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CAMBRIAN GEOLOGY AND PALEONTOLOGY

II

ABRUPT APPEARANCE OF THE CAMBRIAN FAUNA ON THE NORTH AMERICAN CONTINENT

WITH ONE MAP

BY

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INTRODUCTION

In accepting the invitation of the Representatives for Paleontology of the Swedish Committee of the Eleventh International Geological Congress, to take part in the discussion of "The Abrupt Appearance of the Cambrian Fauna," I decided to confine the geological discussion mainly to phenomena observed on the North American Continent and to limit paleontological conclusions to results obtained from studies of material from the oldest fossiliferous Cambrian rocks.

In summing up the Lower Cambrian fauna in 1891 [Walcott,

[1] Read at the Eleventh International Geological Congress, Stockholm, Sweden, August 18, 1910.

1891a, pp. 594-595] I said, when speaking of the "Origin of Fauna":

> If we attempt to classify the *Olenellus* fauna by its genesis, an almost impenetrable wall confronts us. That the life in the pre-*Olenellus* seas was large and varied there can be little, if any, doubt. The few traces known of it prove little of its character, but they prove that life existed in a period far preceding Lower Cambrian time, and they foster the hope that it is only a question of search and favorable conditions to discover it. As far as known to me, the most promising area in which to search for the pre-*Olenellus* fauna is on the western side of the Rocky Mountains in the United States and on their eastern (western) slopes in British Columbia. There the great thickness of conformable pre-*Olenellus* zone strata presents a most tempting field for the student collector. Another of the known possible areas is that of New York and Vermont, but the prospect is not as favorable as in the West. Other and better fields may exist in Asia and Africa, but as yet they are unknown, with the exception of the areas described by Baron Richthofen in China [Richthofen, 1882, Vol. 2, pp. 94, 100, and 101] where a great thickness of conformable sedimentary beds exists beneath a horizon that is comparable with the Middle Cambrian of western North America.

With the above thought in mind I have for the past eighteen years watched for geological and paleontological evidence that might aid in solving the problem of pre-Cambrian life. The great series of Cambrian and pre-Cambrian strata in eastern North America from Alabama to Labrador; in western North America from Nevada and California far into Alberta and British Columbia, and also in China,[1] have been studied and searched for evidences of life until the conclusion has gradually been forced upon me that on the North American Continent we have no known pre-Cambrian *marine* deposits containing traces of organic remains, and that the abrupt appearance of the Cambrian fauna results from geological and not from biotic conditions. I do not mean by this to infer that Brooks' hypothesis [Brooks, 1894, pp. 455-479] of the origin of the earlier forms of life in the surface waters of the open ocean is incorrect, but I mean that we have no known record in the strata of the marine life of the period between those earlier open-sea forms and the first records of life found in the Lower Cambrian strata. That such life existed there can be no question. It is the imperfection of the geological record as known to us that is the cause of the present uncertainty as to the pre-Cambrian faunas, and the abrupt appearance of the Cambrian fauna.

It is my present view that the known later Algonkian rocks in-

[1] Willis and Blackwelder, 1907, Vol. 1, pt. 1, pp. 21-44, 99-156, 265-274.

cluded in the Grand Canyon, Llano, and Belt series, and in formations correlated with them [see Van Hise and Leith, 1909, pp. 45, 46], were deposited in fresh- or brackish-water seas to which the marine life of the extra-continental seas very rarely had access. Such access occurred in mid-Beltian time when a protozoan, a crustacean, and a few annelids penetrated and became adapted to the conditions of the Montana sea, and more or less similar forms to the Arizona sea. Other and different forms may have lived in these and other interior bodies of water, but as yet we have no knowledge of them.

On the eastern side of the continent the unconformity between the oldest Cambrian and the known Algonkian rocks is so marked that there is no question of a great stratigraphic and time break between the two systems. The same is true of the Lake Superior, Hudson Bay, and Cordilleran areas. The Algonkian sedimentary rocks of the Atlantic coast region and the central interior continental areas, like most, if not all, of those of the western interior or Cordilleran areas, are of terrigenous origin, and in the absence of a marine fauna are considered as having been deposited in epicontinental seas or lakes of fresh or brackish water.

