Thuringia.[1] The characteristic *Holoptychius nobilissimus* has recently been detected in the Psammite de Condroz, which in Belgium forms a characteristic sandy portion of the Upper Devonian rocks. These are interesting facts, as helping to link the Devonian and Old Red Sandstone types together. But they are as yet too few and unsupported to warrant any large deduction as to the correlations between these types.

It is in the north-east of Europe that the Devonian and Old Red Sandstone appear to be united into one system, where the limestones and marine organisms of the one are interstratified with the fish-bearing sandstones and shales of the other. In Russia, as was shown in the great work *Russia and the Ural Mountains* by Murchison, De Verneuil, and Keyserling, rocks intermediate between the Upper Silurian and Carboniferous Limestone formations cover an extent of surface larger than the British Islands. This wide development arises not from the thickness but from the undisturbed horizontal character of the strata. Like the Silurian formations above described, they remain to this day nearly as flat and unaltered as they were originally laid down. Judged by mere vertical depth, they present but a meagre representative of the massive Devonian greywacke and limestone of Germany, or of the Old Red Sandstone of Britain. Yet vast though the area is over which they form the surface rock, it is probably only a small portion of their total extent; for they are found turned up from under the newer formations along the flank of the Ural chain. It would thus seem that they spread continuously across the whole breadth of Russia in Europe. Though almost everywhere undisturbed, they afford evidence of some terrestrial oscillation between the time of their formation and that of the Silurian rocks on which they rest, for they are found gradually to overlap Upper and Lower Silurian formations.

The chief interest of the Russian rocks of this age lies in the fact, first signalized by Murchison and his associates, that they unite within themselves the characters of the Devonian and the Old Red Sandstone types. In some districts they consist largely of limestones, in others of red sandstones and marls. In the former they present mollusks and other marine organisms of known Devonian species; in the latter they afford remains of fishes, some of which are specifically identical with those of the Old Red Sandstone of Scotland. The distribution of these two palæontological types in Russia is traced by Murchison to the lithological characters of the rocks, and consequent original diversities of physical conditions, rather than to differences of age. Indeed cases occur where in the same band of rock Devonian shells and Old Red Sandstone fishes lie commingled. In the belt of the formation which extends southwards from Archangel and the White Sea, the strata consist of sands and marls, and contain only fish remains. Traced through the Baltic provinces, they are found to pass into red and green marls, clays, thin limestones, and sandstones, with beds of gypsum. In some of the calcareous bands such fossils occur as *Orthis striatula*, *Spirifera prisca*, *Leptæna productoides*, *Spirifer calcaratus*, *Spirorbis omphaloides*, and *Orthoceras subfusiforme*. In the higher beds *Holoptychius* and other well-known fishes of the Old Red Sandstone occur. Followed still further to the south, as far as the watershed between Orel and Woronesch, the Devonian rocks lose their red colour and sandy character, and become thin-bedded yellow limestones, and dolomites with soft green and blue marls. Traces of salt deposits are indicated by occasional saline springs. It is evident that the geographical conditions of the Russian area during the Devonian period must have closely resembled those of the Rhine basin and central England during the Triassic period.

The Russian Devonian rocks have been classified as follows:—

Upper....	Red and white sandstone and green marls,—numerous fish remains, particularly *Holoptychius nobilissimus*, *Glyptolæus favosus*, *Diplopterus macrocephalus*.
Middle..	Limestones, clays, marls, dolomite, and gypsum,—numerous characteristic Devonian shells and crinoids, also *Holoptychius nobilissimus*.
Lower....	In some districts red and green limestones with red marls and Middle Devonian fossils; in others (North Livonia) sandstones and clays, with numerous fish remains of the genera *Osteolepis*, *Dipterus*, *Diplopterus*, *Asterolepis*, and others found also in the Caithness flags of Scotland.

There is an unquestionable passage of the uppermost Devonian rocks of Russia into the base of the Carboniferous system. The Devonian rocks of North America are noticed at the end of the next section.

