No. IX. — THE PHYSICAL CONDITIONS UNDER WHICH THE DEUTOZOIC ROCKS OF SCOTLAND WERE DEPOSITED. PART I. THE OLD RED SANDSTONE. By Prof. PETER MACNAIR, F.R.S.E., F.G.S., President of the Society.

I. INTRODUCTION.

IN the course of my occupancy of the Presidential chair I hope to direct your attention to the present position of our knowledge regarding the physical conditions under which the Deutozoic Rocks of Scotland were deposited, that is to say, the conditions that prevailed during the formation of the rocks known as the Old Red Sandstone, Carboniferous and Permian formations. I also hope to be able to show that, notwithstanding the apparent lithological and palæontological differences that exist between the Scottish Old Red Sandstone and Carboniferous Formations, that upon closer examination a somewhat striking parallel can be drawn between the two types of sedimentation characteristic of the Devonian rocks of the British Isles and the two types characteristic of the Carboniferous rocks of the same area. In fact, it seems quite clear to me that the marine type of the Devonian as developed in Devon might be regarded as analogous with the marine phase of the Carboniferous rocks as developed in the British Isles, while, on the other hand, the Old Red Sandstone type of the Devonian as developed in Scotland and along the Welsh border might be regarded as analogous with the estuarine phase of the Carboniferous rocks as developed in Scotland and England. But an examination of this proposed comparison will be deferred till next session, when we come to a consideration of the physical conditions under which the Carboniferous rocks of Scotland have been accumulated.

II. PRE-OLD RED SANDSTONE CONTINENT.

Before passing to the more immediate subject of this address let me glance at the available evidence bearing upon the character of the pre-Old Red Sandstone platform upon which the later Palæozoic Rocks of Scotland are seen to rest with a strong unconformity. These rocks constitute what are geologically known

as the Crystalline Schists of the Highlands. They stretch from the Highland border north-eastwards to the Moine thrust plane which has been traced from the eastern shore of Loch Erribold S.S.W. to Loch Alsh. From this thrust plane south-eastwards to the Grampians there occurs a prominent type of crystalline schists, the Moine Series of the Geological Survey. They cover large areas in the counties of Sutherland, Ross, and Inverness, and consist for the most part of granulitic quartzose schists, which appear to have been originally of sedimentary origin. Associated with these are found masses of still older Lewesian Gneiss. From an examination of these rocks in the field it has been concluded that the Moine Schists represent a sedimentary series resting unconformably on the Lewesian Gneiss, the latter being brought to the surface by a series of inverted folds.

In the south-eastern Highlands, and occupying large parts of the counties of Aberdeen, Perth, and Argyll, constituting what we call the Grampian Mountains, we find that the Moine Schists of the north-west have been replaced by a group of metamorphic rocks, which have been termed the Dalradian Schists by Geikie. In this region there is a great series of sedimentary rocks which have been altered by metamorphism from such normal sediments as conglomerates, sandstones, shales, and limestones into schistose conglomerates, quartzite, slates, and crystalline limestones. These sedimentary rocks, prior to their metamorphism, were penetrated by intrusive igneous rocks, which have also suffered in the general metamorphism, passing into gneisses epidiorites and hornblende schists. Contemporaneous volcanic rocks have also been found associated with certain of the sedimentary groups.

All the sedimentary rocks show evidence of having been originally laid down in more or less horizontal beds or strata. They are, however, no longer seen to occupy the original horizontal position in which they were formed, but have usually been bent into a series of complex folds. These rocks have been so intensely folded that the synclines and anticlines have become closely packed together in such a way that the axes of the folds are no longer perpendicular, but are seen to be inclined in a definite direction over great areas, this being known as the isoclinal type of folding.

Two views have been advanced regarding the tectonics of these Highland rocks, but these need not be discussed here. Sufficient be it to say that the officers of the Geological Survey and the writer consider that they have been thrown into a series of anticlinoria and synclinoria in which the axes of the isoclinal folds are arranged either as pseudo-synclines or pseudo-anticlines. The other view advanced by Mr. E. B. Bailey, of the Geological Survey, is that the rocks of the Scottish Highlands are arranged in a series of recumbent folds in which the bending powers of the rocks affected have reached their limit, and the rocks have been driven forwards along slides or thrust planes. This view was originally advanced by Mr. Bailey to account for the structure of the ground south-east of Loch Linnhe, and extending from the River Spean in the north to Loch Creran in the south. More recently he has sought to show that similar structures can be traced in Argyllshire and Perthshire, still farther to the east in the Grampian Mountains. As this problem, however, does not deal directly with the question under consideration, we pass it over in the meantime. In a word we may look upon the Scottish Highlands as the basal wreck of what was in pre-Old Red Sandstone time a great mountain chain, the superstructure having been completely removed by denudation, and it is necessary before we can form a picture of the physical features of the ancient continental area upon which the later Deutozoic rocks of Scotland were accumulated that we should determine as far as the evidence will permit at what time and to what extent this denudation had taken place before the Old Red Sandstone rocks began to be accumulated.

It has been established by the Geological Survey that the Moine Schists of the north-west Highlands have been pushed along the Moine thrust plane across rocks of Cambrian age, the youngest member of which has been identified by Dr. Peach¹ as being homotaxial with the Beckmantown Chazy and Trenton Limestones of America, and he concludes that they must be older than the Arenig rocks of Wales, and probably represent the Welsh Tremadoc strata, if not part of the Lingula Flags,

¹ Presidential Address to the Geological Section of the British Ass., 1912. *Nature*, vol. xc., p. 49.

both of which, according to the English classification, are grouped with the Cambrian system.

Turning now to the rocks along the Highland border, we find that north of Stonehaven and near Aberfoyle there exist lenticular bands apparently wedged in between the crystalline schists of the Highlands and the conglomerates forming the basement beds of the Lower Old Red Sandstone. The fossils obtained from the cherty beds at Aberfoyle, according to Professor Jehu and Dr. Campbell,² point to them as Upper Cambrian or the passage beds into the Ordovician, the upper series or Margie Beds being placed higher up in the Ordovician. It would appear, then, that the great processes of mountain building in the Scottish Highlands had not ceased towards the close of the Cambrian and the beginning of the Ordovician period.

It is somewhat difficult to determine at what exact period the movements connected with the upheaval of the Highland mountain chain ceased. We have seen that rocks of late Cambrian and early Ordovician age have been tucked in between the crystalline schists on their north-west and south-east boundaries respectively.

We now proceed to consider the evidence bearing upon the formation of the plane of marine denudation that truncated the Caledonian mountain chain reducing it to a base level of erosion. Everywhere along the line of the great Highland boundary fault we find to the south of the fault the massive basal conglomerates of Lower Old Red Sandstone age. Lithologically these conglomerates are of two types—first, those in which boulders of quartzite or other Highland rocks predominate; and, second, those made up of fragmental materials and lavas derived from contemporaneous volcanic rocks. It is also of great significance to note that at certain localities, as, for instance, between Crieff and Comrie, and at Blairgowrie, these basal conglomerates lie on the north side of the great boundary fault, and are seen to rest with a strong unconformity upon the underlying slates and grits, and therefore presumably upon the Upper Cambrian rocks, to which reference has already been made.

Dr. R. Campbell has shown that in the neighbourhood of

² The Highland Border Rocks of the Aberfoyle District. *Trans. Royal Soc., Edin.*, 1917, vol. lii., p. 177.

Stonehaven there occur rocks of Upper Cambrian, Silurian, and Lower and Upper Old Red Sandstone age. The Cambrian rocks are overlaid unconformably by a series of over 2000 feet of strata, which from palæontological and lithological evidence must be looked upon as of Downtonian age. The presence near the base of this series of a set of tuffs affords evidence that the volcanic activity which culminated in Lower Old Red Sandstone time had already begun to manifest itself.

It should also be kept in mind that an outlier of Upper Old Red Sandstone rocks occurs to the north-west of Guallin Hill, near Balmaha, where it is seen to be faulted against the serpentine gabbro mass along the line of the Guallan fault. In the neighbourhood of that fault it is unconformable to the Lower Old Red Sandstone, and to the north and west it overlaps successively the metamorphic belt, the black shales, cherts, and spilites of the Lower Series—the cherts, as we have already pointed out, carrying an Upper Cambrian fauna—and the beds of the Upper or Margie Series. Finally, it is found resting on the Leny grits.

Another interesting outlier of Upper Old Red Sandstone age occurs still further to the west on the shores of Scalpsie Bay, in the Island of Bute. In this case only a small fragment rests apparently between the escarpment of the 25-foot beach and high-water mark. This hillock is locally known as the Haystack, and is about 20 yards in diameter and 25 feet high, composed of coarse conglomerate, consisting mainly of large angular blocks of schist and of fragments of vein-quartz. At this point the Highland boundary fault throws down the Lower Carboniferous rocks against the schists, so that the fault is in part at least later than Old Red Sandstone times.

