Palæozoic formations in the Light of the Pulsation Theory

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Vol. II

III. THE CAMBROVICIAN PULSATION

Introduction and Definitions

The term Cambrovician is proposed to cover the formations of Upper Cambrian and Lower Ordovician age, which form one pulsation. In general, we may consider that the Upper Cambrian portion as originally used by the British geologists, forms a transgressive series, that is, up to and including the Tremadoc series. The Lower Ordovician, or the Arenig of British terminology, forms the retreatal series. The fact has been generally recognized that there is an intimate relationship between the Upper Cambrian and the Lower Ordovician and that faunally they have much in common. Moreover, there can now be no longer any doubt that the Lower Ordovician retreat is universally recognizable in the rocks. I have called attention to this feature in American stratigraphy in a number of publications and in 1916 I summarized all the facts then known to me for Europe and America, bearing on this problem.[1]

Since then we have been able to show the same phenomena to be characteristic of the Cambrovician formations of both North and South China. There can then be no longer any question, that we are dealing here with a major pulsation, and if it can be shown that the period of Lower Ordovician retreat is accompanied or followed by a tectonic disturbance, such as characterizes practically all the later

1 A. W. Grabau. Comparison of American and European Ordovicic formations. Bull. of the Geol. Soc. of America. Vol. XXVII, pp. 565-622, Nov. 29th, 1916.

inter-pulsation periods in at least some sections, the evidence for the independence of the Cambrovician pulsation will be complete.

In lieu of the tectonic disturbance we may place the pronounced volcanic activity which characterized the period of Lower Ordovician retreat, and formed part of the emergent series. Moreover, it is significant that this volcanic activity was largely confined to the marginal portion of the Old Land, from which a very large supply of the original sediments was derived.

Since both the Cambrian and Ordovician divisions of the geological column are founded on the European, especially the British succession, we must base our subdivisions, though not necessarily their limitations, on the European standard, but we are bound to recognize the important fact, that the European sections give us a very imperfect and incomplete representation of the deposits formed during these periods. In their typical marine development they are often of surprisingly small thickness, and where the deposits are thick, they are to a very large extent of the continental type.

It is perhaps but natural that British geologists, in whose country we have such extensive development of the Cambrovician succession, should have for a long time failed to recognize the true significance of large parts of them as continental deposits, and even felt constrained to regard their remarkable volcanic series, as representing submarine outpourings.

Two reasons may perhaps be cited for this. In the first place Great Britain, where the principles of our science were originally formulated, is today a region in which sedimentation is largely confined to the surrounding marine waters, or to lakes of very limited extent. Of broad river plain sediments, such as characterize North China, northern India, Mesopotamia etc., or even of extensive inland river deposits, like those of the interior of Australia, no representation is found on the British Isles, or for that matter in Europe generally.

If the old Chinese philosophers had developed their (on the whole surprisingly modern) theories of earth origin into a practical science — in other words, if modern geology had taken its rise in Eastern Asia instead of Western Europe, an earlier understanding of continental sedimentation would have been obtained, and the Old Red Sandstone would never have been regarded as a lacustrine deposit.

The second cause of a misinterpretation of the nature of the early Palæozoic sediments is, in my belief, the mistaken doctrine of the deep-water origin of the graptolite shales, so brilliantly promulgated by the late Professor Lapworth, and so ably championed by Walther and Marr in Europe and by Ruedemann in America.

I was first led to question the correctness of this doctrine, which I believe is still very generally held, by a study of the graptolite-bearing beds and associated sediments, in the Moffat District in southern Scotland, the classical region which served Lapworth for the basis of his doctrine.

Subsequent study of many of the American graptolite-bearing beds confirmed rather than weakened my conviction of the seaborder, mud-flat, or delta origin of most of these deposits. The results of these studies, supplemented by the careful work on the literature of the subject by Dr. O'Connell, were presented in 1916 before the Palæontological Society of America and published in 1917.[1]

1 Bull. G S.A. Vol. 28, pp. 959-964, Dec. 1917

Several years later, in 1921, the same question was raised by Dr. Hans Scupin, with reference to the *Dictyonema* shales of the Baltic region.[1] Finally in 1929 I again discussed this subject at length, comparing the argument on both sides of the question.[2]

Without repeating the argument, I may briefly state that I consider the main mass of the graptolite-bearing deposits, which consist of arenaceous sediments, as river-plain or delta deposits of the type now forming on the great China Plain or the Plain of Northern India, and that the thin films of black mud, which are the chief graptolite repositories, represent a succession of temporary floodings by the sea of a more or less extensive marginal belt of these plains, the graptolites being the holoplanktonic or epi-planktonic organisms, left stranded over these mud-flats on the retreat of the sea and buried by the renewed extension of the river-spread sediments.

I would like to refer to this process of repeated short-lived submergence of the delta or coastal plain by the sea as a process of "MARINING" and shall designate such coastal deposits as having been repeatedly MARINED, it being clearly understood that such marining is a very temporary flooding, not long enough to permit the immigration into, or development of a normal marine fauna in the submerged area. When the submergence is sufficiently long enough to permit the development or entrance of such a

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1 Zeitschrift der Deutschen Geologischen Gesellshaft. Vol. LXXIII, pp. 153-165.

2 A. W. Grabau. Origin, Distribution and mode of Preservation of the Graptolites. Memoirs of the Institute of Geology of the National Reserch Institute of China No. 7, August 1929, pp. 1-52.

fauna the phenomenon will be referred to as a *marine submergence.*

Such a submergence may be a part of the transgressing or positive pulsatory movement, or it may occur even during the negative portion of the pulsation, when the effects of the retreating sea are locally nullified by a more pronounced subsidence of the geosynclinal area; in other words by oscillatory movements of the land. In this way we can explain the occasional occurrence of strata indicating submergence, within the general retreatal series of deposits.

It is a well known fact that graptolites made their world-wide appearance in Tremadoc time, that is, during the period of extreme transgression of the Cambrovician seas. That graptolites existed before this time, is not only indicated by the fact that the first wide-spread types are of a highly complex and specialized character, and therefore must have had a long series of ancestors in the succeeding Cambrian period, but is proved by the fact already referred to, that graptolites have now been found in fair numbers, not only in Upper Cambrian sediments, but in Middle Cambrian as well. (see *ante* I, p. 182, *(IV, p. 348)* also Science July 6th 1934 Vol. lxxx p. 15.)

In my 1929 graptolite paper, I suggested that as the graptolites could obviously not exist as floating organisms in the Cambrian seas which supplied the faunas of most of the known Cambrian regions, because they were so conspicuously absent from these deposits, they must have originated in a water body then isolated from the other Cambrian seas and only establishing connection with them at the opening of Ordovician time. The western Pacific seems to qualify in this respect, and I have given the palæogeographic evidence which indicates, that on the basis of the present location of continents and ocean basins, the distinctness of the Pacific from the neighbouring Indian Ocean was indicated (see maps pp. 5 & 7 of the article referred to).

If however, we have to accept the existence of Pangæa in early Palæozoic time, it is much more difficult to explain this Cambrian isolation of developing graptolites. Either we have to postulate an extensive barrier by a pronounced prolongation of Cathaysia, or else we have to make the assumption that graptolites were purely benthonic organisms until the opening of Ordovician time and that their mero-planktonic stage, if it existed, was of such short duration that extensive floatation was out of the question.

So far as the evidence now available indicates, the main center of distribution remained in the Indo-Pacific Province throughout the period of existence of the Graptozoa, and that was apparently also the region of their chief evolution, although it is possible that some modifications of varietal if not of specific nature may have occurred within the geosyncline.

If then, we regard the presence of graptolites as indicative, not of deep waters, but of shore conditions, and the repeated marining of the coastal areas of continental deposits, we obtain a new and, as I believe, a more correct picture of the palæogeographic conditions that existed in the British region during early Palæozoic time, especially the period of Arenig retreat.

This retreatal period is marked in the Baltic region by limestone deposits, the limestones merging very often into black graptolite shales, especially in the landward portion. The relatively slight thickness of these shales, and the frequent uniform character and colour throughout, cannot of course be interpreted in the same way as the British Arenig rocks, though the inclusion of the graptolites would indicate a similar process of marining. These Baltic graptolite beds may perhaps better be regarded as pure mud-flat deposits, formed on a low coast, where streams of very low grade spread only the finest muds, comparable somewhat to those of the Mississippi delta.

In considering the extensive clastic sands of the late Cambrian and early Ordovician, which in some of the British sections reach as much as 3,000 ft, we are at a loss for a proper designation for the deposits of this nature. It would not be correct to speak of them as river flood-plain deposits, for that term includes those deposits formed on the periodically river-submerged or "fluviated" portions within the stream valley, and may be far removed from the coast or even entirely inland. Nor can we speak of these as coastal plain deposits, for, as that term is now used by physiographers, it represents a coastal belt of deposits which are in part at least older marine sediments, that have been exposed again by the retreat of the sea, as in the typical example, the Atlantic coastal plain of North America.

As already noted, I regard these ancient sediments as more nearly represented among modern deposits by the great plain of North China, formed chiefly by the Yellow River or Huang-Ho, or by the Indo-Gangetic Plain of Northern India and the Euphrates-Tigris Plain of Mesopotamia. These are formed of river sediments deposited in slowly subsiding geosynclinal regins, in which the surface remains for the most part at a uniform elevation above the sea-level, sedimentation of the continental type keeping pace with the slow depression of the geosyncline. Thus the material retains a relative uniformity of grain throughout, while the thickness of the series is only limited by the period of continuity of the processes of subsidence and sedimentation.

We know that the Indo-Gangetic Plain has been sounded to a depth of approximately 1,000 ft. below sea-level, without evidence of marine invasion. The Huang-Ho Plain has been sounded to a somewhat lesser depth and is likewise of continental character, except in its upper portion, where a single temporary submergence permitted the accumulation of marine shells in the Tientsin region, and of great oyster shell deposits in the region between Tientsin and Taku Bar. Excavations at Tientsin however, have disclosed beds of fresh-water mussels (*Lamproteula*) about 70 ft. below sea-level, while wells drilled in the Peking area, have furnished fresh-water shells from beds several hundred feet below the surface.

In Shantung, wells over 500 ft. in depth have shown only uniform river-laid sands, like those on the surface. Besides the one recognized late marine submergence, which extended at least as far as Tientsin, there have been numerous coastal floodings or marinings many to them within the period of Chinese recorded history. These I have summarized in my 1929 graptolite paper, (pp. 28-32) where I record 27 of them ranging from A. D. 146 to A. D. 1628.

Since the great Huang-Ho Plain extends for nearly its entire front along the sea coast, except where interrupted by the rocky Monadnock Island mass of Shantung, which it is gradually enveloping as it grows seaward, this plain may well serve as a type of such deposits which we now realize have occurred in all geologic periods.

As is well known the plain is roughly triangular or delta-shaped with a frontage along the coast of some 300 miles and extending back to its head at the foot of the mountains, for a distance of another 300 miles.[1] The greatest elevations of this plain at its head is not much over 400 ft., thus giving a surface slope averaging 1 1/3 ft. per mile.

I propose to use the term HUANGHO PLAIN DEPOSITS, or briefly HUANGHO DEPOSITS for sediments in all geologic periods, comparable to those of the modern Huang-Ho Plain. Two types may perhaps be recognized, the HUANGHO deposits of oxidized sands and muds and those of unoxidized material. The greater part if not the whole of the modern Huang-Ho Plain is made of oxidized material, analysis giving as high as 7 per cent or more of hydrous oxide of iron, so finely distributed that it is responsible for the yellow colour, and incidentally that of the Yellow river and Yellow Sea, murky with suspended sediments.

Such deposits are destined to produce a red-bed series in the geological future, for it is well known that the amount of iron disseminated in Red Bed Series generally is no greater and often even less, than is that of the deposits of the Huang-Ho Plain, or of the loess, which to a large extent forms the source of the sediments of this plain. The Old Red Sandstone of Western Europe is perhaps our best example of a fossilized huangho plain, composed of oxidized material.

When the source of the material of such a plain is the more normal type of river sediments, derived from erosion and disintegration of the rock in non-arid regions, the sediments will lack the oxidized iron content and the

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1 It should be noted however, that in a number of localities, the material of the plain forms merely a veneer over the Tertiary or older roks.

deposit will remains light-coloured or assume bluish or gray colours when consolidated. It is the latter type of huangho deposit, which appears to be dominant in the Cambrovician series of Wales, though red colours among these strata are not uncommon.

Not until late Silurian or Devonian time howexer, was oxidation of the sediment so wide-spread, in Great Britain, that the rocks became prevailingly red sandstones and shales.

I have referred on an earlier page of these studies (Vol. I, p. 172 (*IV. 368*)) to the improbability that a persistent and important hiatus will be discovered in Europe between the Upper Cambrian and Tremadoc or between the latter and the Arenig, such as is required for the insertion of Ulrich's Ozarkian system. In the discussion of these sections which follows, it will appear that though there are local interruptions in the series, the general continuity of the Cambrovician sediments cannot be questioned. It must however be emphasized that there has been found a well-marked local hiatus between the Tremadoc and Arenig in a number of places in North Wales, but this hiatus is readily explained as a consequence of emergence at the beginning of the regressive period of the Cambrovician pulsation. As a result of this emergence, the old sediments of the transgressive series, themselves to a large extent of the huangho type, but temporarily covered by the sea in the Tremadoc period, became subject to erosion, and were covered by a subsequent deposit of the backward aggrading river sediments in Arenig time. (see the more detailed discussion *postea*)

In southern Sweden there is a suggestion of slight interruption of sedimentation between the Upper Cambrian and the *Ceratopyge* limestone, the representative of the Tremadoc, but a more marked one between the latter and the basal

Ordovician *Planilimbata* limestone. In North China, local erosion features and basal conglomerates occur between the Upper Cambrian (Fengtien series) and the basal Ordovician Yehli limestone in the Kaiping Basin of Hopei Province. This has already been referred to on page 514 of Vol I (*IV, p. 710*). Though pronounced locally, this has not the magnitude or significance of the hiatus found at the base of the Upper Cambrian or that between the Middle and Lower Ordovician of the same region.

That the Upper Cambrian of the Caledonian geosyncline, especially in the Baltic region, is incomplete, can hardly be questioned in view of the slight thickness of the sediments, though at present we are not in a position to evaluate these deposits as fully as was possible in the case of the Middle Cambrian.

A comparison of the Baltic and British section however, brings out the fact of pronounced inequality, for the Baltic Upper Cambrian can at best represent only a part of the upper or Dolgelly division of the Upper Cambrian of the British section, and only a part of the Mæntwrog or lower, the middle part being unrepresented by sediments.

But the greatest problem with which we are confronted is the problem of the origin of the Cambrovician faunas of the Caledonian geosyncline. Those of the Appalachian and of the Palæo-Cordilleran geosynclines are easily explained, the first as being derived from the Ozarkian Epi-Sea and the second from the Boreal Epi-Sea, with perhaps a limited amount of intermingling of the two. But whether the Caledonian geosyncline derived its fauna from the Siberian Epi-Sea or from some other source is at present wholly undetermined. As we shall see in the discussion of the known Siberian deposits there is at present little or no evidence that the Caledonian Cambrovician faunas were derived from that source, and there is indeed some indication that the Siberian Epi-Sea was the home of the Beekmantown Lower Ordovician fauna, as found in the Northern Appalachian geosyncline and the North Chinese portion of the Cathaysian geosyncline. If the Siberian region is ruled out we may have to look to the Indo-Pacific Epi-Sea and South China for the source of both the Upper Cambrian and Lower Ordovician faunas of the west European region, unless we may assume the existence of an independent Fenno-Scandian Epi-Sea, or hold that the Atlantic was in existence and provided this fauna. But to both of these assumptions there are certain grave objections which will be considered later.

I have already adduced evidence that a very important element of the Cambrovician fauna, namely the graptolites can be regarded as of Indo-Pacific origin, but the source of the trilobite element is at present obscure, and investigations now going on in South China are directed towards the elucidation of this problem. That the essential elements of the Middle Ordovician fauna of Europe are of Indo-Pacific origin, has already been emphasized repeatedly in the works dealing with the corresponding faunas of South China.

In my original article on the Pulsation Theory, (in the Proceedings of the 16th International Geologied Congress I have called attention to the remarkable correlation between the periods of tectonic disturbances, recognized by Stille, and the interpulsation periods of the Palæozoic succession. No pre-Taconic disturbances have been positively demonstrated so far, but if I understand correctly the meaning of the Polish geologist, there is some evidence of a period of folding and erosion in the region of the St.

Croix Mountains of Central Poland, while some statements of Obrutchew lead to the supposition that a similar folding is indicated in Western Siberia. These facts will be more fully discussed after the details of the sections have been given. There can however, be no doubt of the significance of the Cambrovician-Ordovicien inter-pulsation igneous activity in Great Britain, and though this was not accompanied by any known folding, its period of occurrence is as significant as are those of the successive periods of folding in the subsequent inter-pulsation periods.

Although the European succession must serve as our standard of correlation for the Upper Cambrian, by virtue of its historic priority, it cannot be compared in magnitude of development with the corresponding deposits of the southern Appalachian geosynclines. Because of their lithological and faunal distinctness, these southern American deposits were regarded as representing a distinct system, the Ozarkian. In the establishment of the sequence and unity of this system, Dr. E. O. Ulrich has rendered such service to our science, that his name must henceforth be included, with those of the older geologists, among the founders of the Stratigraphy of the Palæozoic Systems. That I cannot agree with him in regarding this system as an independent intercalation between the Cambrian and the Ordovician, in no wise detracts from my admiration for the importance and magnitude of his pioneer work in American Stratigraphy. The absolute uniqueness of the Ozarkian series is in itself suggestive of its distinct systemic position. It is only when viewed in the light of the palæogeographic development of the earth as a whole, that it becomes possible to explain its uniqueness, and enables us to recognize its true position as a preeminently American representative of the Upper Cambrian transgressive portion of the Cambrovician Pulsation.

Except for the fact that Ulrich's term Ozarkian is limited to the transgressive series, while the regressive series is covered by his term Canadian, it would have been possible to use the term Ozarkian Pulsation, instead of Cambrovician. As it stands, the Ozarkian epoch is the transgressive portion and the Canadian epoch is the regressive portion of the Cambrovician Pulsation.

Because of the historic importance of the European Upper Cambrian and Lower Ordovician deposits, we shall begin our detailed discussion with the Caledonian geosyncline, and because of the possible relation of the Chinese deposite to them, they will be considered in the second place. Afterwards we shall turn to the American deposits.

THE CAMBROVICIAN OF THE CALEDONIAN GEOSYNCLINE

North Wales.

North Wales is the classical district for the Cambrian system, for it was there that Sedgwick first studied this portion of the Old Greywack Series. In his Cambrian system he included the rocks now separated as Ordovician which together with the Cambrian forms the greater part of the mountainous country of the two northwestern counties of Wales, *i. e.* Merionethshire and Caernarvonshire. Though the rocks are much disturbed, especially by faults and igneous intrusion as well as flows, the broader structural features are comparatively simple. The central portion of the structural unit is formed by the great truncated HARLECH DOME, which constitutes the northwestern part of Merionethshire, with an east-west diameter of some fifteen miles, and a north-south diameter of about twenty miles. Its eroded western side forms the coast line of Cardigan Bay from Portmadoc south to Barmouth. Just south of its central axis is Cader Idris and a few miles north of this peak is the classical locality of Dolgelly, from which the upper or Dolgelly division of the Upper Cambrian has received its name. A little north of the eastern end of the east-west axis of the dome, is Mount Arenig (Arenig Fawr) the classical locality for the Arenig division of the Ordovician. Less than ten miles to the east is the town of Bala, another classical locality for late Ordovician rocks. Along the northern border of the dome, are the hamlets of Ffestiniog on the central axis, and Maentwrog about 2½ miles further west, the localities which have lent their names to the middle and lower division of the Upper Cambrian of Wales. Six or seven miles due west from Maentwrog, and only about a mile north of Portmadoc is Tremadoc the type region for the Tremadoc shales, which by the British geologists have generally been classed with the Upper Cambrian, while Continental geologists are inclined to refer them to the base of the Ordovician. All of these localities lie near the outer rim of the Harlech dome.

Originally this dome was covered by the Ordovician as well as by the Silurian strata, but during the peneplanation of the region, these have been cut away from the top of the dome and now form a series of rimming belts. Walking outward in all directions from the center of the dome, one meets the Ordovician strata except on the west, where they have been removed by erosion on the seacoast, though both on the north in the peninsula which forms a large part of Caernarvonshire, and on the south they are still preserved. Outside of the rimming belt of the Ordovician, is that of the Silurian.

North of the Harlech dome, and forming the northern part of Caernarvonshire, is a second eroded dome, the Llanberis Dome in which the early Cambrian strata are again exposed. The centers of these two domes are less than 25 miles apart, and they are separated by a syncline in which the Ordovician strata are preserved for a width of from 8 to 10 miles. Near the northern edge the Ordovician strata of this syncline rise to form the summit of Mount Snowdon, the highest mountain of Wales (3560 ft.). This lies about 20 miles in a straight line northwest from Mount Arenig and about 30 miles, slightly west of North from Cader Idris (2,929 ft.).

Simple then as the broader structure of this region proves to be, the complications are brought about by the numerous igneous intrusions and lava-flows which locally modify the series, and the many faults which transect it. A number of these faults are parallel thrusts, forming only slight angles with the bedding planes and thus obscuring the stratigraphic succession.

The most detailed recent studies in this classical region are those by Professor W. E. Fearnsides, of Cambridge, and they are especially concerned with the Tremadoc and the Arenig.[1]

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1 W. E. Fearnsides. The Tremadoc slates and associated rocks of Southeast Caernarvonshire. Quarterly Journal of the Geological Society of London, Vol. LXVI, 1910, pp. 142-188, with geological map and section. *Ibid.* On the Geology of Arenig Fawr and Moel Llyfnant. Quarterly Journal of the Geological Society of London Vol. LXI, 1905, pp. 608-640. with geological map and sections.

In the earlier studies of Belt on the Upper Cambrian of this region the threefold subdivision of the old *Lingula flag* series into the Maentwrog, Ffestiniog and Dolgelly are established and their distinctness from the underlying Menevian series is shown.[1] The recent studies of Nicholas on the St. Tudwal's region of the Lleyn Promontory of Caernarvonshire, have already been referred to (Vol. I page 359 (*IV, p. 591*)) and though his work was chiefly concerned with the Middle Cambrian, he also gives important facts concerning the higher beds, of which we shall take note.

The general succession of the Ordovician and Upper Cambrian beds in the Ynyscynhaiarn district of southeast Caernarvonshire is as follows:

ORDOVICIAN

CARADOC SERIES

In the western or Criccieth region:

6 Rhyolitic ashes and agglomerates, variable dark-gray and shivery slates, banded, but with no distinguishable horizons.

(In the Tremadoc District 4-5 miles northeast, this horizon is represented by a gray slate series often strongly banded, with *Trinucleus* and *Orthis* etc. in the upper part, and preceded by andesitic ashes and ashy shales.)

LLANDEILO SERIES.

5 Dark-banded slates, with intense cleavage, no fossils found.

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1 Thomas Belt. On tbe Lingula Flags or Ffestiniog group of the Dolgelly District. Geological Magazine Vol. IV for **1867**, pp. **493-495**, and **536-543**.

(In the Tremadoc District, vesicular andesites are preceded by blue-black slates, containing graptolites of the zone of *Nemagraptus gracilis*)

4 Earthy slates with occasional "tuning fork" graptolites

Hiatus & disconformity

CAMBROVICIAN

III. ARENIG SERIES

3 Shivery slates, passing downward into the underlying beds.

2 Flaggy grits yielding *Calymene parvifrons*

1 Basal conglomerate grit 75 ft.

(In the Tremadoc District, the conglomeratic grit of Ynys Towyn is immediately succeeded by the Middle Ordovician *Nemagraptus gracilis* beds, with apparently a disconformity between them.)

Disconformity

II TREMADOC SERIES

I. *Garth Hill Beds.* 120 ft. +

Gray blue slates with *Angelina* etc.

H. Penmorfa beds. 100 ft. +

Flaggy sandstones and thin-bedded slates with *Shumardia* and the Shineaton fauna.

G. *Portmadoc Beds.* 200 ft.

Thickly bedded feldspathic slates with occasional *Asaphellus* and *Bellerophon* in the upper part.

F. *Moelygest Beds.* 240 ft.
Banded gray slates and mud-stones, few fossils *Acrotreta* and *Bellerophon.*

E. Dictyonema band. 20 ft.
Bright rusty, blue-gray mud-stones with abundant *Dictyonema socialis*

D. Tynllan or Niobe beds. 200 ft.
Thin-bedded rusty shales with some hard gray mud-stone bands, containing *Niobe* and *Psilocephalus* (*Symphysurus*)

I UPPER CAMBRIAN SERIES

C. Dolgelly Group. 275 ft.+

7. Sooty black mud-stones with *Peltura scarabæoides*
6. Blue black mud-stones, with *Agnostus trisectus*
5. Black slates with calcareous bands, often crowded with *Orthis* (*Orusia*) *lenticularis*
4. Dark flaggy slates with *Parabolina spinulosa.*

B. Ffestiniog Group. 1750-1850 ft.

3. Gray-blue slates and flags, crowded with *Lingula davisii* 50 ft.
2. Gray flags and graywacks, with some coarser bands. 1700-1800 ft.

A. Mæntwrog Group. 300 ft.

1. Rusty, gray and blue shales,

with thin bands of feldspathic graywacks

The base of the section is not exposed, but as has already been shown (Vol. I p. 396) the contact with the Middle Cambrian is seen in St. Tudwal's Peninsula, some 20 miles west along the coast. The Mæntwrog beds rest disconformably on the Nant-Pig mudstones of Menevian or Middle Cambrian age.

The characters and relationships of these several subdivisions may be noted more in detail. Reference to the paper by Fearnsides should also be made, especially to his map and sections.

A. Maentwrog Beds. These are also known as the rusty flag series and consist of an alternation of thicker masses of shales and extremely fine-grained flaggy beds with layers or bands of feldspathic graywack, often gritty and massively bedded and quite distinct from the enclosing beds, ranging in thickness from a few inches to a foot.[1] There are some thin intruded sills of doloritic rock. Fossils are few and ill-preserved in this section, but specimens of *Olenus cataractus* from one to two inches long have been found as well as specimens of *Agnostus* and *Conocoryphe*. A few *Lingulas* have also been found.

B. The Ffestiniog Flags. This great series of flags and alternating fine and coarse material has been referred to as a shallow water deposit, but it would probably be

1 These are the "ringers" of Fearnsides.

more correct to regard it as a great river delta-plain deposit, comparable to the modern Huangho beds in all respects except the oxidation of the material. That the region was occasionally flooded by the sea is shown by the sporadic occurrence of a few fossils, though these are said to be exceedingly rare. As a matter of fact, Fearnsides only cites *Scolithus* and *Cruziana* as evidence of the presence of organisms, but these borings and tracks could just as readily have been made above sea-level. A few *Lingulella* have also been found in the middle part of the series. In the graywacks, feldspars are common, though these are generally more or less decomposed. Cross-bedding is also characteristic of these graywacks.

Fearnsides has found it possible to make the following lithological subdivision, each generally grading into the next. In descending order.

5.	Dark-rusty-coloured flags with about 7 major masses of graywack	350 ft.
4.	Thick-bedded gray grits, with gray flag partings, passing upward into gray flags	250 ft.
3.	Flags with occasional *Lingulellas*, with from 3-5 subdivisions	300 ft.
2.	Massive grits with a few layers of flags with 4 or 5 minor subdivisions	400 ft.
1.	Dark-gray flags, alternating thin and thick beds, subdivisible into 8 or 9 subzones	400 ft.

The Lingulella Beds of the Ffestiniog. This is the topmost layer about 50 ft. in thickness. It contains numerous shells of *Lingulella davisii*, but no other fossils have been recorded. The beds however, seem continuous and recognizable over a wide area.

C. The Dolgelly Beds. These are also known as the Black Band series in this district and they form a readily mappable lithological unit. Resting immediately upon the *Lingulella* flags, are dark-gray to black shales and flags, characterized by the trilobite *Parabolina spinulosa.* Flakes of mica either primary or secondary are characteristic of the beds higher up and cone-in-cone ironstone concretions also occur. Some bands of the higher portions are crowded with shells of *Orthis* (*Orusia*) *lenticularis*, these making calcareous layers. They are succeeded by the *Agnostus trisectus* bed, which also contains *A. pisiformis*, *Peltura* and *Dicellocephalus.* Sooty-black mud-stones, with *Peltura scarabæoides* form the highest division of the Dolgelly Beds.

D. Tynllan Beds. Fearnsides has argued that the next overlying *Niobe* or Tynllan beds which are commonly referred to the base of the Tremadoc Series should be included with the Dolgelly, and the Tremadoc series made to begin with the *Dictyonema* beds. The Tynllan beds consist of dark, massive fine-grained and often pyritous lutytes and very fine arenytes, which break in a splintering manner. They are continuous downward into the Black Band of the Dolgelly and have a thickness of about 200 ft. The most abundant fossils are found about one third the thickness from the base. These include:

TRILOBITES

Niobe homfrayi Salter
Psilocephalus innotatus Salter
Shumardia sp.
Agnostus sp.

PHYLLOPODS

Hymenocaris vermicauda.

BRACHIOPODA

Acrotreta sp.
Lingulella lepis Salter
Lingulella sp.
Obolus sp.

HYOLITHIDS

Hyolithis (*Theca*) sp.

E. The Dictyonema Bed. This is a persistent and readily traceable dark shale, 15-20 ft. in thickness and abounding in *Dictyonema sociale* Salter. The dark shale in which the *Dictyonemas* occur is banded with pale bandings which comes to a maxima 3 or 4 times in each inch and consists of fine-grained material. A few other fossils have been found but they are rare. Those recorded include a few *Lingulas*, some *Acrotreta* and sponge-spicules which may be *Protospongia*. An occasional pygidium of *Psilocephalus*, some thoracic segments and a cephalon of a *Peltura*-like trilobite have also been obtained as well as a trilobite not unlike *Hysterolenus törnquisti*.

F. Moelygest Beds. These gray rusty weathering shales, which overlie the *Dictyonema* beds, appear to be almost devoid of fossils. Those found are an orthoid resembling *Orthis cristianiæ*, a few *Acrotreta* and poorly preserved *Bellerophon*.

G. Port Madoc Flags. These mark a return to the more or less feldspathic arenaceous deposits, which in large part are probably of river flood-plain origin (huangho type). Occasional marine flooding carried fragments of *Asaphellus* into these deposits, which were then enclosed in cone-in-cone concretions. The higher beds of this series again show more marked flooding, by the presence of *Asaphellus* and *Belleropon* in some abundance.

H. Penmorfa Beds. These are again more markedly fossiliferous consisting usually of pyritiferous lutytes with occasional coarser bands. At a certain horizon in the upper portion, trilobites are common, these including the genera, *Dicellocephalus*, broad forms of *Asaphellus*, *Shumardia*, *Holometopus*, *Agnostus*, *Symphysurus*, *Cheirurus* and *Angelina*, the latter the most abundant and characteristic form in the upper part. *Macrocystella* also occurs.

I. Garth Hill Beds. This is the highest division of the Tremadoc and comprises a variety of slaty lutytes in which the trilobites *Angelina sedgwicki* and *Ogygia* form the dominant fossils. *Dicellocephalus furca* also occurs. Sometimes thin beds of limestones are made up almost wholly of the broken fragments of *Angelina*, this suggesting shallow water, with periodic exposure.

The Arenig Grits. Fearnsides has presented the evidence for a disconformity, between the upper Tremadoc Garth-Hill Beds and the overlying Ordovician. In the Ynystowyn or Tremadoc region, the Garth-Hill Beds are succeeded by a massive quartzose pea-grit, the base of which rests upon a rough surface, which shows erosion pockets a few inches deep and a foot or two wide. There is however no discordance of dip. The lower 20 feet form a clean quartz grit, with a bed of quartz pebbles up to an inch in diameter near its middle. Some shale flakes also occur here. In the next 20 ft, some shale pebbles and shale partings divide the series into beds from 1 to 3 ft. thick. The upper 30 ft. are again without pebbles. The quartz grains have usually suffered secondary enlargement and there are occasional fresh feldspar crystals present.

The age of these quartzites is entirely unknown, though they have been called basal Arenig. They however, contain no fossils.

Farther west in the Criccieth region, a massive feldspathic grit; much crushed by faulting, overlies the higher Tremadoc beds. In one or two places this is seen to be followed by a fine-grained gritty rock, which contains the only true Arenig fossils found in this region. These comprise

Obolella (Monobolina) plumbea
Ogygia selwyni
Calymene parvifrons.

These beds are succeeded by shales, with "tuning-fork" graptolites i.e. *Didymograptus murchisoni*, referable according to Fearnsides to the Middle Ordovician or Llandeilan. If there is no fault, there is here a pronounced hiatus. In his section across this district Fearnsides shows continuity of superposition without faulting, though both the thin Arenig beds and the thick over-lying Llandeilo slates are finely wrinkled by compression. Thus there seems no doubt that even if there is a minor disconformity at the base of the Arenig in this region, the great disconformity and hiatus lies between the lower Arenig and the later Llandeilo.

In the region around Tremadoc, the Penmorpha thrust fault brings the Llandeilo directly in contact with the Penmorpha beds of the Tremadoc series. Excavations made upon the hillside, show beds with *Climacograptus sharenbergi* within a few feet above the Penmorpha beds with *Asaphellus.* The fault is so nearly parallel to the dip that the beds seem to be concordant.

The heds above the fault, though much sheared and complicated by andesitic volcanics, have yielded a rich graptolite fauna. These comprise the following species. (Q. J. G. S. 66, p. 170)

1. *Didymograptus superstes* Lapw.
2. *Dicellograptus sextans* Hall
3. *Dicellograptus intortus* Lapw.
4. *Dicellograptus divaricatus* Hall
5. *Dicellograptus moffatensis* Carr.
6. *Dicranograptus ramosus* Hall
7. *Dicranograptus rectus* Hopk.
8. *Dicranograptus ziczac* Lapw.
9. *Dicranograptus furcatus* var *minimus* Lapw.
10. *Dicranograptus nicholsoni* Hopk.
11. *Nemagraptus gracilis* Hall
12. *Climacograptus schärenbergi* Lapw.
13. *Climacograptus bicornis* Hall
14. *Climacograptus bicornis* var. *peltifer* Lapw.
15. *Climacograptus antiquus* Lapw.
16. *Climacograptus antiquus* var *bursifer* (Elles & Wood)
17. *Amplexograptus perexcavatus* Lapw.
18. *Glyptograptus teretiusculus* His.
19. *Orthograptus priscus* E. & W.
20. *Orthograptus whitfieldi* Hall
21. *Glossograptus hincksii* var. *fimbriatus* Nich.
22. *Cryptograptus tricornis* Carr.

This is a typical Middle Ordovician fauna. These beds are succeeded by andesitic ashes and ashy shales, together with vesicular andesite, which show that the volcanic activities which marked the emergent phase of the Lower Ordovician had not yet ceased, though some of the older volcanic ashes may have become reworked by the transgressing Middle Ordovician sea. These ash-beds sometimes contain *Diplograptus* and they are followed by slates with *Trinucleus* and *Orthids*.

The Arenig Region

Mount Arenig or Arenig Fawr, Sedgwick's classical locality for the Arenig rocks lies on the eastern border of the Harlech dome near the center of Merionethshire. It rises to a height of 2800 ft., but the plateau surrounding it stands from 800-1200 ft. above sea-level. The great mass of the mountain consists of pyroclastic rocks, and their age is commonly considered to be Middle Ordovician or Llandeilan. Lower Ordovician rocks however, that is, strata referable to the Arenig as commonly used, occur in the plateau country surrounding it, and on the borders of the Harlech dome. These rest upon the Upper Cambrian. We may give here the section in descending order, bearing in mind the fact that although the strata are only moderately folded, there are complications by faults and especially by intrusives.

Section in the vicinity of Mount Arenig

(After Fearnsides Q. J. G. S., 61, 1905)

ORDOVICIAN (*sens. strict.*)

IX UPPER ORDOVICIAN OR CARADOC SERIES

8. *Dicranograptus* shales.
7. Derfel or *Orthis* limestone — 0-30 ft.
   This is included in the lower part of the *Dicranograptus* shales.

VIII MIDDLE ORDOVICIAN OR LLANDEILO SERIES

F. Upper ashes of Arenig. — 1000 ft.+?

6. Upper or Rhyolitic ashes
5. Middle or massive ashes
4. Lower or acid andesitic ashes

VII UPPER LLANVIRN SERIES

	E. Beds with Didymograptus murchisoni	
	3. Daerfawr shales (maximum)	150 ft.
	D. Lower hypersthene-andesite ashes of Arenig.	300-400 ft.
	2. Platy ashes	
	1. Great agglomerate	
	(*Probable hiatus and disconformity*)	
CAMBROVICIAN		
VI	LOWER LLANVIRN SERIES	
	C. Zone of Didymograptus bifidus (generally included in the Arenig)	
	6. Olchfa or Bifidus shales	20- 30 ft.
V	ARENIG SERIES	
	B. Zone of Didymograptus hirundo.	
	5. Filltirgerig or *Hirundo*-Beds Includes an ash band	250-300 ft.
	4. Erwent or *Ogygia*-limestone	10- 12 ft.
	A. Zone of Didymograptus extensus	
	3. Henllan or Calymene-ashes	150-200 ft. ?
	2. Llyfnant or Extensus-flags	150-200 ft.
	1. Basal grit.	0-50-100 ft.
	Mild Disconformity	
IV	TREMADOC SERIES	
	10. Amnodd or *Shumardia*-Beds	100 ft.
	9. Tai-Herion or *Asaphellus* Flags	80-100 ft.
	8. Nant-ddu or *Bellerophon* Beds.	150-200 ft. ?
	7. *Dictyonema* Bed	15- 20 ft.
III	DOLGELLY SERIES.	
	6. *Niobe* and *Psilocephalus* Beds	250-300 ft. ?
	5. *Peltura*-Bed or Black Band	250-300 ft.

	4. *Orthis* (*Orusia*) *lenticularis* Bed	4-5 ft.
	3. *Parabolina* Beds	200 ft.
II	FFESTINIOG SERIES	
	2. *Lingulella* Beds	30-40 ft.
	1. Grits and Flags.	great thickness
I	MAENTWROG SERIES	not exposed

The *Lingulella* bed forms the top of the Ffestiniog series, and though slightly thinner is essentially the same bed noted before in the Portmadoc region farther north. It abounds in *Lingulella davisii* McCoy, which is sometimes so abundant as to form the greater part of certain bands. The *Parabolina spinulosa* beds of the Dolgelly series, about 200 ft. thick, are finer grained and less gritty than the *Ligulella* beds and of a dark bluish gray colour and conchoidal fracture. The zone fossil occurs chiefly in the middle and upper part, the lower being unfossiliferous. It is separated from the *Peltura* beds, or Black Band by the thin limestone crowded with *Orthis* (*Orusia*) *lenticularis.* The Black Band, so-called because it produces a black streak, is a fine-grained homogeneous lutyte the black colour of which Fearnsides thinks is due to finely divided slightly decomposing iron sulphide and not to carbon. In the lower part near the *Orthis* (*Orusia*) band *Sphærophthalmus alatus* (Boeck) and *Ctenopyge pecten* (Salter) have been found. In other parts *Peltura scarabæoides* (Wahl.) and *Agnostus trisectus* Salter are common fossils.

These beds pass upward into the *Niobe beds* for which reason Fearnsides has included the latter in the Dolgelly. The lithological change is from silky slates to cleaved mud-stones, with the colour progressively becoming lighter and the amount of iron pyrites increasing. The main mass of this series is lithologically similar to the *Parabolina* beds at the base of the Dolgelly. The leading fossils are *Niobe homfrayi* Salter and *Psilocephalus innotatus* (Salter), which gradually replace the *Peltura*.

The *Dictyonema* Bed, with which Fearnsides would begin the Tremadoc in the North Wales region, is a dark-bluish-gray shale, characterized by the abrupt appearance of *Dictyonema sociale*. This is the first of the graptolites to appear in the geological series of Europe and as I have elsewhere suggested, it marks the establishment of the connection between the geosynclines and the region of evolution of graptolite faunas, which throughout Cambrian time was separated from the geosynclines of both Europe and Asia either by a barrier or because the graptolites had not yet acquired the floating habit. As we have seen graptolites were however able to gain access to the southern Appalachian trough in Cambrian time. The *Dictyonema* beds have a thickness of only 15 to 20 ft. and no further graptolite invasion occurred in this region until Arenig time.

Nant-ddu Beds. The beds succeeding the *Dictyonema* beds constitute a monotonous series of gritty shales with cone-in-cone concretions at certain horizons. *Lingulella* and *Acrotreta* have been found in the lower part together with indeterminable *Bellerophon*. In the upper beds *Asaphellus homfrayi*, a broad form, and *Olenus* (*Parabolinella*) *triarthrus* Call. and *O.* (*P.*) *salteri* Call. have been obtained.

Tai-Herion Beds. The succeeding *Asaphellus* flags are much coarser and contain numerous worm-tracks and castings, filled with white quartz sand. There is also a curious form of "ripple" marking described by Fearnsides (1905, p. 615) and regarded by Nicholas as the result of creep or gliding of the unconsolidated sandy muds.

The broad form of *Asaphellus homfrayi* is most characteristic of these beds, but otherwise fossils are not very abundant.

Amnodd Beds. The *Asaphellus* beds grade into the overlying *Shumardia* shales by a change towards softer and finer fossiliferous blue-gray mudstones. The narrow type of *Asaphellus homfrayi* predominates here, together with the striking little trilobite *Shumardia salopiensis.* The fauna which may be taken as a typical upper Tremadoc fauna includes the following:

SPONGIDÆ
Protospongia sp. (Spicules)

BRACHIOPODA
Acrotreta sabrinæ Call.
Lingula cf. *nicholsoni* Call.

PELECYPODA
Ctenodonta sp.

GASTROPODA ETC.
Bellerophon multistriatus Salter
Theca (*Hyolithes* *operculata* Salter.
Conularia homfrayi Salter

CYSTOIDEA
Macrocystella mariæ Call.

TRILOBITA
Asaphellus homfrayi Salter
Shumardia salopiensis (Call.) (cf. *S. œlandica* Moberg)
Ogygia (*Niobe*) *scutatrix* Salter.
Olenus (*Parabolinella*) *triarthrus* Call.
Agnostus siedenbladhi Linn.
Symphysurus croftii Call.
Remopleurides sp.
Holometopus sp.
Dicellocephalus sp.
Cheirurus sp.

Fearnsides points out that these Tremadoc and Cambrian beds are essentially those recognized in the Portmadoc region farther north, where each one of the fossiliferous bands is represented. Although the thickness at Arenig is greater than at Tremadoc, he thinks "that the difference is due rather to subsequent packing by earth movement than to diversity in original deposition."

As in the Tremadoc region, there appears to be a disconformity between the Tremadoc and Arenig Beds, which Fearnsides thinks indicates "the passing of some early Caledonian earth wave, which had left but little permanent impress upon the dip and strike of the rocks which it affected."

It is however apparent, from the fact that in the westward direction the basal grit of the Arenig "rests successively upon all members of the Tremadoc Series, and at the Nant-y-Derbiniad slate quarry comes into the Black Band or *Peltura* bed of the Dolgelly, or upper Lingula flags."

In the same direction, it is often found that the various members of the Lower Ordovician overlap each other against the surface of disconformity. As we have already seen in the Portmadoc region, this basal grit is followed by beds with *Didymograptus murchisoni*.

Before discussing this disconformity more at length, we may review the characters of the beds immediately overlying.

The Arenig Series

The Basal grit of the Arenig. This is a bed of variable thickness. "Sometimes it may be as much as 50 to 100 ft. thick, but usually it thins off rapidly and may entirely die out in something less than 50 yards." Occasionally it is clean and white and from the abundance of vein-quartz, it may become almost a quartzite. Usually however, it is rather impure with much ashy material. Though generally a fairly coarse, even-grained grit, it may become conglomeritic in the thicker part. "In all cases, the constituent grains are rounded rather than angular. Grains of hyaline quartz are fairly common, but pebbles directly derivable from the underlying Tremadoc or Dolgelly beds, are conspicuous by their absence" (Fearnsides 1905, p. 618).

These features and the very gentle character of the disconformity suggest that we have here the phenomena of a retreatal series accompanied by a very slow rising of the Old Land and the consequent erosion of the Upper Cambrian beds (Transgressive Series) previously deposited. The grit is evidently a purely continental deposit and its age may vary from place to place. As we have already seen, "The similar grit at Ty-obry, Minffordd (Portmadoc) is directly overlain by shales, belonging to the zone of *Didymograptus murchisoni* Beck." that is, the transgressive series of the Middle Ordovician, which belongs to the 4th pulsation.

Llyfnant Flags. The fact that the Llyfnant flags, 150-200 ft. thick with *Didymograptus extensus* also overlie this grit in the Arenig series, might at first appear as not in harmony, with the idea of a retreatal series. These flags are remarkably well-bedded with shaly micaceous partings, and under the microscope "it is seen that calcite and shreds of detrital mica make up quite as large a portion of the finer material as do the actual quartz grains. There is also a great deal of unresolvable muddy paste and some secondary quartz. The quartz grains are much more angular than those of the underlying grit, and are often also curiously ragged at the edges".[1]

Certain layers contain numerous graptolites, the most abundant being *Didymograptus deflexus* E. & W. while *D. extensus* Hall is not rare. *Loganograptus logani* and *Tretragraptus* cf. *amii*, are also found, as well as pygidia of *Ogygia*. Worm tracks and castings, both small and great, are extremely abundant.

Those who accept the prevalent interpretation of graptolite-bearing beds as deposited in deep water bodies stagnant and toxic in their lower portion, will regard these Llyfnant flags as marine deposits. I have however elsewhere[2] presented the evidence for the origin of the graptolite beds as due to periodic flooding of low subaerial coastal plain or river flood or delta plain deposits (huangho deposits) and if this interpretation is valid, these flags are to be regarded as fluviatile deposits, occasionally and very temporarily flooded or marined along the coast by the rising sea water, which left its wrack of floating graptolites behind to be buried by succeeding river deposits. In that case, this series very evidently is to be regarded as the emergent phase of the Arenig retreat. Even the presence of the fragmentary trilobites cannot be considered evidence against such interpretation, for such fragments would likewise be floated on to the temporarily submerged surface of the flood plain deposit.

Henllan Volcanic Series. That the retreat of the sea from this region in Arenig time was not a uniform or regular one, but punctuated by repeated, though probably

1 Fearnsides 1905, p. 619.

2 A. W. Grabau. The origin, distribution, and mode of preservation of the graptolites. Academia Sinica. Memoirs

only temporary submergences is indicated by the character of the succeeding Arenig beds. The Llyfnant beds pass upward into the Henllan volcanic ashes, which Fearnsides believes were derived from some more or less distant volcanic source probably towards the south, as is shown by the thickness and increase of material in that direction. This material is "richer in lime (and therefore more basic) than any of the products of the later volcanoes of the district."

These ashes, probably as thick as the underlying flags, may also be river flood-plain deposits (huangho type), though the disappearance of the bedding also suggests direct settlement from the air of these products of eruption. As they are only sparingly fossiliferous, the greater portion is probably also of subaërial origin, the occasional presence of marine fossils indicating temporary flooding. Those found are a *Calymene* probably *C. parvifrons* Salter, and a few large gastropods, such as *Raphistoma* or *Maclurea* and many indeterminable *Orthoceratidæ* including possibly an *Endoceras*.

Eru ent Limestone. That the intermittent flooding was occasionally pronounced due no doubt to the somewhat irregular subsidence of the Caledonian geosyncline in this section, rather than to renewed advancing of the generally retreating Lower Ordovician Sea, is shown by the Erwent or *Ogygia* limestone, which overlies the ash-beds just discussed. This highly fossiliferous band is not more than 10 or 12 ft. thick and consists of shaly lentils an inch or two in length, which give the rock a streaky-bacon-like appearance. There is still much ash present, while the calcareous character is given to the rock by the fossils. There are also a good many chips of that acid plagioclase which is so characteristic of higher beds. "The most abundant trilobite is *Ogygia selwini* (Salter) which must sometimes have attained a length of 8 or 9 inches, although most freqently it is represented by specimens only 2 or 2½ inches long, or by numerous tails, not more than ½ an inch across. Tails of this species are much more abundant than heads and nearly all the moderately complete specimens are more or less enrolled." The entire fauna of this limestone band comprises the following.

Fauna of the Erwent or Ogygia limestone

TRILOBITA
- *Ogygia selwini* Salter
- *Calymene parvifrons* Salter
- *Ampyx salteri* (?) or *A. domatus* Linnæus

CEPHALOPODA
- *Orthoceras encrinale* Salter
- *Orthoceras sericeum* Salter
- *Orthoceras* sp.

GASTROPODA
- *Raphistoma* sp.
- *Maclurea* sp.
- *Bellerophon* sp.

PELECYPODA
- *Palæarca* sp.
- *Ctenodonta* sp.

BRACHIOPODA
- *Orthis calligramma* Dalman
- *Orthis carausii* Salter
- *Obolella (Monobolina) plumbea* Salter
- *Lingula rouaulti* Salter

GRAPTOZOA
- *Callograptus radiatus?* (Hopkinson)

These are considered as the truly Arenig species of this region, though the presence of *Orthis calligramma*, if it is that species, is rather suggestive of a higher horizon.

Fearnsides compares this fauna with the fauna of the *Nesuretus* beds of South Wales, which were originally regarded as representing the Tremadoc.

Filltirgerig Beds. The Erwent limestone is succeeded by another great series of ashy and other clastic beds, which in the upper part contain two well-defined beds of volcanic tuff up to 20 ft. in thickness. These beds contain a great deal of remarkably angular chips of quartz and flakes and threads of mica. The more shaly beds are well stratified and show rapid alternations of sandy shaly and micaceous material. Fossils are not especially abundant, but graptolites, where found, are usually pyritized, and preserved in relief. *Didymograptus hirundo* Salter is most frequent, but small forms of *D. nitidus* Hall or *D. patulus* Hall, have also been found. Many ill-preserved *Tetragraptids* occur, including *Tetragraptus serra* Brongn. and *T. reclinatus* E. and W. A single example of *Didymograptus gibberulus* Nicholson has been found and associated are fragments of *Asaphid* trilobites and of *Aeglina.* At the base of the series *Obolella* (*Monobolina*) *plumbea* Salter, characteristic of the lower bed, is still abundant and with it occurs *Azygograptus suecicus* Tbg.

It is evident that unless we believe in the deep sea origin of the graptolite shales, we must consider these beds the continuance of the river plain or huangho deposits in a generally sinking geosyncline, which tended more or less to counteract the retreatal movement of the Arenig Sea and permitted occasional over-wash or marining, and the spreading of sea-wrack over the submerged plain, with a single pronounced submergence due to rapid sinking of the geosyncline. The thickness of these *Hirundo* or Filltirgerig beds appears to be between 200 and 300 ft. according to the section given by Fearnsides, and they are succeeded by some 20 to 30 ft. of *Bifidus* shales.

The Bifidus or Olchfa shales. These mark a rather sharp and complete change in the graptolite fauna. "Within a foot of the bed in which the last *Didymograptus hirundo* was collected, quite a selection of species belonging to the *Bifidus* fauna may be found."

The beds too lose their calcareous character gradually and become pyritous, but the change is not so abrupt. Though fine-grained, the microscope shows chips of detrital quartz and shreds of mica much too coarse for the rest of the material. It also shows many ragged flakes of what is probably graphite, together with pyrite.

The fauna is the typical lower Llanvirn fauna of Hicks, but without the trilobites common in South Wales. It is a rich graptolite fauna which includes the following species:

Graptolite Fauna of the Olchfa or Bifidus beds of Mt. Arenig.

In the lower part:

Didymograptus nanus Lapworth
Didymograptus patulus Hall
Cryptograptus tricornis Carruthers
Dendograptus sp.
Didymograptus bifidus Hall

At the top the species are:

Diplograptus dentatus Brongniart (abundant)
Didymograptus artus E. and W.
Didymograptus acutidens Lapworth
Didymograptus stabilis E. and W.
Glossograptus sp.
Cryptograptus tricornis Carruthers

Didymograptus bifidus var., (intermediate between typical *D. bifidus* and *D. murchisoni*)

Also pygidia and other fragments of *Ogygia* (*O. peltata* Salter or *O. buchii* Brongn) and a *Dionide*.

The abrupt appearance of tuning-fork graptolites is rather significant, and although these beds are usually classed with the Arenig when they are not separated as Lower Llanvirn it is possible that they represent advance types of the *D. murchisoni* group which becomes dominant in the Middle Ordovician Sea.

It is however, after this series of strata, that the great volcanic series of Arenig begins, and if they truly represent Lower Ordovician, this great outbreak of volcanic material belongs to the interval of final emergence, and as such is comparable to the tectonic disturbances which have marked most of the later intervals between successive pulsations.

The lower part of this volcanic series begins with platy ashes, which in the course of some 30 ft. or less, pass almost imperceptibly into massive agglomerates, which form the great bulk of the lower series and which sometimes lie directly on the shales beneath. The agglomerate reaches a thickness of from 300 to 400 ft and are followed by 150 ft. or so of more platy ashes, which vary in thickness inversely as does the agglomerate. "The agglomerate consists of shattered blocks and particles of a hypersthene-andesite. ....The blocks of the agglomerate are set in a matrix of smaller particles of the same material, and the whole mass is usually to a considerable extent silicified. Most of the blocks in the agglomerate are about the size of a hen's egg or of a cricket ball but sometimes quite large masses are seen." (Fearnsides 1905, p. 624).

Masses of shale with *Lingulella davisii* brought up from the underlying Ffestiniog have been found. The material of the agglomerate corresponds to the older series of intrusions, forming the so-called Arenig porphyry.

This agglomerate series is followed by the Daerfawr shales, which contain graptolites of Middle Ordovician age, including *Diplograptus foliaceus* Murchison and *Diplograptus angustifolius* Hall and *Dicellograptus moffatensis* Carr.

These are again followed by other volcanic ashes, which show that volcanic activity continued into if not through Middle Ordovician time. According to Miss Elles[1] the Arenig rocks of Wales show 3 well-defined graptolite zones. These are in descending order.

3. Zone of *Didymograptus bifidus*
2. Zone of *Didymograptus hirundo*
1. Zone of *Didymograptus extensus*

There are still Lower graptolite zones in the Lower Ordovician of western Europe, but they are not known from North Wales.

Overlying the *Didymograptus bifidus* zone is the zone of *Didymograptus murchisoni*, which is generally referred to as the lower zone of the Middle Ordovician or Llandeilan. Both *D. bifidus* and *D. murchisoni* belong to the dependent two-branched forms, the so-called "tuning-fork" type of graptolite, whereas those of the lower zones differ markedly in being laterally extended types, the two branches extending outward in the same plane. In view of this distinctness Hicks separated the two zones with tuning-fork graptolites as the Llanvirn, and from a purely palæonto-

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1 Gertrude Elles. Some graptolite zones in the Arenig rocks of Wales. Geological Magazine. New Series, Decade V, Vol. I, 1904. pp. 199-211.

logical point of view the line of disconformity between the Middle and Lower Ordovician, should be drawn between the extensi-form and the pendant types. This of course would place the entire volcanic series of North Wales into the Middle Ordovician, rather than in the gap between the Lower and the Middle.

