THE ENIGMA OF THE EARLIEST FOSSILS

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ABSTRACT

The occurrences of Pre-Cambrian organic remains are reviewed. There is little indisputable evidence of fossilised animals but there are more reliable indications of plants. Some of the hypotheses purporting to explain the dearth of Pre-Cambrian fossils are critically examined ; the only tenable explanation is one which is applicable to the world as a unit. Mention is made of Milne's cosmological model and of Haldane's biological deductions therefrom. The conclusion is reached that the appearance of animals with hard parts may be attributed, first, to the results developing from a variation in the rate at which energy is generated by chemical change, and, secondly, to radial evolution instead of to the classical model of the tree of evolution.

THE mediæval dogma that all fossils are special creations was discredited in the 18th century and, when the law of the order of superposition of rocks was acknowledged, a method of seeking the origin of life was clear for all to see. The early decades of the 19th century witnessed the establishment of the stratigraphical sequence, and thereby of the succession of life, from recent times as far back in geological history as the Old Red Sandstone. In this vast interval the amphibians, reptiles, birds and mammals had appeared on the Earth, and many animal and plant groups had risen to an acme only to be succeeded by a decline and extinction. The elucidation of the stratigraphy of the Transition Zone, which bridged the gap between the Old Red Sandstone and the crystalline rocks of the Primordial Zone, held a promise that the history of life could be followed far back in remote time and its very origin discovered. The results of the labours of Sedgwick and Murchison in Britain, of Barrande in Bohemia, and of Hall and Logan in North America have often been related, and their brilliant stratigraphical insight eventually led to an understanding of these complex strata. Older, and yet older, fossiliferous rocks were met, until the oldest fauna of the Cambrian with its remains of numerous and, in some cases, advanced animals was found to succeed a thick series of Pre-Cambrian sediments which are virtually unfossiliferous. Yet greater effort was directed to the uncovering of Pre-Cambrian faunas but without avail, and the hopes of discovering the origins of life dwindled. But why is it that Pre-Cambrian rocks carry no abundant evidence of organic remains when they may be unmetamorphosed and have all the appearances of proving to be fossiliferous? The answer to that question still defeats scientists. It will be as well, first, to survey generally the faunas of the Lower Cambrian and, secondly, to refer to the specimens claimed to be Pre-Cambrian fossils before reviewing the hypotheses which purport to explain their extreme scarcity.

I. Lower Cambrian Faunas

Raymond (1947, p. 23) has traced 455 species of fossils from the Lower Cambrian of the world. The allocation of these species to the different phyla is as follows: Porifera, in which are included the Archaeocyathinae, 84; Coelenterata, all of which are jellyfish, and Echinodermata, including rare cystids and edrioasteroids, 10; Vermes, including tubes, trails and burrows, 19; Brachiopoda, 125; Mollusca, comprising gastropods and hyolithids, 52; Arthropoda, 165, of which 133 are trilobites.

The fauna is varied but there is a notable absence of heavily shelled forms. Most shells or exoskeletons were composed of chitin or a comparable substance, but some brachiopods and the Archaeocyathinae were calcareous. Furthermore, most of the invertebrate phyla are represented, but many important groups, most of which in stratigraphically higher deposits are characteristically provided with thick, calcareous shells or calcareous colonies, are unknown in the Lower Cambrian; these are: Protozoa, but there are some doubtful records from the Lower Cambrian; corals and stromatoporoids; blastoids, crinoids, starfishes, and echinoids; Polyzoa, although problematical fragments have been attributed to this phylum; lamellibranchs; cephalopods.

II. Pre-Cambrian "Fossils"

In the majority of cases almost all palaeontologists would agree that a particular specimen from Cambrian or younger rocks is, or is not, a fossil. But it is otherwise with the so-called fossils of the Pre-Cambrian because opinion is invariably divided; such conflicting interpretation is of itself significant.

