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ORIGIN, DISTRIBUTION, AND MODE OF PRESERVATION OF THE GRAPTOLITES.

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I. ORIGIN OF THE GRAPTOLITES.

The origin of the graptolites is still shrouded in obscurity. One of the most remarkable facts in the distribution of Palæozoic organisms is the sudden appearance of the graptolites at the beginning of the Ordovician period; for it is now generally conceded that the Tremadoc shales of Britain and the *Dictyonema* shales of Sweden, and other parts of continental Europe, and the *Dictyonema* shales of Eastern North America, mark the beginning of Ordovician sedimentation, although by some American authors, these are still classed as uppermost Cambrian. The fact, however, remains, that throughout the great mass of Cambrian strata, so rich in marine organisms, graptolites are practically unknown. It is true Dr. Sun has described a species doubtfully referred to *Clonograptus* (*Cl? cambria* Sun) from the Kaolishan Limestone of Tai-an, Shantung, a formation which still contains many Cambrian types of trilobites, and overlies the Chaumitien formation. He correlates this with the Orthoceras limestone, which overlies the Chaumitien Limestone in the Changhia region of Shantung, the Fengshan limestone of the Kaiping Basin, Chihli, in which similar trilobites of Cambrian type still occur, and the Shakuotun limestone of Fengtien. But all of these represent the uppermost Cambrian and in the Changhia region at least, they contain already an important Ordovician element in the Orthocera. Thus in a measure, these divisions can be regarded as transitional to the Ordovician, and may even represent the time equivalent, at least in part, of the *Dictyonema* shales of the Atlantic province.

Sun calls attention to the fact that *Cl. cambria* very closely resembles *Cl. tenellus* from the *Dictyonema* shale of Sweden and England, but that it has half again as many thecæ in a centimeter than have the European species.

Dictyonema has not yet been discovered in China, although other genera of the Dendroidea are represented. Pending the discovery of the *Dictyonema* in Eastern Asia, we must consider it essentially an Atlantic type so far as distribution is concerned But then the question immediately arises, why, if *Dictyonema* lived in the Atlantic Ocean or its

[1] *Palæontologia Sinica*, Series B, Vol. 1, Fasicle 4, page 15.

dependencies, is its appearance such an abrupt one, for the high organization of this type argues a long antecedent period of evolution. It is true that the young *Dictyonema* has essentially the characteristics found in such types as *Bryograptus*, or even in *Clonograptus*, but the only known representatives of this type, excepting the Chinese species referred to, have been obtained from these same *Dictyonema* shales. Even if we assume that the development of *Dictyonema*, from an ancestral *Bryograptus* or *Clonograptus*, proceeded very rapidly, within the Tremadoc period, there still remains the problem of the ancestry of the *Bryograptus* and *Clonograptus* types.

It is a well known fact, that in the Atlantic region of North America as well as of Europe, the Upper Cambrian beds, which precede the *Dictyonema* shales, *i.e.*, the *Olenus* horizon is entirely devoid of graptolites, although the shales would seem to be admirably adapted for their preservation had they been present. Likewise no traces of graptolites have been found in the Middle and Lower Cambrian of this region, although here again the conditions for preservation would seem to have been admirably complied with.

In view of these facts, it would seem impossible to escape from the conclusion that the ancestral forms of the graptolites, did not live in the Atlantic region, but were introduced into it at the end of Cambrian time.

Dictyonema is recognized to have been a type which was affixed by a root-like or disc-like structure to a substratum.[2] But whether this substratum was a portion of the sea-bottom, or one capable of flotation, such as algæ, whether in other words, the habitat of the *Dictyonema* was benthonic or epiplanktonic, is still an undetermined problem. In either case, it is of course quite possible that *Dictyonema* may have developed essentially in the Atlantic district from non-*Dictyonema*-like ancestors which were introduced to it at the beginning of Ordovician time, but though this would settle the problem of the *Dictyonema* itself, it in no wise brings us nearer to the settlement of the problem of the class of the Graptozoa as a whole, nor does it reveal their center of origin, and of radiation. This, as we have seen, could not have been in the Atlantic province, unless we make the highly improbable assumption that the ancestors of the graptolites had no structures capable of preservation. Such an assumption would be perfectly gratuitous, a begging of the question, and could only be advanced if we had exhausted the possibilities of all other regions as centers of origin of these animals.