Some of the graptolites associated with *D. bifidus* in North Wales also suggest Middle Ordovician affinities. Along the river Seiont in Caernarvonshire, North Wales, Miss Elles found the following association in the *D. bifidus* zones,

1. *Didymograptus bifidus* Hall (very common)
2. *Diplograptus dentatus* Brongn.
3. *Climacograptus confertus* Lapw.
4. *Climacograptus scharenbergi* Lapw.
5. *Caryocaris* sp.

The Extensus beds of Menai Straits and Lleyn Peninsula have furnished the following species.

1. *Didymograptus extensus* Hall
2. *Didymograptus nicholsoni* Lapw.
3. *Didymograptus nitidus* Hall
4. *Didymograptus* (*Isograptus*) *gibberulus* Nicholson
5. *Didymograptus uniformis* Elles and Wood
6. *Tetragraptus serra* Brong.
7. *Tetragraptus amii* Lapw.
8. *Tetragraptus* cf. *headi* Hall
9. *Trinucleus gibbsi* Salter?
10. *Calymene* sp.
11. *Cariocaris* sp.
12. *Lingulella* sp.

The absolute distinctness of the two faunas is thus evident.

The basal Arenig disconformity is well-marked in the

St. Tudwal's Peninsula, about 20 miles southwest of Portmadoc and nearly twice that distance west of Mount Arenig.[1]

As we have already seen, the Maentwrog Beds of the Upper Cambrian rest disconformably upon the Middle Cambrian. The lower 40 ft. of the Mæntwrog series consists of hard fine textured silicious grits in beds from 1-3 ft. thick, of the type named by Lapworth "ringers," separated by shales, In the next 30 ft, the "ringers" are more numerous and thinly bedded and their weathered edges show the curled bedding described by Fearnsides as ripple-marks. Nicholas regards these as indicating some kind of creep of the still unconsolidated muddy grits, this creep often involving considerable over-folding. They probably are analogous to the gliding deformations found in certain bedded limestones and other rocks of various ages[2]

The next 30 ft. of beds exposed are banded, black, bluish-gray, and greenish shales, with numerous thin grit layers but ringers are thin and infrequent. Worm tracks etc. are common on these rocks, but actual organic remains are rare. The only ones found are *Olenus* sp. and *Agnostus pisiformis* var *obesus* Belt near the top of the series. A further outcrop of the Maentwrog beds, shows 42 ft. of bluish black shales with sandy and gritty interlaminations and with ringers rare and thin. These beds lie about 700 ft above the base.

The remainder of the Maentwrog series as well as the lower Ffestiniog Beds are not exposed, but the upper 350

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1 T. C. Nicholas. Geology of the St. Tudwal's Peninsula. Caernarvonshire. Quarterly Journal of the Geol. Society of London. Vol. LXXI, 1917 pp. 83-143. map and illustrations.

2 See Grabau. Principles of Stratigraphy p. 781.

ft. of the Ffestiniog, including the beds with *Lingulella davisii* McCoy, are found. These are gray-blue shales passing down into sandy shales and lower still into massive siliceous grits.

From the general character of the rocks and the scarcity of fossils, it is apparent, that these Upper Cambrian beds, represent primarily river-plain or hangho deposits on the margin of the sea, which occasionally flooded them and finally transgressed to form the fossiliferous *Lingulella* Beds. The Dolgelly and the Tremadoc Beds are not preserved in this section, but it is probable that they were deposited here and again eroded during the early period of the Arenig retreat, when the coastal and Old Land region began to rise. This represents the period during which the older *Dichograptus* Beds of other regions were deposited, these beds being generally absent in North Wales. Subsequently, with a change in the rising movement of the coastal region, the later continental sands of the Arenig were deposited over the eroded surface, coming thus to rest on various portions of the Upper and even the Middle Cambrian.

St. Tudwal's Sandstone. The basal Arenig Beds form the St. Tudwal's sandstone and grits, with a thickness of about 400 ft, though they appear thicker by repeated thrust faulting. They are chiefly streaky sandstones and grits in the lower 230 ft. and their only fossils are a few graptolites. In the lower portion *Dictyonema* sp. and other *Dendroidea* have been found. The upper portions of this sandy series have furnished *Didymograptus deflexus* E. & W. and *Didymograptus extensus* Hall.

Higher grits and shaly sandstones follow, some with extensiform *Didymograpti*, and near the top, sandstones and shaly layers, with *Azygograptus lapworthi* (Llanengan beds).

The greater part of the rock under the microscope shows angular grains of quartz, together with some feldspar flakes, some granular magnetite and a considerable amount of ferruginous carbonates. Much of the sandstone is streaky in appearance, due to the presence of thin curling films of dark argillaceous material among the sand grains (Clay galls? see Grabau Principles p. 711). These characters are quite consistent with the interpretation of the rock as a river flood deposit with eolian activity. Some of the grit beds are similar to the sandstone, except that the cement bed is of siliceous material. Coarser grits, with the quartz grains mostly rounded, but enlarged by secondary silica which forms the cement, appear to represent occasional eolian deposits. They are often markedly cross-bedded and usually occur in beds one foot or more thick, often without shale partings and never presenting the streaky appearance of the sandstones.

Llanengan Shales. The Tudwal sandstones and grits are succeeded by the Llanengan mud-stones, some 200 ft. or more of blue sandy mud-stones striped with fine yellowish lines, due to thin layers of arenaceous sediments. Only graptolites have been reported from these beds, *Azygograptus lapworthi* Nicholson being the most plentiful, ranging through all the beds. A doubtful specimen of *Phyllograptus?* a single specimen of *Tetragraptus amii* E and W? and one of *Tetragraptus serra* (Brongn.) were obtained in the lower part. These represent the horizon of *Didymograptus extensus.* It must however be remembered that elsewhere this is preceded by an older horizon, in which *Tetragraptus* is the normal type. As we have already noted, these older beds, where deposited, probably correspond to the erosion in the St. Tudwal's area, which accompanied the slow rise of the Old Land.

The Hen-dy-Capel mud-stones. The beds immediately succeeding are a series of soft black shales and mud-stones "which have often been crushed out of all reconition by intense local earth movement and contain great lenticular masses of pisolitic iron ore." They contain a late Middle Ordovician (Glenkiln) graptolite fauna (Nicholas p. 123).

The lowest bed of pisolitic iron ore, about 12 ft. thick, rests upon comparatively undisturbed Llanengan mud-stones, in which a number of specimens of *Azygograptus lapworthi* were found only a few inches below the junction. The pisolitic iron ore is overlain by the intensely crushed shales.

A fact of considerable interest is the occasional presence in the crushed shales of recognizable specimens of graptolites, indicating the zone of *Nemagraptus gracilis* i.e. the Norman's kill (Glenkiln) horizon of the late Middle Ordovician. Nicholas says "A great gap, comprising a large part of the Arenig and the whole of the Llanvirn series is, therefore, apparent in the succession, and all the evidence is in favour of the view that this gap is due – not to an unconformity or to a normal faulting, but to an overthrust. The idea of an unconformity is *prima facie* improbable, for the Llandeilo beds are of the deep-water Glenkiln type and all the missing beds (up to and including the *Didymograptus bifidus* zone) are well developed five miles away to the west about Llanfaelrhys; moreover, an examination of the junction of the two series supplies conclusive evidence against both unconformity and normal faulting." (*loc. cit.* p. 114)

That thrust-faulting has occurred here seems to be sufficiently indicated by the condition of the shales and the slickensides, but that such faulting is wholly responsible for the gap in the stratigraphic succession may be questioned.

Of course, if the Llandeilo beds above the pisolitic iron ore were of deep water origin, as Nicholas assumes, his *prima facie* reasonig might be satisfactory. If however, these graptolite shales are shallow water deposits, representing the occasional flooding or marining of low river plain or huangho muds as is overwhelmingly indicated by the character of the graptolite-bearing beds in all parts of the world, the evidence is rather for than against indicating a disconformity. Moreover, since in widely separated portions of the earth's surface, the gap between the Lower and Middle Ordovician is clearly recognizable, there need be no surprise to find the evidence for it in the regions near the Old Land of Ordovician time, where indeed one would expect it to be most strongly marked. Fearnsides has presented the evidence for it in the Criccieth regions, though in the Tremadoc region the disconformable contact is also complicated by thrust-faulting.

The pisolitic iron ore, which seems to be a characteristic deposit along the junction line of the Lower Arenig and upper Llandeilan beds "varies from a massive black rock, built up almost entirely of pisolitic or oolitic grains to a black mud-stone, in which these grains are distributed sparingly or aggregated into small nodules. The ore often contains streaks and lenticles of black mud-stone, which differ from the more argillaceous portions of the ore only in the absence of pisolitic grains—in fact, the two types appear to shade one into the other and may contain fossils." (Nicholas *loc. cit.*). Speaking of the thoroughly pisolitic and the more argillaceous portions of the ore Nicholas says "There is no discontinuity at the junction, and hand-specimens can be obtained in which pisolitic ore and black mud-stone, with detached siculæ of graptolites and horny brachiopods, seem to be inseparably welded together." (*Loc. cit.* p. 124)

Nemagraptus gracilis is cited from this mud-stone portion, showing that it is intimately associated with the Normanskill or Glenkiln sedimentation of this region.

Nicholas stresses the fact, that the ore itself is very little affected by the thrust crushing, although the shales and sandstones above and below are intensely crushed and slicken-sided. Occasional planes of slicken-sides and deformation of the grains is noticeable in the marginal portion, "but the bulk of the bed is totally undisturbed." He cites however, exceptions where the ore is also sheared.

Nicholas has come to the conclusion "that the pisolitic iron ore of the St. Tudwal's Peninsula, was in existence before the thrusting took place and is of sedimentary origin."

If these iron ores mark the horizon of a great disconformity between the Middle and Lower Ordovician, their origin as a continental deposit—lake, pond or even subaerial is not very difficult to understand. It might then be considered that they belong to the same category of intra-systemic deposits, to which the pisolitic iron ore of Wisconsin belongs, which there marks a disconformity between the Ordovician and the Silurian.[1]

The Dolgelly Region

Dolgelly lies on the southern border of the Harlech Dome in Merionethshire, North Wales, on the Afon Wnion (River) which opens into the Mawddach estuary, which in

1 Grabau, A. W. Bull. Geol, Soc. America Vol. 24, 1913 pp. 444.

turn joins the sea at Barmouth. Along the coast of the estuary and for some distance south along the sea coast, the Cambrian and Ordovician strata are exposed in a series of parallel bands, and as this is the type region for the upper division of the Upper Cambrian, we may consider it somewhat more fully.

Recently the section between Dolgelly and Arthog near Barmouth junction has been described and mapped in detail, on the scale of 3 inches to the mile by Cox and Wells.[1] The beds of this region dip at angles varying from 40 to 60^0 to the S. E. with high uniclinal ridges formed by the harder rocks, and the sediments are complicated by igneous intrusions. The stratigraphic succession in descending order is as follows:

SUPERFORMATION

Llandeilo? Lower Basic Volcanic Series.

(Part of this may be emergent Arenig beds)

CAMBROVICIAN (Retreatal Series)

Lower Llanvirn.

4.	Cefnhir ashes, about	300 ft.
3.	Crogenen slates, about	300 ft.
2.	Brynbrith grits and ashes about	150 ft.
1.	Moelyn slates	0-40-150 ft.

Lower Llanvirn and Arenig. Lower Acid or Mynydd-y-gader rhyolitic series 800 ft.

3. The China Stone ashes.
2. Pontkings slates (Lower half Arenig)

1 Arthur Hubert Cox and Alfred Kingsley Wells. The Lower Palæozoic rocks of the Arthog-Dolgelly District (Merionethshire). Quarterly Journal of the Geological Society of London Vol LXXVI part 3, 1921 pp. 254-322 with Geol. map, sections & 3 plates.

1. Lower ashes (Arenig)

Arenig

Basement series 150-200 ft.

Disconformity?

CAMBROVICIAN (Transgressive Series)

Tremadoc Beds. 900 ft. +

6. Upper Pencil Slates
5. Upper *Dictyonema* Band
4. *Asaphellus* Beds
3. Lower Pencil Slates
2. Lower *Dictyonema* Bed
1. *Niobe* Bed.

Upper Cambrian

3. Dolgelly Beds 600 ft.
2. Ffestiniog Beds 3,000 ft. +
1. Maentwrog Beds, not exposed south of the estuary but shown at north side.

The Ffestiniog Group. This is a great series of grayish blue flaggy slates, interbedded with white laminated quartzite bands with fine-grained siliceous grits or "ringers" which show the peculiar curled structure elsewhere seen, the more flaggy strata being often highly micaceous.

The upper beds are dark-blue slates, grading into the overlying division. They are characterized by an abundance of *Lingulella davisii* Mc'Coy, but this is also found scattered in the lower strata in many localities.

The Dolgelly Beds. Dark-blue to black, highly pyritus mud-stones, generally rusted on the weathered surfaces, occasionally thin gritty layers are intercalated in the fine rock. The black-band of other sections is found near the center. Characteristic fossils are:

Parabolina spinulosa Dalman

Orthis (Orusia) lenticularis Wahlenberg

These beds grade up into the Tremadoc.

The Tremadoc Slates. A thick rather monotonous series of slates and mud-stones usually gray-blue. The several sub-divisions from below upwards show the following characters.

1. Niobe Beds. These succeed without break the Dolgelly Beds, but they show no obvious lamination and contain less pyrite. In the course of 200 ft. the beds become harder and more flaggy. The upper beds have a chert-like appearance, because of metamorphism by intrusives. The fossils include.

Niobe homfrayi Salter
Lingulella lepis Salter

2. The Lower Dictyonema Band. This consists of dark-blue shales passing up into harder blue-gray mud-stones weathering to a light gray. *Dictyonema sociale* is most abundant in the Lower part. With it occurs *Lingulella lepis.*

This is correlated with the *Dictyonema* bed of both the Mount Arenig and the Tremadoc region.

3. The Lower Pencil Slates. The *Dictyonema* slates pass up into hard gray mudstones, poorly cleaved and then in the course of some 40 ft, into blue slates, which usually take on a distinct needle or pencil cleavage. Some coarse-grained beds occur near the middle. This division is correlated with the *Bellerophon* beds of Mount Arenig and the Moelygest beds of Tremadoc.

4. The Asaphellus flags and shales. Hard flaggy beds grayish and somewhat striped, owing to the incoming of sandy material. Other bands are bluish, and highly micaceous nodules of cone-in cone ironstone are found. Some of the upper beds are remarkably fossiliferous, but nearby beds may be very poor in fossils. Characteristic species are:

Asaphellus homfrayi Salter
Agnostus calvus Lake
Ormetopus praenuntius Salter
Lingulocaris sp.
Conularia homfrayi Salter
Centrotheca cuspidata Salter
Theca sp.
Obolella sp.

This bed is correlated with both the *Asaphellus* flags and *Shumardia* flags of Mount Arenig and the Portmadoc and Penmorpha beds of Tremadoc.

5. *The upper Dictyonema band.* This is similar to the Lower *Dictyonema* bed, with the same *Dictyonema* and more rarely *Callograptus.*

6. *Upper Pencil Slates.* Soft shales, with irregular cleavage producing splinters or pencils. *Bellerophon* sp. and *Asaphallus*? have been found but because of the cleavage, fossils are difficult to obtain. This and the Upper *Dictyonema* band are correlated with the Garth Hill beds of Tremadoc, while in Mount Arenig, it seems to be missing.

On the whole the Tremadoc of this section and that of the type region seem to agree very well in thickness and general character, being in each case about 900 ft. thick, and showing essentially the same subdivision. In the Mount Arenig region however, the total thickness of these beds is less than 700 ft. and there, as we have seen, a slight disconformity seems to separate it from the higher division. Again while in the Dolgelly region, the Dolgelly beds are 600 ft. thick, they are 400-500 in the Mount Arenig, and only 275 in the Tremadoc region. The

Ffestiniog beds also have decreased from about 3,000 ft. on the south of the Harlech Dome to 1800 ft. on the north.

The Arenig Basement Grit. The change from the Upper Tremadoc to the base of the Arenig is abrupt, from shales to grits and sandy flags without transition. No physical evidence of a disconformity however has been found, nor is there any perceptible discordance of dip. There is merely an abrupt change in lithology, the shallow-water marine Tremadoc beds being replaced by unfossiliferous sands of continental type, in which only worm-tracks occur, though a few undeterminable graptolite fragments have been reported. We have here evidently the effect of the beginning of the negative movement of the Cambrovician pulsation, that is, the retreat of the sea and the concomitant advance of the river-borne sands. As we have seen, some 30 or more miles to the northwest, there is evidence of erosion preceding the deposition of the basal grits, but there the basal grits are not the same as in this more southerly region but higher. For the lower beds in the latter evidently correspond to the erosion in the former, but not until much later, were the continental beds spread over the erosion surface. This looks like a transgression and over-lap of the Arenig beds and if these beds were purely marine, they would have to be so regarded. But since they are river plain deposits, this northwestward over-lap, represents a case of backward aggrading, brought about by stationary condition of the Old Land.

A characteristic feature of these basement sands is the appearance of thin striping due to shreds and lenticular wafers of argillaceous material, these sometimes curving around sandy lentils. They appear to be clay-galls, that is, thin curly masses of clay, formed by the drying of a film of mud, deposited in temporary bodies of stagnant water between dunes, and after complete drying and curling being carried by the wind into the sandy beds. (See Grabau. Principles of Stratigraphy p. 711).

The Lower Acid or Mynydd-y-Gader Rhyolitic Series. This series, which reaches a thickness of perhaps 800 ft, marks the beginning of volcanic activity, which we have seen everywhere accompanied and followed the retreating Arenig Sea in North Wales. It consists primarily of rhyolitic rocks, both ashes and flows. In the N. E. the ashes are most fully developed with a flow of rhyolite in their midst. There are also agglomerates with fragments of all sizes up to a foot in diameter. They are composed of rhyolite and vesicular rocks of more andesitic composition. As there are no andesites in the region, these must have come from some neighbouring source. Layers of grit, usually feldspathic, up to 6 ft. in thickness, but of very limited distribution, occur. Southeastward the ashes become thinner and are intercalated with beds of slate. The lower ashes consist of a variety of material all essentially acidic, the variation in texture being due to the amount of pumice dust and pyroclastic feldspar crystals.[1]

Trachitic or andesitic material is absent in the southwestern section, but the strata have been extensively invaded by later diabase intrusions which are generally sill-like in form.

Pont-King Slates. Of marked significance however are the interbedded Pont-King Slates, of which there are 2 prominent layers, thickest in the S. W. but thinning away entirely towards the N. E. They are separated by layers of rhyolitic ash, of which the upper slates contain also thin layers.

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1 See the detailed petrographic discriptions by Cox & Wells.

The slates and the ash form a normal stratigraphic sequence, and the series appears to be mostly river-laid on the occasionally flooded or marined coastal plain. The lower slate band has furnished numerous graptolites, the following being characteristic.

Didymograptus nitidus Hall
Didymograptus bifidus Hall (small form)
Climacograptus scharenbergi Lapworth

This is interpreted as representing the junctions of the *Didymograptus hirundo* and *Didymogratus bifidus* zones, that is the Arenig-Llanvirn boundary.

This places the lower ashes in the *Didymograptus hirundo* zone and the overlying China-stone ashes in the *D. bifidus* zone. The lower part of the Pont-King beds is correlated with the Hirundo beds of Mt. Arenig, i.e. the Moelyn slates, and the Crogenen slates with the Bifidus beds of Mt. Arenig.

The China-stone ashes, which form the top of the volcanic series, are so called because of their fine-grained or porcelain-like texture and the fact that they break with a smooth conchoidal fracture into sharp-edged chips. The color is bluish when fresh, but weathers white. They pass into coarser-textured, cream-coloured rhyolitic ash on the one hand and into normal slates on the other.

The Moelyn slates. These slates rest directly upon the ash beds, but range in thickness from 40-50 ft. in the Arthog Valley in the south-western part of the district, but up to 150 ft. on the slopes of the high sandstone ridge known as Bryn-Brith, a mile or two to the N. E. They are of a darker blue than the other slates and contain much pyrite. Because of the cleavage, fossils are not readily obtained. *Didymograptus bifidus* however has been obtained and so has *Orthoceras* cf.

caereesiense Hicks. These slates also die out towards the North-east.

The Bryn-brith slates. This group of ashy grits is the resistant rock which forms the high uniclinal ridge of Bryn Brith (1259 ft). The beds dip 60 to the S. E. and are conformable with the underlying beds. The thickness is about 150 ft, but in the lower part is an intercalated slate bed, with *Didymograptus bifidus*.

"The matrix of the main body of the rock consist of greenish-gray ashy or gritty particles of a medium degree of coarseness, the constituents having diameters up to one or two mm, the ashy or gritty particles are cemented in a thin paste of argillaceous material, which locally increases considerably in amount."

Upward in the series, there is an increased appearance of siliceous masses, which represent gradations "from dark rather hard, but otherwise normal slaty material to highly silicified rocks, which are harder than steel, possess a splintery fracture and are closely comparable in appearance, with the China-stone ashes at the top of the Lower Ashy Series."

These masses are sporadically distributed and range in size from less than a quarter of an inch to irregular lumps and lenticular masses from a foot thick, to 2 or 3 ft. long. Cox and Wells regard this series as a marine formation and think these ball-like masses due to the action of strong currents, but the formation of the deposits exhibits rather the character of a subaerial or coastal river-plain deposit and in my belief this is the prevailing nature of these rocks, the graptolites indicating intermittent flooding from the sea or marining.

Northeastward, where the slates have died out, the grits rest directly on the ashes of the Lower acid series, the two apparently grading into each other.

The Crogenen slates. These slates, which have a thickness of about 300 ft. are of the usual dark-blue pyritous character. Ashy material is present in scattered form or in beds of various thickness. These are the most fossiliferous beds of the section and evidently indicate a more pronounced submergence. As usual, graptolites are the most abundant, but a few specimens of trilobites have been found, one probably *Aeglina caliginosa*, the other *Trinucleus* sp. The graptolites comprise the following.

Didymograptus bifidus Hall
Didymograptus stabilis E. & W.
Didymograptus artus E. & W.
Didymograptus nanus Lapw.
Climacograptus sp.

The Cefn-hir Ashes. These higher volcanic ashes which form a series of about 300 ft. thick, consist of fine-grained andesitic beds in the lower part and coarser ashes in the upper, together with massive agglomerate beds, the fragments of which are rhyolitic to andesitic, with the material set in a fairly coarse ashy matrix. Some shale of the *Bifidus* type is intercalated below and on Cader Idris the upper beds, again more slaty, have yielded "a rather starved-looking *Didymograptus bifidus*."

The Lower Basic Volcanics. The higher ashes just described are followed by a great thickness of basic lavas, with various ashy and slaty intercalations and with numerous intrusions of basic material. Many of the lavas are typical spilites. The series is most typically developed on the northern slopes of Cader Idris but pillow-lavas and associated ashes can be seen at many places.

This is the great volcanic series, which marks the interval of exposure after the Arenig retreat, that is, the Cambrovician-Ordovician interval, and it was not until late Mid-Ordovician time that the sea returned to this section. A band of volcanic slates apparently of this series on Cader Idris, has yielded undeterminable graptolites apparently of Llandeilo age "The strata that immediately overlie the lavas probably belong to a high horizon in the Llandeilo." (*loc. cit. p.* 280)

Although the succession of the strata is a fairly regular and determinable one in the isoclinal ridges which face the Mawddoch Estuary, they are complicated by faults and especially by intrusions. Of the latter, the great granophyre intrusions are the most pronounced having prevailingly a sill-like or laccolitic character. Sills of diabase are abundant and occur at all horizons. They form an older intrusion than the acid series. From their field-relations, Cox and Wells conclude that the intrusions of the granophyres are closely related in time to the rhyolitic flows of the Upper Acid series on Cader Idris, which is the highest volcanic horizon of the district.......No igneous rocks, whether intrusive or extrusive occurring above this level, nor are there even any distinct ash-bands in the slates above the upper acid series". (*loc. cit.* p. 305)

The slates above the acid series are of the age of the upper *Dicranograptus* shales which are low down in the Bala Series.

From this Cox and Wells conclude that the age of the intrusions is at the very latest quite early in Bala time, and thus all the volcanic activities in this region as elsewhere in North Wales, seem to be concentrated in the interval preceding the return of the sea in late Middle

Ordovician time. The main acid mass of this region the Croganen granophyre, forms a laccolite over 1200 ft. in thickness.

South Wales

In his original descriptions of the rocks of the St. David's promontory in South Wales. Hicks confined himself largely to the Middle Cambrian deposits and these we have discussed on a previous page (vol. I p. 399 (*IV p. 595*)). He mentions however, the occurrence of Lingula flags. In a subsequent paper[1] he describes a group of formations, which overlie the Lingula flags and which are best exposed at Ramsay Island, off the St. David's promontory. These rocks he refers to the Tremadoc and describes a considerable fauna. The dominant form is the new trilobite genus *Neseuretus*, an early form of Calymenoid. *Lingula davisii* appears to be the only species represented in the older rocks, the others are all new. The original fauna described by Hicks comprise the following species.

Fauna of the Ramsay Island or Neseuretus Beds

TRILOBITA

Neseuretus ramseyensis Hicks
Neseuretus quadratus Hicks
Neseuretus recurvatus Hicks
Neseuretus elongatus Hicks
Neseuretus elongatutus var. *obesus* Hicks
Niobe meenapiensis Hicks

1 Hicks, Henry. On the Tremadoc rocks in the neighbourhood of St. David's, South Wales and their fossil contents. Quarterly Journal of the Geological Society of London. Vol. XXIX. 1873, pp. 39-52, Pl. 3-5.

Niobe solvensis Hicks

ECHINODERMATA

Palasterina ramseyensis Hicks
Dendrocrinus cambriensis Hicks

CEPHALOPODA

Orthoceras sp. Hicks

GASTROPODA etc.

Theca (*Hyolithes*) *davidii* Hicks
Bellerophon ramseyensis Hicks
Bellerophon solvensis Hicks

PELECYPODA

Ctenodonta menapiensis Hicks
Ctenodonta cambriensis Hicks
Palæarca hopkinsoni Hicks
Palæarca oboloidea Hicks
Glyptarca primaeva Hicks
Glyptarca lobleyi Hicks
Davidia ornata Hicks
Davidia plana Hicks
Modiolopsis ramseyensis Hicks
Modiolopsis homfrayi Hicks
Modiolopsis solvensis Hicks
Modiolopsis cambriensis Hicks

BRACHOPODA

Lingulella davisii M'Coy
Lingula petalon Hicks
Obolella plicata Hicks
Orthis carausii Salter
Orthis menapiae Hicks

TRAILS

Eophyton explanatum Hicks.

This fauna has since been shown to be a Lower Arenig fauna and the rocks thought by Hicks to rest conformably on the Lingula flags are now known to be in fault contact with them. This fault cuts out the true Tremadoc series. Fearnsides, as we have already noted, believes this horizon is represented in North Wales, by the Frwent or *Ogygia* limestone, which lies some 300-400 ft. above the basal grit and just above the *Didymograptus extensus* beds and below the *Didymograptus hirundo* beds. Dr. Cox on the other hand regards these beds as equivalent to his Abercastle and Port Gain Beds which underlie the *Tetragraptus* or *D. extensus* beds. (See below).

The entire Upper Cambrian of the St. David's region is referred by Hicks to the Lingula flags, which overlie the Menevian with apparent conformity with a thickness of about 2000 ft. It consists of alternating beds of sandstones and shales and occasional thick bands of slates, and in some sections *Lingulella davisii* is abundant and characteristic. The series represents a very even deposit throughout, without abrupt changes in the character of the rock, and other fossils seem to be absent. This suggests that they are in large measure river deposits, with occasional incursions of the sea, which left behind the Linguloid shells. Apparently, these fossiliferous beds represent the Ffestiniog of North Wales, while the Maentwrog beds may be represented by the lower part, though the fossils have not been obtained. The Dolgelly series on the other hand, seems to have been cut out by the fault, which brought the lower Arenig *Neseuretus* beds in contact with the Lingula flags.

These *Neseuretus* or Ramsay Island beds, consist of less than 1000 ft. of dark earthy flags and flaggy sandstones, with some iron-stained slates at the top, and they contain the rich fauna already listed. They are succeeded, with apparent conformity by black slates, which Hicks originally regarded as Lower Arenig.[1] From their original locality, Road Uchaf on Ramsay Island, we shall refer to them here as *Roaduchaf Beds.*

These beds are especially characterized by graptolites. The following have been described from them by Hopkinson and Lapworth.[2]

Didymograptus extensus Hall
Didymograptus pennatulus Hall
Didymograptus sparsus Hopk.
Phyllograptus stella Hopkinson
Trigonograptus ensiformis Hall
Trigonograptus truncatus Lapworth
Ptilograptus cristula Hopkinson
Ptilograptus hicksi Hopkinson
Dendrograptus arbusculus Hopkinson
Dendrograptus diffusus Hall
Dendrograptus divergens Hall
Dendrograptus flexuosus Hall
Dendrograptus flexuosus recurvus Hopkinson
Callograptus radiatus Hopkinson

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1 Henry Hicks. On the succession of the ancient rocks, in the vicinity of St. David's Pembrokeshire, with special reference to those of the Arenig and Llandeilo groups and their fossil contents. Quarterly Journ. of Geol. Soc. of London Vol. XXXI, 1875, pp. 167-195, with Geol. map and section and 3 plates of fossils (pls. VIII-XI)

2 Hopkinson, John, and Lapworth, Charles. Descriptions of the graptolites of the Arenig and Llandeilo Rocks of St. David's. Quart. Journ. of the Geol. Soc. of London. Vol. XXXI, 1875, pp. 631-672. pls. XXXIII-XXXVII.

Callograptus radicans Hopkinson
Dictyograptus homfrayi Hopkinson

With the exception of the *Phyllograptus*, of which only one specimen was found, Dr. Elles cites the same fauna. She adds *Didymograptus gibberulus* and she holds that this division represents the upper part of the *D. extensus* zone and the lower part of the *D. hirundo* zone.

Other fossils found in this series are
Trinucleus sedgwicki
Conularia homfrayi Salter
Lingula petalon Hicks
Lingulella davisii M'Coy
Obolella plicata Hicks.

Hicks regarded this series as a deep sea deposit, partly because of the fine character of the sediments, and partly because of the abundance of graptolites, but like all other graptolite shales, they are probably near-shore, partly lagoonal mud-deposits, if not actually in part at least, subaërial mud deposits submerged at intervals. Beds identified by Hicks as representing the same series occur in the creek north of Trwynhwrddyn, Whitesand Bay. These have furnished:

TRILOBITA
Asaphellus homfrayi Salt.
Ogygia scutatrix Salt.
Trinucleus sp.

BRACHIOPODA
Lingulella davisii M'Coy
Lingula petalon Hicks
Orthis (*Orusia*) *lenticularis* Dalm.
Obolella plicata Hicks

CONULARIDA

Conularia homfrayi Hicks

GRAPTOZOA (Hopkins. & Lapworth col. 1)

Dendrograptus arbusculus Hopk.
Dendrograptus persculptus Hopk.
Callograptus radiatus Hopk.
Callograptus radicans Hopk.
Dictyograptus cancellatus Hopk.

A second series of sediments is exposed at Whitesand Bay on the northwestern end of the St. David's promontory. These comprise the more flaggy series some 1500 ft. in thickness, and were thought by Hicks, to rest conformably upon beds referred to the Ramsay Island Series.

These flaggy beds which will here be referred to as Whitesand Bay beds have yielded a number of trilobites, most numerous among which are the following.

Fauna of the Whitesand Bay Beds.

TRILOBITA

Aeglina boia Hicks
Aeglina grandis Salter
Agnostus hirundo Salter
Ampyx salteri Hicks
Ogygia bullina Salter
Ogygia peltata Salter
Trinucleus gibbsi Salter
Trinucleus sedgwicki Salter

BRACHIOPODA

Lingula petalon Hicks
Orthis sp.
Siphonotreta sp.

GASTROPODA ETC.

Hyolithes harknessi (Hicks)
Bellerophon multistriatus Salter

CEPHALOPODA

Orthoceras sericeum Salter

Hopkinson and Lapworth have described the following graptolites from these beds (loc. cit. table, Col. 3)

Graptolites of Whitesand Bay Beds

Didymograptus patulus Hall
Tetragraptus quadribrachiatus Hall
Tetragraptus halli Hopkinson
Tetragraptus (*Azygograptus*) *hicksi* Hopkinson
Tetragraptus sera Brongniart
Clematograptus implicatus Hopkinson
Dendrograptus arbusculus Hopkinson
Dendrograptus flexuosus Hall
Callograptus elegans Hall
Callograptus salteri Hall
Dictyograptus irregularis Hall

Hicks referred these beds to the middle Arenig, believing them to overlie his lower Arenig of Ramsay Island. Dr. Elles however, who obtained almost the same fauna (with addition of *Tetragraptus amii* Lapworth) from these rocks at Whitesand Bay and Porth Llenog, considers them to indicate a horizon considerably below that of the Ramsay Island shales, and she places them in the lower part of the zone of *Didymograptus extensus*. The strata are all highly inclined, and carry the graptolites chiefly in the lower, and the trilobites in the higher portion. According to Dr. Elles, the underlying shales, which Hicks thought to be the equivalent of the Ramsay Island shales, are therefore still older than the Lower *D. extensus* zone.

Hicks describes a third series of rocks which he refers to the Upper Arenig. They resemble the Ramsay Island Beds, being like them, fine-grained dark slates and shales, with a thickness of nearly 1500 ft. They are well exposed along the north coast, resting on beds of "Middle Arenig" and underlying the middle Llandeilo. These beds are well exposed in the Llanvirn slate quarry on Abereiddy Bay, north coast of the St. David's peninsula, and they constitute the typical lower Llanvirn division of Hicks or the zone with *Didymograptus bifidus*. We will refer to them here as Abereiddy Beds. The species recorded from the beds of this quarry are the following.

Fauna of the Lower Llanvirn or Abereiddy Beds.

TRILOBITA

Aeglina obtusicaudata Hicks
Barrandea homfrayi Hicks.
Calymene hopkinsoni Hicks
Illænus hughesi Hicks
Illænopsis? acuticaudata Hicks
Placoparia cambriensis Hicks
Phacops llanvirnensis Hicks
Trinucleus ramsayi Hicks

OSTRACODA

Beyrichia sp.

BRACHIOPODA

Dinobolus? hicksi Davidson
Discina sp.
Orthis sp.

GASTROPODA ETC.

Ophileta sp.
Pleurotomaria llanvirnensis Hicks
Bellerophon llanvirnensis Hicks

Hyolithes (*Theca*) *caereesiensis* (Hicks)
Conularia llanrianensis Hicks

CEPHALOPODA

Orthoceras caereesiense Hicks

GRAPTOZOA (Hopkinson & Lapworth table Col 5)

Didymograptus bifidus Hall
Didymograptus nanus Lapworth
Didymograptus nicholsoni Lapworth
Didymograptus patulus Hall
Nemagraptus capillaris Emm.
Dicellograptus moffatensis Carruthers
Diplograptus dentatus Brongniart
Glossograptus ciliatus Emm.
Climacograptus confertus Lapworth[1]

Beds considered of the same age were found at Porthhayog Ramsay Island. These have furnished the following.

Fauna of the Porthhayog Beds of Ramsay Island, S. Wales

TRILOBITA

Calymene parvifrons Salter var. *murchisoni* Salter
Trinucleus etheridgii Hicks

BRACHIOPODA

Lingula attenuata Sowerby

GRAPTOZOA (Hopk. and Lapw. table Col. 6)

Didymograptus affinis Nicholson
Didymograptus bifidus Hall
Didymograptus furcillatus Lapworth
Didymograptus indentatus Hall
Climacograptus confertus Lapworth
Diplograptus dentatus Brongn

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1 Recorded by Cox

With the exception of the last one and of *D. bifidus*, all the species of Porth-hayog are distinct from those of the Llanvirn quarry and may belong to a somewhat different horizon[1]

According to Elles, (*loc. cit.* page 208) "the relation of the lowest Llandeilo beds forming the zone of *D. murchisoni*, to the uppermost Arenig slates is particularly clear.........At the extreme south end of Abereiddy Bay, a series of much cleaved black slates, dipping a few degrees W. of N. is seen crowded with *Didymograptus murchisoni*; ascending the cliff, a well-marked band of feldspathic ash separates these black slates from an underlying series of lighter-coloured slates." These latter are the *D. bifidus* beds of the Llanvirn quarry as described by Hicks. Dr. Elles cites in addition to the species above listed from this quarry:

Didymograptus euodus Lapworth and
Cryptograptus tricornis Carruthers

The presence of the ash-bed is noteworthy, occupying as it does, the inferred Arenig-Llandeilo hiatus and representing the volcanics at this horizon in the Arenig region and

1 In their list of graptolites Lapworth and Hopkinson give only *Didymograptus bifidus* and *Diplograptus dentatus* as occurring in both localities. (*Loc. cit.* page 635 table Cols. 5-6) In his preliminary list however (p. 177) Hicks also cites as common to both,

Didymograptus affinis Nicholson
Didymograptus indentus Hall
Didymograptus patulus Hall, besides the two species noted by Hopkinson and Lapworth.

The list given by these latter authors is probably the more complete.

the pisolitic iron-ore of St. Tudwal's. Of this dividing tuff bed, Hicks says (*loc. cit.* Vol. 31, p. 178) "The thickest one [of several tuff beds in the series] which occurs directly at the base of the series is in part a conglomerate, but its upper portion has been pulverized and rearranged by the action of water and made to assume a flaggy appearance." *Didymograptus murchisoni* and *Diplograptus foliaceus* occur here most plentifully and in well-preserved state. Other fossils found in these beds are[1]

Upper Llanvirn Fauna (Chiefly after Hicks.)

TRILOBATA

Trinucleus ramsayi Hicks
Calymene murchisoni? Salter
Ogygia sp.
Aeglina sp.

BRACHIOPODA

Lingula attenuata Sowerby
Siphonatreta sp.

GASTROPODA ETC.

Bellerophon perturbatas Sowerby
Hyolithes caereesiensis Hicks

GRAPTOZOA

Didymograptus mnrchisoni Boeck
Didymograptus murchisoni var. *geminus* (Hisinger)
Didymograptus murchisoni furcillatus
Diplograptus foliaceus Murchison
Orthograptus calcaratus var. *priscus* Elles & Wood
Cryptograptus tricornis Carruthers
Ptilograptus acutus Hopkinson
Dendrograptus serpens Hopkinson

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1 Hick's *loc. cit.* p. 179, See also Cox. Q. J. G. S. Vol, 71, p. 304.

Dendrograptus ramsayi Hopkinson
Dictyonema sp.
Nemagraptus sp.
Climacograptus cœlatus Lapworth

This is a typical upper Llandvirn or Lower Llandeilan fauna, and its complete distinctness from the faunas of the lower beds is evident. These beds are about 100 feet thick.

The higher Llandeilo beds of this region will be more fully considered in a subsequent article.

The coastal region of Pembrokeshire farther northeast, that is between Abereiddy Bay and Abercastle, has been made the subject of a separate memoir by Dr. Arthur H. Cox.[1]

In the more northeasterly portion of this region, the rocks are strongly disturbed by folds and numerous faults, but from a point near Llanvirn to Traeth Llyfn, the dip though steep, is fairly constant, and faults occur only beyond Abereiddy.

The succession here is as follows in descending order:

LLANDEILAN SERIES	
Dicranograptus Beds	
Castell limestone (Mydrim limestone)	50 ft.
Dicranograptus shales	300
Upper Llanvirn	
Didymograptus murchisoni shales	100
Murchisoni ash and Llanrian Volcanic Series	400-500 ft.

1 Arthur Hubert Cox. The Geology of the district between Abereiddy and Abercastle, Pembrokeshire. Quart. Journ. of the Geological Soc. of London. Vol. LXXI, 1917, p. 273 to 342, with Geological map and sections and photographic plates.

Probable hiatus and Disconformity

ARENIGIAN	
Lower Llanvirn	
Didymograptus bifidus beds	800-1000 ft.
Arenig (*sens. strict.*)	
Tetragraptus shales	700-1000 ft.
Porth Gain Beds	120 ft.
Abercastle Beds	120 ft.

Hiatus and Fault contact

UPPER CAMBRIAN	
Ffestiniog	
Lingula Flags (exposed part)	500 ft.

The *Lingula* flags are always isolated by faults, and only 500 ft. are exposed. This appears to represent the upper part, if we may judge by comparison with the North Wales section. The group consists of alternations of argillaceous and siliceous beds, the former metamorphosed into slabby and highly micaceous green slates, the latter into laminated white or gray, fine-grained quartzites and feldspathic grits. These grits are very numerous and range in thickness from less than an inch up to one or two feet. Individual beds may show great and rapid variation in thickness and the contortion characteristic of the beds in North Wales, and probably due to gliding deformation, usually accompanies such variation. At certain levels, the siliceous beds or "ringers" have a lenticular character, dying out laterally. Locally the sandy material of these beds may increase in coarseness and even become pebbly, the pebbles reaching a diameter of 2 inches. Such pebbly layers range in thickness up to 6 inches.

These beds have thus the ear-marks of river plain (huangho) deposits, which, towards the close of Ffestiniog time, suffered a certain amount of submergence or periodic flooding, thus spreading the shells of *Lingulella davisii*, the only fossil in these beds. This brachioped "is abundant at several localities and is especially common in some of the regularly laminated quarzitic bands. The shells are frequently found in a comminuted condition, as though broken up by current action." This characteristic of the deposits, indicates rather repeated exposure of the shell-strewn sands to the influence of the weather.

The Abercastle Beds. These and the succeeding Porth-Gain Beds, were in the early days referred to the Tremadoc, and it is from these as exposed on Ramsay Island, that Hicks obtained his early molluscan fauna. (See *ante*) The Abercastle beds consist of a series of hard sands and gray-blue mud-stones, with streaks and patches of dark-blue argillaceous material. They contain numerous large lenticular concretions of the same material as the beds, and some of the weathered concretions are represented by patches of limonite. *Ogygia selwyni* Salter is represented in many of the beds by fragments of various sizes, as a rule highly distorted by cleavage. Some specimens even so, measure four inches across. Other beds have furnished fragments of *Trinucleus sedgwicki* and *Orthoceras*. The thickness of 120 ft. is estimated from the section.

The Porth-Gain Beds. These consist of a lower portion of micaceous sandy mudstones or hard arenaceous slates, about 60 ft. thick, followed by a similar thickness of a coarse feldspathic grit into which they grade and which in turn grade upwards into the *Tetragraptus* shales. The grit sometimes contains small pebbles and occasional shaly intercalations up to 2 or 3 inches in thickness.

Feldspar, especially orthoclase, is more abundant than the quartz grains, and most of it is very fresh. Recrystallized rhyolite and rhyolite-tuff fragments are very abundant, while grains of trachytic or andesitic rock are less common. Cox thinks that "these igneous grains were probably derived from the pre-Cambrian (Pebidian) rocks, while some of the mudstone-grains may well have come from the *Lingula* flags. The various grains are embedded in an abundant paste of chlorite in which sericite has been largely developed". (*loc. cit*, p. 285)

The fossils of the Porth Gain, Beds include:

Orthis proava Salter.
Orthis menapiæ Hicks
Lingula sp.
**Orthoceras* sp.
**Trinucleus sedgwicki* Salter
Dendrocrinus cambrensis Hick
Callograptus sp.

The Tetragraptus Shales. These comprise the lower and middle Arenig of Hick's classification. They consist of a series of blue-black cleaved mud-stones and slates with occasional thin bands of ash or ashy shales, these becoming prominent in the upper portion. They succeed the Porth-Gain beds conformably and pass upward conformably with scarcely any perceptible lithological change, into the *Didymograptus bifidus* shales. In the lower part of the series, small dark phosphatic concretions are very abundant. These contain on an Average 4.7 per cent of P_2O_5. They are oval because of crushing and usually about half an inch long, but others up to 2 or 3 inches in diameter are occasionally found. They are sometimes formed around a

* Occur also in Abercastle beds

trilobite. Concretions of chalybite (siderite) up to 6 inches in diameter also occur sometimes. These are usually sharply differentiated from the surrounding slates. In the lowest beds *Trinucleus* cf. *sedgwicki* and *Ogygia selwini* are found, while the higher beds have yielded numerous specimens of *Didymograptus nitidus* Hall and *D.* cf. *extensus*. Elsewhere *Didymograptus* cf. *sparsus* and badly preserved extensiform graptolites have been found.

Lower Llanvirn or Abereiddy beds, or Didymograptus bifidus beds. These are the upper Arenig Beds of Hick's 1875 classification. They consist predominantly of gritty ashy and slaggy beds in the lower portion and of bluish slates and mud-stones in the upper. They succeed the *Tetragraptus* shales without any break and "in the absence of fossils therefore, it becomes almost impossible to draw any exact boundary line between the two groups." (*Loc. cit.* page 293.)

In general the Bifidus or Abereiddy slates are darker than those of the *Tetragraptus* or Whitesand-Bay beds and frequently more like mudstones in appearance. They are often highly pyritous. The ashy beds are mostly blue ashy and flaggy slates, weathering red and resembling those of the *Tetragraptus* group near the top. The fossils have already been recorded (*ante* page 65-66).

The highest beds of the zone, underlying the Abereiddy ash, yield abundant examples of:

Didymograptus bifidus Hall
Didymograptus stabilis Elles and Wood
Didymograptus artus Elles and Wood
Climacograptus sp.

These beds again appear in the large quarry on the north side of Abereiddy Bay. Here they have been faulted down against the Castell Limestone which overlies the *Dicranograptus* shales of the Llandeilo. According to Cox, these are the beds described by Hicks in 1875 as Upper Llandeilo. Hicks did not observe the fault and assumed the beds to form a continuous series, normally overlying the *Dicranograptus* beds. These upper Bifidus beds, of which about 250 ft. are exposed beyond the fault, are again seen to underlie the Llanrian volcanic series. From the upper portion Cox has obtained the following species. (1917, p. 295.)

Didymograptus bifidus (Hall)
Didymograptus geminus (Hisinger)
Didymograptus nanus Lapworth
Didymograptus stabilis Elles & Wood
Didymograptus artus Elles & Wood
Glossograptus cf. *hincksi* Hopkinson, and the trilobite
Ogygia buchi (Brongniart)

In the lower part of this exposed series that is about 250 ft. below the volcanic series, a considerable trilobite fauna has been found, which was listed by Hicks (1875, p. 180) as characteristic of the upper Llandeilo, but according to Cox is in the repeated series of the Bifidus shales. Cox records the following as found by him in these trilobite beds

(For Hick's list see Table A-II Column 19)

Ogygia buchi (Brongniart)
Calymene sp.
Barrandia sp.
Orthoceras sp.
Conularia cf. *homfrayi* (Salter)
Bellerophon perturbatus (Sowerby)
Monobolina plumbea (Salter)

The presence of *Ogygia buchi* in beds below, and in close association with, *Didymograptus bifidus* opens up a rather interesting question. *Ogygia buchi* is commonly considered a characteristic trilobite of the Llandeilan, while *Ogygia selwini*, a much narrower form, is characteristic of the Lower Arenig. *O. selwini* differs from other species of the genus, in having the head and pygidium of similar length, the genal spines short and stout, and the marginal rim of the pygidium broad and indistinctly marked off from the rest of the pygidium, while the lateral grooves of the limb do not extend to the margin. *Ogygia buchi* on the other hand is much broader, with the head shorter than the pygidium and the latter more strongly grooved. It would seem desirable that a closer study be made of these trilobites from the Bifidus beds and to make certain of their absolute identity with typical *Ogygia buchi*.

Cox concludes "That the advent of the Llanrian volcanic conditions did not immediately affect the *D. bifidus* fauna, as the graptolites are still abundant in the shales of the Llanrian lavas" He finds this in agreement with conditions observed by Lapworth and Watts[1] among the Hope shales and Stapeley ashes of Shropshire.

If, as I believe, these later Arenig beds mark the progress of retreat of the sea from the Old Land, with the volcanicity taking the place of the usual interpulsation tectonic disturbances it is easy to understand that occasionally floating graptolites may still be washed ashore and embedded in sediments overlying the early volcanic flows. In that case, there is no reason for considering

1 C. Lapworth and W. W. Watts. The geology of South Shropshire. Proceedings of the Geologists Association, Vol. XIII, 1894, p. 317. (See also this volume, *postea*.)

such flows as submarine outpourings, unless indeed the character of the lava itself shows such an origin.

These lava flows, in the region under consideration, are ryholites and usually rather thin, while they appear not to have a very great lateral extension. As there are several such flows, they cannot always be correlated, through sometimes they are superposed one upon the other, giving rise to a considerable thickness of igneous rocks.

"The lavas are non-vesicular and non-porphyritic while nodular spherulitic and perlitic structures are entirely absent. Xenoliths of slightly hardened shale, may be occasionally observed." (Cox 1917 page 303). These extrusive rocks are associated with a considerable amount of pyroclastic material, chiefly in the form of fine-grained tuffs. The lowest of these ash beds is commonly known as the *Didymograptus murchisoni* ash, following abruptly upon the fossiliferous *D. bifidus* shale. These ashes, which are about 150 ft. thick are largely composed of pumiceous lapilli, but there are also present shale fragments measuring up to 3 inches in diameter.

These ashes are so called, because in their upper pulverized and rearranged portion, *Didymograptus murchisoni* and *Diplograptus foliaceous* are found in abundance in the Abereiddy region.

There is nothing inconsistent in this occurrence with the assumption that the main period of volcanic activity occurred between the emergence of the region on the retreat of the Lower Ordovician Sea and the readvance of the Middle Ordovician Sea. The latter would then rework the upper portion of the volcanic ashes, and leave its organic remains in these reworked pyroclastics. Of course, if we regard the series as a continuous and uninterrupted one, as the British succession taken by itself would lead one to assume, and especially if one believes that graptolites are deposited only in deep water, one is forced naturally to regard these flows and ash beds as sub-marine deposits. Freed from these predispositions however, it seems apparent that all of these sections perfectly harmonize with the general progress of palæogeographic development recognized in the Lower and Middle Ordovician in widely separated regions of the earth.

The Ynys-Castell Ashes. There is another formation which is interesting in this connection and that is the Ynys-Castell series of ashes and grits. These appear in the headlands some 4 miles east of Abereiddy Bay. They begin with a basal grit or breccia, which rests apparently with a disconformity on the *Tetragraptus* shales. The contact is a sharp one and not due to faulting, as exposed at Ynys-Castell Headland. The bed is gritty and conglomeritic, consisting of fragments, varying from sand grains up to blocks 18 inches or more in length, embedded in abundant argillaceous matrix. The largest pebbles consist of hard feldspathic mud-stones, apparently derived from Cambrian rocks. Fragments of dark-blue shales or mudstones, impure feldspathic grits or graywackes, cherts?, cherty sandstone, and less commonly, a trachytic rock, are among the other consituents of this conglomerate, while the finer grains consist of more or less angular quartz fragments and feldspars of various kinds. This basal grit is about 18 ft. in thickness and is of limited horizontal extent and it has been thought that it might be of volcanic origin.

The basal grit passes up into a series of fine-grained silicified ash rock, of bluish green colour, splintery conchoidal fracture and semi-vitreous lustre. Many of the beds are massive from 4 to 6 ft. in thickness, but others attain only a few inches. The maximum thickness has been estimated at 200 ft. and they are succeeded by mud-stones, often highly pyritous, and well exposed at Castell-Coch after which locality they were formerly named. Their thickness is about 200 ft. and they are often capped by a diabase sill.

No fossils have been obtained from these beds, but from their position they have been referred to the *Didymograptus bifidus* beds, which elsewhere have furnished similar pyroclastic rocks. It is quite probable that they represent the continental or emergent phase of the later Arenig emergence, and have furnished some of the material for old delta surfaces, in which some of the stranded *Didymograptus bifidus* types were enclosed.

It is thus seen that the effect of the retreating Cambrovician Sea became apparent in the St. David's region of South Wales, during the period of deposition of the Porth-Gain Beds, more marked during the deposition of the *Tetragraptus* shales and that the region became all but free from marine invasions in the Lower Llanvirn or period of *Didymograptus bifidus*, although occasional individuals of this species were sometimes cast ashore here and there. As we shall see presently in western Ireland, more than 200 miles to the northwest, the retreat of the sea began during the period of the *Tetragraptus* or late *Didymograptus extensus* period though an occasional member of the *D. hirundo* group was still cast ashore. In both cases, the series is followed by volcanic rocks. In both cases too, the emergent phase is represented by pyroclastics and in the more western region by volcanic flows[1] Ordovician rocks form a belt through the center of Caermarthenshire (the county next east to Pembrokeshire in Wales) both west and east of Llandeilo, and throughout the northeasterly region they are in contact with the early Silurian rocks. The Cambrian rocks however, are not exposed in this district, the series beginning with the Arenig. The Ordovician rocks of western Caermarthenshire were studied and mapped by Evans, and those of the more easterly region by Cantrill and Thomas.[2]

In western Caermarthenshire the central belt of the Ordovician is formed by the *Tetragraptus* shales, flanked on either side by beds of Llanvirn age, beyond which occur the Llandeilo and still further north and south respectively the Bala Beds. Thus the general structure is that of an east-west extending eroded anticline, but this is complicated by minor folds and many faults. The amount of folding and thrusting has been such that according to Evans "points that are now within 3 miles of one another were, previous to the movement 4 or 5 times that distance apart." This is emphasized by the fact that corresponding formations on the north and south side of the main

1 For detailed discussion of the petrographic characters of these igneous rocks see, James Vincent Elsten. On the Igneous rocks occurring between St. David's Head and Strumble Head, Pembrokeshire. Quarterly Journal of the Geol. Soc. of London Vol. LXI, 1905, pp. 579-607. Map, 2 plates.

2 David Cledlyn Evans. The Ordovician rocks of western Caermarthenshire. Quart. Journ. of Geol. Soc. of London. Vol. LXII, 1906, pp. 597-643 with a geological map.
Thomas C. Cantrill and Herbert H. Thomas. On the igneous and associated sedimentary rocks of Llangynog (Caermarthenshire). *ibid.* p. 223-252, with maps and plates of rock sections.

anticline differ markedly not only in their lithological characters but in their faunas as well, as shown by the following two sections given by Evans.

SECTION I. Succession of Rocks on the Northern Limb of the Caermarthen anticline.

V. *Bala-Caradoc*

- b. Brown-gray mud-stones, shales and grits
- a. Black-slaty beds with *Dicranograptus*

IV. *Llandeilo*

B. *Dicranograptus beds*

- c. Ashy-black shales, with lenticular bands of limestone containing *Dicranograptus*, *Leptograptus* etc.
- b. Black shales and mud-stones, weathering buff and yellow, containing graptolites and trilobites.
- a. Black shales with crowds of *Diplograptus* and shells.

A. *Asaphus tyrannus beds*

- a. Ashy beds and sandy flags, with *Asaphus tyrannus* etc.

III. *Upper Llanvirn*

A. *Didymograptus murchisoni beds*

- c. Striped gritty flags, with abundance of *Didymograptus murchisoni*
- b. Blue-gray ash, weathering rusty-brown.
- a. Soft sandstone with crowds of *Didymograptus murchisoni*

Probable Hiatus & Disconformity

II. *Lower Llanvirn*

A. *Didymograptus bifidus beds.*

a. Shales, mud-stones and bands of ash, with graptolites and trilobites.

I *Arenig*

A. *Tetragraptus Beds*

g. Blue-black shales and mud-stones, containing *Tetragraptus* and trilobites

f. Striped flaggy shales with *Ogygia marginata* etc.

e. Gritty beds, with *Dictyograptus* and *Dendrograptus*.

d. *Orthis* mud-stones

c. Grits and conglomerates with *Orthis* and trilobites

b. Black, ashy shales, with local bands of blue ash.

a. Blue-black shales, with few fossils.