Reference will presently be made to those outliers of Old Red Sandstone which occur at various points between the Highland boundary fault and the extreme north of Scotland. But before proceeding to these let me briefly refer to the remarkable outlier of Lower Old Red Sandstone lavas that occurs on the summit of Ben Nevis. Both in Glencoe and on the summit of Ben Nevis there occurs rocks which were undoubtedly accumulated at the surface during Lower Old Red Sandstone times. They are mainly represented by lavas and agglomerates. In

Glencoe plant remains have been identified as belonging to *Psilophyton* and *Pachytheca*. These plant remains have not as yet been found on Ben Nevis, but the lavas and fragmental rocks found on the summit of that mountain are so exactly like those seen in Glencoe that there can be no doubt as to their identity. It will be remembered that this fact was pointed out by Professor Judd in the year 1814. It seems, however, to have been generally overlooked that Professor James Nicol twenty-seven years earlier, with that marvellous prescience which enabled him to see far in advance of his contemporaries,³ had recognised the similarity between the volcanic rocks of Lower Old Red age in the Cheviots and those of Glencoe and Ben Nevis. Under these circumstances I need not apologise for quoting his words in full. Speaking of the Cheviot lavas he says, "Compared with similar formations in our own country, they bear some resemblance to the Claystone porphyry of the Pentlands, but are in general harder and more compact. In the latter the basis of the formation approaches nearer to clay, and is more liable to decomposition than the Cheviot porphyries, which are more granular in their texture, and exhibit a much higher lustre. The southern formation is also far more varied in mineral character, possessing many rocks, as the dark pitch stone, to which nothing analogous is found in the north. They have a far closer resemblance to the porphyry rocks of Glencoe and Ben Nevis, from some of which they are hardly distinguishable in mineral character. Thus some of the dark porphyries of Woodside Hill on the Beaumont are almost identical in appearance with that forming the upper part of Ben Nevis, which in some places also contains red masses similar to the veins in the porphyry of Kirk Yetholm Hill. Similar dark rocks are common in Glen Coe, where most of the brown and red varieties may also be matched, confirming the truth of MacCulloch's observation, that in that glen porphyry of every variety of colour and composition found in any other part of Scotland also occurs. Even in their conical forms the Buachaile Etive mountains resemble many of those in the Cheviots, though on a far grander scale and with a great predominance of the harsher

³ On the Geology of Roxburghshire. "Prize Essays of the Highland Society," 1845, new series, vol. ii., p. 35.

features. The difference, however, in the two formations are not more than the rocks with which they are associated would lead us to expect, less, indeed, than between the greywacke and coal sandstones of the south and the granites, gneiss, and mica slate of the north.

It would appear, then, from the foregoing that the great processes of mountain building had not ceased towards the close of the Cambrian and the beginning of the Ordovician periods, as we find rocks of these ages involved in the north-west and south-east of the Highland mountain chain. If the Ordovician and Silurian rocks ever swept across the Scottish Highlands, no trace has now been left of their former existence. It seems not unlikely, however, that such did happen, and that during Ordovician and Silurian times the great mountain massive, of which the Scottish Highlands only form a part, was subjected to prolonged subaerial and marine denudation. The recent discoveries made along the Highland border and in the Glencoe and Ben Nevis districts all go to show that the Highlands must have been covered by a mantle of rocks the basal members of which were probably of Downtonian and Lower Old Red Sandstone age, and it is to this age that we must refer the date of the Highland plateau of marine and subaerial denudation.

That this break is a widespread one and of more than local importance has long been realised. In 1913 Dr. Olaf Holtedahl, of the University of Christiania, showed that there was a remarkable parallel between the sequence of events that took place in the early Palæozoic history of Scotland and Spitsbergen. He points out that the Spitsbergen Old Red Sandstone series rests upon the so-called Hecklahook system, the latter consisting of a thick series of crystalline sediments, phyllites, mica schists, quartzites, and limestones, which he regards as being the equivalent of the Ordovician and Silurian deposits of Scandinavia. He also points out that on Bear Island, half-way between Spitsbergen and Norway, fossils of Upper Ordovician age were found in rocks lithologically the same as those of Hecklahook. He still further points out that these crystalline sediments were invaded during the

⁴On the Old Red Sandstone Series of North-Western Spitsbergen. *Congress Geologique International*, 1913, p. 707.

processes of folding and mountain building by huge masses of intrusive granites and gneisses found in the north-western corner of West Spitsbergen. These were formerly regarded as of Archæan age. Here, again, we find a striking parallel between the Spitsbergen-Scottish formations, as it seems to us that the Hecklahook rocks might be compared with the Upper Cambrian or early Ordovician rocks seen along the Highland border. Finally, Dr. Holteðahl points out that these strong crustal movements have naturally been considered as a northern phase of the Caledonian crust movements of Scotland and the Scandinavian peninsula, and therefore were regarded as having taken place at the end of Silurian times. However, he says we have learned from our studies of the younger rocks that the chief movements probably were somewhat earlier, for we find resting on the remnants of the folded mountains a series of coarse clastic rocks containing fishes that seem to be of Silurian time. These are probably contemporaneous with the Downtonian of Great Britain and with the Red Sandstone Series of the Christiania area in Norway, where in the last few years a fauna of fishes and Eurypterids indicating rocks of younger Silurian age have been found. Before the oldest known of the Old Red Sandstone Sediments of Spitsbergen were deposited erosion worked far down into the folded range into the zones of mica schist and intrusive granite masses.

III. HISTORY OF OPINION.

It is necessary that we should here give a brief summary of the various opinions that have been held regarding the physical conditions under which the Scottish Old Red Sandstone was formed. These views have been classed under two headings, namely, the marine and the continental, the latter being further subdivided into those who advocate a lacustrine origin, those who believe that they were formed under desert conditions, and those who maintain that they are of fluviatile origin. Hugh Miller,⁵ Murchison,⁶ and Symonds⁷ advocated a marine origin

⁵ Old Red Sandstone, 7th edition, p. 73.

⁶ Siluria, 3rd edition, 1859, p. 270 *et. seq.*

⁷ Records of the Rocks, 1872, p. 215.

for these deposits, and more recently Reid⁸ and the present writer supported this view. Stratigraphically Murchison⁹ divided the Old Red Sandstone rocks of Scotland into three members, the lower, the middle, and the upper, each characterised by a distinctive fauna, the lower group as seen in Scotland being principally developed along the northern and southern margins of the Midland Valley, and characterised by the presence of *Pterygotus* and *Cephalaspis*; the middle group seen in Caithness and along the borders of the Moray Firth, and containing *Dipterus*, *Osteolepis*, &c. The upper is well developed in Dura Den, Fife, and the more central parts of the Midland Valley, where they are seen to emerge from beneath the Lower Carboniferous rocks. It is characterised by *Holoptychius*, *Bothriolepis*, and other genera of fishes. Murchison also correlated the three divisions of the Scottish Old Red Sandstone lower, middle, and upper, with the similar division of the Devonian of Devon and Russia, also pointing out that in the latter country the Devonian rocks containing marine shells were also interstratified with red sandstones in which no shells were found, but which were replete with the piscine fauna common to the Scottish rocks.

Latterly, however, principally through the writings of Goodwin, Austen,¹⁰ Ramsay,¹¹ and more particularly Sir A. Geikie, the Old Red Sandstone of Scotland¹² came to be looked upon as a freshwater deposit accumulated in isolated basins formed by the ridging up of the older rocks. No doubt a very attractive theory if one could simply regard the present boundaries of the Scottish Old Red Sandstone as defining the original limitation of these deposits, a view, however, which could not be entertained for one moment by any one conversant with the stratigraphical, physical and palæontological details.

⁸ Palæontological considerations on the Old Red Sandstone of Scotland. *Geological Mag.*, 1896, p. 217. On the Old Red Sandstone of Scotland. *Geological Mag.*, 1896, pp. 106 and 570.

⁹ *Quart. Journ. Geol. Soc.*, 1858, vol. xiv., p. 501.

¹⁰ On the possible extension of the Coal Measures beneath the South-Eastern part of England, *Quart. Journ. Geol. Soc.*, 1885, vol. xii., p. 38.

¹¹ On the Red Rocks of England of older date than the Trias. *Quart. Journ. Geol. Soc.*, 1871, vol. xxvi., p. 189.

¹² On the Old Red Sandstone of Western Europe. *Trans. Royal Soc. of Edinburgh*, 1878, vol. xxviii., p. 345.

The researches of Goodwin, Austen, and Ramsay were principally directed to the petrological characters of the rocks. Sir A. Geikie was the first to isolate the Scottish areas of the Lower Old Red Sandstone into separate basins of deposit with the distinctive names of Lake Orcadie, Lake Caledonia, Lake Lorne, and Lake Cheviot. He believes that they were all contemporaneous, doing away with the existence of the Caithness rocks as a middle group, and explaining the discrepancies of their fossil contents on the ground that they are no greater than those of contiguous fresh-water basins at the present day. In the scenery of Scotland he also presents some of the physical problems connected with the Old Red Sandstone and its formation. Sir A. Geikie and his brother, the late Professor James Geikie, may be looked upon as the principal upholders of the isolated lake and freshwater origin of these deposits, and from the positions that they held in connection with the Geological Survey of Scotland their views have received a widespread acceptance by geologists of all countries.

Goodchild,¹³ writing later, adopted the continental theory as to the origin of these deposits. He says there is no satisfactory reason for regarding any of the Scottish rocks of Devonian age as of marine origin, and, on the other hand, there is much to be said in support of the view that they were all formed under continental conditions and under conditions of climate which, though doubtless varying much from time to time, are yet on the whole characterised by an annual rainfall decidedly below the average in amount. It is this feature which has imparted a common character to the whole of the series of rocks. The fauna of the Upper Old Red consists almost exclusively of fishes which probably found their way into the sediments from the rivers of upland origin, whose waters were dissipated by excessive evaporation when they reached the lowland area.

