EVIDENCES OF PRIMITIVE LIFE

BY

CHARLES D. WALCOTT

FROM THE SMITHSONIAN REPORT FOR 1915, PAGES 235-255
(WITH 18 PLATES)

(PUBLICATION 2389)

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

EVIDENCES OF PRIMITIVE LIFE

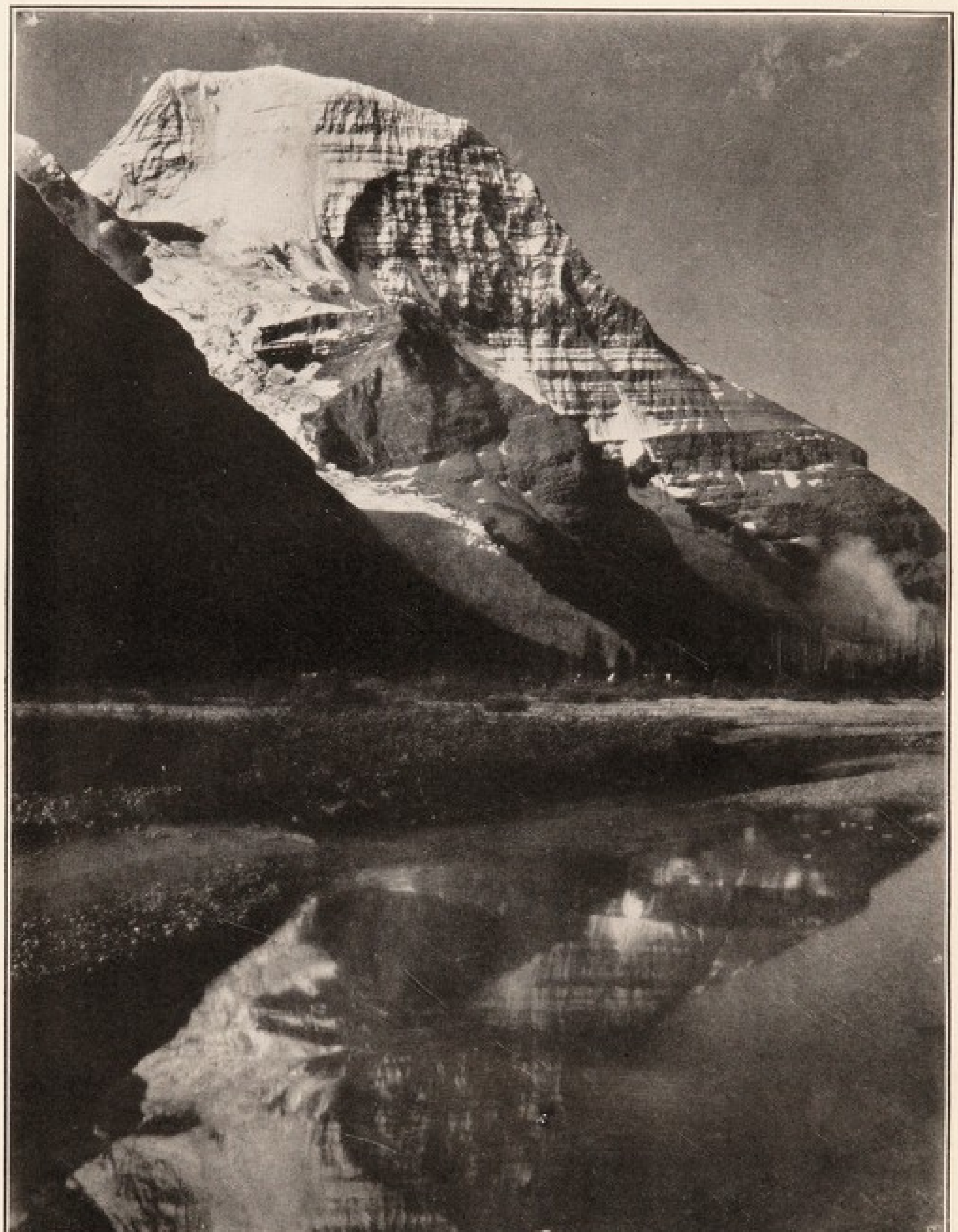
BY

CHARLES D. WALCOTT

FROM THE SMITHSONIAN REPORT FOR 1915, PAGES 235–255
(WITH 18 PLATES)

(Publication 2389)

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916



ROBSON PEAK FROM THE NORTHERN SIDE OF ROBSON PASS.

To the left the dark base of Iyatunga (Black Rock) Mountain with Blue Glacier extending down to Berg Lake. Robson Peak rises 7,060 feet above the lake to its snowy crest. Photograph by Mary Vaux Walcott.

EVIDENCES OF PRIMITIVE LIFE.

By CHARLES D. WALCOTT.

[With 18 plates.]

INTRODUCTION.

Few of us have a clear realization of the age of the earth. Under many deceptive aspects she carries with her the secrets of a long and busy life, one of such fascinating activity that it is not surprising that students are ever seeking to unravel the mysteries of the past. With all the evidences of youth there is to be felt, especially among the mountains, a sense of age and infinite power, and we are inspired with awe as we trace the base of worn-down rocks, miles in thickness, that formed the mountain ranges far back in geologic time.

The age of the earth in years I shall not attempt to discuss. A recent résumé[1] shows the relative age of the sedimentary strata for each period of its history. These figures point to a minimum time limit of scarcely less than 90,000,000 of years since water and wind began to transport continental earth and rocks over the land and into seas and lakes. How long before that the earth history began it is difficult even to conjecture. With the discovery of the stored-up energy of radium and the development of the planetesimal hypothesis by Dr. T. C. Chamberlin, the supposed fixed standards of the past generation have been swept away and new conceptions are being slowly formulated and subjected to all the tests that modern earth science can conceive.

A concrete conception of the age of life on the earth is suggested by recalling that the Cambrian system, with its early and semiprimitive forms of invertebrate marine fossils, stands, roughly speaking, midway in the earth's history; approximately as long a period of time was required to develop life to the Cambrian stage of evolution as has since elapsed up to the present time.

My own investigations have been mainly in the Cambrian and pre-Cambrian strata and have involved new and somewhat startling

[1] M. Joly: The Age of the Earth, Ann. Rept. Smithsonian Inst., 1911, Washington, 1912, pp. 271–293.

discoveries that helped to show how very much earlier life was developed on our planet than we had previously supposed. These researches have taken into consideration the records left on all the continents and many of the great islands. The Cambrian rocks of China and their included traces of life were compared and reviewed; the problem of the abrupt appearance of the Cambrian fauna on the North American continent was considered; comparisons were instituted from measurements of sections in the Cordilleran and Appalachian regions of the United States and Canada, including the Bow River Valley of Alberta, and the Robson Peak and Mount Burgess districts of British Columbia, where peculiarly rich fossil beds were discovered; more recently certain horizons of the Cambrian formations of the Mississippi Valley were discussed with their faunas, followed by the study now in hand of pre-Cambrian Algonkian traces of life.

In these inquiries I have had generous assistance in obtaining collections and exchanging publications with students all over the world, including geologists, paleontologists, zoologists, and paleobotanists in America and Europe and in far-away outposts of China, Siberia, India, Australia, and New Zealand.

Field work, with compass, hammer, and chisel, has been the rule, followed by laboratory and critical comparison of many thousands of specimens of fossil genera and species of ancient marine life, and often study of microscopic sections of rocks and fossils in the hope of finding evidence of the presence of minute and active bacterial and simple algal workers, such as exist in modern seas and lakes, which by their united efforts form great masses of the recent sea and lake deposits.

PRE-CAMBRIAN ALGONKIAN NORTH AMERICA.[1]

In North America, with its great epicontinental formations, the Algonkian era, between the inchoate Archean and the well-defined Cambrian, was a time of continental elevation and largely terrigenous sedimentation in nonmarine bodies of water, and of deposition by aerial and stream processes in favorable areas. Marine sediments undoubtedly accumulated in the waters along the outer ocean shores of the continent, but they are unknown to us, and great quantities of eruptive matter were extruded into the central Lake Superior region (Keweenawan). The agencies of diastrophism exerted their influence throughout this long period, though with decreasing energy, until they became practically quiescent during the latter part of Algonkian time.

[1] Problems of American Geology, Yale Univ. Press, 1915, pp. 166–167. Walcott: The Cambrian and its problems.

The North American continent was larger at the beginning of known Cambrian time than at any subsequent period, other than possibly at the end of Paleozoic time and the end of Cretaceous time, when the land area was equally extensive. Indeed, it is highly probable that its area was even greater then than now, for no marine deposits containing pre-Cambrian life, as they were laid down in Lipalian[1] time immediately preceding the Cambrian period, have been discovered in the North American Continent or elsewhere, so far as known.

I gradually came to the conclusion[2] that the most natural explanation of the absence of the traces of a distinct marine pre-Cambrian fauna is that the North American continent in pre-Cambrian time was at such an elevation above the sea that there is now no record of the sediments deposited on the under sea shelf about the continental area of that time. This presupposes that the great series of pre-Cambrian Algonkian sediments in the Rocky Mountain region were deposited in an inland mediterranean, or a series of great lakes and flood plains such as existed in Tertiary times.[3] The same conclusion applies to all of the later pre-Cambrian Algonkian formations of the Lake Superior region, Texas, Arizona, and so forth.

On this hypothesis the evolution of the pre-Cambrian fauna was taking place in waters contiguous to the continental area, and their remains, buried in the sediments then accumulating, have not been found, owing to the fact that those sediments are now hidden beneath the sea off the present coast lines of the continent. That such a condition existed is suggested by the almost total absence of any traces of life in the existing pre-Cambrian sediments.

EXTENT OF WITHDRAWAL OF SEAS IN ALGONKIAN TIME.[4]

That the present area of the North American Continent was higher than the level of the Atlantic and Pacific Oceans at the beginning of known Cambrian time is, I think, well established, and with the data available it would appear that all other continental areas were in a similar condition. What diastrophic action caused the with-

[1] Abrupt appearance of the Cambrian fauna on the North American Continent. Smithsonian Misc. Coll., vol. 57, no. 1, 1910, p. 14 (footnote). Lipalian (λειπα+αλς) was proposed for the era of unknown sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna. It represents the period between the formation of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea.

[2] *Olenellus* and other genera of the Mesonacidæ, Smithsonian Misc. Coll., vol. 53, no. 6, 1910.

[3] The crustacean and annelid faunas described from these sediments [Walcott, 1899, Pre-Cambrian fossiliferous formations, Bull. Geol. Soc. America, vol. 10, p. 238] might quite as well have been fresh-water as marine forms. There is nothing as far as known to indicate that they were necessarily limited to a marine habitat.

[4] Abrupt appearance of the Cambrian fauna on the North American Continent. Smithsonian Misc. Coll., vol. 57, no. 1, 1910, p. 12.

drawal of the oceanic waters from the continental areas during the great period represented by the non-marine deposition of the later Algonkian sediments and the period of erosion preceding the deposition of the superjacent Cambrian sediments, is unknown. It may have been produced by a sinking of the ocean bed that lowered the shore line of all the continents. It was of world-wide extent and of great duration, and it was during this period that the open-sea fauna was presumably first developed in the open ocean, as outlined by Brooks.[1] It probably found its way to the littoral zone and developed in the protected waters along the ancient epicontinental shelves. Of this period we have no known record either in marine sedimentation or in life, but I think that the life of the oceans became adapted to littoral and shore conditions in Algonkian time during a period when the relation of all the continents to the sea level was essentially the same as at the present time, or possibly the continents may have been still more elevated in relation to the surrounding oceans.

The known fossils contained in the Algonkian sediments of the Cordilleran geosyncline lived in fresh or brackish waters that were rarely in connection with marine waters on the margins of the Algonkian continent of North America. This will explain the abrupt appearance of *Beltina*, a highly specialized shrimp-like crustacean, deep down in the Beltian series.

When the oceanic waters gained access to the Algonkian continental areas at the beginning of Cambrian time they brought with them the littoral marine fauna which had been developed during the Lipalian sedimentation, and buried its remains in the sands and muds which form the Lower Cambrian deposits. The apparently abrupt appearance of this fauna is to be explained by the absence on our present land areas of the sediments, and hence the faunas of the Lipalian period. This resulted from the continental area being above sea level during the development of the unknown ancestry of the Cambrian fauna.

I fully realize that the conclusions above outlined are based primarily on the absence of a marine fauna from the Algonkian rocks, but until such is discovered I know of no more probable explanation of the abrupt appearance of the Cambrian fauna.

ALGONKIAN FORMATIONS.

The Algonkian rocks are largely formed of mud, sand, gravel, and volcanic rocks that were deposited in lakes, on plains, or in valleys by the action of water, wind, and eruptive agencies.

[1] Brooks, W. K.: The origin of the oldest fossils and the discovery of the bottom of the ocean, Jour. Geol., vol. 2, 1894, pp. 455–479.

On the eastern side of North America the rocks are mostly formed of siliceous mud and sand; in the Lake Superior region, siliceous mud, sand, gravel, and an immense mass of eruptive rock; in the Rocky Mountain and adjacent areas, siliceous and calcareous muds, fine sands, and a small amount of eruptive rock. In Montana the Algonkian rocks are from 12,000 to 25,000 or more feet in thickness and contain great beds of limestone, in which traces of life have been found. One of them, called the Newland limestone, is particularly rich in algal deposits.[1]

UNCONFORMITY BETWEEN THE CAMBRIAN AND PRE-CAMBRIAN ROCKS.[2]

The variation in thickness of the basal Cambrian conglomerate seems to indicate that the pre-Cambrian surface over which it was deposited was broadly irregular. The Cambrian sea was evidently transgressing across the dark siliceous shales of the pre-Cambrian land and reducing them to rolled pebbles, angular fragments, and mud. The mud gave origin to small lentiles of shale similar in character to the shale below the unconformity, while lentiles of sandstone of greenish tint indicate that fine material was being derived from still older pre-Cambrian formations than the shale.