Discovered by Barrois at the end of the last century in carbonaceous quartzites interbedded with shales of the Pre-Cambrian Brioverian rocks of Brittany are small rounded bodies, 1μ—22μ in diameter, which have been claimed to be radiolaria by Cayeux (1894a, p. 203, pl. xi), but other palaeontologists have denied that these minute structures are organic in origin. Cayeux reiterated his belief in their radiolarian character when he had more material to hand (1929, p. 356). According to Deflandre (1949, p. 351), the systematic position of these micro-organisms remains uncertain; he expels them from the Radiolaria, but suggests they might be classified along with the Microhystrichosphaeridae. Cayeux also described objects which he identified as foraminifera (1894b, p. 116; 1894c, p. 1433) and as sponge-spicules (1895a, pp. 54–58; 1895b, p. 279), but here the structural evidence is far from convincing. Kerforne (1923, pp. 126, 131) has affirmed that the 'radiolarian' deposits and, indeed, other fossiliferous strata are really of Palaeozoic and not Pre-Cambrian age, and are preserved as infolds within the Brioverian rocks, but some continental geologists still maintain that Pre-Cambrian 'radiolaria' occur in Brittany and Normandy (Ters, 1937, pp. 11–12; Dangeard, 1951, p. 29; Pruvost, 1951, p. 61).

Two species of the problematical *Atikokania* have been described from the Pre-Cambrian of Ontario (Walcott, 1912, pp. 17–19). Additional and well-preserved material of one species proved on sectioning to consist of radiating quartz crystals embedded in a matrix of limestone; the second species, first ascribed by Walcott to the Archaeocyathinae and later referred to a spongoid form, is likewise probably inorganic (Raymond, 1947, p. 31).

Manchuriophycus (Endo, 1933, p. 47; Yabe, 1939, p. 205) from the Sinian of southern Manchuria was placed in the algae but, supposing it is organic in origin, it might be a worm-burrow. Trails of many kinds and non-annulated, sinuous, infilled burrows have been recorded by many authors from a variety of localities in other parts of the world, and, although these are notoriously difficult to interpret, they may in some cases indicate the existence of worms in Pre-Cambrian times (Fenton & Fenton, 1937, p. 1950; Faul, 1950, p. 103).

Horny brachiopods are recorded from the Vindhyan System of India.* The many species erected by Chapman (1935, p. 114) were reduced to one by Sahni (1935, p. 465), who doubted their brachiopod affinity; Howell expressed his opinion that they are algae (*in* Chapman, 1935, p. 113; see also Faul, 1950, p. 102). The specimens of *Lingulella montana* from the Belt Series of Algonkian age show a characteristic shape, and the concentric markings certainly have the appearance of growth-lines of brachiopods (Fenton & Fenton, 1936, pp. 616–7), but Cooper (*in* Shimer & Shrock, 1944, p. 284) considers there is no authenticated example of a Pre-Cambrian brachiopod.

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* Modern opinion is not in agreement on the Pre-Cambrian age of these rocks. Pascoe (1950, pp. 39–41) places the Vindhyan System in the Lower Palaeozoic.

Walcott described *Beltina danai* from the Belt Series and claimed it to be an arthropod (1899, p. 238) ; later (1911, p. 21, pl. 7), he illustrated additional specimens because they exhibited a tuberculate surface, which, he considered, showed their affinity with eurypterids. The illustrations are unconvincing and current opinion maintains that the material includes inorganic and organic matter, the latter being represented by the broken fronds probably of brown algae (White, 1929, p. 393 ; Fenton & Fenton, 1936, p. 616).

Protadelaidea was obtained from the lower division of the Adelaide Series by David and restored by Tillyard, who claimed for it a common ancestry with the eurypterids (David & Tillyard, 1936 ; David & Browne, 1950, pl. 8). Unfortunately, the illustrations are ineffective and the description gives no proof that the specimens are organic ; there is a real possibility that they are inorganic and comprise ferruginous concretions of moderately uniform shape. That the interpretation of the specimens is difficult and uncertain is obvious from David's description of the state of preservation: " on account of the heavy leaching to which the rock has been subjected, as well as crushing and spreading of the rock-material under pressure, only very few of the fossils retain their original shape " (David & Tillyard, 1936, p. 41). The same uncertainty attends the " fossils " of arthropods, annelids and radiolarians previously reported by David (1928, p. 199).