(Lower Beds not exposed)

SECTION II. Shows the succession of formations in the southern limb of the Caermarthenshire anticline.

VI. LOWER LLANDOVERY

b. Gray sandstones and flags with dark mudstone partings, very few fossils.

a. Gray grit and conglomerate.

Probable Hiatus & Disconformity

V. BALA CARADOC.

D. Slade Beds

a. Blue-gray mud-stones, with bands of shelly limestone usually rotten.

C. Redhill Beds.

a. Blue-gray sandstone, with trilobites and brachiopods (*Trinucleus seticornis* etc.)

B. Sholeshook Beds
  a. Arenaceous limestone with many fossils
A. Robeston-Wathen limestone.
  a. Black limestone with calcareous shale partings

IV. Llandeilo
B. *Dicranograptus shales*
  a. Black shales with graptolites etc.
A. *Asaphus tyrannus* limestone
  a. Black limestone with *Asaphus tyrannus* and *Ogygia buchi*

III. Upper Llanvirn
A. *Didymograptus murchisoni Beds*
  a. Black mudstones with *Didymograptus murchisoni?*

Probable Hiatus & Disconformity

II. Lower Llanvirn
A. *Didymograptus bifidus Beds*
  a. Black shales and mud-stones, with bands of ash and containing *Didymograptus bifidus* etc.

I. Arenig
A. *Tetragraptus Beds* (as in Table I)

The higher beds of this series will be discussed in another article. We are here concerned with the Arenig and Llanvirn.

The Arenig.

IA. a. In the eastern part of the area, these beds are mostly shales and the region is more deeply eroded. In the western half, which is nearer to the Old Land, there is a considerable development of grits and conglomerates and the ground is more hilly.

The lowest beds are black iron-stained mud-stones, in which fossils are so rare, that their precise age has not been determined. In the absence of sufficient proof to the contrary, they are placed at the base of the *Didymograptus extensus* zone. A few trilobites, belonging to the genera *Aeglina*? and *Trinucleus* and specimens of *Orthoceras* have been found. Fragments of a *Caryocaris*, trails, and *Orthis carausii* Salter, have also been found associated with graptolite fragments.

IA. b. *Ashy mud-stones etc.* The black shales of the preceding series pass into beds of coarser texture and take on the character of ashy mudstones and finally of gritty beds. They are sparingly fossiliferous, though in some beds *Orthis carausii* Salter is fairly numerous. A few fragments of dendroid graptolites have also been obtained and there are several bands of igneous rocks.

IA. c. *Grits with Orthis and trilobites.* Grits of variable character and thickness, ashy in some localities, conglomeratic in others with *Ogygia marginata* Crosf. and Skeat and *Orthis carausii* (Salter). Other species are *Trinucleus* cf. *sedgwicki* Salter, and *Orthis menapiæ* Hicks. Besides these, fragments of *Dendrograptus* were obtained.

IA. d. *Orthis mudstone* and IA. *e*. *Dictyograptus Beds.* The gritty black mud-stones abound in *Orthis carausii* Salter. Some beds are crowded with graptolites and the following have been recorded.

Callograptus radiatus Hopk.
Callograptus salteri Hall
Callograptus salteri var *attenuatus* Elles (Ms.)

Dictyograptus homfrayi Hopk.
Clematograptus implicatus Hopk.
Dendrograptus flexuosus Hall
Orthis carausii Salter
Lingula sp.

Among trilobites *Ogygia marginata* Crosfield and Skeat and *Trinucleus* sp. may be mentioned. The first species is characteristic of the overlying flaggy beds.

IAf. *Ogygia selwini beds* These contain:

Ogygia marginata C. & S. var.
Ogygia selwini Salter
Orthis carausii Salter
Orthis menapiæ? Hicks
Callograptus salteri attenuatus Elles

Ogygia selwini stamps this fauna as Lower Arenig.

IA. g. *Tetragraptus beds.* The *Ogygia marginata* beds pass upwards into the *Tetragraptus* shales, characterized by *Tetragraptus quadribrachiatus*, *T. headi* Hall, and *Didymograptus extensus*. These are normal graptolite shales, consisting of blue-gray mud-stones and darker shales with graptolites. The graptolites include the followiug species.

Dendrograptus extensus Hall
Didymograptus nitidus Hall
Didymograptus patulus Hall
Didymograptus sparsus Hopk.
Tetragraptus headi Hall
Tetragraptus amii Lapworth
Tetragraptus serra Brongn.
Tetragraptus bigsbyi Hall
Tetragraptus quadribrachiatus Hall
Callograptus salteri Hall

Callograptus persculptus Hall

The trilobites include:

Aeglina binodosa Salter
Trinucleus sedgwicki Salter

Orthis calligramma has also been reported from these beds, but this is probably only a broad identification.

Zone of D. hirundo. East of the river Fenni, a somewhat higher graptolite zone, that of *Didymograptus hirundo* appears with

Didymograptus extensus Hall
Didymograptus nitidus Hall
Didymograptus patulus Hall
Didymograptus sparsus Hopk.
Didymograptus hirundo Salter
Tetragraptus serra Brongn.
Tetragraptus amii Lapw.
Tetragraptus bigsbii Hall
Callograptus salteri Hall
Dendrograptus persculptus Hopk.
Dendrograptus flexuosus Hall
Ptylograptus hicksi Hopk.
Dictyograptus cf. *cancellatus* Hopk.

Also with these

Aeglina caliginosa
Trinucleus cf. *sedgwicki* Salter
Asaphus sp,

and species of *Orthis*, *Lingula*, *Obolella* and *Siphonotreta*. Also *Conularia*, *Hyolithes*, *Orthoceras* cf. *sericeum* Salter and *Caryocaris*.

D. bifidus Beds. Beds with *Didymograptus bifidus* on the other hand are well developed on the southern limb of the anticline, where perhaps 900 ft.[1] of shales, thin grits, and ash-beds are seen between two faults. From these beds have been obtained

GRAPTOZOA

Didymograptus bifidus Hall
Didymograptus euodus? Lapw.
Didymograptus nicholsoni Lapw.
Didymograptus nicholsoni planus Elles & Wood
Didymograptus indentus Hall.
Didymograptus affinis Nicholson
Didymograptus acutidens Lapw.
Didimograptus geminus Hisinger[2]
Phyllograptus typus Hall
Phyllograptus anna Hall
Diplograptus dentatus Brongn.
Climacograptus teretiusculus Hisinger
Climacograptus confertus Lapw.

TRILOBITA

Agnostus mccoyi Salter
Aeglina binodosa Salter
Calymene parvifrons Salter
Placoparia cambriensis Hicks
Illænus hughesi Hicks
Phacops llanvirnensis Hicks
Trinucleus cf. *etheridgii* Hicks
Trinucleus cf. *murchisoni* Salter
Barrandea homfrayi Hicks

MOLLUSCA

Bellerophon multistriatus? Salter
Bellerophon sp.
Ophileta sp.

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1 Measurement made from the section which is drawn to scale
2 *D. murchisoni* var. *geminus* His. in upper beds.

Conularia sp.
Hyolithes sp.
Orthoceras cf. *caereesiense* Hicks
Orthoceras cf. *encrinale* Salter

BRACHIOPODA

Monobolina plumbea (Salter)
Orthis sp.
Lingula sp.

These beds are much less satisfactorily exposed on the northern limb of the anticline where they are less fossiliferous and also more strongly disturbed.

Didymograptus murchisoni beds. These are well developed, on the north but poorly so or absent, on the south side of the anticline. These beds begin with black mud-stones, followed by beds of blue ash and ashy shales and these by thick-bedded arenaceous mud-stones. Graptolites are the chief fossils including *Didymograptus murchisoni*, *Diplograptus foliaceus*, *Climacograptus cœlatus* Lapw. etc.

Besides this the lower division has furnished a fragment of *Ogygia* and the upper *Siphonotreta micula* Mc' Coy and *Lingula* cf. *attenuata* Sow. The middle member has furnished no fossils.

It is still a matter of doubt whether there is a pronounced hiatus between the *D. murchisoni* and the *D. bifidus* zones. Evans says: "there is in this district a natural well-defined line of demarcation between the *D. murchisoni* Beds and those of *D. bifidus* age—a line characterized by lithological and faunal conditions and easily traced wherever the two series appear in normal succession." (*loc. cit.* p. 619). As the original zoning of these Lower Ordovician rocks is largely based on the British occurrences where probably the Lower and the Middle Ordovician are incomplete, the former at the top, the latter at the bottom, we lack a perfect standard for comparison. Not until we have a more complete series of zones, between that of *Didymograptus extensus* below and that of *Nemagraptus gracilis* above, shall we be able to evaluate the graptolite-bearing beds in the regions of incomplete development, such as, if we interpret the facts correctly, practically all the British sections are. It is possible that the more complete successsion will some day be found in South China or some other Asiatic region, for that seems to have been nearer the center of original dispersal.

Very little needs to be said regarding the Arenig sediments in the more easterly region of Caermarthenshire as described by Cantrill & Thomas. Here the *Didymograptus bifidus* beds are in fault contact with the *Tetragraptus* beds and both include thick beds of grits in their lower portions. The region is much disturbed by faults and there are many igneous intrusions. Other fossils than graptolites are rare.

In the neighbourhood of Caermarthen, the more or less complete section of the Tremadoc and the Arenig is shown.[1] The Tremadoc shales at Nant-y-Glasdwr and at Cwm Ffrwd are fine blue gray shales, with interstratified bands of micaceous sandstone at the former, and gritty mudstones at the latter locality. They have yielded *Ogygia marginata* Crosfield & Skeat, *Parabolinella* sp. *Peltura punctata* Crosfield & Skeat, (abundant), *Orthis* sp., *Orthoceras* sp. and *Modiolopsis* sp.

The Arenig consists (at *Glan Pibwr cottage*) of fine grained, dark-blue mud-stones like the Tremadoc, but

1 Margaret C. Crosfield and Ethel G. Skeat. On the Geology of the neighbourhood of Caermarthen, Quarterly Journal of the Geol. Soc. Vol. LII, pp. 523-541. 1896

harder and without the grits. The beds have yielded *Ampyx* sp. and *Ogygia marginata*, *Ctenodonta* sp., and *Phyllograptus* cf. *angustifolius* Hall. Elsewhere in the region in the same or somewhat higher beds, occur also *Calymene parvifrons* and var. *murchisoni* Salter, and *Calymene tristani?* Brongniart, *Asphus* sp. etc.

The BIFIDUS BEDS are sometimes shales and sometimes bands of alternating shales and grits. Here *Phacops llanvirnensis* is found. Elsewhere: *Didymograptus indentus* Hall, *D. bifidus* Hall, and *Diplograptus dentatus* Brongn. The complete list of fossils from the *Bifidus* shales is as follows (Crosf. & Skeat *loc. cit.* p. 528)

GRAPTOZOA;

Didymograptus bifidus Hall
Didymograptus indentus Hall
Didymograptus murchisoni Beck?
Didymograptus patulus (group)
Diplograptus dentatus Brongn.
Climacograptus confertus Lapworth
Climacograptus coelatus Lapworth?
Dendrograptus cf. *flexuosus* Hall

TRILOBITA:

Acidaspis buchi Barrande
Phacops llanvirnensis Hicks
Ampyx sp.
Aeglina sp.

BRACHIOPODA

Siphonotreta micula
Lingula sp.

The presence of *D. murchisoni* in one section of this series suggests that there may be some commingling.

The *Didymograptus murchisoni* shales are also exposed in this region. These are dark gray shales with some sandy beds, containing *Didymograptus murchisoni* Beck and *Siphonotreta micula.* The authors state that "no certain boundary line can at present be drawn between these beds and the underlying Bifidus shales, as fossils are so exceedingly rare in the upper part of the latter" (p. 529.) If there is a disconformity here, as it seems we must assume, it is evidently masked.

The Llandeilo limestone is not present in this region but it may be represented by gritty and sandy flags which overlie the Murchisoni beds. They contain *Asaphus tyrannus and Orthis striatula.*

The *Dicranograptus* shales next succeeding are dark blue or black in colour, with *Climacograptus bicornis* Hall and *Diplograptus foliaceus* Murchison.

Finally the Bala is represented by mudstones, grits, sandy flags, sandstones and conglomerates. These have yielded *Lingula tenuigranulata, Lingula laevis, Orthis alata Orthis calligramma, Orthis flabellulum* Sowerby *Nucula laevis* etc.

These sections mainly bring out the fact that the Tremadoc Beds, evidently cut out by faulting in the more western district, are nevertheless present in their normal position between the Upper Cambrian and the Arenig. The *Dictyonema* Bed however, has not been found.

Ireland

The western coast of Ireland is characterized by a group of projecting headlands and islands of ancient rock in the vicinity of 54° latitude north and longitude 10° west. These form the western portion of Galway and Mayo, and consist largely of pre-Cambrian crystallines and intrusive granites, but they include a few scattered patches of Ordovician and Silurian rock, all of which have been more or less strongly disturbed. Resting unconformably upon these is the Carboniferous Limestone series, (Viséen) which covers such a large part of central Ireland. The boundary line between the Carboniferous Limestone series and the older rock is indicated by a series of lochs, which extend most of the way from Galway Bay on the south to Clew Bay. West of one of these, Loch Mask, a considerable area of older Palæozoic strata is exposed and from two districts, the Tourmakeady District of County Mayo, and the Glensaul district of County Galway, beds of Ordovician age have been described[1].

The general sections for each of the two districts is as follows.

Section in the Tourmakeady District.

3. Bala? conglomerates and sandstones with pebbles mainly of granite and felsite.
2. Shangort and Tourmakeady beds. (Llandeilo)
    2b. Shangort grits and tuffs, coarse and fine, the prevalent type a calcareous gritty tuff, includes the Tourmakeady limestones about 30 ft. thick, and limestone breccias

1 G. H. Gardener and Sidney Hugh Reynolds On the Igneous and associated sedimentary rocks in the Tourmakeady District, County Mayo with a palæontological appendix by Frederick Richard Cowper Read. Quarterly Journal of the Geological Society of London Vol. LXV, 1909, p. 104-154. Map and 2 plates (1 of fossils). *Ibid* the Igneous and associated rocks of the Glensaul District, County Galway. *Ibid* Vol. LXVI, pages 253-280, with map and two plates of fossils.

formed from the fragmentation of the limestones 40 ft. about 1000 ft.

2a. Red felsite, or rhyolite. A series of flows varying greatly in thickness, maximum 300 ft.

(Probable hiatus and disconformity)

1. Mount Partry Beds. (Arenig.) about 1300 ft.
   1c. Coarse quartzose grits, with occasional chertbands and tuffs (up to 400 ft.)
   1b. Fine grits, graptolitic shales and slates
   1a. Coarse conglomerates.
   Base of section not exposed.

The best section of the lower beds is exposed in the vicinity of Mount Partry about $\frac{1}{2}$ mile north of the village of Tourmakeady, in the bed of Treanlaur Stream, which crosses the area approximately at right angle to the strike. The beds dip at a strong angle to the N. N. W. The lowest beds are not exposed they probably extend under the cover of Dinantian rocks which unconformably overly them. A detailed section of the Mount Partry beds is as follows (*Loc. cit.* p. 107) in descending order

Section of Mount Partry Beds.

7.	Coarse green grits, very quartzose and feldspathic.	? ft.
6.	Fine grits and cherts, exposed part	about 20 ft.
5.	Fine gritty tuff	60 ft.
4.	Coarse tuff	50 ft.
3.	Fine gritty tuff	60 ft.
2.	Fine grits, cherts and slates including a black band with graptolites at about 20 feet above the base	50 ft.

1. Coarse conglomerate, estimated thickness 850 ft.

The following graptolites were found in bed 2 according to Elles and Wood, who refer the assemblage to the zone of *Didymograptus hirundo.*

1. *Didymograptus acutidens* Elles & Wood.
2. *Didymograptus bifidus* Hall (small variety)
3. *Didymograptus extensus* Hall
4. *Didymograptus filiformis* Tullberg
5. *Didymograptus gracilis* Törnquist
6. *Didymograptus hirundo* Salter
7. *Tetragraptus bigsbyi* Hall
8. *Tetragraptus pendens* Elles
9. *Tetragraptus* sp. nov.
10. *Diplograptus* (*Glyptograptus*) *dentatus* Brongn.
11. *Clonograptus lapworthi* Rued.
12. Dendrograptid

The tuffs which overlie the graptolite beds, with a thickness of some 170 ft, mark the beginning of volcanic activity in this region, since they are evidently contemporaneous deposits. Overlying as they do, the shales with the *Didymograptus hirundo* fauna, they may be correlated essentially with those of North Wales, in which occasionally have been included members of the *D. bifidus* fauna. What is regarded as an ancient volcanic vent, is an oval mass of coarse breccia, about 300 ft. long, lying to the west of the village of Shangort.[1] Some of the felsites are regarded as contemporaneous flows, others as intrusive. Among the former is a great red felsite (rhyolite mass) which forms a series of lava flows, which aggregate 300 ft. or more in thickness. In their several sections Gardener

1 Geikie A. Ancient volcanoes of Great Britain Vol. 1, p. 253, 1897.

and Reynolds show this felsite to rest disconformably upon the Mount Partry beds, which show an eroded surface, (Section I, Fig. 2, p. 110) or even unconformably (Section II Fig. 3, p. 110). It is followed concordantly by the Shangort beds. This is the character throughout most of the area, but in the northern region, (Section IV, Fig. 6, page 114) a great intrusive felsite cuts the Mount Partry Beds and they are disconformably succeeded by the Shangort Beds, which themselves contain a minor bed of contemporaneous felsite and are in turn disconformably succeeded by the Bala? Beds.

The Shangort beds of grits and tuffs, which overlie the felsite or rest disconformably on the Mount Partry beds, as well as the Tourmakeady limestones and breccias which the former include, constitute the higher series. The gritty and ashy Shangort beds and tuffs are mostly free from fossils, these being segregated in certain localities. Among them are such characteristic Ordovician forms as

Plectambonites sericea Sowerby
Orthis calligramma Dalman etc.

In the first study of these faunas Cowper-Reed referred them to the Llandeilo, but after studying the fossils from the Glensaul District, he decided against the Llandeilo and for the Arenig age of these beds. We shall discuss this more at length presently.

The Glensaul Section.

This small area lies from 3-5 miles southwest of Tourmakeady Lodge in Galway County, and is virtually a continuation of the Mayo County rocks just described. The section there is as follows in descending order :

3. Bala? Beds (or younger)
Conglomerates and sandstones

Hiatus and disconformity

2. SHANGORT AND TOURMAKEADY BEDS

2h.	Calcareous gritty tuffs, of no great coarseness. Sometimes becoming so calcareous as to pass into fairly pure limestone, enclosing also bands and patches of limestone breccias and more rarely bands of fossiliferous limestone, which in some cases has been shattered by earth movements	
	Probable hiatus & disconformity	
2g.	Very coarse tuff or breccia, mainly composed of feldspar fragments, with associated impersistent bands of fine tuff	750 ft.
2f.	Coarse and fine tuff, with occasional patches of calcareous beds. A graptolite bed at one point, indicating zone of *Didymograptus hirundo*.	150 ft.
2e.	Great felsite sill of Tonaglanna and Greenaun about	1100 ft.
2d.	Coarse grit	20 ft.
2c.	Gritty tuff	520-620 ft.
2b.	Coarse tuff or breccia, mainly composed of feldspar fragments	75 ft.
2a.	Fine-banded tuff	55 ft.

1. MOUNT PARTRY BEDS.

1d.	Coarse grit	150 ft.
1c.	Fine grits and tuffs, with associated black chert, graptolite beds and a prominent band of coarse tuff or breccia. The graptolites	

	indicate the upper part of *Didymograptus extensus zone.*	? 150 ft.
1b.	Coarse grits.	110 ft.
1a.	Coarse conglomerates, its exposed part about)	600 ft.

Division 1a and 1b of the Mount Partry beds are unfossiliferous and represent continental deposits. The coarse conglomerates have blocks composed mainly of grit and frequently as much as 2 ft. in length. Formation 1c, though finer and associated with tuffs and Radiolarian cherts, marks the beginning of volcanic activity in this region, but is still in large part a continental deposit. It contains only graptolite beds and therefore represents repeatedly flooded or marined low-lying coastal river-plain deposits. The following graptolites have been identified by Dr. Elles from these beds.

1. *Clonograptus lapworthi* Rued.
2. *Dictyonema*
3. *Didymograptus affinis* Nich.
4. *Didymograptus bifidus* Hall (common, small form)
5. *Didymograptus extensus* Hall (common)
6. *Didymograptus fasciculatus* Nich. (rare)
7. *Didymograptus filiformis* Tullberg
8. *Didymograptus gracilis* Törnquist
9. *Didymograptus nanus* Lapw. (common)
10. *Didymograptus nicholsoni* Lapw.
11. A Dendrograptid.
12. *Glyptograptus dentatus* Brongn. (rare)
13. *Tetragraptus amii* Lapw.
14. *Tetragraptus fruticosus* Hall
15. *Tetragraptus pendens* Elles

16. *Tetragraptus quadribrachiatus* Hall
17. *Tetragraptus serra* Brongn.
18. *Thamnograptus* sp.
19. *Trichograptus fragilis* Nich.

Dr. Elles refers this to the upper part of the zone of *Didymograptus extensus*, which would make this horizon slightly lower than that of the Tourmakeady region. Gardener and Reynolds think that the two are essentially the same zone, while Dr. Elles remarks that the fossil evidence is not inimical to this view. The horizon may thus be placed at the Fxtensus-hirundo boundary line. The *Didymograptus bifidus*, abundant at both localities, is pronounced by Miss Elles a small and early mutation of the form characteristic of the Bifidus zone proper. Thin sections of the cherts and fine silicified tuffs have disclosed the presence of Radiolaria and these are found under similar conditions in the corresponding beds of the Tourmakeady District.

The Mount Partry beds in both regions are terminated by coarse grits which overlie the graptolite beds, showing the return of the continental conditions after the temporary flooding which spread the graptolites and Radiolaria over the flat surface.

The surface flow of felsite overlying the Mount Partry beds in the northern region, appears to be absent in the Glensaul District, where tuffs and breccias, mainly composed of feldspar fragments, succeed the terminal grit of the Mount Partry beds. The felsite of the southern section forms an intrusive sill between these tuffs and the higher series, in which another graptolite bed is found. This is 2f of the section given above. The graptolite bed has furnished

Didymograptus extensus Hall

Didymograptus gibberulus Nicholson
Didymograptus hirundo Salter.
Didymograptus nitidus Hall

This represents the *Didymograptus hirundo* zone, and therefore is still to be classed with the Arenig. The succeeding coarse tuffs and breccias, the latter composed mainly of felsitic fragments (2g of the section) apparently represent the final emergent series of the Cambrovician retreat, while the Shangort grits and Tourmakeady fossiliferous limestone represent the subsequent return of the sea to this region.

These are the beds which in the northern section were first referred to the Llandeilo. The study of the fossils from the Glensaul District, has led Cowper Reed to reconsider the question of their age, and in his second contribution he refers them to the Arenig or Lower Ordovician.

Before considering the validity of this conclusion, we will give a list of the positively identified species from these formations, omitting all those that are referred to with a query or cf.(+ = represented by related species.)

In this list the new species are marked with an asterisk and the distribution of some of the others elsewhere is shown in the later columns. There can be no question that this fauna has more a Middle than a Lower Ordovician aspect and so we must critically examine Reed's reasons for changing his opinion. He says on page 271 of his second article (1910) "It appears that we must now correlate it [the fauna] with the Scandinavian equivalent of the English Arenig, that is with the main mass of the Orthoceras limestone." He especially refers to *Nileus armadillo* as evidence of the earlier age. He compares

Table A-II

Partial fauna of the Tourmakeady Beds of Western Ireland. (after Cowper-Reed.)

	Tourmakeaky District	Glensaul District	Baltic Region	
			Megalaspis beds	Asaphus beds etc.
	1	2	3	4
Brachiopoda				
1. Camarella thomsoni Dav.	×	×		
2. Christiania youngiana Dav.	—	×		
3. Lingula ovata M'Coy	×			
4. Orthis calligramma Dalm.	×	—	—	×
5. Orthis obtusa Pander var.	×	×	+	+
6. Orthis parva Pander	×	×	×	
7. Orthis simplex M'Coy	×			
8. Orthis (Dalmanella) testudinaria (Dalm.)	?	×		
9. Orthisina adscendens Pander	×	—	—	×
10. Plectambonites quinquicostata M'Coy	×	?		
11. Plectambonites sericea Sowerby	×	×		
12. Rafinesquina imbrex semiglobosina Dav.	—	×	—	+
*13. Streptis affinis Cowper-Reed	×	×		
14. Strophomena antiquata Sowerby	×			
15. Triplecia spiriferoides Portlock	×			
Trilobita				
1. Agnostus agnostiformis M'Coy	×			
*2. Bathyurellus glensaulensis Cowper-Reed	—	×		
*3. Cybele connemarica Cowper-Reed	×			
*4. Encrinurus octocostatus Cowper-Reed	—	×		
*5. Illænus weeveri Cowper-Reed	×	×		
6. Nileus armadillo Dalman	—	×		
7. Pliomera benevolens Salter	×			
8. Pliomera pseudoarticulata Portlock	×	×		
*9. Telephus hibernicus Cowper-Reed	×	×		

his species with the variety *depressus*. Thus he says "the presence of *Nileus armadillo* may be regarded as specially important, since this species occurs only in the *Expansus* stage (B_2b) in the Baltic provinces, although in Sweden, it ranges up into the Cystidian limestone and in Norway into Etage 4.[1] But the variety *depressus* which most resembles our form is most particularly characteristic of the Expansus stage."

Reed here uses the older classification of the Baltic sections by F. Schmidt.[2] More recently however, Lamansky[3] has studied these sections in great detail and has given us a revised classification. This with its palæogeographic significance, I have previously discussed[4] and it will be more fully considered below. Here it is sufficient to note that the formation designated as *Expansus-kalk* by Schmidt, (Schmidt's division B2b) comprises a number of distinct horizons, which Lamansky has designated in descending order

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1 Both of these divisions are late Middle Ordovician.

2 On the Silurian (and Cambrian) strata of the Baltic Provinces of Russia as compared with those of Scandinavia and the British Isles by Professor F. Schmidt, St. Petersburg. Quarterly Journal of the Geol. Soc. of London, Vol. XXXVIII, 1882, pp. 514-536 with map.

3 W. Lamansky. Die ältesten Silurischen Schichten Russlands. Etage B. Mem. Com. Geol. Russ. Nouvelle Series, Livr. 20, 1905. German resumé. pp. 148-203. with plates. *Ibid.* Neue Beiträge. zur. Vergleichung des Ost-Baltischen und Skandinavischen Untersilurs. Centralblatt für Mineralogie and Paläontologie 190, pp. 611-618.

4 A. W. Grabau. Comparison of American and European Lower Ordovicic Formations. Bull. Geol. Soc. America. Vol. XXVII, pp. 555-622. 1916 (590-601).

B III α
B II γ
B II β

The last including only the upper part. It is BIII α which is the true Expansus limestone for here *Asaphus expansus* appears for the first time. Here too *Orthis calligramma* makes its first appearance in the Baltic region, as well as *Illænus esmarki*, to which *I. weaveri* of the Irish region is closely related. On the other hand *Nileus armadillo* var. *depressa* Sow. belongs to horizon B II β and B II γ, but *N. armadillo* itself is characteristic of the true Expansus beds *i. e.* beds with *Asaphus expansus* in Scandinavia. In this horizon too *Orthisina adscendens* occurs, both in the Baltic and the Scandinavian region, a species likewise unknown in the lower division (B II γ). On the other hand *Orthis parva* is characteristic of B II but a variety is confined to B III.

Finally, it is important to note that there is a pronounced hiatus between B II and B III, marked by the progressive off-lapping of the lower divisions and the over-lapping of the higher, as clearly brought out by Lamansky's studies and shown in his diagram. (See Text Fig. 1). In view of this, we are constrained to return to Reed's original classification of these beds and place them again in the Middle Ordovician, though they may have little in common with the typical Llandeilo Beds of Wales, representing as they do a very late portion of the Middle Ordovician transgression.

The main period of vulcanicity may still be placed in the emergent phase of the Cambrovician i. e, post Arenig, pre-Llandeilan. The effusive porphyrys of the Tourmakeady District rest on the plane of disconformity, while the intrusive porphyrys of the Glensaul District lie in the Arenig portion of the section. In general then we may say that the volcanic activity began in the retreatal phase i. e, the Arenig and continued through the emergent phase. Some of it belongs to a later stage, for intrusions occur in the Middle Ordovician as well. The fossiliferous tuffs however of the Middle Ordovician, may very well represent older tuffs reworked by the advancing Middle Ordovician Sea.

In the following table (B-II) the fossils of the Cambrovician beds of Wales and Ireland recorded in the preceding pages are listed in order with their regional and zonal distribution.

TABLE B-II

FOSSILS OF THE CAMBROVICIAN BEDS OF WALES AND WESTERN IRELAND

Cols. 1-10 Cambrovician of North Wales
Col. 1 Meantwrog Series of the Upper Cambrian
Col. 2 Ffestiniog Series of the Upper Cambrian
Col. 3 Dolgelly Series of the Upper Cambrian.
Col. 4 Tremadoc Formation of North Wales.
(For the distribution in the several sub-divisions see the text.)
Col. 5 Lower Arenig of North Wales.
Col. 6 *Didymograptus extensus* beds of North Wales.
6a Llyfnant or Extensus bed of Mount Arenig.
6b Henllan Volcanic ashes of Mount Arenig
6c Extensus beds of Lleyn Peninsula
Col. 7 Upper Arenig or Hirundo Beds.
7a Erwent or *Ogygia* limestone. Mount Arenig
7b Filltirgerig or Hirundo Beds of Mount Arenig.
7c Portkings beds of Dolgelly
Col. 8 Bifidus Beds of North Wales.
8a Olchfa or Bifidus Beds of Arenig
8b Moelyn slates of Dolgelly Beds
8c Bifidus or Crogenen Beds of the Dolgelly region.
Col. 9 St. Tudwal's sandstone. Basal Arenig
Col. 10 Llanengan mud-stones of Lleyn Peninsula

Cols. 11-20 Cambrovician localities and divisions of S. Wales

Col. 11 Tremadoc of Cærmarthenshire

Col. 12 Lower Graptolite shales of Cærmarthenshire

12a *Dictyograptus* beds

12b *Tetragraptus* beds

Col. 13 Ramsay Island Beds or *Neseurctus* Beds of Ramsay Island.

13a Abercastle of Pembrokeshire

13b Porthgain Beds of Pembrokeshire

13c *Ogygia marginata* beds of Cærmarthenshire

Col. 14 White-Sand-Bay Beds or *Didymograptus extensus* beds.

14a Trwyn-hwrddyn Creek, White-Sand Bay

Col. 15 Roaduchaf Beds of Ramsay Island, includes upper *D. extensus* in the lower part and lower *D. hirundo* in the upper part

Col. 16 *Didymograptus hirundo* Beds of West Cæmarthenshire

Col. 17 Upper Arenig of Abereiddy Bay. Hick's typical Lower Llanvirn

Col. 18 Porthhayog Beds of Ramsay Island. Lower Llanvirn

Col. 19 Lower Abereiddy Trilobite beds. The original Upper Llandeilo of Hicks.

Col. 20 Typical Abereiddy Beds or Lower Llanvirn of South Wales.

20a Bifidus beds of W. Cærmarthenshire

Cols. 21-23 Counties Mayo & Galway W. Ireland

Col. 21 Mount Partry beds of the Tourmakeady district Co. Mayo. *D. hirundo* zone.

Col. 22 Mount Partry beds of Glensaul district Upper *D. extensus zone*

Col. 23 Bed 2f of Glensaul section. *D. hirundo* zone

Note: When the letters *a*, *b*, *c* etc. are in italies it signifies that both the horizon represented by the column alone and that represented by the letter contain that species. Thus in colum 14 the letter *a* (after graptolite species 16) inplies that that species is both in no 14 and 14a of the list of horizons; whereas a signifies that it is represented in 14a only (cf. graptolite species 6)

Table B.-II

Fossils of the Cambrovician Beds of North and South Wales and of West Ireland

Region	Series	Beds	No.	1	2	3	4	5	6
West Ireland		Hirundo bed of Glensaul	23						
		Mt. Partry beds of Glensaul	22						
		Mt. Partry beds of Tourmakeady	21						
South Wales	L. Llanvirn	Abereiddy or Bifidus beds	20						
		Lower Abereiddy Trilobite bed	19						
		Porth-haog beds Ramsey Isl.	18						
		Hicks typical Abereiddy or typ. L. Llanvirn	17						
	Arenig	Hirundo beds W. Caermarthen	16						
		Roaduchaf beds Ramsay Isl.	15					×	×
		White Sand Bay & Trwynhwrddyn Creek beds	14			×		a	a
		Ramsay Island beds etc.	13			|		|	|
		Lower Graptolite Sh. Caermarthen	12			|	b	a	|
		Tremadoc of Caermarthen	11			|	|	|	|
North Wales	Arenig	Llangan mudstone Lleyn Peninsula	10	×		|	|	|	|
		St. Tudwal's sandstone	9	|		|	|	|	|
		Bifidus beds	8	|		|	|	|	|
		Hirundo and Ogygia beds	7	|	b	|	|	a?	|
		Extensus beds	6	|	|	|	|	|	|
		Lower Arenig	5	|	|	|	|	|	|
		Tremadoc Formation	4	|	|	|	|	|	|
	U. Camb.	Dolgelly group	3	|	|	|	|	|	|
		Ffestiniog group	2	|	|	|	|	|	|
		Maentwrow group	1	|	|	|	|	|	|

Graptozoa

1. Azygograptus lapworthi Nicholson
2. Azygograptus sueicus Tbg.
3. Callograptus elegans Hall
4. Callograptus persculptus Hall
5. Callograptus radiatus Hopk.
6. Callograptus radicans Hopk.

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Graptozoa (cont.)																							
7. Callograptus salteri Hall	—	—	—	—	—	—	—	—	—	—	—	a,b	—	×	—	×							
8. Callograptus salteri attenuatus Elles	—	—	—	—	—	—	—	—	—	—	—	a											
9. Clematograptus implicatus Hopk.	—	—	—	—	—	—	—	—	—	—	—	a	—	×									
10. Climacograptus coelatus Lapw.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
11. Climacograptus confertus Lapw.	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	×	×	—	a			
12. Climacograptus scharenbergi Lapw.	—	—	—	—	—	—	c	×															
13. Climacograptus teretiusculus Hisinger.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
14. Clonograptus lapworthi Rued.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	
15. Cryptograptus tricornis Carr.	—	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	×						
16. Dendrograptas arbusculus Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	*a*	×								
17. Dendrograptus diffusus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
18. Dendrograptus divergens Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	a	×								
19. Dendrograptus flexuosus Hall	—	—	—	—	—	—	—	—	—	—	—	a	—	×	×	×	—	—	—	cfa			
20. Dendrograptus flexuosus recurvus Hopkinson.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
21. Dendrograptus persculptus Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	a	—	×							
22. Dendrograptus sp.	—	—	—	—	—	—	—	a															
*23. Dicellograptus moffatensis Carruthers.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						

*Typical of Middle Ordovician

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Graptozoa (cont.)																							
24. Dictyograptus cancellatus Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	a	—	cf.							
25. Dictyograptus homfrayi Hopk.	—	—	—	—	—	—	—	—	—	—	—	a	—	—	×								
26. Dictyograptus irregularis Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
27. Dictyonema socialis Salt.	—	—	—	×																			
28. Dictyonema sp.	—	—	—	—	—	—	—	—	×														
29. Didymograptus acutidens Lapw.	—	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	—	—	—	a	×		
30. Didymograptus affinis Nich.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	a	—	×	
31. Didymograptus artus E & W.	—	—	—	—	—	—	—	a,e	—	—	—	—	—	—	—	—	—	—	—	×			
32. Didymograptus bifidus Hall	—	—	—	—	—	—	—	a,b,c	—	—	—	—	—	—	—	—	×	×	×	*a*			
33. Didymograptus bifidus var.	—	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	—	—	—	—	×		
34. Didymograptus bifidus small form	—	—	—	—	—	—	c	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
35. Didymograptus deflexus E & W	—	—	—	—	—	a	—	—	×														
36. Didymograptus euodus Lapw.	—	—	—	—	—	—	—	—	—	—	—	a	—	—	—	—	×						
37. Didymograptus extensus Hall	—	—	—	—	—	a, e	—	—	×	—	—	—	—	—	×	×	—	—	—	—	×	×	×
38. Didymograptus fasciculatus Nicholson,	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
39. Didymograptus filiformis Tullberg	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	
40. Didymograptus fruticosus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
41. Didymograptus furcillatus Lapworth	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×					
42. Didymograptus gemminus (Hisinger)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
43. Didymograptus gracilis Tornquist	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Graptozoa (cont.)																							
44. Didymograptus (Isograptus) gibberrulus Nicholson	—	—	—	—	—	c	b	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	×
45. Didymograptus hirundo Salter	—	—	—	—	—	—	c	c	—	—	—	—	—	—	—	×	—	—	—	—	×	—	×
46. Didymograptus indentus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	a			
47. Didymograptus indentatus nanus Lapworth	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
48. Didymograptus murchisoni Beck	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a?			
49. Didymograptus nanus Lapw.	—	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
50. Didymograptus nicholsoni Lapworth	—	—	—	—	—	c	—	—	—	—	—	—	—	—	—	—	×	—	—	a			
51. Didymograptus nicholsoni planus E. & W.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
52. Didymograptus nitidus Hall	—	—	—	—	—	c	b	—	—	—	—	b	—	—	—	×	—	b	—	—	—	—	×
53. Didymograptus patulus Hall	—	—	—	—	—	—	b	a	—	—	—	b	—	×	—	×	×	—	—	a			
54. Didymograptus pennatulus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
55. Didymograptus sparsus Hopk.	—	—	—	—	—	—	—	—	—	—	—	b	—	—	×	×							
56. Didymograptus stabilis E & W	—	—	—	—	—	—	—	a, c	—	—	—	—	—	—	—	—	—	—	—	×			
57. Didymograptus uniformis E & W	—	—	—	—	—	c																	
58. Diplograptus (Glyptograptus) dentatus Brngn.	—	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	×	×	—	a	×	×	
59. Glossograptus hincksi Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	cf.			
60. Glossograptus ciliatus Emm.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
61. Loganograptus logani (Hall)	—	—	—	—	—	a																	

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Graptozoa (cont.)																							
62. Nemagraptus capillaris Emm.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
63. Phyllograptus anna Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
64. Phyllograptus stella Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
65. Phyllograptus typus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
66. Phyllograptus? sp.	—	—	—	—	—	—	—	—	—	×													
67. Ptilograptus cristula Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	a	×								
68. Ptilograptus hicksi Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×							
69. Tetragraptus amii Lapworth	—	—	—	—	—	cfa,c	—	—	—	?	—	b	—	—	—	×	—	—	—	—	—	×	
70. Tetragraptus bigsbyi Hall	—	—	—	—	—	—	—	—	—	—	—	b	—	—	—	×	—	—	—	—	×		
71. Tetragraptus halli Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
72. Tetragraptus headi Hall	—	—	—	—	—	cfa	—	—	—	—	—	b											
73. Tetragraptus (Azygograptus) hicksi Hopkinson	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
74. Tetragraptus pendens Elles	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	
75. Tetragraptus quadribrachiatus Hall	—	—	—	—	—	—	—	—	—	—	—	b	—	×	—	—	—	—	—	—	—	×	
76. Tetragraptus reclinatus E & W	—	—	—	—	—	—	b																
77. Tetragraptus serra Brngnt,	—	—	—	—	—	a,c,	b	—	—	×	—	b	—	×	—	×	—	—	—	—	—	×	
78. Trichograptus fragilis Nicholson	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
79. Trigonograptus cristula Hopk.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
80. Trigonograptus ensiformis Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
81. Trigonograptus truncatus Lapw.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
Brachiopoda																							
1. Acrotreta sabrina Hall.	—	—	—	×																			
2. Dinobolus? hicksi Davidson.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Brachiopoda (cont.)																							
3. Lingula attenuata Sow.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×					
4. Lingula cf. nicholsoni Call	—	—	—	×																			
5. Lingula petalon Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×	*a*	×								
6. Lingula ramsayi Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
7. Lingula rouaulti Salter	—	—	—	—	—	—	a																
8. Lingulella davisii M'Coy	—	×	—	—	—	—	—	—	—	—	—	—	×	a	×								
9. Lingulella lepis Salter	—	—	—	×																			
10. Monobolina plumbea Salter	—	—	—	—	×	—	a,b	—	—	—	—	—	—	—	—	—	—	—	×	a			
11. Obolella plicata Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×	a	×								
12. Orthis calligramma Dalman	—	—	—	—	—	—	a?	—	—	—	—	b?											
13. Orthis carausii Salter	—	—	—	—	—	—	a	—	—	—	—	*a*	×										
14. Orthis christianiæ Kjerulf	—	—	—	cf																			
15. Orthis lenticularis Dalman	—	—	×	—	—	—	—	—	—	—	—	—	—	a	×								
16. Orthis menapiæ Hicks	—	—	—	—	—	—	—	—	—	—	—	xa?	*b*										
17. Orthis proava Salter	—	—	b	—	—	—	—	—	—	—	—	—	b										
18. Orthis remota	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
19. Siphonotreta micula	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
Pelecypoda																							
1. Ctenodonta cambrensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
2. Ctenodonta menapiensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
3. Ctenodonta sp.	—	—	—	×																			
4. Davidia ornata Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
5. Davidia plana Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
6. Glyptarca loblyi Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
7. Glytarca primæva Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										

Table BII (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Pelecypoda (cont.)																							
8. Modiolopsis cambriensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
9. Modiolopsis homfrayi Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
10. Modiolopeis ramseyensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
11. Modiolopsis solvensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
12. Palæarca oboloidea Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
13 Palæarca hopkinsoni Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
Gastropoda etc.																							
1. Bellerophon llanvirnensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
2. Bellerophon multistriatus Salter	—	—	—	×	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	a?			
3. Bellerophon perturbatus Sow.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
4. Bellerophon ramseyensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
5. Bellerophon solvensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
6. Centrotheca cuspidata Hall	—	—	—	×																			
7. Conularia homfrayi Salter	—	—	—	×	—	—	—	—	—	—	—	—	—	a	×	—	—	—	cf.				
8. Conularia llanrianensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
9. Hyolithes caereesiensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
10. Hyolithes davidii Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
11. Hyolithes harknessi Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
12. Hyolithes operculata Salter	—	—	—	×																			
13. Hyolithes sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
14. Pleurotomaria llanvirnensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
15. Raphistoma? sp.	—	—	—	—	—	b	a																
Cephalopoda																							
1. Endoceras? sp.	—	—	—	—	—	b																	

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Cephalopoda (cont.)																							
2. Orthoceras caereesiense Hicks	—	—	—	—	—	—	—	cfa	—	—	—	—	—	—	—	—	×	—	—	a			
3. Orthoceras encrinale Salter	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	—	—	—	—	cfa			
4. Orthoceras sericeum Salter	—	—	—	—	—	—	a	—	—	—	×	—	—	×	—	cf.							
5. Orthoceras? sp.	—	—	—	—	—	b	a																
Trilobita																							
1. Agnostus calvus Lake	—	—	—	×																			
2. Agnostus hirundo Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
3. Agnostus mccoyi Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	a			
4. Agnostus pisiformis	—	—	×																				
5. Agnostus pisiformis obesus Belt.	×																						
6. Agnostus siedenbladthi Linn.	—	—	—	×																			
7. Agnostus trisectus Salter	—	—	×																				
8. Acidaspis buchi Barrande	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a			
9. Aeglina binodosa Salter	—	—	—	—	—	—	—	—	—	—	—	b	—	—	—	—	—	—	—	a			
10. Aeglina boia Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
11. Aeglina caliginosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×							
12. Aeglina grandis Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
13. Aeglina obtusicaudata Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
14. Ampyx salteri Hicks	—	—	—	—	—	—	cfa	—	—	—	—	—	—	×									
15. Ampyx nudus Murchison	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
16. Angelina sedgwicki	—	—	—	×																			
17. Asaphellus homfrayi Salter	—	—	—	×	—	—	—	—	—	—	—	—	—	a	×								
18. Barrandea caudai M'Coy	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Trilobita (cont.)																							
19. Barrandea homfrayi Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	a			
20. Barrandea longifrons Edgall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
21. Calymene duplicata Murchison	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
22. Calymene hopkinsoni Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
23. Calymene parvifrons Salter	—	—	—	—	×	b	a	—	—	—	—	—	—	—	—	—	—	—	—	a?			
24. Calymene parvifrons var. murchisoni Salter	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	×					
25. Calymene tristani Brongn.	—	—	—	—	—	—	—	—	—	—	—	×											
26. Cheirurus sedgwicki M'Coy	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
27. Cheirurus sp.	—	—	—	×	—	—	—	—	—	—	—	—	—	×									
28. Ctenopyge pecten Salter	—	—	×																				
29. Dicellocephalus furca	—	—	—	×																			
30. Dicellocephalus sp.	—	—	—	×																			
31. Dionide sp.	—	—	—	—	—	—	—	×															
32. Holometopus sp.	—	—	—	×																			
33. Hysterolenus tornquisti	—	—	—	cf.																			
34. Illænopsis acuticaudata Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
35. Illænus hughesi Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	a			
36. Neseuretus elongatus Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
37. Neseuretus elongatus var. obesus Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
38. Neseuretus quadratus Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
39. Neseuretus ramseyensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
40. Neseuretus recurvatus Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
41. Niobe homfrayi Salter	—	—	—	×																			

Table B II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Trilobita (cont.)																							
42. Niobe menapiensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
43. Niobe scutatrix Salter	—	—	—	×																			
44. Niobe solvensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
45. Ogygia bollina Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	×									
46. Ogygia buchi Brongn.	—	—	—	—	—	—	—	a	—	—	—	—	—	—	—	—	—	—	×	×			
47. Ogygia marginata Crosf. & Skeat	—	—	—	—	—	—	—	—	—	—	—	*a*											
48. Ogygia peltata Salter	—	—	—	—	—	—	—	a	—	—	—	—	—	×									
49. Ogygia scutatrix Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	a	×								
50. Ogygia selwini Salter	—	—	—	—	×	—	a	—	—	—	—	a	a	×									
51. Olenus cataractes Salter	×																						
52. Olenus (Parabolinella) salteri Call.	—	—	—	×																			
53. Olenus (Parabolinella) triarthrus Call.	—	—	—	×																			
54. Ormetopus praenuntius Salter	—	—	—	×																			
55. Parabolina spinulosa Dalman	—	—	×																				
56. Peltura punctata Crosfield & Skeat,	—	—	—	—	—	—	—	—	—	—	×												
57. Peltura scarabaeoides Wahlenberg	—	—	×																				
58. Phacops llanvirnensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	a			
59. Placoparia cambriensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	a			
60. Psilocephalus innotatus Salt.	—	—	—	×																			
61. Remopleurides sp.	—	—	—	×																			
62. Shumardia salopiensis Call.	—	—	—	×																			

Table B II (*Concluded*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Trilobita (cont.)																							
63. Sphaerophthalmus alatus Boeck.	—	—	×																				
64. Symphysurus croftii Call.	—	—	—	×																			
65. Trinucleus etheridgii Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	cfa			
66. Trinucleus fimbriatus Murchison	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
67. Trinucleus gibbsi Salter	—	—	—	—	—	c ?	—	—	—	—	—	—	—	×									
68. Trinucleus murchisoni Salter	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	cfa			
69. Trinucleus ramsayi Hicks	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
70. Trinucleus sedgwicki Salter	—	—	—	—	—	—	—	—	—	—	—	cf;b.	a,b	×	×	cf.							
Other crustacea																							
1. Cariocaris sp.	—	—	—	—	—	b	—	b															
2. Hymenocaris vermicauda	—	—	—	×																			
3. Lingulocaris sp.	—	—	—	×																			
Echinodermata																							
1. Dendrocrinus cambrensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	*b*										
2. Macrocystella mariae Hall	—	—	—	×																			
3. Palasterina ramseyensis Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
Varia																							
1. Eophyton explanatum Hicks	—	—	—	—	—	—	—	—	—	—	—	—	×										
2. Portospongia sp.	—	—	—	×																			

The Midland Region of England

Malvern Hills. The section of the Malvern Hills on the border of Hertfordshire and Worcestershire has already been given (Vol. I. p. 87. *IV. p. 113*). Here the Upper Cambrian White-leaved-Oak shales, lie directly upon the Lower Cambrian Hollybush sandstone, the Middle Cambrian being entirely cut out either by faulting, or by a great disconformity. The lowest bed (I, p. 88) contains only the ostracod *Polyphema lapworthi* Groom, probably allied to *Beyrichia angelini* Barrande. Associated with this are *Protospongia fenestrata* Salter, *Agnostus* sp., *Acrotreta*? *sabrinæ* var. *malvernensis* Groom, *Kutorgina cingulata pusilla* Linrs., and *Lingulella nicholsoni* Callaway, besides doubtful plant remains and Foraminifera. The character of the contact has already been discussed. (vol. I p. 90.)

The lower White-leaved-Oak formation is chiefly a basaltic rock, but with 30 to 50 ft. of grits and shales interbedded. The succeeding 250 ft. of Lower Black shales are characterized by *Agnostus trisectus*, *Peltura scarabæoides* and *Sphaerophthalmus* and represent the Upper Dolgelly horizon. This probably makes the underlying *Polyphemus* Beds, the Lower Dolgelly with the Ffestiniog and Maentwrog Beds wholly absent by overlap.

Sphærophthalmus alatus and *Agnostus trisectus* continue into the upper White-leaved-Oak shale, to within about one hundred feet of the top. These therefore belong to the Dolgelly type of sedimentation which would imply that the Bronsill shales which overlie it and which in the upper part carry a *Dictyonema* fauna represent the Tremadoc. Although the lithological phase of the upper Lingula flags or Ffestiniog is not developed in this region, it is conceivable that the lower White-leaved-Oak shales represent the upper portion of this middle part of the Upper Cambrian. A comparison of the faunas of the White-leaved-Oak and Bronsil shales shows that with the exception of *Acrotreta* (*Bröggeria*) *salteri* and doubtfully *Linnarssonia belti* the recorded fossils of the two series are entirely distinct. They are given in Table C-II. cols 3.

The Bronsil shales are disconformably succeeded by the Mayhill sandstone.[1] The distance of this section is about 80 miles slightly north of east of Caermarthen, S. Wales.

The Comley District. This lies about 1 mile north-east of Caer Caradoc in western Shropshire and about 90 miles north-east of Caermarthen in South Wales and from 45-50 miles N.N.W. of the southern Malvern Hills, and is of interest in this connection. The Lower Cambrian has already been described (Vol. I. p.90 *IV. p. 116*). The *Protolenus* horizon of the Middle Cambrian has been discussed on p. 352 (*548*) and the Acadian or *Paradoxides* horizons on page 415 et seq. (*611*).

In his latest paper on this district Cobbold[2] gives a geological map of the area on the scale of 6 inches to the mile, which shows the complicated structure of this small patch of country at the eastern base of Caer Caradoc. It also shows the distribution of the Upper Cambrian *Orusia* shales, and the Shineton shales, in the Shootrough Wood area. Unfortunately, these Upper Cambrian

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1 Groom. Quart. Journ. Geol. Soc. of London. Vol. LV, p. 144, fig. 13, and p. 166.

2 Edgar S. Cobbold. The Stratigraphy and Geological structures of the Cambrian area of Comley, Shropshire, Quart. Journ. Geol. Soc. of London Vol. LXXXIII, 1927, p. 551-573 with map.

beds (Shoot-rough Road) (see Text-Fig. 10, Vol. I, p. 419 (*IV. 615*) are seen only in fault contact, with the Middle Cambrian or even the Lower Cambrian, if we may judge by the map, though they appear to be in disconformable contact with the *Billingsella* beds, which overlie the Davidis beds, and are supposed to represent the Forchhammeri zone

The *Orusia* shales (Ca) through a thickness of some 500 ft. probably represent the later Upper Cambrian or Dolgelly. They contain in addition to *Orusia lenticularis* and *Acrothele* cf. *coreacea* Linnrs, a number of characteristic trilobites, among them *Parabolina spinulosa* (Wahlenberg) *Beltella* sp?, and Phyllocarid carapaces etc. and Lingulellas of the type characteristic of the *Olenus truncatus* zone of Sweden.

The Orusia shales are succeeded with apparent conformity by the Shineton shales, of Tremadoc age. These in turn are disconformably succeeded by the Hoar Edge grit of the Caradocean.

The Wrekin District. The Shineton shales have been fully described in the Wrekin District of Shropshire. The Wrekin is a dome-shaped hill, rising to a height of 1,335 ft, and is largely formed of rhyolitic lavas of pre-Cambrian (Uriconian) age. It lies perhaps 12 miles N. E. of Caer Caradoc and perhaps 9 miles southeast of Shrewsbury, the county seat of Shropshire.[1] The Shineton

1 C. J. Stubblefied and O. M. B. Bulman. The Shineton shales of the Wrekin, with notes on their development in other parts of Shropshire and Hertfordshire. Quart. Journ. Geol. Soc. of London Vol. LXXXIII, 1927, pp. 96-146; with plates and map and correlation table.

shales crop out on the south and south-east of the Wrekin, extending for an area of about 9 miles. In this region they succeed the Comley sandstone, of Lower Cambrian age and although no actual contact has been found it is believed that it is everywhere a fault contact. This supposition is strengthened by the fact that only about 10 miles to the south, the *Orusia* shales underlie the Shineton shales, forming with them a part of the Cambrovician transgression. The fact that in the Comley district, the Middle Cambrian is preserved does not necessarily imply that it must also occur in the Wrekin District, for it may have been worn away again before the Upper Cambrian transgression, if it was deposited there; so that the Upper Cambrian rest directly on the Lower as it apparently does in the Malvern Hills. Moreover, it is not impossible that even the Upper Cambrian is over-lapped in this section and that the Shineton (Tremadoc) rests directly upon the Old Land surface of Comley sandstone. The total thickness of the Shineton in this region was estimated by Callaway, as at least 1500 ft, but Stubblefield and Bulman would make it more than 3,000, with the assumption that there is no important faulting to increase the apparent thickening. The Shineton shales themselves are disconformably succeeded by the Hoaredge grit (Lower Caradocian) or by Silurian or Carboniferous formations. The succession in descending order is as follows.

(*To be Continued*)

Section of the Shineton Shales of the Wreking District, Shropshire

6. *Arenaceous Beds.* Shales with nodules of crumbly sandstone or thin layers of fine-grained blue micaceous sandstone which grade into the normal shales. Though not more than 5 inches thick, they often show false bedding, with casts of burrows, up to the size of a three-penny piece. Fossils are rare, those found are

Acrotreta sabrinæ
Lingulella nicholsoni
Primitia sp.
Bellerophon sp.
Shumardia pusilla (doubtfully reported)

5. *Zone of Shumardia pusilla.* Normally well-bedded and even colored blue shale, splits readily, and sporadically carries cone-in-cone nodules often containing trilobites. Among the fossils are

Asaphellus homfrayi (common)
Shumardia pusilla
Orometopus pyrus
Leptoplastus salteri
Apatokephalus serratus? var.
Agnostus calvus var. *latemarginalis*

(See Table C-II, col. 9)

4. *Brachiopod shale.* Somewhat nodular shale with abundant cone-in-cone concretions. A characteristic feature is the presence of large brachiopods in the position at right angles to the bedding planes. Only 3 species are recorded

Obolus quadratus (fairly common)
Lingulella nicholsoni (common)
Acrotreta sabrinæ (common)

The first of these also occurs in the highest levels of the *Clonograptus tenellus* zone.