PRE-CAMBRIAN ROCKS

With our present information it appears that toward the close of Archean time a period of diastrophism ensued, resulting in an uplift of the North American, and probably other continental masses. It was accompanied by local disturbances that resulted in the profound folding and metamorphism of the Archean complex and the formation of high mountains and uplands. Large areas of low lands existed between the higher lands, and in these the terrigenous sediments began to accumulate in inland seas and lakes and in the marine waters along the shores. Great quantities of eruptive matter were extruded, the agencies of diastrophism continued to exert their influence, but with decreasing energy, and during the latter part of Algonkian time they were still less active. When the continental area that had largely been a land surface since the first great uplift at the close of the Archean began to admit the Cambrian sea, or what is more probable, the sea began to rise, the latter found a surface of relatively low relief, and in some districts great areas of sediment that had been deposited in the inland lakes, so situated that the Cambrian sediments were laid down almost conformably superjacent to them.

In a word, the thought is that the Algonkian period, with its great epicontinental formations, was a period of continental elevation and largely terrigenous sedimentation in non-marine bodies of water, also a period of deposition by aerial and stream processes over considerable areas.

The recent map of the pre-Cambrian rocks of North America by Van Hise and Leith [1909, pl. 1] shows that the distribution of the Algonkian rocks is confined to areas well within the margins of the continental platform. The strata we have to consider on this map are in the areas placed under the Algonkian, including Keewatin areas in Canada and the Lake Superior region. Van Hise and Leith [1909, p. 21] define the Algonkian as including "the major part of the pre-Cambrian sedimentary rocks, though it also contains sediments so deformed and metamorphosed that their stratigraphy cannot be deciphered. The Archean is the basement complex, perhaps including several series or groups upon which the Algonkian rests, so far as known, with unconformity."

The sediments of other Algonkian areas of North America were much like those of the Lake Superior region in having immense quantities of sand and mud, and, more rarely, great thicknesses of calcareous matter.[1]

Briefly, the rocks of the later Algonkian formations may be outlined as follows:

WESTERN NORTH AMERICA

Grand Canyon series, Arizona. [Walcott, 1899, pp. 215-216.]

	FEET
Chuar terrane (composed of fine-grained sandstone, argillaceous and arenaceous shales, and 285 feet in thickness of limestone)	5,120
Unkar terrane (composed mainly of sandstones with a bed of magnesian limestone 150 feet in thickness and a series of basalt flows 800 feet in thickness	6,830
Total thickness	11,950

There are no conglomerates except a bed not exceeding 30 feet in thickness at the base.

The Llano series of Texas is much like the Grand Canyon series [Walcott, 1884, pp. 431, 432].

The Belt series of Montana [Walcott, 1899, pp. 201-209; 1906, pp. 2-15, 17-21] and British Columbia, Canada [Walcott, 1906, pp. 21-

[1] For data relating to the description of the Algonkian rocks see Van Hise and Leith, Bull. No. 360, U. S. Geol. Survey.


BOUNDARY OF CONTINENTA
N O R T
A L A S K A
D O M I N
G R E E N L A N D
D A V I S S T R A I T
H U D S O N B
HUDSON STRAIT
Cockburn Island
Grinnell Land
ICELAND

MAP OF NORTH AMERICA SHOWING DISTRIBUTION OF FRE-CAMBRIAN ROCKS (AFTER VAN HISE AND LEITH, 1909.)

26], include in the Belt Mountain section 4,400 feet of limestone and 7,600 feet of arenaceous and siliceous strata [Walcott, 1899, p. 204], and in the Mission Range section about 6,000 feet of calcareous strata and over 18,000 feet of arenaceous and siliceous beds [Walcott, 1906, p. 18].

In the Lake Superior region the Keweenawan system is made up of a great series of mainly igneous rocks in the lower portion, with sedimentary sandstone and siliceous strata above, that form about 15,000 feet of the 50,000 feet in thickness provisionally assigned to this system [Chamberlin and Salisbury, 1906, p. 192].