Xenusion auerswaldae (Pompeckj, 1927) is a problematical fossil which shows affinities with annelids and arthropods. The specimen was collected from a glacial erratic ; the rock has been compared with the Dala Sandstone of Sweden but its age cannot with certainty be proved to be Pre-Cambrian.

The supposed medusa from the Algonkian strata of Basalt Canyon in the eastern part of the Grand Canyon, Arizona, is the most acceptable animal fossil so far recorded from the Pre-Cambrian (Bassler, 1941, p. 519 ; Van Gundy, 1951, p. 957). The impression is 18 cms. in diameter, lobate, and shows a central mouth. There appears to be no doubt of the Pre-Cambrian age of the rocks which yielded the solitary specimen because about 12,000 feet of rocks elsewhere separate this stratigraphical horizon of the Algonkian from fossiliferous Lower Cambrian.

Evidence of plant-life is more acceptable than for animals but yet there is little that is undeniably genuine. Walcott was the first to propose that certain calcareous, banded structures present in Pre-Cambrian rocks, particularly in the Belt Series of Montana, were caused by lime-depositing algae ; similar accretions have now been reported from many countries.* In his classical paper (Walcott, 1914, pp. 104–117), one genus was redescribed and

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* See Faul (1950, p. 102) and Schaub (1950, pp. 19–21) for references.

eight new genera were defined; but unlike algal deposits of Ordovician or younger age, they do not show that structural detail which would be conclusive as to their origin—in fact, they might be inorganic. Holtedahl (1921) compared the inorganic and secondary concretions of the Magnesian Limestone of Durham with many of Walcott's figures and the correspondence is too close to be fortuitous; consequently, many of the 'algal' genera are now relegated to the rank of pseudofossil (Fenton & Fenton, 1936, p. 612). *Collenia* is still considered valid because it is clearly an original structure. Gruner (1923, p. 146; 1925, p. 151) has claimed the existence of blue-green algae of Huronian age in Minnesota.

Walcott also recorded fossil bacteria enclosed in calcareous algae; they are represented by strings of cell-like bodies each about 1μ in diameter (1915, p. 257). The preservation of bacteria is so improbable that few palaeontologists have been able to lend their authority to Walcott's discovery. On the other hand, the considerable thickness of banded iron-ore and chert of the Animikie Series might owe its origin at least in part to iron-depositing bacteria and algae (Gruner, 1922, p. 457).

There are few Pre-Cambrian structures which are unequivocally fossils but the fact remains that carbon, whether it be in the form of graphite, a modified anthracite, or a carbonaceous film, is not an unusual material and many localities show an abundance in the rocks. Carbonaceous substances have been interpreted as indicators of organic matter and in unaltered sediments there is no other obvious explanation. Some graphite, as for example in the Grenville Limestone, may possibly have originated "from carbon monoxide or carbon dioxide emanating from igneous rocks or from the carbon dioxide set free by the interaction of the limestone with silica emanating from intrusives" (Wilson, 1931, p. 121; 1939, p. 305). The carbon was liberated either by reaction of the oxides with hydrogen, or by two molecules of carbon monoxide producing carbon dioxide and making free the remaining carbon. Theoretically, inorganic carbon can be formed, but geologists have not accustomed themselves to the view that it is present in rocks generally in any significant amounts. A new technique has been applied by Rankama to the study of the proportion of carbon isotopes particularly in carbonaceous substances collected from the Pre-Cambrian rocks of Finland. Plants* tend to concentrate the lighter C^{12} isotope, and the heavier C^{13} is, for instance, concentrated in limestones (Nier &

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* Recently, Wickman (1952, p. 253), has determined the C^{12}/C^{13} ratio for 105 plants, and finds the figures range from 89.19–91.43. He concludes that the enrichment of the light carbon isotope is connected with the carbon dioxide cycle, and identifies the variation in the isotopic ratio of carbon primarily as an ecological problem.