As regards the mode of origin of the Old Red Sandstone of the Caledonian area (Lower Old Red) there appears to be evidence of a satisfactory nature that the whole of this vast formation was accumulated under continental conditions partly in large inland lakes, partly as torrential deposits of various

¹³ The older Deutozoic Rocks of Great Britain. *Geol. Mag.*, 1904, p. 591.

kinds, partly as old desert sands, and partly as the result of extensive volcanic action.

The late Professor Barrell¹⁴ identified himself as being closely in accord with the views just cited as held by Goodchild, except that he would give first place to true fluviatile deposition spreading sediments on broad and flat river planes a form of sediment intermediate between torrential and lacustrine, and yet quite distinct from either. He comes to the conclusion that the deposits which make up the Old Red Sandstone, although they undoubtedly contain lacustrine beds laid down in shifting, shallow, and variable bodies of water, are dominantly fluviatile in origin. The great valley in California may therefore in the present epoch, both in physiography and in climate, be cited as a striking illustration of the nature of the Old Red Sandstone basins. He also examines the evidence for the hypothesis of the continental origin of fishes, and decides in favour of it as against that of their marine origin.

IV. THE OLD RED SANDSTONE OF SCOTLAND.

Turning now to a brief consideration of the geographical distribution, physical, stratigraphical, and palæontological characteristics of the Old Red Sandstone rocks of Scotland, we find that they occur in four principal areas, namely, Caithness and the Moray Firth, Lorne, the Midland Valley, and the Cheviot Hills. In addition, there are a number of small outliers resting on the crystalline schists of the Highlands—one in Glencoe, and three in Aberdeenshire, at Tomintoul, south of Huntly, and Gamrie respectively.

We shall consider in the first place the largest of these three areas, namely, that occupying the Midland Valley, where the lower and upper divisions are best developed. Overlooking minor details the deposit of the lower division may be arranged as follows in three groups:—(1) A lower, consisting of conglomerates, sandstones, and flags, which, as we have seen, pass downwards conformably into rocks of Upper Silurian age; (2) a middle group, consisting almost entirely of lavas, tuffs, and agglomerates, as seen in the Sidlaw and Ochil Hills; and (3) an upper, consisting of conglomerates, sandstones, flags, and mudstones.

¹⁴ Dominantly fluviatile origin under Seasonal Rainfall of the Old Red Sandstone. *Bulletin of the Geol. Soc. of America*, 1916, vol. xxvii., p. 27.

The various members of the upper group are magnificently developed along the broad valley of Strathmore from Stonehaven to the Braes of Doune, and from thence to the shores of Loch Lomond. They are seen to be arranged in a broad syncline or trough, whose axis passes approximately down the centre of Strathmore. The fossiliferous horizons in this division are confined to near the middle of the group, the Carmyllie horizon being pre-eminently the richest. Certain other horizons as Tulliewhanland Quarry, near Turin Hill, may be in the higher beds known as the Cairconnan Series. The fish fauna from the latter locality may be taken as characteristic of the series. They include the following:—*Mesacanthus mitchelli*, *Ischnacanthus gracilis*, *Climacium scutiger*, *C. uncinatus*, *C. reticulatus*, *Parexus recurvus*, *P. falcatus*, *Euthacanthus mitchelli*, *E. elegans*, *E. gracilis*, *E. curtus*, *Cephalaspis pagei*, *C. asper*, and *Thelodus pagei*. The Eurypterids are represented by *Pterygotus anglicus* and *Stylonurus ensiformis*. At a lower horizon near Newtyle, but still above the volcanic rocks, occurs a led which has yielded *Cephalaspis lyelli*, *Pteraspis mitchelli* and some few acanthodians.

The lavas and ashes which form the main mass of the Ochil and Sidlaw Hills rise from beneath the syncline of younger rocks just described. The members of the lower group, consisting of massive conglomerates and sandstones, abut against the boundary fault, and, as we have seen in the neighbourhood of Stonehaven where they enter the sea, graduate down conformably into rocks of Downtonian age.

We now pass to a consideration of the development and relationship of these rocks as seen along the southern margin of the Midland Valley. In the Pentland Hills in the Esk section, and again in the Lyne Water, green shales and mudstones (Upper Ludlow) pass upwards into a conformable series of strata (Downtonian) composed of conglomerates with red sandstones and green and grey shales and greywackes. Between the Wenlock Ludlow and Downtonian strata on the one hand, and the volcanic series of the Lower Old Red Sandstone on the other, there is in the Pentlands a complete discordance, for the conglomerates, with greywacke pebbles derived from the Silurian tableland, and forming the base of the volcanic series, rest on the upturned

edges alike of Wenlock, Ludlow, and Downtonian strata. In the Upper Ward of Lanarkshire a similar strong unconformity can be seen in the neighbourhood of Tinto, where the Old Red Sandstone volcanic series of the Pentland Hills come in between Covington and Lamington and rest upon the upturned edges of the underlying Downtonian sandstones and conglomerates.

It is somewhat remarkable to find that about ten miles further to the west in the Lesmahagow Inlier no existence of an unconformity can be traced. Here the Silurian and Old Red Sandstone rocks have been folded into a dome-shaped anticline, with rocks of Wenlock age in the centre, and these pass up without a break through rocks of Ludlow and Downtonian age into the basement members of the Lower Old Red Sandstone. It has always seemed to me that the folding and unconformity seen in the Pentland Hills is in some way connected with the intense volcanic activity that existed over this area during Lower Old Red Sandstone times, and that it is of an entirely local character. Such areas must be considered in relation to the stratagraphical conditions which are known to obtain over a much wider area. But we shall return to this question presently. Reference has been made to the occurrence of lavas of Lower Old Red Sandstone age on the summit of Ben Nevis. In this district rocks of a similar age cover a large area in Lorne between Loch Melfort, Oban, and the Pass of Brander. This is Geikie's Lake Lorne; they have yielded the characteristic plant and fish remains of this division. Still another area in which these rocks are developed lies on the south side of the Southern Uplands over the east of Berwickshire and the north of Northumberland, including the area of the Cheviot Hills. This is Geikie's Lake Cheviot. It has yielded linear grass-like plants, *Zosterophyllum* and *Pterygotus anglicus*, which clearly links it with the Lower Old Red Sandstone of Forfarshire.

We now turn to a consideration of the Moray Firth and Caithness areas. The Middle Old Red Sandstone in the basin of the Moray Firth rests on a highly eroded platform of crystalline schists. At the base there occurs a course brecciated conglomerate of very irregular thickness which is overlaid by sandstones, shales, and clays. From the limestone nodules embedded in the shales numerous ichthyolite have been obtained. This

fossiliferous band, commonly known as the fish bed, forms an important horizon in the Lower Old Red Sandstone of the Moray Firth. It is exposed at Dipple and Tynet Burn. The sandstones lying above the fish bed have yielded some large specimens which are probably fragments of *Pterygotus*. The following list of the fish remains found in these rocks has been determined by Dr. Traquair:—*Diplicanthus striatis*, *D. tenuistriatus*, *Radinacanthus longispinus*, *Mesacanthus pusillus*, *Cheiracanthus murchisoni*, *C. latus*, *Pterichthys Milleri*, *P. productus*, *P. oblongus* *Dipterus Valenciennesii*, *Glyptolepis leptopterus*, *Gyroptychius microlepidotus*, *Osteolepis macrolepidota*, *Diplopterus agassizii*, *Coccosteus decipiens*, *Homosteus Milleri*, *Cheirolepis Trailli*. Regarding this list Traquair remarks, "As nearly all these fishes reappear in the flags of Caithness and of Orkney, it is clear that those, along with the Moray Firth beds, form one great palæontological series, the Orcadian." Supposed by Sir A. Geikie to have been deposited in the hypothetical Lake Orcadie of the Devonian period. Of this assemblage of species not one occurs in the Lower Old Red Sandstone of Forfarshire, or of any part of Great Britain south of the Grampians.

Between the Highland border and the Moray Firth there occurs two interesting and important outliers of Old Red Sandstone age, namely, at Tomintoul and Rhynie respectively. The former runs up the valley of the River Avon above Tomintoul, where it reaches a height of 1300 feet above the sea. It consists of massive beds of exceedingly coarse conglomerate, which rest unconformably in the crystalline schists. Some of the blocks measure over 6 feet in length, and have been derived from the underlying schists. At several points the conglomerates may be seen resting upon and wrapping round isolated stacks of the reddened schists and slates, indicating the very irregular nature of the surface upon which they had been deposited. Geikie contended that this outlying portion of the Old Red Sandstone was formed in a long valley connected with the main area of deposit to the north or in a separate and isolated hollow. He insists that it is not an outlier like the Ben Griam, Bheag, or Morven outliers, where mountains are capped with conglomerate, which must have had formerly a far wider

extension. This seems to us to be very specious reasoning, and that it is much more likely that the Tomintoul outlier is but a fragment of the local basement beds of the Old Red Sandstone formation that swept eastwards to Aberdeen and Stonehaven and northwards to the Moray Firth.