Of greater importance is the evidence that the sediments of the two periods were deposited under different physical conditions. The Cambrian sandstones are composed of clean, well-washed grains, and the Cambrian calcareous and argillaceous shales were deposited as muds offshore along with the remains of an abundant marine life. The Algonkian Hector shales[3] of the pre-Cambrian are siliceous and without traces of life; the sandstones are impure and dirty, with the quartz grains a dead milky white or glassy and iron stained. These sediments were evidently deposited in relatively quiet, muddy, fresh or brackish waters.

I do not compare the limestone formations, as in the Cambrian they are 2,000 feet or more above the plane of unconformity at the base of the Cambrian and much farther below in the Algonkian series.

ORIGIN OF ALGONKIAN LIMESTONES.[4]

The stream flow and drainage into the Algonkian lakes undoubtedly afforded all of the soluble mineral matter necessary to account for the limestones, siliceous shales, and calcium carbonate deposits of

[1] Pre-Cambrian Algonkian algal flora, Smithsonian Misc. Coll., vol. 64, no. 2, 1914.

[2] Pre-Cambrian rocks of the Bow River Valley, Alberta, Canada, Smithsonian Misc. Coll., vol. 53, no. 7, 1910, p. 426.

[3] Algonkian, Hector-Corral Creek series, Bow River Valley, Alberta, Canada. See section, Smithsonian Misc. Coll., vol. 53, no. 7, 1910, p. 428.

[4] Pre-Cambrian Algonkian algal flora, Smithsonian Misc. Coll., vol. 64, no. 2, 1914, p. 84.

the Algonkian series of formations,[1] but the origin of the great pre-Cambrian limestones of western America has long been a mooted question, and the nature of the concretionarylike *Cryptozoon* (pl. 2) has not been so definitely determined as to be accepted by common consent either as of plant or animal origin. Twenty years ago I had a number of thin sections made of the matrix and "fossils" from the limestone of the Chuar terrane of the Grand Canyon series of Arizona[2] and later of specimens from the Belt series of Montana. Not being able to discover any traces of detailed or minute structure, the specimens and slides were put aside for future study. Recently I have had occasion to consider the question of the origin of the limestones of the great pre-Cambrian Algonkian formations of the Cordilleran area, and in this connection to determine if possible whether there was any relation between the so-called *Cryptozoon* and the presence of the Algonkian series of limestones.

The carbonaceous matter in the dark Newland limestones is shown by the black, flocculent residue that accumulates when a fragment of limestone is dissolved in hydrochloric acid and by the bituminous odor given off when the rock is struck with a heavy hammer. This carbonaceous matter was probably derived from the bacteria and algæ of the time.[3]

The limestones of the Newland formation have more or less magnesian content, but many of the layers are pure limestone, especially those containing the reefs or banks of algal remains. The specimens of algal remains are usually magnesian and siliceous, which accounts for the weathering in relief (pls. 2 and 3) and the ease with which they are etched by the solution of the limestone in weak hydrochloric acid.

The purer limestones are of considerable vertical thickness and their distribution indicates bodies of water several thousand square miles in area. The banks or reefs of algal deposits make a small percentage of the total mass of limestone, but if we assume, as I think we may, that the bacteria were active agents in the deposition of the soluble bicarbonate of lime in Algonkian waters, a plausible explanation is found for the occurrence of the homogeneous limestones of the Algonkian in which no traces of fossils have been found.[4]

FOSSIL BACTERIA.

The occurrence of bacteria in a fossil state has long been known.

Dr. Clement Reid, in an article on Paleobotany, states that[5]—

> the first evidence for the existence of Paleozoic bacteria was obtained in 1879 by Van Tieghem, who found that in silicified vegetable remains from the coal

---

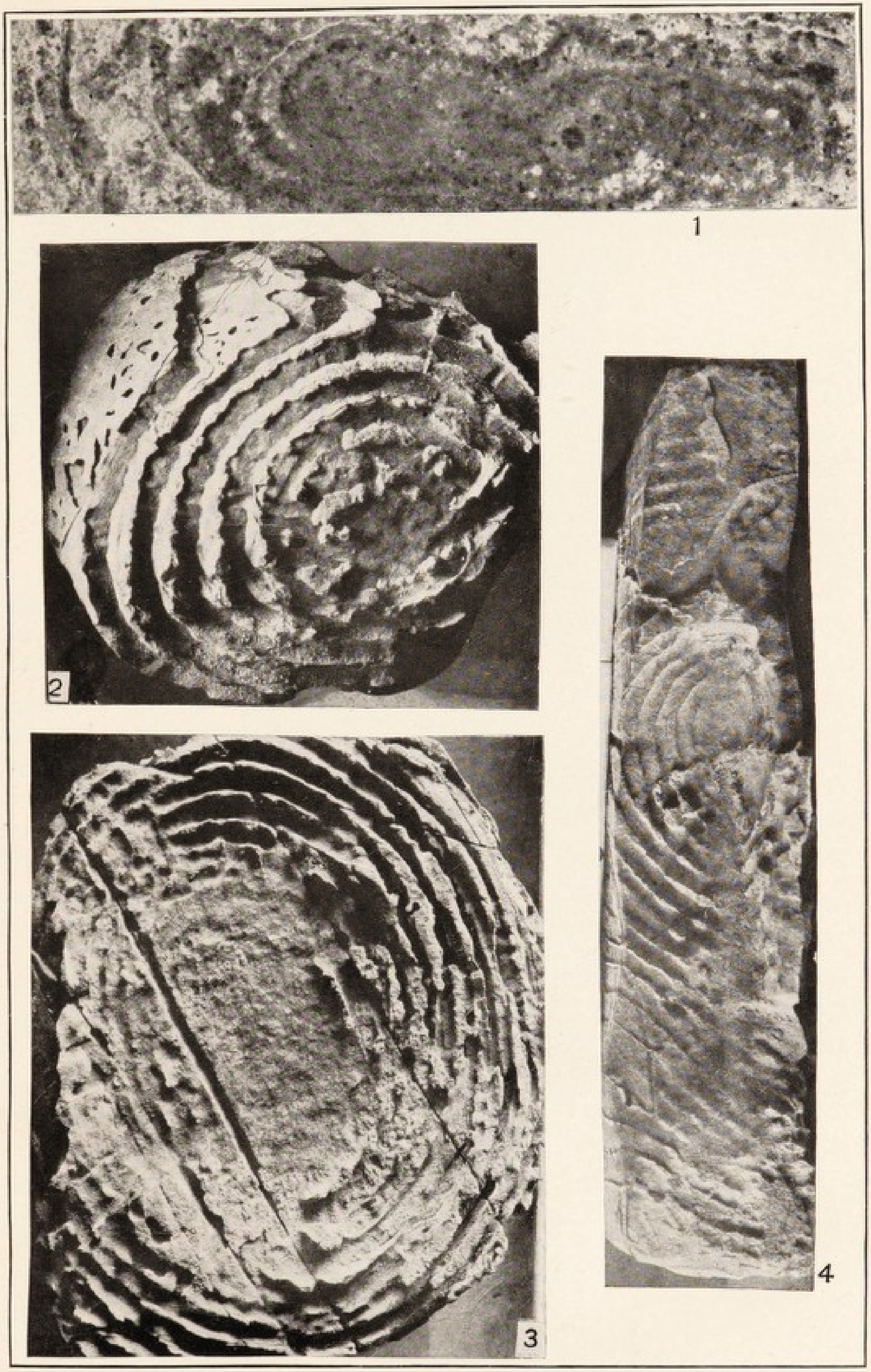
[1] Smithsonian Misc. Coll., vol. 64, no. 2, 1914, p. 89.

[2] *Cryptozoan ? occidentale* Dawson, Bull. Geol. Soc. America, vol. 10, 1899, pp. 232–234, pl. 23, figs. 1–4.

[3] Pre-Cambrian Algonkian algal flora, Smithsonian Misc. Coll., vol. 64, no. 2, 1914, p. 95.

[4] Idem, p. 94.

[5] Encyclopædia Britannica, 11th ed., vol. 20, 1911, p. 525.



SECTIONS OF MODERN AND ALGONKIAN ALGAL FORMS.

1, Lake Ball; 2, 3, *Newlandia concentrica* Walcott; 4, *Newlandia frondosa* Walcott.

PLATE 3.

CURIOUS PATTERN IN LIMESTONE, SUPPOSED TO BE THE RESULT OF ALGAL DEPOSITS.

measures of St. Étienne the cellulose membranes showed traces of subjection to butyric fermentation such as is produced at the present day by *Bacillus amylobacter;* he also claimed to have detected the organism itself. Since that time a number of fossil bacteria, mainly from Paleozoic strata, have been described by Renault, occurring in all kinds of fossilized vegetable and animal débris. The supposed micrococci present little that is characteristic; the more definite, rodlike form of the bacilli offers a better means of recognition, though far from an infallible one; in a few cases dark granules, suggestive of endospores, have been found within the rods. On the whole, the occurrence of bacteria in Paleozoic times, so probable a priori, may be taken as established, though the attempt to discriminate species among them is probably futile.

M. Renault, in 1895, wrote:

It may be surprising that beings like the bacteria, whose teguments are so slightly distinct, should have been preserved in a manner clear enough so that their presence is often easier to discover when they are fossil than when they are living.[1]

The reason for this, M. Renault continues, is because this delicate tegument has taken on a certain discoloration, which makes it stand out clearly from the surrounding matrix. Though, of course, highly microscopic, its form is preserved with absolute perfection. In the secondary and Tertiary (Permian) strata he distinguished several varieties, both of bacteria and micrococci, resembling almost identically the living forms, and he stated that the only reason he hesitated to identify them as positively the same was because of the impossibility of subjecting fossil bacteria to the culture test. In this test, as is well known, the various genera of bacteria, though often looking alike, behave very differently and thus are distinguishable and separable. At present, therefore, we may only point out apparent generic differences in the fossil bacteria revealed by the microscope.

PRE-CAMBRIAN ALGONKIAN BACTERIA.

The presence of minute forms of algæ and bacteria in the ancient pre-Cambrian rocks was suspected for several years before they were found. From the part they both play in the deposition of calcium carbonate in modern waters and the fact that bacteria are usually present when animal or vegetable matter is broken down by decomposition it seems that they must have existed almost from the beginning of life on earth, and that in this way we may explain the presence of limestone of pre-Cambrian Algonkian time that is found in Montana and other parts of North America.

In the spring of 1914 after careful study of the problem it was concluded to be quite probable that bacteria were an important fac-

[1] M. Renault, Recherches sur les Bactériacées fossiles, Ann. Sci. Nat., Bot., Vol. 2, Paris, 1896, pp. 274–349.

tor in the deposition of the Algonkian limestones, but no definite bacteria had been discovered. From specimens collected in the summer of that year many thin sections were prepared, and in these Dr. Albert Mann, microscopist and student of diatoms and bacteria, discovered individual cells and apparent chains of cells (pl. 4, figs. 2 and 3) which correspond in their physical appearance with the cells of micrococci (pl. 4, fig. 1), a form of bacteria of to-day. The world at large has believed that bacteria were modern forms of life, but they had been found as explained above in fossil wood of Carboniferous time and now we are made to realize that they existed in the first known epoch of the earth's life history, many millions of years ago.

For the purpose of comparison an illustration is given of a group of recent forms as illustrated in the Encyclopædia Britannica[1] and of the form of cells shown in the thin sections cut from the fossil algal remains of the Newland limestone (pl. 4).

ALGONKIAN FOSSIL ALGAL REMAINS.

In Montana it was found that a great series of pre-Paleozoic sedimentary rocks was exposed by the uplift of the granite mass forming the summit of Mount Edith of the Big Belt Mountains, in such a way that the thickness of the sandstones, limestones, and shales could be readily measured in the numerous sections exposed in the canyons worn by waters descending from the higher points to the valley surrounding the range. Nearly 5 miles in thickness of rock were measured, and in them limestone reefs of fossil algal remains were found and large numbers of typical specimens were collected.

It was observed that some of the algal remains were deposited very much in the same manner as those that are now being deposited in many fresh-water lakes, and that many of the forms had a character similar to those being deposited through mechanical and algal agencies in the thermal springs and pools of the Yellowstone National Park. A comparison of microscopic cells from recent blue-green algæ and their Algonkian representatives disclosed surprising similarity (pl. 5) and led to the conclusion that this type of alga existed very early in the history of life.

On the north side of the East Gallatin River two very rich beds of algal remains were found, many of which, on account of the fossil being silicified and imbedded in a softer limestone, were weathered out in relief, as shown by plate 3.

[1] Eleventh ed., vol. 3, p. 160, fig. 5.