There is another point that must not be left out of the consideration of any problem of Palæozoic faunas, and that is the possibility of the non-existence of an Atlantic Ocean Basin in Palæozoic time.

[2] Hahn Felix, the *Dictyonema* shales. New York Academy of Science, Proceedings.

The hypothesis of Wegener has many adherents and it must be said that many obscure palæogeographic, as well as other geological problems are brought nearer to solution by the supposition of the former contiguity of Eur-Africa and the Americas, than by any other hypothesis yet advanced. It is true that even if we accept the general postulates of Wegener, we must still hold that some local water-body, more or less of the nature of an epeiric sea, existed in the northern part of what is now the Atlantic Basin, even though the margins of the continental shelf of Europe and North America were in contact, for it has been fairly well established that in Cambrian time, this was a distinct faunal province, apparently completely severed from the Boreal province on the north, the only one with which it could have been in contact. This severance continued to be complete through Lower and Middle Cambrian time, at least in those parts which are now represented by sediments in the Maritime provinces of Canada and the New England region in Eastern North America on the one hand, and the British-Baltic as well as the Bohemian region on the other. From the British district, however, we must exclude the North Scottish region, the Cambrian sediments of which are characterized by true *Olenellus*. This distribution of the Atlantic province is evidenced by the fact that the known Lower Cambrian sediments of these regions carry the *Holmia* fauna, while the Middle Cambrian beds carry the *Paradoxides* fauna, neither of which is known from any other province.[3] Even the Upper Cambrian *Olenus* fauna is largely distinct, although apparently during its existence connections were made with the extensions of the Boreal province both in Europe and North America. No direct connection, however, came into existence with the Indo-Pacific region until the opening of Ordovician time, the period which as we have seen, is the beginning of graptolite entombment. And this is also the period of the simultaneous appearance of graptolite remains (barring *Dictyonema* itself) in Asia as well as in Europe. If then the ancestors of graptolites invaded the Atlantic province at the beginning of Ordovician, or close of the Cambrian time, this invasion could have proceeded only from one or the other of two possible centers of origin, the Boreal, or the Indo-Pacific.

If the Boreal Sea was the center of origin of the graptolites, then we should expect to find the remains of the ancestors of these forms in some of the later Cambrian strata which marked the extension of the Boreal Sea into North America and into Asia, and it would be reasonable to assume that such remains should be associated with the beds carrying

[3] The *Paradoxides* fauna seems to have temporarily invaded the Northern Appalachian trough where the *Olenoides* fauna existed if recent pronouncements are based on accurate determinations. *See* B. P. Powell, *The Cambrian Pardoxides beds of North-Western Vermont.* 16th Biennial Report; Vermont State Geologist, 1927-1928, pp. 249-273.

the *Olenoides* or Middle Cambrian fauna, if not those carrying the *Olenellus* or Lower Cambrian fauna of the Boreal extension. As has been said, however, so far no graptolites have been found in Cambrian strata, and unless we postulate a long unrepresented interval between the Upper Cambrian and the *Dictyonema* horizon, an interval during which this entire group of organisms came into existence, and reached the high stage of development seen in *Dictyonema,* we cannot regard the Boreal Sea as the original home of the graptolites.

This leaves only the Indo-Pacific as the possible source of a graptolite fauna, and we must next enquire into the availability of this water-body for such a center.