Gulbransen, 1939, p. 697; Murphey & Nier, 1941, p. 771) and other carbonates (Wickman, Blix & von Ubisch, 1951, pp. 143–150). Rankama (1948a, p. 203) has determined from 100 samples that the C^{12}/C^{13} ratio in meteoric carbon is 89.8–92.0, in inorganic carbon 87.9–90.2, and in organic carbon 90.3–93.1.* In the Finnish rocks the carbonaceous segregations include *Corycium enigmaticum* from the Bothnian phyllites which Sederholm (1912, p. 516; 1924, p. 717; 1925, p. 350), in the face of intense opposition, unwaveringly maintained was organic and probably vegetable, and a seam, 6 feet thick, of a Jatulian anthracitic substance to which the name of shungite has been given. *Corycium* occurs in crinkled, elongated, sac-like bodies, circular in cross-section and usually distributed parallel to the bedding. The carbonaceous matter, which is less than 1 mm. thick, gave a proportion of 90–92.3 which undoubtedly shows it is organic carbon (Rankama, 1948b, p. 410). Shungite occurs in four varieties and in one the material is jet black, of an adamantine lustre and analyses 89.77% carbon (Sudovikov, 1937, p. 51). Metzger believes shungite to represent a genuine anthracitic coal-seam which accumulated as a sapropelic layer in mudstone (1924, pp. 62–64). The C^{12}/C^{13} ratio of 92.9 supports an organic origin (Rankama, 1948b, p. 413). At the moment, however, the data provided by the carbon isotopes should be accepted with caution, because doubt as to the validity of the conclusions made by Rankama and others has been expressed by Craig, who maintains that the chemical evidence is insufficient (1953, p. 84).

A review of the ' fossils ' of the Pre-Cambrian thus demonstrates that the medusa from the Grand Canyon is the only specimen which might be animal in origin, but among the plants there are reliable indications of algal masses. The implication that plants were antecedent to animals conforms with modern biological belief. The energy that is sunlight can be harnessed only by plants which construct from it carbohydrates, such as sugars and starches, and fats. In the presence of available phosphorus, nitrogen and sulphur, the plants manufacture complex proteins. Animals are thus forced to feed directly on plants, or on other animals which take plants as part or as the whole of their diet, because in these ways only can they obtain the substances essential to their life processes, that is, the carbohydrates, the fats and the proteins. As animals fundamentally depend on plants, it is improbable that they preceded them.

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* Mars (1951, p. 137) considers 91.3 to be the lowest value for organically formed carbon, but later determinations by Wickman (1952) for plants are not in agreement.

III. Hypotheses to explain Rarity of Pre-Cambrian Fossils

Many are the hypotheses which have been formulated to explain the dearth of organic remains in Pre-Cambrian rocks; only a few need be considered. The belief that metamorphism has destroyed all signs of fossils is no longer tenable, because great thicknesses of unaltered sedimentary rocks of many different kinds have now been found and investigated in several widely scattered parts of the world, and, if animals with hard parts had existed, there is no reason why some should not have come down to us as fossils.

(*a*) *Cambrian unconformity*

The base of the Cambrian has for too long been assumed to be marked by an unconformity approximately contemporaneous all over the world. The logical, but nevertheless unacceptable, inference to be drawn from such an assumption is that at the beginning of the Cambrian Period the surface of the world was almost covered by a shallow sea, and land was well nigh non-existent. That the Cambrian is unconformable, particularly in many of the classical areas which were studied first, is undeniable, and this relationship was seized upon by some to explain the emergence of Cambrian faunas. The time-interval connoted by this unconformity was claimed to be sufficiently long to permit of the development by rapid evolution of the many animal-groups represented in Cambrian faunas. The hypothesis found few advocates, it being difficult to accept that the unconformity marked an interval of time adequate not only for the origin and differentiation of animal-groups, but also for the evolution of highly developed organisms such as the trilobites and brachiopods. Latterly, a cogent counter argument has become available with the discovery that in some parts of the world the olenellid, or comparable, faunas are concordantly underlain by unfossiliferous rocks. Over a distance of 120 miles, from the Grand Canyon in the east to eastern California in the west, the vertical distance between the top of the *Olenellus* Zone and the underlying unconformity increases, and permits, first, the maximum expression of that zone, and secondly, in the Nopah Range, the appearance of 8,520 feet of unfossiliferous rocks between the base of the *Olenellus* Zone and the selfsame unconformity, which hitherto has been interpreted as marking the Cambrian—Pre-Cambrian junction (Wheeler, 1947, p. 155). Similarly, in the Appalachians, considerable thicknesses of sedimentary rocks, previously classed as Cambrian, are found below the lowest Cambrian fossiliferous horizon (Erwin Formation and Hesse Quartzite), and they lie unconformably upon a surface eroded in igneous and metamorphic rocks (Snyder, 1947, p. 149). In both the Cordilleran and Appalachian provinces, therefore, several thousand feet of unfossiliferous strata have been relegated to the Lower Cambrian on no firmer evidence than that they have an unconformity beneath them and a fossil-bearing Lower Cambrian sequence above them. These are the deposits laid down during the time-period of the Lipalian interval, and in Norway and Greenland have been called Eocambrian, and in North Africa and France Infracambrian (Menchikoff, 1949, p. 309, footnote) ; as Holtedahl observes (1952, p. 71, footnote), these stratigraphical terms are not synonymous.