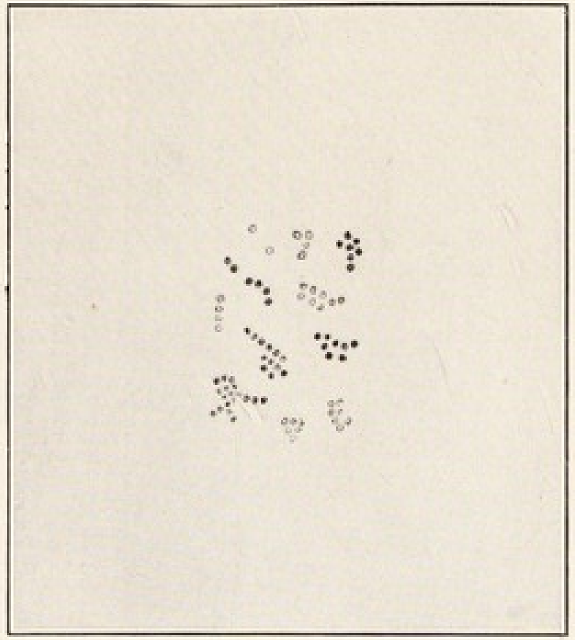
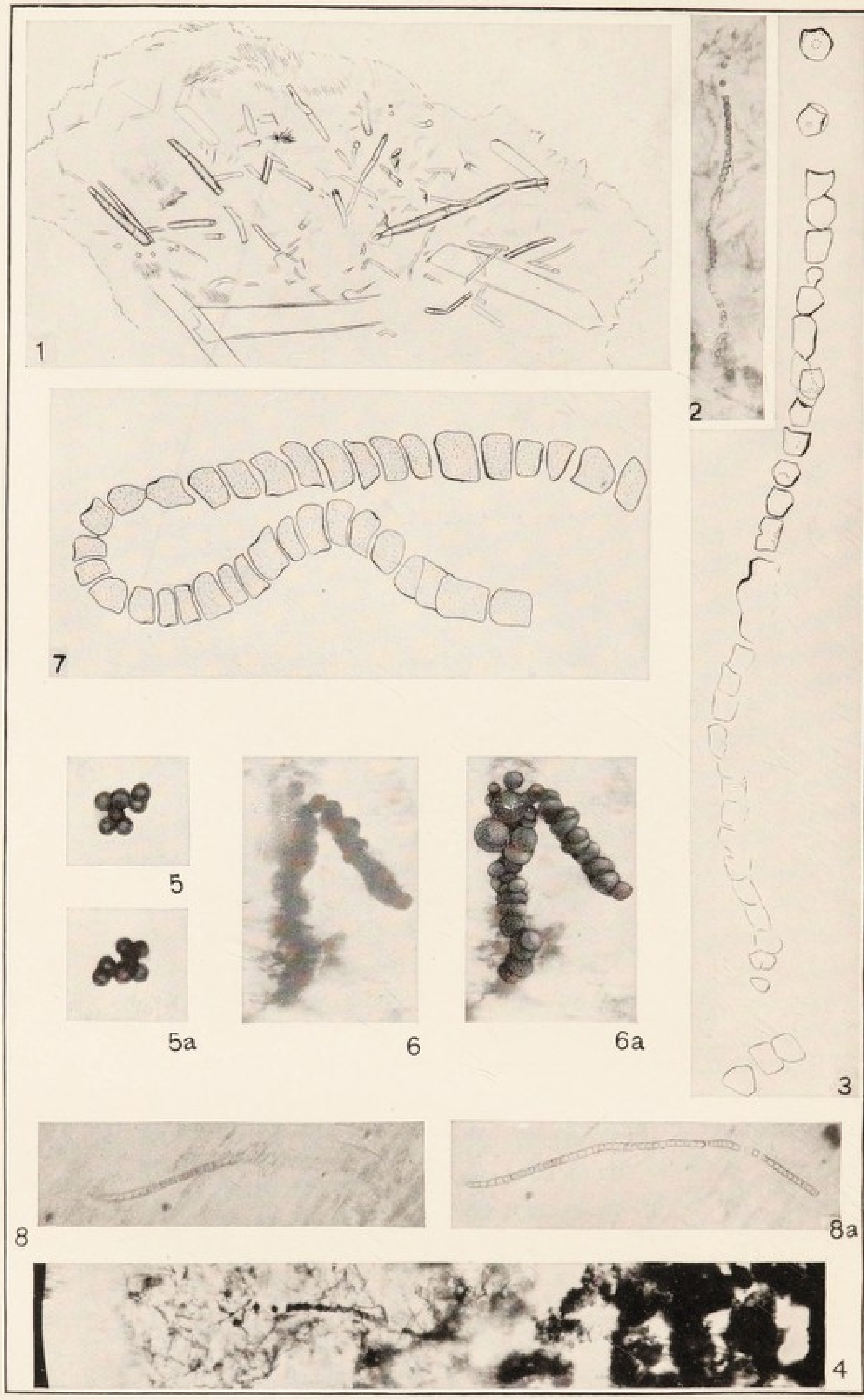


FIG. 1.—Characteristic groups of *Micrococcus vaccinae*. (After Cohn.) Very highly magnified. [Encyclopædia Britannica, 11th Ed., Vol. III, p. 160, fig. 5–B.]

FIGS. 2 and 3.—*Micrococcus* sp. undt. (× about 1,100 diameters.) Average size of Micrococci 0.95 to 1.3 microns in diameter. (Slide D.) From locality 401b, Algonkian: Gallatin formation; north side of East Gallatin River, 5 miles (8 km.) east of Logan, Gallatin County, Mont. [Reprinted from Proc. Nat. Acad. Sci., 1915.]



MICROSCOPIC CELLS FROM RECENT BLUE-GREEN ALGÆ AND THEIR ALGONKIAN REPRESENTATIVES.

Figs. 1 to 6*a* are from the ancient forms *Newlandia* and *Camasia;* figs. 7 to 8*a* are from the recent Blue-Green Algæ.

THE SEARCH AMONG THE ROCKS OF CAMBRIAN TIME, AND EARLY INCENTIVE TO GO TO THE ROCKY MOUNTAINS.

Friends have often asked how I happened to take up geologic work in the Rocky Mountains. The reason is a very simple one. As a boy of 17 I planned to study those older fossiliferous rocks of the North American Continent which the great English geologist, Adam Sedgwick, had called the Cambrian system on account of his finding them in the Cambrian district of Wales.[1]

The early explorers of the Rocky Mountains and large plateaus wrote of great masses of ancient bedded rocks exposed by mountain uplifts and deep canyons, and so I have taken advantage of every opportunity to visit and work in that great wonderland. This study has led me to many wild and beautiful regions, where nature has glorified these old sea beds by thrusting them up into mountain masses, with forests below and crowns of perpetual snow and ice on their summits.

From the vicinity of our Burgess Pass camp in the Canadian Rockies the views were most beautiful and varied, changing from hour to hour during the day and from day to day with the varying atmospheric conditions. Emerald Glacier was most attractive in the bright sunlight, in the gray light of early morning, the shadows of sunset, or when snow and fog were sweeping over the range, giving only now and then a glimpse of the ice and cliffs. The light-colored moraines on either side of its foot and the dark rocks afforded a beautiful setting for the ice, and across the Yoho Pass the cliff of Mount Wapta stood in bold relief, with a steep slope of broken rock on the west, and a huge bank of snow on the eastern side of its south ridge.

Our camp at Lake O'Hara (7,000 feet) (pl. 6) was in a beautiful mountain meadow at the foot of Mount Schaffer, where the morning and evening views of the surrounding mountains were often superb. Snow squalls are not infrequent on the higher summits, and on July 17 snow fell at the camp nearly all day. As seen from a slope of Mount Odaray, Lake O'Hara rests like an emerald in a bowl of mountains, reflecting the glaciers of Mounts Lefroy and Hungabee.

CAMBRIAN SECTIONS.

My first study of a great section of Paleozoic rocks of the western side of North America was that of the Eureka mining district of Nevada.[2] This was followed by the section of the Grand Canyon of

[1] Cambria (or Cymru) was the ancient name for Wales.

[2] Monograph 8, U. S. Geol. Survey, 1884.

the Colorado River, Arizona.[1] In this section the Cambrian strata extend down to the horizon of the central portion of the Middle Cambrian (Acadian) where the Cambrian rests unconformably on the pre-Cambrian formations.[2]

The object of my preliminary correlations of the several sections studied, was to show in a broad way the interrelations of the strata and faunas in the North American Cordilleran area west of the great continental land area of Lower and much of Middle Cambrian time.

In the course of my studies, particularly in recent years, data have also come to light which help us more definitely to outline the boundaries of the three great marine incursions of Cambrian time. There are also presented to us new conceptions of geological conditions in that period and more accurate information indicating the probable sources of the Cambrian fauna of the Cordilleran area.[3]

The change in the species from the Lower to the Middle Cambrian fauna is very great.[4] Of 77 species of brachiopods in the Lower Cambrian, six are found in the Middle Cambrian. Among the trilobites the disappearance of the Mesonacidæ[5] is the most marked change. Some of the species of the Conocephalidæ may have continued on into the Middle Cambrian, but the study of this and other crustaceans of the Cambrian time has not yet advanced so that any reliable data are available.

Most of the genera of the Lower Cambrian pass up into the Middle Cambrian, and this leads to the thought that the interruption, though important and of considerable duration, was not of a degree comparable with the unconformity immediately preceding the pre-Cambrian revolution, nor like the great faunal change that came at the close of Cambrian time, although the later diastrophic movement appears to have been relatively insignificant on the western side of the continent.

After the close of Middle Cambrian time the waters of the Pacific, the Gulf of Mexico, and the Atlantic began to rise and to flood lands that had not known the presence of marine waters since far back in the Proterozoic and may be since Archeozoic time. The margin of this area was as far westward as the present position of the main range of the Wasatch Mountains in the vicinity of Salt Lake, Utah; from this point the shore-line trended gradually south-southwest to southwestern Utah.

---

[1] Tenth Ann. Rep. U. S. Geol. Survey, 1891, pp. 509–774: The fauna of the Lower Cambrian or *Olenellus* zone.

Smithsonian Misc. Coll., vol. 53, no. 5, 1908, p. 167. Cambrian sections of the Cordilleran area.

[2] See American Jour. Sci., 3d ser., vol. 26, 1883, pp. 437–442.

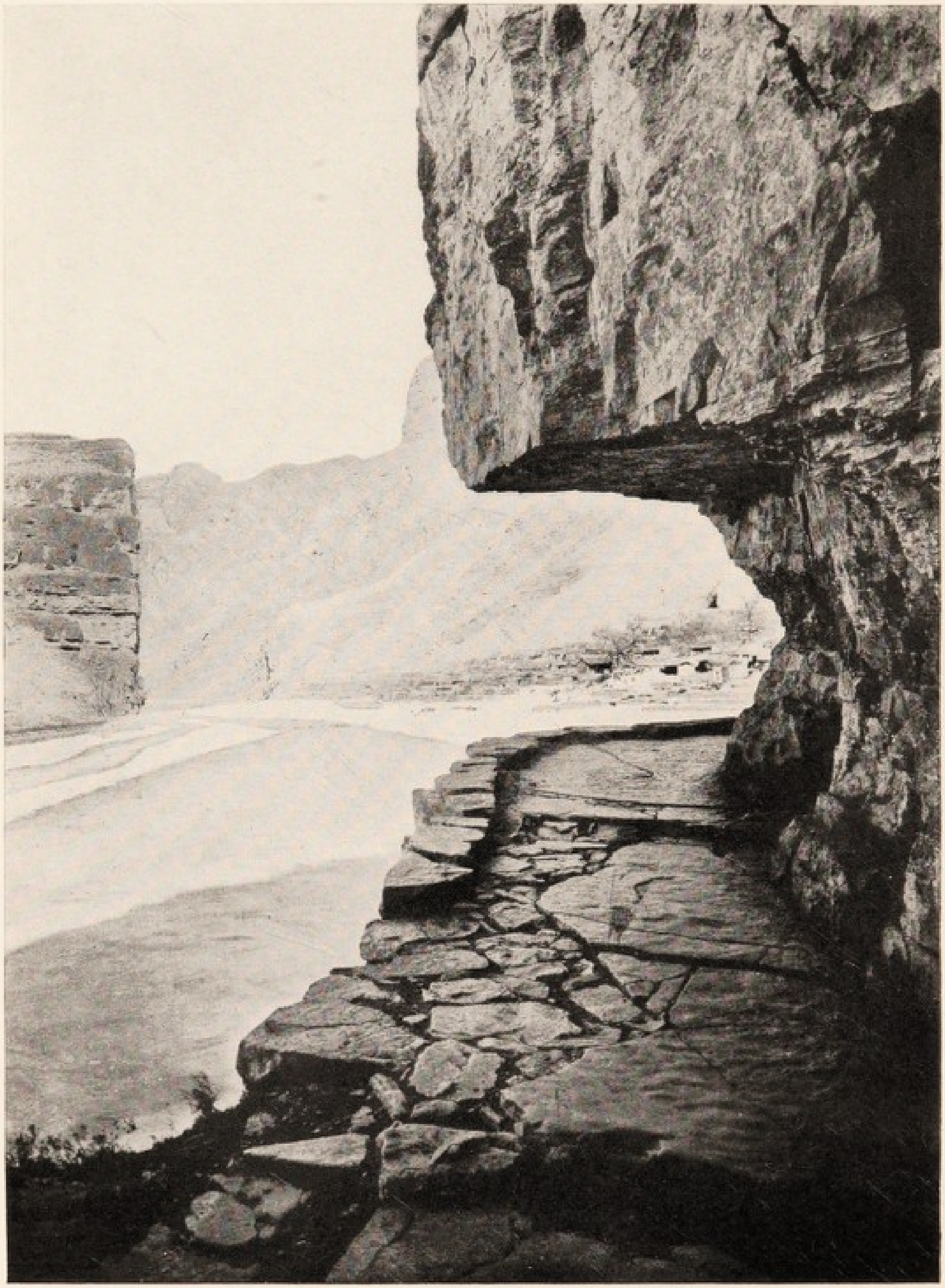
[3] The Cambrian and its problems, Yale Univ. Press, in Problems of American Geology, 1915, p. 162.

[4] Idem, pp. 189–190.

[5] See plate 14, Lower Cambrian trilobites, facing p. 252, this paper.

