

6 The possibility of a creature of the shape of the Siluric scorpion finding congenial conditions in the waterlime sea is clearly brought out by Eusarcus, which bears, especially in its earlier growth stages, a striking resemblance to the scorpion [pl. 36, fig. 1] as evinced by its specific name s c o r p i o i d e s , and that of the British congener, E . s c o r - p i o n i s . We have little doubt that Eusarcus and Proscorpius were close competitors in the same field. Through these Eusarci, Pro-
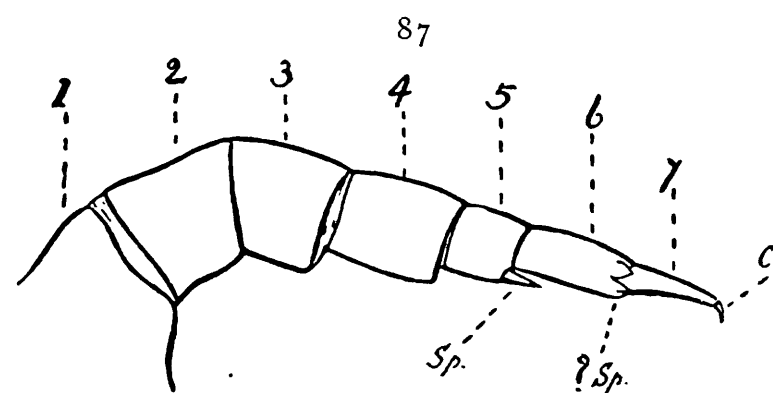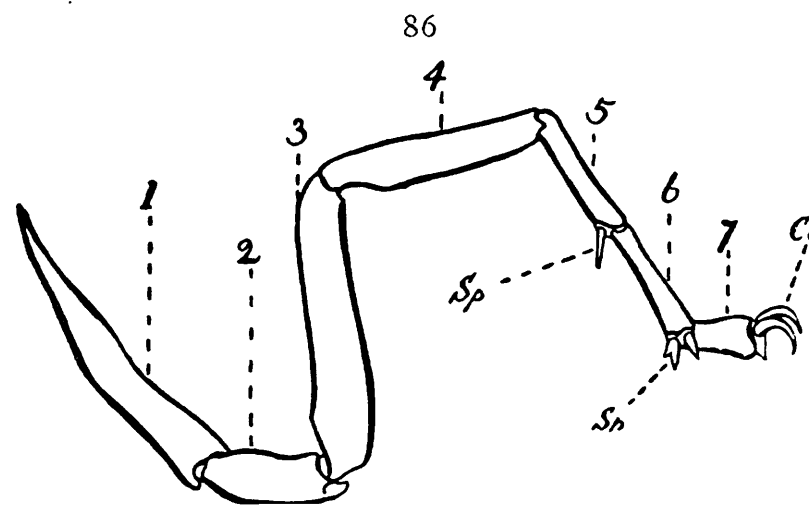
scorpius and Palaeophonus become also in aspect integral elements of the eurypterid waterlime fauna.

7 As Eusarcus and the Siluric scorpions are so much alike in their body form, they may be assumed to have had similar habits, and it follows that these scorpions were probably also given to burying themselves in the mud, waiting there for their prey as undoubtedly many of the eurypterids, and especially Eusarcus, did. In this connection the fact becomes extremely significant that P a l a e o p h o n u s   n u n c i u s was blind, according to Thorell and Lindström's observations, and that, for this reason, Lindström [1855, p. 8] infers some difference in habits from those of the recent scorpions,[1] and believes that it may have possessed a burrowing mode of existence.

It would be singular indeed if, of all the Siluric terrestrial fauna, the scorpions alone should have been repeatedly carried out to sea in a good state of preservation; much more plausible is the assumption of their coexistence in the sea with the similarly constructed and closely related eurypterids, with which their remains are found associated.

The genus Hastimima White

David White has described [1909, p. 589] under the name H a s t i - m i m a   w h i t e i certain fragmentary remains from the Carbonic plant beds ot Santa Catherina, Brazil, as doubtful plants, but under protest, as it were, after various paleontologists had failed to recognize them as belonging to any other group. Seward [1909, p. 484] has referred a similar fragment from the Witteberg series of South Africa to Hastimima, suggesting that it represents part of a body segment of an eurypterid. This suggestion was fully verified by Henry Woodward after inspection of the specimen. This pioneer and leader among the investigators of eurypterids, has also subjected White's photographs of the Brazilian types to critical notice

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[1] Thorell [op. cit. p. 22] cites for comparison the single known recent scorpion which is destitute of eyes, namely, B e l i s a r i u s   x a m b e u i .

[1909, p. 406], and has recognized the two largest fragments as parts of a segment and a telson of an eurypterid, referring them tentatively to Pterygotus; and the smaller fragments as portions of segments, the sculpturing of which recalls that of certain later species of Eurypterus, such as E. punctatus and E. hibernicus. He suggests that the Brazilian material of Hastimima includes specimens of more than one species, if not of more than one genus.

Figure 88 Hastimima whitei White. Fragment of tergite. Natural size

Through the courtesy of the National Museum, we have been enabled to study the Brazilian specimens of Hastimima and have derived the following notes on these interesting fossils.

The material, although fragmentary, includes three specimens that may be referred without doubt to parts of the integument of an eurypterid and these we describe more fully.

One is a portion of a segment, another of the telson and a third a proximal part of a leg with the coxa.

The fragment of a segment is represented by White's figures 1, 1a, and 2 of plate 10.

The first [text fig. 88] is a subtriangular fragment bounded on two sides by the original margins that meet in an acute angle. One of these margins is

much thickened and produced at an angle into a falcate lobe; and the other is marked by a distinct darker band obviously representing a doublure. The thickened margin shows different surface sculpturing on the two surfaces that are separated by matrix, and is also due to a doublure. From the direction of the droplike surface scales or spines and the form and direction of the lobe at the angle, as well as the presence of the doublures on the margins, we infer that the fragment is the postlateral portion of a segment. From its angular form we further infer that it belongs to a tergite and from the fact that the lateral thickened margin rapidly diverges in posterior direction from the main axis, that it was an anterior tergite and also that the preabdomen of this species must have rapidly expanded, as in Eusarcus.

The ornamentation is distinctly eurypteroid. It consists of widely separated, rather irregularly distributed, blunt or club-shaped spines; on the body of the tergite of closely arranged oblong to angular interior thickenings of the upper test of the thickened lateral margin, and one row of subangular impressed scales, probably originally spines, along the posterior margin. The scales of the lateral margin are also impressed on the cast of the underside of the integument and consisted of local thickenings.