The other outlier is exposed about 25 miles to the east of that just described. It extends from Glaschul Hill, near Kildrummy Castle, northwards for a distance of 12 miles, coinciding with the valley of the Bogie by Auchindoir and Rhynie. This tract was first laid down upon MacCulloch's map, and fossil fish like those from Lethen on the Moray Firth were said to have been obtained from it as far back as 1839, and at a later period, 1854, obscure plant remains were found, one of which was described by Murchison as unquestionably a fragment of a large stem of a plant which measured 4 feet in length by 5 inches in width. It is nearly cylindrical, and is fluted irregularly near the pointed top. No joints or nodes are visible as in *Calamites*, but the surface is coarsely striated. It has been estimated that the total depth of Old Red Sandstone preserved in this district probably measures between 1500 and 2000 feet. The lowest member of the series is a bed of yellow and red conglomerate and breccia, which rests directly on the crystalline schists. This is succeeded in ascending order with some 40 or 50 feet of red shales with calcareous red nodules, above which come 300 to 400 feet of soft crumbling grey and red pebbly sandstones and conglomerates. Following these comes a group of hard pale grey and reddish or purplish sandstones, seen in the Rhynie Quarries, the whole being capped with a series of greenish grey shales and flaggy beds of sandstone. It was in the former beds that Dr. Mackie, of Elgin, discovered near the village of Rhynie a remarkable fossil peat bed preserved in bands of chert. The plants forming the peat bed grew in a gregarious fashion in peaty soil, consisting almost entirely of the decaying remains of several genera and species, which have been described by Dr. Kidston and Professor Lang. This land surface was evidently situated along the edge of some ancient shore line, and liable to periodic inundations. After the formation of the bed of peat the local conditions must have changed, for water possibly discharged from fumaroles and geysers passed over

the peat bed and sealed it up, the plants having been preserved in such a marvellous state of perfection as to be comparable with fresh sections cut from a living plant.

The Middle Old Red Sandstone of Caithness rests unconformably upon the crystalline schists and granites of the Highlands. The lower beds consist of red sandstones and conglomerates, which graduate upwards into blue and grey bituminous flagstones charged with abundant fish remains, having the same general faunal facies as that already referred to as occurring in the Moray Firth area. The late Dr. Traquair pointed out that, though the Eurypterid *Pterygotus* so typical of the Upper Silurian and Lower Old Red Sandstone rocks occurs in the Caithness flagstones, yet there are only two genera of fishes, *Cephalaspis* and *Mesacanthus*, common to the Caithness flagstones and the Old Red Sandstone south of the Grampians. It was also pointed out long ago by the late James Reid and myself that the assemblage of plants found in the Caithness beds differed in many important respects from those found in the Lower Old Red Sandstone of Strathmore. Further, Traquair pointed out that at Achanarras Quarry, south of Thurso, there occurs a peculiar fish fauna not found in any other part of Caithness. It contains, amongst others, *Palæospondylus Gunni*, *Pterichthys Milleri*, *P. productus*, *P. oblongus*, *Osteolepis microlepidotus*, and *Cheirolepis Trailli*, which had up till that time not been found anywhere else in Caithness together with *Diplopterus Agassizi*. The fish fauna from Achanarris differ from the peculiar fish fauna of John o' Groats, where the prevailing forms are *Microbrachius Dicki*, *Dipterus macropterus*, and *Tristichopterus alatus*. It also differs from the assemblage of fishes in the Thurso flagstones.

The Upper Old Red Sandstone usually consists of a series of conglomerates, sandstones, marls, and cornstones, which rest unconformably upon the upturned edges of the various members of the Lower Old Red Sandstone, and graduate upwards into the basement beds of the Carboniferous system. It is clear that the Lower Old Red Sandstone had been folded and subjected to extensive denudation before the Upper Old Red had been laid down. In the Midland Valley they usually form a fringe round the basement beds of the Carboniferous system, being

especially well developed along the north side of the Southern Uplands boundary fault. In the Midland Valley these southern deposits, as a rule, are unfossiliferous, one notable exception being the Dura Den beds in Fifeshire, where the fish remains occur in shoals. These include *Phaneropleuron Andersoni*, *Pterichthys hydrophilus*, *Glyptolæmus Kinnairdi*, *Glyptopomus minor*, *Holoptychius Andersoni*. The last form seems to have been fossilised in shoals. *Holoptychius nobilissimus* and *Pterichthys major* are found in the underlying red sandstones. Rocks of the same age have been found at the Heads of Ayr, where they have yielded *Bothriolepis major* and *Holoptychius*. North of the Grampian rocks of Upper Old Red Sandstone age fringe the coasts of the Moray and Dornoch Firths, where they have yielded the characteristic fish fauna. They also appear in Caithness at Dunnet Head, though at this locality they have not as yet yielded any fossils, in the Island of Hoy, Orkney, and in Shetland.

V. THE OLD RED SANDSTONE AND DEVONIAN OF ENGLAND AND WALES.

Along the eastern border of Wales the highest member of the Silurian, namely, the Downtonian, passes upwards conformably into the red strata which form the base of the Lower Old Red Sandstone. Where the exact line of demarcation between the two systems is to be drawn is still a matter of dispute, and will have to be considered in the succeeding part of this address, as we consider it to have an important bearing upon the physical condition under which the Old Red Sandstone was accumulated. They have a thickness of something like 10,000 feet, and stretch from Shropshire across South Wales. Lithologically the sediments are characterised by their red colour. The lower parts consist of red and green shales and flagstones with sandstones and thin cornstones. There is no coarse conglomerate in this part of the series comparable with that of the north of England and Scotland. The middle group or Flagstone Series is of great thickness, and contains partings of red shale and irregular beds of cornstone. *Cephalaspis* and *Pteraspis* is met with in this series. The upper group consists of conglomerates and sandstones of red, purple, and green hue. The pebbles are mostly

of quartz, and vary in size from an inch or two across to small white grains. *Bothriolepis* and *Holoptychius* occur in this series.

The typical or more intensely marine conditions of the Devonian is in England confined to Devon and Cornwall, and, though it presents a striking contrast both in its lithological and palæontological characters to those of the Old Red Sandstone, it is now recognised as the geological equivalent of that system, and is capable of a similar triple subdivision into Lower Middle and Upper Devonian. They have been subdivided in Cornwall as follows:—

	Cornwall.	Belgium and North of France.
Upper	{ Entomis Shales Calcareous Slates }	Famennien and Frasnian.
Middle	{ Torquay and Plymouth Limestones Slates and Volcanic Rocks }	Eifelian.
Lower	{ Staddon Grits Meadfoot Beds Dartmouth Slates }	Coblentzian and Taunusian.

It is pointed out by Jukes-Browne¹⁵ that the only definite marine fossil yet found in the Dartmouth Slates is *Bellerophon trilobatus*, which is fairly common though badly preserved. It is of importance to note that three of the characteristic genera of fishes of the Lower Old Red Sandstone of Forfarshire, *Pteraspis*, *Cephalaspis*, and *Parexus*, occur in these slates. He then remarks, "hence there is no reason for regarding the Dartmouth slates as other than a truly marine deposit. At the same time, they must have been deposited in a land-locked sea or channel the waters of which were in some way rendered congenial to the marine life of the period. It is probable that large rivers emptied themselves into the sea and brought down so much iron in solution that few creatures except fish were able to live in the water." The frequent purple and red colouring of the slates is some confirmation of this view. The succeeding Meadfoot group consists of slates, grits, and quartzites, with their lenticular limestones containing numerous fossils, principally crinoids and brachiopods.

The Devonian rocks as they are developed in the type locality,

¹⁵ "The Building of the British Isles," 3rd ed., 1911, p. 102.

Devonshire, are to a great extent of a normal character, and comprise grits, sandstones, slates, and limestones. These rocks enter into that part of Devon which lies north of Barnstaple and South Molton. But there also occur red sandstones, though of diminished thickness when compared with the Old Red Sandstone of Wales. These are the Foreland Grits and Pickwell Down Sandstones, both of which are coloured red, and are like those formed further north. Professor Marr remarks that the recognition of this fact induces one to believe that the contrast between the two types of rock which are found at a short distance from one another on opposite sides of the Bristol Channel is not so marked as one is sometimes led to suppose. The rocks of South Devon are characterised by more important masses of limestone as at Chudley, Newton Abbot, Torquay, and Plymouth, the beds being largely made up of corals and brachiopods. Here, again, Professor Marr remarks the apparent difference is positively greater than the real one, the limestones in North Devon having been stretched out after their formation, and thus rendered thinner. He also points out that the highly-cleaved limestones are often mistaken for shales. On the other hand, there is evidence of an apparent thickening of the limestones, really due to folding.

The fauna of the Devonian system, the phylum Cœlenterata, is represented by a vast number of corals. The Echinoderms of the period are mostly crinoids, which are abundant and widely distributed. The Annelides are numerous, one of the most common genera being *Spirorbis*. The Arachnidæ are principally *Eurypterids* and *Trilobites*. The former, occurring as they do in Silurian rocks, are far more abundant in those of Devonian age, and are found indifferently in sediments of the Old Red and Devon types. The trilobites belong to the genera *Phacops*, *Homalonotus*, *Prætus*, and *Bronteus*. The *Brachiopods* are represented in great force through all the Devonian deposits. They include the older genera, such as *Orthis*, *Strophomena*, *Lingula*, *Athyris*, and *Rhynchonella*, as well as the newer *Spiriferidæ* and *Productidæ*. The *Lamelli-branchiata* include such genera as *Pterinea* and *Megalodon*. The *Gasteropods* are represented by many interesting forms, as *Platyceras*, *Euomphalus*, and *Bellerophon*. The *Cephalapods*

are extremely abundant, and, besides the ancient types, *Orthoceras* and *Cyrtoceras*, we have now a predominance of the spirally coiled chambered shells of *Goniatites*, *Glymenia*, and *Nautilus*. The fishes include the genera, *Coccosteus*, *Phyllolepis*, *Holoptychius*.