LAKE O'HARA (6,664 FEET).

From the lake to the top of Mount Lefroy 4,000 feet of Cambrian strata are seen in one unbroken section. Photograph by Charles D. Walcott. Courtesy of National Geographic Magazine.



VIEW SHOWING MASSIVE CHARACTER OF CAMBRO-ORDOVICIAN LIMESTONE, IN BROAD SYNCLINE EAST OF YAU-T'ÓU COAL FIELD, PROVINCE OF SHAN-SI, CHINA.

Illustrates abrupt walls of recent canyons cut in heavy limestone. On the T'ai-shan-ho 4 miles southwest of Shi-pan-k'óu, in the district of Wu-t'ai-hién, Province of Shan-si. (After Willis, Research in China, Pub. No. 54, Carnegie Institution of Washington, 1907.)

Attention is called to the close relationship between the great Cambrian section of the Province of Shantung, China, and the Cordilleran sections of North America. The thickness of the strata is very much less, but the general character and stratigraphic succession of the Cambrian faunas is very much the same. This relationship is further verified by the association of genera and species as shown by my subsequent study of the Cambrian faunas of China.

THE CAMBRIAN FAUNAS OF CHINA.[1]

When looking over the descriptions of China by Baron Ferdinand von Richthofen[2] and their contained Cambrian fossils described by Dr. W. Dames[3] from Liautung, and Dr. Emanuel Kayser,[4] I was impressed with the necessity of having the stratigraphic sections studied in detail, and extensive collections of fossils made, in order that comparisons of value might be instituted between the Cambrian sections and faunas of the western portion of North America and the Paleozoic sections and their contained faunas in eastern Asia. This project was held in abeyance 18 years, until in 1907 an expedition was sent by the Carnegie Institution of Washington, under the charge of Dr. Bailey Willis and his associate geologist, Mr. Eliot Blackwelder, resulting in the acquisition of large and interesting collections, of which I have made a careful study, comparing them with other collections from abroad, which I also had the opportunity to examine.

The chief results obtained from the study of the Chinese collections were the discovery of portions of the upper part of the Lower Cambrian fauna and a great development of a Middle Cambrian fauna of the same general character as that of the Cordilleran province of western North America; also an Upper Cambrian fauna comparable with that of the Cordilleran province and the upper Mississippi province of the United States. The fauna of the upper zone of the Lower Cambrian was found to be of the same general type as that of the Cambrian fauna of the Salt Range of India, and we were thus enabled definitely to locate the faunal horizons in India which had been referred to Upper Cambrian and post-Cambrian formations.

Another important discovery was that of the occurrence in the Middle Cambrian of China of a fauna comparable with that of the Middle Cambrian of Mount Stephen, British Columbia (pp. 246, 247), and the southern extension of the same fauna in the Middle Cambrian of Idaho, Utah, and Nevada in the United States.

[1] Research in China, Carnegie Inst. of Washington, Pub. No. 54, 1913, Walcott: The Cambrian Faunas of China.

[2] China, 1882, vol. 2.

[3] Idem, 1883, vol. 4, pp. 1–33.

[4] Idem, pp. 34–36.

There is much still to be learned by larger and more systematic collections in the Cambrian of China, and the future student of the Cambrian system in Asia should also consider carefully the Siberian Cambrian. The field is a large one, and what we now know of it indicates a rich reward to the individual who takes the time to thoroughly work out the formations and their contained faunas.

THE GREAT MIDDLE CAMBRIAN FOSSIL QUARRY OF BRITISH COLUMBIA.

Nature has a habit of placing some of her most attractive treasures in places where it is difficult to locate and obtain them. Nearly 30 years ago rumors came of a wonderful find of glaciers, forests, mountain peaks, lakes, and fossil beds along the line of the rugged pass through which the Canadian Pacific Railway was building,[1] but it was only during the past four or five years, while making researches in the Canadian Rockies, that it was my good fortune to discover highly organized marine fossils deep in thé Middle Cambrian formation. In these the minutest details of the internal structure are wonderfully preserved and reveal a great deal not before known of the life history of that period.

To secure as complete a series of the fossils as possible work has been continued for several seasons. The great fossil quarry is 3,000 feet above Field and 8,000 feet above sea level on the southwestern flank of Mount Wapta. The conditions were such that in order to reach the finest fossils it was necessary to blast the solid beds out to a depth of 22 feet (pl. 8).

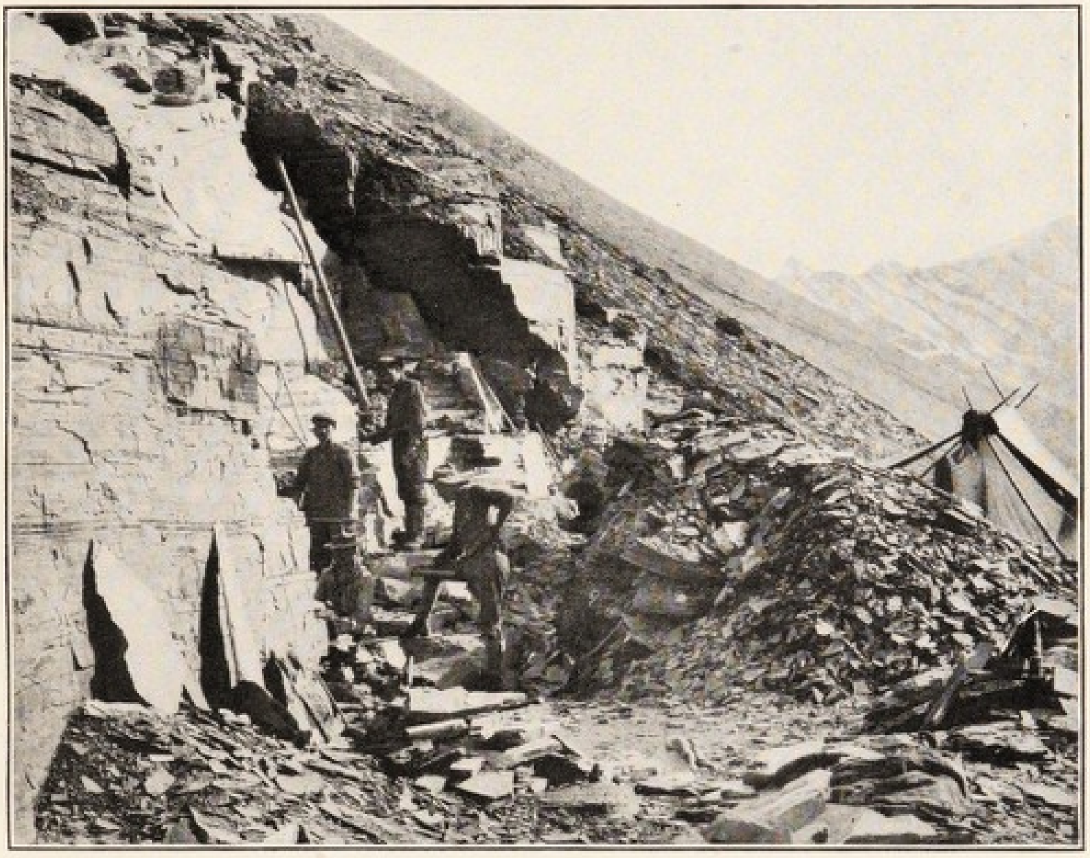
Most of the Cambrian rocks of this quarry section were deposited in waters teeming with marine invertebrate life.[2] As far as now known, this was before the day of fish or of any other vertebrate animal; no land plants are known to have existed then, and even marine vegetable life, except in the lowest forms, was unrepresented. Other animals, however, lived in great profusion, and here and there conditions were so favorable for their burial in the mud and sand of the Cambrian sea that they were imbedded unbroken, and throughout all the processes of rock making and mountain building they have escaped destruction (pl. 9).

One of these favorable places was at the quarry, where the most readily destroyed organisms, like the jellyfish (pl. 11, figs. 1, 2), have been exquisitely preserved; and we have crustaceans of numerous varieties (pls. 9, 10, 15), many of which preserve the most delicate branchiæ and appendages. One can hardly realize that these were buried in the mud 15,000,000 to 20,000,000 years or more ago and have remained undisturbed while several miles of thickness of

---

[1] Walcott, A Geologist's Paradise, Nat. Geog. Mag., June, 1911.

[2] Idem.



SOUTH END OF FOSSIL QUARRY, WHERE MANY OF THE MOST BEAUTIFUL SPECIMENS WERE SECURED FROM THE LOWER 3 FEET OF BEDS.

Near Field, British Columbia. Photograph by C. D. Walcott.

MIDDLE CAMBRIAN TRILOBITES.

Fragments of colony of marine animals on slab of black rock, with many trilobites (*Neolenus serratus* Rominger), (dark), and shells of the Sidney crab (light), whose claws are shown on plate 10. These creatures and other animals, like the delicate jellyfish, have been preserved many millions of years while sediment several miles deep was deposited over them. From Burgess Pass shale, Field, British Columbia. Photograph by Thomas W. Smillie.

sediment were deposited over them, changed into rock, elevated into mountain masses, and later eroded to form the present mountains and canyons.

We have long considered that the trilobite (pl. 9) was the most highly developed animal in Cambrian time, but a few summers ago[1] a crustacean was found by the author's son, Sidney, in the great fossil bed, that was the king of the animal world in its day (pl. 10, *Sidneyia inexpectans*). That it was prepared to assert its right to the control of the Cambrian sea is shown by the claws with which it was armed (pl. 10).

EVOLUTION OF EARLY MARINE LIFE.

Marine life, as already noted, began in times long antedating our oldest fossil records, but we are obliged to take up its study at the beginning of Cambrian time. Several groups have been studied in a preliminary way, and from these certain deductions have been drawn. The first that I will mention is one of the most unlikely of animals to be preserved in fine condition in the fossil state.

MIDDLE CAMBRIAN HOLOTHURIANS.[2]

That the tests or shells of trilobites and merostomes should be finely preserved in a fine-grained, silico-argillaceous rock is rather to be expected, but, with past experiences in mind, I was not prepared to find entire holothurians. That they are present and show many details of structure (pl. 11) is most instructive and satisfactory, since their occurrence records for the first time, with the exception of some scattered calcareous spicules and plates, the presence of this class of organisms in any geologic formation. Any calcareous matter that may have been present in them was probably removed by solution while the animal was in the mud and before it became fossilized. That carbonic acid was present in the mud and immediately adjoining water is suggested by the very perfect state of preservation of the numerous and varied forms of life. These certainly would have been destroyed by the worms and predatory crustaceans that were associated with them if the animals that dropped to the bottom on the mud or that crawled or were drifted onto it had not at once been killed and preserved with little or no decomposition or mechanical destruction. This conclusion applies to nearly all parts of a limited deposit in the fossil quarry (pl. 8) about 6 feet in thickness, and especially to the lower 2 feet of it.

---

[1] In 1910.

[2] Smithsonian Misc. Coll., vol. 57, nos. 2 and 3.

A holothurian is defined as a sea-cucumber or similar echinoderm.

Medusa, a jellyfish.

CAMBRIAN ANNELIDS.[1]

I had often searched the fine shales of the pre-Cambrian and Cambrian strata for remains of annelids, but it was not until the summer of 1910 that anything more than trails and borings were found.

The annelids of the Burgess shale, like the holothurians and medusæ, are pressed so flat that the worm is represented by only a thin film. Fortunately this is darker than the shale and usually shiny, and the contents of the animal are often preserved as a glistening silvery surface, even to the fine details of structure. How clearly the specimens exhibit both external and internal characters is shown by the plate figures (pl. 12), which are reproduced from photographs made by reflected light.

RELATIONS TO LIVING ANNELIDS.

The discovery of this remarkable group of annelids in the Burgess shale member of the Stephen formation opened up a new point of view on the development of the Annulata. The fact that from one very limited locality there were collected 11 genera belonging to widely separated families points clearly to the conclusion that the fundamental characters of all the classes had been developed prior to Middle Cambrian time.

CAMBRIAN BRACHIOPODA.[2]

The chief characters of the Cambrian brachiopod are illustrated on plate 13. It may be studied in three ways—historically, geologically, and zoologically.