B. *Old Red Sandstone.*

Under this name is comprised a vast and still imperfectly described series of red sandstones, shales, and conglomerates, intermediate in age between the Ludlow rocks of the Upper Silurian formations and the base of the Carboniferous system in Britain. These rocks were termed "Old" to distinguish them from a somewhat similar series overlying the Coal-measures, to which the name New Red Sandstone was applied. When the term Devonian was adopted, it speedily supplanted that of Old Red Sandstone, inasmuch as it was founded on a type of marine strata of wide geographical extent, whereas the latter term described what appeared to be merely a British and local development. For the reasons already given, however, it is desirable to retain the title Old Red Sandstone as descriptive of a remarkable suite of formations to which there is nothing analogous in typical Devonian rocks. It is in Great Britain that the Old Red Sandstone of Europe is almost entirely developed. This interesting series of deposits must from the first have been deposited in separate areas or basins, the sites of some of which can still be traced. Their diversities of sediment and discrepance of organic contents point to the want of any direct communication between them. It was maintained many years ago by Mr Godwin Austen, and has been more recently enforced by Professor Ramsay, that these basins were lakes or inland seas. The character of the strata, the absence of unequivocally marine fossils, the presence of land-plants and of numerous ganoid fishes which have their modern representatives in rivers and lakes, suggest and support this opinion, which has been generally adopted by geologists. The red arenaceous and marly beds which, with their fish remains and land-plants, occupy a depth of many thousand feet between the top of the Upper Silurian and the base of the Lower Carboniferous formations, are regarded as the deposits of a series of lakes or inland seas formed by the uprise of portions of the Silurian sea-floor. The length of time during which these lacustrine basins must have existed is shown, not only by the thickness of the deposits formed in them, but by the complete change which took place in the marine fauna between the close of the Silurian and the commencement of the Carboniferous period. The prolific fauna of the Wenlock and Ludlow rocks was extirpated over the British area by the physical changes which produced the lake-basins of the Old Red Sandstone. When a marine population—crinoids, corals, and shells—once more overspreads the area it is found to be completely different. So thorough a change must have demanded a long interval of time.

Murchison, who strongly advocated the opinion that the Old Red Sandstone and Devonian rocks represented different geographical conditions of the same period, and who had with satisfaction seen the adoption of the Devonian classification by Continental geologists, endeavoured to trace in the Old Red Sandstone of Britain a threefold division like that which had been accepted for the Devonian system. He accordingly arranged the formations as in the subjoined table.

Old Red Sandstone as classified by Murchison.	
Upper.	Yellow and red sandstones and conglomerates (*Pterichthys major*, *Holoptychius nobilissimus*, &c.)—Dura Den beds.
Middle.	Grey and blue calcareous and bituminous flagstones, limestones, and red sandstones, and conglomerates (*Dipterus*, *Osteolepis*, *Asterolepis*, *Acanthodes*, *Pterichthys*, &c.)—Caithness flags.
Lower.	Red and purple sandstones, grey flagstones, and coarse conglomerates (*Cephalaspis*. *Pteraspis*. *Pterygotus*)—Arbroath flags.

It is important to observe that in no district can these three subdivisions be found together, and that the so-called "middle" formation occurs only in one region—the north of Scotland. The classification, therefore, does not rest upon any actually ascertained stratigraphical sequence, but on an inference from the organic remains. The value of this inference will be estimated a little further on. All that can be affirmed from stratigraphical evidence in any Old Red Sandstone district in Britain is that a great physical and

[1] *Op. cit.*, 423.

palæontological break can generally be traced in the Old Red Sandstone, dividing it into two completely distinct series—a Lower, which graduates downward into the Upper Silurian, and an Upper, which passes upward into the base of the Carboniferous system.