It seems to be well established, that the Lower Cambrian with *Redlichia,* which characterizes Eastern China, the Himalayan geosyncline and Eastern Australia, is entirely distinct from any of the other Cambrian faunas known, and must have had a distinct center of origin. That this was the Palæozoic predecessor of the Indian Ocean, seems to be indicated by all the known facts, for not only is this fauna confined, so far as at present known, to that biologic province, but the invasions of the East Cathaysian geosyncline of China and the Himalayan geosyncline, could only have proceeded from that water-body. There is at present no positive record of the presence of higher Cambrian formations in this region, unless the Archæocyathid limestones are to be regarded as such, though there are some reasons for the belief that these may actually represent Lower Ordovician. It is true that Middle and Upper Cambrian strata are known in Eastern China and even in Indo-China, but these contain the Boreal fauna, for the junction of the East-Cathaysian geosyncline with the Boreal Sea was effected by Middle Cambrian time. But it is not certain that this northern fauna ever was able to enter the Indian Ocean or the Himalayan geosyncline. If then, it can be established that we have up to the present a preserved record of only the lower Cambrian fauna of the Indian Ocean Basin, the absence of ancestral graptolites in these lower Cambrian deposits need not give us much concern, for graptolites may well have come into existence during Middle and Upper Cambrian time, in the Indo-Pacific realm.

But we are not limited to this single hypothesis of graptolite origin, for it is a quite reasonable supposition that the Indian Ocean region may have been distinct in Palæozoic time, from the Pacific, and that graptolites originated in the Pacific in Cambrian or even in pre-Cambrian time. In Fig. I we reproduce a bathymetric map of the Southwest Pacific region compiled and published by Professor W. N. Benson of Otago University, New Zealand. This map clearly shows the distinctive character of the two Oceanic Basins, when the 2,000 fathom line is seen to separate them completely. The possibility is not excluded that this submerged ridge, from which New Zealand and the Polynesian Islands arise, represents a foundered continent which extended from Antarctica to Cathaysia, and which was intact in Cambrian time. This is indeed in part indicated on

Fig. 1. Bathymetrical map based on data assembled by Sieberg, Marshall, Croll and J. K. Davis. (Structural features of eastern Australia, after David's Map. Reproduced from Benson, 1925).

Benson's map of the Cambrian seas in the southern realm, reproduced here as Fig. 2. This supposition further derives some confirmation from the fact that the *Redlichia* fauna is unknown outside of the basin of the Indian Ocean. It is moreover highly probable that even if there had been a connection with the Pacific, these trilobites would have not been able to migrate across that water body, and that even if the Cambrian epeiric seas of Western North America had any connection with the Eastern Pacific their fauna would be entirely distinct.

If then the Indian and Pacific were distinct in Cambrian time, we can readily understand that graptolites may have had a Cambrian history in the Western Pacific Ocean. That they did not migrate across the Pacific and enter the Cambrian Basins of Western America, need not surprise us, since it is probable that these organisms did not assume a planktonic mode of life until their development had proceeded to a considerable extent. Even if they did lead a planktonic life in Cambrian time, the size of the Pacific may well have acted as a barrier element against migration, especially if we consider that in the Palæozoic the size of that ocean may have been vastly increased, on the supposition that America had not yet assumed its present position. Nevertheless, if the hypothesis here sketched is the correct explanation, there is a possibility that ancestral graptolite types may be found in Cambrian strata, deposited in American embayments from the Pacific.

Of the Cambrian and early Ordovician formations of North America exclusive of the Atlantic phase, those of the Northern Appalachian geosyncline and those of the Cordilleran geosyncline are best known, and in each the faunal elements of the Cambrian and Ordovician periods are quite distinct. The Northern Appalachian geosyncline most certainly represents an extension from the Boreal sea, and the probabilites are that the Cambrian sea of the Cordilleran geosyncline also belongs to the Boreal Province the connection with the Pacific, commonly assumed, being non-existent at least during the early Cambrian. The southern Appalachian geosyncline, however, and the south central region of North America most probably were flooded in Cambrian as well as early Ordovician time by invasions from the Pacific on the south. If this was the case, and if the Pacific was the center of origin of some of the dominant faunal elements of the Ordovician, such as the graptolites, etc, we should expect that the Cambrian fauna of this province show transitional elements, and that types which make their sudden appearance in Ordovician faunas, originated in this province in later Cambrian time, their remains being included with those of Cambrian types in the upper, if not the Middle Cambrian strata of this region. But it is just this region in which these early Palæozoic strata are least understood, and of which the faunal elements are as yet too little known. Perhaps when the "Ozarkian" fauna of Ulrich is more fully understood, its known Cambro-Ordovician transition elements will furnish an answer to the, as yet, obscure problem of the origin of so many of the faunal elements of the early Ordovician. As no Cambrian or Ordovician strata are known from the West Pacific realm, no evidence for or against the Pacific origin of early Ordovician faunal elements is obtainable from this region.