The eastern or Atlantic Province Algonkian strata are represented in Newfoundland by about 10,000 feet of mainly siliceous sediments, and in Nova Scotia there may be 15,000 feet of similar sediments [Chamberlin and Salisbury, 1906, p. 204].

Sources of Sediments.—Of the sources of the sediments of the Algonkian (Proterozoic) formations of the Lake Superior region, Chamberlin and Salisbury consider [1906, Vol. 2, p. 199] "that a large portion of the sediments was produced by *mature decomposition* of older rocks, and this implies that they were not derived by rapid mechanical abrasion such as that which accompanies and follows great elevation and excessive precipitation. The great series of quartzites were derived from the complete decomposition of quartz-bearing rocks, and involved the almost complete separation of the quartz grains from other constituents, while the thick beds of shale arose from the complementary clayey products of decomposition from which most of the basic oxides had been removed by carbonation." These authors consider that the sediments were deposited on the bed of the Algonkian sea [p. 200].

The sources of the sediments of the Algonkian formations of the Cordilleran and Atlantic Provinces appear to have been similar to those described above, and all indicate relatively low elevations and quiet conditions of deposition except in the case of the massive, coarse sandstones in the lower Belt series of northwestern Montana [Walcott, 1906, p. 26].

The Algonkian formations of the Belt, Grand Canyon, Llano, and Avalon series all contain a large amount of bluish-black, red, and green, finely arenaceous, siliceous shales. These often form beds hundreds of feet in thickness, and extend over wide areas. With the exception of *Cryptozoan ? occidentale* Dawson [Walcott, 1906, p. 18] in some of the interbedded limestones there is no evidence of the presence of life in them.

There are also thick masses of limestone interbedded in the Algonkian series. The Blackfoot terrane has over 4,800 feet of calcareous beds. The Siyeh limestone is 4,000 feet thick, and the Newland limestone 2,000 feet. Similar blue, red, and green deposits, if deposited in the ocean, would probably have been accumulated in deep, quiet water [Chamberlin and Salisbury, Vol. 1, 1904, pp. 361-363], but (a) the large amount of calcareous matter; (b) the presence of shrinkage cracks and ripple markings on shales, sandstones, and limestone shales; (c) the presence in calcareous shales of fossils that lived in shallow water [Walcott, 1899, pp. 235-238], indicate that the Algonkian sediments were deposited in relatively shallow water.

In speaking of the climatic significance of red-colored deposits, Barrell [Barrell, 1908, pp. 292 and 293] says:

> Turning to the climatic significance of red, it would therefore appear both from theoretical considerations and geological observations that the chief condition for the formation of red shales and sandstones is merely the alternation of seasons of warmth and dryness with seasons of flood, by means of which hydration, but especially oxidation of the ferruginous material in the flood-plain deposits is accomplished. This supplements the decomposition of the source and that which takes place in the long transportation and great wear to which the larger rivers subject the detritus rolled along their beds. The annual wetting, drying, and oxidation not only decompose the original iron minerals but completely remove all traces of carbon. If this conclusion be correct, red shales or sandstones, as distinct from red mud and sand, may originate under intermittently rainy, subarid, or arid climates without any close relation to temperature and typically as fluvial and pluvial deposits upon the land, though to a limited extent as fluviatile sediments coming to rest upon the bottom of the shallow sea. The origin of such sediment is most favored by climates which are hot and alternately wet and dry as opposed to climates which are either constantly cool or constantly wet or constantly dry.

Origin of Later Algonkian Rocks.—The question under this heading is as to whether the rocks of the Belt series of Montana, the Grand Canyon series of Arizona, the Llano series of Texas, the Avalon series of Newfoundland, and more doubtfully the Keweenawan series of the Lake Superior region, are of marine or of terrestrial origin.

By referring to the accompanying map of the later Algonkian rocks we find that all of the known areas are within the limits of the outline of the continental platform, even those of Newfoundland and Nova Scotia being 150 miles within that platform. With this in view I will first call attention to the origin of the great series of Tertiary terrestrial non-marine sediments in the western section of the continent, for the solution of that problem has a most important bearing on the probable origin of the Algonkian sediments.