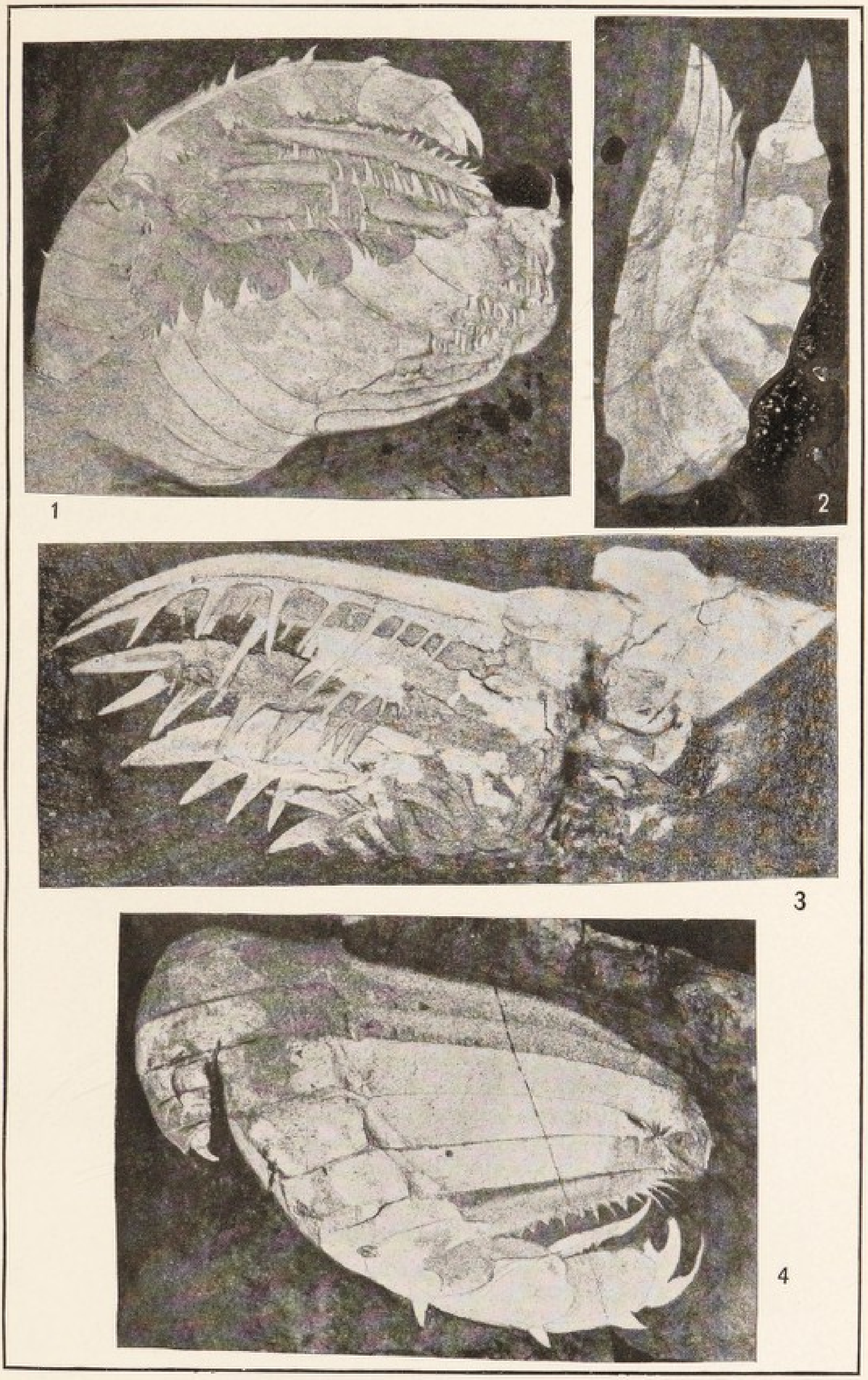
The conditions in which the Cambrian brachiopods are found indicate that some of them were gregarious in habit, and that many persisted through marked changes of environment and sedimentation. One species,[3] for instance, is found in sandstone, siliceous and argillaceous shale, and limestone. It has a wide distribution in the Cordilleran province of western North America and has a vertical range in the layers of rock of 2,000 feet or more. Other forms, such as *Micromitra haydeni*, are known only from one locality and one layer of rock. A large number of species occur in sandstone and shales that are evidently of shallow-water origin; others occur in limestones that were probably deposited in relatively deep water. The evidence indicates that their habitat largely ranged from between tides to a depth of 1,000 to 2,000 feet. Some forms may have

---

[1] Middle Cambrian Annulata, Smithsonian Misc. Coll., vol. 57, no. 5, 1911. Annelid, from *anulus*, ring; applied to worms.

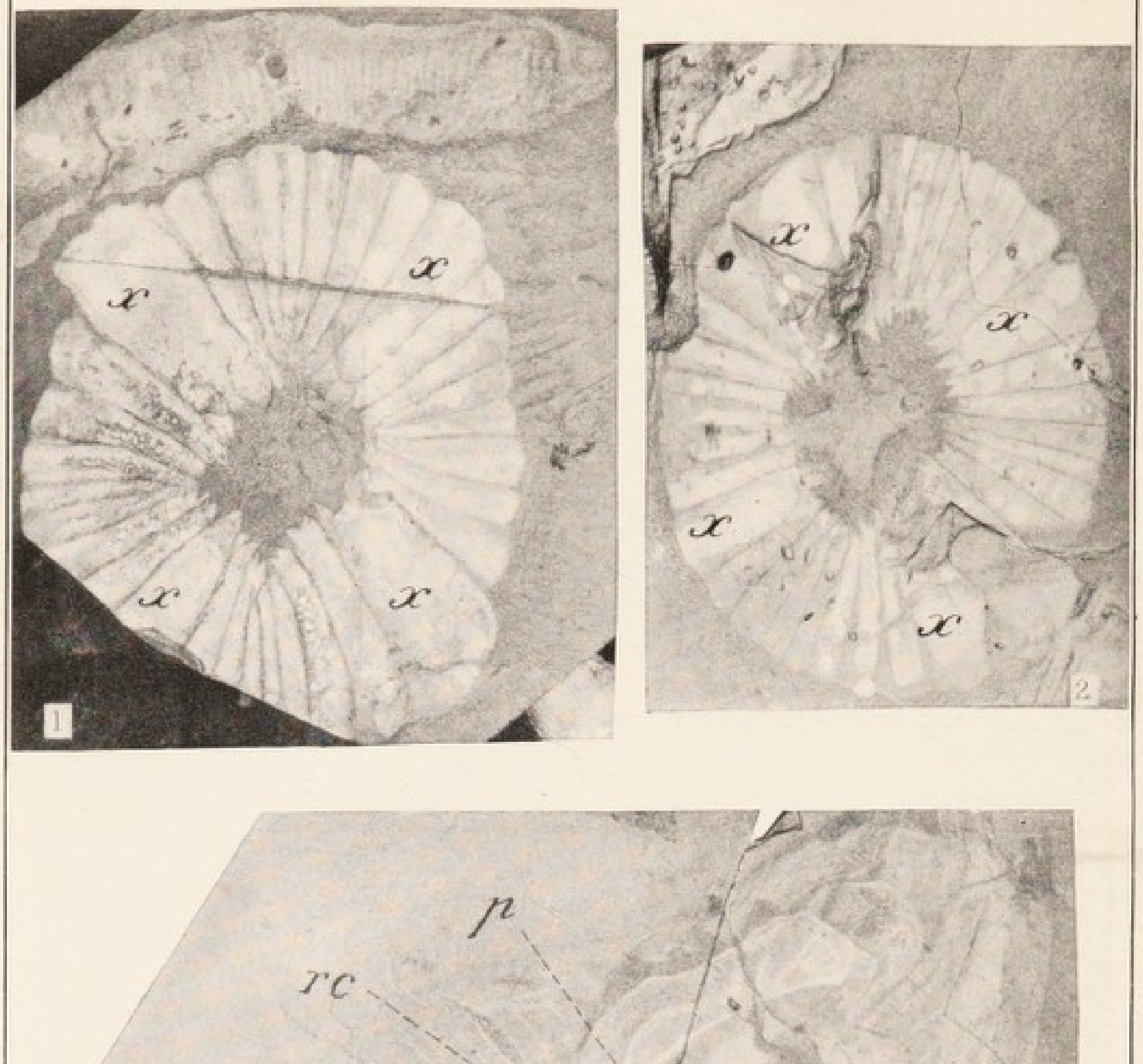
[2] Walcott, Monogr. 51, U. S. Geol. Survey, 2 vols., 1912.

[3] *Micromitra* (*Iphidella*) *pannula* Walcott.



SIDNEYIA INEXPECTANS WALCOTT.

The king of the animal world 15,000,000 years ago; discovered by Mr. Walcott. The spiny claws of the Middle Cambrian crustacean (*Sidneyia inexpectans* Walcott) are shown as a light patch in the center of Plate 9. From Burgess Pass shale, Field, British Columbia.



MIDDLE CAMBRIAN MEDUSA AND HOLOTHURIAN.

cr=central ring; *p*=digitate tentacle; *rc*=radial canals; *s*=stomach; *x*=four large lobes.
1, 2. *Peytoia nathorsti* Walcott. (Medusae, or jellyfish.) 3. *Eldonia ludwigi* Walcott. (Holothurian.)

From locality 35k, Middle Cambrian: Burgess shale member of the Stephen formation, west slope of ridge between Mount Field and Wapta Peak, 1 mile (1.6 km.) northeast of Burgess Pass, above Field, British Columbia.

had a greater bathymetric range, but the evidence in favor of such a range is not known to me. A table of the species in the monograph showed that with few exceptions each of the species is confined to one type of sediment.

More than 500 species and varieties of Cambrian brachiopods were studied and between 40 and 50 of Ordovician. Of the Cambrian forms, 10 genera, 2 subgenera, 21 species, and 1 variety persisted into the Ordovician.

Approximately 1,050 different localities bearing brachiopods were examined, and the same genera were found often to exist in widely separated regions, as, for example, a clear relationship was shown between brachiopods from the Scandinavian Peninsula and those of eastern Canadian localities, while in many other instances those of the western Cordilleran region of North America were related to those from China.

MICROSCOPIC STRUCTURE.

One important deduction from microscopic examination of the shells was the differentiation of certain genera and species from the Cambrian and Ordovician hitherto classed together,[1] the microscopic shell structure of one being of granular material pierced by small pores, and in the other of fibrous material. On the other hand, the microscopic structure of two other orders[2] in question is so similar that an unbroken line of descent is indicated.

We do not know of any brachiopods in strata older than that containing Lower Cambrian fauna. Yet when the advanced stage of development of some of the earliest-known forms is considered it seems almost certain that such existed far back in pre-Cambrian time.

THEORETICAL EVOLUTION OF CAMBRIAN CRUSTACEA FROM THE BRANCHIOPODA.[3]

The Cambrian crustacean fauna suggests that five main lines or stems (Branchiopoda, Malacostraca, Ostracoda, Trilobita, and Merostomata) were in existence at the beginning of Cambrian time, and all of them had already had their inception in Lipalian time or the period of pre-Cambrian marine sedimentation, of which no known part is present on the existing continents. Examples of some of these forms are shown in plates 9, 10, 14, and 17.

In the accompanying diagram (p. 250) the attempt is made to show the relations of Cambrian crustaceans to a theoretical ancestral stock,

---

[1] Cambrian Billingsellidæ and Ordovician Protremata.

[2] Cambrian and later Pentameracea.

[3] Walcott: Middle Cambrian Branchiopoda, Malacostraca, Trilobita, and Merostomata, Smithsonian Misc. Coll., vol. 57, no. 6, 1912.

which for convenience is correlated with the Apodidæ. From this stock it is assumed that the Branchiopoda came, and from the Branchiopoda stock three distinct branches were developed prior to or during Cambrian time. Of these the one of greatest interest in the present connection is that on the right of the diagram. In this line of descent it is assumed that the Trilobita are directly descendent from the Branchiopoda, and forms grouped under the order Aglaspina are derived from the Trilobita. The order Limulava is considered as being intermediate between Aglaspina and the Eurypterida, and that the two orders Limulava and Aglaspina serve to connect the Trilobita and the Eurypterida.

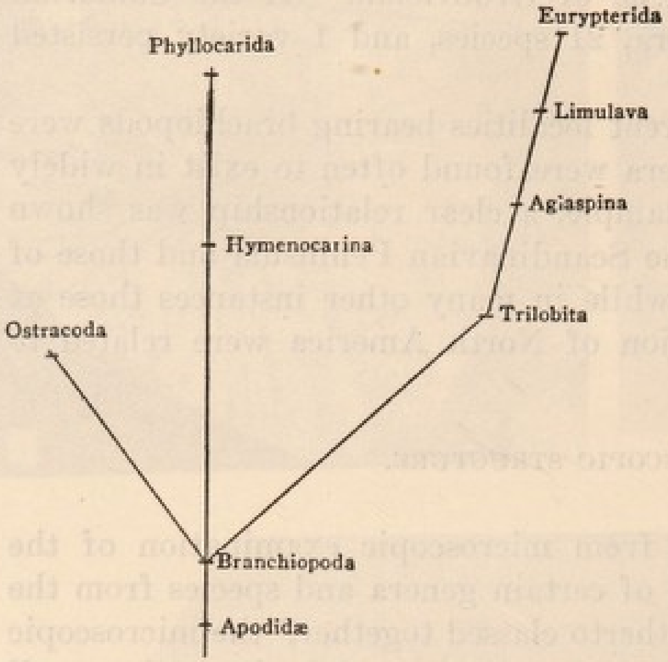


FIG. 1.—Theoretical evolution of Cambrian Crustacea from the Branchiopoda.

The line of descent of the various genera of the Mesonacidæ of the Lower Cambrian series[1] is indicated on plate 14, from figures 1 to 9, as stated in the description of the plate.[2]

MIDDLE CAMBRIAN CRUSTACEANS.[3]

Examples of a few others of the Middle Cambrian crustaceans found at the great quarry are illustrated on plate 15.

DISCOVERY OF ANOTHER CAMBRIAN FAUNA IN THE CANADIAN ROCKIES.