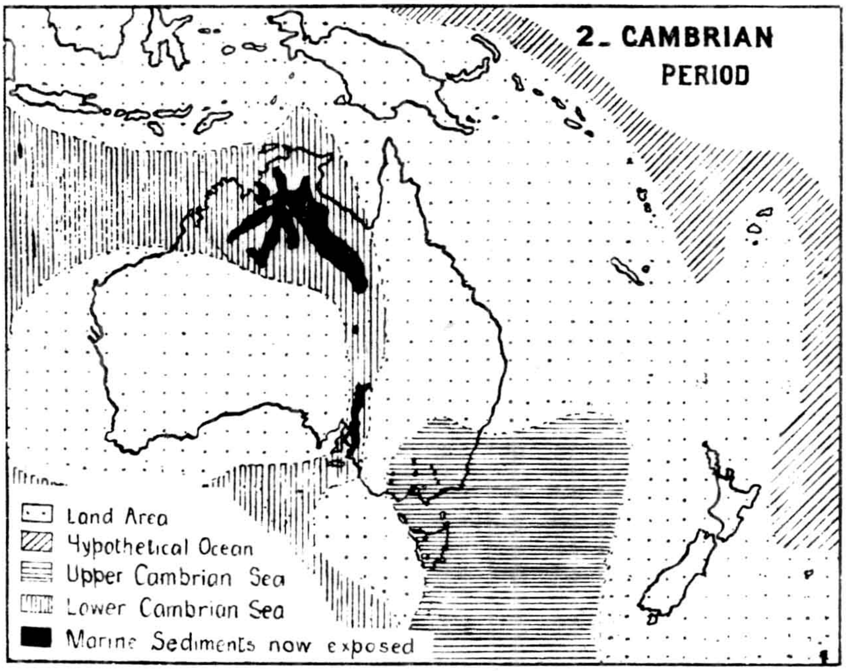

Fig. 2. Palæogeographic Map of the Australian region in Cambrian time. (After Benson)

In Lower Ordovician deposits of New Zealand graptolites make their first appearance. All of these are types known from Western Europe and Eastern North America, and a number of them are now also known from China. This region probably belongs to the border of the Indian realm. The following species are recorded from the Lower Ordovician deposits of Golden Ridge near the West Wangami Inlet, these species being also known from the Deepkill formation of Eastern North America and the Middle Skiddaw slates of England.

Bryograptus lapworthi Ruedem.
Dichograptus octobrachiatus Hall,
D. gibberulus Nicholson,
D. nitidus Hall,
D. nanus Lapw.
Goniograptus perflexiles Ruedem.

G. geometricus Ruedem.
Loganograptus logani Hall,
Phyllograptus anna Hall,
P. ilicifolius Hall,
P. typus Hall,
Tetragraptus amii Elles and Wood,
T. bigsbli Hall,
T. quadribrachiatus Hall,
Didymograptus extensus Hall,
D. gibberulus Nicholson,
D. nitidus Hall,
D. nanus Lapw.

The occurrence of many of these species in the Lower Ordovician of China shows that the Indo-Pacific barrier was partly broken down by the beginning of Ordovician time, and that the migration of these organisms, which by this time had assumed a planktonic habitat, was through the Himalayan geosyncline and across central Asia to Europe and North America.

This interpretation of the history and migration of the graptolites seems to explain the sudden appearance of these organisms in an advanced stage of development in the Lower Ordovician strata, wherever these are known, a phenomenon which seems to be entirely inexplicable on any other hypothesis.