The second determinable fragment is the posterior portion of the telson. Its detail is well shown in White's photographs [*op. cit.* pl. 10, fig. 3, 4]. It is acutely hastate in outline and of somewhat complicated structure. Our conception of it as obtained from the relievo and intaglio specimens, is best understood by the diagrammatic transverse section, text figure 92. It consists of two separate laminae. One of these is covered with the large droplike scales as on the rest of the integument and for this reason is considered by us as the dorsal lamina. The other is smooth. The interspace between the two is occupied by rock, as shown by a patch clinging to the dorsal side. The dorsal side was of one uninterrupted lamina, as is well shown at the proximal end of the intaglio; the ventral side, however, consisted of two laminae, separated by a median cleft. This is distinctly shown by the proximal and distal ends of the specimen [text fig. 90]; at the
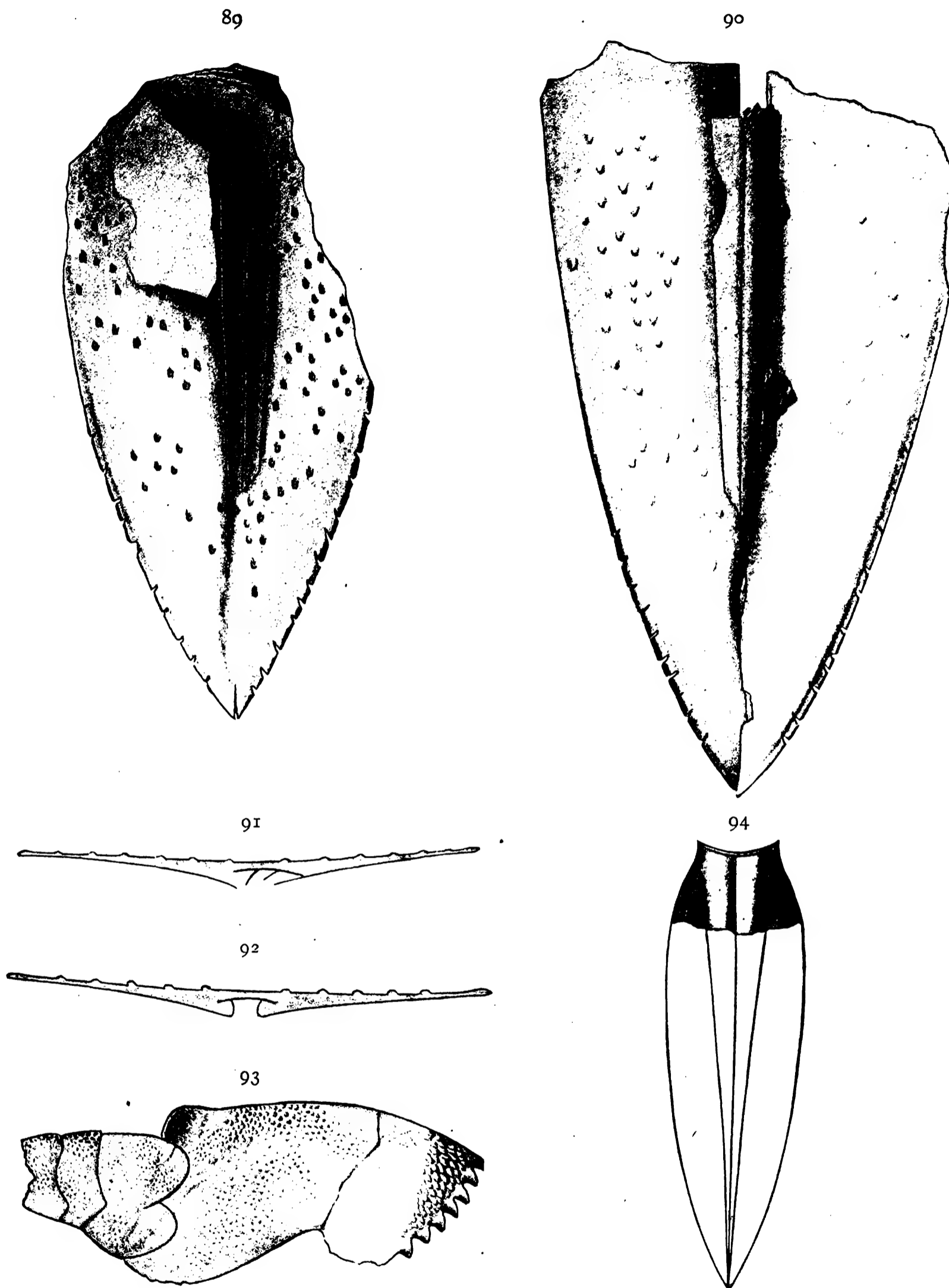
Figures 89–93 H a s t i m i m a w h i t e i White. Figure 89, dorsal view of telson; figure 90, ventral view of telson; figure 91, transverse section of proximal end of telson; figure 92, restoration of transverse section of telson; figure 93, coxa, with several attached leg segments. Natural size

Figure 94 Eurypterus ? Salter, from Coal Measures at the Joggins, Nova Scotia

proximal end a transverse section of the lamina is seen and a broad cleft
exposed while at the distal end the interior margin of one of the laminae
is pushed over the other.   A third element of the telson consists of a thicker,
narrower longitudinal plate intercalated between the dorsal and ventral
plates along the median line.   The transverse section at the proximal end
of the telson fragment gives the view reproduced in text figure 91.
The median plate is seen resting on one of the ventral plates without being
attached to it, and beneath it the sections of two inclined plates are notice-
able.   The latter were, we surmise, originally the supporting plates of
the median plate, as shown in reconstruction in text figure 92.   While
this structure reminds one of the T-like keel of the underside of the telson
of Eurypterus, it differs from the latter in being introverted between the
two plates instead of standing out on the ventral side.

Along the median line of the middle plate, just above the median
ventral cleft, a suture passes.   The presence of the cleft and of the middle
plate with the median suture, all combine to suggest that the two halves
of the broad telson may have been capable of being bent slightly in the
back stroke of the flapping telson.

The margin of the telson has a thickened rim which is cracked at
irregular intervals, as in Eurypterus, giving it a serrate appearance.

The third fragment is the proximal portion of a leg [text fig. 93].
It retains the coxa with the gnathobase and portions of the three suc-
ceeding segments.   The form of the coxa would indicate that it be-
longs to an endognathite.   Its form is elongate quadrangular; the man-
ducatory edge is slightly curved and bears a series of nine or more, rather
blunt teeth, which become flatter posteriorly.   The part adjoining the
manducatory edge is furnished with a pavement of flat polygonal scales
which are elongate and slightly imbricated near the anterior edge.   The
rest of the coxa bears small subcircular flat scales and minute tubercles.

The outlines of the following segments of the leg are very faint and can
be made out only with difficulty by turning the specimen to the light.
The surface of these segments is finely granulate.

Besides these three more important fragments there are small patches of lobate fringes such as the posterior margins of the tergites of the later eurypterids frequently exhibit. Their variation in length and form, as well as their characteristic sculpturing, are shown in White's photographs, reproduced on his plate 11, figure 2, 2a, 6-10. The smaller of the lobes, which are invariably blunt and closely arranged, are smooth on the underside and show the impression of spines or short bristles on the other. The adjoining integument shows a pavement of polygonal scales similar to those observed on the gnathobase of the coxa. The largest lobes reproduced by White in figure 2, 2a of plate 11 are rounded and thick and represent a radiating group of stout, hollow processes. These are also covered with oblong, umbilicate impressions, obviously the molts of imbricating plates with perforations that probably were connected with spines.

We may point out in this connection that Salter in 1862 [p. 78] described as *Eurypterus* (?) from the Coal Measures at the Joggins, N. S., the proximal portion of a telson which seems to be a fair expression of the posterior portion of such a telson as that of H a s t i m i m a w h i t e i, even down to the suture of the median carina. We introduce here [text fig. 94] a copy of the Joggins specimen with the outline restored to correspond to that of the telson of Hastimima. This telson fragment is associated with fragments of segments bearing the characteristic thick, drop-shaped or club-shaped tubercles of the later eurypterids. It has been kindly loaned to us by Professor Frank D. Adams from the Redpath Museum of McGill University. We agree with Salter " that it can hardly be supposed to be other than the caudal joint (broken) of an Eurypterus or allied form." It is evident from the specimen that there was an elevated median part, apparently with a sulcus in the middle, flanked by two lateral wings with a flat border.

The Brazilian fragments of the segment and telson are so much alike in their ornamentation that they are safely referred to the same species and genus and properly considered as the type specimens of the eurypterid

H a s t i m i m a w h i t e i , and it is probable that this generic term will have an independent value, for though the telson in its outline is certainly comparable to that of certain species of Pterygotus, as P . m i n o r Woodward, its section is totally different from that of any of the Pterygotidae and the fragment of segment indicates a different inclination of the side of the body than is observable among other pterygotids.

Note on Sidneyia inexpectans Walcott

Among the remarkable remains which have been described by Dr C. D. Walcott from the Cambric is a wonderful arthropod S i d n e y i a i n e x p e c t a n s, which has been brought to public notice just as this work is completed.[1]

This organism is extraordinary in the preservation of its anatomy and as both it and its associate, A m i e l l a o r n a t a , are referred by Dr ¡Walcott to the Merostomalta, they invite brief notice in this place. Both are from the Middle Cambric (Stephen formation) of British Columbia.

A m i e l l a o r n a t a is based on a fragmentary portion of an abdomen and for this reason will not be included in our annotations. These refer entirely to the splendid material secured of the species S i d n e y i a i n e x p e c t a n s .

Sidneyia and Amiella are united in a new suborder L i m u l a v a of the Eurypterida.

The suborder is described as follows:

Body elongated with a thin epidermal skeleton either smooth or ornamented by lines or ridges. Cephalothorax with lateral or marginal eyes, on the ventral side with five pairs of movable appendages; mouth posterior to a large epistoma.

Abdomen with twelve segments, the anterior nine of which have a pair of ventral appendages to which the branchiae are attached; the posterior segment has a central spatulate-shaped section that, combined with swimmerets, forms a strong caudal fin.

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[1] C. D. Walcott. Middle Cambrian Merostomata. Smithsonian Miscellaneous Collections. 1911. v. 57, no 2. p. 15.

The description of the branchiae will be found under the description of Sidneyia, the typical genus of the Limulava.

Observations. The suborder Limulava differs from the Eurypterida, to which it is most nearly related, in having a large epistoma similar to that of the Trilobita; in not having a metastoma, chelate antennae, and swimming cephalic appendages; and in having a broad, fan-shaped caudal fin, and branchial appendages more or less unlike the lamellar branchiae of the Eurypterida and Xiphosura.