During the summer of 1911 a Smithsonian expedition, in cooperation with Mr. Arthur O. Wheeler, of the Alpine Club of Canada, visited the Robson Peak district.[4] My son Charles, who accompanied the party, brought back a few Cambrian fossils picked up while hunting and told me that ridge after ridge encircled the great Robson Peak with rocky layers, all sloping back toward and under the mountain. This suggested an opportunity to study another

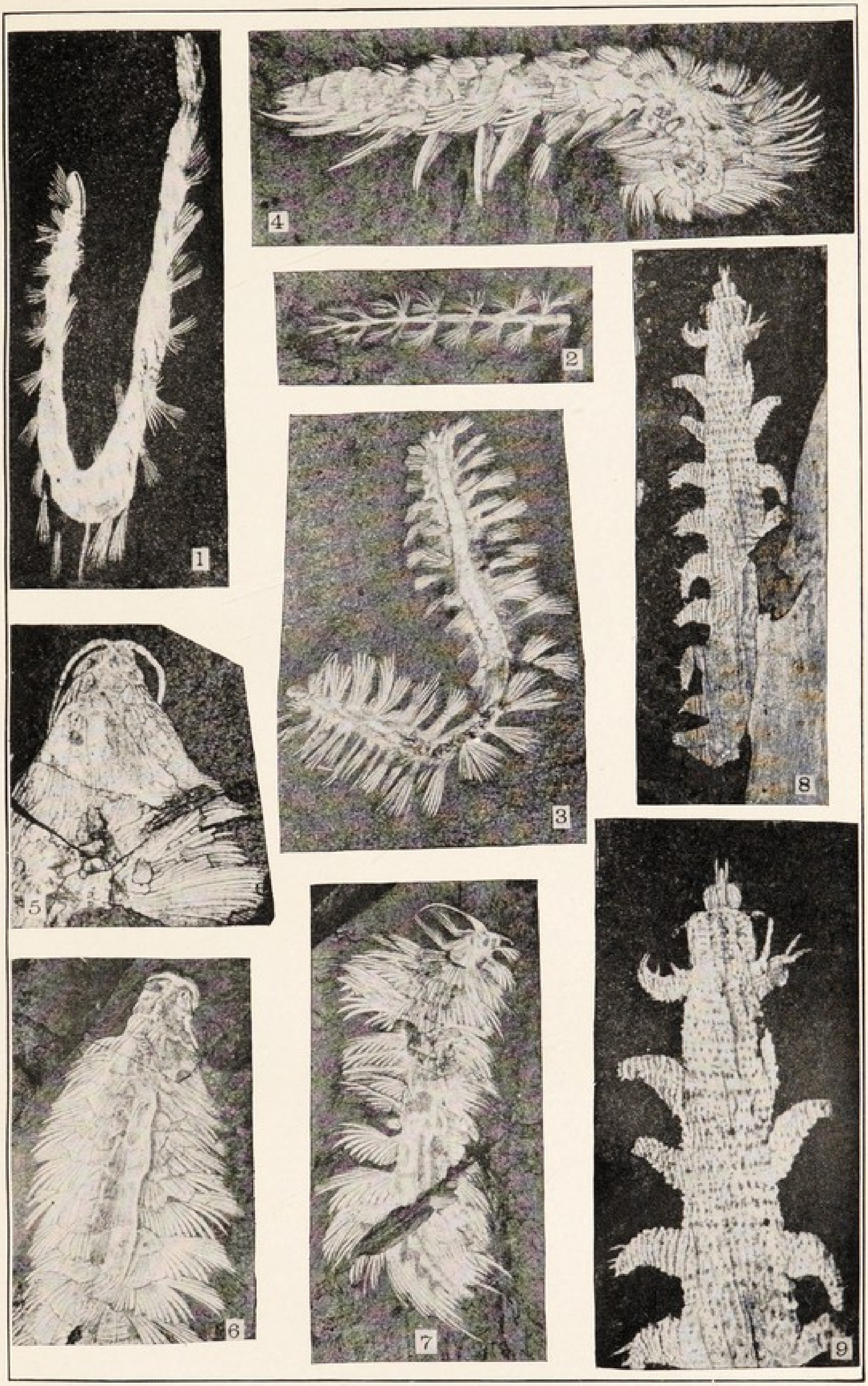
[1] Walcott: Fauna of the Lower Cambrian or *Olenellus* zone, Tenth Ann. Rept., U. S. Geol. Surv., pt. 1, 1890, pp. 509–763.

Olenellus: A large trilobite characteristic of the Lower Cambrian rocks. See pl. 14, fig. 9, this paper.

[2] Walcott: *Olenellus* and other genera of the Mesonacidæ, Smithsonian Misc. Coll., vol. 53, no. 6, 1910.

[3] Smithsonian Misc. Coll., vol. 57, no. 6, 1912.

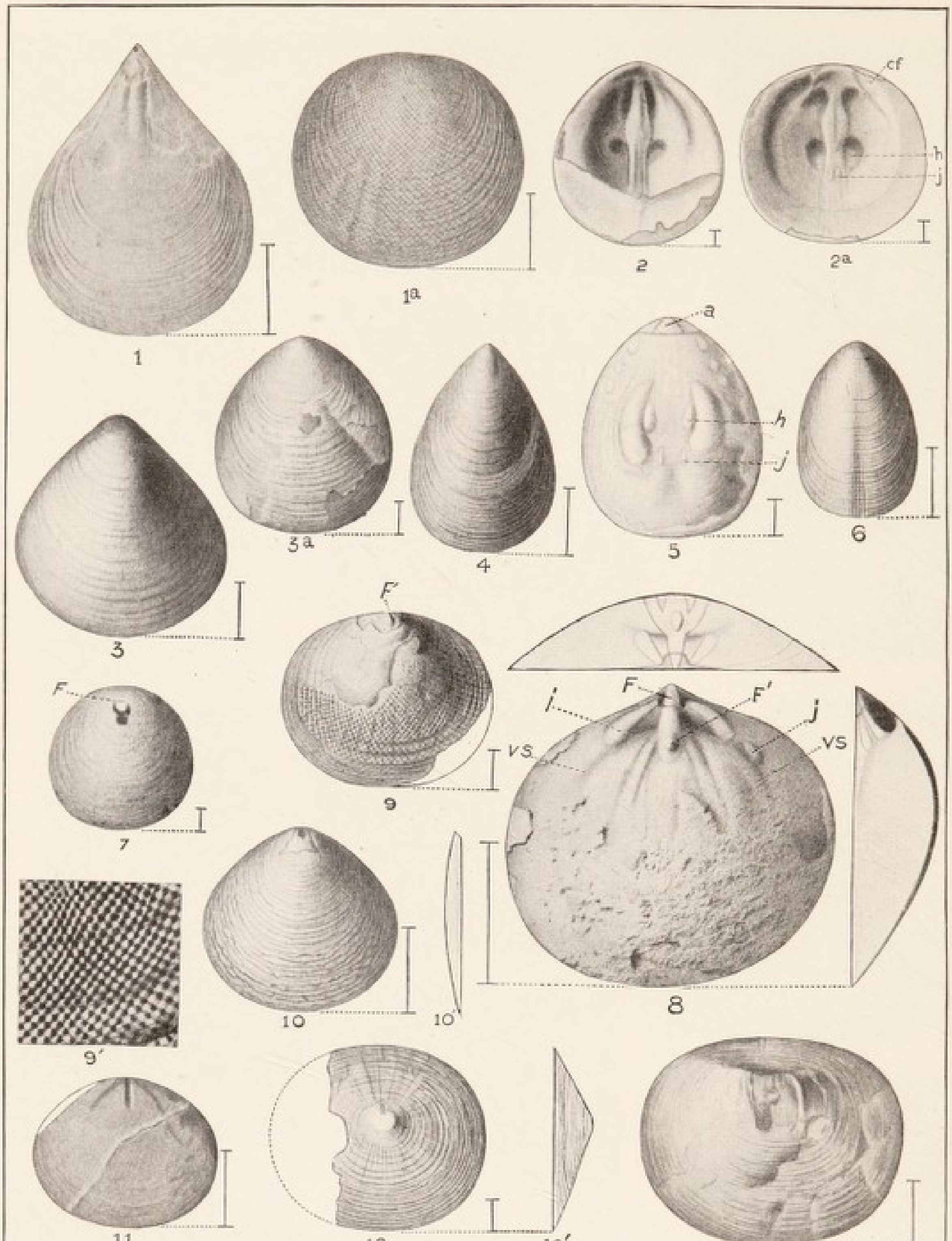
[4] Walcott: The Monarch of the Canadian Rockies, Nat. Geog. Mag., May, 1913.



MIDDLE CAMBRIAN ANNULATA.

1–3. *Canadia setigera* Walcott. 4–7. *Canadia spinosa* Walcott. 8, 9. *Aysheaia pedunculata* Walcott.

From locality 35k, Middle Cambrian: Burgess shale member of the Stephen formation, west slope of ridge between Mount Field and Wapta Peak, 1 mile (1.6 km.) northeast of Burgess Pass, above Field, British Columbia.



CAMBRIAN BRACHIOPODA.

a=area; *cf*=cardinal muscle scar; *F*=foramen; *F'*=cast of foraminal tube; *h*=central muscle scar; *i*=transmedian muscle scar; *j*=anterior lateral muscle scar; *vs*=vascular sinus.

Obolus, Dicellomus, Lingulella, Acrothele, and other genera are represented from localities in the United States, Canada, Sweden, France, and China.

great section of the Cambrian of the Rockies 200 miles (328.8 kilometers) northwest of the Burgess Pass section near Field, British Columbia, and the following season accordingly found me again exploring new fossil localities in the midst of magnificent scenery.

Robson, the most majestic peak of the Canadian Rockies (pl. 1), is situated northwest of the Yellowhead Pass, through which the Grand Trunk Pacific and the Canadian Northern Railway have been building their lines to connect the great interior plains and granary of Canada with the Pacific coast. Known to trappers of the Hudson Bay Co. and a few hardy explorers who have penetrated the region in search of a practicable trail to the Pacific, it has until now remained to the rest of the world almost an undiscovered country.

NOMENCLATURE.

Although not an original explorer of the Robson Peak district it fell to my lot to be the first to study the geologic section, and in this connection it was necessary to apply additional names in order to properly locate, describe, and name the geologic formations.

In this region of ancient Indian association it seemed to me especially fitting that some appropriate Indian terms should be used in order to preserve from total oblivion a curious language typical of a picturesque and fast disappearing people. With the help of the Bureau of American Ethnology of the Smithsonian Institution I prepared a list of such names, of which the following are examples:

Titkana[1] (bird) Peak.
Iyatunga[1] (black rock) Mountain.
Hunga (chief) Glacier.
Hihuna (owl) River.
Chupo (fog, mist) Glacier, etc.

FOSSIL DISCOVERIES.

Chupo, the glacier of fog and mist, is usually half concealed by clouds and banks of mist that form on the edge of the mountain and drift over it. This glacier proved of great interest and service to us in our geologic work. On its surface blocks of rock from high up on the peak were carried down to the great moraine at its foot, and in those blocks I found the evidence that proved the upper third of the mountain to be of post-Cambrian age by the presence in the limestone of marine shells and fragments of crablike animals that lived in so-called Ordovician time.

The beautiful Hunga Glacier is literally a flowing river of ice. At its left Titkana (bird) Peak rises as a black limestone mass that

[1] Approved by National Geographic Board of Canada, December, 1912.

with Iyatunga (black rock) Mountain forms the mighty portals of the great glacier.

Day after day we passed between these portals and climbed over the crevassed and hummocky ice in order to trace the connection of the rocky section of Titkana Peak with that of Robson (pl. 16). Thanks to the fine fossil fauna found in Billings Butte and the slope of the layers of rock a satisfactory "tie" was made across the glacier to the limestones of Robson.

The work was trying and tedious, but nature kindly assisted by bringing down long trains of bowlders on the ice of the glacier. From these was revealed the story concealed in the cliffs far above, and thus we learned the history of the rocks connected with those of the more accessible cliffs on the opposite side of the glacier.

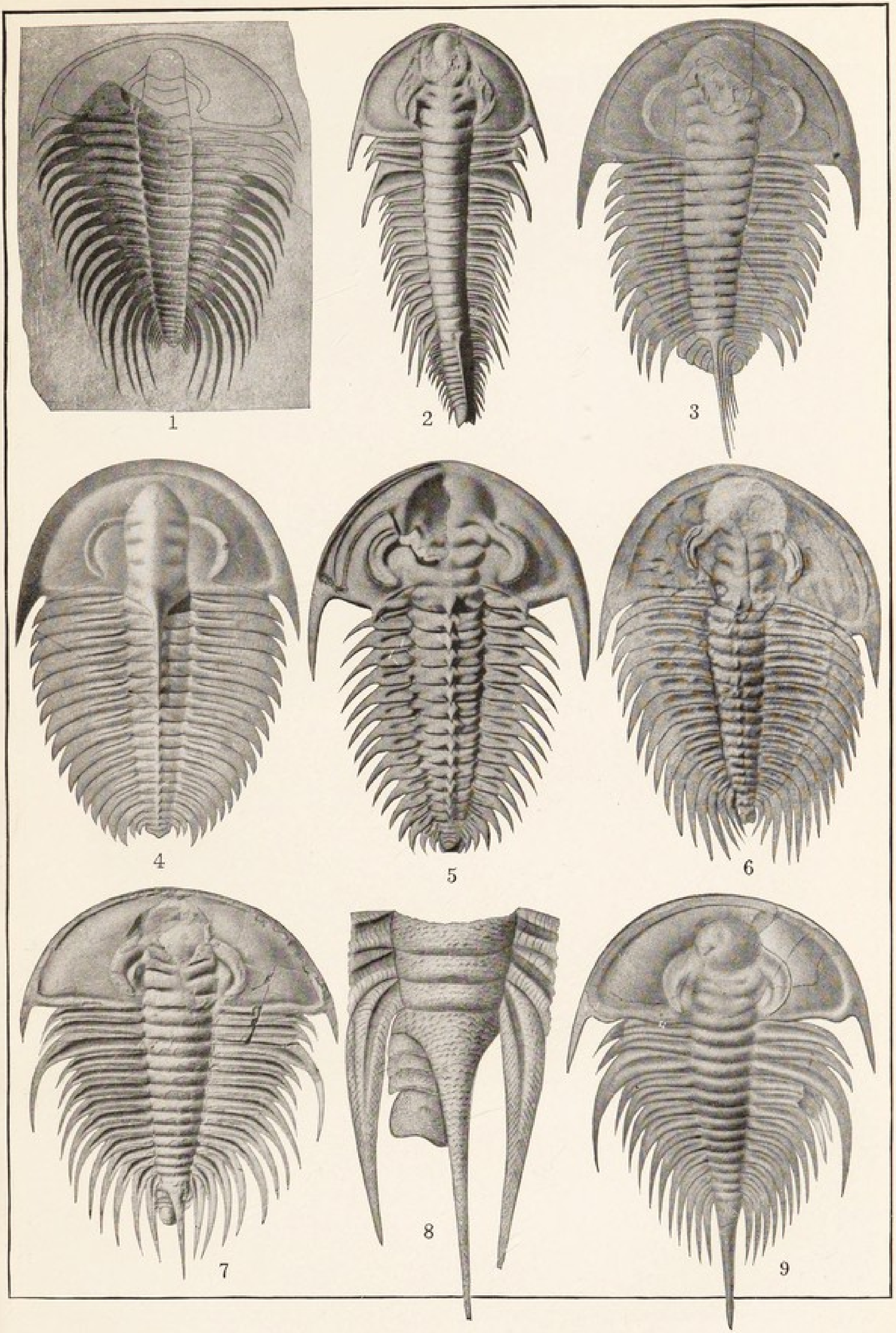
The geologic story of this enchanting region is too long and complicated to be related here. Suffice it that I found over 12,000 feet in thickness of Cambrian beds capped by 3,000 feet or more of Ordovician strata high up on Robson Peak.