Which of the data is the more reliable in correlation? For instance, are the strata yielding an olenellid fauna transgressive relative to the datum-line of the unconformity, or does the unconformity cut across time? Lower Cambrian faunas, although variable from place to place, if considered in a world picture are well-defined and specific. In the American Cordilleran province the *Olenellus* Zone can be correlated with confidence and can be equated within reasonably narrow limits. The unconformity thus proves to be an original land surface which persisted much later in time in the east of that province, in the Grand Canyon, than in the west, in eastern California, and is valueless in correlation. No longer can the unconformity be utilised as the time-interval during which animals with hard parts evolved, because it is separated, in the examples already mentioned and in some of those next to be considered, by many thousands of feet of sedimentary rock from the first acceptable, or Lower Cambrian, fauna.

Several other regions in the world exhibit either an upward gradation or a slight depositional gap between the sedimentary Pre-Cambrian and the Lower Cambrian. In northern China a core of gneisses and schists is unconformably covered by a vast series of sedimentary beds estimated to be about 18,500 feet thick. These comprise the Sinian Series which Kao and his co-workers describe as being disconformably overlain by the Lower Cambrian Manto Shale (1934, p. 249) ; Lee, however, extends the Lower Cambrian downwards to include the next subdivision, the Chengeryü Limestone, stating that it carries a *Redlichia* fauna and that there is no stratigraphical break (1939, p. 70). Whatever be the correct interpretation of the relationship in northern China, the Lower Cambrian is in unbroken sequence with the Sinian Series from the region of the Yangtze Gorge and south-west Hupeh in a south-westerly direction to eastern Yunnan (Lee, 1939, p. 87). On Ella Island, East Greenland, the fossiliferous Lower Cambrian is separated from the Tömmer Bay Group (topmost Eleonoren Bay Formation) by a disconformity (Schaub, 1950, p. 9). The hiatus is probably unimportant at this locality, but Messrs. Adams and Cowie have verbally informed me that the stratigraphical break becomes an unconformity to the north, and probably to the south, of Ella Island. Among other regions where the Lower Cambrian passes conformably down, or with a slight break, into a Pre-Cambrian succession are Norway (Eocambrian), Brittany (Brioverian), Montagne Noire, Leningrad, and South Australia (Adelaide Series) (Pruvost, 1951, p. 51).