II. CONDITIONS OF PRESERVATION OF GRAPTOLITES.

There seems to be pretty general agreement among students of graptolites that the majority of these organisms led either a holoplanktonic or an epiplanktonic existence. This being granted, the question arises " what conditions favour their preservation?" All students of graptolites have been struck by the fact that wherever graptolites occur in abundance in the Palæozoic rocks, other classes of animals are poorly represented or entirely wanting. There are of course cases where graptolites are associated with other fossils, and this appears to be especially true for the *Dictyonemas* of the later formations from the Silurian on. But all such occurrences must be considered exceptional when these formations are compared with the bulk of the graptolite-bearing rocks of the earth, which are notable for their general absence of all life, except these members of a very circumscribed group of marine organisms. This does not imply that the graptolite-bearing beds may not alternate with others in which other classes of marine organisms are represented, nor that they may not grade laterally into contemporaneous beds in which such other organisms are preserved. The former relationship is not infrequently met with and the latter, the horizontal gradation into normal marine beds, though difficult of observation, may readily be inferred from the study of adjacent sections. But it is nevertheless true that the prolific graptolite-bearing beds occur as layers usually of very slight thickness, intercalated among beds which are virtually, if not actually, barren of organic remains. Personal acquaintance with the graptolite-bearing beds of eastern New York, Southern Scotland, Scania, and Bohemia, and extensive study of the graptolite-bearing beds of different parts of China has convinced me of the essential uniformity of conditions under which such deposits are formed over these widely separated regions of the earth. Though now and then, as in the Utica and other black shale masses of New York, and in the great Silurian black shale of Bohemia, the graptolite-bearing beds lie within a mass of similar and more or less uniform black shale, by far the larger number of such graptolite beds are thin black layers, interstratified with beds of the grey-wacke type, and not infrequently they are found upon the laminæ, whose colour does not vary markedly from that of the rest of the rock layers.

It is a well known fact that the formations rich in graptolites present the phenomenon of zoning, that is—as we progress from the lower to the higher of these graptolite beds, we find that they are divisible into a succession of zones of definite horizons, each of which is characterized by its distinctive graptolite association. Some of the species of graptolites may have a wide range through the successive zones, others are restricted to a few or even to a single zone, which they characterize exclusively. Furthermore, these zones appear to be of wide extent, so much so, that there seems to have been more or less simultaneous deposition of graptolites over very extensive regions. Thus essentially the same species are found associated in Kansu, W. China, in Eastern North America, and in West Europe, and it appears, so far as the studies which have been made permit us to judge, that the graptolite zones in China correspond closely to those recognized for Western Europe.

This is all the more remarkable when we realize the large number of successive graptolite zones. Thus no less than 12 are recognized for the Ordovician of Western England, and 22 have been determined for the Silurian of that region and of Scandinavia. Not all of the zones are recognized everywhere, and up to now, only a comparatively small number of these zones has been determined for China. But the remarkable fact remains, that where successive zones are recognized, they are characterized by the same leading index species, a fact which makes these graptolites the best known horizon markers of the older Palæozoic rocks.

It is facts like these which must be taken into consideration in any attempt at elucidation of the condition of preservation of these organisms, and no theory which does not satisfactorily account for all the phenomena of distribution, both horizontally and vertically of these organisms can be considered as sound.

The first seriously to address himself to a solution of this problem seems to have been the late Professor Charles Lapworth, whose extensive acquaintance with the graptolite-bearing strata of Great Britain and neighbouring countries, gave him the proper basis for such an attempt.

Lapworth held that the majority of Dendroid graptolites (Dendroidea) undoubtedly grew attached to seaweeds, rocks or other supports in the manner of most modern hydroids. Some, however, were attached to floating algæ, and led what we now call an epiplanktonic existence. Cases of such attachment have been observed among these fossils. Lapworth recognized the fact that whereas some graptolites were attached to floating seaweeds (epiplanktonic), others were holoplanktonic. The carbon of the graptolite beds, he held, was derived from the decaying seaweed. The absence of other organisms is explained by the depth of the water, Lapworth considering that these animals were deposited in the abyssal regions.