VI. THE DEVONIAN OF CENTRAL EUROPE.

Rocks of Devonian age have been traced across the heart of Europe from the north of France through the Ardennes, the south of Belgium, and Rhenish Prussia, Westphalia, and Nassau. A ridge of Devonian rocks stretches below the younger formations eastwards under the south of England, where its existence has been proved by well borings at London. It seems highly probable that it joins the Devonian area of the Boulonnais. The correlation of the different subdivisions of the Devonian of Belgium and the north of France with those of Cornwall is given on page 122. Fish remains occur in the Famennien, that is, the summit of the Upper Devonian. They occur at Evieux and elsewhere, and include the following genera:—*Bothriolepis*, *Cricodus*, *Holoptychius*, *Glyptolepis*, *Dendrodus*, *Phyllolepis*, and *Glyptolepis*. They have *Holoptychius giganteus* and *Dendrodus Traquairi* common to the Upper Old Red Sandstone of Scat Craig and Clashbennie, and *Holoptychius* (*Glyptolepis*), *Flemingii*, and *Glyptolepis Kinnairdi*, common to Dura Den. The higher horizon consists of sandy limestones; they contain the remains of *Dipterus*. Dr. Evans¹⁶ states that, in a letter from M. Lohest, the fish remains consist only of the teeth and indeterminable head bones, so that we cannot be quite certain that they do not belong to *Phaneropleuron* or the Carboniferous Dipnoan *Ctenodus*. These teeth ascribed to *Dipterus* occur in the same beds with *Spirifer*.

VII. THE DEVONIAN OF RUSSIA.

Murchison¹⁷ has given us a clear account of the Russian Devonian—"The lowest known Devonian strata in the north of Livonia, and thence ranging into the Government of St.

¹⁶ "The Geology of the North-East of Caithness," 1891, p. 39.

¹⁷ "Siluria," 2nd ed., p. 381.

Petersburg repose transgressively upon various members of the Silurian rocks. The uppermost Silurian rocks of Russia (with *Cephalaspis*) correspond to those of this country, the lowest Devonian, or Old Red stage being there absent. In Russia the lowest Devonian stage consists of the sandstones and shales which contain the fossil fishes of the north of Livonia and those of the environs of Dorpat and of Tellin on the Lake of Rustuck. The fish include *Asterolepis* and *Coccosteus*. These beds graduate upwards into limestone and shale, with mollusca of Middle and Upper Devonian types." This Murchison considered rendered the theory of the fresh-water origin of the Old Red Sandstone fish quite untenable. He further points out that where the rocks have the sandy character of the chief masses of Old Red Sandstone in the British Isles—there they are also tenanted by fishes—a remarkable geological phenomenon showing an accordance between the lithological character and organic contents of the rocks of the same age in very distant countries.

Another and not less remarkable fact obtained by the survey of these rocks as we have just stated is that fossil fishes of species well known in the Old Red Sandstone of Scotland have in several places been found to be intermixed in the same bed with those shells that characterise the system in its slaty and calcareous form as exhibited in Devonshire and many parts of the Continent. This phenomenon, first brought to light by my colleagues and myself, demonstrates more than any other the identity of deposits of this age so different in lithological aspect in Devonshire on the one hand and Central England and Scotland on the other.

The uppermost Devonian stage of Russia, whether composed of red or whitish soft sandstone or of greenish marls, as on the Priutschka River, in the Valdai Hills, contains *Holoptychius noblissimus*, *Bothriolepis favosa*, and *Diplopterus Agazzi*. Murchison also gives a table of species common to England and Russia; of these, thirteen (including *H. noblissimus*, *C. favosus*, *Bothriolepis major*, *Asterolepis minor*) are common to the recognised Upper Old Red Sandstone of Scotland, especially Scat Craig and other localities near Elgin.¹⁸

¹⁸ *Op. cit.*, p. 382.

In Geikie's criticism of Murchison's triple division of the Devonian of the Continent, he objects to the establishment of a Middle Old Red Sandstone in Scotland with the Middle Devonian of the Continent. Amongst the reasons which he advances he says—"If one may judge from the sections in Russia and the Ural Mountains, does not attain a great thickness. It would appear to represent merely the upper part of the Old Red Sandstone of Great Britain. The occurrence in it of a few other types of fishes like those just cited cannot be regarded as evidence sufficient to establish a 'Middle' Old Red Sandstone series in Britain. It may merely show that in the basin of the east of Europe certain species of fishes survived longer than any seem to have done in Lake Orcadie."¹⁹

VIII. THE OLD RED SANDSTONE OF SPITSBERGEN.

Reference has already been made to Professor Høltedahl's work on the Old Red Sandstone of north-western Spitsbergen. He has recognised the following divisions and their correlation with the Scottish Old Red Sandstone:—

In Spitsbergen.

In Scotland.

Wijde Bay Series (Upper Devonic).	Upper Old Red.
Grey Hoek Series (age unknown).	Middle Old Red (Orcadian).
Wood Bay Series (Lower Devonic).	Lower Old Red (Caledonian).
Red Bay Series (Highest Siluric).	Downtonic.

The Red Bay series rest upon the more or less crystalline sediments of the Hecla hook system, which consist of phyllites, mica schists, quartzites, and limestone, and which are regarded as equivalent to the Ordovician and Silurian system of Scandinavia. The Red Bay series constitute the basal member of the overlying clastic series. Resting directly on the Hecla hook schists are massive conglomerates. The contact between the Hecla hook system is usually marked by huge sharp-edged pieces of loose rock that have not been moved at all, but represent the fractured older formation. Higher up the conglomerate materials become smaller, more rounded, and exclusively quartzose. The thickness of the conglomerate is 500 to 600 m., in some places probably more. These basal beds are followed by a yellowish white, coarse, moderately cross-bedded

¹⁹ "Old Red Sandstone of Western Europe," p. 366.

and unfossiliferous sandstone 100 to 200 m. thick. These are succeeded by the oldest known fossiliferous beds of Spitsbergen, which consist of a great thickness, grey green, and in some layers reddish sandstone. In certain layers there occurs a rich and well-preserved fauna, consisting of placoderm fishes belonging to the genera *Pteraspis*, *Palæaspis*, *Cephalaspis*, and some new genera. On two horizons are found badly preserved ostracods, *Leperditia* or *Isochilina*, and in addition some species of lamellibranchs. According to Professor Kiær, of the University of Christiania, these fishes probably represent highest Siluric time.

The succeeding division, namely, the wood Bay series, have been correlated with our Lower Old Red Sandstone (Caledonian). They consist of red and chocolate coloured sandstone and shales. They have yielded the following genera of fishes:—*Pteraspis*, *Cephalaspis*, and *Acanthaspis*. Beside the fishes ostracods and plant remains have been found; the ostracods are a big *Leperditia* and an *Isochilina*.

The next division in ascending order is the Grey Hoek series. The age of this series is not definitely known, but they have been provisionally placed as Middle Old Red (Orcadian). The fauna consists of a vast number of individuals belonging to but a few species of lamellibranchs and a gastropod. The lamellibranchs include the genera *Avicula*, *Myalina*, *Palæonodonta*. No other fossils, except some fish and plant remains, have been found.

The Grey Hoek series is overlain without any marked unconformity by the uppermost known Devonian group, namely, the Wijde Bay series. They consist of grey sandstones and slates, with the Upper Devonian fishes belonging to the genera *Holoptychius* and *Psammosteus*. Professor Høltedahl points out that the Downtonic-Devonic beds of Spitsbergen have an enormous thickness, amounting to about 10,000 m. We have here, in fact, he says, a very interesting parallel to the famous Scottish Old Red system.

As regards the physical conditions under which these rocks were deposited, the professor makes the following remarks:—“A point of difference between the two areas is that in Spitsbergen conditions from Lower to Upper Devonian time were

more stable with a less interrupted deposition in one great basin, while in Scotland great tectonic disturbances took place during this period, causing a strong denudation and the formation of more isolated troughs of deposition. Another and very interesting difference is indicated by the occurrence of fossils of distinctly marine type, such as some of the lamellibranchs and big ostracods in the Spitsbergen series. It looks as if the Spitsbergen basin was at no time during the periods of deposition far beyond the reach of the sea. We probably shall come nearest the truth by imagining a widespread delta deposition, with partly fresh partly brackish water that periodically covered great areas of the flat delta land. The Grey Hook series, with its homogeneous shale deposits and its small fauna of lamellibranchs, was probably laid down in a large lagoon-like body of water, in which the scanty fish remains were carried down by rivers.

“That we know from investigation both in Great Britain and in the Scandinavian countries that in general in Ordovician and Silurian times a land of great extent lay to the north-west, that is, on the Atlantic side. In Scotland and the north of England we find immense masses of coarse clastic material coming from this land, and in Norway the Silurian limestones of the Christiania area are replaced to the north-west by clastic material that was derived from the west. We are able to see how the western upheaval gradually spread towards the south-east accompanied by a deposition of red sandstones along the south-eastern border. In the north-south belt of unmetamorphosed sediments in south-eastern Norway—the Christiania area—we observe that the marine deposition is replaced to the north by the barren sandstone in late Wenlock time, while to the south a similar change first appears at the beginning of Downtonian time, where the marine beds are followed by fish bearing red sandstone.”