The relations of the order and suborder are shown in the following tabular view:

Subclass MEROSTOMATA

Order Eurypterida	Suborder Limulava
1 Cephalothorax long	1 Cephalothorax short
2 Cephalothorax with six (6) pairs of appendages; the anterior pair chelate antennae, and the posterior pair, long, strong swimming legs	2 Cephalothorax with five (5) pairs of appendages; the anterior simple antennae, the third pair multichelate, and the posterior pair short, the outer joint serving as a branchial organ
3 Epistoma present in Pterygotus where it is narrow. Metastoma large	3 Epistoma large. Metastoma unknown
4 Six anterior abdominal segments bear leaflike branchial appendages	4 Nine anterior abdominal segments bear leaflike branchial appendages
5 Surface of test with scalelike ornamentation	5 Surface of test smooth or with imbricating lines, as in many of the Trilobita
6 Terminal segment a simple lanceolate or spatulate telson	6 Terminal segment a caudal fin formed of a central expanded telson and one or more swimmerets on each side

In view of the unusual structures here set forth it is germane to this work to inquire whether these Limulava should be construed as belonging to the Eurypterida in the capacity of a suborder or if they may not more properly assume a higher grade as an independent and coordinate group.

The Eurypterida, as represented by the genera hitherto referred to them, constitute a very compact order with well fixed characters. If

we place the Limulava with them their definition has to be completely changed.

In the Eurypterida the cephalothorax bears six pairs of appendages, the first of which are chelate antennae or chelicera; these are apparently absent in Sidneyia inexpectans, where there are only five pairs, the first of which consists of simple antennae. In Slimonia the corresponding pair of legs is also tactile and the antennae of Sidneyia apparently bore coxae, so that the character of the first pair of legs would not constitute a difference of more than generic value. Chelicera, however, are characteristic of the Eurypterida, and if Sidneyia is an eurypterid, it is to be assumed that these, often delicate organs, will be found on further research. The third pair of legs is one of the remarkable features of this organism. It is described as " multichelate," or as possessing "broad, strong joints in small specimens, and in large specimens it is developed into peculiarly constructed and complex chelate terminal sections; this is formed of twelve or more joints of a forward curving appendage to which are attached on the anterior side long spines carrying numerous smaller spines on the margin opposed to the main body of the appendage." If indeed the leg consists of two jointed appendages, as reproduced in *op. cit.* pl. 4, figures 1 and 4, then we have here a biramous leg such as would be characteristic of the Crustacea in contrast to the Merostomata, and a feature which indicates that the fossil is a crustacean rather than an arachnid. The long bladelike appendages resemble those of the legs of Stylonurus excelsior and Echinognathus clevelandi and might, like the latter, have served to make a swimming organ of the third pair of legs. There is still a bare possibility that they are analogous to the male clasping organ observed by Holm on the second walking leg of Eurypterus fischeri and which had a sexual function. However that may be, these complex legs of Sidneyia are important in showing a certain advanced adaptation of the genus in the form of these organs. The last pair is described as short and bearing an outer, broad joint or palp fringed with five branchial setae or spines. This is another character entirely foreign to the arachnids and ascribable to the crustaceans.

The carapace is stated to possess a large epistoma and to lack a metastoma. In eurypterids the epistoma is only known in the Pterygotus-Slimonia group. It is there a separated part of the marginal shield and originated from a part of the carapace being bent over, as shown by the direction of the sculpture. The organ figured as epistoma of Sidneyia (*op. cit.* pl. 5, fig. 3) is hardly comparable to the epistoma of Pterygotus, as it is not separated by sutures from the marginal shield. The view referred to is obviously a dorsal one and there seems to us much probability that the large " epistoma " may prove to be the anterior part of the carapace pushed out of position.

There is nothing visible in the figures of these finely preserved remains to suggest the presence of a metastoma. The latter is distinctly a characteristic and important organ of the order Eurypterida. If it is actually absent in the Limulava this fact would militate against the inclusion of the latter in the eurypterids.

The most important differences between the Eurypterida and Limulava appear, however, in the constitution of the abdomen. The abdomen of the Eurypterida consists invariably of six tergites on the dorsal side, to which correspond five sternites on the ventral side, and six ringlike postabdominal segments. Sidneyia, however, appears to possess as many segments on the dorsal as on the ventral side. The operculum or first ventral plate which covers both the first and second segment and which bears the genital appendage, was hence not yet developed. This would be a most primitive condition, as compared with the eurypterids, and constitutes a difference of ordinal rank. Sidneyia is further described as bearing branchiae on nine segments. The Limulava have accordingly nine abdominal segments and but three postabdominal segments, for the gill-bearing ventral segments must be movable plates of the character of sternites. This is also a difference of ordinal rank, for the number and division of segments in the Eurypterida is absolutely fixed, but if Sidneyia is in any way related to the ancestral stock of the Eurypterida it is bound to throw most interesting light on the morphogeny of the abdomen. The gills themselves must also have

been different from those of the eurypterids. As a rule the eurypterids show only the attachment areas of the branchiae, but the gills themselves are, as in Limulus, extremely delicate, leaflike appendages visible only under the most favorable conditions, when separated from the body. The gills of Sidneyia as figured lack the thickened attachment scars and are themselves of such size as to overlap several sternites (*op. cit.* pl. 2, fig. 1; pl. 6, fig. 3), all features that are not found in the eurypterids or Limulus.

The most picturesque feature of the Sidneyia is its fanlike tail, consisting of the last segment and one or more swimmerets on either side. The development of such a tail fin is not entirely absent in the Euryp-terida, as evidenced by the bilobed tail of Erettopterus, but it is the telson spine in the latter genus which assumes the finlike form, while here the swimmerets are attached to the anterior side of the last segment. The telson spine is therefore apparently not developed in Sidneyia and it would seem possible that the swimmerets are a further development of the lateral lobes of the last segment. We infer from figures 2 and 3, plate 3 of Mr Walcott's paper that they may even have been articulated. As pointed out by Mr Walcott, this telson is like that of the Macrura and it is a feature foreign to the eurypterids.

It seems to us probable that the Limulava as described are not eurypterids, but constitute a primitive order, though exhibiting some remarkable adaptive features. This order possibly belongs to the Merosto-mata but it is distinctly allied to the crustaceans in such important char-acters as the structure of the legs and telson, and is therefore much gen-eralized.

Mr Walcott has rightly pointed out the similarity in the carapaces of Strabops and Sidneyia and suggests that Strabops may have but five pairs of cephalothoracic appendages. Strabops, however, has the eyes and telson spine of an eurypterid and the similarity of the carapaces is probably due to the primitive nature of both genera.

EURYPTERIDS FROM THE NORMANSKILL SHALE OF NEW YORK

After the foregoing discussion of the Frankfort shale eurypterids had been prepared our attention was directed by Professor G. H. Chadwick to similar remains which he had observed in the sandstones of the Broom street quarry at Catskill, N. Y.   The only fossils heretofore known from the so called "Hudson River beds" about Catskill are the Normanskill graptolites, indicating horizons of Upper Chazy age,[1] and the presence of eurypterid remains in this early stage was a matter of so much interest as to justify a careful examination of the locality.

The lithologic and faunal conditions at the Broom street quarry exposure were found to be a singularly complete duplication of those of the eurypterid-bearing exposures in the bluestone quarries at Schenectady. The Broom street quarry is also a bluestone quarry, the rock being mostly used in the crusher.   The courses of "bluestone" (here an impure argillaceous sandstone) are very compact, from 3 to 30 feet thick between the intercalations of black shales.   There is distinct evidence of shallow-water conditions, one bed being conglomeritic and largely composed of pebbles, many of which appear to be mud pebbles; another beautifully exhibiting very regular, widely separated wave marks with winnows of comminuted seaweeds and eurypterids in the troughs.

Quite as in the bluestone quarries of the Schenectady beds, the surfaces of some of the sandstones are densely covered with rather poorly preserved seaweeds and eurypterids.   It was therefore natural to expect that here too the black intercalated shales would contain better material

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[1] In the body of this work the species from the Schenectady beds have been referred to the "Schenectady facies" of the Frankfort beds.   Investigations since carried on by the junior author in the thick formation of sandstones and shales in the lower Mohawk valley, hitherto referred by all authors to either the Hudson River shale or the Frankfort beds, have shown that the faunal differences which induced us to distinguish the beds as Schenectady facies are of such nature that the whole formation has to be placed within the middle and upper Trenton.   It will therefore in a forthcoming bulletin be distinguished as the *Schenectady formation*.

of these fossils and possibly also graptolites that would indicate the age of the beds. They have indeed afforded a layer with an association of finely preserved seaweeds, the eurypterids herewith described, and the following graptolites: D i c e l l o g r a p t u s   g u r l e y i Lapworth, C l i m a c o g r a p t u s   b i c o r n i s Hall, C l i m a c o g r a p t u s b i c o r n i s var. p e l t i f e r Lapworth, C r y p t o g r a p t u s t r i - c o r n i s (Carruthers), the first three forms in great abundance. This graptolite association is one of undoubted Normanskill age. The sea-weeds occur in large perfect fronds [1] and are of the same type as those in the Schenectady shale. The eurypterids also are strikingly similar to those from the Schenectady beds.