A new fossil find was made by chance. Mr. Harry Blagden and I were sitting on a huge block of rock at the lower end of Mural Glacier, munching our cold luncheon, when I happened to notice a block of black, shaly rock lying on the ice. Wishing to warm up, for the mist drifting over the ice was cold and wet, I crossed to the block and split it open. On the parting there were several entire trilobites belonging to new species of a new subfauna of the Lower Cambrian fauna (pl. 17).

There were also some fine marine shells of a kind that occurs in the Lower Cambrian rocks west of Petrograd, Russia. We found the bed from which this block had come by carefully tracing fragments of the shale scattered on the upward-sloping surface of the ice to a cliff 2 miles (3.2 kilometers) up the glacier at the foot of Mumm Peak, which is a high point (9,740 feet=2,968 meters) directly north of Robson Peak. The fossil locality is high up, where rain, fog, and snow squalls may be expected nearly every day of the year. Working until late in the afternoon, we carried all of the rock we could pack over the glacier and down through the cliffs to the valley of the Smoky River.

One of our horses had taken leave on his own account, so we loaded faithful Billy with the rock specimens, two rifles, two shotguns, a camera, and our raincoats and plodded over the muddy trails, forded two icy-cold rivers, and "dropped" in at camp three hours after dark. At the last ford the powerful animal carried us both and all our impedimenta through the broad, rushing glacial stream.

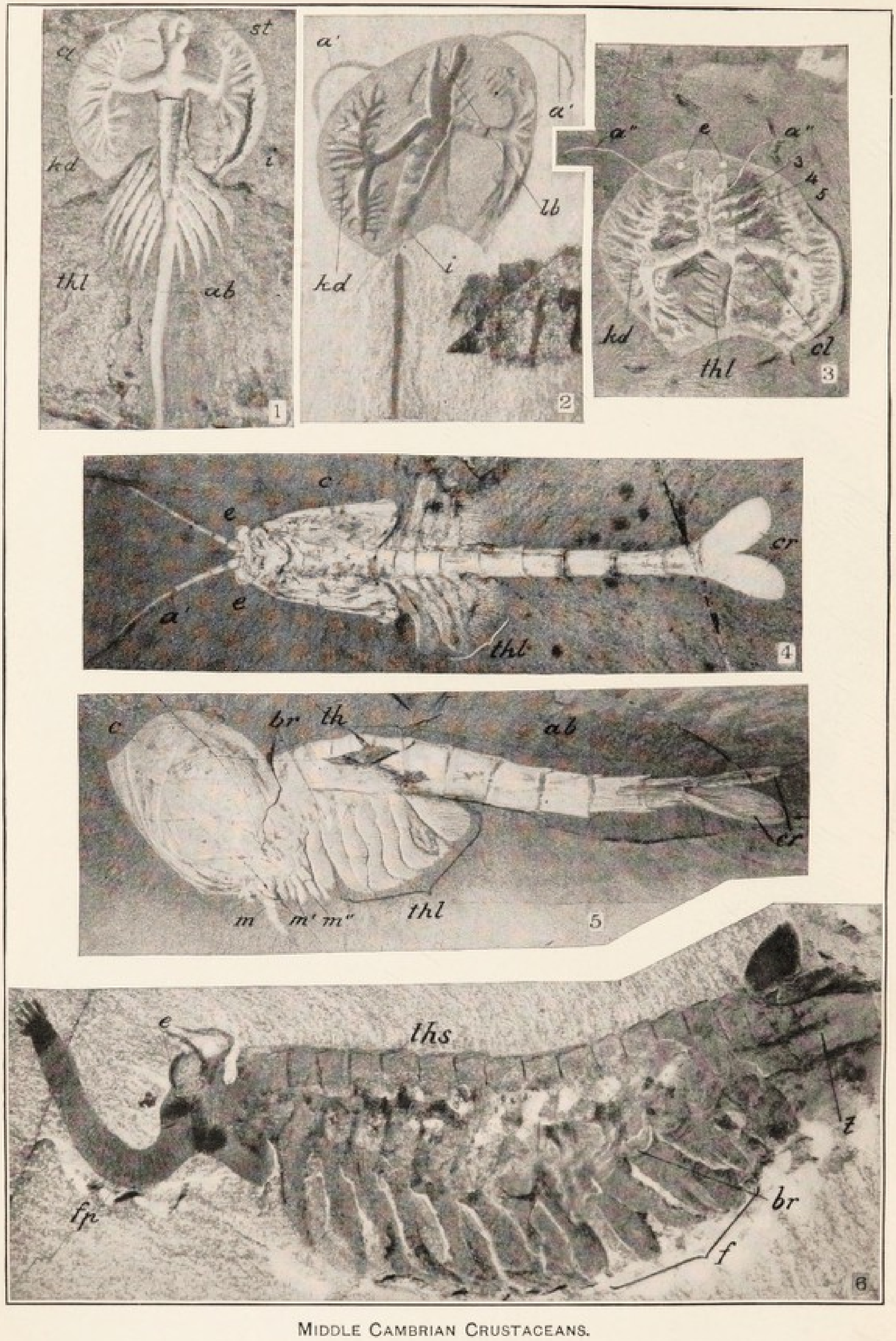
If any readers wish to visit Robson Peak they can readily do so by going to Edmonton and thence by railroad to Mount Robson Station, which is in sight of Robson Peak. The Alpine Club of



LOWER CAMBRIAN TRILOBITES.

1. *Nevadia weeksi* (Walcott); 2. *Mesonacis vermontana* (Hall); 3. *Elliptocephala asaphoides* Emmons; 4. *Callavia bröggeri* (Walcott); 5. *Holmia kjerulfi* (Linnarsson); 6. *Wanneria walcottanus* (Wanner); 7, 8. *Pædeumias transitans* Walcott. Fig. 8 is an enlargement of the posterior portion of figure 7, showing the rudimentary segments and pygidium beneath the telsonlike segment. 9. *Olenellus thompsoni* Hall.

Illustrates variation in principal genera of the Mesonacidæ; shows changes from most primitive form *Nevadia* (figure 1) through one line of descent, as represented by figures 2, 3, and 7, to *Olenellus* (figure 9), also another line of descent through figures 1, 3, 4, 5, and 6, probable line of descent from *Nevadia* (figure 1) to *Holmia* (figure 5), and on to *Paradoxides*. (See pl. 17.)



MIDDLE CAMBRIAN CRUSTACEANS.

1–3. *Burgessia bella* Walcott; 4, 5. *Waptia fieldensis* Walcott; 6. *Opabinia regalis* Walcott.
From Burgess Pass fossil quarry, near Field, British Columbia.

Canada has recently held its summer camp on the shores of Berg Lake, and soon this wonderland will be open to all who love the mountains and outdoor life.

Some of the fossil trilobites of this region are illustrated on plate 17 (*Olenellus truemani* Walcott, figs. 2–10),[1] and may be correlated with another similar species (pl. 14, fig. 9, *Olenellus thompsoni* (Hall)) from a Lower Cambrian shale in Pennsylvania and other Appalachian localities. Often the discovery of these correlations proves of great importance in the assignment of strata to their proper formations, and it has frequently been of great service in prospecting and exploiting mining districts in the West and elsewhere. A fault or break in the strata is sometimes detected only by this means.

UPPER CAMBRIAN FAUNA OF THE MISSISSIPPI VALLEY.

The importance of the distribution of a single family or genus in determining the stratigraphic position and succession of layers is shown in a recent study of the Dikelocephalinæ[2] (pl. 18).

It had been evident for several years that the various Cambrian formations of the Upper Mississippi Valley, which had been referred first to one formation (Potsdam) and then to another (St. Croix sandstones), needed careful revision in relation to their stratigraphic position and succession. This was accomplished through the study of the distribution of the *Dikelocephalus*[3] fauna in this wide region, and its correlation with related genera and species elsewhere.

THE SARDINIAN CAMBRIAN GENUS *OLENOPSIS* IN AMERICA.[4]

An example of the significance of distribution in showing unsuspected relationship of widely separated faunas, and consequently a bond between the marine bodies of water which covered the land at an early age, is found in the study of the geographic distribution of a remarkable trilobite. Until the publication of the report in 1912 the presence of the genus *Olenopsis* in America had not been announced, although a number of the cranidia of species referred to the related *Ptychoparia* were very much like the cranidia of *Olenopsis*.

The type species, *Olenopsis zoppii*, occurs on the island of Sardinia at Canal Grande and vicinity. Investigation in North America

---

[1] Fig. 1 on this plate represents a related species, *Holmia ? macer* Walcott, from the Lower Cambrian shale, Fruitville, Lancaster County, Pennsylvania.

[2] Walcott: *Dikelocephalus* and other genera of the Dikelocephalinæ. Smithsonian Misc. Coll., vol. 57, no. 13, 1914.

[3] *Dikelocephalus*, a large trilobite characteristic of the later (Upper) Cambrian rocks. *Dikelocephalus*, from Greek δικελλα, a mattock or two-pronged hoe, and κεφαλε head. This trilobite has been called "shovel-head," well suggested by fig. 1, pl. 18.

[4] Walcott, Smithsonian Misc. Coll., vol. 57, no. 8, 1912.

disclosed *Olenopsis roddyi* on the eastern side of the continent, near Lancaster, in the central part of Pennsylvania; on the western side of the continent *Olenopsis americanus* in the northern central part of Montana, and *Olenopsis ? agnesensis* on the line of the Continental Divide, near the Canadian Pacific Railway, in both Alberta and British Columbia. It is quite probable that if entire specimens of a number of species now represented by cranidia and referred to the genus *Ptychoparia* were available for study other species of *Olenopsis* would be found at approximately the same stratigraphic horizon.

AN EARLY DISCOVERY BY THE AUTHOR.

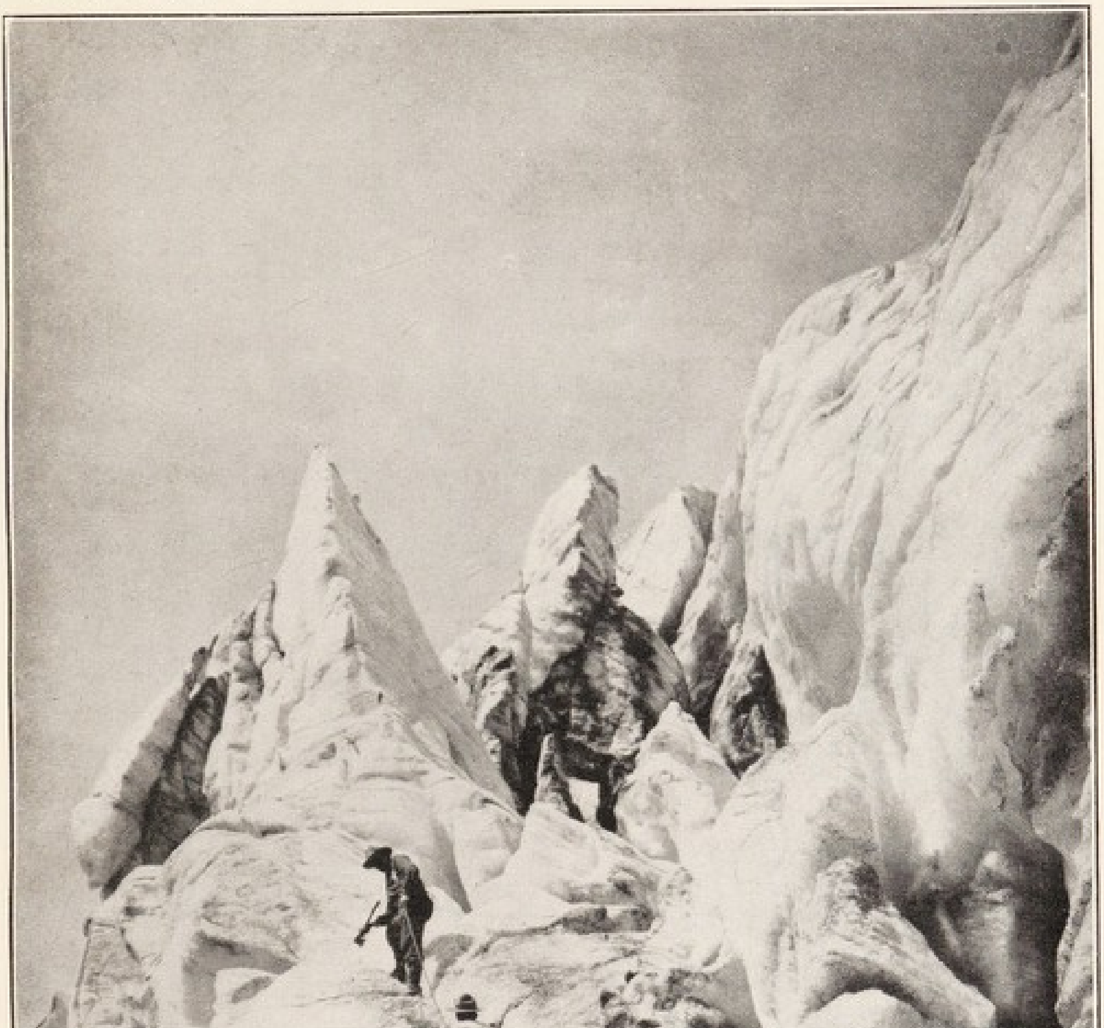
Another instance of settling a disputed horizon[1] recalls a personal experience. In a small drift block of sandstone which I found in 1867 on the road from Trenton to Trenton Falls, Oneida County, N. Y., there is an unusual apparent association of Upper Cambrian (Hoyt limestone) and Ordovician (Aylmer sandstone, Chazy) fossils. The Hoyt limestone species are *Ptychaspis speciosus* and *Agraulos* cf. *saratogensis*. The Aylmer sandstone species are *Leperditia armata* and *Bathyurus* cf. *angelina* Billings.