In speaking of the terrestrial formations of the Eocene, Chamberlin and Salisbury [1906, Vol. 3, p. 204], when comparing the sedimentation of the Eocene with the present time, say:

Then as now, temporary and permanent streams were doubtless aggrading their valleys, and building fans and alluvial plains where the appropriate conditions were found, while sheet-floods spread debris washed down from the higher lands on the tracts below. The deformative movements which initiated the modern era probably gave rise to basins here and there, in which lakes were formed, and the flows of lava from the unnumbered vents of the time doubtless sometimes obstructed valleys, ponding the streams and giving rise to lakes. Under these conditions, it is probable that much of the debris which was started seaward by the swift waters of the higher lands found lodgment long before it reached the sea, some of it at the bases of steep slopes, some of it on river plains, and some of it in lakes. The wind also made its contribution. The result was an inextricable combination of fluvial, pluvial, eolian, and lacustral deposits.

Terrestrial formations of Eocene age and of fluvial, pluvial, lacustral, and eolian origin are widespread throughout the western interior, occurring even in proximity to the western coast. Many of them are of limited extent, while others are spread over great areas.

Again, in describing the terrestrial deposits of the Miocene, the above authors say [p. 266]:

The terrestrial Miocene formations (the Truckee Miocene[1] of King) are said to reach a thickness of 4,000 feet (King) at some points in the vicinity of the 40th parallel. In general, they are made up of sandstones, conglomerates, volcanic debris, infusorial earths, and fresh-water limestones, overlain by great thicknesses of volcanic tuffs. The John Day series, the upper portion of which is perhaps Miocene, is also thick (said to be 3,000 or 4,000 feet), and is made up largely of volcanic ash and sand, much of which seems to be eolian.[2]

Other areas of deposition, some of them lakes, existed during the Miocene in Nevada and Montana. In the southwestern part of Nevada, the Miocene beds (Esmeralda formation) described as lacustrine, consist of the usual sorts of clastic rocks, pyroclastic material, and workable coal, the latter showing that the formation is not altogether lacustrine. The formation also carries some sulphur. The remarkable thickness of 14,800 feet (which may include Pliocene beds) is reported for this formation.[3]

In the fresh-water Morrison formation of Colorado Mr. Darton notes the presence of 66 feet of limestone [Darton, N. H., 1905, p. 97] in a section 166 feet in thickness.

[1] King, Geol. Expl. of the 40th Parallel, Vol. 1, pp. 412, 458.

[2] Merriam, Journ. Geol., Vol. 9, p. 71, and Bull. Dept. Geol., Univ. of Cal., Vol. 2, p. 306.

[3] Turner, Amer. Geol., Vol. 29, p. 268, and 21st Ann. Rept. U. S. Geol. Survey, Pt. 2.

I find in my field notes of 1879, on the Tertiary section at the head of the Upper Kanab Valley in southern Utah, the following on the fresh-water beds:

	Feet
a. Light gray limestone with Physa and Planorbis	125
b. Pink arenaceous marls	180
c. Light gray limestone	20
d. Marl	40
e. Pink limestone	50
f. Light gray limestone	125
g. Pink limestone	100
h. Sandstones with fine conglomerate at the base	625

The limestones extend over a considerable area west, north, and east, and were deposited in massive layers in a deep, quiet lake.

The Tertiary sedimentation described above, omitting the eruptive materials, is very similar in many respects to that of later Algonkian time. The sediments of the Algonkian are as a whole more siliceous, but the variation in thickness and character of the various beds [Walcott, 1906, pp. 17-21] is of the same general type.

The sediments of the two widely separated periods of Algonkian and Tertiary time were accumulated within the limits of the great Cordilleran geosyncline, and, with our present knowledge, I think, under essentially similar physical conditions. At the time of the Tertiary deposition there was abundant life, both on the land and in the water, but in Algonkian time only a fragment of the pre-Cambrian life had had the opportunity of adapting itself to the conditions of the inland seas of late Algonkian time.