In one case (P t e r y g o t u s ? n a s u t u s) we have been unable to distinguish the Schenectady and Normanskill types. This striking similarity of the two faunas (one of Chazy, the other of Trenton age) amounting almost to identity, seems to indicate a very slow progressive development of the eurypterid faunas, probably owing to their early

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[1] More or less shapeless patches of these seaweeds and possibly also of eurypterid integument from the Normanskill shale at Kenwood near Albany were described by R. P. Whitfield [Am. Mus. Nat. Hist. Bul., v. 1, no. 8, 1886, p. 346, pl. 35] as *Rhom-bodictyon* and referred to the sponges on account of an apparent spongelike fibrous structure consisting, according to Whitfield, of two or three sets of rods, the principal ones of which are " straight, rigid and apparently cylindrical." This peculiar struc-ture is shown by all the thicker specimens from the shale of the Broom street quarry and is there obviously only a system of parallel shrinkage or cleavage cracks found wherever the carbonaceous films become rather thick; and is entirely independent of outlines of the fossil but strictly parallel on all fossils of the same slab, thereby indi-cating its connection with a latent cleavage of the folded beds. The parallel main cracks are connected by more irregular cross cracks, the whole forming a very decep-tive pattern. Sometimes these cracks have become secondarily filled by calcite or pyrite and the carbonaceous matter subsequently destroyed, whereby an apparent spongelike system of rods has resulted. Inspection of Whitfield's types in the Amer-ican Museum of Natural History has shown that the types of the two species of Rhom-bodictyon are of quite the same nature as the thick carbonaceous patches of seaweeds from the shale at Catskill.

adaptation to particular marine conditions. Similar stability of the eurypterids is also suggested by the identity or extremely close relation-·ship of the species in the Shawangunk grit at Otisville and the possibly older beds at the Delaware Water Gap and Swatara Gap [*see* p. 417] in Pennsylvania; and again in the probably somewhat younger McKenzie formation of Pennsylvania [*see* p. 88], and finally also by the continuation of the same genera apparently from the Ordovicic, but surely from the Siluric into the Carbonic. The eurypterids are then, as a rule, to be accorded but little value for purposes of correlation.

The following species are quite obviously but a meager part of the eurypterid fauna of the Normanskill stage, and future discoveries, now that the attention of collectors is directed to these interesting fossils, will undoubtedly add much to the list. As in the Schenectady shale the generic determinations are entirely provisional, as but few legs and telsons have been found in connection with the carapaces and fragmentary abdomina.

Eurypterus chadwicki nov.

See text figure 95

Carapace semioval to semicircular; lateral and frontal margins form-ing a uniformly rounded curve; length to width as 2 : 3; basal margin straight transverse. All margins apparently with a broad flat border. Lateral eyes large, about one fourth the length of the carapace, elliptical in outline, prominent, situated for-ward, in front of the middle transverse line, less than their length distant from the margin. Length of cara-pace of type, 11.6 mm; width, 16.2 mm.

Fig. 95 Eurypterus chadwicki nov. Holotype. x 1.5

Eusarcus linguatus nov.

See text figures 96, 97

Carapace semioval, with a tonguelike process in front; length to width as 4 : 5. Lateral margins moderately convex; frontal margin produced into a squarish process with rounded anterior angles; one

fourth the width and one eighth the length of the carapace; basal margin slightly concave, the postlateral angles subrectangular. Eyes marginal, circular, small, a little longer than one fifth the length of the carapace, situated in an angle between the lateral margins and the base of the frontal process. Surface densely covered with relatively large flat nodes. The type measures 9.4 mm in length and 10.5 mm in width.
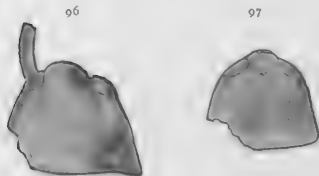

Fig. 96, 97 Eusarcus linguatus nov. Fig. 96 Holotype. x 2. Specimen somewhat distorted. Fig. 97 Cotype. x 1.5. Younger individual showing traces of the sculpture, the frontal process and the ocellar mound

This species strongly suggests the Eusarcus vaningeni, with which it has not only the peculiar anterior snout in common, but also the general outline and the position of the eyes. It is also closely related to the species here described from the Normanskill and Schenectady shales as Pterygotus? (Eusarcus) nasutus, which possesses a less prominent anterior process and more distant eyes but is very similar to this species in outline and surface ornamentation.

We also refer to this species a number of specimens which correspond to the above description in all particulars but lack the anterior process and assume that the latter may either be broken off or be folded under normally like the epistoma of Pterygotus; with present material we have no means of deciding which.

Dolichopterus breviceps nov.

See text figure 98

A small carapace differs from the others in the position of its lateral eyes which are submarginal in the antelateral angles, thereby suggesting the presence of a species of Dolichopterus. The carapace is rather short subquadrangular, its length to its width as 5 : 7; the lateral margins slightly concave, diverging forward at a small angle, the frontal margin broadly
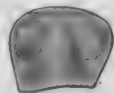

Fig. 98 Dolichopterus breviceps nov. Holotype. x 3

convex, the antelateral angles prominent, well rounded; the basal margin straight transverse. The lateral eyes are large, a little more than one third the length of the carapace, subcircular, situated as stated. The type is 4.7 mm long and 5.5 mm wide.

Stylonurus modestus nov.

See text figures 99–101

This species is based on several small carapaces with portions of the abdomen and a leg [*see* text fig. 99] which suggest the following description:

Carapace subrectangular, broad, length to width as 5 : 8. Lateral margins nearly straight, slightly converging forward, anterior margin gently emarginate in the middle, posterior margin straight transverse. Lateral eyes very large, between one half and one third the length of the carapace, circular, situated subcentrally, as far apart as their length Basal margin straight transverse. Lateral and anterior margins with a broad thick border, probably originating from a doublure on the underside. Body slender, hardly expanding posteriorly and gradually contracting to postabdomen. One leg [*see* text fig. 99] observed which appears to consist of spineless tubular, striated segments, as in Stylonurus. Length of carapace of type [text fig. 99], 5 mm; width, 7.5 mm.

We have referred this species to Stylonurus rather than to Eurypterus on account of the aspect of the carapace, with its broad border, large eyes and broad, subrectangular outline; the slender form of the body, and the character of the leg which resembles the posterior walking leg of Stylonurus.

Fig. 99–101 Stylonurus modestus nov. Fig. 99 Holotype. x 2. Specimen showing carapace, with broad border, portion of walking leg and of abdomen. Fig. 100 Small well preserved carapace, showing the subcircular eye nodes. Cotype. x 2. Fig. 101 Specimen with similar carapace to preceding, broad border, large eye nodes, and very slender abdomen. Cotype. x 2

Pterygotus ? (Eusarcus) nasutus nov.

See text figures 102, 103

A number of carapaces from Catskill fail to show any distinguishing features from P t e r y g o t u s ? (E u s a r c u s) n a s u t u s (described on p. 382) from the Schenectady beds at Schenectady, and we therefore refer t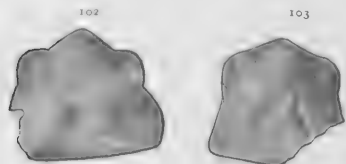hem to that species, although the considerable difference in age between the forms makes it somewhat improbable that they are conspecific. The sculpture is well shown in several specimens and consists of flat closely arranged rather large nodes or tubercles, as in E u s a r c u s n a s u t u s. A like sculpture is shown in some of the specimens from the Schenectady shale.

Fig. 102, 103 P t e r y g o t u s ? (E u s a r c u s) n a s u t u s nov. Two carapaces showing the characteristic angular front and the position of the eyes. Fig. 102 x 2; fig. 103 x 1.5

In the first description the species is assigned to Pterygotus, but the closely related species from these Normanskill shales, E u s a r c u s l i n g u a t u s, indicates that it may more likely be an Eusarcus.

Pterygotus normanskillensis nov.

See text figure 104

This name is proposed for carapaces of distinctly pterygotoid aspect.