The thesis suggested by Lapworth was further developed and amplified in Britain by Dr. J. E. Marr, the eminent Woodwardian Professor of Geology in Cambridge University, than whom few have a more intimate knowledge of the field relations of the graptolite-bearing beds in Great Britain and on the continent. In America, the subject was developed along similar lines by my friend of many years, the eminent state Palæontologist of New York, Dr. R. Ruedemann, the leader in graptolitology in America and the able exponent of the older Palæozoic sediments and their faunas in the State of New York. Any pronouncement by these two men on the subject of graptolite bionomy demands the most attentive consideration, and any deviation from their views must be supported by strong argument in order to deserve attention. If in spite of my great admiration for the achievements of these men, I am forced to differ from their conclusions regarding the mode of preservation of the graptolites, this is no wise implies that I do not consider their arguments extremely weighty ones, but rather that approaching the subject from a different angle, the physiographic one, I am constrained to give greater weight to certain considerations which the purely stratigraphic and palæontogical one does not demand. The final test of the validity of either contention must await the unbiassed investigations of the graptolite-bearing beds, with these alternative hypotheses in view.

In order that I may give as nearly as may be the view-points of my two eminent colleagues, I shall first of all quote from their latest pronouncements at sufficient length to enable the reader to grasp the essentials of their views, while at the same time recommending the advisability of a detailed study of the articles themselves.

Professor Marr's paper is entitled:

"Conditions of deposition of the Stockdale shales of the Lake district[4]" and is divided into 6 sections: I, Introduction; II, Lithology; III, The Organisms; IV, Conditions of Deposition; V, Summary and Conclusions; VI, Petrographical notes on the Stockdale shales by Dr. R. H. Rastall. The paper concludes with discussions by a number of British Palæontologists and geologists.

The Stockdale shales are primarily of Silurian age, resting upon the Ashgillian, and comprising the graptolite zones from that of *Diplograptus acuminatus,* to that of *Monograptus crispus,* with higher beds free from graptolites. The total series is not over 250 feet in thickness and is followed by the higher Silurian or Salopian Brathay Flags, about 1,000 feet thick, which again contain graptolites. The lower 50 feet of the Stockdale shales are known as The Skelgill Beds and contain most of the graptolite zones, consisting of dark often black shales, interstratified with 5 blue bands containing calcareous nodules, and a thin limestone at the base. The upper division of about 200 feet in thichness form the Browgill Beds, and begin with graptolite shales, which are thin, grey rather than black, and are followed by two beds with inconstant calcareous nodules, largely replaced by iron and inclosed in greenish-gray mud-stones with red mud-stones near the top. The Ashgillian deposits underlying the Stockdale shales are fine muds, though nodular bands of limestone occur. The fine muds of the Ashgillian, to quote Marr:

"Continued almost uninterruptedly, save by the above mentioned limestones to the end of Wenlock times. There are fine grits in the Browgill division of the Stockdale shales, and the nodular limestone bands are almost absent in the Brathay Flags, of Wenlock age. Otherwise, conditions of sedimentation, so far as supply of mechanical material is concerned, were very similar in Ashgillian, Valentian and Lower Salopian times, and graptolites are found (with certain exceptions) in the deposits of these three periods" (page 113).

"The various sediments of the Stockdale shales are similar in that their main constituent is a fine mud. This mud is, in the greater part of the Browgill Beds, and in a small portion of the Skelgill Beds, of a pale-green colour, and the other sediments differ from these in the nature of their colouring-matter." These green sediments "appear to be due to the abundance of felspar and ferromagnesian minerals in the rocks which supplied the sediment. The decomposition of these minerals would give rise to chlorite products, and the abundance of the minerals would result from the extensive exposures of rocks of igneous and metamorphic character" (page 114).

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[4] Quarterly *Journal of the Geological Society of London,* Vol. 81, 1925, pp. 113-136.

The most striking feature is the great uniformity in character of the detrital material of the Stockdale shales as shown by Rastall's descriptions:

"Na urally there are variations in the size of the component particles when traced from place to place or at various horizons in the same locality, but in the area under consideration these are not great. Ordinary sandstones are absent, and the few deposits, chiefly found in the Browgill Beds, which approximate to grits, have the particles still so small that they may be spoken of as 'silts,' rather than very fine grits."

The green beds are regarded as the normal deposits, but the following three variations occur: 1, Black to grey graptolite-bearing sandstones; 2, Blue non-graptolitic Beds; 3, Red Beds.