Dr. Joseph Barrell has given a full review of the evidence favoring the continental origin of most of the Algonkian rocks of the Cordilleran area. He argues that from the presence of mud-cracks in the Belt and Grand Canyon series that many of the formations were deposited on flood plains. He says [1906, p. 566]:

> The discussion of these pre-Cambrian deposits but especially of the Montana occurrences, shows how completely in accord is the hypothesis of the dominant flood-plain origin of mud-cracks with the other marks of subaerial deposition in an arid climate. The mud-cracks are confined to just such formations as from other characteristics suggest a flood-plain origin and these formations are usually separated from the deposits of limestone by transitional formations which differ in color, in character, and in the absence of mud-cracks, suggesting the true submarine deposits originating between the shore and the open sea.

Doctor Barrell's view that the limestones are of marine origin is similar to the one that largely influenced me in the past to consider that the Grand Canyon and similar series of Algonkian formations were of marine origin.

PRE-CAMBRIAN CONTINENTAL SURFACE

In 1892 I published the opinion that the North American continent

> Was larger at the beginning of Cambrian time than during any epoch of Paleozoic time and probably not until the development of the great fresh-water lakes of the lower Mesozoic was there such a broad expanse of land upon the continental platform between the Atlantic and Pacific oceans.
>
> The continent was well outlined at the beginning of Cambrian time; and I strongly suspect, from the distribution of the Cambrian faunas upon the Atlantic coast, that ridges and barriers of the Algonkian continent rose above the sea, within the boundary of the continental plateau, that are now buried beneath the waters of the Atlantic. On the east and west of the continental area the pre-Cambrian land formed the mountain region, and over the interior a plateau existed that at the beginning of, or a little before, Upper Cambrian time was much as it is to-day. Subsequent mountain building has added to the bordering mountain ranges, but I doubt if the present ranges are as great as those of pre-Cambrian time that are now known only by more or less of their truncated bases. The Interior Continental area was outlined then and it has not changed materially since. Its foundations were built in Algonkian time on the Archean basement, and an immense period of continent growth and erosion elapsed before the first sand of Cambrian time was settled in its bed above them. [Walcott, 1892, pp. 562-563.]

When the Californian Cambrian sea began its invasion of the Algonkian land in southwestern California and Nevada there awaited the incoming waters a land surface deeply disintegrated and more or less base-leveled by erosion. As compared with the earlier epoch of the Algonkian it was a featureless continent, the elevations caused by folding and uplift in the geosynclines of the Cordilleran, Lake Superior, and Appalachian areas having been largely degraded. The rising waters of the Cambrian sea met with few marked elevations in the Cordilleran and Appalachian troughs, as is evidenced by the absence of coarse conglomerates and the presence above the basal conglomerates of immense deposits of very fine sandstone and mud rocks in the Lower Cambrian.

The character of the pre-Cambrian surface in the southern Appalachian area is well indicated in the description by Mr. Arthur Keith,

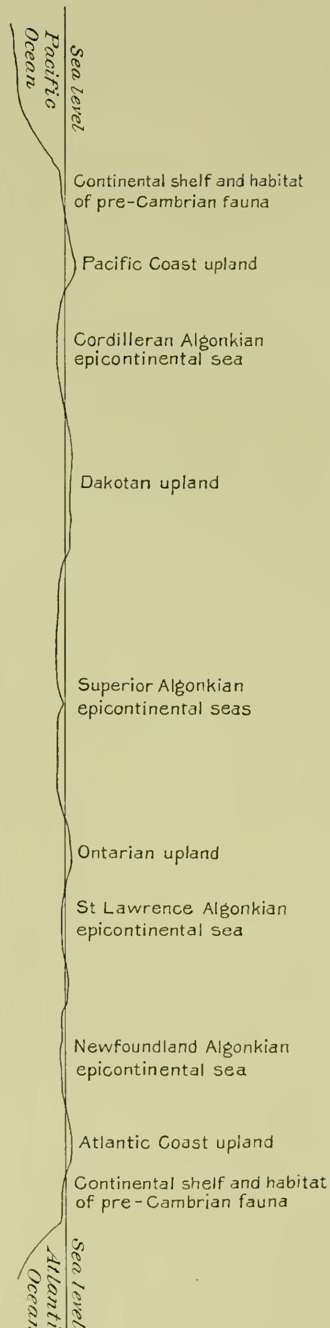

FIG. 1.