3. *Zone of Clonograptus tenellus.* Blue-green blotchy shale and even-coloured shale, sometimes reddish-purple. Cone-in-cone concretions common at various levels. The fossils include:

Clonograptus tenellus and var. *calavii*
Bryograptus cf. *hunnebergensis*
Symphysurus croftii
Bröggeria salteri
Tomaculum problematicum (fairly common)
Agnostus calvus
Agnostus callavei
Euloma monile

(See Table C-II Col. 7)

2. *The Transition Beds.* About 45 ft. of shales, carrying alternately the faunal assemblage of *Clonograptus tenellus* and that of *Dictyonema flabelliforme.*

In addition there are a number of trilobites including :

Shumardia curta
Symphysurus croftii
Euloma monile
Hospes clonograpti
Leptoplastus salteri

(See further Table C-II, Col. 6)

1. *Zone of Dictyonema flabelliforme.* Bluish green shale, frequently mottled with large irregular purplish or greenish patches. Cone-in-cone concretions occur occasionally.

   Dictyonema flabelliforme is the leading fossil, but the lower beds have also yielded *Tomaculum problematicum.* Among the trilobites are *Agnostus callavei, Shumardia curta* and *Euloma monile.*

   Practically all of these zones are recognized in the *Dictyonema* shales of Sweden and the *Dictyonema* and *Ceratopyge* shales and limestones of the Oslo district. For further details see the correlation table in Stubblefield and Bulman's paper.

One further fact is noteworthy. The highest member of the Arenaceous Beds of the Shineton (Tremadoc) (No 6) "affords evidence of a shallowing of the upper Tremadoc sea; the absence in this area of any fauna comparable with the *Apatokephalus serratus* fauna of Scandinavia or with the *Angelina sedgwicki* fauna of Ynyscynhaiarn, is most probably connected with this change in sedimentation." (loc. cit. p. 115). This then seems to mark in this region the beginning of the negative or retreatal phase of the Cambrovician pulsation.

TABLE C-II

CAMBROVICIAN OF THE MIDLAND REGION OF ENGLAND

Cols. 1-3 Malvern Hills

Col. 1. Lower White-Leaved-Oak Shales, *Polyphema* beds

Col. 2. Middle and Upper White-Leaved-Oak Shales; zone of *Sphærophthalmus alatus.*

Col. 3. Bronsil Shales (Tremadoc)

Col. 4. Comley district

Col. 4. *Orusia* shales of Comley

Cols. 5-10. Shineton Shales of Shropshire and Herefordshire

Col. 5. Hor. 1. *Dictyonema shales*

Col. 6. Hor. 2. Transition beds

Col. 7. Hor. 3. *Clonograptus tenellus* beds

Col. 8. Hor. 4. Brachiopod shales

Col. 9. Hor. 5. *Shumardia* shales

Col. 10. Hor. 6. Arenaceous beds.

Table C-II

Cambrovician Fossils of the Midland Region, England.

(Q.J.G.S. London Vol. 58 p. 109-110, Vol. 83 p. 118)

	Malvern Hills: Polyphema beds	Malvern Hills: Sphærophthalmus beds	Malvern Hills: Bronsil Shales	Comley: Orusia Shale	Shineton Shales of Shropshire & Herefordshire: Dictyonema Shales	Shineton Shales: Transition beds	Shineton Shales: Clonograptus beds	Shineton Shales: Brachiopod Shales	Shineton Shales: Shumardia Shales	Shineton Shales: Aranaceous beds
	1	2	3	4	5	6	7	8	9	10
Foraminifera										
1. Crystellaria cf. acutiauricularis F. & M.	—	×								
2. Dentalina abnormis Reuss	—	cf								
3. Glandulina pygmæa Terq.	—	cf								
4. Marginulina soluta Reuss	—	cf								
5. Lagena apiculata Reuss	—	×								
6. Lagena lævis Montagu	—	×								
7. Lagena ovum Ehrenberg	—	×								
8. Spirillina groomiana Chapman	—	×								
Spongidæ										
1. Protospongia fenestrata Salter	×									
2. Protospongia sp.	—	—	—	—	×	×	×	—	×	

Table C-II (*Continued*)	1	2	3	4	5	6	7	8	9	10
Graptozoa										
1. Bryograptus hunnebergensis Moberg	—	—	—	—	—	cf	cf			
2. Bryograptus sp.	—	—	—	—	—	—	×			
3. Clonograptus tenellus (Linnars.)	—	—	—	—	—	×	×			
4. Clonograptus tenellus callavei E. & W.	—	—	—	—	—	×	×			
5. Dictyonema flabelliforme (Eichw.)	—	—	—	—	×	×				
6. Dictyonema sociale Salter	—	—	×							
Brachiopoda										
1. Acrothele? coriacea Linnrs.	—	—	—	cf						
2. Acrotreta nicholsoni Davidson	—	—	cf	—	×	—	×			
3. Acrotreta socialis von Seebach.	—	—	cf							
4. Acrotreta sabrinæ (Callaway)	—	—	×	—	×	×	×	×	×	×
5. Acrotreta sabrinæ malvernensis Groom.	×									
6. Bröggeria salteri (Holl)	—	×	×	—	—	×	×			
7. Eoorthis wimani (Walc.)	—	—	—	—	—	—	—	—	aff	
8. Kutorgina cingulata pusilla Linrs.	×									
9. Lingulella nicholsoni Callaway	?	—	×	—	×	×	×	×	×	×
10. Lingulella pygmæa Holl	—	×								
11. Lingulella sp.	—	×	×	×						
12. Linnarssonia belti Dav.	—	?	×							
13. Obolus quadratus Stubb. & Bulman	—	—	—	—	—	—	×	×		
14. Orusia lenticularis	—	—	—	×						
Hyolithidæ										
1. Hyolithes aratus (Salter)	—	—	—	—	aff	—	—	—	aff	
2. Hyolithes assulatus Groom	—	?	×							

Table C-II (*Continued*)	1	2	3	4	5	6	7	8	9	10
Hyolithidæ (cont.)										
3. Hyolithes belswardinensis Stubb. & Bulman	—	—	—	—	—	—	—	—	×	
4. Hyolithes magnificus Stubb. & Bulm.	—	—	—	—	×	×				
5. Orthotheca exilis Stubb. & Bulm.	—	—	—	—	—	×				
6. Orthotheca lineata (Callaway)	—	—	—	—	—	×	×	—	×	
7. Orthotheca sp.	—	?								
Mollusca										
1. Glyptarca primæva Hicks	—	×								
2. Bellerophon sp.	—	—	—	—	×	×	×	—	×	
3. Murchisonia? sp.	—	×								
4. Orthoceras? sp.	—	×								
Trilobitæ										
1. Acanthopleurella grindrodi Groom.	—	—	×							
2. Agnostus callavei Raw.	—	—	—	—	×	—	×	—	×	
3. Agnostus calvus latemarginalis Stubb. & Bulm.	—	—	—	—	—	×	×	—	×	
4. Agnostus dux Callaway	—	—	×	—	—	×	—	—	×	
5. Agnostus trisectus Salter.	—	×								
6. Agnostus sp.	×									
7. Apatokephalus serratus (Sars & Boeck.)	—	—	—	—	—	—	—	—	×	
8. Asaphellus affinis McCoy	—	—	?							
9. Asaphellus homfrayi (Salter)	—	—	—	—	—	—	—	—	×	
10. Beltella sp.	—	—	—	×						
11. Cheirurus frederici Salter	—	—	×							
12. Ctenopyge bisulcata Phill.	—	×								

Table C-II (*Continued*)	1	2	3	4	5	6	7	8	9	10
Trilobitæ (cont.)										
13. Ctenopyge pecten Salter	—	×								
14. Cyclopyge genatenta Stubb. & Bulm.	—	—	—	—	—	—	—	—	×	
15. Dikellocephalus furca (Salt.)	—	—	—	—	—	—	—	—	×	
16. Euloma monile (Salter)	—	—	—	—	×	×	×	—	×	
17. Hospes clonograpti Stubb. & Bulm.	—	—	—	—	—	×				
18. Hysterolenus törnquisti Moberg var.	—	—	—	—	—	—	×			
19. Leptoplastus salteri (Callaway)	—	—	—	—	—	×	×	—	×	
20. Lichapyge cuspidata Callaway	—	—	—	—	—	—	—	—	×	
21. Macropyge chermi Stubb. & Bulm.	—	—	—	—	—	×	×	—	?	
22. Myinda uriconii Stubb. & Bulm.	—	—	—	—	—	—	×			
23. Niobe homfrayi Salter	—	—	?							
24. Niobe peltata Salter	—	—	aff							
25. Orometopus elatifrons (Ang.)	—	—	—	—	—	—	—	—	×	
26. Orometopus prænuntius (Salter)	—	—	—	—	—	—	—	—	×	
27. Orometopus pyrus Stubb. & Bulm.	—	—	—	—	—	—	—	—	×	
28. Parabolina spinulosa (Wahlenb.)	—	—	—	×						
29. Parabolinella triarthra (Callaway)	—	—	?	—	—	—	—	—	×	
30. Peltura scarabæoides Wahl.	—	×								
31. Shumardia curta Stubb. & Bulm.	—	—	—	—	×	×				
32. Shumardia pusilla (Sars)	—	—	—	—	—	—	—	—	×	
33. Shumardia sp.	—	—	—	—	—	—	×			
24. Sphærophthalmus alatus (Boeck)	—	×								
35. Symphysurus croftii (Callaway)	—	—	?	—	—	×	×	—	×	
36. Sympysurus sp.	—	—	—	—	×	×				
37. Triarthrus shinetonensis Raw.	—	—	—	—	—	—	—	—	×	

Table C-II (*Conclud*)	1	2	3	4	5	6	7	8	9	10
Ostracoda										
1. Polyphema lapworthi Groom	×									
2. Primitia sp.	—	—	—	—	—	—	—	—	×	×
Echinodermata										
1. Macrocystella.	—	—	—	—	—	—	×	—	×	
Varia										
1. Tomaculum problematicum Groom	—	—	×	—	×	×	×	—	×	
2. Plant remains ?	×									
3. Phyllocarid	—	—	—	×						

The Shelve Country, Shropshire, England.

This name is applied to a large oval area of Ordovician rocks of apparently dome-like character in the western part of Shropshire and close to the Welsh border. On the north, west and south it is surrounded by beds of Silurian rocks but on the east where they are steeply upturned these beds rest upon Tremadoc (Shineton) and Cambrian beds, which in turn rest upon the Pre-Cambrian rocks of the Long Mynde Hills. These old rocks form a belt 6 or 7 miles wide that separates the Shelve area on the west from the Comley-Wreking belt of older Palæozoic strata on the east.

Intruded in the Shelve Ordovician rocks are igneous bodies including the famous Corndon Hill laccolith,[1] and intercalated flows.

The Ordovician series begins with quartzites which form the ridge known as the Stiper Stones.

The succession in descending order is as follows:[2]

Section of the Formations of the Shelve District, Shropshire

SUPERFORMATION Silurian, Valentian; Pentamerus beds (Arenaceous phase)

1 See Grabau Principles of Stratigraphy p. 307 fig. 48 and reference to original articles p. 321.

2 W. F. Whittard. The Geology of the Ordovician and Valentian rocks of the Shelve Country Shropshire. Proceedings of the Geologists Association (London) Vol. 42, 1931 pp. 322-339 Section and plates 10-11.

Hiatus and Disconformity

ORDOVICIAN

CARADOCIAN

XI Marrington Stage

a Whittery Shales

X Hagley Stage

c Whittery Volcanic Group

b Hagley Shales

a Hagley Volcanic Group

IX Aldress Stage

b. Aldress shales

a Spywood grit

LLANDEILAN

VIII Rorrington Stage

a. Rorrington Beds

VII Meadowtown Stage

a. Meadowtown Beds

UPPER LLANVIRNIAN

VI Betton Stage

a. Betton Beds

V Weston Stage

a. Weston Grits and Flags

Probable Hiatus and Disconformity

CAMBROVICIAN

LOWER LLANVIRNIAN

IV Stapeley Stage about 900 ft.

b. Stapeley Shales

a. Stapeley Volcanic Group

LLANVIRNIAN—ARENIGIAN

III Hope Stage 800 ft.

c. Upper Hope Shales

b. China-Stones "Ash"
a. Lower Hope shales

ARENIGIAN

II Mytton Stage
b. Mytton Flags
4. Tankerville Flags
3. Shelve Church beds
2. Ladywell and Snailbeach grits & flags
1. Lord's Hill Beds
a. Stiperstones quartzites

Disconformity (?)

TREMADOCIAN

I Habberley Shales

The *characteristics of* the various divisions are as follows :

The Cambrovician Series

The Habberley Shales. Flaggy, sandy shales and greenish-gray shales, with some sandy beds and containing *Lingulella nicholsoni* Callaway, *Orthoceras* cf. *sericeum* Salter and *Asaphellus homfrayi* Salter. On the basis of the latter Whittard would correlate these beds with the *Shumardia pusilla* zone of the Shineton shales.

In an excavation showing the contact between the Habberley shales and the overlying Stiperstones, evidence of a disconformity between the two was discovered. The Habberley shales terminate with a series of micaceous flags and shales and these are followed in apparently conformable sequence by a three-inch band of conglomerate of a type unknown from the Stiperstone quartzite itself. The conglomerate is succeeded by a thin band of broken-up shales and finally by quartzitic flags, "which on lithological factors are definitely Ordovician in age." (*Loc. cit.* page 325) Whittard continues "The junction between the Ordovician and Cambrian (Tremadocian) should probably be taken at the base of the conglomerate and apart from the presence of this conglomerate, between rocks known to be of Cambrian and Ordovician age, its distinctive appearance and general dissimilarity from the usual conglomerate found in the Stiperstones quartzite, suggests that it represents a bed formed by the encroachment of the Ordovician Sea, over the Cambrian stata, and that it is unconformable [disconformable]. The arenaceous nature of the Habberley shales, towards their top, and the apparent correspondence in bedding of the Cambrian and the Stiperstones quartzite are considered as factors, which have tended to mask the true unconformable [disconformable] characters of the Stiperstones quartzite." (*Loc. cit.* p. 325)

The question here is, are we dealing with a minor or a major disconformity? Whittard evidently considers that an exposure was followed by a renewed transgression of the sea, and that there is a considerable faunal break between the Habberley shales and the lowest fossiliferous horizon of the overlying Ordovician. The latter as we shall see carries the *Ogygia selwini* fauna followed by the *Tetragraptus-Didymograptus extensus* fauna, in other words, the fauna which everywhere marks the basal Arenig beds of Wales, where as we have seen there is also evidence of a slight disconformity, which I have interpreted as marking the beginning of the retreatal phase of the Cambrovician pulsation, and corresponds to the *Dichograptus* stage. That the effect of the change from transgressive to regressive movement was felt in the eastern Shelve District is evident by the development of the Stiperstone ridge-forming quartzite, and it may very well be due to this initial negative movement, that the features of the disconformity were developed. That this negative movement was again followed by a moderate advance of the sea is shown by the succeeding fossiliferous beds of the Arenig. These, it will be of interest to note, carry a trilobite and brachiopod fauna in the lower part, while what appears to be the corresponding beds farther west in Wales carry graptolites. As shown by the table (D-II) graptolites only become abundant in the Upper Mytton stage (Col 5) and after that continue as an important element of the fauna. This is consistent with the supposition of a progressive shoaling of the region, with the retreat of the Arenig Sea.

The Stiperstone quartzite. This is a well-bedded, massive grayish-white or liver-coloured quartzite, with bands of conglomerate, and compacted by secondary silicification. Pellets of sandy shale are not infrequent and interleaved with the quartzite and conglomerates are thin bands of greenish-white soapy shales and fucoidal sandy flags. Deep-bluish black sandy shales are occasionally developed. The resistance of the rock with its steep inclination is responsible for the great ridge, known as the "Stiperstones" which extends north and south for 10 miles.

Ripple-marks are seen on surfaces of this rock, these usually being symmetrical, they have been interpreted as indicating wave lengths between 2 and 3 ft. and therefore shallow water. The only fossil reported is a fragment of a large *Calymene.*

Lord's Hill Beds. These form the lowest member of the Mytton flag series, which is the chief mineral-bearing group in this district, having been worked for lead in Roman time, later for zinc ores, but at present only for barytes.

The basal Lord's Hill flags are olive-green ribbed flags and grits, often fucoidal and not usually fossiliferous.

Ladywell and Snail Beach grits and flags. These form the second division of the Mytton flag series and consist of blue-black, rusty-weathering flags and grayish flags. They contain chiefly trilobites, brachiopods and mullusks, graptolites being comparatively rare. The fauna is given in Col 4 of Table D-II and the horizon is said to represent the lowest part of the *Didymograptus extensus* zone and may represent a part of the *Dichograptid* horizon.

The Shelve Church Beds. The road section at Shelve Church has long been well-known for Arenig graptolites. The list of the fauna is given in Col. 5, where it will be seen that we have a sudden increase in the number of the graptolites, which are the dominant forms, *Tetragraptus* and *Didymograptus* together with *Dictyonema* being the principal genera. These beds are correlated with the upper part of the zone of *Didymograptus extensus.*

The Tankerville Flags. These flags contain a few brachiopods and trilobites and in the intercalated shaly beds a number of characteristic graptolites including *Didymograptus hirundo,* to the lower part of which zone they are referred. The fauna is given in Col. 6. The beds are traversed by a thin dolerite dike.

The Hope Stage. In Hope Valley, this shows a nearly continuous section of nearly 800 ft. of blue-black shales with intercalations of China-stone[1] ash. Towards the Middle of the series, this China-stone ash is very massive, dividing the Hope shale into two divisions. It is a flinty gray rock, believed to be a subaqueous tuff deposit, showing banding but containing no fossils.

1 So-called because of its lutaceous texture which gives the rock a resemblance to porcelain, or "China-ware"

Lower Hope Shales. These are massive, rusty-weathering, blue-black shales, with no important bands of pyroclastic material. *Cyclopyge binodosa* is the leading fossil but other species also occur. The fauna is given in Col. 7 and the presence of *Didymograptus bifidus* indicates that it belongs to the Lower Llanvirn division.

Upper Hope Shales. Similar to, but generally more fissile than, the lower shales. Very fossiliferous at certain horizons and with intercalated layers of China-stone ash. The fauna is given in Col. 8 of the table, from which it will be seen that it is rather markedly distinct from the fauna of the lower horizon. Of interest is the presence of Bohemian trilobites such as *Cyclopyge monophthalmus*, *Acidaspis buchi*, and representatives of the genus *Palæura*, though the guide fossil is not reported, the assemblage still indicates that these beds belong to the Bifidus horizon.

The Stapely Volcanic group. This consists mostly of andesitic tuff and ashes, with some hypersthene and augite andesite lavas. The tuffs have been thought to be deposited in water, because intercalated shales carry graptolites and other fossils as shown in Col. 9 of the table. The rocks too, have been invaded by massive sills of andesite which probably represent volcanic activity, during the period of retreat or emergence. A volcanic agglomerate consisting of andesite pebbles, set in a coarse-grained matrix of andesite suggest the neighbourhood of volcanic vents. In many sections, the entire series is divided into 3 parts by an intermediate shale series. The fossils from the bedded pyroclastics of this division are indicated by the letter a in Col. 9. When in italics, *a* indicates that they occur both in the shales and in the pyro-clastics.

The Stapely Shales. Bluish-gray, rusty weathering soft shales with the fauna given in Col. 10. These beds still belong to the Bifidus zone, which thus includes some 1700 ft. of shales etc.

I have suggested that between these and the succeeding beds, there may be a disconformity, this suggestion being based wholly on the evidence from other regions which indicates a hiatus of greater or less extent, between the Middle and Lower Ordovician. As currently understood, the Bifidus beds or Lower Llanvirn belong to the Lower Ordovician, that is the Deepkill group of Eastern North America. On the other hand *Didymograptus murchisoni* is characteristic of the Upper Llanvirn, which is referable to the Middle Ordovician. This is represented in the Shelve District of Shropshire by the Weston and Betton beds, and although the zone fossil is only found in the latter series the assemblage of species in the former is such as to suggest a reference to the Murchisoni zone. This places the dividing line in the table between Cols. 10 and 11, and on consulting the table it will be seen that the number of fully identified species which cross the line is very small. Among graptolites, we have only *Glyptograptus dentatus* Brongniart, which is characteristic of the lower zone, but also is represented in the higher Murchisoni bed (Col. 12). Among brachiopods, *Lingula attenuata*, common in the lower beds, is also reported from the Weston or Lower Murchisoni series (Col. 11) and doubtfully from the Middleton beds of the Llandeilo (Col. 13.)

On the other hand *Siphonotreta micula* McCoy, is characteristic of both divisions of the Lower Llanvirn, and recurs in the upper part of the Upper Llanvirn and the Lower Llandeilo, (Cols. 12, 13.)

Among the trilobites *Ogyginus corndensis* Murchison, characteristic of the upper Llanvirn and lower Llandeilo, also occurs in the Upper Hope shale of the Arenig. (Col. 8.)

Aside from these four forms however, the faunas are entirely distinct and the question may be raised as to a possible doubt of the correctness of identification, or horizon of derivation, for the species in question. As will be seen there is also a change in lithological character, between the Stapely and Weston stages.

Weston Stage. This comprises a lower and an upper coarse-grained grit separated by bluish flags. The grits contain a high percentage of tuffaceous material and there is at least one bed of China-stone ash in the upper grit which differs from that in the Hope beds only, in not usually being banded. The grits are rarely fossiliferous but *Ogyginus corndensis*, *Modiolopsis*, *Ctenodonta* and *Bellerophon* (*Sinuites*) *bilobatus* have been obtained. The fossils of the stage are chiefly found in the Middle flags, but graptolites are unknown. They are listed in Col. 11 of the table.

The Betton Beds. These consist almost entirely of micaceous blue-black shales, with the fauna listed in Col. 12. Here *Didymograptus murchisoni* is an abundant graptolite.

The Llandeilo Series

Although this series does not come within the scope of the present discussion we may briefly characterize the several divisions whose faunas are given in the table.

Meadowtown Beds. Blue-black shales and flags, with beds of limestones and calcareous flags showing continuous transgression of the Middle Ordovician Sea. At the base occurs a bed with *Ogygiocaris buchi* and *Basilicus tyrannus*. The higher beds carry the additional species given in Col.

13. The abundance of *Diplograptus foliaceus*, suggests that this represents the zone of *Glyptograptus teretiusculus*.

Rorrington Beds. Blue-black shales, often appearing sooty. They have been divided into *Nemagraptus* beds below and *Leptograptus* beds above. The fauna as a whole is given in Col. 14.

The Caradoc Series.

Spy-Wood Grits. These mark an abrupt lithological change from the preceding shales but no stratigraphic break has been detected. They consist of flaggy calcareous sandstones, appearing fossiliferous where decalcified. They are interleaved with olive-green-weathering, grayish shales, which increase upwards and merge into the overlying series. The fossils so far described are given in Col. 15.

The Aldress Shales. Gray to greenish brown soft shales with occasional bands of tuffaceous material. These tuffs contain the fauna listed in Col. 16 marked by the letter a. From the shales themselves, the other species recorded in Col. 16 have been obtained. These beds indicate the zone of *Dicranograptus clingani*.

The Hagley Beds. This is a volcanic group with 2 sets of ashes and some lava separated by shales. Each volcanic group begins with white acid tuff and then becomes normally andesitic. This marks the beginning of the Caradocean volcanic activity, which culminated in the Hagley volcanic group. This contains tuffs which are often brecciated and agglomeratic. The Hagley shales are bluish with harder olive-green shales tending to be nodular. The shales carry both graptolites and other fossils as shown in Col. 17 of Table D-II. These indicate the base of the zone of *Pleurograptus linearis* or the top of the *Dicranograptus clingani* zone.

Marrington Beds. Bluish-black soft shales, weathering rusty, with the fossils given in Col. 18.

The highest bed of the Caradocean are apparently not found in this region nor is there any evidence of Ashgillian beds. This emphasizes the disconformity between these higher Ordovician and the succeeding *Pentamerus* beds of the Silurian. In the following table D-II the distribution of the faunas is given.

Table D-II

Cambrovician and Ordovician

Fossils of the Shelve

Country Shropshire

<table>
<tr><th></th><th></th><th></th><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td rowspan="4">Caradocian</td><td></td><td>Whittery Shales</td><td>18</td><td>×</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Hagley group</td><td>17</td><td>|</td><td></td><td>×</td><td></td><td>×</td><td></td></tr>
<tr><td></td><td>Aldress Shales[2]</td><td>16</td><td>|</td><td></td><td>|</td><td></td><td>|</td><td></td></tr>
<tr><td></td><td>Spy Wood grit</td><td>15</td><td>×</td><td></td><td>|</td><td></td><td>|</td><td></td></tr>
<tr><td rowspan="2">Llandeilo</td><td></td><td>Rorrington Beds</td><td>14</td><td>|</td><td></td><td>|</td><td>×</td><td>|</td><td></td></tr>
<tr><td></td><td>Meadowtown</td><td>13</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td rowspan="2">Upper Llanvirn</td><td></td><td>Betton Beds</td><td>12</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td></td><td>Weston grits & flags</td><td>11</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td rowspan="4">Lower Llanvirn</td><td></td><td>Stapeley Shales</td><td>10</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td></td><td>Stapeley Vol. Gr.[1]</td><td>9</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td></td><td>Upper Hope Sh.</td><td>8</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td></td><td>Lower Hope Sh.</td><td>7</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td rowspan="5">Arenig</td><td rowspan="4">Mytton Stage.</td><td>Tankerville Flags</td><td>6</td><td>|</td><td></td><td>|</td><td>|</td><td>|</td><td></td></tr>
<tr><td>Shelve Church beds</td><td>5</td><td>|</td><td>×</td><td>|</td><td>|</td><td>|</td><td>×</td></tr>
<tr><td>Ladywell & Snaibeach grits & Flags</td><td>4</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td>Lord's Hill beds</td><td>3</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td></td><td>Stiperstone</td><td>2</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
<tr><td colspan="3">Tremadoc. Habberley Sh.</td><td>1</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td><td>|</td></tr>
</table>

Graptozoa
1. Amplexograptus perexcavatus (Lapworth)
2. Callograptus sp.
3. Climacograptus bicornis (Hall)
4. Climacograptus scharenbergi Lapworth
5. Cryptograptus tricornis (Carr.)
6. Dendrograptus sp.

1 The fossils from the bedded pyroclastics of this group are marked a in colum 9

2 The fossils of the tuffs of this group are marked a in column 16. *a* in italics means that the species occurs in both divisions of the group

Table D-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Graptozoa (cont.)																		
7. Desmograptus sp.	—	—	—	—	×													
8. Dicellograptus divaricatus salopiensis E & W.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
9. Dicranograptus brevicaulis E & W.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
10. Dicellograptus rectus Hopkinson	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
11. Dictyonema cobboldi	—	—	—	—	—	×												
12. Dictyonema fluitans Bulman	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
13. Dictyonema fragile Bulman	—	—	—	—	×													
14. Dictyonema irregulare Hall	—	—	—	—	×	×												
15. Dictyonema shelvense Bulman	—	—	—	—	×													
16. Didymograptus acutidens E and W.	—	—	—	—	—	—	—	×	cfa	×								
17. Didymograptus affinis Nich.	—	—	—	—	—	—	—	×	—	×								
18. Didymograptus artus E and W.	—	—	—	—	—	—	×	×	×									
19. Didymograptus bifidus (Hall)	—	—	—	—	—	—	×	—	*a*	×								
20. Didymograptus extensus Hall	—	—	—	—	×													
21. Didymograptus hirundo (Salter)	—	—	—	—	—	×												
22. Didymograptus murchisoni (Bœck)	—	—	—	—	—	—	—	—	—	—	—	×						
23. Didymograptus murchisoni geminus (Hisinger)	—	—	—	—	—	—	—	—	—	—	—	×						
24. Didymograptus nicholsoni Lapworth	—	—	—	—	—	—	—	×										
25. Didymograptus nitidens (Hall)	—	—	—	—	×	×												
26. Didymograptus patulus (Hall)	—	—	—	—	×													
27. Didymograptus stabilis E and W.	—	—	—	—	—	—	cf.											
28. Didymograptus superstes Lapworth	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
29. Diplograptus foliaceus (Murchison)	—	—	—	—	—	—	—	—	—	—	—	—	×					
30. Diplograptus pristis (Hisinger)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	cfa	cf.	

Table D-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Graptozoa (cont.)																		
31. Glossograptus acanthus E and W.	—	—	—	—	—	—	—	—	—	cf.								
32. Glyptograptus dentatus (Brong.)	—	—	—	—	×	×	—	×	a	—	—	×						
33. Leptograptus latus E and W.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
34. Leptograptus validus Lapworth	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
35. Nemagraptus graeilis (Hall)	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
36. Nemagraptus gracilis remotus E and W.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
37. Orthograptus calcaratus acutus E and W.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
38. Orthograptus calcaratus basilicus (Lap)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
39. Orthograptus rugosus apiculatus E and W.	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	×	
40. Orthograptus truncatus (Lapworth)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
41. Orthograptus truncatus pauperatus E and W.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
42. Ptilograptus sp.	—	—	—	—	×													
43. Tetragraptus fruticosus (Hall)	—	—	—	cf.														
44. Tetragraptus headi (Hall)	—	—	—	—	×													
45. Tetragraptus serra (Brongn)	—	—	—	—	×													
Brachiopoda																		
1. Cliftonia spiriferoides (McCoy)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	cf.	—	cf.	cf.
2. Dalmanella rankini (Davids.)	—	—	—	—	—	—	—	—	—	—	—	—	cf.					
3. Dalmanella testudinaria (Dalm)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	cf.			
4. Dalmanella unguis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	aff	aff
5. Dalmanella sp.	—	—	—	—	—	—	—	×	a	—	—	×	×	—	×	a	×	
6. Discina sp.	—	—	—	×	—	—	×	—	—	—	—	—	×					
7. Harknessella sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	×	
8. Lingula attenuata J. de C. Sowerby	—	—	—	×	—	—	×	—	×	—	×	—	cf.					
9. Lingula granulata Phillips	—	—	—	—	—	—	—	—	—	—	×	×	×					

Table D-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Brachiopoda (cont.)																		
10. Lingula ramsayi Salter	—	—	—	—	—	—	—	—	—	—	cf.							
11. Lingula sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
12. Lingulella nicholsoni Calloway	×																	
13. Monobolina plumbea (Salter)	—	—	—	×														
14. Orbiculoidea sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
15. Orthis proava (Salter)	—	—	—	×	×	×	—	—	cfa									
16. Orthis turgida	—	—	—	—	—	—	—	—	—	—	—	—	—	—	cf.	—	aff	
17. Orthis sp. a.	—	—	—	—	×	×												
18. Paterula sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
19. Rafinesquina llandeiloensis (Davids.)	—	—	—	—	—	—	—	—	—	—	—	—	cf.					
20. Rafinesquina sp.	—	—	—	—	—	—	—	—	—	—	—	—	×					
21. Rafinesquina sp. (Corrugated form)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	×	
22. Rafinesquina sp. (Finely striated form)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
23. Siphonotreta nucula McCoy	—	—	—	—	—	—	—	—	×	×	—	×	×					
24. Sowerbyella sericea soudleyensis Jones	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	a		
25. Strophonella sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
Pelecypoda																		
1. Ctenodonta sp.	—	—	—	—	—	—	—	—	—	—	×	×	—	—	—	×		
2. Palæarca amygdalus Salter	—	—	—	—	—	—	—	×										
3. Palæarca sp.																		
4. Redonia anglica Salter	—	—	—	×	—	—	—	—	—	—	cf.							
Gastropoda etc.																		
1. Conularia sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
2. Hyolithes simplex (Salter)	—	—	—	—	—	—	×	×										

Table D-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Gastropoda etc. (cont.)																		
3. Hyolithes sp.	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	×		
4. Oxydiscus? perturbatus (Sowerby)	—	—	—	—	×	×												
5. Oxydiscus sp.	—	—	—	—	×													
6. Sinuites cf. bilobatus (Sowerby)	—	—	—	—	—	—	—	—	—	—	cf.	—	—	cf.	—	cf.		
7. Tetranota hippopus (Salter)	—	—	—	—	—	—	—	×										
Cephalopoda																		
1. Cyrtoceras? sp.	—	—	—	—	—	—	—	—	—	—	×							
2. Orthoceras avelini Salter	—	—	—	—	—	×	×	—	—	—	—	cf.						
3. Orthoceras encrinale Salter	—	—	—	—	—	—	×	×										
4. Orthoceras sericeum Salter	cf.																	
5. Orthoceras sp.	—	—	—	—	—	—	—	—	×	—	×	—	×	×	—	×	—	×
Trilobitæ																		
1. Acidaspis (Solenopeltis) buchi Barrande	—	—	—	—	—	—	—	×										
2. Acidaspis sp.	—	—	—	—	—	—	—	—	—	—	—	×	×	×	×			
3. Agnostus morii Salter	—	—	—	—	—	—	×											
4. Ampyx nudus (Murchison)	—	—	—	—	—	—	—	cf.	*a*	×								
5. Ampyx sp.	—	—	—	—	—	—	×											
6. Asaphellus homfrayi (Salter)	×																	
7. Barrandea cordai McCoy	—	—	—	—	—	—	—	cf.	cf.									
8. Barrandea (Homalopteon) portlocki Salter	—	—	—	—	—	—	—	—	×	×								
9. Basilicus tyrannus	—	—	—	—	—	—	—	—	—	—	—	—	×					
10. Calymene duplicata Murchison	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
11. Calymene sp.	—	×	—	—	×	—	—	×	*a*	—	—	—	—	—	—	—	—	×
12. Cheirurus sp.	—	—	—	—	—	×	×	—	×									
13. Cybele sp.	—	—	—	—	—	—	—	—	—	—	—	—	×					

Table D-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Trilobita (cont.)																		
14. Cyclopyge binodosa Salter	—	—	—	—	×	—	×											
15. Cyclopyge monophthalmus (Kloucek)	—	—	—	—	—	—	—	×										
16. Cyclopyge sp.	—	—	—	—	—	—	×											
17. Dionide richardsoni Reed	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	aff		
18. Homalonotus sp.	—	—	—	—	—	—	—	—	—	—	×							
19. Illænus perovalis Murchison	—	—	—	—	—	—	—	×										
20. Illænus sp.	—	—	—	—	×	—	—	—	—	×								
21. Illænopsis thompsoni Salter	—	—	—	—	—	—	—	×										
22. Ogygia (Niobella) selwyni (Salter)	—	—	—	×	—	×												
23. Ogygia sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
24. Ogyginus corndensis (Murchison)	—	—	—	—	—	—	—	×	cf	—	×	×	×					
25. Ogygiocaris buchi (Brongniart)	—	—	—	—	—	—	—	—	—	—	—	×	×					
26. Synhomalonotus murchisoni (Salter)	—	—	—	×														
27. Synhomalonotus parvifrons (Salter)	—	—	—	×														
28. Trinucleus (Cryptolithus) favus (Salter)	—	—	—	—	—	—	—	—	—	—	—	—	—	cf				
29. Trinucleus lloydi Salter	—	—	—	—	—	—	—	—	cf	—	—	—	×					
30. Trinucleus lloydi corndensis Salter	—	—	—	—	—	—	—	—	—	—	—	×	×					
31. Trinucleus murchisoni Salter	—	—	—	×	—	×	—	×										
32. Trinucleus sp. (broad form)	—	—	—	—	—	—	—	×										
33. Trinucleus sp.	—	—	—	—	—	—	—	—	a	×	—	—	—	—	×	a		
34. Trinucleus (Cryptolithus) sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×
Ostracoda																		
1. Leperditia sp.	—	—	—	—	×	×	—	×										
2. Primitia strangulata (Salter)	—	—	—	—	—	—	—	—	—	—	—	—	×	×	×			

Table D-II (*Concluded*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Ostracoda (cont.)																		
3. Tetradella complicata (Salter)	—	—	—	—	—	—	—	—	—	—	—	—	×	×	×	a		
4. Tetradella sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
Phyllopoda																		
1. Ribeiria complanata Salter	—	—	×															
Phyllocarida																		
1. Caryocaris sp.	—	—	×	—	—	—	—	×										
Cirripedia																		
1. Lepidocoleus sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	×				
Echinodermata																		
1. Palæura sp.	—	—	—	—	—	—	—	×										
Sponge spicules	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	×	

The Lake District and the Isle of Man.

The Lake District comprises the roughly circular mountainous area of ancient graywackes in Cumberland, Lancashire and Westmoreland Counties of Northwest England. A northsouth section shows in the center an anticlinorium formed by the great Skiddaw slate series, so-called from the mountain of that name (3054 ft.). This is flanked on either side by the Borrowdale volcanic series which formerly covered it, and this is in turn overlain by the Coniston limestone series followed by Silurian rocks. The Skiddaw shales are mainly of Arenig age but in their lower portion is included a series of beds referable to the Tremadoc. What lies below these is not known. The Borrowdale volcanic series, represents the great outpouring of lava, after the retreat of the Arenig sea, and probably during the advance of the Llandeilo sea, this sea finally covering the region in Caradocean time.

To the west these rocks appear in the Isle of Man, though there they seem to be strongly folded and largely unfossiliferous. This MANX SERIES, probably represents the lower part of the Skiddaw slates. In the east they are again seen in the Crossfell Inlier in the Pennine Range in Eastern Cumberland. In this Inlier, east of the town of Appleby, where the range rises to a height of 2930 ft, the strongly folded Skiddaw slates are covered unconformably by the Carboniferous limestone series, with the great Whinsill intrusion.

These Ordovician rocks are always much contorted and faulted and greatly affected by cleavage. Alteration by intrusive igneous rocks is also seen.

From a study of the graptolites of these slates Dr. Gertrude Elles,[1] was able to subdivide the series as follows.

Subdivision of the Skiddaw Slates.

SUPERFORMATION. Borrowdale Volcanic Series.

C UPPER SKIDDAW SLATES.
 2. Milburn slates. Llandeilo ?
 1. Ellergill Beds with *Diplograptus* and *Placoparia*. Llanvirn

B MIDDLE SKIDDAW SLATES.
 3. Upper *Tetragraptus* Beds. Upper Arenig.
 2. *Dichograptus* Beds. Middle Arenig
 1. Lower *Tetragraptus* Beds. Lower Arenig.

A LOWER SKIDDAW SLATES.
 2. *Bryograptus* beds. Tremadoc
 1. Lower horizons undetermined

The Lower Skiddaw slates (A2) have furnished the following graptolites.

Bryograptus kjerulfi
Bryograptus ramosus var, *cumbrensis* Elles
Bryograptus callavei Lapworth
Clonograptus tenellus (Linnrs.)

None of these occur in the Upper or Middle Skiddaw but they are all found below the *Phyllograptus* skiffer in Sweden.

Among the graptolites of the Middle Skiddaw the genera *Didymograptus*, *Phyllograptus* and *Tetragraptus* predominate, the former with 12 species and varieties, the

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1 Gertrude L. Elles. The graptolite fauna of the Skiddaw slates. Quart. Journ. of the Geol. Soc. of London. Vol. LIV, 1898, pp. 463-539.

2nd with 5, and the 3rd with 7 species and varieties. Among these *Didymograptus bifidus* passes into the upper Skiddaw slates as does also *D. indentus* Hall. *Didymograptus extensus* on the other hand is confined to the Middle division. To this are also confined all the species of *Phyllograptus* and *Tetragraptus*. The full list is given in Table E-II Col. 14. The Upper Skiddaw shales are also characterized by *Didymograptus bifidus*, which they have in common with the Middle, and by *Didymograptus indentus* Hall and var. *nanus*, and finally *Cryptograptus hopkinsoni* Nicholson.

The remaining 17 species however, are distinct, not being known in the lower beds of this region. Several however, have been obtained from the Arenig beds of St. David's and elsewhere, while several occur in the upper *Phyllograptus* shales and the higher shales of Sweden. Among the latter are *Diplograptus teretiusculus* (Hisinger), *Climacograptus scharenbergi* Lapworth, *Glossograptus armatus* (Nicholson) and *Glossograptus hincksi* (Hopkinson). These species suggest the possibility that a part of the series may be of later than Arenig age, or at any rate, that some Middle Ordovician graptolites have been included in some of the reworked volcanic ashes, which now have the characters of shales. The same thing is suggested by the presence of *Dicellograptus moffatensis* Carruthers, though this is also recorded from the Upper Arenig Beds of St. Davids.

As shown in the table of formations the Ellergill Beds are referred by Miss Elles to the Llanvirn and the higher Milburn Beds possibly to the Llandeilo. Unfortunately the thickness and character of this division are not given.

The Skiddaw slates are succeeded by the Borrowdale volcanic group, with a thickness of between 5,000 and

6,000 ft. These were called by Sedgwick green slates and porphyrys and consist principally of stratified feldspathic ashes, associated with contemporaneous traps. The ash beds are mostly cleaved, and in Cumberland and Westmoreland are known as Green Slates. The traps on the other hand are often porphyritic.[1] Nicholson has given a detailed description of the lower portion of this volcanic series and in 4 of his 5 sections, he shows the contact of the basal trap with the underlying Skiddaw slates. In all of these it is represented as an unconformable contact, the Skiddaw beds dipping at a very much steeper angle than the overlying Borrowdale series. Nicholson gives the angle of dip of the Skiddaw slates, in the Derwent water section, in Borrowdale as from 40 to 60 degrees, but he does not give the dip of the Borrowdale series. As given in his section Fig 1, the dip of the Skiddaw shales is approximately 60° and that of the Borrowdale group approximately 40°. However, he does not mention this discordance in the text and as I have been unable to find any reference to it elsewhere, I am in doubt as to this occurrence. If there actually is an unconformity, we would have here a tectonic disturbance between the Cambrovician and Ordovician pulsation, that is after the Arenig retreat and before the Middle Ordovician readvance. Such inter-pulsation orogeny has not yet been recorded from this horizon in western Europe, but by analogy with the later ones, we may well expect its existence. Moreover, as we shall see presently, such an orogeny has now been recorded by

1 Nicholson, Henry Aleyne. Notes on the lower portion of the Green slate and porphyries of the Lake District between Ulleswater and Keswick. Quart. Journ. of Geol. Soc. of London. Vol, XXVI, 1870, pp. 590-610, Figs. 1-5.

Czarnocky, from an even older horizon in the St. Croix Mountains of Poland, namely following the Mid-Cambrian retreat and so falling into the interval between the Mid-Cambrian and Cambrovician pulsation.

Hitherto, the emergent phase of the Cambrovician has been found to be characterized only by volcanic activity, but if it could be proved that an actual orogenic disturbance had taken place, it would help to complete the inter-pulsation series of orogenic movements so far recognized by Stille and others.

As shown most satisfactorily in the Derwent Water in Borrowdale, but reappearing again in the other sections, the basal bed of the Borrowdale Series is a massive dark-green and fine-grained feldspathic trap, in places rudely columnar, hut exhibiting no distinct crystals of any kind. This is directly succeeded by a great band of slates and breccias, the former being in reality a cleaved feldspathic breccia, some of the beds being so fine-grained as to lose their breccia nature. Some of the coarser rocks however, contain numerous angular fragments, from a quarter of an inch in diameter upwards, embedded in the light green feldspathic matrix. The fragments in the breccia are very like pieces of Skiddaw slate. There are also some subordinate beds of trap.

In general the succession is a similar one in other sections, though variations in the thickness of the members and the recurrence of trap sheets is recognized. So far, no fossils have been recorded from the Green Slates of the Borrowdale series and it is not impossible that some of the Llandeilo types of graptolites were actually obtained from these beds, as they were from the volcanic series of North Wales. This is recorded from the Crossfell Inlier, where dark slates with *Didymograptus murchisoni* are interstratified with the lower agglomerate[1]. The Llandeilan age of the Borrowdale series is generally accepted but it is also believed that these eruptions continued into the Carodocean.

The Carodocean beds overlie the Borrowdale with apparent concordance, and they mark a return of the sea to this region in Late Middle Ordovician time. They consist of calcareous and ashy shales and limestones, with beds of volcanic ash and layers of rhyolitic lava. The total thickness is very much less than in North Wales, but the proportion of limestone is greater. The fossils are mostly trilobites and brachiopods. They are in turn succeeded disconformably by the Ashgillean beds, including probably the Keisley limestone. The Caradocean and Ashgillean together have generally been referred to in this region as the Coniston limestone series, and they are succeeded by Silurian beds.

According to Marr[2] the *Tetragraptus* beds and the overlying Ellergill Beds contain the greatest number of trilobites hitherto discovered in the Skiddaw Slates. Marr gives a list of the graptolites of these beds, including *Didymograptus murchisoni*, but this is not given by Dr. Elles in her list, and she thinks that this is based on the misidentification of a large specimen of *Didymograptus bifidus* (*loc. cit* p. 467.) Strangely too, Marr cites *Phyllograptus angustifolius* from these Ellergill Beds.

The list of species from the Ellergill Beds, is given in Col. 3 Table E-II. Those recorded by Marr but not by Elles are marked by a vertical cross.

1 Lake & Rastall. Text book of Geology 1910, p. 321.

2 J. E. Marr. Notes on the Skiddaw slates. Geol. Magazine, New Series, Decade IV. Vol. I, 1894, pp. 122-130.

The Milburn beds represent a series of slates interstratified with volcanic rocks and according to Marr appear in the Crossfell area to form passage beds between the Skiddaw slates and the volcanic series of Borrowdale. Similar beds occur in many places in the Lake district. Marr records only *Didymograptus murchisoni* and *Diplograptus dentatus* from these beds. If these determinations are correct the beds evidently represent reworked ashes during an early and temporary readvance of the Middle Ordovician (Upper Llanvirn Sea).

Table E-II

Graptolites of the Skiddaw beds of the Lake District and their distribution elsewhere

	Skiddaw			Arenig St. Davids.			Arenig Shelve			Sweden, *Phyllo-graptus* Skiffer	Canada, Quebec Grp.	Deepkill of New York	Arenig of Australia	
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Graptozoa														
1. Azygograptus coelebs Lapworth	—	—	×											
2. Azygograptus lapworthi Nicholson	—	×												
3. Azygograptus suecicus Moberg	—	×	—	—	—	—	—	—	—	×				
4. Bryograptus callavii Lapworth	cf.	—	—	—	—	—	—	—	—	a				
5. Bryograptus kjerulfi Lapworth	×	—	—	—	—	—	—	—	—	a				
6. Bryograptus ramosus cambrensis Elles	×	—	—	—	—	—	—	—	—	a				
7. Climacograptus scharenbergi Lapworth	—	—	×	—	—	—	—	—	—	c				
8. Clonograptus flexilis (Hall)	—	×												
9. Clonograptus tenellus (Linnarsson)	×	—	—	—	—	—	—	—	—	a				
10. Clonograptus sp.	—	×												
11. Cryptograptus antennarius Hall	—	—	×	—	—	—	—	—	—	—	×	×		
12. Cryptograptus hopkinsoni (Nich.)	—	×	×											
13. Cryptograptus tricornis (Carr.)	—	—	×	—	—	—	—	×	×	×				
14. Dicellograptus moffatensis (Carr.)	—	—	×	—	—	×								
15. Dichograptus octobrachiatus (Hall)	—	×	—	—	—	—	—	—	—	×	×	×	×	

Table E-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Graptozoa (cont.)														
16. Dichograptus separatus Elles	—	×												
17. Didymograptus affinis Nich.	—	×	+	—	—	×	—	—	×	×				
18. Didymograptus bifidus (Hall)	—	×	×	—	—	×	—	×	—	b	×	×		
19. Didymograptus extensus (Hall)	—	×	—	×	—	—	—	—	—	×	×	×	×	
20. Didymograptus fasciculatus Nich.	—	—	×	—	—	—	—	—	—	×				
21. Didymograptus gibberulus Nich.	—	×	—	—	—	—	—	—	—	×	?	—	×	
22. Didymograptus gracilis Tornq.	—	×	—	—	—	—	—	—	—	×				
23. Didymograptus indentus (Hall)	—	×	×	—	—	×	—	—	—	—	×			
24. Didymograptus indentus nanus Lapworth	—	×	×	—	—	×	—	—	—	—	?			
25. Didymograptus nicholsoni Lapworth	—	×	+	—	—	×	—	—	—	×	—	cf.		
26. Didymograptus nitidus (Hall)	—	×	—	—	—	×	—	—	—	—	×	×	×	
27. Didymograptus patulus Hall	—	×	—	—	×	×	—	×	×	×	×	×		
28. Didymograptus v-fractus Salter	—	×	—	—	—	—	—	—	—	×	×			
29. Didymograptus v-fractus volucer O. H. Nich.	—	×												
30. Diplograptus appendiculatus Tornq.	—	—	×	—	—	—	—	—	—	b	—	—	×	
31. Diplograptus dentatus (Brongn.)	—	—	×	—	—	×	—	×	×	b	×	×		
32. Diplograptus teretiusculus (Hisinger)	—	—	×	—	—	—	—	—	—	c	×			
33. Glossograptus armatus (Nich.)	—	—	×	—	—	—	—	—	—	c				
34. Glossograptus fimbriatus (Hopk).	—	—	×											
35. Glossograptus hincksii (Hopk.)	—	—	×	—	—	—	—	—	—	c				
36. Leptograptus sp.	—	—	×											
37. Loganograptus logani Hall	—	×	—	—	—	—	—	—	—	×	×	×	×	
38. Phyllograptus angustifolius Hall	—	×	+	—	—	—	—	—	—	×	×	×	×	
39. Phyllograptus anna Hall	—	×	—	—	—	—	—	—	—	—	×	×		
40. Phyllograptus ilicifolius Hall	—	×	—	—	—	—	—	—	—	—	×	×		

Table E-II (*Concluded*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Graptozoa (Concl.)														
41. Phyllograptus ilicifolius grandis Elles	—	×												
42. Phyllograptus typus Hall	—	×	—	—	—	—	—	—	—	×	—	×	×	
43. Pleurograptus vagans Nich.	—	×												
44. Pterograptus sp.	—	—	?	—	—	—	—	—	—	b				
45. Schizograptus reticulatus Nich.	—	×												
46. Schizograptus tardifurcatus Elles	—	×												
47. Temnograptus multiplex Nich.	—	×												
48. Tetragraptus bigsbyi (Hall)	—	×	—	—	—	—	—	—	—	×	×	×	×	
49. Tetragraptus crucifer (Hall)	—	×	—	—	—	—	—	—	—	?	×			
50. Tetragraptus headi (Hall)	—	×	—	—	—	×	—	—	—	—	×			
51. Tetragraptus pendens Elles	—	×	—	—	—	—	—	—	—	×	—	×	×	
52. Tetragraptus postlethwaitii Elles	—	×	—	—	—	—	—	—	—	×				
53. Tetragraptus quadribrachiatus (Hall)	—	×	—	—	×	—	—	—	—	×	×	×	×	
54. Tetragraptus serra (Brongn.)	—	×	—	—	×	—	—	—	—	×	×	×	×	
55. Trichograptus gracilis Nich.	—	—	+											
56. Trichograptus fragilis Nich.	—	—	×											
57. Trigonograptus ensiformis Nich.	—	—	×	×	—	—	—	—	—	—	×	×	×	
58. Trigonograptus lanceolatus Nich.	—	—	×											
59. Trochograptus diffusus Holm.	—	×	—	—	—	—	—	—	—	×				

In column 10 — In col. 3. + = recorded by Marr only

a = occur in beds below *Phyllograptus* skiffer

b = Only in zone of *Phyllograptus cf. typus* of *Phyllograptus* skiffer and in higher beds.

c = occur exclusively in higher beds

The Southern Uplands of Scotland

A belt of Ordovician strata stretches nearly across Scotland from near the Firth of Clyde, to the Lammermoor Hills South-east of Edinburgh. These are strongly folded and in many cases stand vertically. On the north-west they are flanked by eruptive rocks and Old Red Sandstone, on the southeast by Silurian rocks similarly folded. In the cores of some of the anticlines of these Silurian rocks, the underlying Ordovician beds are exposed as in the famous Moffat region of Dumfrieshire. This is one of the two well-known localities which have been studied in detail, the other being at Girvan and Ballantræ on the south-east shores of the Firth of Clyde. A belt of this rock is continued south-westward in Ireland from Belfast Lough to the southern part of County Leitrim, though in this the older rocks are as a rule not well exposed. We shall consider only the Girvan and the Moffat Districts.

The Girvan Succession

Lapworth[1] has given us a detailed study of the Girvan rocks. I have previously given a summary of this section[2]. The Ordovician succession as given by Lapworth for this region is as follows.

1. Charles Lapworth. The Girvan Succession, Part I, Stratigraphy. Quart. Journ. Geol. Soc. of London 1882 Vol. XXXVIII, pp. 537-666 with 2 Geol. maps and many sections. *Ibid.* On the Ballantræ rocks of South Scotland and their place in the Upland sequence. Geol. Mag. New Series, Decade III, Vol. VI, 1889, pp. 20-24, 59-69 with sections and correlation table.
2. A. W. Grabau. Comparison of American and European Ordovicic formations. Bull. Geol. Soc. of America. Vol. XXVII, 1916, p. 575-578.

SUPERFORMATION: Upper Girvan Rocks, Silurian

Hiatus and Disconformity

II. LOWER GIRVAN ROCKS. Ordovician.

B. ARDMILLAN SERIES 2,500 ft.

d. DRUMMOCK GROUP 200 ft.

Dark gray mud-stones, with occasional flaggy bands, with *Trinucleus bucklandi* and *Ampyx rostratus*.

c. BARREN FLAG-STONES. 800 ft.

3. *Upper beds*. Thick-bedded pale flags with intermediary bands of buff-weathered shales, with *Diplograptus truncatus*.
2. *Middle beds*. Thick-bedded gray flag-stones, with parting of green and gray shales. No fossils.
1. *Lower beds*. Green shales with occasional flaggy bands, with *Nematolites* sp.

b. WHITE HOUSE GROUP 300 ft.

2. *Variegated mud-stones*. Red mud-stones, gray, green and black shales with *Dionide*, *Ampyx*, *Asaphus*, *Aeglina*, and *Dicellograptus complanatus*.

1. *Cement Stone Group.* Striped gray shales and mud-stones, with cement bands; contains *Leptograptus flaccidus* and brachiopods.

a. ARDWELL GROUP 1,200 ft.

3. *Cascade grits and shales.* Coarse grits with thick zones of striped shales contains *Dicellograptus forchhammeri* and *Climacograptus caudatus.*

2. *Middle Ardwell beds.* Zones of hard dark slaty flags, with seams and banks of dark flaggy shales, contains *Dicranograptus ramosus* and *Diplograptus rugosus.*

1. *Knockgerran shales.* Dark carbonaceous and pyritous shales with occasional cement bands; contains *Cryptograptus tricornis* and *Climacograptus scharenbergi.*

A. BARR SERIES. 850 ft.

d. BALCLATCHIE BEDS 100 ft.

2. *Grits and conglomerates* and ashy grits and boulder conglomerates.

1. *Fossiliferous mud-stones.* Thick zone of nodular green shale, highly fossiliferous.

c. BENAN CONGLOMERATE 500 ft.
Coarse boulder conglomerate, matrix sandy or gritty, colour usually gray or green.

b. STINCHAR LIMESTONE GROUP 150 ft.
4. *Didymograptus shales.* Calcareous and nodular shales, with *Didymograptus superstes* and *Dicellograptus sextans.*
3. *Compact limestones.* Hard, compact, flaggy limestones non-fossiliferous.
2. *Maclurea beds.* Nodular limestone, with *Maclurea logani.*
1. *Orthis confinis beds.* Impure calcareous beds with *Orth. confinis* etc.

a. KIRKLAND CONGLOMERATE 100 ft.
2. Transitional sandstones. Purple and gray sandstones and grits.
1. Purple boulder conglomerates. Boulder conglomerate, matrix usually

calcareous, colour purple
red and white.