Carapace broadly subrectangular, three fourths as long as wide; lateral margins subparallel, slightly convex, antelateral angle distinct, abruptly rounded; anterior margin broadly and evenly convex. Basal margin slightly concave in middle, postlateral angles approximately rectangular. Lateral eyes marginal, situated in the antelateral corners, elliptic, small, less than one fourth the length of the carapace. Surface sculpture not seen. Measurements of type specimen, length, 11 mm, width, 15 mm.
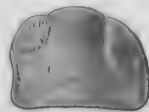
The presence of a genus of the Pterygotus group

Fig. 104 P t e r y g o t u s n o r m a n s k i l l e n s i s nov. Holotype. x 1.5. The parallel lines indicate the cleavage lines appearing in the carbonaceous film

is also attested by telsons, some of which
indicate a true Pterygotus [*see* text fig.
106] while others suggest forms of Eret-
topterus [*see* text fig. 107].' We also fig-
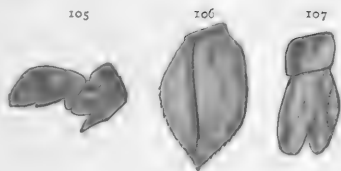ure with these a swimming leg, possibly
belonging to this group.

Fig. 105-7   Fragments of Pterygotidae. Fig. 105
Swimming leg. x 2. Fig. 106   Telson of a
true Pterygotus. Fig. 107   Probably of an
Erettopterus. Both x 2

EURYPTERIDS FROM THE SHAWANGUNK GRIT IN PENNSYLVANIA

On a previous page [87] reference is made to the occurrence of obscure
eurypterids in the Shawangunk grit of the Delaware Water Gap, Pennsyl-
vania. The material we then had proved indeterminable, but since then
through the courtesy of Professor Gilbert van Ingen we have had oppor-
tunity to examine a very large number of specimens from the same locality
recently acquired by him and Mr J. C. Martin. In regard to the horizon
Professor van Ingen writes:

These eurypterids are from the third quartzitic conglomerate, " Medina
white conglomerate, no. 2 " of section B, at Delaware Water Gap, which
is published as plate I, 1882, Report G6 (Second Pennsylvania Geological
Survey). They come from about the middle of this band, and occur in
thin seams of black shale of very irregular extent horizontally and of
variable thickness and character vertically. Some of the shale seams
have none, others abound in the eurypterids.

It thus appears that the occurrence of the eurypterids at the Dela-
ware Water Gap is the same as that in the Shawangunk grit at Otisville.

Unfortunately the maceration, already so prevalent in much of the
eurypterid material at Otisville, has at the Delaware Water Gap reached
such a destructive degree that the shale is filled with a mass of comminuted
eurypterid fragments; and to complete the destruction the chitinous sub-
stance has also been chemically altered until it has a slickensided and
silky appearance and for the greater part has lost all trace of sculpture.
Owing to this extremely unfavorable condition of the material, only a
few small carapaces and patches of integument warrant description, although

there is plenty of evidence that the eurypterids in these waters of the Shawangunk sea reached considerable size and occurred in great profusion.

The best specimens are identical or very closely related to the following species from Otisville:

1   D o l i c h o p t e r u s   o t i s i u s Clarke. A number of carapaces with the characteristic subtrapezoidal outline. Three of these, at least, show the position of the compound or lateral eyes and the marginal doublures.

2   E u r y p t e r u s   m a r i a Clarke. Carapaces with the very uniformly rounded outline of that species but not exhibiting the eyes.

3   S t y l o n u r u s cf. m y o p s Clarke. Its presence is suggested by a patch of integument with the peculiar sculpture of that species. The sculpture resembles especially that of plate 53, figure 2.

4   H u g h m i l l e r i a   s h a w a n g u n k Clarke. A segment with the characteristic linear sculpture. Also several carapaces are referable to this species.

5   P t e r y g o t u s cf. g l o b i c e p s Clarke & Ruedemann. A very small somewhat distorted carapace of a Pterygotus may well represent this species.

Professor van Ingen has also succeeded in discovering still another · eurypterid fauna southwest of the Delaware Water Gap, at the Swatara Gap, Lebanon co., Pa. The interesting feature of this fauna is that it occurs in association with marine fossils suggesting horizons lower than the Salina and corresponding to parts of the Niagaran, possibly as low as the Clinton.

Eurypterid remains were encountered in three beds distinguished as: *182 B 16h, 182 B 23* and *182 C 4x.*

182 B 16h, an olive gray sandy shale, has furnished:

1   Small carapaces, belonging to species closely related or identical with E u r y p t e r u s   m a r i a , H u g h m i l l e r i a   s h a w a n g u n k and P t e r y g o t u s · g l o b i c e p s

2 A patch of integument with finely preserved sculpture, identical with that ascribed here to S t y l o n u r u s sp. *a* and represented on plate 53, figures 10-12

3 S t y l o n u r u s cf. m y o p s . Fragmentary medium sized carapace

    4 Coxa, probably belonging to Hughmilleria

    5 Small telson of an Erettopterus

182 B 23 has afforded a carapace showing the position of the eyes, and not distinguishable from E u r y p t e r u s m a r i a .

182 C 4x contains:

    1 E u r y p t e r u s m a r i a. Large and small carapaces

    2 D o l i c h o p t e r u s cf. o t i s i u s . Medium sized carapace

    3 S t y l o n u r u s m y o p s . Large and small carapaces

    4 H u g h m i l l e r i a s h a w a n g u n k . Large carapace

    5 P t e r y g o t u s cf. g l o b i c e p s . Small carapace

    6 Swimming leg of a Pterygotus or Hughmilleria

These faunules are so similar in their aspect and composition to that of the Shawangunk grit at Otisville, that, although they are too fragmentary for a conclusive identification, it seems proper to infer that they belong to the same or an approximate horizon. It is, therefore, of much interest that Professor van Ingen has in the Swatara Gap section obtained good evidence that these beds which also correspond to the Shawangunk grit in lithology and stratigraphy, contain marine fossils of much greater age than the Salina. Professor van Ingen states that *B8x* of his section carries an apparently Clinton fauna, and *B19x* a Rochester (or Lockport) fauna, while *182 C 4x* contains A r t h r o p h y c u s cf. h a r l a n i Conrad. It will be noticed that the fairly good Shawangunk grit fauna, cited from *B16h*, comes from an horizon between these beds.

Alternative hypotheses are suggested by this recent work; either that the Shawangunk grit is older than Salina age; or in view of the vast thickness of beds of like lithologic character in central Pennsylvania containing the eurypterid fauna of Otisville aspect, these rocks may represent

a very long Upper Siluric time interval, of which a late stage only is repre-
sented by the thinner northern extension into the Shawangunk mountains.
Here again, as in the fauna of the Normanskill and Schenectady beds,
the eurypterids may have changed but very little through several geologic
periods; and in all these cases cited, the Shawangunk grit, the Schenectady
beds and the Normanskill beds at Kingston, there is identity in lithologic
characters and indications of similar littoral conditions, of narrow gulf,
or delta, or estuary.

AN ADDITIONAL SPECIES OF EUSARCUS FROM THE BASE OF THE SALINA FORMATION

After decades of industrious collecting of eurypterids from the New
York Siluric waterlimes, the rich stores of these remains have not been
exhausted. While this work was in press and partly in pages, Professor
Gilbert van Ingen of Princeton University sent us some slabs from a loose
concretion in Oriskany creek in Oneida county, N. Y., which carry three
carapaces and other parts of an Eusarcus of very unexpected and peculiar
character.

Eusarcus vaningeni nov.

See text figures 108–15

Description. The outline of the body is as in E . s c o r p i o n i s .
Cephalothorax. The carapace is broadly subtriangular, about one
third wider than long (not counting a frontal snoutlike prolongation),
the two lateral margins converging at an angle of about 70° toward the
anterior end which is produced into a linguiform process, about one fifth
the length of the carapace. The base is to the lateral margin (excluding
the snout) as 4: 3. The posterior margin is distinctly bent forward in
the middle and the postlateral angles are markedly truncate. The lateral
margins are slightly concave in the posterior and as gently convex in the
anterior half. The anterior process is one fourth as wide at its base as the
basal margin of the carapace. Its lateral margins are nearly straight and
converge slightly; the anterior margin is gently convex. The lateral and

anterior margins are furnished with a filiform border, the posterior with a narrow doublure. The carapace culminates between or just posteriorly of the lateral eyes, a broad ridge extending thence backward toward the posterior margin. The lateral eyes were relatively small, only about one seventh the length of the carapace, submarginal, situated just posteriorly of the base of the tonguelike anterior process, apart about their length and about half their length distant from the lateral margin. The visual surface is as in E . s c o r p i o n i s . The ocellar mound is very prominent and situated between the posterior extremities of the lateral eyes.