Theoretical profile of North American continent on line of Forty-eighth parallel, during part of Algonkian time. The Cordilleran, Superior, St. Lawrence, and Newfoundland epicontinental Algonkian seas are assumed to have been shut off from communication with the oceans during Algonkian time, except an occasional and very brief connection of the Cordilleran lakes with the Pacific Ocean.

of the Cambrian and pre-Cambrian contact in eastern Tennessee, who says [1]:

With the deposition of the Cambrian rocks there came a great change in the physical aspect of this region. The sea encroached on areas which for a long time had been dry land. Erosion of the surface and eruptions of lava were replaced by deposition of sediments beneath a sea. Extensive beds of these rocks were laid down in some areas before other areas were submerged, and the sediments lapped over lavas and plutonic granites alike. The waste from them all was combined in one sheet of gravel and coarse sand, which now appears as shale, sandstone, conglomerate, and rocks derived from them. The thickness of this first formation varies greatly and abruptly in this region, showing that the surface upon which it was laid down was irregular. Subsequent formations of Cambrian age came in a great group of alternating shale and sandstone followed by an immense thickness of limestone and shale. Fossils of Cambrian age, mainly *Olenellus,* are found as far down as the middle of the sandstone group. The strata lying beneath the fossiliferous beds differ in no material respect from those overlying. All are plainly due to the same causes and form part of one and the same group, and all are closely associated in area and structure.

When speaking of the similar contacts in northwestern North Carolina, he says [2]:

Here the sediments lapped over lavas and plutonic granites alike, and the waste from them all was combined in one sheet of gravel and coarse sand which now appears as sandstone, conglomerate, and quartzite. Some of this waste consists of epidote and jasper, the products of alteration in the Linnville metadiabase. It is thus seen that the interval between the Algonkian and Cambrian was at least long enough to permit dynamic movements and chemical changes to effect considerable results, even before the period of erosion and reduction began.

UNCONFORMITY BETWEEN THE CAMBRIAN AND PRE-CAMBRIAN

In my paper on " The North American Continent during Cambrian Time " attention is called to a series of conformable pre-Cambrian rocks found in the Appalachian and Rocky Mountain troughs [Walcott, 1892, p. 544] that were thought to be conformably beneath the Lower Cambrian sandstone. Mr. Keith's detailed work, as cited above, has proven the presence of a marked unconformity in the southern Appalachian area. During the past ten years, as incidental to my Cambrian work, I have been studying the contact between the Cambrian and pre-Cambrian in the Cordilleran area. From

[1] U. S. Geol. Survey, Geological Atlas, Roan Mountain Folio, No. 151, 1907, p. 4.

[2] U. S. Geol. Survey, Geological Atlas, Cranberry Foliò, No. 90, 1903, p. 4.

British Columbia and Alberta, on the main line of the Canadian Pacific Railway, to Arizona and southern California, a distance of over 1,000 miles, I have found evidence of a transgressing Cambrian sea and consequent unconformity between the Cambrian and pre-Cambrian. It may have been the advancing, overlapping Lower Cambrian sea as in southwestern Nevada, the Middle Cambrian sea as in Utah and Idaho, or the Upper Cambrian sea as in Colorado.

The Cambrian rocks may be abruptly unconformable upon the Algonkian [Walcott, 1891, p. 551, fig. 48], or practically conformable as in areas where there has been very little disturbance of the subjacent Algonkian beds [Walcott, 1899, pp. 210-213]. Over the interior of the continent the late Middle Cambrian and Upper Cambrian strata unconformably overlap the Algonkian and Archean [Walcott, 1891, pl. 44, pp. 561-562], and clearly could not have recorded any part of the history of the period indicated by the absence of Lower Cambrian strata or of the sediments deposited in the period represented by the unconformity between the Lower Cambrian and Algonkian strata. I do not know of a case of proven conformity between Cambrian and pre-Cambrian Algonkian rocks on the North American continent. In all localities where the contact is sufficiently extensive, or where fossils have been found in the basal Cambrian beds or above the basal conglomerate and coarser sandstones, an unconformity has been found to exist. Stated in another way, the pre-Cambrian land surface was formed of sedimentary, eruptive, and crystalline rocks that did not in any known instance immediately precede in deposition or origin the Cambrian sediments. Everywhere there is a stratigraphic and time break between the known pre-Cambrian rocks and Cambrian sediments of the North American continent.