Hiatus aud Disconformity

BALLANTRÆ SERIES. Lower Ordovician

No lower rocks exposed in this region.

The age of the Ballantræ series, was long in doubt, because of the great disturbance of the region around Ballantræ and the fact that higher Ordovician rock had been faulted down into the masses of older rock. Lapworth however in 1889, succeeded in eliminating all the later-formed elements, and to show on the basis of the graptolites, that the Ballantræ rocks proper represent the Arenig. The following graptolites were obtained by him from these rocks with their distribution elsewhere. To these are added the brachiopods obtained by Cowper-Reed.

The graptolites indicate a typical middle Deepkill fauna, that is typical Lower Ordovician.

Cowper-Reed[1] has described 3 brachiopods from the Ballantræ rocks. These are Nos. 10, 11 and 13 of the subjoined list.

The succeeding Barr Series, begins with basal conglomerate, which rests upon the eroded surface of the Arenig beds and consists of worn fragments of these rocks and volcanics associated with them. It contains pebbles of chert, black shale, lavas and tuffs, together with serpentine, gabbro, dolomite and even granite.

The succeeding Stinchar group begins with beds carrying *Orthis confinis*, *Orthis calligramma*, *O. flabellulum*

1 F. R. Cowper-Reed. The Ordovician and Silurian Brachiopoda of the Girvan District. Transactions of the Royal Society of Edinburgh, Vol. LI, Part 4, No. 26, 1917.

Table F-II

Fauna of the Ballantræ Series of the Girvan District and its distribution elsewhere

	Ballantræ Beds 1	Skiddaw Slates 2	Arenig. St. Davids 3	Point Lævis Quebec 4	Quebec Newfoundland 5	Phyllograptus shales Sweden 6	Phyllograptus shales Norway 7	Australia 8	Deepkill Beds 9
Graptozoa									
1. Phyllograptus typus Hall	×	×	—	×	×	×	×	×	×
2. Tetragraptus quadribrachiatus Hall	×	×	×	×	×	×	×	×	×
3. Tetragraptus bryonoides Hall (= T. serra (Brongn.))	×	×	×	×	×	×	×	×	×
4. Tetragraptus fruticosus Hall	×	×	—	×	×	×	×	×	×
5. Tetragraptus bigsbyi Hall (=T. similis Hall)	×	×	—	×	×	×	×	—	×
6. Didymograptus extensus Hall	×	×	×	×	×	×	×	—	×
7. Didymograptus bifidus Hall	×	×	×	×	×	×	×	—	×
8. Caryocaris wrightii Murch.	×	×							
9. Dictyonema sp.	×								
Brachiopoda									
10. Lingula crumenoides Reed	×								
11. Acrotreta (or Acrothele) sp.	×								
12. Obolella sp.	×								
13. Paterula balclatchiensis (Davidson)	×								

and *Strophomena expansa*, then follow the *Macleurea* beds, with *M. logani* which can be correlated with the Black River beds (Leray horizon) of North America and also occurs in Bessel's Bay, Arctic America. With it occurs *Tetradium peachi* Nich. and Etheridge, now referred to *Solenopora compacta* (Billings) of the Black River and Trenton of North America. The succeeding compact limestone contains *Saccamina* and *Girvanella*.

Finally the *Didymograptus* shales, No. 4, contain:

1. *Didymograptus superstes* Lapworth.
2. *Dicellograptus sextans* Hall
3. *Clathrograptus cuneiformis* Lapworth
4. *Glossograptus hicksi* Hopkinson
5. *Cryptograptus tricornis* Carruthers
6. *Diplograptus rugosus* Emmons.

All of these, except No. 4 are known from the Normanskill Beds of North America.

It is thus evident, that the Stinchar limestone group represents late Middle Ordovician, the sea returning to this region in Black River and Normanskill time, thus leaving precisely the same hiatus between it and the Ballantræ rock, that is found in Eastern North America, between the Normanskill and the Deepkill Series. The significance of the higher beds will be discussed in a subsequent chapter.

The Moffat District.

The Moffat region, which I had the good fortune to visit in 1910 under the guidance of the late Professor Benjamin Peach, presents us with a very monotonous series of fine-grained sandstones or graywackes, with interlaminated thin layers of black shales, almost identical in appearance and character with the Deepkill rocks of Eastern

North America. The black shales contain abundant graptolites for which this region is famous, while some of the sandstones contain the remains of Eurypterids, but other fossils are rare or absent. Thus, there is here a very interesting alternation of river-borne sediments, spread out on the river plain, which at irregular intervals was inundated by the sea, leaving the planktonic graptolites and probably the sea weeds, spread in a thin layer with the mud over the surface.

The black colour of the muds is probably due to the decomposing seaweeds as suggested by Lapworth. Then on the retreat of the sea, the river-borne sands, barren except for occasional Eurypterid remains, were again spread over the river plain or delta surface. Northwards, the graptolite-bearing beds, merge into unfossiliferous river-borne sands, thus showing the extent of the successive marine floodings. After careful plotting of these it has been possible to reconstruct a composite river delta on the border of the old Palæozoic Sea.[1]

The rocks of the Moffat region are subdivided as follows in descending order.

Birkhill Shales. Lower Silurian

Probable Hiatus and Disconformity

Hartfell Shales. Upper Ordovician
Glenkiln Shales. Middle Ordovician

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1 GRABAU, A. W. AND O'CONNEL M. Were the graptolite shales deep or shallow water deposits. Bull. of the Geol. Soc. of America. Vol. 28, pp. 959-964. Also GRABAU, A.W. Origin, Distribution and mode of Preservation of the Graptolites Memoir No. 7, of the Institute of Geology, National Research Institute China, 1929, pp. 1-52; GRABAU, A. W. Text of Geology Vol. II, p. 351 Fig. 1196

Hiatus and Disconformity

Ballantræ Beds. Radiolarian cherts, mud-stones and volcanic tuffs.

The Lower beds are the continuation of the Ballantræ beds of the Girvan District. The Glenkiln shales, which overlie them, contain *Nemagraptus gracilis*, and other Llandeilo graptolites, but *Didymograptus murchisoni* has not been found here thus indicating that those beds, present further south, are here overlapped.

The Borders of the Highland Boundary Fault.

One hundred miles northwest from Moffat, lies the little village of Aberfoyle, in Stirling County, Scotland. The distance is given across the strike and if the folds were flattened out, the separation between these points would be between 300 and 400 miles. Aberfoyle lies directly on the great boundary fault, which separates the Highland crystallines on the northwest from the Old Red Sandstone beds on the southeast. This fault extends in almost a straight N. E.-S. W. line across Scotland from coast to coast.

Seventy-five miles N. E. from Aberfoyle along the fault, the contact is crossed by the North Esk, this stream exposing a good section. 22 miles further in the same direction, we reach the shore at Stonehaven, from 12-15 miles south of Aberdeen, and here another good section is shown. The 3 localities mentioned show the presence of early Palæozoic rocks between the Boundary fault and the crystallines, and this marks the last known overlapping margins of the Cambrovician advance.[1]

1 B. M. Peach and J. Horne. Chapters on the Geol. of Scotland. Oxford University. 1930, p. 130 et seq.

Aberfoyle, Perthshire. (Approximate Long, 4° 20′ W, Lat. 56° 10′ N.) The narrow strip exposed in this vicinity, between the border fault and the Old Red sandstone, although only 100 yards to half a mile in width, comprises 2 series, a lower black shale and chert series, and an upper series, the Margie group.

The lower series is composed of cherts, cherty shales, black and gray shales and mud-stones passing downward into and interbedded with spilitic lavas. Fossils have been obtained from the gray muddy cherts and cherty shales, the fossiliferous band varying from 1 to 4 inches. The pure cherts are rich in Radiolaria. The following fauna has been obtained.

RADIOLARIA Indeterminate species.

GRAPTOZOA

Poorly preserved fragments referable to Diplograptidæ, (*Trigonograptus* or *Cryptograptus*) and to the Retiolitidæ.

BRACHIOPODA. *Obolus* sp.

Lingulella aff. *ferruginea* Salter
Lingulella aff. *nicholsoni* Callaway
Acrothele maculata Salter
Acrothele (*Redlichella*) *granulata* Linnrs.
Acrothele aff. *coreacea* (Linrs.)
Acrotreta nicholsoni Davidson
Acrotreta socialis von Seebach
Acrotreta aff. *sabrinæ* Callaway
Siphonotreta aff. *micula* McCoy
Siphonotreta aff. *scrotica* Davidson
?*Schizambon*

PHYLLOCARIDA (Leptostraca)
Modiolocaris dakynsi Peach
Other forms allied to
Lingulocaris and to *Peltocaris*

INCERTÆ SEDIS Various remains of Arthropods etc.

These fossils are strongly suggestive of an Upper Cambrian or Lower Ordovician horizon though a few brachiopods suggest possible Middle Cambrian.

"Taking the evidence of the fossils as a whole, we are justified in fixing the horizon of the Lower or Black shale and Chert series as Upper Cambrian or the passage beds between the Cambrian and Ordovician."[1]

The Upper or Margie Series rests unconformably (disconformably?) on the Lower series, and is composed of grits, shales and limestones, with a remarkable breccia at the base. This breccia consists of large angular fragments of cherty shales, resembling some of the bands in the underlying series. Other materials in these breccias are: Vesicular and altered palagonite which is most abundant. Pieces of spilitic lava with well preserved feldspar occur and quartz, pieces of cherty mud-stone, and shale are found.

This is overlain by the quartzitic grits with feldspars, mica etc. the quartz and feldspar being apparently derived from the disintegration of granitic rocks.

Higher, and separated from these beds by beds of serpentine, with which it is in fault contact, is a crystalline limestone, much brecciated and veined with calcite. This

1 Jehu, T. H. and Kendal. The Highland border rocks of the Aberfoyle District. Transactions, Royal Society Edinburgh Vol. LII, Part I, 1917, pp. 175, (193-4)

Aberfoyle or Upper Dounans[1] limestone contains plates of crinoids, fragments of calcareous algæ and round bodies apparently referable to the Foraminifera.

Though the fossil evidence is unsatisfying the Margie Series is believed to represent at least the early Ordovician. Apparently however, it represents the Mid-Ordovician transgression, while the underlying series represent the Cambrovician series. Both series are intruded by igneous rock.

Section in the North Esk. This river crosses the boundary fault at right angles in approximately Long. 2^0 40′ W and Lat. 56^0 45′ N. The Lower Palæozoic rocks form a narrow lenticular strip, between the Highland schist on the N. W. and the boundary fault that truncates the Old Red Sandstone, on the S. E. The largest strip is about 20 miles long and about 3/4 of a mile broad, where it is cut by the North Esk River. The 2 divisions, the Lower or *Jasper and Green Rock Series* and the Upper or *Margie Series*, form a closed anticline, the rocks standing more or less vertically. The central portion is formed by the closely folded Lower series and is flanked on either side by the Margie Series, but the contacts in all cases are fault contacts. The contact with the Old Red on the southeast is likewise a fault and on the North-west, the Highland series is thrust over the Margie Series at a moderate angle. Both series are intruded by igneous rocks. The succession in descending order is as follows.[2]

1 Locality about 1 mile N. E. of Aberfoyle, where the rocks is quarried; the correlation with the Margie limestone of other sections is presumptive.

2 G. Borrow. On the occurrence of Silurian? rocks in Forfarshire and Kincardineshire, along the eastern border of the Highlands. Quart. Journ, of the Geol. Soc. of London, Vol. LVII, 1901. p. 328, et. seq.

North Esk Section

MARGIE SERIES.

5.	Gray shales	
4.	Pebbly limestone. Lenticular, quarried.	1-5 ft. thick
3.	Dark carbonaceous gray, chocolate coloured, and white shales	about 20 ft.
2.	Pebbly grits, with carbonate of iron cement, becoming coarse towards the base	about 120 ft.
1.	Green conglomerate, local occurrence	about 30 ft.

Assumed Hiatus and Disconformity

JASPER AND GREEN-ROCK SERIES

4.	Fine grit, with microcline pebbles	
3.	Fine shales, always cleaved, with a pseudo-crystalline aspect.	
2.	Jasper, (altered radiolarian chert ?) sometimes replaced by jaspery phyllite.	6 ft.
1.	Green rocks, mainly lenticular sills of ophitic dolerite, though some lava flows may also be present. (Upper part only exposed)	

The total thickness cannot be ascertained because of the repeated close folding of the rocks. No fossils are recorded from these strata.

Stonehaven.[1] On the east coast of Scotland at Stoneheaven, approximately Latitude 56° 58′N, a section of these rocks is again exposed. Here the gneiss of the Highland series is in fault contact with a group of cherts, jaspers and black cherty shales, which occur chiefly as intercalations between ancient lava flows, which have become much sheared and folded.

These rocks are unconformably overlain by beds of Downtonian age, which dip steeply seawards and are truncated into a coastal shelf, partly submerged at high-tide. The dark cherty shales have furnished fossils, in which Walcott has recognized *Obolus* (*Broggeria*) *salteri* Hall, and slender shells, suggesting *Hyolithellus*, and a fragment of a Phyllopod. A small species of *Lingulella* may be compared to *Lingulella nicholsoni*. *Obolella*, *Acrotreta*, *Linnarssonia* and *Siphonotreta*, were also identified by Dr. Peach and the age of these rocks has been determined as most probably Upper Cambrian.

It is thus apparent that the transgression of the Caledonian Sea in Cambrovician time, extended to the present southern border of the Scottish Highlands, the line of maximum advance being approximately marked by the great boundary fault of much later date, which separates the Highland gneisses from the younger rock series on the southeast. From Stonehaven, the line continues into Southeastern Norway, passing west of the Oslo region and turning northward into Jemtland in Sweden, then swinging off south-

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1 R. Campbell. The Geology of Southeastern Kincardineshire. Transactions Royal Society Edinburgh, Vol. XLVIII, Part IV, 1913, pp. 923 et. seq.

eastward to follow in a general way, the southern border of Finland and thence extending eastward north of the present parallel of 60°. We shall next discuss some of the important sections along the northern border land.

Summary of the British Cambrovician

The Transgressive Series.

As will be seen from the map Pl III-b, the probable extent of the Cambrovician transgression in Western Europe reached the borderland of the Highland country some small distance beyond the present Highland border fault, between Aberfoyle and Stonehaven. Here the Cambrovician series is represented only by the highest transgressive portion, probably the Cambro-Ordovician passage beds, though in some sections, only the Upper Cambrian portion seems to have been preserved. These rocks are generally disconformably overlain by beds which though they have yielded no characteristic index fossils, nevertheless are judged to represent the mid-Ordovician transgression. They are followed by Downtonian rocks, which in some cases rests directly on the lower series.

If we prolong this line southwestward it skirts the northern and western border of Ireland, where the rocks of Counties Galway and Mayo in the vicinity of Loch Ness previously described, are present.

Unfortunately the base of the West Irish section is not exposed, so it is not possible to say what the lowest beds are, nor how far westward the transgressive series extended. From the fact however, that the Arenig beds are represented by the Mount Partrie series, with a thickness of 1300 ft. or more, it is evident that the old land which supplied the sediment for these beds must have extended for a great distance further to the west. These beds are continental river deposits, often coarse and conglomeratic but with graptolite layers above the middle, these representing the horizon of *Didymograptus hirundo* i. e. late Arenig Beds. Since these beds represent a late stage of the retreatal series, the evidence furnished by the marining of these beds suggests that the previous transgression must have been considerably further westward and probably a good distance beyond the present western coast of Ireland, beyond which extended the unsubmerged old land. As we have seen, these beds are disconformably succeeded by members of the later Middle Ordovician series *i. e.* beds of Chazyan age.

The second belt of strata, which parallels the first are typically shown in the Girvan and Southern Upland region of Scotland. At the best studied locality in the Girvan district the Ballantræ series represent the Cambrovician and these as we have shown also belong to the regressive series, that is, they represent the *Didymograptus extensus-Tetragraptus* horizon. The transgressive series here is not exposed, but as we have seen extended for a long distance towards the northwest.

This belt can be traced south-westward to the Belfast Loch and thence in a direct line to County Leitrim not far from the central portion of North Ireland. If we prolong this line, we reach the Loch Mask region and it may be more correct to regard these two regions as approximately representing the same locus of retreat.

As a matter of fact, when we consider that the Loch Mask Arenig Beds, below the disconformity, represent the Hirundo zone, whereas the Ballantræ series represents the much lower Extensus zone, it might seem as if the former belonged to a later stage in the retreat than the latter.

But as this takes no account of the possibility of differential erosion during the period of emergence, it is perhaps safer to consider the two as representing points on the same line of retreat. But it must be noted that the transgressive beds of the Irish Ordovician series, belong to a lower horizon than do those of the Girvan and Moffat region which may be correlated with the American Normanskill.

The 3rd of our parallel belts passes through the Lake District, the Isle of Man and the eastern coastal districts of Ireland, where they are exposed in the counties of Wicklow and Wexford.

In the Lake District, the great series of Skiddaw slates, form the lowest exposed rocks and the lowest members of these are referable to the Tremadoc, carrying *Bryograptus* and *Clonograptus*. It is of course impossible to say how much of the underlying, unexposed series represents Upper Cambrian, but in view of the fact that the Cambrian transgression extended to the Highland border, it must be evident that a considerable portion of Upper Cambrian strata must underlie the Tremadoc beds of this region, though the lower parts of the Upper Cambrian may be absent by overlap.

If we carry this line northeastward parallel to the line of maximum transgression (see map Pl. III-b) it would pass through the southern provinces of Sweden and it is at least possible, that beds comparable to the Swedish Upper Cambrian are present in the Lake District. Beds of Cambrian age are indicated on the Isle of Man in the Geological map of Great Britain. These beds are much metamorphosed and little is known of them. In Counties Wicklow and Wexford, the strata are much disturbed, and only in a small area, in the promontory of Rosslare are they apparently in contact with the pre-Cambrian crystallines. They comprise massive and purplish red and green shales, slates, grits, quartzites and schists, and apparently attain a thickness of several thousand feet. However, they have so far yielded only the strange markings known as *Oldhamia*, and numerous burrows and trails of annelids, among them the following:

Histioderma hibernicum
Arenicolites didymus
Arenicolites sparsus
Haughtonia poecila

Unless evidence of marine fossils is found, these beds will probably have to be regarded as a Huangho type of deposit of the Upper Cambrian, or possibly even as Arenig beds, which otherwise seem to be largely if not wholly absent, those of Middle Ordovician (Glenkiln and higher) age being the oldest known fossiliferous formations.

This would of course imply that our belts are not parallel as we have assumed, but swing around to the south and east in southern Ireland. This however leaves out of consideration the possibility that the old pre-Cambrian sea floor might have been characterized by marked irregularity, nor does it take account of the differential erosion in the Cambrovician-Ordovician interval.

Accepting for the moment the assumption of parallel belts, out next one evidently passes through North Wales, in the general direction of the Lleyn promontory of Cærnarvonshire and the Harlech dome of Marionethshire. Here, as we have seen, the Upper Cambrian is developed in full force, but to a very large extent as continental sediments, which have suffered repeated submergence and the inclusion of fossiliferous layers. The lower or Mæntwrog series still contains a fair number of marine fossils, but the Ffestiniog flags from 2000 to 3000 ft. in thickness are very largely continental deposits of the Huangho type, with marine beds only in the upper 50 ft. This extensive river-spread series is followed by a renewed marine series, the Dolgelly and Tremadoc beds with a thickness ranging to more than 1,000 ft, and consisting of more or less fossiliferous shales. This may then be regarded as the transgressive deposit and the thickness of these deposits is more or less commensurate with the Upper Cambrovician sea extension, as indicated by the outermost shore-line of our map.

The Retreatal Series.

Throughout North Wales, the evidence for a disconformity between the transgressive series terminating with the Tremadoc and the retreatal Arenig, appears to be conclusive. In the Tremadoc region itself, the basic Ordovician bed is a quartzose pea-grit, resting on a slightly rough surface, with some shallow erosion pockets in the Garto Hill or Upper Tremadoc beds. It is however, impossible to determine the age of this bed as it is without fossils and it may belong to the transgressive series of the Middle Ordovician. Elsewhere in this section the Middle Ordovician beds are in fault contact with the next lower division of the Tremadoc *i. e.* the Penmorpha beds. Farther west however, in the Criccieth region, a massive feldspathic grit overlying the Tremadoc, contains the *Monobolina plumbea* and *Ogygia selwini* fauna and therefore represents lowest Arenig. In the St. Tudwal's peninsula the disconformity is pronounced, for there basal Arenig St. Tudwal's sandstone rests upon the Ffestiniog, both the Tremadoc and the Dolgelly being absent. The St. Tudwal's is primarily a river deposit with occasional rare graptolite intercalations, the horizon being that of *Didymograptus* *extensus*. Thus the older *Dichograptus* beds are absent and this has all the appearance of retreat followed by transgression in Arenig time. It can however be explained by a rather marked elevation of the Old Land at the beginning of the retreatal period with resultant erosion, corresponding to the period of the oldest Arenig, *i. e.* the *Dichograptus* beds. This is followed by the deposition of river-borne sands, through backward aggrading in the Ex-tensus epoch, these river beds showing slight marining as indicated by the graptolites. The highest beds of this section carry *Azygograptus lapworthi*, a species characteristic of the Upper Skiddaw slates of the Lake district. Above this and marking the Ordovician-Cambrovician hiatus is an oolitic iron ore, followed in turn by shales with Glenkiln or Normankill graptolites. The question of faulting here has been raised to account for the hiatus, but in view of the abundant evidence of an inter-pulsation hiatus elsewhere, such an explanation is not needed.

In the Arenig Mountain, the Tremadoc-Arenig disconformity is also recognized and here too the basal sands, 50-100 ft. in thickness and of purely continental origin, rest upon the *Asaphellus homfrayi* beds of the Tremadoc and in one section even upon the *Peltura* beds of the Dolgelly. Again the indication is of a retreat followed by erosion in Tremadoc, and transgression in Lower Arenig time, and the problem here becomes one of the magnitude and extent of this hiatus. In other words, is it a local feature incidental to the beginning of the retreat due primarily to rise of the Old Land, or is it of the value of a pulsation? I believe the evidence is against the latter and in favour of the former, but it is important that the problem be more thoroughly studied.

Of one thing I think we may feel confident, that it is not a hiatus of sufficient magnitude to permit the interpolation of an Ozarkian system, represented in its type region by several thousand feet of dolomitic rocks.

That there was actual marine transgression in addition to the slight marining indicated by the graptolite beds is shown by the occurrence of fossiliferous beds in the succeeding Arenig series, especially the Erwent limestone with the *Ogygia selwini* fauna.

In that section the Arenig is terminated by the *Didymograptus bifidus* beds, after which begins the great volcanic series, which as I view it, marks the emergence of the region and which is in turn succeeded by beds with *Didymograptus murchisoni*. *D. bifidus* and *D. murchisoni* both belong to the dependent or "tuning-fork" graptolites, strikingly distinct from the type of graptolites found in the lower beds, and as is well-known, the two series together form the Llanvirn division of Hicks. It is indeed strange, that these two similar graptolites should be distributed the one in the lower and the other in the higher series, if these two series are separated by a pronounced hiatus. And yet there seems to be no escape from this when we take into consideration the almost universal evidence for such a hiatus. It might of course be argued that the hiatus does not exist in Britain and this might be conceded if we could accept the existence of an Atlantic Ocean in this period and believe that it was the source of the graptolite fauna of these shales. But as we have already repeatedly shown, the existence of the Atlantic involves so many other difficult questions, that we are no nearer a solution of the problem.

The evidence for the basal Arenig disconformity is less pronounced in the Dolgelly region, there being no physical features to indicate it except the abrupt change from the Tremadoc shale to the sandy grits and flags of the Arenig. As usual these basal grits are continental sediments from 150-200 ft. in thickness and they are readily interpreted as the first sedimentation effect of the change from transgression to regression, with possible elevation of the Old Land. Here the evidence for volcanicity is found in the immediately overlying beds, some of the shales of which carry graptolites indicating *Didymograptus hirundo* succeeded by the *Didymograptus bifidus* zones. These shales, ashes aud minor rhyolitic flows comprise a thickness of some 1500 ft. and are followed by the great Basic Volcanic Series, which marks the interval of exposure between the Cambrovician and Ordovician. The beds immediately overlying the lava belong apparently high in the Llandeilo series thus making the hiatus a very pronounced one.

In South Wales, the Tremadoc is mostly cut out by faulting, beds formerly regarded by Hicks as of that age, now being referred to the Arenig. They have however, been found in the neighbourhood of Caermarthen, where they are characterized by *Parabolinella*, *Peltura* and *Ogygia marginata*. This last species again occurs in the succeeding Arenig beds, associated with *Phyllograptus* cf. *angustifolius* etc. This suggests that the basal Arenig disconformity does not occur here. As a rule, the Arenig beds of South Wales are dominantly shales, while graptolites of the genera *Callograptus*, *Dendrograptus*, *Tetragraptus* and *Didymograptus* characterize the lower graptolite beds. These are more generally spoken of as *Tetragraptus* beds, and probably represent the zone of *Didymograptus extensus*. The *Dichograptus* zone is apparently unrepresented by fossiliferous strata, as in North Wales, or else represented by trilobite-bearing beds with *Ogygia marginata*, *Calymene*, *Asaphus* etc. Both the zones of *Didymograptus hirundo* and *D. bifidus* are represented, some beds of the latter being also characterized by trilobites, with *Placoparia cambriensis* Hicks as the leading form. (*Placoparia* fauna).

The Middle Ordovician throughout this section begins with beds carrying *Didymograptus murchisoni*, and while this is very generally in direct contact with the Bifidus beds, so that the hiatus, if it exists, is masked, the two series in some sections are separated by the ash beds and rhyolite flows of the Llanrian volcanic series, which may reach a thickness of 500 ft. The higher graptolite fauna with *D. murchisoni* is also found in the reworked volcanic ashes.

If we draw the line from South Wales parallel to those previously referred to, it passes through the Shelve and Wreking Districts of Shropshire.

In this region the Upper Cambrian is represented by the *Orusia* shales, about 500 ft. thick which rests with a pronounced disconformity on the Middle Cambrian *Paradoxides* shales. These are succeeded with apparent conformity by the Shineton Shales, with an estimated thickness of probably 3000 ft. This series is richly fossiliferous with *Dictyonema* and trilobites in the lower beds, *Clonograptus*, *Bryograptus* and trilobites in the middle and brachiopods and trilobites in the upper. The highest beds are arenaceous, and in the Wrekin and Comley exposures are succeeded disconformably by beds of Caradocian age. This signifies either an early Arenig retreat or what is more likely a doming and pronounced erosion with the removal of all the Arenig beds, this region continuing as land into Caradocean time.

The Arenig Beds are well-preserved less than 5 miles farther to the west in the Shelve country. Here the basal

Arenig quartzites, the Stiperstones, are in abrupt contact with the sandy shales of the Upper Tremadoc and the existence of a disconformity is suggested. The succeeding beds however, are characterized by trilobites and brachiopods while graptolites become more characteristic of the higher Arenig beds, concomitantly with the progress of the retreat of the sea. The upper beds of the Cambrovician series, that is the *Didymograptus bifidus* beds, include volcanic ashes and some lava flows, but no pronounced volcanic series marks the dividing line between the Upper and Lower Llanvirn. There are however, ash beds of the "China-stone" type in the Weston grits, which appear to be referable to the higher series, though *Didymograptus murchisoni* does not occur below the next succeeding shales, the Betton Beds. If the hiatus exist here between the higher and lower division, it is scarely marked physically, though there is a significant change in fauna.

Finally it may be noted that in the Malvern Hills section, the Upper Cambrian rests disconformably upon the Lower, the Middle being entirely absent. The Upper Cambrian Beds are followed conformably by Tremadoc slates, these in turn being disconformably succeeded by the Mayhill sandstone of Silurian age.

THE CAMBROVICIAN OF NEWFOUNDLAND AND EAST CANADA

Newfoundland.

The Middle Cambrian bed of South-eastern Newfoundland have been described on pages 426 to 444 in Vol. I (*Vol. IV, p. 622-640*). These beds are disconformably succeeded by shales and sandy beds ranging from the Upper Cambrian to the Lower Ordovician and possibly higher.

The succession of these later beds is according to Howell[1] as follows:

CAMBROVICIAN.

ARENIGIAN

7. LINGULA FRASERI BEDS

Black shales, sometimes phosphatic, contain,

Lingula fraseri
Schizocrania striata

These beds may possibly be of Middle Ordovician age.

6. WABANA SERIES.

Black and gray shales, sometimes phosphatic and pyritiferous, gray sandstones and red oolitic hematites. Contains the following

Synhomalonotus chambersi
Hemigyraspis cantleyi
Lingula leseuri
Schizocrania hayesi
Didymograptus nitidus

These beds are referred to the Middle and Upper Arenig.

5. BELL ISLAND SERIES.

Brown and gray sandstones and shales, white sandstone and, at the top, red oolitic hematite. The following fossils have been obtained.

Obolus burrowsi

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1 B. F. Howell. The Cambrian-Ordovician Stratigraphic column in south-eastern Newfoundland. The Canadian Field Naturalist Vol. XL, No. 3, pp. 52-57, *1926*?

Sphærobolus fimbriatus
Lingulobolus affinis
Lingula hawkei
Lingula murrayi
Lingula howleyi
Lingulella billingsi
Lingulella bella

(These beds are referred to the Lower Arenig.)

TREMADOCIAN.

4. CLARENVILLE SERIES.

Gray and brown shales, with a sandy limestone near the top in at least one locality. The following species have been obtained.

Shumardia sp.
Princetonia terranovica
Parabolina harrieta
Niobe howelli
Bellerophon randomi
Bryograptus sp.

(These beds are correlated with the Tremadoc and possibly older beds of western Europe.)

UPPER CAMBRIAN

3. ORUSIA LENTICULARIS BEDS.

Black and brown shales and thin sandstones with
Orusia lenticularis.

2. ELLIOT COVE SERIES.

b. *Olenus* zone. Black shales and thin gray sandstone with *Olenus* and *Agnostus pisiformis obesus*

a. *Agnostus pisiformis* zone. Dark shales with *Agnostus pisiformis.*

1. BASAL BEDS.

Dark sandy shales, with no fossils,

Hiatus and Disconformity

SUBFORMATION.

MIDDLE CAMBRIAN *Paradoxides davidis* beds.

The character of the basal beds (No. 1) has already been described on p. 426 of Vol. I. As there stated Walcott considered the highest bed of Howell's *Pardoxides davidis* zone, that is Bed 125, as a basal conglomerate and with this he begins the Upper Cambrian. Howell's objections to this were also given. He thinks that part of the shales which lie between the *Paradoxides* Beds and the *Agnostus pisiformis* beds, and which have a thickness of about 30 ft. may prove to belong to the *Paradoxides forchhammeri* zone, in which case the Upper Cambrian would begin with the *Agnostus pisifoımis* zone of the Elliot Cove series.

The total thickness of the Cambrian and Lower Ordovician Beds of the Conception Bay region of Newfoundland, has been estimated by the late Professor van Ingen at about 10,000 ft. Since the known Middle and Lower Cambrian of this section totals barely 400 ft., (396 ft.), this would leave a thickness of approximately 9,600 ft. for the Cambrovician, an enormous development when compared with that of western Europe where, moreover, the beds are so largely represented by sandstones. It is of course possible that the thickness of the series in Conception Bay is overestimated, owing to the existence of unrecognized faults, but even so, it is probably very great.

This is easily understood, when we consider this section, on the geographic basis of a Pangæa (see Pl. III), when it would hold the same relation to the Old Land as the formations of Wales and North England, but as an Atlantic border deposit, the thickness seems excessive. That the fauna of these beds is intimately related to the corresponding fauna in Western Europe is as apparent as is the close relationship between the Middle and Lower Cambrian faunas of the two regions and there can be no question that they belong to the same palæogeographic province.

The *Agnostus pisiformis* zone has its counterpart in the Scandinavian region, as has also the *Agnostus pisiformis obesus* zone. The *Orusia lenticularis* zone No. 3, characterizes the Upper Cambrian of the Shropshire sections and the Dolgelly Beds of Wales and the several zones of the European Tremadoc are equally indicated in the Claronville Series. The higher beds likewise show very close faunal relations, to the equivalents of Western Europe.

Cambrovician Beds of New Brunswick.

The Cambrovician beds as exposed within a radius of 20 miles of St. John New Brunswick, comprise the following according to Matthew in descending order:

SUPERFORMATION

Silurian or younger.

Hiatus and Disconformity or unconformity

CAMBROVICIAN

Bretonian of Matthew (Division 3 of St. John Group) 700 ft.

3e? Gray sandstone with *Leptobolus grandis*

3d. Fine black shales with *Tetragraptus quadribrachiatus*, *Didymograptus*, *Parabolinella*, and *Cyclognathus*.

(3d and 3e represent the European Arenig.)

3c. Fine black shales

3c2 Beds with *Asaphellus*, *Parabolinella*, *Triarthrus* and *Bellerophon*.

3c1 Beds with *Dictyonema flabelliforme* *Monobolina*, *Schizambon* and *Acrotreta*. (Division 3c can be correlated with the Tremadoc of Western Britain)

3b. Fine black shales with *Peltura scarabæoides*, *Sphaerophthalmus*, *Leptoplastus* and *Ctenopyge*.

3a. Dark gray shales, with *Parabolina spinulosa*, *Agnostus*, *Anomocare* and Orthoid brachiopods.

(Divisions 3a and 3b are correlated with the Dolgelly of Wales.)

Johannian of Matthew (Division 2 of the St. John Group) 750 ft.

2c. Gray shales and flags with *Lingulella radula*.

2b. Gray flags and sandstone, with *Lingulella starri*.

2a. Gray flags and slates with worm burrows etc.

(These beds probably represent only a part of the Ffestiniog)

Hiatus and Disconformity

SUBFORMATION. Middle Cambrian *Dorypyge* beds.

Though the lower beds of the Johannian are frequently placed in the Middle Cambrian, and regarded as representing the Forchhammeri zone, this is due to the non-recognition of the hiatus, which cuts out not only the upper part of the Middle Cambrian but also the lower part of the Upper Cambrian (See Vol. I, p. 425 (*S.Q. Vol. IV, p. 621*))

Cambrovician Beds of Cape Breton

In this region the Cambrovician beds are more fully developed and are also more fossiliferous than in the St. John region. The Johannian beds consist of micaceous gray slates, flagstones and quartzites, which are iron-bearing in the Myra Valley.

The Lower beds 2a, which are unfossiliferous in the St. John region here contain *Lingulepis exigua.* These as well as Divisions 2b and 2c were originally referred by Walcott to the Middle Cambrian representing the Forchhammeri and higher zones. As such their fauna has been included in Col's 12, 13 and 14 of Table M. Vol. I, pp. 427-435. But it is far more probable that these beds represent at least part of the Ffestiniog Division of the British Upper Cambrian and their fauna is again given in Cols 1-3 Table G-II.

The Bretonian Division (3) of Cape Breton consists of dark gray to black carbonaceous shales often changed to slates. Intercalated within them are a few thin seams and lentils of dark limestones and some thin flags. Division 3a and 3b are referable to the Dolgelly. The fauna of these are given in Cols. 4 and 5 respectively. Division $3c_1$ and $3c_2$ probably represent the Tremadoc and these are given in Cols. 6 and 7 of Table G-II. Division 3d, where developed, carries *Tetragraptus* and *Didymograptus* and is referable to the Arenig. In Table G-II, the faunas of the several Cambrovician divisions of Cape Breton, New Brunswick and Eastern Newfoundland are given.

TABLE G-II

CAMBROVICIAN FAUNA OF THE MARITIME PROVINCES OF CANADA AND EASTERN NEWFOUNDLAND.

Cols. 1-8. Cambrovician Beds of Cape Breton.

Col. 1. Division 2a of the Johannian.

Col. 2. Division 2b of the Johannian.

Col. 3. Division 2c of the Johannian.

Col. 4. Division 3a of the Bretonian, *Parabolina* zone of the Dolgelly.

Col. 5. Division 3b of the Bretonian *Peltura* zone of the Dolgelly.

Col. 6. Division $3c_1$ of the Bretonian *Dictyonema* zone of the Tremadoc.

Col. 7. Division $3c_2$ of the Bretonian *Asaphellus* zone of the Tremadoc.

Col. 8. Division 3d of Matthew. The Arenig Beds.

Cols. 9-17 Cambrovician Beds of New Brunswick.

Col. 9. Division 2a of the Johannian (compare Col. 1)

Col. 10. Division 2b of the Johannian (compare Col. 2)

Col. 11. Division 2c of the Johannian (compare Col. 3)

Col. 12. Division 3a of the Bretonian. Lower Dolgelly (cf. Col. 4)

Col. 13. Division 3b of the Bretonian of New Brunswick (cf. Col. 5)

Col. 14. Division $3c_1$ of the Bretonian of New Brunswick. Dictyomena zone of the Tremadoc (cf. Col. 6.)

Col. 15. Division $3c_2$ of the Bretonian of New Brunswick. *Asphellus* zone of the Tremadoc (cf. Col. 7.)

Col. 16. Division 3d of New Brunswick. *Tetragraptus beds* of the Arenig (cf. Col. 8.)

Col. 17. Division 3e of the Bretonian of New Brunswick. *Leptobolus* bed of the Arenig.

Cols. 18 to 24 Cambrovician beds of South-Eastern Newfoundland.

Col. 18. Division 2a of the Elliot Cove Series, *Agnostus pisiformis* zone.

Col. 19. Division 2b of the Elliot Cove Series. *Olenus* zone.

Col. 20. Division 3 *Orusia* beds.

Col. 21. Division 4 Clarenville Series. Tremadocian.

Col. 22. Division 5 Bell Island Series, Lower Arenig.

Col. 23. Division 6 Wabana Series. Middle and Upper Arenig.

Col. 24. Division 7. *Lingula fraseri* zone.

Table G-II																								
Characteristic Cambrovician Fossils of the Maritime Provinces of Canada and Eastern Newfoundland	Cape Breton								Johannian N. B.			Bretonian New Brunswick						S. E. Newfoundland						
	Upper Camb.					L. Ord.			Upper Camb.			Upper Camb.		Tremadoc		Arenig		Upper Camb.			Trem.	Arenig.		
	Ffestiniog			Dolgelly		Tremadoc		Arenig																
	Division 2a	Division 2b	Division 2c	Division 3a	Division 3b	Division 3c₁	Division 3c₂	Division 3d	Division 2a	Division 2b	Division 2c	Division 3a	Division 3b	Div. 3c₁ Dictyonema	Div. 3c₂ Asaphellus	Div. 3d Tetragraptus	Div. 3e Leptobolus	Div. 2a A. pisiformis	Div. 2b Olenus beds	Div. 3. Orusia beds	Div. 4. Clarenville Series	Div. 5. Bell Isl. Series	Div. 6. Wabana Series	Div. 7. L. fraseri zone
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Graptozoa																								
1. Bryograptus sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
2. Dictyonema flabelliforme Eichw.	—	—	—	—	—	×	—	—	—	—	—	—	×	×										
3. Didymograptus nitidus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	×	
4. Didymograptus patulus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
5. Loganograptus logani Hall.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								

Table G-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Graptozoa (cont.)																								
6. Retiograptus tentaculatus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?								
7. Staurograptus dichotomus Emmons	—	—	—	—	—	—	—	—	—	—	—	—	×	×										
8. Tetragraptus qudribrachiatus Hall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×								
Brachiopoda																								
1. Acrothele sp.	—	—	—	—	—	×																		
2. Acrothyra proavia (Matthew)	—	×																						
3. Acrotreta belti (Davidson)	—	—	—	—	—	cf.	—	—	—	—	—	—	—	?										
4. Acrotreta bisecta Matthew	—	—	—	—	—	×	×	—	—	—	—	—	—	×										
5. Acrotreta convexa Walcott	—	—	—	—	×																			
6. Acrotreta sp.	—	—	×																					
7. Eoorthis atava (Matthew)	—	—	—	—	—	—	—	—	—	—	—	×												
8. Eoorthis johannensis (Matth.)	—	—	—	—	—	—	—	—	—	—	—	×												
9. Leptobolus (Lingulella) grandis Matthew	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×							
10. Lingula fraseri van Ingen	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×
11. Lingula hawkei	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
12. Lingula howleyi Matthew	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
13. Lingula leseuri	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
14. Lingula murrayi	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
15. Lingulella bella (Walcott)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
16. Lingulella billingsi van Ingen	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
17. Lingulella cania (Walcott)	—	×																						
18. Lingulella concinna Matthew	—	×	—	—	—	×																		

Table G-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Brachiopoda (cont.)																								
19. Lingulella davisi (McCoy)	—	—	—	—	—	—	cf.																	
20. Lingulella ferruginea Salter	—	×	—	—	—	×	×	—	—	—	—	—	—	×										
21. Lingulella flumenis (Matthew)	—	—	×																					
22. Lingulella lævis Matthew	—	—	—	—	—	—	—	—	—	—	—	×												
23. Lingulella lævis grandis Matthew	—	—	—	×	—	—	—	—	—	—	—	×												
24. Lingulella lens (Matthew)	—	—	—	×																				
25. Lingulella lepis (Salter)	—	—	—	—	—	—	cf.	—	—	—	—	cf.	cf.											
26. Lingulella minor (Matthew)	—	—	—	—	×	—	—	—	—	—	—	—	×											
27. Lingulella radula Matthew	—	—	×	—	—	—	—	—	—	—	×													
28. Lingulella rotundata (Matthew)	—	×	×																					
29. Lingulella tumida Matthew	—	×																						
30. Lingulepis exigua (Matthew)	×	×	—	—	×																			
31. Lingulepis starri (Matthew)	—	—	—	—	—	—	—	—	—	×														
32. Lingulobolus affinis (Billings)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
33. Obolus acadicus Walcott	—	—	—	—	—	×																		
34. Obolus (Palæobolus) bretonensis (Matthew)	—	—	—	×																				
35. Obolus burrowsi van Ingen	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
36. Obolus (Westonia) escarsoni (Matthew)	—	?	—	?	×																			
37. Obolus refulgens Matthew	—	—	—	—	—	×	—	—	—	—	—	—	—	×										
38. Obolus (Bröggeria) salteri Holl.	—	—	—	×	—	×																		
39. Orusia lenticularis Wahlenberg	—	—	—	—	×	×	—	—	—	—	—	×	—	—	—	—	—	—	—	×				

Table G-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Brachiopoda (cont.)																								
40. Orusia lenticularis atrypoides (Matthew)	—	—	—	—	—	—	—	—	—	—	—	×												
41. Orusia lenticularis lyncioides (Matthew)	—	—	—	—	—	—	—	—	—	—	—	×												
42. Schizambon priscus Matthew	—	—	—	—	—	×	—	—	—	—	—	—	—	×										
43. Schizocrania hayesi	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
44. Schizocrania striata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×
45 Sphærobolus fimbriatus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×		
Pelecypoda																								
1. Modiolopsis ? solvensis	—	—	—	—	—	—	cf.																	
Gastropoda etc.																								
1. Bellerophon bretonensis Matth.	—	—	—	—	—	—	×																	
2. Bellerophon insulæ Matth.	—	—	—	—	—	—	×																	
3. Bellerophon randomi	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
4. Bellerophon semisculptus	—	—	—	—	—	—	×																	
5. Urotheca sp.	—	—	—	—	—	—	×																	
Trilobitae																								
1. Agnostus acadicus declivis Matth.	—	—	—	—	×																			
2. Agnostus cyclopyge Tullb.	—	—	—	—	cf.																			
3. Agnostus pisiformis Linn.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×						
4. Agnostus pisiformis obesus Belt	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×					
5. Agnostus trisectus Salt.	—	—	—	—	?																			

Table G-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Trilobitae (cont.)																								
6. Agnostus trisectus germanus	—	—	—	—	×																			
7. Agnostus trisectus ponepunctus Matth.	—	—	—	—	×																			
8. Angelina ? sp.	—	—	—	—	—	—	×																	
9. Asaphellus homfrayi var.	—	—	—	—	—	—	×																	
10. Asaphellus ? planus Matth.	—	—	—	—	—	—	×																	
11. Conocephalites contiguus Matth.	—	—	—	—	—	—	—	—	—	—	—	×												
12. Ctenopyge lobata Boeck	—	—	—	—	?																			
13. Ctenopyge pecten (Salt)	—	—	—	—	×	—	—	—	—	—	—	×												
14. Hemigyraspis cautleyi	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
15. Niobe howelli van Ingen	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
16. Olenus sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×					
17. Parabolina dawsoni	—	—	—	—	×																			
18. Parabolina harrieta Howell	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
19. Parabolina spinulosa Wahl.	—	—	—	—	—	—	—	—	—	—	—	×												
20. Parabolinella ? limitis Matth.	—	—	—	—	—	—	cf.																	
21. Parabolinella? quadrata Matth.	—	—	—	—	—	—	×																	
22. Peltura scarabæoides (Wahl.)	—	—	—	—	×																			
23. Princetonia terranovica Howell	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
24. Protopeltura acanthura tetracanthura Matth.	—	—	—	—	—	—	—	—	—	—	—	×												
25. Shumardia sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×			
26. Sphærophthalmus alatus (Boeck)	—	—	—	—	×																			

Table G-II (*Concluded*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Trilobitae (cont.)																								
27. Sphærophthalmus fletcheri	—	—	—	—	×																			
28. Synhomalonotus chambersi	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	
29. Triarthrus belli Matth.	—	—	—	—	—	—	×																	
Ostracoda																								
1. Beyrichona triceps Matthew	—	×																						
2. Bradoria robusta (Matthew)	—	—	—	—	×																			

The Baltic Region

In the lands bordering the Baltic, and its extension, the Gulf of Finland we meet with a variant in the character of both the Upper Cambrian and the Ordovician deposits. The latter especially are represented by more pronounced calcareous facies. The region included here embraces, besides a number of minor localities, the Oslo or Kristiania Graben the southern half (at least) of Sweden, and the Esthonian and Russian border lands of the Gulf of Finland. Despite the fact, that the Upper Cambrian formations are typically developed in Sweden and practically absent in the Russian region, the latter must be regarded as the key to the stratigraphy of the Baltic region, for not only have we here the most complete development of the Ordovician series in calcareous facies but it is one of the most carefully studied of the European sections. The early work of the academician F. Schmidt is recognized as a classic, but it is to the more recent work of W. Lamansky,[1] that we are indebted for a clear understanding of the true stratigraphic relation of this region. Lamansky has treated this district not only palæontologically, but has gone into the details of the lithology and stratigraphic relations of the formations, and has clearly recognized their bearing on the palæogeographic history of the region. As a result, we have for the first time, a clear stratigraphic view of the real significance of the long-known "Orthoceras Limestone"

1 W. Lamansky. Die Aeltesten Silurischen Schichten Russlands Memoire du Comite Geol. Nouvelle Series, Livr. 20, 1905. German Text p. 148-203, Pls 1-2.

Ibid. Neue Beiträge zur Vergleichung des Ost-Baltischen und Skandinavischen Unter-Silurs. Centralblatt für Mineralogie Geologie und Palæontogie, 1901, pp. 611-618, with correlation table.

of the entire Baltic region, and of the all important fact that this apparent lithologic unit really encloses a pronounced hiatus of varying magnitude in its different manifestations. It is perhaps unfortunate, that Lamansky gave unqualified adherence to the old doctrine of the deep water origin of the graptolite shales, a doctrine which had not been questioned at the time of his researches, but which, if he had carefully considered it in the light of his field studies, would no doubt have led him to question its validity, and might have given him a more complete understanding of the facts and a more accurate interpretation of the sequence of events.

Von Huene too, studied this region in company with Lamansky in 1889, and in the following year examined some of the important Swedish and Norwegian sections. He too recognized the gaps in the series, and his deductions apparently received the approval of F. Schmidt. His paper appeared in 1904[1].

My own studies of some Swedish sections. were made in 1910 in connection with the excursion of the 11th. International Geological Congress, but not published until 1916. We shall begin with the Esthonian region, returning later to the Swedish sections.

The Esthonian-Russian Sections

The Cambrovician base. Over much of this region the Cambrovician transgression is marked by a basal sandstone, which carries complete shells as well as fragments of the brachiopod *Obolus apollinus* Eichwald, on which

1 F. v. Huene (in Tübingen). Geologische Notizen aus Oeland und Dalarne, sowie über eine Meduse aus dem Untersilur. Central-Blatt für Mineralogie etc. 1904, pp. 450-461, with 6 text figs.

account, this rock is generally known as the *Obolus* or *Ungulite*[1] sandstone. In the region under consideration, this rests on the eroded surface of the Fucoid Sandstone (*Mickwitzia* Sandstone) of Lower Cambrian age, to which reference has been made in an earlier part of this work (Vol. I, page 98, *IV, 126*). Elsewhere, as in Sweden, this rock is represented by a conglomerate the *Obolus* conglomerate, which in Dalarne lies directly on the old granite, but in Oeland on various members of the Middle Cambrian, fragments of which it includes. *Obolus apollinus* is generally found in the cementing limestones, which in some sections also include *Dictyonema flabelliforme, Agnostus pisiformis* and *Olenus* as at Grünicken on Oeland (See below).

The conglomerate also sometimes includes beds carrying *Agnostus pisiformis*. In the section given by von Huene, at Aeleklinte on Oeland, the beds of the *Paradoxides tessini* horizon are followed by about 0.5 meters of dark ferruginous and arenaceous limestone, upon which in turn rests 1.5 m of *Olenus* shale. This is followed by 20 c.m. of greenish black glauconite sand, with concretions containing *Orthis*, which apparently represents the *Obolus conglomerate*. This is in turn succeeded by the *Ceratopyge* limestone.

The intimate association of the *Dictyonema* shale and the *Obolus* sandstone or conglomerate, indicates that they form a part of the same transgression. Lamansky however, falls into the error of believing this to be a marked submergence of the region. In discussing the relationship of the *Dictyonema* shale and the Ungulite or *Obolus* sandstone,

1 From the resemblance of the interior impressions to that of an ungulate hoof.

Scupin[1] brings out evidence for their near shore origin. Beginning with the Lower Cambrian blue clay he says: "The blue clay grades through a series of alternate deposits, into the Eophyton deposits, and later the Fucoidal sandstones. The appearance of casts of medusa-mouths, clearly indicate a temporary exposure, consequently a negative strand displacement, which is apparently continued in the Fucoidal sandstones in the formation of which the wind has already played a certain role. This interpretation would fit in well, with that of F. Schmidt who holds that there exists a break in sedimentation, between the Fucoidal sandstone and the overlying Ungulite sandstone............ Especially in view of the existence of pebbles of the Fucoidal in the Ungulite sandstones, it appears that the Ungulite or *Obolus* sandstone indicates again a slight positive strand displacement."

"The accumulation in irregular masses especially of the upper part of this formation, gives entirely the impression of a strand formation, a deposit between ebb and flood tide. Noteworthy moreover, is the frequently observable crossbedding. The prolonged exposure is therefore followed by short periodic ones, which precede the formation of *Dictyonema* shales. That this shale can consequently not be a deep sea or even a deep water deposit, would therefore seem to appear from the sequence of development. Such a rapid subsidence of the land, which would have to be assumed [if the *Dictyonema* shales were deep-water deposits] cannot be considered under any circumstances. Moreover, the fact that the *Dictyonema* shale,

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1 Hans Scupin. Ist der Dictyonema-Schiefer eine Tiefseeablagerung? Zeitschrift der Deutschen Geologischen Gesellschaft, Vol. LXXIII. Monatsberichte 1921, pp. 153-155, 1922.

which in the west, reaches a thickness of 7 meters, wedges out eastward, having already disappeared at Narva, shows sufficiently the character of the deposits.

"Here the coastal deposits of the Ungulite sandstone lie in the same niveau as the *Dictyonema* shale, and are covered by the Silurian [Ordovician] glauconite sands and limestones. Of special significance however is the fact that already in the *Obolus* sandstone there are intercalations, *i. e.* lenses, of a bituminous shale, which from the point of view of sediment petrography is already *Dictyonema* shale, and must have been due to the same conditions of deposition as the overlying principal mass of this shale." Scupin here gives essentially the interpretation of the origin of the graptolite shale, which we had published 5 years previously with reference to the graptolite shales of the Ordovician and Silurian, namely that they are flat low coastal regions, temporarily flooded by a slight rising of the sea-level, and the floating-in of the planktonic organisms, which are left stranded after the retreat of the sea. Scupin sums up the evidence bearing on the *Dictyonema* shale in the following words (translated):

"How then was the graptolite shale formed? It is a veritable sapropelite [Faulschlammablagerung] of the transgressing sea, which was dammed up behind the dunes of the *Obolus* sandstone, there becoming stagnant. Whether the content of bituminous matter is due to the *Dictyonema* itself, is so far an undetermined matter. Whatever organic remains were washed in perished and decayed. Perhaps there were great masses of seaweeds, similar to those of the Sargasso Sea, which together with the *Dictyonema* drifted about......Minor floodings already occurred in the period of deposition of the *Obolus* sandstone, of which the bituminous shale in its lower part appears to be a subordinate facies ...." (*loc. cit.*).

The *Dictyonema* shale is designated A3 in the nomenclature adopted by the Russian geologists. It ranges in thickness from 4.40 meters to 0.40 m. and in one place is even absent. The *Obolus* sandstone designated A2 is always present beneath it, and where the shale itself is absent, the lowest member of the next division B1 lies directly upon it.

Throughout the Baltic region, the *Dictyonema* shale, or in its absence the *Obolus* sandstones are succeeded by beds equivalent to the Lower Arenig of Great Britain. This series is designated by Lamansky BI and it is conformably succeeded by his division BII. In the older designation of F. Schmidt, B1, (Glauconite sand) is used for the lower part only of the group designated BI by Lamansky, the remainder together with Lamansky's BII, and the lower part of Lamansky's BIII are included by Schmidt in his B2 *i. e.* his *Glauconite limestone.* This he divides into the lower B2a, or *Planilimbata* limestone in the higher B2b, *Expansus* limestone.

The true Expansus limestone is however only the upper part of this as shown by Lamansky who designates it BIII α, while the lower part of Schmidt's Expansus limestone (his B2b) includes Lamansky's BII γ and the upper part of BII β. It is thus evident that the alphabetical and numerical designations of formation's is confusing while the palæontological designation used for various subdivisions is not much better, and it is highly desirable to have geographical terms for the designation of these formations.

Marcou has used the name *Esthonia formation* for the Lower Cambrian of this region, which includes the blue clay of the St. Petersburg region and the Eophyton and Fucoidal sandstones. These belong to the first Pulsation. The second or Middle Cambrian Pulsation is wholly unrepresented in this region as is also the Upper Cambrian part of the 3rd or Cambrovician pulsation. The Tremadoc however, is represented by the *Obolus* sandstone and the *Dictyonema* shale. The remainder of the Lower Ordovician, BI and BII of Lamansky, corresponds as we have seen to the British Arenig, but is so distinct in type of lithology and fauna, that it would be misleading to designate it by that term. I have not been able to find a distinctive name, that has been applied to this series and unfortunately the name Esthonia Series has been preoccupied. These beds are most completely developed in the banks of the River Volkhoff (Wolchow) in the old government of St. Petersburg though here the higher series (BIII and C) are also present. For many reasons, the name Volkhoff or Wolchow Series is best applied to the higher division, that is BIII, which is there most complete as is also CI which conformably succeeds it. I propose for the present to use the term *Estland group* for the older series and include in this BI and BII of Lamansky. BII is again, fully developed from Putilovo eastward, and this division may be further designated the *Putilovo Series*, or Putilovo division of the Estland series, and the three divisions BII α BII β and BII γ, may be respectively designated the Lower, Middle and Upper Putilovo formations.