IX. THE DEVONIAN OF NORTH AMERICA.

The Devonian system is extensively developed in North America, its conditions and successions being persistent over large regions. The State of New York and the Canadas, with the Gaspé region in the east, exhibit the different members of

the system in its fullest development. The Hamilton and Upper Helderberg groups, with the Catskill, Chemung, and Portage groups above, occur in the States of Pennsylvania, Ohio, Illinois, Missouri, and Michigan in full development. In Iowa and Tennessee the Upper Devonian only is present. In New York State the eleven recognised divisions make up a mass of limestones, sandstones, shales, flagstones, and conglomerates upwards of 8000 feet in thickness. In Pennsylvania the Devonian rocks are 12,000 feet thick.

On the Lower Devonian series traces of terrestrial plants, *Psilophyton*, *Caulopteris*, &c., have been detected as far west as Ohio. This division has also yielded corals of a cyathophylloid type, *Favosites*, *Syringopora*, &c. The brachiopods include the genera, *Pentamerus*, *Stricklandia*, *Rhynchonella*, *Spirifer cultrijugata*, a European form, and *Atrypa reticularis*, which has a world-wide distribution. Trilobites, belonging to the genera *Dalmanites*, *Proëtus*, and *Phacops*, are present. Fishes are represented by ichthyodolites and teeth of Cestraciont and hybodont placoids, with plates, bones, and teeth of some peculiar ganoids, *Macropeta-lichthys* and *Onychodus*.

The Portage and Chemung groups contain land plants and fucoids, some crinoids, numerous broad-winged Spirifers, with Aviculæ and a few other lamellibranchs, as well as the characteristic Upper Old Red Sandstone genera of fishes, *Holoptychius* and *Bothriolepis*. Succeeding the Chemung there comes an immense thickness of red sandstones and conglomerates which bear a striking resemblance to the Old Red Sandstone deposits of Scotland. They are known as the Catskill group. Professor J. J. Stevenson²⁰ states that the study of the fauna of these three divisions of the Upper Devonian rocks of the Appalachian Basin shows us that as far as any evidence exists the conditions were marine from the beginning of the Chemung period to the close of the Catskill, that in the early Chemung, or possibly in the Hamilton, the conditions within north-east Pennsylvania and the adjacent portions of New York, became unfavourable to the free development of animal life; and that

²⁰ Address before Section of Geology and Geography, American Ass. for the Advancement of Science. *Proceedings*, vol. xl, 1891.

as time went on these conditions were gradually extended southward and westward, so that towards the close of the Chemung they prevailed in Columbia County 50 miles south-east from the Delaware River, and in Bradford County about the same distance west from the outcrop line. Before the close of the Catskill they had reached southwards beyond James River, in Virginia, but had not extended much further west in Pennsylvania and New York. But while prevented from existing in the muddy shallows the animals existed further west in the basin beyond reach of the river silts, just as soon as an opportunity was afforded by a lull in the untoward conditions. The active fishes found their way eastwards again, to be followed if the interval were long enough by the more sluggish molluscs as in New York and in Roanake and Russell Counties of Virginia.

The following is Professor Stevenson's summary of his paper:—

First, that the Chemung and Catskill deposits were laid down in a shallow basin subsiding most rapidly at the east and along a line roughly parallel to the Blue Ridge trend.

Secondly, that the deposits would be much greater near the mainland than at 200 miles away; so that 600 feet more or less of fine material in Ohio would more than fairly represent the 4000 feet of Chemung in eastern Pennsylvania; and

Thirdly, that the water beyond the reach of the great land wash held a Chemung fauna throughout the whole time of the Catskill deposit. There will be no serious difficulty in the way of accepting these suggestions.

The conclusions to which I am led are—

First, that the series from the beginning of the Portage to the end of the Catskill forms but one period, the Chemung, which should be divided into three epochs, the Portage, the Chemung, and the Catskill.

Secondly, that the deposits of the Catskill epoch were not made in a closed sea or in fresh-water lakes.

Thirdly, that the disappearance of animal life over so great a part of the area towards the close of the period was due to gradual extension of the conditions in south-eastern New York as early perhaps as the Hamilton period.

Fourthly, that the Chemung period should be retained in the Devonian.

Professor Stevenson insists that wherever the fishes of this period are associated with any other form of animal life, that form is marine, so that the ordinary presumption should be that the fishes themselves are marine.

Devonian rocks are widely distributed over Canada. The earlier beds are often largely calcareous, and their fossils indicate true marine conditions, but with these are associated shales and sandstones rich in the remains of land plants, and at once reminding us of the Scottish Old Red Sandstone type. These no doubt represent contemporaneous estuarine or lagoon conditions. In Nova Scotia and New Brunswick the so-called Knoydart Formation of red shales and sandstones and calcareous bands apparently overlies the Silurian (Arisaig series) unconformably, and a volcanic ash bed in the series contains pteraspidian and ostracoderm fish (*Cephalaspis*, *Pteraspis*), and eurypterids (*Pterygotus*). It resembles the cornstones of the Lower Old Red Sandstone of Great Britain. At Scaumenac Bay, Chaleur Bay, in Quebec, these fish-bearing sandstones and shales seem to lie above marine deposits, containing a lower middle Devonian fauna.

X. CONSIDERATION OF THE STRATIGRAPHICAL AND PHYSICAL EVIDENCE.

We now proceed to discuss the bearing of the stratigraphical and physical evidence upon the conditions under which these rocks have been accumulated, and it will be necessary for us to institute a comparison between the Scottish areas and others in the British Islands as well as point out the bearing which the Devonian rocks of the Continent and other parts of the world have upon the problem. The question of the contemporaneity of the Caithness and Moray Firth Beds with those of the Midland Valley and of the existence of the Cheviot, Lorne, Caledonian, and Orcadian areas as separate fresh-water lake basins, though still upheld by Sir A. Geikie, need not be here discussed, as this view has been generally abandoned by Scottish geologists. In Fig. 1 we have given Jukes Browne's idea of the geography of the Lower Devonian period. It will be seen

that he here adopts Geikie's contemporaneous fresh-water lakes. This restoration of the palæogeography of the British Isles during Lower Devonian times was given by Jukes Browne in the first and second editions of the "Building of the British Isles."

Fig. 1.—Geography of the British Isles in Devonian Time.
After Jukes Browne, 1886.
This map is based on Sir A. Geikie's Theory.

In a later edition of the same work the author resiles from his former position, and, whilst still retaining the Lake Monmouth of South Wales, he sweeps the whole of the Scottish areas into one great basin, which includes Lake Orcadie, Lake Caledonian, Lake Lorne, and Lake Cheviot. He still looks upon Lake Monmouth as a separate lake basin; his reasons for sweeping Geikie's separate Scottish basins into one are given as follows:—

It must be admitted that the occurrence of Lower Old Red in Lorne makes it very probable that difference of level was not sufficient to exclude that series entirely from the Orcadian area. Hence the most reasonable view when all the facts are taken into consideration is that all the areas of deposition eventually communicated with one another, but that it was only during the later part of the Caledonian stage that deposition began in the Orcadian area. There may have been at that time some differential sinking in of the interment tracts increasing the relative depth of the Orcadian basin, and at the same time it seems to have become stocked with fish which could not have reached it by any southern route. With regard to Lake Caledonia, he further states that he sees no reason for imagining that the Lorne and Cheviot areas were not parts of it. He admits that Messrs. Macnair and Reid were certainly on the right track when they pointed out that some of the fish genera found in the Caithness flagstones occur also in the Middle Devonian of Russia and North America, and he points out that since they wrote Dr. Traquair has shown that the fish fauna of Caithness is undoubtedly newer than that of Forfar, and much nearer in its general affinities to that of the Upper Old Red. This view has also been supported by the authority of Dr. Smith Woodward. On the other hand, Jukes Browne points out that Macnair and Reid were disposed to regard the whole succession of deposits from the Downtonian of Lanark to the top of the Caithness Beds as a marine series formed on successive platforms during the subsidence of the whole region beneath the sea. This theory, he further says, ignores some important facts and creates as many difficulties as it explains. Map II. gives his more recent view as to the geography of the Lower Devonian period. It will be seen that whilst putting Geikie's separate Scottish basins into one he still retains the Anglo-Welsh area as a separate fresh-water basin. It seems to me that nothing could exceed the specious character of the whole of Jukes Browne's reasoning on the palæogeography of the British Isles during Devonian times as set forth in the third edition of the "Building of the British Isles." The following may be taken as an example. In attempting to explain the middle or Orcadian Old Red and its relation to the Lower or Caledonian

Old Red on the supposition that they were both deposited in the same lake basin, and also the divergence of the fish fauna, Jukes Browne says that in Middle Devonian time there was

Fig. 2.—Geography of the British Isles in Devonian Time.
After Jukes Browne, 1911.

an unequal tilting movement of the Continental region, its south-west portion (Ireland and Wales) being raised, while its northern and eastern parts were depressed. This would lead to some alterations in the drainage system, and, whereas the outlet of the Caledonian lake had previously been a river flowing across the centre of Ireland into the southern sea, the subsidence in the north-east may have caused an outlet to be

established from the Orcadian basin into the Polar Sea, and by this outlet the fish of the Middle Devonian Seas would obtain access to the Orcadian basin.