The appendages, so far as seen, are like those of E . s c o r p i o n i s .

Abdomen. The tergites and sternites have the form and relative dimensions of those of E . s c o r p i o n i s ; of the postabdomen only one segment has been seen which indicates a tail as tubular and scorpionlike as in the genotype; and the telson has not been observed. The ornamentation is that of E . s c o r p i o n i s , but the scales are smaller and more closely arranged.

Horizon and locality. The concretionary block which contained the remains of the three specimens was found loose at the foot of a high bank of Salina beds in Oriskany creek, near Farmers Mills, 3 miles south of Clinton, N. Y. The block is also full of lingulas and orbiculoideas by means of which its horizon in the bluff could be determined. It is there located about 21 feet below the base of the red Vernon shale in dark gray shales with intercalated waterlimes and dolomite beds. This shale formation has been considered by Mr Hartnagel as equivalent to the Pittsford shale, the lowest formation of the Salina beds in New York; or, as it combines the dark gray Pittsford shale with the typical Lockport dolomite, as the interlocking boundary of the Niagaran and Cayugan groups, or the closing stages of the Niagaran. However that may be, it is safe to consider this eurypterid horizon as situated at the base of the Salina beds, and either of Pittsford age or still older.

Remarks. E . v a n i n g e n i is in more than one way a very puzzling form. Its general features are undoubtedly like those of E . s c o r -
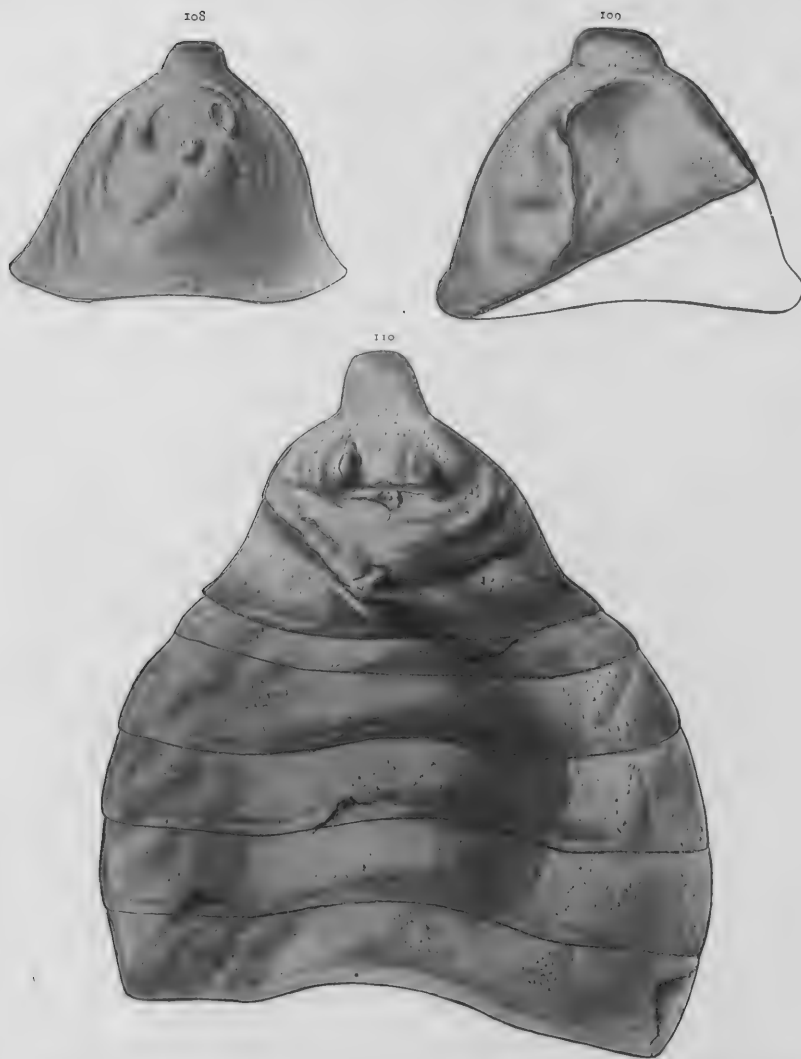
Fig. 108-10 Eusarcus vaningeni nov. Fig. 108 Carapace, the frontal process bent down-
ward. Holotype. Natural size. Fig. 109 A larger carapace showing the relatively broader
frontal tongue, also bent downward. Cotype. Natural size. Fig. 110 Carapace and nearly
complete preabdomen; the frontal process fully extended. Cotype. Natural size
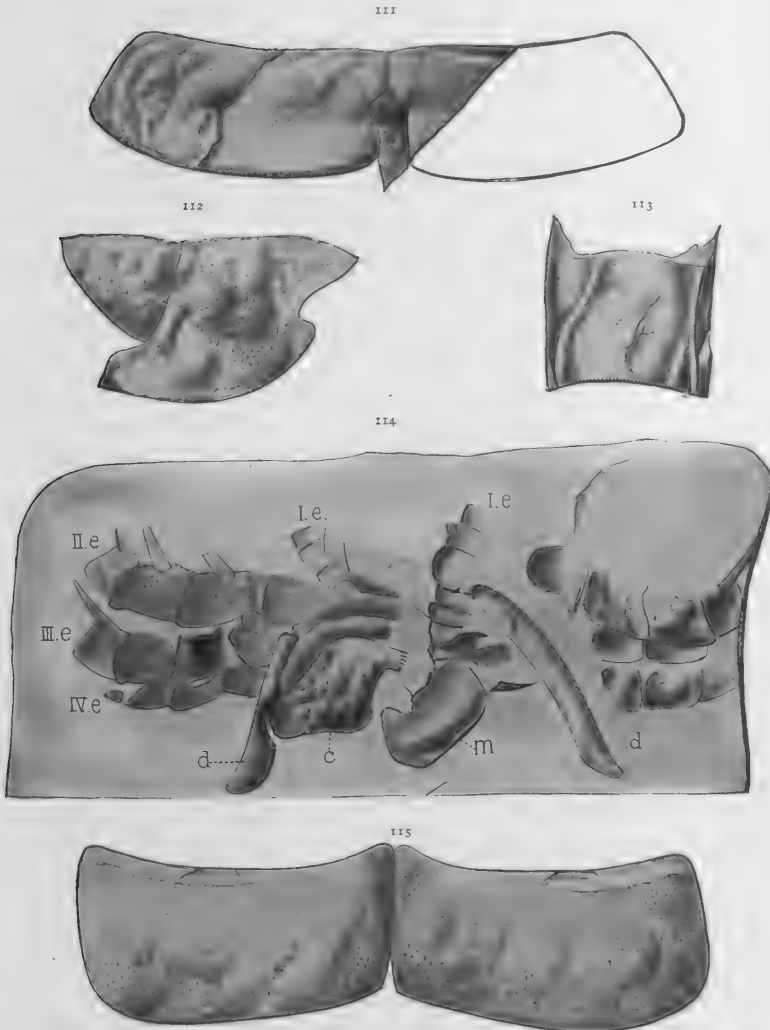
Fig. 111–15 Eusarcus vaningeni nov. Fig. 111 Female operculum with portion of opercular appendage. Fig. 112 Seventh segment of swimming leg. Fig. 113 Postabdominal segment. Fig. 114 Ventral view of the appendages of carapace, I–IVc, the four pairs of endognathites or walking legs, showing the same relative lengths as in Eusarcus scorpionis, the second being the longest. c, coxa of swimming leg, with gnathobase; d, broad marginal doublure of carapace, not observed in other specimens of Eusarcus; m, portion of metastoma. Fig. 115 Sternite. All figures natural size

p i o n i s or Eusarcus in general, which is properly considered as a very aberrant eurypterid genus. But while the species is in almost all features an E . s c o r p i o n i s , its distinctive characters are such as would indicate a still higher degree of aberrancy than seen in the considerably younger E . s c o r p i o n i s from the Bertie waterlime. The most important of these characters are the tonguelike anterior process of the carapace and the position of the ocelli between the lateral eyes. The first would seem to be a further advanced adaptation to the mud-grubbing habit of the species, the snout being used as a digging and perhaps also a feeling organ.[1] The second character, the forward position of the ocelli in distinction of the still central position in E . s c o r p i o n i s [see pl. 29] would also seem a further advance in the anteriorly raised carriage of the carapace peculiar to Eusarcus and indicated by the position of the lateral eyes and the forwardly progressing length of the walking legs.