When as a boy I found the rounded block of sandstone referred to I broke out all the fossils possible, as at the time I was well acquainted with the Trenton limestone fauna, and the fossils in the block were strangers to me, with the exception of *Leperditia armata*. The following winter I endeavored to locate the stratigraphic position of the trilobites, but could not, further than that they were evidently of pre-Trenton age. This study aroused an interest in the American early Paleozoic fossils that gradually led me to take up the Cambrian rocks and faunas as my special field of research.

The block of sandstone I had found was about 3 inches in thickness by 12 in diameter. The impact of the wheel of the wagon in which I was riding split the block open and exposed several cranidia of the trilobite now known as *Ptychaspis speciosus*. Neither this nor *Agraulos* cf. *saratogensis* occurred in direct association with the Chazy *Leperditia* and *Bathyurus*.

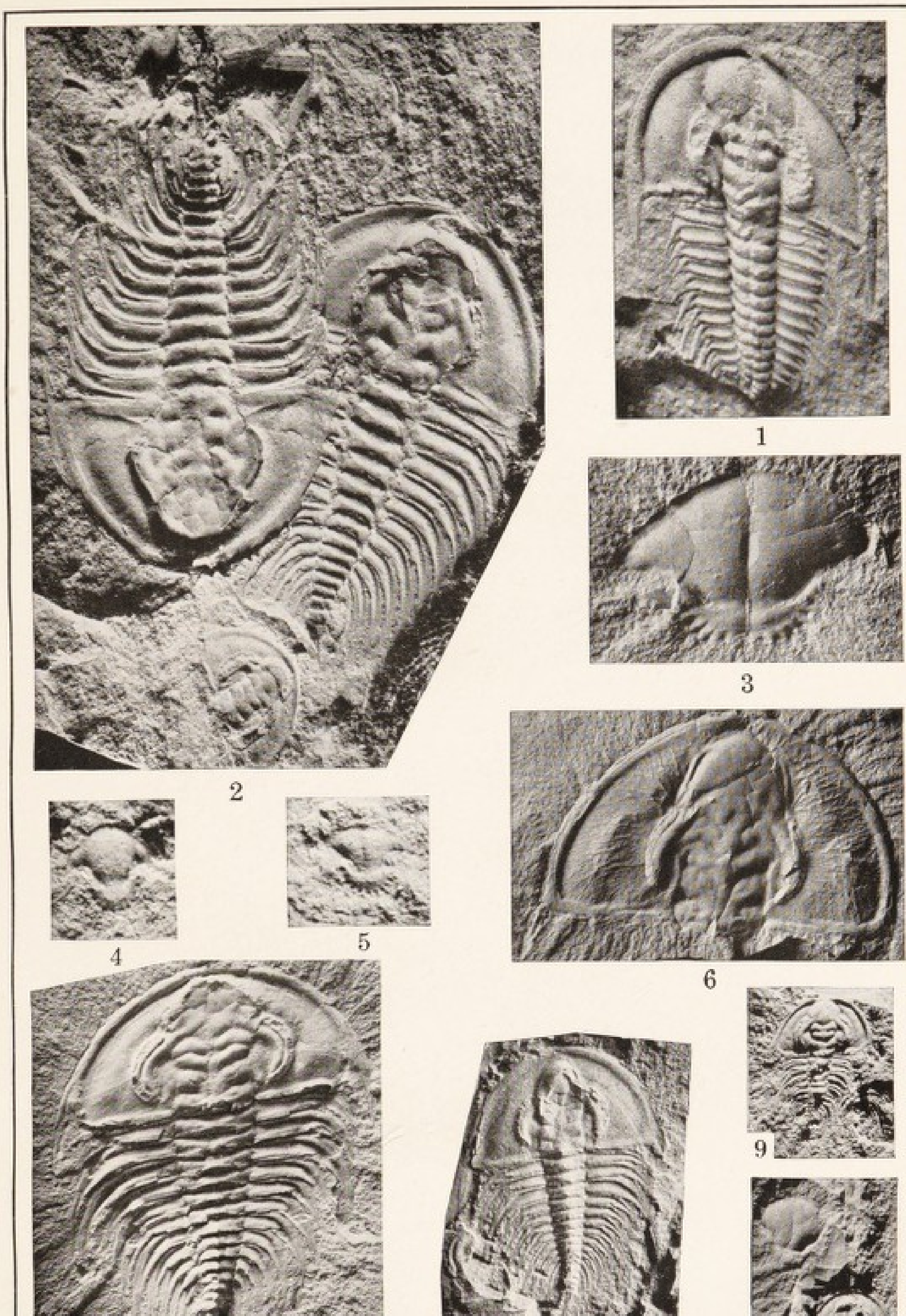
In explaining this connection I have recently been led to adopt a suggestion of Dr. E. O. Ulrich that the block of sandstone was part of a bed formed by the overlap of the Aylmer sandstone of the Chazy on a layer of Potsdam sandstone. This would make the line of demarcation between the Cambrian and Ordovician deposits within the block of sandstone that I found. With this view in mind, the Hoyt limestone species have now been referred by me to the Upper Cambrian and the Aylmer sandstone species to the Ordovician.

[1] Walcott: New York Potsdam-Hoyt fauna, Smithsonian Misc. Coll., vol. 57, No. 9, 1912.



WORKING UP THROUGH THE VAST AND BROKEN FRONT OF HUNGA GLACIER.

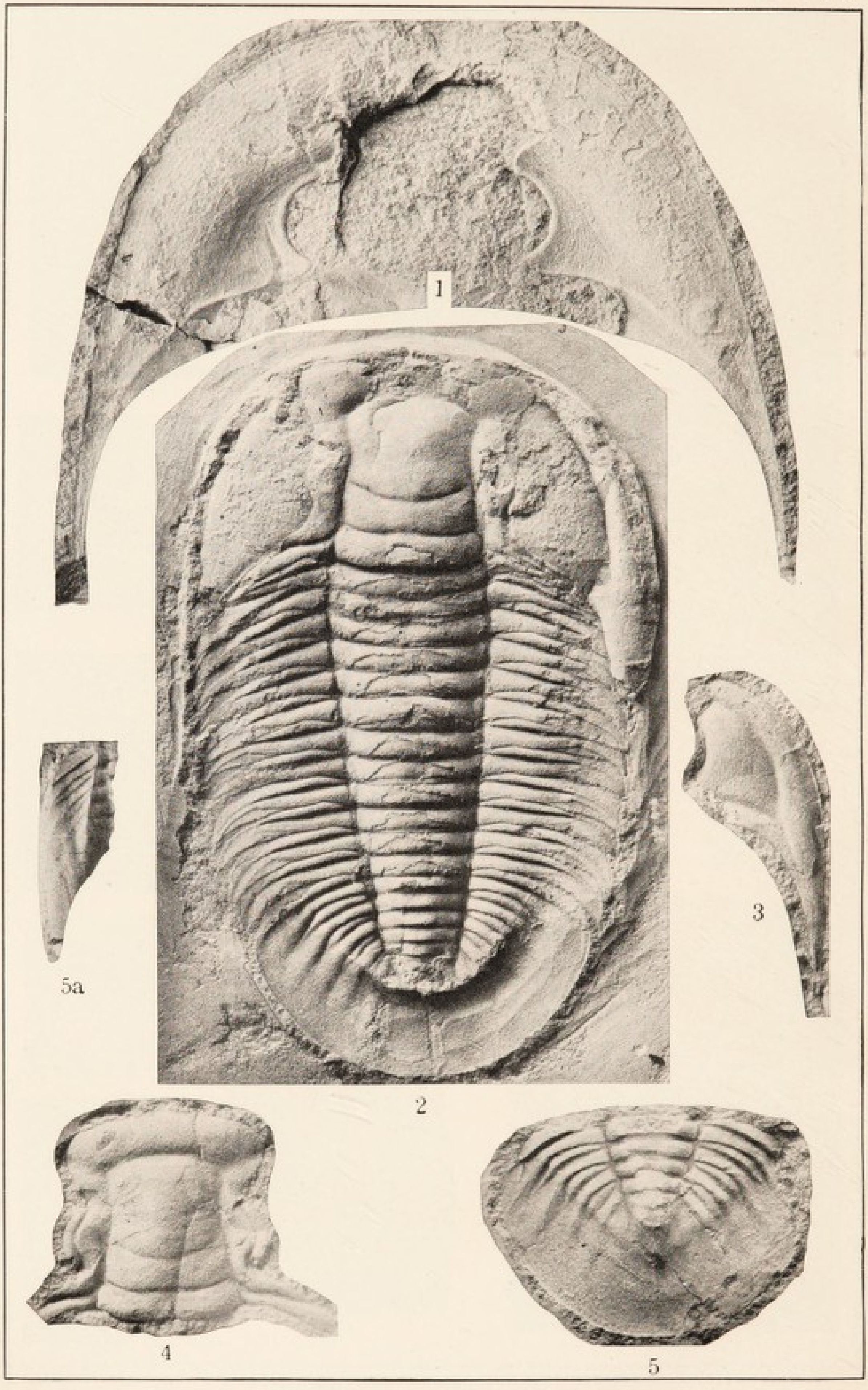
Photograph by R. C. W. Lett, by courtesy of Grand Trunk Pacific Railway. Reprinted from National Geographic Magazine.



LOWER CAMBRIAN TRILOBITES.

1. *Holmia ? macer* Walcott; 2–10, *Olenellus truemani* Walcott.

Mahto formation: From Mumm Peak, 6 miles north of Robson Peak and northwest of Yellowhead Pass, in western Alberta. (See pl. 14).



DIKELOCEPHALINÆ: UPPER CAMBRIAN TRILOBITES.

1. *Dikelocephalus minnesotensis* Owen. From Goodhue County, Minn.
2–5, 5a. *Saukia crassimarginata* (Whitfield). From Sauk County, Wis.

CAMBRO-ORDOVICIAN BOUNDARY WEST OF CONTINENTAL DIVIDE.[1]

As a third instance of similar kind, the discovery of fairly well-characterized specimens of the trilobitic genus *Ceratopyge* associated with brachiopods of the same general type as those found in the *Ceratopyge* shale of Sweden is most important, as it gives the first definite suggestion of a base for the Ordovician in the section along the Canadian Pacific Railway west of the Continental Divide. In Sweden the *Ceratopyge* shale and limestone are now by general assent placed at the base of the Ordovician, and with our knowledge of the stratigraphy of the upper portion as determined by Mr. Allan[2] I am inclined to agree with him in placing, at least tentatively, the boundary between the Cambrian and the Ordovician at the summit of the Ottertail limestone and the base of the Goodsir formation.

The broad question of the Cambro-Ordovician boundary in other sections of North America is one that is still in process of adjustment, owing to the absence of detailed information as to the boundaries between formations and the character of the faunas in the formations. Investigations now in hand will throw new light on the relations of the Appalachian formations and their invertebrate faunas.[3]

CONCLUSION.

The varied investigations of the past few years have opened very interesting problems which have been barely touched upon in this brief review.

How much earlier than the pre-Cambrian and Algonkian faunas the study of primitive life may be extended will depend very largely upon the discovery and study of now unknown fossil faunas and floras. All of this comparative study requires a world-wide activity in the fields of geology and paleontology. That science is universal is shown by a recent incident. The writer lately received a scientific pamphlet from a European paleontologist, with the request that it be forwarded to a fellow paleontologist in a country with which his nation was at war, and there was no communication between the two. The friend replied, through the intermediary, acknowledging its receipt and asking that his thanks and kind wishes be conveyed to the sender.

Students and investigators everywhere are invited to cooperate with the writer in his studies of the evidences of primitive life, and in his effort to correlate all procurable data on the subject and make them available for study and research by all those interested in these fascinating problems.

---

[1] Smithsonian Misc. Coll., vol. 57, no. 7, 1912.

[2] Allan, John A.: Ice River District, British Columbia, Geol. Survey of Canada, Sum. Rept., Dept. of Mines, 1910, pub. 1911, pp. 135–144.

[3] Smithsonian Misc. Coll., vol. 64, no. 3, 1916, Cambrian Trilobites.