Division BI is most fully developed at Baltic Port, near the mouth of the Gulf of Finland and the name *Balticport* series may be used for it. The Balticport series is again divisible into two horizons, a Lower, (BI α) with *Obolus siluricus* etc., and an upper (BI β) shown on the River Popovka, with early *Megalaspids* etc. We may give these divisions in tabular form.[1]

Lower Palæozoic Beds of Baltic Russia

(In Stages F to C the designations of F. Schmidt are used. In Stages B. & A. those of Lamansky and my own.)

SUPERFORMATION Silurian

Hiatus and Disconformity (?)

ORDOVICIAN SYSTEM (108.5-128 m+

STAGE	F.	(Referred to Ashgillian)	(100 ft.)	32 m.
	F2	Borkholm Series		
	F1	Lyckholm Series		
STAGE	E.	(Upper Caradoc.) Wesenberg Series	(30 ft.)	9.6 m.
STAGE	D.	(Caradoc.)	(100 ft.)	32 m.
	D2	Kegel Series		
	D1	Jewe Series		
STAGE	C.	(Caradoc-Llandeilo)	(70-130 ft.)	22.4-41.6 m.
	C3	Itfer Series	(20-30 ft.)	

1 F. Schmidt. On the Silurian (and Cambrian) Strata of the Baltic Provinces of Russia as compared with those of Scandinavia and the British Isles. Quart. Journ. Geol. Soc. of London Vol. 38, 1882, pp. 514-530 with Geol. map.
W. Lamansky. Die ältesten silurischen Schichten Russlands. Mem. Com. Geol. Russ. N. Ser, Livr. 20.
W. Lamansky. Neue Beiträge zur Vergleichung des Ost-Baltischen und Skandinavischen Untersilurs. Centralblatt für Mineralogie Geol. u. Pal. 1901, pp. 610-618, Correlation table.

C2 Kuckers Series (30-50 ft.)
C1 Echinosphærites
Series (20-50 ft.)
C1b Echinosphærites Limestone
C1a Upper Linsenschicht

STAGE BIII (Lamansky) Volkhoff Series
(new) *Asaphus* Series — 12.5 m.

BIIIγ (Lamansky)
Upper Volkhoff
Series (3-20 ft.)
(= 3 b) *Vaginaten* or
Orthoceras limestone
of F. Schmidt)
Horizon of
Asaphus eichwaldi
Ptychopyge globifrons

BIIIβ (Lam.) Middle
Volkhoff Series (2-3 ft.)
(= B3a Lower Lin-
senschicht of F.
Schmidt)
Horizon of
Asapus raniceps

BIIIγ and BIIIβ have a combined
thickness on the Wolchow of — 9.5 m.

BIIIα Lower Volkhoff Series — 3.0 m.
(Expansus Limestone Series
Sens strict.)
Horizen of
Asaphus expansus
Asaphus lamanskii

Hiatus aud Disconformity

CAMBROVICIAN SYSTEM (36m+)

II Estland Series (new term) 11 m+

(Approximately equivalent to British Arenig.)

BII *Putilowo Group* (new) or *Megalaspis* beds 5.20-6.60 m.

BII$^{\gamma}$ Upper Putilowo beds 2.40-2.50 m.

(Locally called "Friese")

Horizon of

Asaphus lepidurus

Megalaspis gibba

BII$^{\beta}$ Middle Putilowo beds 1.15-1.80 m.

(Locally called "Sheltjaki")

Horizon of

Asaphus bröggeri

Onchometopus volborthi

BII$_{\alpha}$ Lower Putilowo beds 1.65-2.30 m.

(Locally called "Dikari.")

Horizon of

Megalaspis planilimbata

Megalaspis limbata

Asaphus priscus

BI *Balticport Group* 0.5-5.0 m.

BI$_{\beta}$ Upper Balticport beds

Horizon of
Megalaspis leuchtenbergi etc.
BIα Lower Balticport beds
Horizon of
Obolus siluricus

I Reval Series[1] (Approximately equivalent to Tremadoc) 25 m ±

AIII Dictyonema shales, with *Distyonema flabelliforme* 0.-4.4 m.

AII Obolus or Ungulite Sandstone with *Obolus apollinus* 2-20 m.

Hiatus and Disconformity

SUB-FORMATION Lower Cambrian (100 m ±)

The Balticport Group, BI

Lower Balticport beds-BIα. The lowest division of the Balticport group corresponds almost entirely to the division B1 of F. Schmidt, commonly known as the Glauconite sand, or greensand, the grains formed by internal molds of what appear to be minute gastropods (protoconchs?) but which were originally referred by Ehrenberg to Foraminifera and Pteropods. At Baltic Port where it reaches its greatest thickness, it consists of rounded quartz and glauconite grains, held together by clay or siliceous cement. Here as everywhere, the base is sharply defined from the underlying *Dictyonema* shale, the surface of which shows

1 In F. Schmidt's map the boundary between the *Dictyonema* shales and overlying beds passes through Reval.

evidence of erosion, while occasionally worn fragments of the shale are found in the basal green-sand. In the lower part we also find fragments of crystalline rocks, worn fragments of bituminous shale and concretions of sulphur. Upwards there is a regular but gradual increase in lime, the rock effervescing with acid. The quartz grains gradually disappear and after one or two intercalations of shaley beds, beds of glauconite limestone with *Megalaspis planilimbata* begin to appear. This marks the beginning of BII α, the higher division of BI (BI β) being not differentiable in the western section.

The green-sands of the lower division contain besides these glauconite molds a sparse fauna, in which *Obolus siluricus* is the leading form. In addition to these there have been found in these lower beds *Obolus linguliformis* Mickwitz, *Discina ?* sp. *Siphonotreta ?* sp. *Salterella* ? sp. and sponge remains, in addition to the conodonts originally described by Pander from these beds.

Upper Balticport Beds. BI β. These are known from the outcrops on the river Popovka near Pavlowsk some 25 km south of St. Petersburg. Here the total thickness of the Balticport beds is only a little over half a meter, but the upper part becomes a glauconitic marl, with scattered quartz grains. This is the division named by Lamansky BI β. Here a number of species of *Megalaspis*, related to but not identical with *M. planilimbata* have been found together with *Orthis recta* Pander and *Orthis christianiæ* Kjer, and nine other species described by Lamansky. The genus *Plectella.* represented by 7 species is a characteristic member of this fauna which is given in Col. 2 Table H-II.

Division BI α, that is the Lower Balticport Beds are correlated by Lamansky, with the *Ceratopyge* shale of

Oeland, and that of Norway, which there is designated 3a β. The division 3a α of the Norway (Oslo) section, which is characterized by *Symphysurus incipiens*, *i. e.* the typical *Euloma-Niobe* fauna of the Tremadoc, is not known in the Baltic region and is there believed to be represented by a hiatus. Finally the division BI β, that is the upper Balticport beds, is correlated with the *Ceratopyge* limestone of Oeland, the Swedish mainland and the Oslo section (3a γ of the latter).

The importance of the disconformity between the Balticport and *Dictyonema* beds may be questioned. Of course to those who still regard these beds as a deep water formation it must assume considerable importance, but when we take the more rational interpretation of this shale, which I think we have no choice but to accept, namely, that it is a strand or coastal mud-flat formation, its relation to the next overlying bed might well give the appearance of a disconformity, since these higher beds too are shallow water if not actually strand sediments, and interformational erosion phenomena may be expected.

The Putilovo Group BII

The Lower Putilovo Group. (BII α) Named from the town some 60 km's east of St. Petersburg. The lower Putilovo beds can be traced from the Volkhoff River east of Putilovo, to Baltic Port, retaining throughout this distance a thickness of 1.65 to 1.80 m. or if the transition bed from the Balticport group is included it attains a thickness of 2.3 meters. The rocks consist of platey limestones the individual layers having a thickness of 13 to 27 cm., and a bright red, yellow, violet or gray-green colour. The beds were extensively quarried for use as paving stones, doorsteps, etc. and are locally known as *Dikari*. They are separated by layers of glauconite grains, which often occupy grooves at the top of the preceding stratum. The fauna is especially characterized by the trilobites *Megalaspis planilimbata*, *Megalaspis limbata*, and *Asaphus priscus* which here make their first appearance. The list of the species is given in Table H-II Col. 3.

Traced into Sweden, the Lower Putilovo Beds (BII α) are represented by both the Planilimbata and the Limbata beds. The Planilimbata limestone is often replaced by *Phyllograptus* shale. Lamansky remarks (1905 p. 183) that the similarity of the limestones of Scandinavia with the Dikari of Esthonia is not only in the occurrence of the same index fossils, but also in the petrographic character.

The Middle Putilovo Beds (BII β). This series, with a maximum thickness of 1.8 meters, consists of relatively thin layers of less compact limestone than the preceding. Their remarkable feature is that these layers are covered with an abundance of yellow and red blotches or figures. Glauconite is either entirely wanting or only occurs sporadically. The rock is locally known as "Sheltjaki" and is characterized by a fairly rich fauna of trilobites, brachiopods etc. Among the former *Asaphus bröggeri* F. Schmidt and *Onchometopus volborthi* F. Schmidt, may be regarded as the index fossils. *Nileus armadillo* Dalman var. *depressa*, Sars and Boeck, also appears here. The list of species from these beds cited by Lamansky is given in Table H-II Col. 4.

This zone begins to disappear to the west of the St. Petersburg region. It is still present but in diminished character at Reval, but has wholly disappeared at Baltic Port and is unknown in Scandinavia where it is represented by a hiatus. This westward diminution and final disappearing is a phenomenon of off-lapping followed by erosion. It marks a progressive retreat of the Lower Ordovician sea in this section, a fact clearly recognized by Lamansky.

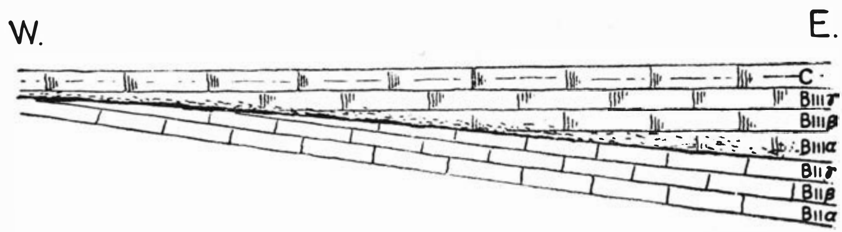
The Upper Putilovo Beds (BII$^{\gamma}$). This division, locally known as "Friese" consists at the base of moderately compact gray limestone with scattered glauconite grains, which locally may form an accumulation. They pass upward into marly beds. The thickness of this horizon varies from 2.40 to 2.70 meters and its characteristic index fossils are *Asaphus lepidurus* Nieszk. and *Megalaspis gibba* F. Schmidt. The fauna is rich both in trilobites and brachiopods and a species of *Echinoencrinites* and one of *Glyptocystides* occur. The fauna is given in Table H-II Col. 5.

This horizon disappears before the underlying one, that is in the region around Reval and this disappearance is also due to the phenomenon of off-lap. In Scandinavia this division is entirely unknown.

The Volkhoff Series BIII.

Throughout the Estonian region from the Volkhoff River to Baltic Port, the Putilovo group or the *Megalaspis* beds, that is the division BII, is disconformably succeeded by the division BIII, the *Asaphus* series or Volkhoff series of our classification. The contact is typical of the inter-pulsation contact. The lower, retreating series of the Cambrovician pulsation, here represented by the several members of the Putilovo or *Megalaspis* group (BII) present the phenomena of progressive off-lap, indicating retreat of the Lower Ordovician Sea. Following retreat came erosion, but no deformation, so that with the advent of the transgressing Middle Ordovician Sea (Positive phase of the Ordovician Pulsation) the position of the beds is concordant, but there is nevertheless a pronounced disconformity and hiatus.

This succeeding series (BIII of Lamansky) clearly shows the phenomena of overlap. Thus the lowest member known in this region (BIII α,) disappears in the St. Petersburg region. At Baltic Port, the second division, BIII β, disappears and is over-lapped by division BIIIγ, which there lies directly on BII α. (Text-Fig. 1). The same evidence



Text-Fig. 1 Diagram illustrating the off-lapping of the Lower Ordovician strata BIIα BIIβ, and BIIγ, and the overlapping of the Middle Ordovician strata BIIIα, BIIIβ, BIIIγ, and C. (modified after Lamansky).

of over-lap is shown everywhere in Scandinavia for here the bed with *Asaphus expansus* i. e. horizon BIIIα, has only been demonstrated for the Oslo region, and the region of Husbyfjöl in Oester-Gotland, Sweden. Elsewhere, only the 2nd and 3rd division BIIIβ and BIIIγ occur in Sweden, where they form the well-known Orthoceras limestone under which term the lower or *Megalaspis* limestones have often erroneously been included, because of the non-recognition of the stratigraphic break.

The Cambrovician-Ordovician Hiatus

Throughout the Esthonian Region the contact between the two series, BII and BIII, generally shows physical evidence of a disconformity, this being of course most pronounced in the western sections The *Megalaspis* limestone shows an irregular erosion surface and the immediately succeeding division BIII begins with sandstones and contains fragments of the underlying beds. Going eastward, this basal sandstone of the overlying series rests successively on the eroded surfaces of the several divisions of the lower series BII, while the sandstone itself gradually becomes replaced by a conglomeratic layer, consisting of phosphate nodules, which by their composition show, that they represent phosphatized fragments of the underlying *Megalaspis* limestones[1]. Even at Putilovo, the contact presents a wavy line, the surface of the *Megalaspis* limestone being covered with shallow grooves, and immediately over the contact, the rock contains accumulations of glauconite grains, lenses of brown oxide and sporadically shiny nodules of phosphorites. All these elements of the basal bed of the overlying series are irregularly arranged and the rock has the appearance of a conglomerate of small limestone fragments, with a calcareous cement and with scattered glauconite grains.

It is of course obvious that the hiatus so clearly represented in the two series in Esthonia is much more pronounced than is there indicated. The two series, that is the *Megalaspis* and the *Asaphus* beds have almost no species in common as can be seen by reference to Table H-II where the three divisions of the *Asaphus* Series (BIII) are represented in Cols. 6 to 8. Lamansky says that a single or at most two fossils are quite sufficient to determine from which division they are derived. If the retreat had only been a local one, followed shortly by the readvance, such faunal distinctness could not exist and since this

1 See Lamansky 1905 p. 81 and his discussion of Andersson's phosphatic deposits of similar character in Sweden.

retreat coincides in point of time essentially with the Arenig retreat of Britain, and the other contemporaneous retreats to which we shall refer in the discussion of the sections of other continents, there can be no doubt that the division BII represent only the lower part of the deposits of the great retreatal phase of the Cambrovician pulsation, elsewhere represented by hundreds of meters and that the upper division, BIII, represents only the upper part of the deposit of the positive phase of the Ordovician pulsation, which likewise is represented elsewhere by many hundreds of meters of deposits. Thus the hiatus in the Baltic region, instead of representing a depositional maximum of a few meters is to be measured rather by hundreds if not thousands of meters of sediments unrepresented in that region.

The old interpretation that the hiatus between these two formations and corresponding gaps in the Scandinavian sections can be explained by submarine erosion[1] must be entirely abandoned, for not only is it inconsistent with the palæogeographic development as indicated elsewhere, but it cannot in itself account for the observed phenomena nor for the abrupt change in fauna.[2]

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1 These problems have been discussed by J. G. Andersson in Bulletin of the Geol. Institute of Upsala Vol. III, and in the Swedish journal Geol. Fören. Förh. Vol. XIX, p. 245-295 and by Hedström who opposes him, in the same volume pp. 560-620.

2 This abrupt faunal change is shown in Table H-II. The only species that pass from BII to BIII are two Bryozoa, *Diamulites annulatus* and *Mont. petropolitana*, the former probably, the latter avowedly used in a comprehensive sense. The only other species recorded from both divisions are two trilobites *Megalaspis gibba* and *Ptychopyge angustifrons* the latter as noted includes several distinct and restricted species. This leaves only *Megalaspis gibba* to be accounted for. (See however, *Note* p. 220).

TABLE H-II

LOWER AND MIDDLE ORDOVICIAN FAUNAS OF ESTHONIA AND ADJOINING DISTRICTS IN BALTIC RUSSIA.

The following table, with some rearrangement is taken from Lamansky, and shows the distribution of the fossils listed by him in the Lower and Early Middle Ordovician strata of the states bordering the Baltic region. The following horizons are represented.

Cols 1 and 2. The Balticport Series. BI. Horizon of *Orthis christianiæ* and *Plectella*

Col. 1. Hor. BIα Lower Balticport beds with *Obolus siluricus*

Col. 2. Hor. BIβ Upper Balticport Beds. Horizon of *Megalaspis leuchtenbergi*

Cols. 3-5. Putilovo Group, BII of Lamansky.

Col. 3. Horizon BIIα with *Megalaspis planilimbata*, *M. limbata* and *Asaphus priscus*

Col. 4. Horizon BIIβ with *Asaphus bröggeri* and *Onchometopus volborthi*

Col. 5. Horizon BIIγ with *Asaphus lepidurus* and *Megalaspis gibba.*

Cols. 6-8. Middle Ordovician Volkhoff Series. BIII of Lamansky.

Col. 6. Horizon BIIIα with *Asaphus expansus* and *A. lamanskii*

Col. 7. Horizon BIIIβ with *Asaphus raniceps*

Col. 8. Horizon BIIIγ with *Asaphus eichwaldi* and *Ptychopyge globifrons.*

In the notation the following additional signs are used a = lower, b = Middle, c = Upper part of zone in question.

Table H II Lower and Middle Ordovician Faunas of Baltic Russia (After Lamansky.)	Lower Ord.					M. Ord.		
	B I α	B I β	B II α	B II β	B II γ	B III α	B III β	B III γ
	1	2	3	4	5	6	7	8
Spongidæ								
1. Siphonia? cylindrica Eich.	—	×						
Bryozoa								
1. Dianulites annulatus Eichwald	—	—	×	×	×	?	×	×
2. Dittopora clavæformis Dyb.	—	—	×	×	×			
3. Monticulipora petropolitana Pander (See *Note* p. 220)	—	—	×	×	×	×	×	×
Brachiopoda								
1. Leptæna imbrex Pander (non Vern.)	—	—	—	—	—	×	×	
2. Leptæna imbrex Vern. (non Pander)	—	-	—	—	—	×	×	
3. Leptæna nefedjewi Eichwald	—	—	—	—	—	×	×	×
4. Lingula birugata Kutorga	—	—	-	—	—	×	×	×
5. Lingula lata Pander	—	—	—	—	-	—	—	×
6. Lingula longissima Pander	—	—	—	×	×			
7. Lycophoria nucella Dalman	—	—	—	—	—	×	×	×
8. Obolus lingulæformis Mickwitz	×							
9. Obolus siluricus Eich.	×							
10. Orthis abscissa Pander	—	×	×					
11. Orthis bocki Lamansky	—	×						
12. Orthis callactis Dalman	—	—	—	—	—	×		
13. Orthis calligramma Dalman	—	—	—	—	—	×	×	×
14. Orthis christianiæ Kjerulf	—	×						
15. Orthis extensa Pander	—	—	—	—	—	×	×	
16. Orthis incurvata Lamansky	—	×						
17. Orthis obtusa Pander	—	—	bc	×	×			
18. Orthis obtusa eminens Vern.	—	—	—	—	—	×	ab	
19. Orthis orthambonites Vern.	—	—	×	—	×			
20. Orthis parva Pander	—	—	×	×	×			
21. Orthis parva (*var. novo*)	—	—	—	—	—	×	×	
22. Orthis parvula Lamansky	—	×						
23. Orthis recta Pander	—	×						
24. Orthis schmidti Wysog.	—	—	×					
25. Orthis striata Pander	—	×						

Table H-II (*Continued*)	1	2	3	4	5	6	7	8
Brachiopoda (cont.)								
26. Orthis tetragona Pander	—	×	×					
27. Orthis tetragona lata Pander	—	×	×					
28. Orthis transversa Pander	—	×						
29. Orthis transversa latestriata Lamansky	—	×						
30. Orthisina adscendens Pander	—	—	—	—	—	c	×	×
31. Orthisina concava Pahl.	—	—	—	—	—	c	×	×
32. Orthisina inflexa Pander	—	—	—	—	—	×	×	×
33. Orthisina ingrica Pahl.	—	—	×	×	a			
34. Orthisina (Leptæna) ornata Vern.	—	—	—	—	—	—	×	×
35. Orthisina plana Pander	—	—	×	×	×			
36. Orthisina plana alta Pahl.	—	—	—	×	a			
37. Orthisina plana excavata Pahl.	—	—	—	—	bc			
38. Orthisina pyron Eichwald	—	—	—	—	—	—	×	×
39. Orthisina radians Eichwald	—	—	—	—	—	×		
40. Orthisina trigonula Eichwald	—	—	—	—	—	—	×	a
41. Philhedra rivulosa Kutorga	—	—	—	—	—	—	—	×
42. Plectella eminens Lamansky	—	×						
43. Plectella extensa Lamansky	—	×						
44. Plectella gracilis Lamansky	—	×						
45. Plectella media Lamansky	—	×						
46. Plectella obtusa Lamansky	—	×						
47. Plectella semiovata Lamansky	—	×						
48. Plectella uncinata Pander	—	×						
49. Plectella sp.	—	—	×					
50. Porambonites altus Pander	—	—	×	×	×			
51. Porambonites bröggeri Lamansky	—	×						
52. Porambonites intercedens Pander	—	—	—	—	—	×	×	×
53. Porambonites parvus Pander	—	—	×	×	×			
54. Porambonites planus Pander	—	—	×	×	×			
55. Porambonites reticulatus Pander	—	—	—	×	×			
56. Porambonites triangularis Pander	—	—	×	×	×			
57. Porambonites sp.	—	—	×					
58. Pseudocrania antiquissima Eichw.	—	—	—	—	—	—	—	×
59. Pseudocrania petropolitana Pander	—	—	—	×	×			
60. Pseudocrania scutellata Huene	—	—	—	—	—	×	×	×
61. Pseudometoptoma siluricum Eichw.	—	—	—	—	—	—	—	×
62. Siphonotreta unquicualata Eichw.	—	—	—	—	—	×	×	
63. Siphonotreta verrucosa Eichw.	—	—	—	×	×			
64. Siphonotretá sp.	×							

Table H-II (*Continued*)	1	2	3	4	5	6	7	8
Gastropoda								
1. Maclurea helix Eichw.	—	—	—	—	—	—	c	×
2. Raphistoma qualteriatum Shal.	—	—	—	—	—	×	×	×
3. Salpingostoma locator Eichw.	—	—	—	—	—	—	—	×
4. Sinuites sp.	—	—	—	—	—	×	×	×
Pteropoda etc.								
1. Conularia buchi Eichw.	—	—	—	—	×			
2. Conularia quadrisulcata Mill. emend. Leuchtbg.	—	—	—	—	—	—	×	
3. Conularia sp.	—	—	—	—	—	×		
4. Hyolithes acutus Eichwald	—	—	—	—	—	—	—	×
Cephalopoda								
1. Cyrtoceras archiaci Vern.	—	—	—	—	—	—	—	×
2. Endoceras commune Wahlenberg	—	—	—	—	—	?	?	×
3. Endoceras duplex F. Schmidt	—	—	—	—	—	?	?	×
4. Endoceras trochleare Hisinger	—	—	—	—	—	×	×	×
5. Endoceras vaginatum Schloth.	—	—	—	—	—	×	×	×
6. Endoceras sp.	—	—	×	×	×			
7. Estonioceras ariense F. Schmidt	—	—	—	—	—	—	c	×
8. Estonioceras imperfectum Schloth.	—	—	—	—	—	—	c	×
9. Estonioceras perforatum Schrœd.	—	—	—	—	—	—	c	×
10. Estonioceras sp.	—	—	—	—	—	—	c	×
11. Orthoceras atavus Brögger	—	×						
12. Planctoceras falcatum Schloth.	—	—	—	—	—	—	—	×
Trilobita								
1. Amphion brevicapitatus Lamsky	—	—	—	×	×			
2. Amphion fischeri Eichw.	—	—	—	—	—	×	×	×
3. Ampyx linnarssoni F. Schmidt	—	—	×					
4. Ampyx nasutus Dalman	—	—	—	—	—	×	ab	
5. Ampyx volborthi F. Schmidt	—	—	—	—	—	×	ab	
6. Asaphus acuminatus Boeck	—	—	—	—	—	×		
7. Asaphus bröggeri F. Schmidt	—	—	—	×	a			
8. Asaphus expansus Dalman	—	—	—	—	—	×	a	
9. Asaphus eichwaldi expansoides Lams.	—	—	—	—	—	—	c	×
10. Asaphus eichwaldi lepiduroides Lams.	—	—	—	—	—	—	c	×
11. Asaphus lamanskii F. Schmidt	—	—	—	—	—	×	—	—
12. Asaphus lepidurus Nieszk.	—	—	—	—	×			
13. Asaphus major F. Schmidt	—	—	—	—	—	—	—	×

Table H-II (*Continued*)	1	2	3	4	5	6	7	8
Trilobita (cont.)								
14. Asaphus pachyophtalmus F. Schmidt	—	—	—	—	—	—	—	×
15. Asaphus priscus Lams.	—	—	×					
16. Asaphus raniceps Dalman	—	—	—	—	—	c	×	a
17. Cheirurus ingricus F. Schmidt	—	—	—	—	—	—	×	?
18. Cheirurus ornatus Dalman	—	—	—	—	—	—	×	×
19. Cybele bellatula Dalman	—	—	—	—	—	×	×	
20. Cybele bellatula genuina F. Schmidt	—	—	—	—	×			
21. Cyrtometopus affinis Angelin	—	—	—	—	—	×	×	×
22. Cyrtometopus cf. aries Leuchtbg.	—	—	×	—	×			
23. Cyrtometopus clavifrons Dalman	—	—	×	×	×			
24. Cyrtometopus gibbus Ang.	—	—	—	×				
25. Cyrtometopus tumidus Ang.	—	—	—	—	×			
26. Harpes spasskii Eichwald	—	—	—	—	×			
27. Illænus centrotus Dalman	—	—	×	×	×			
28. Illænus centrotus var.	—	—	—	—	—	×		
29. Illænus esmarckii Schloth.	—	—	—	—	—	×	×	×
30. Illænus ladogensis Holm	—	—	—	—	—	×		
31. Illænus laticlavius Eichw.	—	—	—	—	—	—	bc	×
32. Illænus revaliensis Holm	—	—	—	—	—	—	—	×
33. Megalaspis acuticauda Ang.	—	—	—	—	cf.	×	×	
34. Megalaspis centron Leucht.	—	—	—	—	—	×		
35. Megalaspis gibba F. Schmidt	—	—	—	—	×	×	×	
36. Megalaspis heros Dalm.	—	—	—	—	—	—	×	×
37. Megalaspis hyorrhina F. Schmidt	—	—	—	×				
38. Megalaspis kolenkoi F. Schmidt	—	—	—	×	×			
39. Megalaspis lawrowi F. Schmidt	—	—	—	—	—	×	×	
40. Megalaspis leuchtenbergi Lams.	—	×						
41. Megalaspis limbata Sars & Boeck	—	—	×					
42. Megalaspis longicauda Lawr.	—	—	—	—	—	—	—	×
43. Megalaspis mickwitzi F. Schmidt	—	—	—	—	×			
44. Megalaspis planilimbata Ang.	—	—	×					
45. Megalaspis pogrebowi Lams.	—	×						
46. Megalaspis polyphemus Brögger	—	—	×					
47. Megalaspis schmidti Lams.	—	×						
48. Megalaspis sp.	—	×						
49. Metopias celorrhin Ang.	—	—	—	—	—	×	ab	
50. Metopias celorrhin coniceps F. Schmidt.	—	—	—	—	×			
51. Metopias pachyrrhina Dalman	—	—	—	—	—	×	×	×

Table H-II (*Continued*)	1	2	3	4	5	6	7	8
Trilobita (cont.)								
52. Metopias pachyrrhina longerostrata F. Schmidt	—	—	—	—	—	×	×	
53. Metopias verrucosa Eichw.	—	—	—	—	—	—	×	×
54. Nileus armadillo depressa Sars & Boeck	—	—	—	×	×			
55. Niobe emarginula Brögger	—	—	—	—	—	×	×	
56. Niobe frontalis Dalman	—	—	—	—	—	×	×	
57. Niobe læviceps Dalman	—	—	×					
58. Niobe lindströmi F. Schmidt	—	—	—	×				
59. Onchometopus schmidti Lams.	—	—	—	—	×			
60. Onchometopus stacyi F. Schmidt	—	—	—	—	—	—	—	×
61. Onchometopus volborthi F. Schmidt	—	—	—	×	a			
62. Pseudasaphus globifrons Eichw.	—	—	—	—	—	—	—	×
63. Pseudasaphus tecticaudatus præcurrens F. Schmidt	—	—	—	—	—	—	—	×
64. Pterygometopus sclerops Dalman	—	—	—	×	×			
65. Pterygometopus trigonocephala F. Schmidt	—	—	—	—	—	×	×	?
*66. Ptychopyge angustifrons Dalman	—	—	×	×	×	×	ab	
67. Ptychopyge angustifrons truncata Nieszk.	—	—	—	—	×			
68. Ptychopyge inostranzewi Lams.	—	×						
69. Ptychopyge wöhrmanni F. Schmidt	—	—	—	—	×			
70. Remopleurides nanus Leucht.	—	—	×					
Cystoidea and Crinoidea								
1. Asteroblastus sublævis Jæk.	—	—	×					

* Includes, according to Lamansky a number of undescribed species, each characteristic of a definite horizon.

Table H-II (*Concluded*)	1	2	3	4	5	6	7	8
Cystoidea and Crinoidea (cont.)								
2. Asterocrinus (?) münsteri Eich.	—	—	×					
3. Bolboporites semiglobosus Pand.	—	—	×	×	×			
4. Bolboporites triangularis Pand.	—	—	×	×	×			
5. Bolboporites triangularis uncinata Pand.	—	—	×	×	×			
6. Bolboporites sp.	—	—	—	—	—	×	a	
*7. Cheirocrinus sp.	—	—	—	×	×			
8. Cyathocrinus (?) exilis Eichw.	—	—	—	×	×			
**9. Echinoencrinites angulosus Pand.	—	—	×	×				
10. Echinoencrinites lævigatus Jæk.	—	—	—	—	—	×		
11. Echinoencrinites reticulatus Pand.	—	—	—	—	×			
12. Echinoencrinites senckenbergi H. v. Müll	—	—	—	—	—	×		
13. Echinoencrinites senckenbergi interlævigata Jæk.	—	—	—	—	—	×		
14. Echinoencrinites cf senckenbergi Müll	—	—	—	—	—	—	×	
15. Glyptocystites giganteus Leucht	—	—	×	×				
16. Haplocrinus (?) monile Eichw.	—	—	×	×	×			
17. Mesites pusyreffskii Hoffm.	—	—	—	×				
18. Pentacrinus (?) antiquus Eichw.	—	—	—	—	×			

* Basal attachment only
** Includes several mutations or varieties.

Note: Bassler (U. S. Nat. Mus. Bull. 77) has listed the following 8 Bryozoa as crossing from BII to BIII or higher horizons.

Nicholsonella gibbosa Bassler; *Dianulites fastigiatus* Eichw., *D. petropolitana* Dyb.; *Esthoniopora communis* Bassl. *Hemiphragma rotundatum* Bassl. *Dittopora annulata* (Eichw.), *Diplotrypa petropolitana* Nicholson; *D. bicornis* (Eichw.). In this connection it should be remembered that weathered-out Bryozoa of an older formation may readily he re-enclosed secondarily in the sediments of the next transgressing sea.

The Swedish Sections

These sections are particularly significant because they furnish us with the complete succession of the Upper Cambrian and fortunately they have been subjected to an intensive and detailed study by that master of Swedish Stratigraphy Dr. A. H. Westergaard.[1]

Andrarum

According to Westergaard, the most complete development of the *Olenus* beds is in the Andrarum region of Scania where the thickness is 37 meters or more. Here he recognizes the following subdivisions.

Table of the Olenus Beds of Andrarum

SUPERFORMATION *Dictyograptus* shales
(contact concealed.)

OLENUS SHALE

Zone 6. Upper *Parabolina heres*, zone. 5.9 m.

c. Subzone with *Boeckia? illænopsis* and *B. scania*

b. Subzone, with *Cyclognatus granulatus* and *Parabolina heres*

a. Subzone with *Acerocare tullbergi*

Unexposed Interval

Zone 5. *Peltura* zone etc. 4.9 m.

f. Subzone, with *Parabolina longicornis* Westergaard and *Agnostus rudis holmi* Westergaard (Col. 8 Table J-II)

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1 A. H. Westergaard Sveriges Olenidskiffer. Sveriges Geologiska Undersökning. Avhandlingar och uppsatser i. 4:0. No. 18, 1922, pp. 1-188 Swedish, 189-205 English, 16 plates.

e. Subzone with *Peltura scarabæoides, Sphærophthalmus alatus, S. majusculus, Ctenopyge pecten, Ct. linnarssoni, Ct. teretifrons* and *Ct. bisulcata.* (Col. 7, Table J-II)

d. Subzone with *Sphærophthalmus major, Ctenopyge tumida* and *Peltura minor.*

c. Subzone of *Ctenopyge flagellifera angusta* and *Ct. erecta.*

b. Subzone of *Ctenopyge flagellifera* and *Protopeltura præcursor.*

a. Subzone of *Ctenopyge neglecta* and *Protopeltura præcursor.*

Zone 4. Zone of *Leptoplastus* and *Eurycare* 3.0 m.

e. Subzone of *Leptoplastus stenotus*

d. Subzone of *Eurycare angustatum*

c. Subzone of *Leptoplastus ovatus* and *Eurycare latum*

b. Subzone with *Leptoplastus raphidophorus*

a. Subzone of *Eurycare* sp.

Zone 3. Zone of *Parabolina spinulosa* and *Orusia lenticularis* 5.0 m. +

b. Subzone with *Parabolina spinulosa*

a. Subzone of *Parabolina brevispina* and *Protopeltura aciculata*

Zone with unknown fossils 3.4 m.

Zone 2. Zone with *Olenus* 7.4 m.

f. Subzone with *Olenus scanicus* and *Polyphyma angelini*

e'. Shale bed without characteristic fossils
e. Subzone with *Olenus dentatus*
d. Subzone with *Olenus attenuatus*
c. Subzone with *Olenus wahlenbergi*
b. Subzone with *Olenus truncatus*
a. Subzone with *Olenus transversus* and *Olenus gibbosus*

Zone 1. Zone with *Agnostus pisiformis* 7.4 m.

Probable Hiatus and Disconformity

SUBFORMATION: Middle Cambrian, Zone of *Agnostus lævigatus*

The trilobite fauna of the *Olenus* shales of Sweden and their distribution elsewhere is given in Table J-II.

In this table the division zones are grouped as follows

Col. 8. (5d) subzone of *Parabolina longicornis* = 5f of Andrarum section

Col. 7. (5c) subzone of *Peltura scarabæoides* = 5e of Andrarum section

Col. 6. (5b) subzone of *Peltura scarabæoides acutidens* and *P. minor*

Col. 5. (5a) subzone of *Ctenopyge flagellifera* and *Protopeltura præcursor* 5a and 5b (Cols. 5&6 correspond to subzones 5a-d of the Andrarum section)

The Older Zones

The longest continuous section in this region is 12 meters. This begins with the *Agnostus pisiformis* zone at the base and extends for about 2 meters above the horizon of *Olenus scanicus*. The distance between the horizon of

Agnostus pisiformis (zone 1) and that of *Olenus gibbosus* (zone 2a) is a little less than 3 meters. Then the zones follow regularly to that of *Olenus attenuatus*, there being an interval of over 5 m. between the latter zone (2d) and the zone of *Olenus scanicus* (zone 2f)

Another section 11 meters high, shows the zone of *Agnostus lævigatus* at the base, followed by nearly 2 meters of shales, before the *Agnostus pisiformis* zone is reached, which extends through nearly 3 meters. The interval between the two *Agnostus* zones shows no physical hiatus. But if *A. lævigatus* belongs to the Middle Cambrian as is generally considered, the hiatus here is probably masked, and there may be an interval of considerable magnitude.

In other sections, the *Parabolina brevispina* subzone (3a) lies about 3.5 meters above the *Olenus scanicus* beds, while the beds with *Protopeltura aciculata* follow from 1.5 to 2 meters higher, and beds with *Conokephalina olenorum* and *Liostracus pusillus* lie between. The higher subzone 3b, with *Parabolina spinulosa* and *Orusia lenticularis* follow for a meter or two higher.

The beds of zone 4 occur in several dissociated sections, only one of which is in contact with beds containing *Parabolina spinulosa* at the base.

The sections of zone 4 and 5 seldom show contact with each other nor is there any section in which zone 5 is in contact with zone 6. Hence this latter zone is separated from the underlying beds by an unexposed interval of unknown magnitude. We may here give the details of zone 6 and zone 5 in their region of best development.

Zone 6 Parabolina heres Zone

Exposed in the excavations near the Boiler House, south of the East bridge across the Verka River in Andrarum

(In descending order) the numbering being the reverse of that given by Westergard (p. 22, profile No. 11.)

7.	Shales, mostly unfossiliferous, but with fragments of *Parabolina* sp.	1.7 m.
6.	Shales with *Bœckia ? illænopsis*	0.1 m.
5.	Shales with indeterminate fossil fragments	0.2 m.
4.	Shales with *Bœckia scanica, B? illænopsis* and *Parabolina heres ?*	0.3 m.
3.	Unfossiliferous shales	1.1 m.
2.	Shales with *Cyclognathus granulatus* and *Parabolina heres*	0.2 m.
1.	Shales with indeterminate trilobite fragments	1.9 m.
	Total......................................	5.5 m.

Horizon 1, elsewhere carries *Acerocare tullbergi*

Zone 5. Peltura Zone.

In the Andrarum region, this is exposed about 100 meters west of the preceding and though neither the highest subzone (f) nor the lowest (a) are shown, the intermediate ones are well exposed. They comprise the following strata in descending order. (Westergaard, pp. 21-22 profile 10, Loc. 13, numbering reversed)

8. Shales with small orsten[1] balls and characterized by the following species. (subzone e upper part) 0.3 m.

    Peltura scarabœoides
    Sphœrophthalmus alatus
    Sphœrophthalmus majusculus

1 Orsten is the Swedish term for foetid limestone or "Stinkstone". It will be used throughout as a rock name.

Ctenopyge pecten
Ctenopyge linnarssoni
Ctenopyge teretifrons

7. Shales with the following fossils (subzone e, middle part) 0.2 m.
Peltura scarabæoides
Sphærophthalmus alatus
Sphærophthalmus majusculus
Ctenopyge bisulcata

6. Shales with small balls of radiately crystalline barites (subzone e lower part) 0.7 m.
Peltura aff. *scarabæoides*
Sphærophthalmus alatus
Sphærophthalmus major

5. Concretions of orsten (subzone d, upper part) 0.3 m.
Peltura minor
Sphærophthalmus major
Ctenopyge tumida
Parabolinella laticauda
Agnostus trisectus
Agnostus rudis

4. Shales with baryte concretions (subzone d middle part) 0.4 m.
Sphærophthalmus major
Ctenopyge tumida
Ctenopyge affinis

3. Shales like the preceding (Subzone d, lower part) 0.5 m.
Sphærophthalmus major
Ctenopyge tumida
Ctenopyge spectabilis
Obolus (*Bröggeria*) aff. *salteri*

2. Shales with the following trilobites, subzone 2 1.1 m.
Sphærophthalmus major?
Ctenopyge flagellifera angusta

1. Shales (subzone b of general table) 0.3 m.
Ctenopyge flagellifera
(Subzone a not exposed)

While Lower Ordovician beds are only sporadically seen in the Andrarum region, they are more fully developed both to the east and west. Of these I may give the following summary based on Moberg's investigations and on my own field studies under the guidance of Prof. Moberg in 1910.

East Scania

The exposures of the Lower Ordovician strata are best seen in a section 3 km long between the villages of Tommarp and Jerrestad chiefly along the bed of a small stream.

Near Jerrestad, the *Dictyonema* shale appears to lie directly on the *Acerocare* beds of the Upper Cambrian. (Zone 6 of the preceding series p. 224) though the actual contact is not shown. In the lower beds of the Dictyonema shales occurs *Dictyonema flabelliforme* Eichwald. In the following list *a* represents the lower portion of the shale, *b* the middle and *c* the higher.

Dictyonema flabelliforme Eichwald *a*
Dictyonema flabelliforme var. *norwegica* Kjerulf *c*
Clonograptus tenellus callavii Lapworth *b*
Clonograptus tenellus hians Moberg *b*
Bryograptus hunnebergensis Moberg *b*
Bryograptus kjerulfi Lapworth *c*

These beds are followed by alum shales carrying *Ceratiocaris scanicus* Westergaard and are believed to be the equivalent of the *Shumardia* or *Ceratopyge* shales. The *Ceratiocaris* suggests an advent of river sediments. The immediately succeeding limestone is classed by Moberg as *Ceratopyge* limestone, though typical fossils have not been found in it. It has however, yielded indeterminable fragments of trilobites, brachiopods and an *Orthoceras.*

The Lower *Didymograptus* shales follow, though they are only partly exposed. The following species have been obtained.

Didymograptus balticus Törnquist
Didymograptus geometrieus Törnquist
Didymograptus constrictus Hall
Tetragraptus quadribrachiatus Hall
Schizograptus rotans Törnquist

Somewhat higher the following are found;
Phyllograptus densus Törnquist (= *P. angustifolius* Hall) Törnquist's zone c.
Isograptus gibberrulus Nicholson. Törnquist's zone b

These beds are overlain by the so-called *Orthoceras* limestone, the lower beds of which are believed to represent the horizon of *Megalaspis limbata,* though this is not definitely ascertained.

The section is interrupted, but in the limestone quarry at Tommarp the *Orthoceras* limestone is overlain by limestones with *Trinucleus coscinorhinus.*

In the Jerrestadt region, the covered interval above the *Didymograptus* shale is followed by an outcrop of shales which contain

Dicranograptus clingani Carruthers

Climacograptus bicornis Hall and others representing a Middle Ordovician horizon. The covered interval thus conceals the disconformity and hiatus between the Cambrovician and Ordovician.

A nearly continuous section is exposed in the stream bank, south of Tommarp (Text-Fig 2). The beds dip at a gentle angle to the north, the dip increasing progressively northward. A quarry has been opened in the so-called *Orthoceras* limestone, which here represents the

Text-Fig 2 Section in the stream Bank south of Tommarp, Scania in Southern Sweden.

a, *Megalaspis limbata* limestone; *b Trinucleus coscinorhinus* beds; *c*, Black Shale with *Dicranograptus clingani*; *d* covered; *e*, *Trinucleus* shale. The hiatus lies between division a, and c, but the exact relationship of bed b is not certain.

horizon of *Megalaspis limbata.* The limestone is in thin layers with shaly partings, the whole dipping 20^0 to the north. Fossils are scarce but I obtained a pygidium of *Megalaspis limbata.*

Immediately above this Limbata limestone is a thin-bedded, dark, mainly fine-grained calcarenite. From this bed *Trinucleus coscinorhinus* Ang. and some other fossils have been reported, although we were unsuccessful in finding these.

These beds are succeeded by dark shales with *Dicranograptus clingani*, which represent the Middle Ordovician.

It is evident that the Cambrovician-Ordovician disconformity falls between the Limbata limestone below and the *Dicranograptus* shales above, but whether the thin *Trinucleus coscinorhinus* beds belong with the lower or with the higher series is not quite clear. In the exposures accessible, we were unable to find any physical evidence of the break which apparently is masked. That it exists here is of course evident from the absence of a considerable series of strata represented between them elsewhere in Sweden and in the Baltic region.

According to Bubnoff (p. 669) *Isograptus gibberulus* is found in the *Trinucleus coscinorhinus* bed and if this is substantiated the bed must be classed with the lower or Arenig (Deepkill) division. On the other hand, Tullberg has found *Ampyx rostrata* in the *T. coscinorhinus* zone and he therefore referred it to the horizon of the Chasmops limestone. If this is substantiated, then the disconformity falls below this bed and between it and the Limbata limestone.

These is however, another possibility which must not be overlooked, namely that this bed *b* of the section represents an old residual limesand formed during the exposure which followed the Cambrovician retreat, from the disintegration of the *Megalaspis* limestone. The transgressing mid-Ordovician sea would rework such a limesand and destroy the physical evidence of a disconformity. Organic remains of the newer series might thus become mingled with the residual, more or less fragmentary remains of the older series and thus produce the deceptive appearance of a transition bed. In this respect it would be comparable to the *Orthis Sand*, (Division III) (bed 6) of the Polish section discussed on page 292 etc. and of the St. Peter sandstone of the Central United States.

West Scania

In West Scania these beds are exposed at Fogelsang some 7 to 8 km east of Lund, and at Röstanga. As is the case in Scania generally, the exposures are only partial and discontinuous and many horizons can only be uncovered by digging. Also because of the fact that this is a region of extreme "checker-board" faulting, it is almost impossible to obtain a wholly trustworthy succession. Nevertheless, the very painstaking work of Professor Moberg had made it possible to piece together the various outcrops and the artificial exposures and so get a fairly complete picture of the succession.

The lowest beds are found at Fogelsang bäck (brook) where they are exposed in the low banks of the Sularps-bäck and the Fogelsang bäck. It must be especially emphasized however, that contacts between the various formations are very rarely exposed. The Upper Cambrian beds are represented by the *Acerocare* zone with *Acerocare ecorne* Ang. in the lower, and *Parabolina heres* in the upper parts. These beds rest disconformably on the Exulans limestone of the *Paradoxides tessini* zone of the Middle Cambrian. The next succeeding beds are the shales with *Dictyonema flabelliforme* followed in another locality by beds with *Clonograptus tenellus* and higher up by beds with *Bryograptus kjerulfi.* These beds however, are not in contact, all the outcrops being discontinuous. But it is possible by digging, to expose the contact between the upper beds of the *Dictyonema* series and the *Ceratopyge* group, of which both the lower *Shumardia* zone and the *Ceratopyge* limestone proper are represented, both however, in slight thickness. The continuity of the section is interfered with by a diabase dyke, after which appear the strongly metamorphosed lower *Didymograptus* beds, which however, still contain recognizable graptolites. This same zone appears again farther north on the banks of the Fogelsang brook, where it carries *Phyllograptus cor* Strandmark.

In the quarries near the river bank, a limestone is shown, which has been identified as *Orthoceras* limestone. The west wall of this quarry shows the lower part of the upper *Didymograptus* bed or zone with *Phyllograptus* cf. *typus*, overlying the "*Orthoceras*" limestone. This shows that the "*Orthoceras*" limestone of this section is not the true *Orthoceras* limestone, but rather the *Megalaspis* limestone, either the Limbata or the Planilimbata horizon. There are 3 quarries and this feature is shown in the middle one. The most southerly one shows apparently this same limestone. Of this Moberg says, "At the bottom of the most southerly limestone quarry, on the occasion when it was pumped dry, a slaty limestone was found, rich in trilobites, among which may be noted *Trinucleus coscinorhinus* Ang. and *Aeglina umbonata.* (Ang)" This bed was not exposed at the time of our visit, but if this slaty limestone was in place, and faulting is excluded, then the *Trinucleus coscinorhinus* beds belong below the Upper *Didymograptus* shale with *Phyllograptus typus*, if not actually in or below the *Megalaspis* limestone.

This is rather a remarkable position, we hardly expect to find *Trinucleus* at so low a horizon as the basal beds of the lower Ordovician. It may perhaps be well to regard this as a doubtful occurrence, until verified by other more reliable exposures. In this connection, it should be noted that Tullberg has recorded in the Tosterup regien, 12 km NE of Ustad, South Scania, *Orthoceras* Limestone, with *Illænus esmarki* and other Asaphus limestone fossils as overlain by beds of the *Trinucleus coscinorhinus* zone with *Ampyx rostratus* and these were directly succeeded by beds with *Dicranograptus clingani*, *Climacograptus bicornis* Hall etc., that is graptolite beds of the later Middle Ordovician.

The Upper *Didymograptus* beds are well shown in a steep bank in the south side of the Sularp river, just above the mouth of the Fogelsang creek. Both the lower division with *Phyllograptus* cf. *typus* Hall, and the upper or Geminus division with *Lonchograptus ovatus* Tullberg, are here shown, but no higher beds. They are also shown farther down the Sularp river, at several localities, both in the bed and bank, and on the Fogelsang creek as well, but in isolated outcrops, which show no relation to higher or lower beds. The difficulty of establishing a complete section in these beds is thus apparent. This is emphasized by a group of outcrops, about 500 m above the mouth of the Fogelsang creek. Here Lower *Dictyonema* beds are exposed in a ditch close to the north bank, while Geminus Beds are shown in the river bed and south bank only a short distance away. Again, a short distance from this point is an exposure of middle *Dicellograptus* shales, representing the zone of *Ampyx rostratus* of the *Chasmops* beds and therefore high in the Middle Ordovician series of the 4th Pulsation. Their close proximity to the Geminus beds can probably be explained only by faulting as it is hardly likely that within so small an area, there is so pronounced a variation in the magnitude of the hiatus between the 3rd and 4th pulsation.[1]

One of the great drawbacks to an understanding of the stratigraphic succession is the use of the term "*Ortho-*

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1 For further detail see Moberg Guide to Scania, and Grabau A. W. Bull. G. S. A. Vol. XXVII, pp. 614 et seq.

ceras Limestone" for all the limestone beds enclosed between the graptolite shales of both the Lower and Middle Ordovician. The true *Orthoceras* limestone, if that name is to be used at all, belongs in the Middle Ordovician and its lowest manifestation in the Baltic region is the *Asaphus expansus* bed, the equivalent of Lamansky's BIII *α*. This lowest division is however very generally wanting in Sweden, where the *Orthoceras* limestone group proper begins with the *Asaphus raniceps* beds, that is Lamansky's BIII *β*. It is in these and the succeeding beds that we have the rich development of the Orthoceratites, which have given these beds their name. *Orthoceras* itself is perhaps less frequent than *Endoceras*, *Vaginoceras* and other genera of the Holochoanites, which often make up the mass of the rock.

These *Orthoceras* beds proper occur in the Röstanga district of West Scania, 38 km N. of Lund, but most of the limestone of at least southern Scania, to which the name *Orthoceras* limestone is currently applied, belongs to the *Megalaspis* limestone of the Lower Ordovician, and lies below the great hiatus, which separates the Lower from the Middle Ordovician. The confusion has of course arisen from the fact, that in a number of sections, both in Sweden and in the Baltic region, there appears to be a continuous limestone series, the lower part of which was characterized by the early Megalaspis (*M. planilimbata* and *M. limbata*) and the higher part by Orthoceracones and by *Asaphus* and other Middle Ordovician trilobites. There was of course no reason to suspect the existence of a hiatus within the limestone series, although the occurrence of phosphatic layers and even of conglomeritic beds was recognized. These were however, generally considered as due to contemporaneous submarine erosion, and not regarded as being of great importance. Moreover, in many sections the disconformity was masked. Now however, that we understand the true relationship of these strata, thanks largely to the detailed work of Lamansky, we should no longer include the Lower Ordovician limestones, that is the *Megalaspis* beds, in the *Orthoceras* limestone. If that name is to be retained at all—for historic and sentimental reasons,—it should be reserved for the Middle Ordovician limestones of the Baltic region. Recent studies by Chinese geologists have shown that the rich cephalopod fauna of these limestones is of Indo-Pacific origin, the fauna being characteristically developed in the corresponding rocks of South China. This problem will be more fully discussed in the article on the Ordovician pulsation.

Sections in Westergötland

KINNEKULLE. One of the most complete sections of the Cambrovician and succeeding Ordovician strata in Central Sweden is that of the Kinnekulle on the South-west border of Lake Vänern in Westergötland. This hill and the neighbouring regions of Lugnås and Billingen have been famous in the geology of Sweden since the days of Kalm (1742) and Linnaeus (1747). The hill which rises 263 meters above Lake Vänern (307 meters above sea-level) is an erosion monadnock of horizontal strata capped by a layer of basalt[1]. The successions of the strata is as follows in descending order.

1 See the sections in Nordenkjöld and De Geer, Guide 36, 11th International Geol. Congress, 1910 pp. 42-47. Figs 11-12 and literature there cited. Also Grabau A. W. Bull. Geol. Soc. of America Vol. XXVII, pp. 586-588, 1916.

DIABASE, forming the top of the hill. 30.0 m.

SILURIAN Llandovery

Upper Graptolite shales 56.0 m.

b. *Retiolites* shale with *R. geinitzianus* and *Monograptus*

a. *Rastrites* shale, with *R. hybridus* and *Monograptus*

Hiatus ?

Brachiopod shales 2.0 m.

Sometimes placed in the Upper Ordovician probably equivalent to Ashgillean.

ORDOVICIAN

C. *Trinucleus shale* 32.0 m.

3. Red Trinucleus shale, with *Remopleurides radians* Barrande, *Cybele verrucosa* Dalman, *Trinucleus wahlenbergi* Rault, *Ampyx tetragonus* Angelin, *Dionide euglypha* Angelin, *Agnostus trinodosus* Salter etc. 18 m

2. Limestone stratum 2 m

1. Black and green *Trinucleus* shale 12 m

B. *Chasmops Beds* 10.0 m.

Dark shales, with graptolites and numerous concretionary limestone masses and beds of impure limestone containing.

Chasmops sp.
Remopleurides sexilineatus Angelin
Ptychopyge glabrata Angelin
Ampyx rostratus Sars
Ampyx costatus Boeck
Agnostus trinodus Salter

Beyrichia costata Lnrs.
Primitia strangulata Salter
Echinosphærites aurantium Gyllenh.
(this last is especially abundant in the Lower part)

A. *Orthoceras Limestone* (Restricted) 40 m.

3. Upper gray or Chiron limestone 10 m.
Contains
Illænus chiron H. M.
Ogygia dilatata Brunn var. *barisi* Ang.
Ancistroceras undulatum Boll.
Discoceras teres Eichw.

2. Upper Red *Orthoceras* limestone
(= BIII γ of Lamansky) 24 m.
b. *Platyurus* limestone with
Asaphus platyurus Ang.
Orthoceras tortum
a. Gigas limestone, with
Megalaspis gigas[1]

1. Lower gray *Orthoceras* limestone or *Asaphus* limestone
(= BIII β of Lamansky) 6 m.
This contains a rich fauna including the following.
Trilobites.
Cyrtometopus clavifrons Dalman
Phacops sclerops Dalman
Asaphus raniceps maxima Er
Megalaspis heros Dalman
Megalaspis rotundatus Ang.

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1 This species has not been reported from the Kinnekulle but occurs elsewhere in Westergotland.

Megalaspis explanata Ang.
Illaenus esmarki Schloth.
Ampyx nasutus Dalman
Cephalopoda
Endoceras wahlenbergi Foord
Orthoceras kinnekullensis Foord
Estonioceras proteus His.
Bathmoceras linnarrsoni Ang.
Gastropoda
Gonionema bicarinatum His.
Raphistoma gradatum Koken
Brachiopoda
Orthis sp.
Cystoidea
Sphæronis pomum Gyllenh.
(this species in rock-forming masses)

Hiatus and Disconformity

This hiatus includes BIII α, and BII γ and BII β of the Estonian region, in addition to the hiatus of unknown length between BII and BIII.