E u s a r c u s c i c e r o p s , an Otisville species, has these two features, the anterior process and the forward position of the ocelli, in common with E . v a n i n g e n i . The former, in the position of the lateral eyes and the broad base of the carapace, seems closely allied to E . v a n i n - g e n i , and as our specimens of E . c i c e r o p s are all of early growth stages, it is possible that the mature specimens were still more like E . v a n i n g e n i . The presence of these two closely related aberrant types in the lowest Salina beds of Oneida county and in the Shawangunk shale, strengthens our inference as to the probable equivalence of the Shawangunk grit with the Pittsford shale. E u s a r c u s n a s u t u s

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[1] The fact that this process is more or less bent downward in two of the specimens might lead to the assumption that it is homologous to the epistoma of Pterygotus and might have been bent under entirely. Several considerations disprove this assumption, namely, the absence of a suture separating it from the anterior part of the cara- pace and the passing of the filiform thickened border around the process; and above all, the existence of another species of Eusarcus (E . c i c e r o p s) with a similar but much less developed anterior process [see pl. 36, fig. 3, 4] which is clearly a straight extension of the carapace.

from the Frankfort beds at Schenectady and the still earlier E u s a r c u s
l i n g u a t u s from the Normanskill shale at Catskill also exhibit median
extensions of the frontal margin of the carapace similar to the frontal
lappet of E . v a n i n g e n i .

The compound eyes in E . v a n i n g e n i appear to be placed con-
siderably farther inward than in E . s c o r p i o n i s . We do not know,
however, how much this difference is due to the fact that in E . v a n -
i n g e n i the entire carapace is spread out, having been rather flat along
the lateral margin, while in E . s c o r p i o n i s the marginal parts were
more or less vertical and bent under, thus bringing the submarginal lateral
eyes on the margin of the compressed specimen. This latter condition
is seen in the types of plates 29 and 30.

NOTES ON ANTHRACONECTES

When investigating this genus we were unable to locate the types
of the Pennsylvania Carbonic species described by C. E. Hall and James
Hall. These have been found in the Hall collection of Chicago University,
whence we were able to borrow them through the courtesy of Professor
Stuart Weller. For the purposes of completeness and facility of reference
some notes on the species are here given:

Eurypterus (Anthraconectes) mansfieldi C. E. Hall

D o l i c h o p t e r u s · m a n s f i e l d i C. E. Hall. Am. Phil. Soc. Proc. Phila.
1877. 16: 621

E u r y p t e r u s m a n s f i e l d i James Hall. Sec. Pennsylvania Geol. Sur. PPP.
1884. p. 32, pl. 4, fig. 1–8; pl. 5, fig. 1–11; pl. 6, fig. 1; pl. 7, fig. 1; pl. 8, fig. 1–3

E u r y p t e r u s s t y l u s James Hall. *Ibid.* p. 34, pl. 5, fig. 12–15

Cf. E . p o t e n s James Hall. *Ibid.* p. 37, pl. 4, fig. 9, 10

See text figures 43–47, page 220

E . m a n s f i e l d i and E . s t y l u s are associated in the " shale
immediately below the Darlington cannel coal,[1] near Cannelton, Darling-
ton township, Beaver county, Pennsylvania." Hall cites [*op. cit.* p. 35]
as the distinguishing feature of E . s t y l u s and E . m a n s f i e l d i ,

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[1] Allegheny formation of the Pennsylvanian.

that the former has a "shorter carapace, comparatively wider body, longer and stronger telson and the eyes are more oblique and distant." All these are differences due to compression. The specimens of E. mans-fieldi are squeezed laterally, as shown by the longitudinal wrinkles, while those of the E. stylus are compressed longitudinally, as evinced by the transverse wrinkles [*see* Hall, pl. 5, fig. 15] and by the pushing together of the tergites. For the same reason the telson appears relatively longer in E. stylus than in E. mansfieldi. The types of both species have all other characters in common, even to the remarkable sculpture and the anterior median process of the carapace.

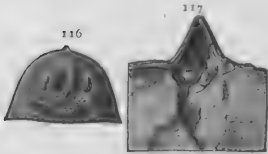The frontal margin of the carapace bears a peculiar small, triangular lobe in the middle, which is well shown in the originals of Hall's figures, plate 5, figure 3, 12 and 15. In others it is broken out. In figure 12 it was clearly originally drawn in, but later erased again [*see also* our text fig. 44] and in his plate 6 it is still visible in outline. It is hollow, or spoonlike, on the upper side and has very strong walls.

Fig 116, 117 Eurypterus (Anthraconectes) mansfieldi C. E. Hall. Fig. 116 One of the originals of E. stylus refigured to show the frontal spine and outline of carapace. x 2. (Hall, 1884, pl. 5, fig. 12) Fig. 117 A frontal spine. x 5

The sculpture is beautifully preserved in the specimens, is of striking character and not exaggerated in the drawings. The scales of the carapace are broad and roundish in the middle part between the lateral eyes and become more angular and protruding at their posterior points as they approach the base of the carapace giving that part a shagreened aspect. The same feature is still more emphasized on the tergites and postabdominal segments. On these the anterior half is ornamented with extremely small, crowded, broad scales, which abruptly are replaced by the posterior zone of large pointed scales and imbricating larger and smaller ones. In the middle line a number of scales unite and rise into nodes, the scales themselves thickening into bulblike bodies [*see* Hall, pl. 5, fig. 3; pl. 8, fig. 1 and our text fig. 44]. The character of the scales is entirely that of A. mazonensis, the type of the subgenus [*see* pl. 26, fig. 1] and

the median nodes are also found there. As we have already intimated these features are phylogerontic characters which are more fully developed in British Carbonic forms.

In the same class of phylogerontic characters belong the exaggerated development of the postlateral angles of the epimera of the tergites and postabdominal segments into thick, striated falcate spines [*see* text fig. 44]. In many specimens they seem to be absent [text fig. 43]. This is entirely due to the brittle nature of these defensive organs which easily broke away and are frequently found detached.

A similar explanation may be offered for the apparent spineless character of the legs [*see* text fig. 43], for in reality the spines are much stronger and thicker than in most earlier eurypterids; and also mostly broken away in the specimens. They were also strongly striated [*see* text fig. 46].

The same phylogerontic tendency to spinosity is also shown in the development of the distal fringes of the leg joints into spines [text fig. 46] and of the posterior margins of the tergites and the fringe of rather long teeth developed on the outside of the palette of the swimming leg [*see* text fig. 43]. Finally the extreme length and slenderness of the telson-spine is also a character pointing to the same condition.

Two large fragments which Hall supposed to be those of ectognaths were figured and, in the explanations of his plates, referred to a new species, E . p o t e n s . One is apparently a gnathobase and the other a portion of a sternite. Both indicate specimens of a size much larger than the types of E . m a n s f i e l d i with which they are associated, but as they exhibit an ornamentation quite as in that species, it is quite probable that E . m a n s f i e l d i grew to corresponding proportions.

Eurypterus pennsylvanicus C. E. Hall

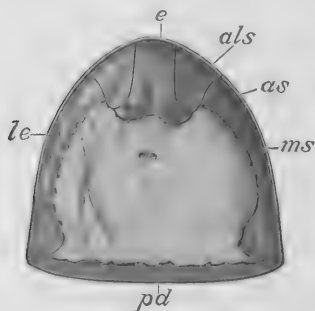E . p e n n s y l v a n i c u s C. E. Hall. Am. Phil. Soc. Proc. 1877. 7: 621

E . p e n n s y l v a n i c u s James Hall. Sec. Pennsylvania Geol. Sur. Rep't of Progress, PPP. 1884. p. 31, pl. 5, fig. 18

This species was based on a single small carapace, very similar in its characters to that of E . m a n s f i e l d i but markedly shorter (length to width as 3 : 5), and coming from an arenaceous Carbonic shale at the

Rooker farm, Pithole City, Venango co., Pa. The outline is quite regularly semicircular; the posterior parts of the lateral margins slightly concave and the postlateral angles slightly produced but not into distinct mucros as in the original figure. The eyes are small (between one fourth and one fifth the length), the nodes prominent. They are separated by a distance about one half the breadth of the carapace. As in other specimens from sandy beds, the glabellalike ridge of the middle of the carapace is well preserved between the eyes and bears a distinct circular ocellar mound just back of the lateral eyes. This species is probably closely allied to E. mansfieldi.