It is necessary that we should here consider in some detail the nature of the palæontological characteristics of the passage beds between the Silurian and the Old Red Sandstone of the Midland Valley and compare them with those of England and the Continent. In the Lesmahagow district, as we have already seen, there appears to be a conformable upward succession from the Wenlock of the Upper Silurian to the Lower Old Red Sandstone. The lowest well-defined fossiliferous horizon is that seen in the Logan Water above Logan House, which has yielded the following species:—*Archidesmus loganensis*, *Ceratiocaris longa*, *C. Murchisoni*, *C. papilio*, *C. stygus*, *Slimonia acuminata*, *Pterygotus bilobus*, *Physocaris* sp., *Lingula minima*, *L. Lewisi*, *Pterinea retroflexa*, *Platyschisma* (*Trochus*) *helicites*, and the fishes *Thelodus planus* and *T. scoticus*. These are regarded to be of Ludlow age, and the beds are clearly of marine origin, and the genus *Thelodus* must be considered as a marine fish. It is interesting to note here that *Thelodus* occurs in the Downtonian fish bed. In the Hagshaw Hills the Ludlow rocks have yielded such brachiopods as *Orthis*, *Strophomena*, *Rhynchonella*, and *Glassia*, and, as we have seen, they are accompanied on this horizon by a molluscan fauna in which species of *Pterinea*, *Modiolopsis*, and *Orthoceras* are the most abundant types. The description of the transition from the Upper Silurian rocks into the Lower Old Red Sandstone of Shropshire, as given by Dr. H. L. Hawkins, might equally apply to those of the Lesmahagow inlier.

After describing a similar Ludlow fauna to that found at Lesmahagow, he says, "As the flags pass up towards the Downtonian Sandstones the proportions of the groups undergo reversal. Almost the only brachiopods are *Lingula*, *Orthoceras* disappears, and the bulk of the fauna is composed of *Pelecypods*, with occasional tubiculous annelides and Eurypterid Arthropods. The Ludlow Bone bed gives striking testimony to almost catastrophic changes at this stage, and in the Downtonian that supervenes even *Pelecypods* have gone. *Lingula* alone survives, represented by dwarfed forms, such as *L. minima*. The

micaceous strata of the passage beds enclose *L. cornea*, and then almost all palæontological evidence is lost in the marls of Lake Monmouth. The gradual transition from marine through brackish to fresh-water conditions is very clearly shown in the faunal sequence. The higher brachiopods are exclusively marine, and disappear at the first suspicion of estuarine contamination. Many Pelecypods (especially the Mytilidæ, a group nearly related to *Modiolopsis*) are indifferent to dilution of sea-water, although they cannot survive when sweetness has been quite attained. The Cephalopods are as definitely marine as the Brachiopods, but *Lingula*, one of the simplest members of the latter phylum, may well have possessed the catholicity of taste common to the most lowly forms.”¹⁹

Dr. Lawrence Dudley Stamp,²⁰ who has recently reviewed the question as to the proper base of the Devonian, more especially in the Welsh borderland, urges a return to Murchison's original base line, namely, the Ludlow Bone Bed, as being the most natural line of delimitation. It consists of fish remains, all of which just appear on this horizon, and are genetically connected with higher Devonian faunas. It passes laterally into a conglomerate, and thus forms a natural physical base; it marks a palæontological and lithological break, which can be correlated all over north-western Europe. Dr. Stamp says a study of the palæontology of the Downtonian of the Welsh borderland shows that the fauna of the lower beds (Ludlow Bone bed, Downton Castle Sandstone, and *Platyschisma* Shales) falls into three groups—

- (a) Upper Ludlovian marine species, which survived the change of conditions indicated by the bone bed and lived on in diminished numbers, but gradually die out. The *Platyschisma* Shales of Clun Forest are of deeper-water type than the Downton Castle Sandstone, and still other marine forms occur.
- (b) Species which flourished for a short time under the changing conditions.

¹⁹ “Invertebrate Palæontology,” 1920, p. 85.

²⁰ On the Determination of the Limit between the Silurian Devonian Systems. *Geol. Mag.*, vol. lvii., p. 164, 1920. The Base of the Devonian with especial reference to the Welsh Borderland. *Proceedings Geol. Soc.*, No. 1075, 1921.

- (c) New forms—chiefly fishes—which persist or are closely connected with later Devonian forms.

In the Lesmahagow inlier the Downtonian fish bed, lying immediately below the quartzite conglomerate, carries a fauna of ostracods, phyllocarid crustaceans, eurypterids, and fishes. One of the most striking features of this horizon is the remarkable assemblage of fishes in a wonderful complete state of preservation which it has yielded. Amongst them is the genus *Thelodus*, which we have seen occurs in the underlying Ludlow Bone Bed and in the Lower Old Red Sandstone of Forfarshire and Oban. The general aspect of the faunal association of the Downtonian fish bed at once recalls that of the lower or Ludlow horizon, both of which are of a clearly marine type, as pointed out by Drs. Peach and Horne. Now, if *Thelodus* is marine in the Ludlow and Downtonian, how does it come to be fresh-water in the Lower Old Red Sandstone? Further, the occurrence of the Polyzoon *Glaucanome*, together with *Spirorbis* and sponges, also indicate a marine origin for the Lesmahagow Downtonian. In connection with this matter Dr. Stamp suggests that from the association of the early Devonian fishes with marine invertebrates that they could live in either salt or brackish water, but gradually became specialised—some for a lacustrine habitat, others perhaps for marine conditions.

It seems to us that when we consider the widespread area over which these physical conditions prevailed, namely, Scotland, Wales, Devon and Cornwall, Northern France, the Ardennes, Brittany, Portugal, the Baltic lands, Spitsbergen, and North America, that it entirely precludes the possibility of there having been any great terrestrial earth movements such as could have ridged up the Silurian sea floor into basins as required by Sir A. Geikie's theory. Further, the gradual transition from the Downtonian to the Lower Old Red Sandstone type of deposition over such a large region of the earth's surface is only explicable on the assumption that the whole region involved shows the transition from a widespread Downtonian sea to more localised littoral conditions.

In the Silurian of the Lesmahagow inlier the marine Ludlow is succeeded conformably by a band of local conglomerate which in turn passes upwards into a series of red and yellow false

bedded sandstones having a thickness of 1300 feet, and which are entirely destitute of fossils. These are succeeded by 100 feet of green and red mudstones in which occurs the Downtonian fish band, with its overlying quartzite conglomerate. This is followed by 1200 feet of chocolate-coloured sandstones, also destitute of fossils, which have been placed by the Survey in the Downtonian. According to the Survey view, then, the Downtonian strata range from the strata above the Upper Ludlow to the *Cephalaspis Lyelli* beds of the Lower Old Red Sandstone.^{20a}

The occurrence of the marine Downtonian between the underlying yellow sandstones and the overlying chocolate-coloured sandstones points to the fact that sea could not have been at any great distance away, and the fact that the Downtonian fish bed conformably intercalated between the sandstones precludes any great ridging up movement into isolated basins.

Turning now to the lithological aspect of the question, we find that there is a strong similarity between the conglomerates of the Torridon sandstones and those of the later Old Red Sandstone rocks, and it has been claimed that both of them show evidence of glaciation. It seems to us that this may be connected in some way with the fact that they both seem to follow a great process of mountain building. This fact we think would indicate that the great mountain mass had been upheaved above the limit of the snow line, the consequent descent of glaciers having played an important part in contributing their morainic débris to the formation of these massive conglomerates now lying at the base of both the Pre-Cambrian and the Old Red Sandstone deposits, the origin of which is not, we believe, to be sought for in any lacustrine deposits as has been maintained by Ramsay, Geikie, and others. They are rather types of a great series of shore deposits gradually accumulating along the margin of a slowly sinking continental area which in its upper regions is rapidly undergoing subaerial denudation.

^{20a} So far as I am aware the only locality at which *Cephalaspis Lyelli* has been found in the Lesmahagow inlier is in the rocks of the Nethan Water at Lesmahagow, where some years ago Mr. Wm. Clarkson found a head shield of that fish. According to the officers of the Survey this is on the same horizon as those exposed in the River Clyde for a few miles both above and below Lanark. See *Memoirs of the Geol. Survey Explanation of Sheet 23*, p. 13.

This type of deposit is not uncommon all through the geological scale, and to it we believe the Old Red Sandstone conglomerates of Scotland belong. The whole petrological aspect of the Old Red Sandstone rocks as seen in Scotland is, of course, highly indicative of littoral origin, the entire absence of any of the deeper oceanic types of sedimentation, such as limestones, also confirming this view.

The great feature of the Scottish Old Red Sandstone rocks is their characteristic red colour. Now, we think that this red colour, due to the presence of the red oxide of iron in the rocks, cannot be fairly claimed as an argument for the fresh-water origin of these deposits. Professor Gosselet²¹ has shown that in the Devonian basin of Dinant the same beds are in one part red and barren of organic remains and in another part of the same area are of the usual colour and full of marine fossils. In the area he recognises two bands—a northern and a southern—and sums up his conclusions as follows:—

What distinguishes above all the two bands is—

- (1) The presence in the northern band of red schists intercalated throughout the series, whilst in the southern band the red colour is concentrated towards the base and the upper part.
- (2) The absence of fossils in the same band. This second fact is perhaps a consequence of the first, for fossils are lacking also in the red shales of the southern band.
- (3) The grit rock of Montigny is lacking in the northern band, or else is replaced by the gres de Wepion, where one finds the débris of *Sagenaria*.