CAMBROVICIAN

E. Lower Red or Limbata limestone (= BII α Lamansky) 12 m.
Contains
Megalaspis limbata S. and B.
Nileus armadillo Dalm. var.

D. Lower *Didymograptus* shale 10 m.
Light greenish shale with
Phyllograptus densus Törnquist
Didymograptus extensus Hall
Tetragraptus quadribrachiatus Hall
Tetragraptus fruticosus Hall

C. *Planilimbata* limestone 0.5 m.
Gray limestone, with
Megalaspis planilimbata
Eoorthis christianiæ etc.

B. *Ceratopyge* limestone 2 m.
Upper part glauconitic limestone,
Lower part glauconitic shale correlated
by Lamansky, with his BI β.
The fossils recorded are :

Trilobita
Ceratopyge forficula Sars.
Euloma ornatum Ang.
Cyrtometopus primigeus Ang.
Niobe insignis Lnrs.
Symphysurus angustatus Boeck
Nileus limbata Brögger

Brachiopoda
Eoorthis christianiæ Kjerulf
Lycophoria lævis Stolley

The last occurs in the lower or glauconitic shale. The others in the glauconitic limestone.

A. Upper Cambrian Alum shale 10.0 m.+

3. Alum shale with lenses and beds of orsten 7 to 8 meters, containing in the upper beds, *Peltura scarabæoides*, in the middle part *P. minor*, and in the lower *P. scarabaeoides acutidens* with other species of Zone 5 of Andrarum
2. Phosphatic conglomerate with *Orusia lenticularis, Parabolina spinulosa* (zone 3)

1. Orsten limestone layers 1 to 1.6 m. thick some beds of which are entirely composed of *Agnostus pisiformis* Linnæus others largely of *Olenus gibbosus* Wahlenberg

Hiatus and Disconformity

MIDDLE CAMBRIAN. *Paradoxides* Beds 6.4 m.

Hiatus and Disconformity

LOWER CAMBRIAN. 30 m.

B. *Lingula* sandstone 20 m.

A. *Mickwitzia* sandstone with Dreikanter 10 m.

Hiatus and Unconformity

ARCHÆAN Weathered gneiss.

In only one section, that is, at Haggaerden on the eastern flanks of the Kinnekulle is the contact between the *Agnostus lævigatus* and *Agnostus pisiformis* zones exposed, the two being apparently conformable. Of the lower shale 0.7 meters are exposed, consisting of shale with an occasional concretion of orsten or foetid limestone. It is apparently followed by 2.9 meters of similar shale with increasing numbers of orsten concretions and with several irregular beds of orsten in the upper part. Then with a rather irregular contact surface follow orsten beds of the *Olenus* zone.

Farther north at Gössäter on the north east slope of the Kinnekulle, the *Agnostus pisiformis* zone, of which here 0.7 meters are exposed, consists of a bed of orsten below and shale with small and large orsten lenses above. This is followed by the *Olenus* zone consisting of one meter of orsten (foetid limestone).

Finally at Hönsäter, on the northern side of the Kinnekulle, the *Agnostus pisiformis* and *Olenus gibbosus* zones form a continuous bed of foetid limestone (orsten) 1.6 meters thick, with only a thin intercalation of shale. It also includes beds with *Agnostus pisiformis obesus.*

To judge by the Haggaarden section, the sedimentation from the Middle Cambrian *Agnostus lævigatus* bed, to the Upper Cambrian *A. pisiformis* bed is continuous, but since we know that the hiatus between the Middle and Upper Cambrian is of world-wide extent we can hardly doubt its existence here, and that the disconformity between the two is masked.

The Olenus Zone. In the Kinnekulle sections, this ranges from 0.9 to 1.75 m in thickness and is everywhere a foetid limestone (orsten). *Olenus gibbosus*, is generally the principal form present, but with it occurs *O. transversus.* These too are characteristic of the Lower *Olenus* zone of Andrarum. *O. truncatus* and *O. wahlenbergi*, characteristic of zones 2b and 2c, are also listed from this bed at Gössäter and with them occur *Agnostus pisiformis obesus.*

The higher *Olenus* zones d to f, found at Andrarum, appear however, to be absent in this section. This is apparently due to a hiatus at this point, for it is in the upper portion of this limestone or at its top that we commonly meet with layers of phosphoritic conglomerate as well as conglomerates of foetid limestone fragments. Here within the space of 20 or 25 cm, we find representatives of zone 3 with *Orusia lenticularis* and *Parabolina spinulosa* of subzone 4c with *Leptoplastus ovatus* and *Eurycare latum* and subzone 5c with *Ctenopyge flagellifera* and *Protopeltura praecursa* the intermediate zones represented in Andrarum being wanting. Westergaard has summarized this as follows. "The zones of *Orusia* and *Leptoplastus* and the subzone of

Ctenopyge flagellifera are very thin, and often altogether wanting. Most constant is the *Orusia* zone, which always contains phosphorites and usually possesses a conglomeratic structure. Sometimes the zones in question form together a conglomerate or breccia, in the uppermost part of the Stinkstone (Orsten) bed with *Olenus*. The *Olenus* zone too, has sometimes brecciated structure as shown by fig. 24, p. 57." (Loc. cit p. 190). The figure referred to, shows a pronounced conglomerate of more or less rounded pebbles of darker, in a fine grained matrix of light gray limestone (orsten), with fragments of *Olenus* and *Agnostus pisiformis obesus.*

In this connection it is of interest to note that in the British section the Maentwrog or Lower division of the Upper Cambrian contains the zones of *Agnostus pisiformis obesus*, *Olenus gibbosus* and *Olenus truncatus*, that is, zones 1 and 2a and 2b of the Andrarum section. Then follows the great series of Ffestiniog beds, up to 3000 ft. in some sections and largely of continental type, with only *Lingulella devisi* in the upper 50 ft. This is followed by the Dolgelly series which begins with the *Orusia lenticularis* zone, and carries *Parabolina spinulosa*, that is zone 3 of the Andrarum section and continues to the *Peltura scarabœoides*, *Sphaerophthalmus alatus* and *Ctenopyge bisulcata* zone, that is subzone 5e of the Andrarum section, after which the Tremadoc beds follow. Thus it is that at the horizon of the great continental or Huangho type of river deposits, which form the Ffestiniog, we have evidence of the interrupted sedimentation and probably actual exposure in the Kinnekulle region, though in the Andrarum region of Scania some few degrees of latitude further south, the series is more complete.

The various subzones of zone 5 are generally developed in the sections on the Kinnekulle. Thus subzone 5d, with *Ctenopyge flagellifera* and *Protopeltura præcursa* with which the shale series of the upper division begins, is followed by the zone with *Peltura scarabæoides acutidens, Sphærophthalmus major* and *Ctenopyge tumida* representative of subzone 5c. and the lower part of subzone 5d. This Acutidens zone varies in the different sections from 2.4 to 2.8 m. in thickness and always consists of shales with lenses and more rarely continuous layers of orsten. The next succeeding zone is that of *Peltura minor* with which are associated *Sphærophthalmus major, Ctenopyge affinis* and more rarely *Ctenopyge tumida.*

This usually consists of more limestone than shale and sometimes overlaps the Acutidens zone, and again the succeding *Peltura scarabæoides* zone, so that both these species may be present in it. Its thickness ranges from 0.5 to lm.

The subzone with *Peltura scarabæoides* (5e of the Andrarum section) occupies the greatest portion of the section, ranging through 4 m. or more of shales with lenses of orsten (fœtid limestone) and over-lapping both the preceding and extending beyond the succeeding zones in some sections. The leading fossils of the zone are *Peltura scarabæoides, Sphærophthalmus alatus* and *Sphærophthalmus major.*

The highest subzones of this division (5f) is sometimes represented by limestones and sometimes it occurs in limestone fragments in the overlying gravel. This is the subzone of *Parabolina longicornis* with which is associated *Agnostus rudis holmi* and more rarely species of *Niobe* and *Megalaspis. Peltura scarabæoides* also commonly extends into it. Its exposed thickness ranges up to a meter or slightly more, but the succeeding beds are not exposed in contact with it, and so its maximum thickness is unknown. It is mainly a fœtid limestone (orsten).

The highest *Parabolina heres* zone (zone 6 of Andrarum which there has a thickness of 5.9 m.) is not shown in any other quarry on the Kinnekulle but is exposed in ditches at Storängen and Trollmen where it has a thickness of no more than 0.6 m. and is covered by thin glauconitic shale, belonging to the *Ceratopyge* zone. The *Dictyonema* (*Dictyograptus*) shale is wanting.

Apparently only a portion of the Planilimbata limestone is replaced by *Phyllograptus* shale in the Kinnekulle region. In a small stream on the west side of the Kinnekulle near Trollmen we found in 1910 an outcrop of the lower *Didymograptus* shale and some distance below a limestone forming a series of steps in the stream bed. In the upper bed of the limestone, we found numerous pygidia of *Megalaspis planilimbata*, together with a few other trilobites and *Eoorthis christianiæ*. The lower limestone contains *Ceratopyge*. No actual contact with the lower *Didymograptus* shale was seen but the latter was exposed some distance up the hill.

The absence of the *Dictyonema* shales in this region may be due to another hiatus or the shale may be entirely replaced by the *Ceratopyge* limestone, which then forms the deeper water equivalent of the mud flat deposits, which gave rise to the graptolite-bearing shales. The relationship of these two formations is well shown in the Christiania region. The *Ceratopyge* limestone in the Kinnekulle varies from 2 m. in the western to 0.5 m. in the eastern region. Among its characteristic fossils here and elsewhere in southern Sweden are the following.

Trilobitæ

Ceratopyge forficula Sars.
Euloma ornatum Ang.
Symphysurus angustatus S. and B.

Niobe insignis Linrs.
Orometopus elatifrons Ang.
Apatocephalus serratus S. et B.
Dicellocephalina dicraneura Ang.
Cyrtometopus primigenus Ang.
Harpides rugosus S. et B.
Triarthrus angelini Linrs.
Agnostus sidenbladhi Linrs.
Megalaspis planilimbata Ang.

Brachiopoda
Orthis christianiae Kjerlf.

Cephalopoda.
Orthoceras atavis Brögger.

The limestone is generally hard, compact with much pyrite in irregular beds, and lumps. The limestones is as a rule thick-bedded, sometimes interstratified with alum shale, but may also occur as lenses in glauconite shale. In some sections as at Falbygden Mountain, it is both underlain and followed by phosphorite-bearing glauconitic limestone, generally devoid of fossils, though these may occur in interbedded shales.

Billingen-Falbygden Hills. This rudely triangular area lies 40-70 km southeast of the Kinnekulle. These hills too are capped by diabase under which occur both Silurian and Ordovician strata preceded by the Cambrian.

In the Stolan region, the northern end of Billingen Hill the following section of the lower strata has been given by Westergaard.

C. Cambrovician

III. Clay shale, with beds of limestone, forming the Lower *Didymograptus* shale 1.35 m.

II.	Ceratopyge limestone, with phosphorite nodules and glauconite grains		0.75 m.
I.	Upper Cambrian Alum shale		10.5 m.
	7. *Peltura scarabæoides Zone* (5e)	3.5 m.	
	Alum shale, with lenses of foetid limestone, contains:		
	Peltura scarabæoides		
	Sphærophthalmus alatus		
	Sphærophthalmus majusculus		
	Ctenopyge pecten ?		
	6. *Petura minor Zone*	2.7 m.	
	b. Alum shale with foetid limestone lenses. 0.6 m.		
	Contains :		
	Peltura scarabæoides		
	Peltura minor		
	Sphærophthalmus alatus		
	Sphærophthalmus majusculus		
	Ctenopyge bisulcatus		
	a. Alum shale with lentils of kolm[1] 2.1 m.		
	5. *Acutidens Zone*	1.8 m.	
	b. Fœtid limestone (orsten) 0.4 m.		
	Contains:		
	Sphærophthalmus major		
	Peltura scarabæoides acutidens		
	a. Alum shale, with scattered lenses of fœtid limestone 1.4 m.		

1 An impure coal, with about 30 per cent ash, contains minute quantities of uranium and radium.

Contains: *Sphærophthalmus major*, *Peltura scarabæoides acutidens* (continued in a different section)

4. *Præcursor Zone* 1.2 m.

b. Mainly large lenses of fœtid limestone 0.6 m.

Contains *Ctenopyge flagellifera angusta*
Protopeltura præcursor
Ctenopyge neglecta

a. Shales with fœtid limestone lenses 0.6 m.

Contains fragments of *Leptoplastus* sp. and *Eurycare latum*.

3. *Orusia Zone* 0.2 m.

Fœtid limestone of conglomeratic structure with phosphate nodules with
Orusia lenticularis, *Parabolina spinulosa*, *Protopeltura aciculata*

(*Possible Hiatus*)

2. *Olenus Zone* 0.6 m.

Fœtid limestone, with
Olenus wahlenbergi (2c)
Olenus truncatus (2b)
Olenus gibbosus (2a)
Agnostus pisiformis obesus (2a)

1. *Agnostus pisiformis zone* 0.5 m.

Fœtid limestone, with :
Agnostus pisiformis.

Probable hiatus and Disconformity

B MIDDLE CAMBRIAN

7. *Alum shale* without fossils or limestone lenses 3.0 m.

6. *Agnostus lævigatus Zone* 1.5 m.
Alum shales with limestone lenses
Contains : *Agnostus lævigatus*
Leperditia primordialis

5. *Complex limestone Bank* 0.6 m.
c. Exporecta conglomerates with *Billingsella exporecta*
b. Dark, fine-grained fœtid limestone (orsten) with *Agnostus parvifrons*.
a. Green, coarse and fine-grained limestone without fossils.

4. *Alum shales*, with some clay shale and some unfossiliferous limestone 2.6 m.

3. *Alum shales* with *Agnostus intermedius* 0.2 m.

2. *Alum shales* without fossils 0.9 m.

1. *Unexposed interval* 1.9 m.

Hiatus and Disconformity

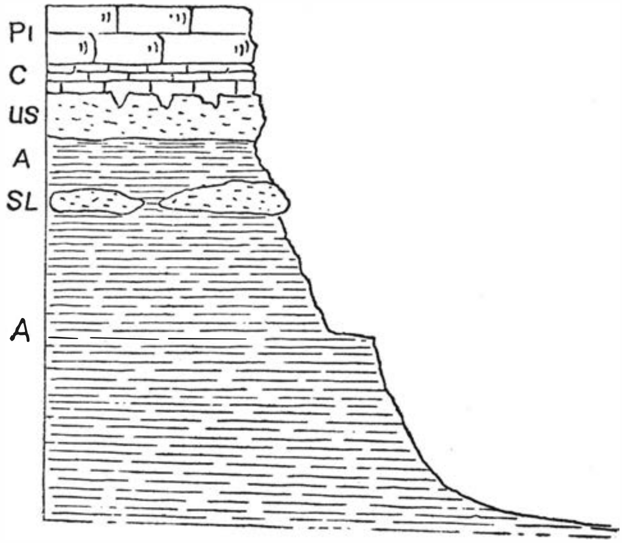
A SUBFORMATION. Lower Cambrian *Lingula* sandstone.

The contact between the Upper and Middle Cambrian appears to fall at the base of the *Agnostus pisiformis* zone, where the limestone rests with somewhat wavy basal contact on 3 meters of unfossiliferous alum shale, beneath which lies the *Agnostus lævigatus* zone. The contact between the Lower and Middle Cambrian may fall within the unexposed interval above the Lingulid sandstone.

In another section in this region, the upper beds of the *Peltura scarabæoides* zone contain thin lenses of true coal. Similar coal up to 13 or 14 cm. in thickness is found in the lower division of the *Didymograptus* shales in the Billingen and Falbygden regions, the thickest being in this shale near where our section is taken. "It has a chemical conposition of a real coal ; is pure with very little ash. It contains about 0.2 per cent vanadium. As to the origin of the coal, it may be noted that nothing has been found that resembles in any way plant-organ, plant structure or parts thereof, or anything derived from plant structures (R. Thiessen). Its occurrence also as fissure fillings indicates that the coal does not result from primary depositions of plants or animals, but may be a secondary product originating in the bitumina of the alum shales." (Westergard *Loc. cit.* p. 192)

Oedegarden. The interesting section at Oedegärden in Falbygden, the south-eastern part of the Palæozoic fault block, and about 6 km west of Tidaholm station, shows further detail. This section we were ennabled to study in 1910 under the guidance of Professor Carl Wiman and the important part of the section is here reproduced from my field note-book (Text-Fig. 3.) According to Westergaard, (*loc. cit.* p. 68) the entire Upper Cambrian series is included in 12 meters of alum shale, with lenses and beds of fœtid limestone. The top is formed by such a bed, 1 meter thick, with *Peltura scarabæoides* etc. and the lower part by shales with *Agnostus pisiformis* which rest with apparent conformity on shales with *Agnostus lævigatus* the Middle—Upper Cambrian disconformity being masked. In this section too, the *Olenus gibbosus aud O. truncatus* zones are followed disconformably by *Orusia* conglomerates.

The terminal part of the section is formed by glauconitic and phosphoritic *Ceratopyge* limestone 0.3 meters in thickness, containing *Niobe obsoleta* Linrs, *Symphysurus angustatus* (S & B) and *Eoorthis christianiæ* (Kherlf). This in turn is succeeded by *Planilimbata* limestone. The upper surface of the fœtid limestone of the *Peltura scarabæoides* zone (Text-Fig. 3. US.) is characterized by corrosion hollows, which are often several centimeters deep, and are filled by glauconitic *Ceratopyge* limestone. The two are so firmly united that it was possible to remove specimens showing both beds. Moreover, the base of the *Ceratopyge* limestone is characterized by brown phosphate nodules, which contain fossils of the underlying fœtid limestone, and represent altered fragments of the same.



Text-Fig. 3. Section at Oedegarden Sweden (Original). Showing contact between Ceratopyge limestone and Upper Cambrian orsten.
Pl. = Planilimbata limestone ; S.L. = Stinkkalk (orsten) Lenses
C. = Ceratopyge limestone ; A. = Alum Shale (Upper Cambrian)
U.S. = Upper Stinkkalk (orsten) ;

While the corrosion hollows in themselves might perhaps be considered a secondary feature, formed by interstratum solution somewhat after the manner of stylolites,[1] the phosphate nodules in the basal part of the *Ceratopyge*

1 See Grâbau. Principles of Stratigraphy p. 788 fig. 173.

limestones, and the fact that they are composed of altered fragments of the underlying rock, as shown by the fossils, certainly indicate a hiatus and erosion interval. The *Dictyonema* shales are absent here, which might be accounted for by their being replaced by *Ceratopyge* limestone but what is more to the point, the Upper Cambrian zones of *Acerocare* and *Parabolina heres*, which in Scania have a conbined thickness of 5 m. are also absent here. Thus there appears to be no escape from the conclusion that we have here a hiatus between the *Ceratopyge* and the Upper Cambrian beds. What the extent of this hiatus is, however, we have at present no means of estimating. It may be regarded as a temporary withdrawal of the sea from central Sweden, during the period of the formation of the *Dictyonema* shales in the mud flat region, or it may be due to the formation of a "Schwelle" or Limen, such as have been invoked as explaining the many minor disconformities in the Cambrian rocks of Sweden. (Vol. I, p. 483 .

On the other hand, we may have here a more pronounced withdrawal than would at first appear, one comparable to the repeated withdrawal which I have suggested as explaining the many disconformities and many changes in fauna, which are so characteristic of the Middle Cambrian of this geosyncline and are apparently repeated in the Olenus-Orusia disconformity of the Upper Cambrian Sections here given and shown in Britain by the Ffestiniog sands.

The *Planilimbata* limestone of this section P. L. is in intimate association with the *Ceratopyge* limestone which underlies it, there being here no indication of a hiatus between the two. There is however, a great faunal change, marked by the incoming of the *Megalaspis* fauna, and this sudden change of fauna must be accounted for. It might indicate a second hiatus between the *Ceratopyge* and Limbata limestones, the physical evidence for which is masked, or it might be the sudden incursion of a fauna from a new center of evolution by the disappearance of barriers, which formerly restrained it. Evidently these are problems for further investigation.

However I may add, that I see as yet no evidence of such a pronounced disconformity and hiatus as would be required if we were to introduce an entirely new system, the Ozarkian, either below or immediately above the *Ceratopyge* limestone.

A general section on Stenbrotted about 10 km S. E. of Falköping shows the following succession in descending order (Westergaard *loc. cit.* p. 68)

CAMBROVICIAN

5.	Orthoceras limestone (Probably in part at least *Megalaspis* limestone. Upper part may be *Asaphus* limestone)	(max)	4.5 m.
4.	Lower *Didymograptus* shale Gray-green clay shale with limestone bank.		0.65 m.
3.	*Ceratopyge* limestone Gray-green limestone with glauconite and phosphorite		0.20 m.
2.	*Dictyonema* shale Alum shale with orsten.		0.32 m.
1.	*Olenus* shales Alum shale with orsten and a 0.5 m. bed of orsten (fœtid limestone) in shale. Also orsten lenses.		5.00 m.

HUNNEBERG AND HALLEBERG. These small hills lie at the south end of Lake Vänern. The general succession is

DIABASE

CAMBROVICIAN

Lower *Didymograptus* shale

Ceratopyge limestone and shale

Dictyonema shale

Olenus shale

Hiatus and Disconformity

MIDDLE CAMBRIAN

Paradoxides Shale

Sandstone (Lower Cambrian?)

The interruption between the *Olenus* and *Orusia* beds is still indicated though less obvious.

Northern Sweden

NÄRKE In the Province of Närke (Latorpsbruk) the succession is also incomplete.

Resting disconformably on the Exporecta conglomerate of the Middle Cambrian is shale with *Agnostus pisiformis*, followed by shales and "orsten" with *Olenus* (*O. transversus*, *O. gibbosus O. wahlenbergi*, *O. truncatus*). Then comes a disconformity followed by alum shale with orsten concretions enclosing the fossiliferous zones from *Ctenopyge flagellifera angusta* and *Protopeltura præcursor* (5c) to that of *Parabolina spinulosa* (5e)

Another disconformity cuts out the higher beds, the Glauconite limestone (*Ceratopyge* horizon) and the Lower Ordovician (So-called *Orthoceras* limestone) follows.

The *Orusia* zone is cut out, and elsewhere in Närke it and even the *Olenus* zones may be replaced by thin conglomerates.

DALARNE. The series of fault blocks of Palæozoic rocks, preserved within the granite mass in the vicinity of

Siljan See, is one of the most significant as well as readily accessible areas. This we were enabled to study in the summer of 1910 under the expert guidance of Prof. Carl Wiman, and Dr. Elsa Warburg.[1]

The succession according to Warburg is as follows in descending order, modified by the introduction of my classification.

SILURIAN

Upper Graptolite Shales	
Retiolites shales	10 m.
Rastrites shales	20 m.
Leptæna limestone, partly replaced by brachiopod shale or klingkalk. (This is included by Warburg in the Ordovician)	

Hiatus and Disconformity

ORDOVICIAN

Trinucleus shales	
4. Red *Trinucleus* shales	15 m.
3. Gray limestone	5-9 m.
2. Black *Trinucleus* shales	6 m.
1. Masur limestones or Knyckekalk	9-15 m.
Chasmops limestone	
2. Macrurus limestone & shale	9-10 m.
1. *Echinosphærites* limestone	15-18 m.
Orthoceras limestone (Restricted)	
Upper gray *Orthoceras* limestone	

1 Elsa Warburg. Geological description of Nittsjö and its environs in Dalarne. Guide 21, XIth International Geol. Congress, Excursion 1, Geol. Fören. i Stockholm Förhandle. Bd. 32 Häft 2, Feb. 1910, pp. 425-450 2 maps.

2. *Ancistroceras* limestone 5 m.
1. Chiron or *Centaurus* limestone 5 m.

Upper Red *Orthoceras* limestone

2. Platyurus limestone (CI α) 13 m.
   Contains:
   Asaphus platyurus Ang.
   Endoceras belemnitiforme Holm
1. Gigas limestone (BIII$^{\gamma}$) 12 m.
   with *Megalaspis gigas*

Lower gray *Orthoceras* limestone

Asaphus expansus limestone (BIII$^{\beta}$ & BIIIα) 8 m.

These beds contain the following species

Trilobita

Asaphus expansus Wahl.
Asaphus vicarius Tqt.
Megalaspis polyphemus tornquisti Schmidt
Illænus esmarki Schloth,
Nileus armadillo Dalm.

Brachiopoda

Orthis callactis Dalm.
Orthisina ascendens Pand.
Lycophoria nucella Dalm.

Gastropoda

Bucania planorbiformis (Linrs.)
Salpingostoma cristatum (Linrs.)
Lytospira angelini Lindst.

Cephalopoda

Vaginoceras vaginatum (Schloth.)

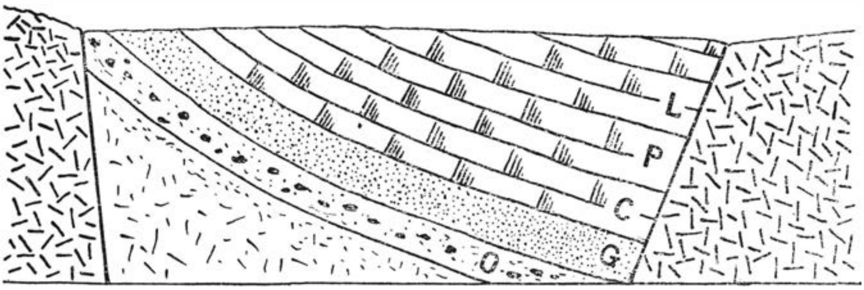
Hiatus and Disconformity

CAMBROVICIAN	
Megalaspis limestone	
Lower Red or Limbata limestone	3 m. +
Megalaspis limbata Boeck	
Niobe læviceps Dalm.	
Nileus armadillo Dalm. (var.?)	
Green or Planilimbata limestone	3 m. +
Megalaspis planilimbata Ang.	
Ceratopyge beds	
Ceratopyge Limestone	0.14-0.16 m. +
Obolus fragments	
Lycophoria lævis Stolley	
Eoorthis christianiæ Kjerulf.	
Glauconite Sand	0.1 m.
Obolus conglomerate	0.15-0.80 m.
Obolus apollinis Eichw.	

Hiatus and Unconformity

PRECAMBRIAN GRANITE	
Weathered granite	0.1-0.4 m.
Fresh granite	————

The *Obolus* conglomerate is more often a mass of crystalline sand derived from the weathering of the underlying granite or gneiss and represents the re-working of the products of weathering on the old land surface by the transgressing Cambrovician Sea. The relationships of these beds is shown in the following section in the railroad cut near Sjurberg, about 4.5 km. N. W. of Rättvick taken from my field note book (Text-Fig. 4) Here the top of the granite basement consists of 0.1 to 0.4 meters of weathered granitic material, which passes upward into an irregular bed of fine conglomerate, mostly with quartz pebbles and granite fragments and contains the phosphatic fragments and entire shells of *Obolus apollinis* Eichwald, and grains of phosphatic nodules. This is the *Obolus* conglomerate (Ungulite sandstone) found in many places at the



Text-Fig. 4. Section of the Lower Ordovician Formations in the Railroad cut near Sjurberg, in Dalarne, Sweden (A.W.G. 1910) the Palæozoic beds are faulted into the granite mass. At the base is fresh granite, which upwards becomes decomposed granite and is succeeded by O., *Obolus* conglomerate C. *Ceratopyge* limestone G. Glauconite sand. P. Planilimbata limestone L. Limbata limestone

base of the Cambrovician of this region. It ranges in thickness from 0.15 to 0.80 m. and passes upward into a glauconite sand of about 0.1 m. thickness, which also contains fragments of these shells, and which in turn is succeeded by gray somewhat glauconitic limestone, the *Ceratopyge* Bed. This is characterized by *Lycophoria lævis* Stolley, and also has furnished *Eoorthis christianiæ*, while small fragments of *Obolus* still occur. *Ceratopyge* itself has not been found.

The *Ceratopyge* limestone passes without break into the Planilimbata limestone and this into the Limbata limestone. These beds represent continuous calcareous sedimentation, the material being a typical calcilutite. Organic remains are exceedingly rare in this limestone. The section is terminated by a fault.

The section in the Siljan-See District shows a well marked hiatus between the *Megalaspis* and *Asaphus* limestones, the former representing the horizon BIIα of Lamansky's Baltic shore section and the latter his horizon BIIIα & BIII$^{\beta}$. His divisions BII$^{\beta}$ and BII$^{\gamma}$ of the east Baltic region are absent here and the hiatus is even greater than it is in the region near St. Petersburg.

A section at Skattungbyn in the northern margin of the ring of the Palæozoic strata which form the nearly circular valley, part of which is occupied by Siljan Lake, shows a rather remarkable variation from the more southerly section. This lies about 40 km. N. W. of Rättvick. The section has been described by Tornquist, Warburg and Holm. The base of the section here is formed by a bed of limestone 1 ft. in thickness, resting directly upon the porphyry and enclosing angular fragments of it. This bed is regarded by Wiman as representing the *Ceratopyge* limestone. It is succeeded by green *Phyllograptus* shale, with interbedded layers of limestone. The shales contain the following graptolites.

Tetragraptus serra Brongniart
Tetragraptus quadribrachiatus Hall
Tetragraptus curvatus Törnquist
Phyllograptus densus Törnquist
Dichograptus octobrachiatus Hall
Didymograptus minutus Törnquist
Didymograptus gracilis Törnquist
Didymograptus decens Törnquist

Some brachiopods also occur in these shale. The enclosed limestone layers have furnished according to Holm[1], the following trilobites.

Pliomera törnquisti Holm
Megalaspis dalecarlica Holm
Niobe læviceps Dalman
Ampyx pater Holm
Agnostus tornquisti Holm
"*Trilobites*" *brevifrons* Holm

In this section the *Pyllograptus* shale replaces the Planilimbata limestone, of which a few extensions remain in the interbedded limestones. Among the trilobites obtained from these beds *Niobe læviceps* is characteristic of the Lowest Baltic horizon (BII*a*). As this section lies to the north of the one in which the Planilimbata limestone is fully developed and therefore nearer to the old shore, it fully harmonizes with the interpretation of the graptolite shales as shore deposits.

JÄMTLAND. Farther north in Jämtland, the true *Orthoceras* limestone, that is, the Middle Ordovician *Asaphus* beds overlap the older rocks and sometimes lie directly upon the old crystallines. In a few places however, as between Brunflo (Long. 15⁰, 5′ E., Lat. 63°, 5′ N,) and Oestersund, (Long. 14⁰, 48′ E., Lat. 63⁰ 15′ N.) the *Megalaspis limbata* limestone is still present, followed disconformably by the Middle Ordovician *Asaphus* limestone.

The Limbata limestone is here included with the *Asaphus*, the Gigas and the Platyurus limestone under the general name of *Orthoceras* limestone, which in this section

1 *Holm G.* Uber einige Trilobiten aus dem Phyllograptusschiefer Dalekarliens. Bih. K. V. Akad. Handl., Stockholm 1882, Vol. VI, No. 9.

has a total thickness of 37 cm. Bearing in mind, that between these higher divisions and the Limbata limestone which represent BIIα of the Baltic section, there is a marked hiatus, it is evident that the true *Orthoceras* limestone can be represented here by only a slight thickness. In Delarne the three divisions referred to have a thickness of only 33 meters and although it is probable that only the highest bed of the *Asaphus* limestone BIIIβ, is here represented, there is no escape from the conclusion, that if the Gigas and Platyurus limestones are also present here they have been reduced from a combined thickness of 25 m. in Dalarne, to one very much less than half a meter in this northern section. At some other localities however the thickness is much greater being about 90 m. (Klövsjö, and Skalangen).

In some localities again, as at Näckten Lake between Skarland and Skalangen, *Phyllograptus* shale is found underlying the limestone, and containing in addition to the other graptolites.

Clonograptus tenellus Linrns.

It is underlain by beds identified as *Ceratopyge* limestone, these at Tossasen containing *Eoorthis christianiæ*, *Niobe læviceps* Ang. and *Cyrtometopus* cf. *faveolatus* Ang. From another locality, Klövsjö, these limestone beds have furnished.

Niobe insignis Lrs.

Megalaspis stenorhachis Ang. ?

These beds are preceded by shales and some orsten of Upper Cambrian age in which Westergaard (*loc. cit.* p. 93) has recognized the following zones.

Zone 6 with *Parabolina jemtlandica*

Zone 5c with *Peltura scarabæoides*

[1]Zone 5b with *Peltura minor*
Zone 5a with *Ctenopyge flagellifera* and
Protopeltura præcursor
[1]Zone 4c with *Eurycare angustatum*
Zone 4b with *Eurycare latum* and
Leptoplastus ovatus
Zone 4a with *Leptoplastus minor*
Zone 3 with *Parabolina spinulosa* and
Orusia lenticularis
Zone 2 with *Olenus*
Zone 1 with *Agnostus pisiformis*

Hiatus and Disconformity

Subformation Middle Cambrian Exporecta conglomerate with *Billingsella exporecta.*

The thickness of the Upper Cambrian of Jämtland varies from 2 meters on Lake Storsjön, to 19 meters in Angermanland (about 65° N. lat.)

Olenus beds, and those with *Peltura scarabæoides* and *Shærophthalmus alatus* are also found in Stensele, and beds with *Olenus truncatus* and *Agnostus pisiformis obesus* in Wilhelmina parishes. Scattered remains of these horizons are also found in other parishes of Lapland. The strata in Jämtland are often folded and more or less metamorphosed.

It is evident that the Scandinavian Old-Land had a somewhat irregular surface, over which the transgressing Cambrovician Sea spread its terminal transgressive layers in a patchy way, as is shown by the variation in the horizon of the basal bed at the several localities, and the variable thickness of the series.

Again during and after the Cambrovician retreat,

---

1 This zone is not recognized in Klövsjö but occurs elsewhere in Jämtland.

erosion must have modified this surface to a considerable extent, so that the returning Middle Ordovician Sea left its deposits on various older horizons, sometimes even directly on the crystallines.

Where some of the older Limbata limestone remains, the contact with the succeeding bed might easily be obscured. As a matter of fact the lower bed of the transgressing Ordovician series, usually the *Asaphus* bed, might be in part composed of the fine debris, left on the surface by the disintegration of the older limestones, and as a result the contact between the two might have the appearance of a transitional one and even weathered-out fossils of the older series might be enclosed in the younger.

This is probably the reason why the break within the so-called *Orthoceras* limestone, has so seldom been recognized and depends generally for determination on the faunas of the two adjoining beds.

Oeland

On the island of Oeland close to the Swedish Mainland, the Cambrovician series is very scantily represented especially in the northern portion. In the southern part of the island the Cambrovician has the following succession (the Cambrian according to Westergaard *loc. cit.* p. 33). In descending order:

SUPERFORMATION Ordovician *Asaphus* limestone

Hiatus and Disconformity

CAMBROVICIAN

L. Ordovician

Limbata limestone

Planilimbata limestone

These two carry the fossils found in them elsewhere.

Tremadoc
Ceratopyge shale and limestone with
Shumardia pusilla Sars
Ceratopyge forficula Sars

Dictyonema shale with
Dictyonema flabelliforme

Upper Cambrian shales with orsten beds and concretion 9.2 m.

6. Zone of *Parabolina heres* 1.1 m.
   b. Subzone of *Parabolina heres*
   a. Subzone of *Peltura cornigera*

5. Zone of *Peltura, Sphærophthalmus* and *Ctenopyge* 2.1 m.
   d. Subzone of *Parabolina longicornis, Agnostus rudis holmi* and *Peltura scarabæoides.*
   c. Subzone of *Peltura scarabæoides, Sphærophthalmus alatus* and *S. majusculus*
   b. Subzone of *Peltura minor, P. scarabæoides acutidens* and *Sphærophthalmus major*
   a. Subzone of *Ctenopyge flagellifera* and *Protopeltura præcursor*

4. Zone of *Eurycare* and *Leptoplastus* 0.3 m.

3. Zone of *Parabolina spinulosa* and *Orusia lenticularis* 1.3 m.

2. Zone of *Olenus* 1.6 m.
   c. Subzone of *Olenus rotundatus*
   b. Subzone of *Olenus truncatus*
   a. Subzone of *Olenus gibbosus*

1. Zone of *Agnostus pisiformis* 2.8 m.

Hiatus and Disconformity

SUBFORMATION: *Middle Cambrian,* Exporecta Conglomerate.

In northern Oeland[1] at the shore cliff known as Äleklinta about 15 km. north of Borgholm and between this and Djupviks 5 km. further north, the *Olenus* shale is only 0.9 to 1.5 m. thick as compared with nearly 10 meters in South Oeland. It represents only the *Agnostus pisiformis* zone. Below this shale follows a dark ferruginous and argillaceous limestone not much more than half a meter in thickness often with a conglomeratic base (Westergaard). Disconformably beneath this, lie the *Paradoxides tessini* beds, the Davidis and Forchhammeri beds being wanting. "These Tessini beds are more or less of a sandy character, in the upper part, beneath which in turn lies a dark crystalline limestone, the two together having approximately a thickness of one meter or slightly more. The limestone which is still a part of the Middle Cambrian, rests in turn upon a dark conglomerate, beneath which sandstone forms the remainder of the section. These beds are probably Lower Cambrian, the conglomerate marking the hiatus between them and the Middle Cambrian."

Directly above the *Olenus* shale of Äleklinta is a layer of dark green glauconite sand, 20 cm. thick, and carrying concretions with *Orthis* cf. *christianiæ* in the upper part. This is correlated by von Huene, with Lamansky's BIα.

Next above the green-sand are gray limestones, becoming greenish upwards and having a thickness of 2 meters.

1 F. von. Huene. Geologische Notizen aus Oeland und Dalarne Centralblatt für Mineralogie Geologie und Palæontologie 1904, p. 450 461, 6. Text Figs.

This limestone consists of several strata separated by glauconitic marl layers. The lower gray portion represents the Ceratopyge horizon. It contains pygidia of *Niobe* and *Asaphus* aff. *lepidurus*. Discounting this preliminary specific identification as that species belongs to a higher horizon, we are probably here dealing with the horizon of *Megalaspis planilimbata*, which seems to be inseparable from the *Ceratopyge* limestone as it is at Ödegarden. It is followed immediately by the *Megalaspis limbata* limestone, usually called Lower Red "Orthoceras Limestone" but entirely distinct from the true Orthoceras Limestone which belongs to the Middle Ordovician.

The succession in descending order may be summarized as follows.

Aleklinta Section, Oeland

CAMBROVICIAN

5.	Limbata limestone. Lower Red "Orthoceras" limestone. (partly exposed)	
4.	Planilimbata limestone Green limestone	5 m. (4–3)
3.	Ceratopyge limestone, with glauconitic marl layers	
2.	Dark-green, glauconitic layers with concretions containing *Orthis christianiæ*	0.2 m.
1.	*Olenus* shale. (*Agnostus pisiformis* bed, shale and limestone with basal conglomerate	1.5 m.

Hiatus and Disconformity

SUBFORMATION: Middle Cambrian *Paradoxides tessini* shales

A second section was examined by von Huene at Köping near Borgholm. Here the *Olenus* shale, the lowest exposed bed, is followed by 0.5 m. of glauconite sand, with soft shaly grayish brown clayey limestone at the base, frequently more or less composed of shells and broken fragments of *Obolus apollinis*, together with 2 small species of Linguloid shells and an *Acrothele*. The character of the rock, with its shells mostly broken, suggests, though it does not prove, temporary emergence. It will be recalled, that Scupin, has given evidence for the contemporaneous deposition of the *Obolus* and *Dictyonema* beds and hence the *Obolus* bed of the present section together with the following greensand may represent the *Dictyonema* horizon. The glauconite sand is followed by 80-90 cm. of gray limestone, with interbedded layers of glauconite sand in the lower part.

This glauconitic limestone, which probably represents the *Ceratopyge* horizon contains in its basal layers large irregular brown phosphorite rock masses, and with them occurs *Orthis* cf. *parva* Pander. These beds are succeeded by 5 to 6 meters of thin-bedded red *Megalaspis* limestone, with *M. planilimbata* Ang., *M. limbata* Ang, *Niobe læviceps* (Dalman) and numerous *Orthis christianiæ*, the latter chiefly at the base, where the limestone is dark-violet-red, dark-gray and yellow, and contains anthraconite and shows more or less corroded bedding planes. Summarized we have the following in descending order

Section at Köping near Borgholm (according to von Huene)

CAMBROVICIAN

Red *Megalaspis* limestone	5-6 m
Anthraconitic layers with *Orthis christianiæ*	
Glauconite *Ceratopyge* limestone	0.8-0.9 m
Glauconite sandstone with *Obolus* limestone at base	0.5 m
Olenus shale, base not exposed.	

Westergaard gives the following detailed section for the Köping region near Borgholm (loc. cit. p 36)

Cambrovician

5.	Red glauconitic Planilimbata limestone, about	1.0 m.
4.	Red-brown *Ceratopyge* limestone with glauconite grains, about	0.5 m.
3.	Glauconite shale (*Ceratopyge* shale) with limestone lenses and bituminous alum shale, about	1.6 m.
2.	Alum shale with *Dictyonema flabelliforme norvegicum* max.	0.5 m.

Hiatus and Disconformity

1.	Upper Cambrian limestone with *Agnostus pisiformis* Lower portion conglomeratic	0.3-1.1 m.

Hiatus and Disconformity

Middle Cambrian. Shaly sandstone of the *Paradoxides tessini* zone

In the glauconitic shale (hor. 3) the following brachiopods have been found :

Bröggeria salteri (Holl)
Lingulella ferruginea Salter
Lingulella lepis (Salter)
Acrothele borgholmensis Walc.
Acrotreta seebachi Walc.
Eoorthis christianiæ (Kjerulf)

Regarding the Cambrian portion of this section Westergaard says, "Above the clay shale with its thin beds of sandstone (the *Paradoxides tessini* zone) rests a bed of stinkstone containing *Agnostus pisiformis.* In the lowest part of the stinkstone there is a greenish limestone and a thin conglomeratic layer, replacing the zones of *Par. forchhammeri* and *Agnostus lævigatus*. At the upper surface of the stinkstone is to be seen another conglomerate, replacing the main bed of the Olenidian and the main part of the *Dictyograptus* shale. The overlying bed of alum shale (at Köping Klint, glauconitic shale with thin layer's of alum shale) contains in the very bottom stratum, in several localities, *Dictyonema flabelliforme norvegicum* the characteristic fossil of the uppermost part of the *Dictyograptus* shale. Thus the upper and main part of this bed of alum shale is looked upon as *Ceratopyge* shale.

"In the cement of the upper conglomerate, as well as in pebbles of stinkstone which are sometimes confluent with the cement, occur *Agnostus pisiformis*, *A. pisiformis obesus*, *Olenus gibbosus*, *Orusia lenticularis*, *Peltura scarabæoides* and *Sphærophthalmus alatus*." (*Loc. cit.* p. 189-190)

As a rule the fossils of a given zone occur together, the others occur by themselves. This conglomerate thus indicates that there has been a considerable amount of destruction of the Upper Cambrian beds of which a number of zones were originally present. The fragments of the several horizons have been gathered in the conglomerate before the deposition of the uppermost *Dictyograptus* shales with *Dictyonema flabelliforme norvegicum*. This indicates exposure and subaërial destruction, rather than submarine, and this corresponds essentially to the beginning of the retreatal movement which, as we have seen, is elsewhere marked by the occurrence of a local hiatus. At present the evidence seems to suggest rather a minor oscillation than a great movement of interpulsation magnitude.

North of Djupvik harbor, at Horn Point, only one thin conglomerate with pebbles of orsten and phosphorite nodules separates the *Paradoxides tessini* beds from the glauconitic *Ceratopyge* shale. In the cement of this conglomerate fossils from the upper *Paradoxides* and *Olenus* beds occur. Here too *Obolus apollinis* is not infrequent, associated sometimes with *Agnostus pisiformus* and sometimes with *Olenus*.

Deep borings on Gotland Island show that *Olenidian* and other alum shales are absent, as shown by a deep boring at Visby. In the following Table (J-II) the distribution of the Upper Cambrian Trilobites of Sweden is given.

Table J-II

Trilobite Fauna of the Upper Cambrian of Sweden

(after Westergaard)

Region	Subregion	Locality / Zone	No.	1	2	3	4	5
Other Loc.		Canada	24					?
Other Loc.		England & Wales	23					×
Other Loc.		Oslo district	22					|
Other Loc.		Bornholm	21					|
N Sweden		Lappland	20					×
N Sweden		Jämtland	19				×	×
N Sweden		Närke	18				|	|
South Sweden	Väster-gotland	Hunneberg	17				|	|
South Sweden	Väster-gotland	Kinnekulle	16				|	|
South Sweden	Väster-gotland	Billingen & Falbygden	15				|	|
South Sweden		Oestergotland	14				|	|
South Sweden	Öland	North	13				a	|
South Sweden	Öland	South	12				|	|
South Sweden	Skania	Various loc.	11	×			|	×
South Sweden	Skania	Andrarum	10	|	×		|	×
Swedish Zones		Acerocare Zone	9	×	×		|	|
Swedish Zones		Parabolina longicornis Zone	8	|	|		|	|
Swedish Zones		Peltura scarabæoides Zone	7	|	|		|	|
Swedish Zones		P. scar. acutidens Zone	6	|	|		|	|
Swedish Zones		Protopeltura præcursor Zone	5	|	|		|	|
Swedish Zones		Leptoplastus-Eurycare Zone	4	|	|		|	|
Swedish Zones		Parabolina spinulosa & Orusia Zone	3	|	|		|	×
Swedish Zones		Olenus Zone	2	|	|	×	|	|
Swedish Zones		Agnostus pisiformis Zone	1	|	|	|	×	|

1. Acerocare ecorne Ang.
2. Acerocare tullbergi Mob. & Möll.
3. Acrocephalites (?) rarus Westerg.
4. Acrocephalites stenometopus (Ang.)
5. Agnostus cyclopyge Tullb.

Table J-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6. Agnostus pisiformis (L)	×	?	—	—	—	—	—	—	—	×	—	×	×	×	×	×	×	×	×	×	×	×	×	+
7. Agnostus pisiformis obesus Belt.	—	×	×	—	—	—	—	—	—	×	×	×	a	×	×	×	×	×	×	×	×	×	×	
8. Agnostus reticulatus Ang.	—	×	—	—	—	—	—	—	—	×	×	×	—	×	—	×	—	×	×	—	—	—	×	
9. Agnostus rudis Salter	—	—	—	—	—	×	—	—	—	×	—	—	—	—	—	×	×	—	—	—	—	—	×	+
10. Agnostus rudis holmi West.	—	—	—	—	—	—	×	×	—	×	—	×	—	—	×	×								
11. Agnostus trisectus Salter	—	—	—	—	—	×	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	×	×
12. Agnostus sp.	—	—	—	—	—	—	—	—	×	—	×													
13. Beltella solitaria West'gd.	—	—	×	—	—	—	—	—	—	×														
14. Boeckia (?) illænopsis West.	—	—	—	—	—	—	—	—	×	×	×													
15. Boeckia (?) scanica West.	—	—	—	—	—	—	—	—	×	×														
16. Conokephalina olenorum West.	—	—	×	—	—	—	—	—	—	×														
17. Ctenopyge affinis West.	—	—	—	—	—	×	×	—	—	×	—	×	—	—	×	×	—	×						
18. Ctenopyge bisulcata (Phillips)	—	—	—	—	—	—	×	—	—	×	—	×	—	?	×	—	—	×	×	×	—	—	×	+
19. Ctenopyge directa (Lake)	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	×	
20. Ctenopyge erecta Westerg	—	—	—	—	×	—	—	—	—	×	×	—	—	—	—	—	×	—	?					
21. Ctenopyge flagellifera (Ang)	—	—	—	—	×	—	—	—	—	×	×	×	—	×	×	×	×	×	×	—	—	×	?	+
22. Ctenopyge flagellifera angusta West.	—	—	—	—	×	—	—	—	—	×	×	×	—	×	×	—	×	×	×	—	—	×		
23. Ctenopyge linnarssoni West.	—	—	—	—	—	—	×	—	—	×	×	?	—	—	?									
24. Ctenopyge neglecta West.	—	—	—	—	×	—	—	—	—	×	×	×	—	×	?	—	?							
25. Ctenopyge œlandica West.	—	—	—	—	—	×	—	—	—	—	—	×												
26. Ctenopyge pecten (Salt.)	—	—	—	—	—	—	×	—	—	×	×	×	—	×	×	—	—	×	—	—	—	—	×	×
27. Ctenopyge spectabilis Brögg	—	—	—	—	×	×	—	—	—	×	—	—	—	—	—	—	—	—	×	—	—	×		

Table J-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
28. Ctenopyge teretifrons (Ang)	—	—	—	—	—	—	×	—	—	×	×	?	—	—	?	—	—	—	—	—	—	—	×	
29. Ctenopyge tumida West.	—	—	—	—	—	×	—	—	—	×	×	×	—	—	×	×	×	×	×	—	—	×		
30. Cyclognathus granulatus (Mob. & Möll.)	—	—	—	—	—	—	—	—	×	×	×													
31. Cyclognathus micropygus Linrs.	—	—	—	—	—	—	—	—	×	—	×													
32. Euloma primordiale West.	—	—	—	—	—	—	—	—	×	—	×													
33. Eurycare angustatum Ang.	—	—	—	×	—	—	—	—	—	×	×	—	—	—	—	×	—	×	—	—	—	×		
34. Eurycare brevicauda Ang.	—	—	—	×	—	—	—	—	—	×														
35. Eurycare latum (Boeck)	—	—	—	×	—	—	—	—	—	×	—	×	—	×	×	×	×	—	×	—	—	×		
36. Eurycare spinigerum West.	—	—	—	×	—	—	—	—	—	×														
37. Leptoplastus claudicans Mob. & Möll.	—	—	—	?	—	—	—	—	—	×														
38. Leptoplastus minor West.	—	—	—	×	—	—	—	—	—	?	—	—	—	×	×	—	—	—	×					
39. Leptoplastus ovatus Ang.	—	—	—	×	—	—	—	—	—	×	—	×	—	×	×	×	×	—	×	—	—	×		
40. Leptoplastus paucisegmentatus West.	—	—	—	×	—	—	—	—	—	×														
41. Leptoplastus raphidophorus Ang.	—	—	—	×	—	—	—	—	—	×	—	—	—	—	—	—	—	—	?					
42. Leptoplastus stenotus Ang.	—	—	—	×	—	—	—	—	—	×	—	—	—	—	×	—	—	×						
43. Liostracus pusillus West.	—	—	×	—	—	—	—	—	—	×														
44. Liostracus (?) superstes Linrs.	—	—	×	—	—	—	—	—	—	×														
45. Megalaspis sp. (hypostoma 1)	—	—	—	—	—	—	×	—	—	×														
46. Megalaspis sp. (hypostoma 2)	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	×								
47. Megalaspis ? sp. (pygidium 1)	—	—	—	—	—	—	—	—	×	—	×													

Table J-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
48. Megalaspis ? sp. (pygidium 2)	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	×								
49. Megalaspis ? sp. (pygidium 3)	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	×								
50. Megalaspis ? sp. (pygidium 4 & 5)	—	—	—	—	—	—	—	—	×	—	×													
51. Niobe primæva West.	—	—	—	—	—	—	—	?	×	—	×	—	—	—	—	?								
52. Olenus attenuatus (Boeck)	—	×	—	—	—	—	—	—	—	×	×	—	a	—	—	—	—	—	×	—	×	×		
53. Olenus dentatus West.	—	×	—	—	—	—	—	—	—	×														
54. Olenus gibbosus (Wahl.)	—	×	—	—	—	—	—	—	—	×	×	×	a	×	×	×	—	×	×	×	—	—	×	
55. Olenus rotundatus West.	—	×	?	—	—	—	—	—	—	—	—	×	—	—	—	—	×							
56. Olenus scanicus West.	—	×	—	—	—	—	—	—	—	×														
57. Olenus transversus Linrs.	—	×	—	—	—	—	—	—	—	×	—	—	—	×	×	×	—	×	×					
58. Olenus truncatus (Brünn)	—	×	—	—	—	—	—	—	—	×	—	×	a	×	×	×	—	×	×	×	×	×	×	
59. Olenus wahlenbergi West.	—	×	—	—	—	—	—	—	—	×	—	—	—	—	×	×	—	×	×					
60. Olenus ? sp.	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×					
61. Parabolina acanthura (Ang.)	—	—	—	—	—	—	—	—	×	—	×													
62. Parabolina brevispina West.	—	—	×	—	—	—	—	—	—	×	—	—	—	—	×	×	—	—	×	×				
63. Parabolina heres Brögger	—	—	—	—	—	—	—	—	×	×	×	×	—	—	—	×	—	—	—	—	—	×	—	+
64. Parabolina jemtlandica West.	—	—	—	—	—	—	—	—	?	—	—	—	—	—	—	—	—	—	×					
65. Parabolina longicornis West.	—	—	—	—	—	—	—	×	—	×	—	×	—	—	—	×								
66. Parabolina megalops Mob. & Möll.	—	—	—	—	—	—	—	—	×	—	×													
67. Parabolina mobergi West.	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	×					
68. Parabolina spinulosa (Wahl.)	—	—	×	×	—	—	—	—	—	×	×	×	—	×	×	×	×	×	×	×	×	×	×	×
69. Parabolinella laticauda West.	—	—	—	—	—	×	—	—	—	×	—	—	—	—	×									
70 Peltura cornigera West.	—	—	—	—	—	—	—	—	×	—	—	×												

	Table J-II (*Concluded*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
71.	Peltura costata (Brögg.) ?	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	×	—	—	—	—	—	×		
72.	Peltura minor (Brögg.)	—	—	—	—	—	×	—	—	—	×	×	×	—	×	×	×	×	×	×	×	—	×		
73.	Peltura paradoxa (Mob. & Möll.)	—	—	—	—	—	—	—	—	×	—	×													
74.	Peltura planicauda Brögg.	—	—	—	—	—	×	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	×		
75.	Peltura scarabæoides (Wahl.)	—	—	—	—	—	—	×	×	—	×	×	×	a	×	×	×	×	×	×	×	×	×	×	
76.	Peltura scarabæoides acutidens Brögg.	—	—	—	—	—	×	—	—	—	—	×	×	—	—	×	×	×	×	—	—	—	×		
77.	Proceratopyge nathorsti West	×	?	—	—	—	—	—	—	—	×	—	×												
78.	Proceratopyge tullbergi West	—	—	×	—	—	—	—	—	—	×														
79.	Protopeltura aciculata (Ang.)	—	—	×	—	—	—	—	—	—	×	—	×	a	×	×	×	×	×	×	×				
80.	Protopeltura aciculata pusilla Westerg.	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×					
81.	Protopeltura intermedia Westerg.	—	—	—	×	—	—	—	—	—	—	—	—	—	×	—	—	—	—	×					
82.	Protopeltura præcursor (Westerg.)	—	—	—	—	×	—	—	—	—	×	×	×	—	×	×	×	×	×	×	—	—	×		
83.	Sphærophthalmus alatus (Boeck)	—	—	—	—	—	—	×	—	—	×	×	×	a	×	×	×	—	×	×	×	×	×	×	×
84.	Sphærophthalmus major Lake	—	—	—	—	—	×	×	—	—	×	×	×	a	×	×	×	×	×	—	—	—	×	×	
85.	Sphærophthalmus majusculus Linrs.	—	—	—	—	—	—	×	—	—	×	—	×	—	×	×	×	—	×	×	×	—	×	?	
86.	Trilobite sp. (pygidium)	—	—	—	—	—	—	×	—	—	—	—	×												

+, = related form.
a, = in the conglomerate

Island of Bornholm

As we have seen (Vol. I) the Middle Cambrian of Bornholm is succeeded with apparent conformity, by the *Olenus* beds of the Upper Cambrian which here form a series of Alum shales 15 m. in thickness. That the Upper and Middle Cambrian are however, separated by a hiatus will hardly be questioned, when the conditions in the surrounding regions are taken into account and when it is recalled that the Upper Cambrian everywhere represents a renewed transgression. Six zones have been recognized by Grönwall[1] in this shale, these being as follows in descending order:

Zone 6 with *Peltura* and *Sphærophthalmus*
Zone 5 with *Sphærophthalmus*
Zone 4 with *Leptoplastus*
Zone 3 with *Parabolina* and *Orusia*
Zone 2 with *Olenus*
Zone 1 with *Agnostus pisiformis*

These zones therefore correspond very closely to those of Scania.