(*b*) *Daly's hypothesis*

Daly was impressed by his visit in 1897 to the Black Sea where, under the direction of Androussov, he examined sea-bed samples containing calcium carbonate in a fine state of division. This had been precipitated by the interaction of calcium salts in solution with ammonia and ammonium carbonate " generated in the decay of multitudes of carcasses fallen from the surface layer to the bottom, where no scavengers could live and thus prevent the putrefaction " (Daly, 1912a, p. 503; 1912b, pp. 643–675, which contains references to earlier publications). As a result of this experience Daly constructed his hypothesis which attempted to explain why Pre-Cambrian organisms carried no hard parts and hence are not found as fossils. He argued that the annual contribution of calcium salts from the land to the oceans was small as compared with the rapidity by which these salts, in the absence of scavengers, could be deposited as calcium carbonate under Black Sea, or comparable, conditions which he believed then existed. So complete was this deposition that the seas were rendered limeless. The post-Huronian orogeny, however, exposed a great area of land to denudation, including some of the limestones already formed, and thus the annual contribution of calcium to the oceans was greatly increased; there was an excess, which was available to marine organisms and from which they secreted hard parts suitable for preservation in rocks. The hypothesis involves the *world-wide* persistence of poisoned water conditions and it demands the maintenance of density stratification in all oceans, otherwise a surface layer with teeming but naked life could not exist on top of a zone of foetid water. The post-Huronian orogeny was not world-wide in its occurrence and, during the long history of the Pre-Cambrian, large surfaces must have been laid bare in different parts of the world and eroded at many varying times; furthermore, the pre-Huronian unconformity is probably of greater importance and represents peneplanation on an enormous scale. Be this as it may, there was ample time for Pre-Cambrian animals and plants to form hard parts if lime was made accessible to them either at the beginning, or by the end, of the Huronian, and yet they have not been found. The naive argument that there must have been a lime famine even in Cambrian seas because the trilobites and most of the brachiopods have a chitinous shell unnecessarily presupposes that these animals would have secreted a hard calcareous shell if ample lime had been available.

(*c*) *Lane's hypothesis*

Lane's hypothesis is founded on the premise that the oceans of the world in their early history were rich in chlorides, including iron chloride, and were thereby markedly acid (1917, p. 45). Whether these acid conditions prevented calcareous secretion, as Lane contends, or not, the essential factor is that low pH values would almost certainly be intolerant to any form of abundant life. Nevertheless, the great pile of calcareous material comprising the Grenville Limestone is attributed by Lane to organic activity. The theory again does not join issue with the real problem because there was ample Pre-Cambrian time during which chemical environments suitable for calcareous secretion could have been established.

(*d*) *Termiers' hypothesis*

After a study of the sedimentary rocks of Pre-Cambrian age in the Canadian, Baltic and African Shields, the Termiers founded their hypothesis on the conclusion, which does not materially differ from an opinion expressed earlier by Walcott (1910, p. 2), that the majority of the rocks are continental, lagoonal, littoral or marine in origin, and that the marine sediments accumulated in shallow epicontinental seas (Termier & Termier, 1949, p. 83). These environments, they argue, are not conducive to the preservation of organisms, excepting the stromatoliths, which might even have grown in saline lakes. The remains of Pre-Cambrian life must be sought in deposits of the deeper oceans, and Pruvost suggests a European " mésogée ", assumed to have separated the Baltic and African Shields, and an American " mésogée " encircling the Canadian Shield (1951, p. 55). Apart from the convenience to the hypothesis of confining evidence of a Pre-Cambrian biota to deeper oceans, of which there is no certain information from any locality in the world, the main obstacle in accepting the hypothesis is the probability that animals with hard parts (if living in late Pre-Cambrian times) would have flourished in the littoral and shallow seas at least as much as, or possibly more than, in the deeper seas.

(*e*) *Brooks' hypothesis and Raymond's modification*

Brooks (1894, p. 469) was convinced that animals already possessed a long history prior to the dawn of Cambrian time and he did not doubt that when the primaeval seas became populated by animals and plants it was the surface waters that carried life long before the deeper waters or the sea-floor. The evolutionary development was slow and thus the primitive fauna comprised minute and simple pelagic organisms. Then, near the beginning of Cambrian times, by way of the deep seas, these soft-bodied organisms eventually discovered and began to populate the shallow sea-floor ; the freedom of the open seas was replaced by competition which became more and more intense, and the secretion of hard parts became a protective measure. In such a manner as this, organisms built up structures which were suitable for petrifaction. Many biologists nowadays favour an origin of life in shallow water along shorelines and not in the surface water of big oceans, but it might be said that this is no valid criticism because opinion might change again in the next few years. Brooks does not explain, or account for, certain fundamental difficulties. For example, what were the factors which developed a somewhat sudden sense, according to Brooks, for the colonisation of the shallow sea-bed among nearly all the phyla of the invertebrates and among some plants ? Whatever they were, what is difficult to explain is that their impact was apparently world-wide and, geologically speaking, contemporaneous.