EXTENT OF WITHDRAWAL OF SEAS IN ALGONKIAN TIME

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 withdrawal 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, as described by Brooks, probably found its way to the littoral zone and developed in the protected waters along the ancient continental shelves. Of this period we have no known record either in marine sedimentation or in life.

EVIDENCE OF THE FOSSILS

The evidence afforded by the few traces of pre-Cambrian fossils is inconclusive as far as determining whether their habitat was in marine, brackish, or fresh water.

The fossils from the Chuar group of Arizona [Walcott, 1899, pl. 23, figs. 1-4; pl. 27, figs. 9-13] are not sufficiently characterized to prove their origin or habitat. The *Protozoan, Cryptozoon ? occidentale* Dawson, is very abundant in Arizona, also in the Belt series of Montana, Alberta, and British Columbia. It occurs in limestones similar to those deposited in the fresh-water lagoons of Florida, and similar to the limestones of the lake deposits of the Tertiary formations of the Great Plains region of North America. The fossils of the Beltina zone of Montana and Alberta could as readily have been developed in fresh or brackish waters. There is nothing about the crustacean remains incompatible with their living in fresh water, in fact, the fragments indicate a form more nearly related to the fresh-water *Branchiopoda* with very thin test, rather than the strong *Merostome* (*Eurypterus*, etc.).

The oldest Cambrian fauna now known, with *Nevadia weeksi* and *Holmia rowei* [Walcott, 1910, pp. 257 and 292], is limited to a few forms, but with a careful examination of the region where it occurs in southwestern Nevada it is highly probable that a considerable fauna will be found. The strata in which it occurs were deposited in a depression opening out toward the Pacific ocean, where southwestern California is now located; this depression soon extended northward and presumably connected through to British Columbia and Alberta, as the same species of *Olenellus* occur in the central and upper portions of the Lower Cambrian both in Nevada and Alberta.

I do not know of a Cambrian fauna as old as that of *Nevadia weeksi* on the eastern side of the continent, or on the European continent. It appears to be a portion of the older fauna that is missing everywhere except in southwestern Nevada. I think it was brought in by the advancing Lower Cambrian sea from a sea to the west, the sediments of which are buried beneath later strata or are off the present shore line of the continent beneath the sea.

The theory that life originated and developed in fresh-water ponds and lakes does not appeal to me. More uniform conditions of temperature and environment would be present in the ocean and the sediments of the fresh-water deposits of pre-Cambrian and Cambrian time, if such exist, do not show sufficient evidence of life having existed at the time of their deposition. The Algonkian fossils of the Belt and Grand Canyon series [Walcott, 1899, pp. 227-239] probably came from the marine fauna when a temporary connection existed between the interior fresh- or brackish-water lakes and the ocean.

RÉSUMÉ

1. Life probably first developed in the open ocean, as outlined by Brooks [1894].

2. 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 sea level was essentially the same as at the present time, or the continents may have been still more elevated in relation to the surrounding oceans.

3. The period of Algonkian continental elevation was of sufficient duration to permit of the development along the shores and shelves of the continents of the types of life now found in the basal Cambrian rocks, but the sediments containing the record of this life are probably concealed beneath the present oceans.

4. 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 a highly specialized crustacean deep down in the Belt series.

5. When the oceanic waters gained access to the Algonkian continental areas at the close of that era they brought with them the littoral fauna which had been developed during the Lipalian sedimentation,[1] and buried its remains in the sands and muds which form the Lower Cambrian deposits.

[1] Lipalian (*λειπα + αλς*) is proposed for the era of unknown marine 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.

6. The apparently abrupt appearance of the Lower Cambrian fauna is therefore 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 in Algonkian rocks, but until such is discovered I know of no more probable explanation of the abrupt appearance of the Cambrian fauna than that I have presented.

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