"Lines of nodules occur at various horizons. These nodules were once calcareous, but have been largely converted into carbonate of iron. They are absent from the graptolitic beds, occur abundantly in the blue beds, and one has been found in the green beds of the Browgill division, also another in the red beds of the same."

The dark colour of the black and gray graptolitic muds was once considered to be due to the graptolites, but Lapworth credited it to the carbon of the seaweeds to which the graptolites were attached. Marr presents two analyses of the dark Skelgill Beds, which show the average of carbon content to be 6 per cent. He also quotes one from Barrois, who gives 11 per cent. of carbon. Iron sulphide is present in considerable quantities in the dark British graptolite shales, either disseminated or in crystals.

The blue muds owe their colour to iron carbonate, to the absence of free carbon, and to the paucity of iron sulphide. The once calcareous nodules are now largely replaced by iron. Red beds, in which the colour is indigenous, and not due to subsequent oxidation, occur near the top of the Browgill Beds.

Lamination is by no means a constant feature.

"It is most pronounced in the graptolite-bearing bands, but some of these do not show it in hand specimens. It is not often conspicuous in the blue beds. . . The green and red beds also show intermittent lamination. In connection with this it may be noted that we frequently find beds of different character welded together with no plane of discontinuity; this continuous deposition, accompanied by a sudden change of condition, is often found in a green or blue bed, passes in this manner into a dark graptolitic bed. This furnishes an additional piece of evidence that the mechanical basis of the sediments in the case of the different varities is identical, and shows that the causes which produce colour changes were sudden."

The various types of sediment are represented in the following proportions.

Grey to black graptolitic muds	10 per cent.
Red muds	10 „ „
Blue muds	20 „ „
Green muds	60 „ „

The dark graptolitic muds predominate below, followed by the blue, then the green and finally the red.

" The Skelgill Beds consist of alternations of the dark and blue muds, with thin streaks of the green and no red. The dark muds are most abundant in the lower part of these beds and the blue in the upper part. Furthermore, as the blue material increases and the dark diminishes in the higher beds, the former become (on the whole) paler in hue.

" In the Browgill Beds, the blue muds appear to be absent, the dark graptolitic muds are only found in very thin seams, and are usually of a lighter hue than those of the Skelgill Beds. The green muds form the bulk of the Lower Browgill Beds, while the red muds appear in the Upper Browgill division, though a small thickness of green beds above these marks the change towards the conditions which prevailed in Wenlock times."

Regarding the organisms of these shales and the light they throw on the conditions of deposition, Marr says. " The beautiful state of preservation of the delicate graptolites, strongly supports Lapworth's contention, that the conditions were those of quietness of the sea-floor. This is also borne out by the preservation of the extremely thin tests of the Cephalopoda and the organisms referred to the Phyllocarida belonging to the genera *Aptychopsis, Peltocaris* and *Discinocaris*. Some of these are found alike in the graptolitic and in the blue muds. The two basal plates of *Aptychopsis* and *Peltocaris* are constantly preserved, separated one from the other with a thin line of matrix between them, showing that they were disconnected; but they are not displaced as would have been the case if the slightest current action had affected them. The fact that the rostral plate has so far remained undiscovered in these beds is puzzling."

The usual completeness of the trilobites found in these beds also suggest their deposition in quiet water although there is one bed near Clapham, Yorkshire, almost composed of trilobite remains in a fragmentary state.

" Evidence points to this having been deposited nearer to the shore than its equivalent in the west, and it was probably affected by current-action in shoal water."

In addition to the graptolites which were either holoplanktonic or epiplanktonic[5] several other planktonic types have been found. Radiolaria appear to be absent but are found in equivalent graptolite beds elsewhere. Marr, however, considers that the Phyllocaridæ and the Cephalopoda found in these shales were also planktonic. To this we can agree, unless we entertain the not improbable supposition that the former were in reality river organisms, a supposition suggested by their general mode of occurrence as well as that of the related forms associated with them. One of the species of *Dicinocaris* (*D. gigas*) found in these shales in fragmentary condition, indicates a carapace nearly three inches in diameter. Fragments of *Orthoceras araneosum* found in these beds indicate a shell of considerable size, and its tenuity suggests a planktonic habitat. Marr would refer most of the trilobites of these beds to benthonic types, and in addition to these he cites others from the Stockdale shales, which are distinguished by their dwarfed size. One or two specimens of compound corals grew into fair sized masses, but the solitary corals, brachiopods and trilobites, which form the bulk of the non-graptolitic fauna are very small as compared with their relatives in the shallow waters. We miss the large Pentamerids, Orthids, and other common forms of these littoral deposits. Incidentally one may note the non-occurrence of the horny brachiopods in the Stockdale shales—a somewhat unexpected feature considering their frequency in other graptolitic deposits.