HUGHMILLERIA: VENTRAL SURFACE OF THE CEPHALOTHORAX

The chance exposure of the lower side of the cephalothorax in this genus has brought out a structure which none of the material before examined has displayed and an illustration of the details of this structure is here given. In the anterior median position lies a relatively long plate resembling an inverted lyre, which is identical with the object described by Sarle and reproduced elsewhere by ourselves as the supposed "metastoma of Dolichopterus??" It is the *epistoma*. It is bounded by sharp sutures on the lateral margins and terminates with its bilobate portion in front of the mouth. On its posterior lobes are two sharply outlined circular scars indicating either the attachment of muscles or more probably the bases of the chelicerae. This epistoma

Text fig. 118. Hughmilleria pittsfordensis Sarle. Shows marginal plates of ventral surface of carapace. *e*, epistoma; *as*, attachment scars of chelicerae; *als*, antelateral shield; *ms*, marginal shield; *le*, impression of the lateral eye; *pd*, posterior doublure. x 4/3

is flanked by two semielliptic plates, the *antelateral shields*, which in their turn are separated by distinct sutures from the marginal shields at the sides. The latter show a clavate widening at their posterior ends. The narrow posterior doublure, which is not connected with the marginal shield, completes the system of marginal plates on the ventral side of the cephalothorax which hold the appendages and membranes in place.

A comparison of the structure here described with that of Pterygotus shows that the epistomas of both genera agree in general form. That of Hughmilleria is, however, the longer and more slender, an adaptation to the more elongate form of the head shield in that genus, and there are in Pterygotus no antelateral shields separated by sutures from the marginal shield.

The epistoma exists, so far as we now know, in no other genera than Hughmilleria and Pterygotus; that is, in the two genera which are characterized by a very strong development of the chelicerae, and this fact indicates that the plate itself has resulted from strains originating from these strong and active arms.

NOTE ON PTERYGOTUS COBBI var. JUVENIS nov.

See text figures 119–21

In the description of P . c o b b i , in the body of this memoir, we had only two free rami of the pincers at our disposal, all that was known of the species. A large collection of eurypterid material since obtained by Mr Hartnagel in Herkimer county, contains two small specimens of Pterygotus on the same slab, one of which possesses the characteristic pincer of P . c o b b i with some slight differences, of such nature as to be quite probably ascribable to an earlier growth stage of the species. We therefore refer to these specimens as P . c o b b i var. j u v e n i s .

These two specimens differ in a number of characters from both the common P . b u f f a l o e n s i s of the Bertie waterlime at Buffalo and the P . m a c r o p h t h a l m u s of Herkimer county. The most important of these differences rests in the pincers which
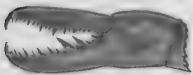
Fig. 119   Pterygotus
cobbi var. juvenis
nov. Pincers. x 3

are rounded in front as in P . c o b b i and the free ramus of which shows the denticles of the type of that species but is stouter and distinctly higher in the middle. The carapace is more evenly rounded anteriorly than in the other two species here cited and especially longer (length to width as 4 : 5); the compound eyes are relatively larger while the abdomen appears slightly broader and stouter (the preabdomen is 26 mm long and 19 mm wide);

and the telson is in both specimens narrower than in P . m a c r o p h -
t h a l m u s , a difference which is surely in part and perhaps wholly due
to preservation, the thin telsons being somewhat laterally compressed.

On account of the scarcity of the material we do not know to what
extent these differences are expressions of different growth stages, but
it is quite obvious that P . c o b b i as represented by these specimens,
was remarkably similar in all its features, save the pincers, to P . b u f -
f a l o e n s i s and P . m a c r o p h t h a l m u s .

Judging from the fragmentary pincers of the specimen figured by
Pohlman [1883, pl. 3, fig. 3] as P . b u f f a l o e n s i s , we surmise that
this also belongs to P . c o b b i .

Horizon and locality. Bertie waterlime, Schooley's farm, Litchfield,
Herkimer co., N. Y.

Fig. 120-21 P t e r y g o t u s c o b b i var. j u v e n i s nov.
Fig. 120 Dorsal aspect. Fig. 121 Ventral aspect. Both
somewhat laterally compressed. Natural size

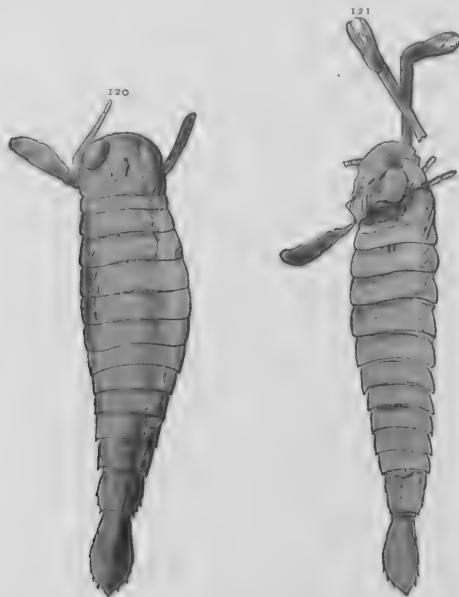GEOLOGIC DISTRIBUTION OF NORTH AMERICAN SPECIES OF EURYPTERIDS AT PRESENT KNOWN

FORMATION	Potosi limestone (CAMBRIC)	Normanskill shale	Schenectady beds a	Utica shale	Richmond beds	Clinton beds	Lockport (Noblesville dolomite)	Guelph dolomite	Pittsford shale	Shawangunk grit b	Bertie waterlime	Rondout waterlime	Manlius limestone	Portage	Chemung-Catskill	Campbellton beds	Waverly	Productive Coal Measures
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Dolichopterus breviceps nov..		x																
2 D. frankfortensis nov.......			x															
3 D. latifrons nov...........			x															
4 D. macrochirus Hall.......											x							
5 D. otisius Clarke..........										x								
6 D. siluriceps nov...........											x							
7 D. stylonuroides nov.......										x								
8 D. testudineus nov.........											x							
9 Echinognathus clevelandi Walcott				x														
o Eurypterus approximatus Hall & Clarke																	xc	
1 E. chadwicki nov...........		x																
2 E. dekayi Hall.............											x							
3 E. lacustris Hall...........											x							
4 E. lacustris var. pachychirus Hall.......											x							
5 E. maria Clarke............										x								
6 E. megalops nov............			x															
7 E. microphthalmus Hall.....												x						
8 E. pittsfordensis Sarle......									x									
9 E. pristinus nov...........			x															
o E. prominens Hall & Clarke..						x												
1 E. pustulosus Hall.........											x							
2 E. ranilarva nov...........							x											
3 E. remipes Dekay..........											x	x						
4 E. ? stellatus nov..........			x															
5 E.(Onychopterus) kokomoensis Miller & Gurley......							x											
6 E. (Tylopterus) boylei Whiteaves................								x										
7 E. (Anthraconectes) mansfieldi C. E. Hall........																		x
8 E. (Anthr.) mazonensis Meek & Worthen............																		x
9 E. (Anthr.) pennsylvanicus C. E. Hall............																		xd
o Eusarcus cicerops Clarke....										x								
1 E. linguatus nov...........		x																
2 E. ? longiceps nov.........			x															
3 E. newlini (Claypole).......						x												
4 E. scorpionis Grote & Pitt...											x							
5 E. triangulatus nov........			x															
6 E. vaningeni nov..........										x								
7 Megalograptus welchi Miller.					x													
8 Strabops thacheri Beecher....	x																	
9 Stylonurus beecheri Hall....															x			
o S. cestrotus Clarke........										x								
1 S. excelsior Hall...........															x			
2 S. limbatus nov..........			x															
3 S. modestus nov...........		x																
4 S. multispinosus nov.......									x									
5 S. myops Clarke..........										x								
6 S. (?) wrightianus (Dawson)..														x				
7 S. (Drepanopterus) longicaudatus nov............						x												
8 Hughmilleria magna nov.....			x															
9 H. shawangunk Clarke......										x								
o H. socialis Sarle..........									x									
1 H. socialis var. robusta Sarle.									x									
2 Pterygotus atlanticus nov....																x		
3 P. buffaloensis (Pohlman)....											x							
4 P. cobbi Hall.............											x							
5 P. cobbi Hall var. juvenis nov.											x							
6 P. globiceps nov..........									x									
7 P. grandis (Pohlman)......											x							
8 P. macrophthalmus Hall....											x							
9 P. monroensis Sarle									x									
o P. ? nasutus nov...........		x	x															
1 P. normanskillensis nov......		x				†												
2 P. prolificus nov...........			x															
	1	6	11	1	1	1	4	1	6	8	14	1	1	1	2	1	1	3

a The Schenectady beds have been termed in this work the Schenectady facies of the Frankfort beds. They are now referred) the upper Trenton as a distinct unit [see p. 411.]

b The Shawangunk grit includes the faunas here described from the Delaware Water Gap and Swatara Gap in Pennsylvania [see p. 417].

c Mr Charles Butts informs us that this specimen must have come from either the Chemung as he has limited it, or his Coneango (Devono-Carbonic) formation.

d The horizon of this species is unknown. It probably came from below the Productive Coal Measures (Pennsylvanian).

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