To the east of Liège the southern band forms an arch which is several times folded, and where are found only the superior beds—puddingstone and red schists. At Pepinster it bifurcates, one branch passes towards Eup and is bounded on the north by the Silurian massive of Stavelot, whilst another branch passing towards the south unites with the southern band.

On the eastern edge of the basin of Dinant the Lower Devonian stage approaches the northern band by the numerous

²¹ *Etudes relatives au Bassin Houiller du Nord de la France. Bull. Soc. Geol., France, T1, p. 409.*

red rocks with which it is intercalated and by the absence of the greywacke of Hièrges. Following step by step the beds towards the south one sees them passing gradually from the northern to the southern facies.

Thus from the beginning and all through the Devonian period the Dinant basin was an arm of the sea wherein the deposits were laid down without any lacuna or breaks. I insist in this latter fact because that in all admitted theories up to the present time the Rhenan Terrain was lacking on the northern edge, whilst the puddingstone of Burnot was very much reduced upon the southern edge.

Some English geologists suppose that the Old Red Sandstone was deposited in lakes. They come to this conclusion from the absence of marine fossils, from the nature of the fishes, and from the red colour of the beds.

The first argument has no weight, as one does not find in them any fresh-water shells. As for the ganoids there, modern representations of which are very few, live, it is true, in fresh water, but if one concludes from this that the primitive ganoids had also the same habitat it must be admitted that in those distant ages all fishes belong to the fresh water, with the exception of a few plagiostomes, the remains of which are found along with marine shells of carboniferous age.²²

At the same time I do not intend to deny that the Old Red Sandstone of the British Isles cannot have had a continental origin; what I wish to protest against is the idea that the red colour is a proof of this origin. In the basin of Dinant the beds of the northern band only differ by their red colour from the beds of the southern band which have the more manifest marine characteristics. One can pass horizontally from the one to the other and show that there existed no separation between the two parts of the basin.

According to Ramsay, the red colour is due to each grain of sand or sediment being covered by a thin coating of sesquioxide of iron, and he supposes that from the protoxide of iron held in solution in the waters of the lake it was deposited under the form of peroxide owing to the oxidising action of the air and to the liberation of the carbonic acid which held it in solution.

²² "Geol. Record," 1876, p. 329.

I admit this theory, but I think that this reaction has been perfectly able to take place in the sea under the influence of a current which carried along the edge of the water feruginous matter from its source or from tributary streams. These mineral waters were inimical to life, and wherever the current was flowing the mollusca fled towards a more hospitable part of the beach. It is because of this that these red rocks are to-day devoid of fossils.

With Sir Charles Lyell²³ we ask the question, why should shells and corals be generally wanting in all sedimentary rocks the colour of which is determined by the red oxide of iron? And we believe that the answer cannot be in the assertion that they are all fresh-water deposits, seeing that even in such undoubted marine deposits as the Devonian, Carboniferous and Permian formations it is common in the ordinary beds to find corals and shells, whilst those coloured with peroxide of iron are entirely barren of organic remains. The solution of the problem rather lies in the fact that the presence of peroxide of iron in these rocks is inimical to the preservation of fossils with a calcareous test, and more especially so the case of sandstones, which even when composed of pure silica are well known to be a bad medium for the preservation of molluscan and other similar organic remains.

We need not stop to discuss here the analogy we propose to draw between the two types of sedimentation found in the Devonian and the two types found in the Carboniferous. That will be fully discussed in the next year's address when we pass to a consideration of the physical conditions under which the Carboniferous rocks were deposited. We may simply indicate, however, the general nature of the argument. In the Lower and Upper Carboniferous Limestone Series of the Glasgow district there is often found interbedded with true marine limestones and shales thick masses of sandstone devoid of organic remains of any kind. Now, this entire absence of fossils has led many of the local geologists to the conclusion that such sandstones as the Giffnock Sandstones and the Barrhead grits and sandstones must have been accumulated in fresh water. The fact that they are intercalated with marine limestones and shales

²³ "Elements of Geology," 3rd ed., p. 435.

is sufficient presumption of their marine origin. It is hardly conceivable that each alternation of such strata represents a withdrawal of the sea and a return to fresh-water conditions. This line of argument was first stated by me in my paper on the Physical Geology and Palæontology of the Giffnock Sandstones and their Bearings on the origin of sandstone rock generally, which may be consulted for further details.²⁴

XI. PALÆONTOLOGICAL CONSIDERATIONS.

In a paper published in the *Geological Magazine* for 1896 by the late James Reid and myself, we sought to show that however paradoxical it may appear to be, we have reason to believe that the occurrence of so-called ganoidan fishes of a fresh-water type in the Old Red Sandstone affords the strongest evidence of its marine origin. That recent representatives of the ganoids and dipnoaus of the Old Red Sandstone inhabit rivers and lakes of the globe is by no means a proof of the fresh-water origin of these fishes. The immense interval of time implied by the comparison renders its value somewhat problematical. Sir A. Geikie, in referring to the fishes of the Old Red Sandstone, says "That some of the fishes found their way to the sea as our modern salmon does is indicated by the occasional occurrence of their remains among those of the truly marine fauna of the Devonian rocks."²⁵

The life history, however, of the salmon presents evidence of a somewhat different kind, for we find that the salmonidæ made their appearance for the first time in the chalk of the Cretaceous System, which would rather indicate a migration from the sea. In like manner the life history of these obscure representatives of the ganoids of the Old Red Sandstone would probably show that they preserved their existence in the struggle for life by a successful adaptation to new surroundings, namely, fresh-water conditions, while their less favoured contemporaries succumbed.

We have seen that the late Professor Barrell regarded the Old Red Sandstone as of fluviatile origin; as regards the fauna he says—"At the opening of the Devonian the acanthodian

²⁴ *Trans. Geol. Soc.*, Glasgow, vol. xi., p. 199, 1897.

²⁵ Palæontological considerations on the Old Red Sandstone of Scotland. *Geol. Mag. Decade IV.*, vol. iii., p. 217, 1896.

sharks were the dominant fishes in the continental waters. Dipnoaus and crossopterygians were not in evidence in the regions where the fossils have been preserved. In the Upper Devonian the sharks were gone from the fresh waters, but the

Fig. 3.—Geography of the British Isles in Devonian Time.
After Barrell, 1915.

The loci of deposition of the Old Red Sandstone of the Lower and Middle divisions are shown and interpreted as river basins not as lakes, though subordinate lacustrine phases would attend fluvial deposition. The outcrops of Devonian formations are shown in black.

crossopterygians had risen in that environment to a dominant place. Their ability to utilise air adapted them better as river fishes to warm climates marked by alternation of wet and dry seasons. It was a semi-arid rather than an arid or humid climate which characterised the regions of the Old

Red Sandstone during late and most of Devonian time. The climate of much of the torrid zone at the present time may give the best illustration of the conditions of temperature and rainfall which in the Silurian and Devonian, but especially in the later Devonian, characterised the northern hemisphere. The few remaining dipnoans and crossopterygians still live as fresh-water fishes under similar climatic conditions.

With regard to the introduction and geographical distribution of the fishes of the Old Red Sandstone, the case of the lake or fluviatile theory displays conspicuous weakness. The Eurypterids and the Cephalaspidians of the Upper Silurian are in evidence, but of the genera *Osteolepis*, *Dipterus*, *Glyptolepis*, and other fishes of the Old Red Sandstone, no undoubted plates or scales occur in the preceding formation. The question therefore arises, whence came these highly organised fishes of the Old Red Sandstone? More especially, from what fresh-water region did they migrate? Not only so, but as the same genera of fishes occur in the Devonian of North America and the St. Lawrence basin, we have an equal right to know by what fresh-water pathway of distribution they were enabled to migrate some 3000 miles between one point and another.

We find Sir A. Geikie stating that no unequivocally marine fossil remains occur in the Old Red Sandstone. We believe we are correct in assuming that our author refers to the fishes and arachnids alike as equivocally marine remains. We have, however, seen no reason assigned why Eurypterids and Placoderms of the same genera which are marine in the later Upper Silurian and fishes of the same genera and species which are equally marine in the Devonian of Russia and Central Europe, as well as in the Devonian of North America, should be termed equivocally marine in the Old Red Sandstone.²⁶

The occurrence of *Anodonta Jukesii* in the Old Red Sandstone of Ireland is often cited as favourable to the fresh-water theory of its origin. It is being regarded as a fresh-water shell; but there is no positive proof of this, for though *A. Jukesii* may have been the ancestor of the modern fresh-

²⁶ "Text-book of Geology," 1882, p. 706.

water *Anodon*, yet its own ancestors were probably marine molluscs, and the theory of its fresh-water habitat is much weakened by its occurrence in the Tuedian beds of Northumberland, which also contain stunted marine shells. It may have preferred brackish water to fresh, or was capable of living in either. It is also interesting to note that a large lamellibranch closely resembling the Irish *Anodonta* is met with in the Devonian of New York.

From all the evidence that has been adduced, we feel justified, upon both physical and palæontological grounds, in concluding that the Old Red Sandstone and Devonian in their respective littoral, shallow-water, and deep-sea deposits, represent the one Devonian system which is marine.