"Not only are the benthonic fossils of small size in the Stockdale Shales but individuals are usually far from abundant. It is true that in the blue muds, the microscope reveals numerous fossil fragments, but even here the deposits are barren, compared with many of those of the littoral, and the green beds yield very few fossil relics, so that it is perfectly certain that the sea floor, when these were deposited was unfavourable to an abundance of organisms, and their growth to large size.

"In the case of the dark graptolite-bearing muds, normal benthonic forms are practically absent." Marr cites the occurrence of one bed with a few dwarfed brachiopods and cirripedes associated with graptolites, and he also cites one specimen of a small *Leptæna* found in one of the pale bands of the graptolitic shale. "Otherwise the graptolitic bands which have been worked so assiduously, and which contain myriads of graptolites, have furnished nothing of normal benthonic character, and the absence of these is an additional argument for assuming a planktonic habit for the Phyllocarida and *Orthoceras* of which mention has been made."

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[5] The term pseudoplanktonic, first applied by Walther and Lapworth is still largely used for the graptolites attached to floating seaweeds, but as I have shown elsewhere (Principles of Stratigraphy, page 994) this term should be restricted to the floating seaweeds alone as well as to floating structures analagous to them, i.e., floating logs, etc. For living organisms attached to such pseudoplanktonic objects, I have proposed the term epiplanktonic.

Considering the conditions of deposition, especially of the graptolitic beds, Marr says "The generally fine character of the muds of the whole of the Stockdale shales undoubtedly indicates their accumulation far from the coast line. It is true that there are lateral and vertical variations, but of small degree, and the above statement is substantially correct. As regards vertical variation, the evidence in the Lake District and neighbouring areas indicates a slightly coarser type of sediment as one passes upward, pointing to a nearer approach of the land-margins towards the area under consideration, in the later part of the period. Lateral variation is shown in the district itself and suggests land lying in an easterly direction. . . ."

"Such lateral variation is still more marked when we pass beyond the confines of the district. On the north, the Birkhill Shales are about three times the thickness of the corresponding Skelgill Beds, and on the south, the equivalents in Central Wales have also a much greater thickness. Variations of the same nature are also observable in the case of the Browgill Beds and their equivalents.

"But notwithstanding these differences, many of the lateral changes take place at the same horizon in these areas and elsewhere as is so well illustrated by the 'green streak' and its equivalent in Wales.

"As the quiet conditions which mark the deposition of the sediments cannot be regarded as due to their formation in abysmal depths, embayments from the main ocean at once suggest themselves as a possible explanation."

Marr gives a map prepared by G. L. Elles which we here reproduce (Fig. 3) showing the distribution of the graptolite shales and outlining the embayments from the Atlantic in which these were deposited. The shore lines are given on the basis of the distribution of the coastal deposits and others which form a fringe around the shore lines. "The map is to some extent hypothetical, although the general lines of the coast are indicated as the result of convincing evidence. The promontory shown as extending from Scandinavia to Britain, might so far as the distribution of the rocks is known, have been broken by a strait, which separated an island occupying parts of Britain and adjoining tracts from the main land on the Northeast. This is unlikely as, in the first place, it would give rise to very powerful surface currents, and secondly because the upper deposits of the Stockdale Shale type of Valentian rock differs so markedly as regards relative importance of the black graptolite muds and the paler non-graptolitic muds, in the case of the northern and central gulfs of the diagram. The matter is of small import as it would produce little difference in the general coastal outlines as represented. So far as the British area is concerned, the coast-lines may be regarded as