As a whole, the Old Red Sandstone, where its strata are really red, is like other masses of red deposits, singularly barren of organic remains. The physical conditions under which the precipitation of iron oxide took place were evidently unfavourable for the development of animal life in the same waters. Professor Ramsay has connected the occurrence of such red formations with the existence of salt lakes, from the bitter waters of which not only iron-oxide but often rock-salt, magnesian limestone, and gypsum were thrown down. He points also to the presence of land-plants, footprints of amphibia, and other indications of terrestrial surfaces, while truly marine organisms are either found in a stunted condition or are absent altogether. Where the strata of the Old Red Sandstone, losing their red colour and ferruginous character, assume grey or yellow tints and pass into a calcareous or argillaceous condition, they not infrequently become fossiliferous. At the same time it is not unworthy of remark that some of the red conglomerates, which might be supposed little likely to contain organic remains, are occasionally found to be full of detached scales, plates, and bones of fishes.

Along the border of the Silurian region from Shropshire into South Wales the uppermost parts of the Silurian system graduate into a mass of red strata not less than 10,000 feet thick, which in turn pass up conformably into the base of the Carboniferous system. This vast accumulation of red rocks, termed the Old Red Sandstone, consists in its lower portions of red and green shales and flagstones, with some white sandstones and thin cornstones; in the central and chief division, of red and green spotted sandy marls and clays, with red sandstones and cornstones; in the higher parts of grey, red, chocolate-coloured, and yellow sandstones, with bands of conglomerate. No unconformability has yet been detected in any part of this series of rocks, though, from the observations of De la Beche, it may be suspected that the higher strata which graduate upward into the Carboniferous formations are separated from the underlying portions of the Old Red Sandstone by a distinct discordance.

Although, as a whole, barren of organic remains, these red rocks have here and there, more particularly in the calcareous zones, yielded fragments of fishes and crustaceans. In their lower and central portions remains of the ganoids *Cephalaspis*, *Didymaspis*, *Scaphaspis*, *Pteraspis*, and *Cyathaspis* have been found, together with crustaceans of the genera *Stylonurus*, *Pterygotus*, and *Prearcturus*, and obscure traces of plants. The upper yellow and red sandstones contain none of the cephalaspid fishes, which are there replaced by *Pterichthys* and *Holoptychius*, associated with distinct impressions of land-plants. In some of the higher parts of the Old Red Sandstone of South Wales and Shropshire, *Serpula* and *Conularia* occur; but these are exceptional cases, and point to the advent of the Carboniferous marine fauna, which doubtless existed outside the British area before it spread over the Old Red Sandstone basins.

It is in Scotland that the Old Red Sandstone shows the most complete and varied development, alike in physical structure and in organic contents. Throughout that country the system is found everywhere to present a division into two well-marked groups of strata, separated from each other by a strong unconformability and a complete break in the succession of organic remains. It occurs in distinct areas which appear to mark the site of separate basins of deposit. One of these occupies the central valley between the base of the Highland mountains and the uplands of the southern counties. On the north-east it is cut off by the present coast-line from Stonehaven to the mouth of the Tay. On the south-west it ranges by the island of Arran across St George's Channel into Ireland, where it runs almost to the western sea-board, flanked on the north, as in Scotland, by hills of crystalline rocks and on the south chiefly by a Lower Silurian belt. Another distinct and still larger basin lies on the north side of the Highlands, but only a portion of it comes within the present area of Scotland. It skirts the slopes of the mountains along the Moray Firth and the east of Ross and Sutherland, and stretches through Caithness and the Orkney Islands as far as the south of the Shetland group. It may possibly have been at one time continued as far as the Sognefjord and Dalsfjord in Norway, where red conglomerates like those of the north of Scotland occur. There is even reason to infer that it may have ranged eastwards into Russia, for some of its most characteristic organisms are found also among the red sandstones of that country. A third minor area of deposit lay 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. A fourth occupied a basin on the flanks of the south-west Highlands, which is now partly marked by the terraced hills of Lorne. There is sufficient diversity of lithological and palæontological characters to show that these several areas were distinct basins, separated both from each other and from the sea.