Raymond (1935, p. 390 ; 1947, p. 36) modified Brooks' hypothesis, and likened the production of a calcareous skeleton to a kind of pathological condition induced by inactivity ; he argued that Pre-Cambrian animals were pelagic and lacked hard parts because, as he thought, they were motile and untroubled by predators. He correctly maintained that thick calcareous shells did not appear in force until Ordovician times and assumed that a sessile mode of life " was a novelty, newly discovered in Cambrian times ". Raymond's opinion is diametrically opposed to the biological implications of Milne's cosmological theory as deduced by Haldane and next to be considered.

(*f*) *Haldane's contribution*

Some sequence of events was clearly operative upon the unit of the world during primaeval times and it should be noted that an unconsciously expressed demand for a *world-wide* happening is inherent to all the hypotheses yet mentioned. No real advance is probable while efforts are made to explain events which are recorded merely as a part of the world's history at a certain time and at a defined place.

At this stage it is apposite to consider a short, but all the more provocative, letter from Haldane (1944, p. 555). Milne's cosmological theory describes events either on the *t*-scale, where the spiral nebulae are receding and matter is expanding, or on the τ-scale, where there is no recession of nebulae and matter is not expanding. If the *t*-scale is applied to geological problems, the length of day, say, in palaeozoic times was much shorter than it is now, and the size of objects would have been smaller ; but the rate at which energy is liberated in a chemical change is constant on the *t*-scale, whereas on the τ-scale it increases. Haldane maintains that it is the τ-scale which most suitably expresses geological and biological science. He claims that, in the past, chemical change was a more inefficient source of energy than it is to-day and argues that " at a sufficiently early stage, a living organism would have been unable to provide even the small energy needed for cell division or amoeboid movements ". 690 million years ago the " energy for motion would only have been generated at half its present rate ". Thus the rate at which chemical change produced energy becomes the controlling factor, and may have permitted only in late Pre-Cambrian time the existence of organisms of a simple kind ; when the rate increased, more active animals like swimmers and crawlers could have existed.

IV. CONCLUSION

Milne's cosmological model employing the τ-scale provides a world-wide control which is not only external to the Earth but is also an essential part of it ; the danger lies in the possibility that the model is wrong. Assuming the correctness of Milne's theory and of Haldane's biological deductions, active animals could not have existed in late Pre-Cambrian (Eocambrian) history owing to the low level of chemically produced energy. Predators, either crawling or swimming, would have been absent, and animals, not being physically in the position of becoming competitors or enemies, would have needed no protective armour. More virile animals appeared as the speed of metabolism increased with the increase in rate at which energy was freed by chemical reactions ; life became competitive, leading to a demand for a hard covering, which is assumed to have developed approximately with the beginning of the Cambrian Period, some 520 million years ago. Even at that time there existed few animals which were encased within a thick calcareous shell, and it was only at the beginning of the Ordovician Period that this type of protection became commonplace.

The τ-scale, however, does not explain the diverse and varied structures shown by the Lower Cambrian faunas so long as scientists accept as a truism the classical model of evolution—the tree of evolution which implies a linear series with some lateral, but fundamentally unimportant, offshoots. Unicellular animals, on *a priori* reasoning, are more primitive than those with a primary double layer of ectoderm and endoderm, but there appears to be nothing in embryology which refutes the proposal that the formation of the mesoderm and the production of the coelom occurred in several radiating lines of evolution, which need not be directly related except in that they arose from two-layered ancestors. The Mollusca might have progressed along one line during approximately the same period of Pre-Cambrian time as the segmented worms and arthropods, while the Molluscoidea underwent another geologically contemporaneous change, and the Echinodermata yet another. The tempo of evolution was, also, not necessarily the same for each group. If it is possible to accept radial, instead of linear evolution, the lengthy duration of previous history normally demanded for the rise of the complicated animal-types which frequented Lower Cambrian seas is not a necessity.

The controls exercised, first, by the increased energy liberated by the speeding up of the rate of chemical change, and, secondly, by radial evolution resulting in the different categories of coelomate animals are suggested as an explanation of the appearance of organisms with protective covering at about the time connoted by the deposition of Lower Cambrian sediments.

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