The *Olenus* shales are followed by beds with *Dictyonema* 5 m. in thickness and these by *Megalaspis* limestone. The *Bryograptus* and *Tetragraptus* zones are either represented by the *Megalaspis* limestone or are absent.

The *Megalaspis* limestone has a thickness of 4 m. and its basal portion consists of a thin dark glauconitic limestone layer, with much pyrite and numerous phosphatic nodules, containing sponge spicules. Desiccation fissures in the underlying shales are represented by ridge-like

1 Grönwall, K. A. and Milthers, V. Descriptions of the Geological Map of Denmark, Map Sheet Bornholm. Denmarks Geologiske Undersögelse I Raekke. No. 13.

markings in the under side of the limestone. These features certainly suggest exposure and an unrepresented interval.

The main part of the *Megalaspis* limestone, is gray, somewhat nodular, with 10 to 15 per cent of clay. It has yielded *Megalaspis limbata* Sars and Boeck, *Ptychopyge applanata* Ang. *Symphysurus palpebrosus* Dalman and *Nileus armadillo* Dalman. It is not clear whether any part of the lower portion of this limestone, represents the Planilimbata division, nor is the *Ceratapyge* limestone known, though this may be represented by *Dictyonema* shales. In any case, the slight development of the formations, *Olenus* shale 15 m. *Dictyonemas* shale 4 m., the *Megalaspis* limestone 4 m. is a very insufficient representation of the Cambrovician and though it represents only the wedge-like end of the series, it is highly probable that it includes several minor disconformities.

The limestone is succeeded by the *Dicranograptus* shale, the equivalent of the Lower Hartfell of Scotland i. e. late Middle Ordovician. Thus the Cambrovician-Ordovician hiatus is greater here than it is in Sweden, which may be partly due to overlap of later and partly to inter-systemic erosion of the older beds.

The Oslo or Christiania Region of Norway

This region is often taken as typical for the west European early Palæozoic succession but it is no more complete, than those further to the east.

As we have seen (Vol. I. p. 386, *IV, p. 582*). The Forchhammeri zone of the Middle Cambrian is succeeded by the zone with *Agnostus pisiformis* and *Olenus truncatus*, the zone of *Agnostus lævigatus* being apparently unrepresented. The following is the succession of the Cambrovician beds in this region in descending order.

Succession in the Oslo Region.

SUPERFORMATION ORDOVICIAN (Etage 4 & 3c γ-β) 700 ft.

4d. *Isoteles beds.* Shales and limestone with *Isoteles gigas, Trinucleus seticornis Ampyx tetragonis* etc.

4c. *Teinucleus shales.* Shales and concretionary limestones, with the second and third species as above and with *Asaphus lævigatus* and other trilobites, *Diplograptus pristis* and *Climacograptus* in the lower part.

4b. *Chasmops Beds.* Calcareous above, shaly below with *Chasmops* and other trilobites and *Echinosphærites aurentium.*

4aγ *Ampyx Limestone* Concretionary limestones with *Ampyx rostratus* and *Echinosphærites aurentium, Nileus armadillo* etc.

4aβ *Ogygia shale* with *Ogygia dilatata* and other trilobites.

4aα *Upper Didymograptus shales,* with *D. geminus, Climacograptus sharenbergi,* etc.

3cγ *Orthoceras limestone,* (sens. strict.) with *Endoceras* etc. & *Megalaspis gigas* & *Asaphus platyurus* 8-13 ft.

3cβ *Expansus limestones* with *Asaphus expansus* etc. 10-15 ft.

Hiatus and Disconformity

(Characterized by layers of phosphorites).

CAMBROVICIAN

C. Lower Ordovician Division (Etage 3cα & 3b)

3cα. *Megalaspis Limestone*, with *Megalaspis limbata* etc. 3-4 ft.

3b. *Lower Didymograptus shales or Phyllograptus shales*, with some trilobites like those below and the following graptolites. 8-80 ft.

Dichograptus octobrachiatus
Tetragraptus bryonoides
Tetragraptus caduceus
Didymograptus patulus
Didymograptus extensus
Didymograptus constrictus
Didymograptus v-fractus
Didymograptus bifidus
Phyllograptus typus
Phyllograptus angustifolius

B-Tremadocian Series (Etage 3a & 2e)

3aγ. Ceratopyge limestone 3-5 ft.

Contains the following species.

Ceratapyge forficula
Cheirurus faviolatus
Remopleurides dubius
Amphion primigenius
Triarthrus angelini
Parabolinella rugosa
Dicellocephalus? angusticauda
Euloma ornatum
Symphysurus angustatus
Niobe insignis
Nileus limbata
Agnostus siedenbladhi etc.

3aβ. Ceratopyge shales 20-23 ft.

Alternating shales with limestone lenses and a series of black graptolite beds, especially in the upper part. These have furnished the following rich graptolite fauna.[1]

Dictyograptus flablliformis (Eichw.)
Dictyograptus flabelliformis Eichw. var. *norvegica* Kjerulf.
Clonograptus tenellus Linnarsson
Clonograptus tenellus callavei Lapworth
Clonograptus (*Staurograptus?*) *heres* Westergaard
Clonograptus cf. *hians* Moberg
Bryograptus ramosus Brögger
Bryograptus bröggeri Monsen
Bryograptus hunnebergensis norvegica Monsen
Bryograptus aff. *hunnebergensis* Moberg
Trichograptus (*Bryograptus*) *retroflexus* Brögger
Dichograptus? sp.
Tetragraptus holderupi Monsen
Triograptus osloensis Monsen
Didymograptus kiæri Monsen
Didymograptus kiæri regularis Monsen
Didymograptus norvegicus Monsen

Two subzones are recognizable according to Monsen.

Subzone b, with *Didymograptus kiæri*, *Bryograptus hunnebergensis* and *Clonograptus tenellus*.

Subzone a, with *Bryograptus ramosus*, *B. bröggeri* and *Triograptus osloensis*.

Besides the graptolites a few brachiopods occur including *Eoorthis christianiæ* (Kjerulf) and poorly preserved

1 Astrid Monsen. Über Eine Neue Ordovicische Graptolithen fauna. Norsk geologisk tidsskrift. Bd. VIII, 1925, pp. 147-187, 4 plates.

fragments of *Ceratopyge forficula* Sars and a specimen of *Hirudopsis koepingesis* Moberg & Segerberg.

3aα. Symphysurus shales and limestones 1-20 ft.
With:
Symphysurus incipiens
Cyclognathus micropygus
Parabolinella limitus

2e. Dictyonema shales (now more generally classed with 3a)
With:
Dyctyonema flabelliforme
Bryograptus kjerulfi
Obolus (Bröggeria) salteri etc.

A. *Upper Cambrian Series*[1] about 120 ft.

2d. Peltura niveau

2dγ. Upper part with
Peltura (Cyclognathus) costata
Peltura (Cyclognathus) transiens
Parabolina heres
Bœckia hirsuta

2dβ. Middle part with
Peltura scarabæoides
Peltura scarabæoides acutidens
Peltura minor
Sphærophthalmus alatus
Sphærophthalmus majusculus
Ctenopyge (?) lobata

2dα. Lower part with
Peltura bidentata
Peltura planicauda
Protopeltura præcursor (P. acanthura)

1 See Westergaard, *loc. cit.* p. 110.

Ctenopyge flagellifer
Ctenopyge flagellifer angusta Westergaard
Ctenopyge spectabilis
Ctenopyge tumida Westergaard
Leptoplastus bröggeri Holtedahl

2c. Eurycare niveau, with
Eurycare latum
Eurycare angustatum
Eurycare angustatum norvegicum Holtedahl
Leptoplastus ovatus
Leptoplastus ovatus explanatus Holtedahl.
Leptoplastus longispinus Holtedahl

2b. Parabolina spinulosa niveau with
Parabolina spinulosa
Orusia lenticularis

2a. Olenus niveau

2aβ. Upper part with
Olenus truncatus
Olenus attenuatus (= *O. aculeatus*)
Agnostus reticulatus
Agnostus pisiformis obesus

2aα. Lower part with
Agnostus pisiformis

Hiatus and Disconformity

SUBFORMATION: Middle Cambrian

Paradoxides forchhammeri zone (See Vol. I, p. 394, *IV, 589*)

SUMMARY OF THE BALTIC SECTIONS

The Cambrovician of the Baltic region begins with Upper Cambrian alum shales and fœtid limestones or "orsten", in Scandiavia, but generally with *Obolus apollinis* sands or conglomerates in the Russian Esthonian region. Where present the Upper Cambrian beds rest disconformably upon various members of the Middle Cambrian while the *Obolus* sandstone rests on Lower Cambrian or as in Dalarne on the pre-Cambrian crystallines.

The Upper Cambrian is usually thin commonly less than 100 ft. in thickness but nevertheless it presents a series of distinctive palæontological zones, which must probably be regarded as indicating successive faunal invasions from the center of evolution.

Compared with the British sections, we find that zones 2 (Table J-II) correspond to the Maentwrog beds in which *Agnostus pisiformis obesus*, *Olenus gibbosus* and *O. truncatus* occur. The *Agnostus pisiformis* zone (zone 1) is often overlapped in great Britain. The species of *Olenus* cited represent only the subzones 2a & 2b of Andrarum Scania, while subzones 2c to 2f are not represented except by the unfossiliferous lower Ffestiniog series. This great series of "Huangho" sediments marks an excess of deposition over subsidence and a consequent retreat of the shore line. This correlates with the evidence of emergence and fragmentation of the beds seen in so many of the Swedish sections and the distinct hiatus between the *Olenus* and higher beds so often encountered.

The higher beds of the Swedish Upper Cambrian are to be correlated with the British Dolgelly. This begins with the zone of *Orusia lenticularis*, *Parabolina spinulosa* and *Agnostus cyclopyge* all characteristic of zone 3 of the Swedish succession. Beds with *Agnostus rudis* and *A. trisectus* follow representing zone 5b and beds with *Peltura scarabæoides*, *Sphærophthalmus alatus*, *Ctenopyge bisulcata* and *C. directa* representing zone 5c of the Swedish succession (Table J-II Cols. 6 and 7). The higher zones, (5d Col. 8 and

6 Col. 9) are not necessarily unrepresented, except by their typical faunas, for according to all the characteristics of the section, deposition in the British region appears to have been continuous from Dolgelly to Tremadoc time, the hiatus there indicated being between the Tremadoc and Arenig.

In the Baltic region on the other hand there appears to have been an interruption of sedimentation with perhaps some erosion between the Upper Cambrian (Dolgelly) and Tremadoc series, so that locally some of the higher Upper Cambrian beds as well as the lower Tremadoc are wanting. Elsewhere the renewed transgression in Tremadoc time resulted in further overlap so that *Obolus apollinis* sandstone and conglomerate (Ungulite sandstone etc.) and *Dictyonema* shales rest directly upon older rocks. As pointed out by Scupin these two formations are very probably equivalent deposits.

In the Baltic region the hiatus between the Tremadoc and Arenig found in Wales is not indicated. Here the *Ceratopyge* limestone representing Tremadoc, and the *Megalaspis* beds representing Arenig, appear to be in perfect sedimentary conformity. When not represented by limestones, the Arenig is wholly or in part represented by *Phyllograptus* shales.

Throughout the entire Baltic region, the hiatus between the Lower and Middle Ordovician, indicating the Cambrovician-Ordovician interpulsation interval, is clearly marked not only by such physical features as conglomeratic beds and layers of phosphate nodules but more especially by the very marked off-lap of the Lower Ordovician and over-lap of the Middle Ordovician beds. In the past the hiatus has generally not been recognized because of the fact that the strata on both sides are limestone. After its existence was demonstrated by the work of Lamansky however, it was not defficult to recognize it in all the Baltic sections. The name *Orthoceras Limestone*, formerly applied to the entire series, must now be restricted to the part above the hiatus *i. e.* the Middle Ordovician, as that is the portion characterized by the abundance of orthoceraconic cephalopods (*Endoceras*, *Vaginoceras* etc, and *Orthoceras*.)

Cambrovician of The St. Croix Region of Central Poland

We have seen in our discussion of the Middle Cambrian of this region (Vol. I, p. 478, (*Vol. IV, p. 674*)) that beds of the *Paradoxides tessini* zone (8a) are succeeeded by coarse sandstones 8b, with *Ellipsocephelus polytomus*, *Paradoxides* sp. and *Lingulella* sp, which evidently represent the retreatal phase of the Middle Cambrian, but cannot be definitely referred to any one of the higher zones. These are followed disconformably by shales and quartzites without fossils, 9a and these by 9b with the *Parabolina* fauna and 10 quartzites with the *Peltura* fauna.

The Upper Cambrian is well developed only in the northern portion of the St. Croix Massif. Here it consists in general of clay shales, with intercalations of sandstones or quartzites often micaceous. The total thickness of the Cambrian in the St. Croix Mountain is between 1500 and 2000 meters as compared with less than 100 m. in the Scandinavian region but I have so far been unable to find any record of the thicknesses of the several divisions. Apparently the Upper Cambrian is the smallest portion of this series as it is also the most restricted in distribution.

The following 3 subdivisions of the Upper Cambrian have been recognized, the numbering here being that used by Bubnoff p. 631 and adopted in Vol. 1, (p. 478).[1]

UPPER CAMBRIAN

Division 10, Chabowe Beds. Clay shales and gray-wackes, with a thin sandy layer containing the following species :

Trilobites

1. *Sphærophthalmus alatus* Boeck
2. *Peltura scarabæoides* Wahlenberg
3. *Parabolina mobergi* Westergaard
4. *Parabolina longicornis* Westergaard

Brachiopoda

1. *Lingulella ferruginea* Salter
2. *Lingulella* cf. *lepis* Salter
3. *Acrotreta klonowkæ* Czarnocki

Hyolithids

Torellella sp.

Trails etc.

1. *Cruziana* sp.
2. *Planolites* sp. (aff. *Pl. congregatus* Billings)
3. *Arenicolites communis* Czarnocky

This corresponds to Zone 5 of Westergaard's division of the Upper Cambrian of Sweden, the trilobites Nos 1 and 2 of the above list being essentially typical of 5c of Sweden (2 also in 5d) No 3 appears in zone 5 b, No. 4 in 5d.

Lingulella ferruginea often forms shell beds, in which *Acrotreta klonowkæ* is mingled in lesser numbers. The presence of the numerous trails and borings indicate the

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[1] J. Czarnocki. Le Cambrien et la Faune Cambrienne de la Partie Moyenne du Massif de Swiety Krzyz (Ste. Croix).
Compte-Rendu XIV Congrès Géologique International 1926 (1927) pp 1—18.

general shallow water or even the continental character of most of these deposits.

Division 9b.—Machocice Series. Clay shales, with intercalations of rusty coloured sandstones and quartzites. The sandstones at the base of this series often contain a rich fauna of the following species :

Trilobites.

1. *Beltella samsonowiczi* Czarnocki
2. *Parabolina acuminata* Czarnocki
3. *Eurycare* (sp. nov.)
4. *Liostracus? mochocicensis* Czarnocki
5. *Protopeltura* sp.
6. *Ctenopyge flagellifera* var *angusta* Westergaard
7. *Parabolina* sp.
8. *Peltura* sp. (cf. *P. cornigera* Westergaard

Brachiopoda

1. *Lingulella ferruginea* Salter
2. *Orusia clathrata* Czarnocki
3. *Eoorthis radostowæ* Czarnocki

This division probably represents zones 3 and 4 of Westergaard as noted by Czarnocky. The new trilobite *Beltella sansonowiczi* is the most abundant. It is comparable to *Olenus attenuatus* of zone 2 of Sweden. The new species of *Parabolina* resembles both the older and newer species of Sweden. *Liostracus machocicensis* approaches especially *L? superstes* characteristic of the 3rd zone of Westergaard, in which *Protopeltura* also occur.

Orusia clathrata is a close relative of *O. lenticularis*, of the third Swedish zone. Of the others the *Eurycare* is characteristic of the 4th Swedish zone while *Ctenopyge flagellifera* is typical of the basal part of the 5th zone. *Peltura cornigera* Westergaard on the other hand is restricted to zone 6 in Sweden. It should be noted however that the Polish specimens are doubtfully identified. On the whole then, the relation is most closely with zones 3 and 4.

Division 9a. Basal sandstone. Shales and quartzites without fossils representing the transgressing base of the Cambrovician, believed to be equivalent to the *Olenus* beds proper, zones 1 and 2 of Westergaard. This indicates overlap.

There is another zone in Sweden, zone 6 with *Acerocare* and *Cyclognathus* (Table III. col 9) which apparently is unrepresented by fossiliferous beds in the Polish region.

On the whole, the Cambrian beds of the region and especially the Upper Cambrian, are of the Flysch type, according to Czarnocki, that is, they have the character of the Huangho deposits, though they are only slightly oxidized, with intervals of marine submergence during which the fossiliferous layers were formed. In this repect too the formation is not unlike the Middle and Upper Cambrian of the Upper Mississipi Valley.

Finally it must be noted that the Polish series represents primarily the Dolgelly horizon of Great Britain, the Ffestinog and Maentwrog being essentially unrepresented except by the unfossilferous basal sands of the series.

Where the Upper Cambrian is absent, the Middle Cambrian or older beds are unconformably succeeded by the Ordovician.

The entire Ordovician of the St. Croix Massif does not exceed 30 meters in thickness.

"Everywhere in the Massif it is the lower part of the Ordovician which possesses the greatest extension. Its beds,-almost exclusively of sandy facies,—nowhere form a continuous series of sediments but occur in isolated patches, often with wide distances between them. This is a consequence of the transgressive character of the deposits for it has been constituted, that the Ordovician always reposes in discordance and in transgression on different horizons of the Lower or Middle Cambrian. This discordance is always indicated by a basal conglomerate and by a considerable divergence in the dip of the Ordovician strata, these giving proof of the existence of pre-Ordovician folds formed most probably during the Upper Cambrian" (Czarnocki pp. 572-573)[1].

From the statement quoted above it would appear that the central Polish region suffered a folding of the older strata (including Lower and Middle Cambrian), sometime during the interval characterized by the Mid-Cambric retreatal movement (negative phase of Albertan pulsation) and before the final readvance of the Late Cambrian Sea (positive phase of Cambrovician pulsation). No direct reference is made by Czarnocky to the relationship of the older Cambrian formations to the Late Upper Cambrian beds, but we are led to infer that, were the contact exposed, it would be an unconformable one, while that between the Upper Cambrian and Lower Ordovician is conformable. Possibly the effect of the folding of the older rocks is not evident in the region where the late Upper Cambrian beds are found but the statement that the folding occurred in Upper Cambrian time would seem to imply that it antedated the deposition of the later Upper Cambrian beds. So far then as we are able to interpret the history, renewed transgression took place after the folding and partial

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1 J. Czarnocki: Le profil de l'Ordovicien inferieur et superieur a Zalesie près Lagów comparé à celui des autres regions de la partie centrale du Massif de S-te Croix. Bull. du Service Geologique de Pologne Vol. IV, liv. 3-4. 1928, pp. 569-581.

erosion of the older rocks, this being first manifest in the central Polish region in late Upper Cambrian time, and continued into the early Ordovician as shown by the overlap of these strata and their unconformable contact with the Middle and Lower Cambrian. This *Polonian orogeny* in the Albertan-Cambrovician interpulsation epoch is the oldest yet recorded.

Two Ordovician profiles have been recorded by Czarnocky, the first (A) at Zalesie Nowe (Lagow facies), and the second (B) at Bukôwka-Mójcza (Kielce facies). In the former the entire thickness of the Ordovician is less than 30 meters in the latter it is near 50 meters. The succession is as follows in descending order, the beds being disconformably succeeded by Silurian.

Section A Zalesie-Nowe

ORDOVICIAN

Divison VII (Beds 15-18) (=Division F. of Baltic Series)

Bed 18. Marls and shales with calcite veins and argillaceous shales, with a rich fauna of trilobites, ostracods and mollusks 0.80 m.

Among the species are:

Dalmanites mucronatus Brongn.
Proetus sp.
Acidaspis olini Trœdss.
Lepidocoleus succinus Moberg
Orthis cf. *honorata* Barr.
Orthis sp.
Acrothele sp.
Hyolithes fimbrosus Trœdss.

Bed 17.	Shales and grits, the beds with rough surfaces and with dendrites and pelicles of manganese. Fauna depauperate	1.60 m.
Bed 16.	Clay shales passing downward into the marls of bed 15 with abundant trilobite fragments	0.80 m.

Among the species are:

Trilobita

Dalmanites kiæri Trœdss.
Lichas sp.
Proetus cf. *distans* Lindstr.
Proetus sp.
Cyphaspis cf. *clavifrons* Lnrs.
Ampyx sp.
Plumulites delecarlicus Moberg.
Plumulites sp.

Ostracoda

Primitia tenera Trœdss.
Primitia sexpapillosa Trœdss.
Primitia bursa scanensis Trœdss.
Primitia conica Trœdss.
Bollia biplicata Trœdss.
Bollia harparum Trœdss.

Brachiopoda

Lingulella sp.
Acrotreta sp.
Plectambonites comitans Barr.
Orthis cf. *honorata* Barr.

Bed 15. Yellowish and greenish dolomitic marls with rusty spots

	and indeterminable trilobite fragments	0.40 m.

Division VI. Beds 9-14 (= Divisions D. & E. of the Baltic section)

Bed 14.	Marly dolomites, yellow and rusty	0.40 m.
Bed 13.	Dolomites in layers 10-15 cm.	1.00 m.
Bed 12.	Dolomitic marls, platy dolomites with intercalated green shales in layers from 2 to 3 cm. thick. The series contains in places abundant detritus of trilobite fragments poorly preserved	1.00 m.
Bed 11.	Varicolored shales, ochery at the base, with limonitic concretions (of decomposed pyrite) and passing upwards into violet-grayish green and reddish shales with concretions of iron stone	0.60 m.
Bed 10.	Clay shales streaked with dark green, and containing *Lingulella* sp., *Acrothele* sp. and rare *Climacograptids.*	1.20 m.
Bed 9.	Dolomitic marls, finely stratified, passing gradually into dark-green shales, in thin layers and containing concretions of lydite	2.00 m.

Division V. (= Division C of Baltic Section)		
Bed 8.	Compact yellowish dolomites in layers 15-20 cm. thick passing upwards into dolomitic marls	2.40 m.
Division IV. (= Division BIII of Lamansky's Baltic section)		
Bed 7.	Yellowish dolomites with sandy beds at the base, and compact upwards with small pockets of manganese	3.00 m.

ORDOVICIAN-CAMBROVICIAN

Division III. *Orthis Sands* apparently enclosing a *hiatus* and representing parts of horizons BII & BIII of the Baltic region, with a commingling of the faunas.

Bed 6.	Yellowish, rusty and ferruginous sandstones, generally friable, sometimes spongy	2.00 m.

The fossils (Col. 5) are:

Trilobitæ
- *Megalaspis* sp.
- †*Nileus armadillo* Dalm.
- †*Cybele bellatula* Dalm.
- *Illænus* sp.
- **Cyrtometopus* cf. *clavifrons* Dalm.

Gastropoda
- *Bellerophon polonicus* Gürich

Brachiopoda
- *Orthis moneta* Eichwald
- †*Orthis calligramma* Dalm.
- **Clitambonites plana* Pand.

The species marked with an asterisk (*) also occur in division BII of the Baltic provinces, those marked by a dagger (†) in Div. BIII. This bed then may be regarded as marking the meeting place of the top of the Cambrovician retreatal series and the base of the Ordovician transgressive series holding essentially the position of the St. Peter Sandstone of the Mississippi Valley region.

CAMBROVICIAN

Division II. (= Div. BI β of Lamansky's Baltic Section)

Bed 5. Thick bedded sandstones (0.30 m.), yellowish with small rusty pockets and much glauconite 3.00 m.

The fauna is largely composed of Oboloids including. (Col. 3)

Obolus lingulæformis
Lingulella lepis
Acrotreta cf. *circularis*

and an enormous number of a small unidentified *Siphonotreta*.

Division I. (= Division BI α of Lamansky's Section)

Bed 4. Siliceous fossiliferous shales and quartzitic beds alternating with layers of chalcedony up to 25 cm in thickness. Some beds very rich in sponge remains forming sometimes compact agglomeration 2.80-3.00 m.

Among the fossils are: (Col. 1)

Obolus siluricus

Obolus cf. *salteri*
Obolus linguläformis
Obolus sp. nov.
Linguldlla lepis
Acrothele ceratopygarum
Acrotreta cf. *circularis*
Siphonotreta sp.

Bed 3.	Compact quartzites, shales and sandy layers with interspersed glauconite	2.00 m.
Bed 2.	Quartzitic shales, shales, and micaceous and glauconitic sands 2-3 cm think	2.80 m.
Bed 1.	A thin bed of basal conglomerate with well-rounded pebbles of Cambrian quartzite, embedded in a glauconitic sand	0.05-0.10 m.

Hiatus and Unconformity

SUBFORMATION Folded Middle and Lower Cambrian

In this section beds 1-3 comprise not only the lower *Ceratopyge* beds but probably also the upper *Dictyonema* beds. The transgression in this section then corresponds closely to that of the Baltic region.

Section B. at Bukowka-Mojcza (Kielce facies)

In this section the higher divisions found in the Zalesie section are wanting although the entire thickness is greater (nearly 50 meters). The numbering is distinct but the Divisions correlate approximately.

ORDOVICIAN

Division V. (=Div. C of the Baltic region)

Bed 9' Red limestones and marls with *Lichas* sp., *Phacops* sp., *Orthoceras* and *Cystoids*.

Division IV. (= Div. BIII of Lamansky's Baltic Section)

Bed 8' Limestones with Middle Ordovician fossils including: (See Table K-II, Col. 8)

Asaphus cf. *tyrannus*
Illænus revaliensis
Illænus polonicus
Cheirurus polonicus
Phacops cf. *sclerops*
Agnostus glabratus

ORDOVICIAN-CAMBROVICIAN

Division III. *Orthis Sandstone* with a mixed fauna of BII & BIII of the Baltic section and enclosing a masked hiatus. The lower portion represents the retreatal deposits of the Cambrovician series, the higher the transgressive portion of the Ordovician (Middle) series.

Bed 7' Yellow massive bedded sandstone with (Col. 7)

Brachiopoda

Orthis moneta
† *Orthis calligramma*
† *Lycophoria nucella*
* *Clitambonites plana*
† *Clitambonites inflexa*

Trilobita

† *Cybele bellatula*
Cheirurus cf. *polonicus*
Asaphus etc.

Those marked* occur in Div. BII, and those marked† in BIII of the Baltic section.

Bed 6' Finely stratified sandstone yellowish green with (Col. 6)

Orthis moneta

Lycophoria nucella

Bellerophon polonicus etc.

CAMBROVICIAN.

Division II (= Div. BI β and perhaps part of BII, of Lamansky's section)

Bed 5' Yellow clay with lentils of red limestone containing: (See also Col. 4)

Brachiopoda

Orthis cf. *christianiæ*

Orthis parvula

Orthis moneta

Trilobita

Nileus armadillo

Cybele bellatula

Cyrtometopus cf. *clavifrons*

Agnostus glabratus etc.

Bed 4' Yellow and green clay-shale with glauconite.

Bed 3' Yellow clay shale with intercalations of manganese

Division I (= Horizon BI α of Lamansky's section)

Bed 2' Light sandstone, massive bedded poor in glauconite, and glauconitic sands, and quartzites with (See Col. 2)

Obolus siluricus

Obolus cf. *salteri*

Acrothele ceratopygarum etc.

Bed 1' Glauconitic sand with pebbles of Cambrian quartzite.

Hiatus and Unconformity

SUB-FORMATION Disturbed Middle and Lower Cambrian beds.

The following table (K-II) shows the vertical range of the species so far recorded and their occurrence in the Baltic region. The horizons are:

Cols. 1-8. Central Poland massif.

Col. 1. Bed 4 of Zalesie (Section A)

Col. 2. Bed 2′ of Bukówka-Mójcza (Section B)

Col. 3. Bed 5 of Zalesie (Section A)

Col. 4. Bed 5′ of Bukówka etc. (Section B)

Col. 5. Bed 6 of Zalesie (Section A)

Col. 6. Bed 6′ of Bukówka etc. (Section B)

Col. 7. Orthis sandstone, Bed 7′ of Bukowka etc. (Sect. B) cfr Bed 6 of Zalesie (Section A)

Col. 8. Bed 8′ of Bukowka etc. (Sect. B)

Cols. 9-16. Horizons of the Baltic Section of Esthonia.

Cols. 9 & 10 Division BI α and BI β.

Cols. 11-13. Division BII α, BII β and BII γ.

Cols. 14-16. Division BIII α, BIII β, and BIII γ.

Table K-II

Lower Ordovician Fossils of the Central Poland Region and their distribution elsewhere

	Central Poland								Baltic Region							
									Div. BI		Div. BII			Div. BIII		
	Bed 4 Sect. A.	Bed 2′ Sect. B.	Bed 5 Sect. A.	Bed 5′ Sect. B.	Bed 6 Sect. A.	Bed 6′ Sect. B.	Orthis Sandst 7′ Sect. B, cf. Bed 6 Sect. A.	Bed 8′ Sect. B.	BI α	BI β	BII α	BII β	BII γ	BIII α	BIII β	BIII γ
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Brachiopoda																
1. Acrothele ceratopygarum	×	×														
2. Acrotreta circularis	cf.	—	cf.													
3. Acrotreta sp.	—	—	—	×	—	—	×									
4. Leptæna imbrex Vern.	—	—	—	—	—	—	cf.	—	—	—	—	—	—	×	×	
5. Leptæna nefediewei Eichw.	—	—	—	—	—	—	cf.	—	—	—	—	—	—	×	×	×
6. Lingulella ferruginea	—	—	—	×												
7. Lingulella lepis	×	—	×													
8. Lingulella sp.	—	—	—	—	—	—	×									
9. Lycophoria nucella Dalm.	—	—	—	×	—	×	×	×	—	—	—	—	—	×	×	×
10. Obolus fimbriatus Hdg.	—	—	—	—	—	—	—	×								
11. Obolus lingulæformis Mickwitz	×	—	×	—	—	—	—	—	×							
12. Obolus salteri	cf.	cf.														

Table K-II (*Continued*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Brachiopoda (cont.)																
13. Obolus siluricus Eichw.	×	×	—	—	—	—	—	—	×							
14. Orthis calligramma Dalm.	—	—	—	—	×	—	×	×	—	—	—	—	—	×	×	×
15. Orthis christianiæ Kjerulf	—	—	—	cf.	—	—	—	--	—	×						
16. Orthis moneta Eichw.	—	—	—	×	×	×	×	×								
17. Orthis parvula Lamansky	—	—	—	×	—	—	×	—	—	×						
18. Orthisina (Clitambonites) hemiprionites Buch	—	—	—	—	—	—	×									
19. Orthisina (Clitambonites) inflexa Pand.	—	—	—	—	—	—	×	—	—	—	—	—	—	×	×	×
20. Orthisina (Clitambonites) plana Pand.	—	—	—	—	×	—	×	?	—	—	×	×	×			
21. Porambonites sp.	—	—	—	—	—	—	—	×								
22. Siphonotreta unguiculata Eichw.	—	—	—	—	—	—	×	—	—	—	—	—	—	×	×	
23. Siphonotreta sp.	×	—	×													
24. Strophomena quinquecostata	—	—	—	×												
Bryoza																
1. Micropora gracilis Eichw.	—	—	—	—	—	—	cf.									
2. Monticulipora petropolitana Pand.	—	—	—	—	—	—	×	—	—	—	×	×	×	×	×	×
Gastropoda																
1. Bellerophon polonicus	—	—	—	×	×	×										
Trilobitæ																
1. Agnostus glabratus Ang.	—	—	—	×	—	—	—	×								
2. Ampyx costatus Ang.	—	—	—	—	—	—	—	×								
3. Asaphus tyrannus Murch	—	—	—	—	—	—	—	cf								
4. Cheirurus polonicus Czarn. et Sams.	—	—	—	—	—	—	cf.	×								

Table K-II (*Concluded*)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Trilobitæ (cont.)																
5. Cybele bellatula Dalman	—	—	—	×	×	—	×	×	—	—	—	—	—	×	×	
6. Cybele sp.	—	—	—	—	—	—	—	×								
7. Cyphaspis sp.	—	—	—	—	—	—	—	×								
8. Cyrtometopus clavifrons Dalman	—	—	—	cf.	cf.	—	×	—	—	—	×	×	×			
9. Harpes spasskii Eichw.	—	—	—	—	—	—	—	×	—	—	×					
10. Illænus polonicus Gürich	—	—	—	—	—	—	—	×								
11. Illænus revaliensis Holm.	—	—	—	—	—	—	—	×	—	—	—	—	—	×		
12. Illænus sp.	—	—	—	—	×	—	×									
13. Megalaspis sp.	—	—	—	—	—	—	×									
14. Nileus armadillo Dalm.	—	—	—	×	×	—	×	×								
15. Phacops (Pterygometopus) sclerops Dalman	—	—	—	—	—	—	—	cf	—	—	—	×	×			
16. Remopleurides sp.	—	—	—	—	—	—	—	×								

The Cambrovician of Bohemia

As we have seen (Vol. I, p. 469, *IV* p. *665*) the Upper Cambrian of the Bohemian Basin is represented by the *Brezove-Hory* conglomerate Cγ ranging from 200 to 500 meters in thickness and entirely a continental deposit. It rests disconformably on Middle Cambrian.

Renewed marine transgression did not reach the Bohemian Basin until Tremadoc time when over a part of the Area the *Krusnahora beds* (designated dα in the new terminology, (= part of Barrandes Dd_1) were deposited. These are mainly grayish-green ferruginous graywackes and quartzites of limited distribution and with a maximum thickness of 38 meters. Where fully developed they are divisible into three parts as shown below.

The Krusnahora beds are followed by the *Komarov beds* (dβ) from 40 to 70 meters in thickness and representing essentially the Arenig. With the deposition of these beds began the outpouring of volcanic magmas and ashes, forming chiefly diabases and diabase tuffs. Locally these may show a retreat, but on the whole they indicate continuous transgression, overlapping the Krusnahora beds in many sections and resting locally on the Pre-Cambrian.

This series is succeeded by the *Kvân-Oseker* shales, a portion if not the whole of which is referable to the Llandeilo.

The succession of the formations included in Barrande's Dd_1 is as follows in descending order.

Division dγ. *Kvân-Oseker* beds 50-60 m.

Etage dγ_2 Dobrotiva shales Dark shales with soft concretions with 42 species of trilobites belonging to the genera *Ampyx*, *Asaphus*, *Ogygia* (*glabrata*)

Carmon, *Proetus*, *Sarkia* etc. Mollusca of the genera *Orthoceras*, *Endoceras*, *Bellerophon*, *Nucula*, *Leda* etc. and Brachiopods of the genera *Chonetes*, *Orthis*, *Lingula*, *Discina*, *Strophomena* etc. besides Conularians, Hyolithids etc.

Hiatus and Disconformity (?)

Etage dγ_1. Pale shales with hard concretions with 54 species of trilobites of the genera *Acidaspis*, *Aeglina*, *Amphion*, *Areia*, *Cheirurus*, *Dindymene* *Placoparia*, *Batycheilus*, *Bohemilla*, *Calymmene* (*Arago*), *Pharostoma*, *Dalmanites*, *Dicellocephalina*, *Dionide*, *Harpes*, *Trinucleus*, *Holometopus*, *Asaphellus*, *Ptychocheilus*, *Megalaspides*, *Platypeltis*, *Symphysurus*, *Barrandeia*, *Illænus*, *Bumastus*, *Lichas*, *Agnostus*.

It is to be noted that while both divisions are characterized by the same genera of trilobites they have only 6 species in common. *Dicellocephalites bohemicus* and *Holometopus bohemicus* are hold-overs from older horizons.

Hiatus and Disconformity (?)

Division dβ. Komarov heds 38-70 m.

Dark shales with red ironstone, and diabase and diabase-tuffs. Near Beraun, where the greatest thickness is found, they overlap on the pre-Cambrian.

Among the species recorded from this division are:

Graptozoa :

Didymograptus pennatulus Hall var. *hamatus* Perner (c)
Didymograptus lonchotheca Perner (c)
Didymograptus barrandei Perner (d)
Didymograptus lapworthi Perner (d)
Dictyonema sp. (6)
Tetragraptus bigsbyi Hall (6)
Dichograptus (?) *leptotheca* (e)
Dendrograptus? constructus Perner (e)
Holograptus expansus[1] Holm
Schizograptus tardifurcatus[1] Elles

Brachiopoda

Orbiculoidea undulosa Barr. (2)
Orbiculoidea sp.
Lingula rugosa
Lingula sulcata
Paterula? prima Kloucek (2)
Obolus complexus
Orthis nocturna Barr. (3)
Orthis (*Billingsella*) sp. (4)
Orthis desiderata Barr. (4,f)
Orthis grimmi
Acrotreta sp. (2)

Trilobita

Aeglina bröggeri
Agnostus splendens
Amphion lindaueri Barr. (b)
Asaphellus perneri
Aspidæglina miranda
Barrandeia primula

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1 Described by Bedrich Boucek in Zvlastni Otisk Z. Vestniku Statniho Geologicheho Ustavu CSL. Republiky Vol. IX No. 2, 1933.

Cheirurus hoffmani Perner (b)
Euloma bohemica (5)
Euloma inexpecta
Illænus cuspidatus
Lichas præcursor
Megalaspides cuspidatus
Nileus pater
Niobe sp. (5)
Ptychocheilus decoratus
and others

Kloucek[1] has recognized 12 horizons in this division six in the south and southwest part of the Barrandian area where the rocks are prevailingly shales with *Euloma* (numbered 1-6) and six in the northern and northeastern part where the rocks are largely eruptives and semi-eruptives (lettered a-e). Only two of these 12 zones are found in common leaving a total of 10 zones for this division. 4 are characterized by brachiopods 4 by graptolites and 2 by trilobites. The number or letter after the species indicates the zones so far as differentiated.

TREMADOCIAN

Division dα KRUSNAHORA Beds[2-4] 38 m.

Etage dα^3 Olesna Beds Graywackes, fine-grained shales, of brick red

1 C. Kloucek. Niveaux paléontoglogiques dans les couches de Komârov dβ (Dd1β) Zvlastni Otisk Z Vestniku Statniho Geologického Ustavu CSL Republiky Vol. II, par. 2 1926.

2 Jan Koliha. Facies baltico-polonais de l'Ordovicièn inférieur en Boheme. Vestnik Statniho Geologickeho Ustavu Ceskoslovenske Republiky Vol. II, pp. 317-328. 1920.

3 C. Kloucek: Sur la faune des couches de Krusna Hora dα (Dd1α). *Ibid.* Vol. II, Nos. 4-6, 1926, pp. 190-196.

4 C. Kloucek: *Orometopus* et outres fossiles nouveaux dans le dα^2, d'Olesna. *Ibid.* Vol. VII, pts. 4-5, 1931.

colors with intercalations of bluish gray shales 15 m.

Fauna: All Brachiopods.

Obolus complexus Barr.
Obolus klouceki Koliha
Obolus novaki Klou.
Orbiculoidea undulosa Barr.
Orbiculoidea sp.
Lingulella insons Barr.
Acrotreta minima Barr.
Orthis cfr. *O. slaviki*

Also sponge and próblematic organisms

Etage da[2]. *Milina Beds* Graywackes of reddish-brown color in upper and lower parts, with red phtanites and coarse sandstones in the Middle. Also some tuffites. 18 m.

The fauna comprises 56 species with 23 trilobites. These include:

Brachiopoda

Acrotreta grandis var.
Lingulella insons Barr.
Orbiculoidea cf. *sodalis* Kloucek
Orbiculoidea undulosa Barr.
Obolus cf. *complexus* Barr.
Acrotreta minima Barr.
Orthis (*Billingsella*) *incola* Barr.
Obolus barrandii Klou.
Obolus cfr. *O. mensi*
Obolus cf. *klouceki*? Koliha
Orthis grimmi Barr.
Orthis soror Barr.

Orthis potens Barr.
Orthis sp.
Orthis slaviki Klouc.

Trilobita (*Kloucek* ref. 4, p. 304)

Agnostus aff. *bavaricus* Barr.
Symphysurus behemicus Klou.
Apatocephalus aff. *serratus* (Sars. & Boeck.)
Euloma cf. *ornatum* Ang.
Euloma sp.
Harpides cf. *grimmi* Barr?
Orometopus aff. *elatiformis* (Ang.)
Orometopus aff. *prænuntius* (Salter)
Holubia bohemica Kloucek (gen. et sp.)

Also specifically unidentified forms of the following genera *Ceratopyge*, *Parabolinella*, *Euloma*, *Ptychoparia*? *Nileus*, *Niobe*, *Megalaspis*, *Symphysurus*, *Cheirurus*, *Amphion*, *Lichas* and *Asaphellus*, the first four with Cambrian, the others with Ordovician affinities.

Etage da^1. *Tresnice Beds*. Graywackes, gray-brown siliceous or tuffitic above, violet colored and coarser grained below, with a basal conglomerate 20 m.

The fauna of this stage includes only brachiopods of which some 20 species and varieties have been determined including:

Obolus feistmanteli Barr.
Obolus feistmanteli var. *prima* Kol.
Obolus barrandei Klou.
Obolus cf. *complexus* Barr.
Obolus lamellosus Barr.
Orbiculoidea sodalis Barr.
Orbiculoidea undulosa Barr.

Lingulella expulsa Barr.
Lingulella bukovensis Koliha
Lingulella arachne? Barr.
Lingulella insons? Barr.
Lingulella sp.
Orthis kettneri Klou.
Orthis incola Barr.
Acrotreta minima Barr.

Hiatus and disconformity

SUBFORMATION Upper Cambrian continental rocks or Middle and Lower Cambrian or pre-Cambrian.

Is thus appears that the Cambrovician marine transgression did not reach the Bohemian Basin until Tremadoc time.

The lowest division corresponds to the Baltic *Obolus apollinis* sandstone and the *Dictyonema* shales. *Dictyonema flabelliforme* also has been found in some of these beds in Bohemia.

In general division dα and the lower part of dβ are correlated with the Tremadoc, while the upper part of dβ and the lower part of dγ (dγ_1) are correlated with the Arenig. The upper part dγ (dγ_2) is referred to the Llandeilo. This would place the Cambrovician Ordovician hiatus between dγ_1 and dγ_2.

That the lower subdivisions of the Kvan-Oseker beds are to be correlated with the Arenig and the higher with the Llaneilo, is further shown by the graptolites obtained from them. These include *Didymograptus murchisoni* representing the Upper Llanvirn (Graptolite zone 7) of Great Britain, and *Didymograptus indentus* var. *nanus*, *D. bifidus* var. *incertus* and *D. v-fractus* var. *volucer* which may be considered representatives of zones 4 to 6 of the

British section, *i. e.* the *D. extensus*, *D. hirundo* and *D. bifidus* zones. If these correlations are valid the lower part must be referred to the Arenig and the hiatus and disconformity must lie between the two subdivisions where the Bohemian geologists generally place it. The hiatus may of course be marked by an intermingling of the faunas and sediments.

According to Kettner[1] the wide transgression of the lower Tremadoc ($d\alpha^1$) is followed by a retreatal movement and change of strandlines during the middle Tremadoc ($d\alpha^2$). Finally a renewed transgression occurred in upper Tremadoc time ($d\alpha^3$) and continued into the Lower Arenig ($d\beta$). This was even more extensive than that of the lower Tremadoc.[2]

This new transgression was followed by volcanic activity regarded by Kettner as sub-marine outpourings of diabasic magmas and maintained with different intensity during different periods of the entire Ordovician, continuing even into the Ludlow. At the end of the Tremadoc and the beginning of the Arenig, this volcanic activity had attained its first maximum. A considerable part of the upper Tremadoc and the lower Arenig is formed almost exclusively of volcanic material, *i. e.* extensive nappes of diabase and diabasic mandelstein and of tuffs. The diabase tuffs often pass into schalstein, and the beds of sedimen-

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1 Radim Kettner. Paléogéographie des formations entrant dans la composition du Barrandien Extrait du Compte-Rendu XIVe Congrès Géologique International 1926.

2 For a map showing these movements see Kettner R. Transgression et regressions de la mer du Silurieu inférieur dans la Bohème. Bull. Int. de l'Academie des Sciences de Bohème 1921 French resumé.

tary iron ore, so frequent in the Lower Ordovician, have a genetic connection with this volcanic activity.

The Armorican Region.

In south-western Europe, France and Spain, the Cambrovician Series is very incompletely developed, and our knowledge of it still lacks many essential details.

Montagne Noire. Perhaps the most complete development is in the Montagne Noire, that outlier of ancient strata in south-eastern France, south of the Central Plateau. Here as we have already seen, the Cambrian, which has an estimated thickness of about 2000 m., is represented by fossiliferous beds chiefly in the Middle division. The Upper Cambrian is represented by sandy shales devoid of fossils.

Renewed marine transgression appears to have begun in this region in Tremadoc time, rocks of that age being followed by the Armorican grit and fossiliferous shales of Arenig age. These are succeeded, probably after a hiatus, by beds of Llandeilo age.

The succession is as follows in descending order as summarized by Bubnoff. (p. 233)

Superformation: Llandeilan Shales etc.

Probable hiatus and disconformity

Cambrovician:

Arenigian

5. Shales with
Phyllograptus angustifolius
Didymograptus v-fractus
Orthis desiderata
Orthis menapiæ
Orthis carausi
Amphion cf. *lindaueri*

Asaphus sp.
Acidaspis sp.

4. Armorican sandstone with
Lingula lesueuri
Dinobolus brimonti

Tremadoc Series

3. Shales with
Asaphelina miqueli
Niobe ligniersi
Amphion escoti

2. Shales with
Euloma filacovi
Agnostus terralsensis
Asaphelina barroisi
Bellerophon œhlerti

Upper Cambrian

1. Unfossiliferous sandy shales

Hiatus and Disconformity

SUB-FORMATION: Middle Cambrian

The Boutoury graptolites shales, described by Barrois probably locally replace the Armorican sandstone of the above succession. They have furnished (Bubnoff p. 234)

Didymograptus v-fractus
Didymograptus balticus
Didymograptus pennatus
Didymograptus nitidus
Didymograptus escoti
Tetragraptus serra
Tetragraptus quadribrachiatus

Probably belonging in part to a somewhat higher

Arenig horizon and in part to the Llandeilo is the fauna described by A. Born from this region.[1] This includes.

Phyllograptus angustifolius
Tetragraptus bryonoides
Redonia deshayesiana
Ogygia glabrata
Trinucleus primitivus
Synhomalonotus arago
Dalmanites socialis
Dalmanites phillipsi etc.

The trilobites mostly suggest Llandeilo, age, while the graptolites indicate an Arenig horizon. This suggests that two faunas are conmingled here.

Barcelona. In Spain the Upper Cambrian is poorly or not at all developed in fossiliferous facies, and the Tremadoc horizon is represented by fossiliferous beds only in the vicinity of Barcelona in North-east Spain, a region probably within the same embayment as the Montagne Noire.

This horizon is represented by the purple shales of Papiol which have furnished the following species

Ogygia cf. *desiderata* Barr.
Asaphellus cf. *solvensis* Hicks
Asaphellus innotatus Barr.
Asaphellus cf. *wirthi* Barr.
Niobe cf. *homfrayi* Salter.

This is followed by Arenig sandstones with the peculiar trail-like markings known as *Bilobites* and *Tigillites* and evidently indicating a retreatal movement of the sea,—corresponding to the widespread retreatal movement at the beginning of the Arenig recorded in many sections. These sandstones are disconformably succeeded by beds of Car-

1 A. Born, Eine Untersilur Fauna aus der Montagne Noire. Senckenbergiana, Vol. III, 1921.

adocian age with *Orthis actoniae O. vespertilio, O. calligramma* etc. which represent the renewed transgression of the Ordovician pulsation.

Throughout the greater part of the Iberian peninsula, as well as in the Brittany region of North-west France, the Arenig is largely or wholly represented by the so-called Armorican sandstone (Grès Armoricain). This is a residual sandstone of variable character probably formed primarily from the disintegration of the crystallines that form the nucleus of the old Armorican land mass. This sand was repeatedly worked over by wind, transported by rivers and again reworked by both transgressing and regressing sea in Cambrovician time. Its precise age, as indicated by fossils may thus vary from place to place, as its thickness varies from 50 meters or less to 500 meters. Spread widely by continental agencies its incorporation into the marine series would vary from place to place in accordance with the time when the transgressing Cambrovician sea reached each locality.

Normandy and Brittany. Here the Armorican sandstone has a thickness of 500 meters in the northern, but only of 50 meters in the southern region. It begins with arkoses and basal conglomerates (poudingues d'Erpuy) containing pebbles of Cambrian rocks, on with formation the Armorican beds rest disconformably. The succeeding portion contains both marine and supra-marine layers the latter exhibiting numerous trails and related markings including *Cruziana, Tigillites, Vexillum, Dædalus, Lumbricaria* etc, while the marine beds contain among others:

Brachiopods

Lingula lesueuri
Lingula salteri
Lingula hawkei
Dinobolus brimonti

Pelecypods

Lyrodesma armoricana
Modiolopsis caillardi
Ctenodonta costæ
Nuculana incola
Actinodonta cuneata

Trilobites

Orgygia armoricana

In south-eastern Brittany at Angers (Approx. Long. 0°38'W; Lat. 47° 28'N)) a shaly facies has leen found to locally replace the Armorican sandstone. This has furnished

Didymograptus deflexus
Didymograptus v-fractus
Didymograptus hirundo
Didymograptus nitidus.

This represents a lower horizon in the Arenig than the fossiliferous beds of the north, where these graptolite shales are replaced by unfossiliferous continental beds.

The Armorican sandstone is followed disconformably by the *Schistes d'Angers* with *Synhomalonotus tristani* and other fossils of Llandeilo age. This series often begins with a graptolite shale characterized by

Didymograptus murchisoni
Didymograptus euodus
Didymograptus nanus
Didymograptus furcillatus etc.

This represents the Upper Llanvirn of the Wales sections.

A noteworthy feature of the Arenig-Llandeilo contact is the wide-spread occurrance of an oolitic iron ore ranging from 5 to 6 and sometimes 8 meters in thickness. This is a hematite, probably formed by alteration of iron-carbonate deposit. It contains from 45 to 52% of iron, 13-16%

of silica, and 0.55 to 0.7% of phosphorus. This may represent a residual deposit during the interval of exposure between the Cambrovician retreat and the Ordovician readvance of the sea[1].

Other Localities. In the Almaden region of the Sierra Morena, province of Huelva, Spain (approximately Long. 4° 50′ W, Lat. 38° 47′ N,) the Middle Ordovician shales with *Calymene tristani* rest on white or red quartzites and pudding-stones with *Bilobites*, which indicates that the Cambrovician transgression did not extend to this section though the subsequent Ordovician transgression did. Similar conditions prevailed in the province of Caceres Estremadura where the *Angers Shales* of Middle Ordovician age, rest upon quartzites with *Cruziana* referred to the Armorican sandstone, but evidently a basal continental bed of indeterminate age.

In Aragon (Iberian Chain) the Armorican Sandstone, 30 meters thick, rests on continental beds referred to the Cambrian and is disconformably succeeded by shales with *Calymene tristani* i. e. Middle Ordovician.

In the Asturias the Arenig is represented by the Cabo-Busto sandstone with *Scolithes* which rests on sandstones, shales, and pudding-stones with *Lingulella heberti*, and is succeeded disconformably by Middle Ordovician shales with *Calymene tristani.* The hiatus is emphasized by the occurrence of a thin bed of iron ore. On the Ria de Navia Asturias North Spain (Long. 6° 45′ W, Lat. 43° 30′ N) the Cabo Busto sandstone has a thickness of 300 meters and the *Calymene tristani* shales a thickness of 100 meters.

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1 It should be noted however that Bubnoff says the iron ore deposit lies above the *Didymograptus murchisoni* shales in Normandy, though elsewhere below it. (Bubnoff 1930, p. 178)

Summary of the Cambrovician Deposits of the Caledonian Geosyncline.

The marine Cambrovician formations of the Caledonian Geosyncline everywhere rest disconformably on older rocks, these ranging in age from Middle Cambrian to the pre-Palæozoic crystallines. In some cases as in Bohemia the *Marine Series* begins very late, so that overlapping Tremadoc strata rest with a basal conglomerate upon the older beds. These are often Middle Cambrian, but in some sections a series of continental beds, formed during the emergent period, are referred to the Upper Cambrian. The possibility must however, not be overlooked that these too represent, in part at least, deposits formed during the retreat of the Middle Cambrian sea, and so are referable to the closing stages of the Middle Cambrian pulsation. In the Baltic region, as we have seen, the basal beds of the transgressing series are also referable to the Tremadoc, but there they rest on the eroded surface of the Lower Cambrian series.

The end of the positive phase of the Cambrovician pulsation was reached with the deposition of the Tremadoc beds after which the negative phase, *i. e.* the sea-retreat began. This reversal is sometime very abruptly marked in this geosyncline, for the initial retreatal movement was frequently inaugurated by a sudden upward movement (oscillation) of the old-land, thus causing, locally, a more pronounced retreat than would have taken place under normal conditions. Erosion in the abruptly exposed shore zone then removed some of the Tremadoc or even earlier beds, whereupon a readjustment, manifested by a slight renewed transgression, resulted in depositing Arenig beds upon the eroded surfaces of the Upper Cambrian formations.

The absence of the Tremadoc, due to erosion, in this old coastal belt gives the formations a disconformable relationship with overlap of basal Arenig beds.

While the Arenig beds of the shore are represented by graptolite shales intercalated in continental huangho sediments, those nearer the center of the geosyncline are limestones with a rich trilobite (Megalaspid) fauna. The source of this fauna is not yet ascertained. It may have been the Siberian Epi-Sea or it may be of Indo-Sinian origin as is probably the graptolite fauna of the Arenig.

Only one region is at present known where the Albertan-Cambrovician interpulsation period was marked by tectonic disturbance. This is in the St. Croix Mountains of Central Poland where Cambrovician beds rests unconformably on more or less disturbed older Cambrian strata.

The Cambrovician-Ordovician interpulsation hiatus is almost always recognizable. Sometimes as in the Baltic region actual offlapping strata of the lower and overlapping of the Middle Ordovician strata is clearly shown. In other cases erosion surfaces, pebble beds, or beds of phosphate nodules indicate the break and in still others there is a bed of residual more or less modified iron ore, indicating a period of exposure. Even when the physical evidence of the break is masked, the abrupt change in fauna indicates it, though sometimes, as in the Polish sections, a parting sandstone series may contain a commingled fauna having been reworked both by the retreating and the readvancing sea, and enclosing organisms of both.

The distribution of the Cambrovician fauna of the Caledonian Geosyncline will be given in Summary Table VIII at the end of the volume.