In the central basin of Scotland between the Highlands and the southern uplands, the twofold division of the Old Red Sandstone is typically seen. The lower series of deposits attains a maximum depth of upwards of 20,000 feet. In Lanarkshire it is found to pass down conformably into the Upper Silurian rocks; elsewhere its base is concealed by later formations, or by the unconformability with which different horizons rest upon the older rocks. It is covered unconformably by every formation younger than itself. It consists of reddish-brown or chocolate-coloured, grey, and yellow sandstones, red shales, grey flagstones, coarse conglomerates, and occasional bands of limestone and cornstone. The grey flagstones and thin grey and olive shales and "calmstones" are almost confined to Forfarshire, in the north-east part of the basin, and are known as the Arbroath flags. One of the most marked lithological features in this central Scottish basin is the prodigious masses of interbedded volcanic rocks. These, consisting of porphyrite-lavas, felsites, and tuffs, attain a thickness of more than 6000 feet, and form important chains of hills, as in the Pentland, Ochil, and Sidlaw ranges. They lie several thousand feet above the base of the system, and are regularly interstratified here and there with bands of the ordinary sedimentary strata. They point to the outburst of numerous volcanic vents along the lake or inland sea in which the Lower Old Red Sandstone of central Scotland was laid down; and their disposition shows that these vents ranged themselves in lines or linear groups parallel with the general trend of the great central valley. The fact that the igneous rocks are succeeded by thousands of feet of sandstones, shales, and conglomerates, without any intercalation of lava or tuff, proves that the volcanic episode in the history of the lake came to a close long before the lake itself disappeared.

As a rule the deposits of this lake are singularly unfossiliferous, though some portions of them, particularly in the Forfarshire flagstone group, have proved rich in fish remains. In Lanarkshire about 5000 feet above the base of the system a thin band of shale occurs, containing a graptolite, *Spirorbis Lewisii*, and *Orthoceras dimidiatum*,—undoubtedly Upper Silurian forms. This interesting fact serves to indicate that, though geographical changes had elevated the Upper Silurian sea-floor partly into land and

partly into isolated inland water-basins, the sea outside still contained an Upper Silurian fauna, which was ready on any favourable opportunity to re-enter the tracts from which it had been excluded. The interval of its reappearance seems to have been very brief, however, for the band of shale containing these Upper Silurian marine organisms is only a few inches thick, and the fossils have not been detected on any other horizon. With these exceptions, the fauna of the formation consists entirely of fishes and crustaceans. Nine or more species of crustaceans have been obtained, chiefly eurypterids, but including one or two phyllopods. The large pterygotus (*P. Anglicus*) is especially characteristic, and must have attained a great size, for some of the individuals indicate a length of 6 feet with a breadth of 1½ feet. There occur also a smaller species (*P. minor*), two *Eurypteri*, three species of *Stylonurus*, and abundant clusters of crustacean egg-packets termed *Parkia decipiens*. Seventeen species of fishes have been obtained, chiefly from the Arbroath flags. They belong to the suborders *Acanthodidæ* and *Ostracostei*. One of the most abundant forms is the little *Acanthodes Mitchelli*. Another common fish is *Diplacanthus gracilis*. There occur also *Climatius scutiger*, *C. reticulatus*, and *C. uncinatus*, *Parexus incurvus*, *Euthacanthus* (four species), *Cephalaspis Lyellii*, and *Pteraspis Mitchelli*. Some of the sandstones and shales are crowded with indistinctly preserved vegetation, occasionally in sufficient quantity to form thin laminæ of coal. In Forfarshire the surfaces of the shaly flagstones are now and then covered with linear grass-like plants like the sedgy vegetation of a lake or marsh. In Perthshire certain layers occur chiefly made up of compressed stems of *Psilophyton*. The adjoining land was doubtless clothed with a flora in large measure lycopodiaceous.

The Old Red Sandstone of the northern basin is typically developed in Caithness, where it consists chiefly of the well-known dark-grey bituminous and calcareous flagstones of commerce. It rests unconformably upon the metamorphosed Lower Silurian schists, and must have been deposited on the very uneven bottom of a sinking basin, seeing that occasionally even some of the higher platforms are found resting against the schists and granites. The lower zones consist of red sandstones and conglomerates which graduate upward into the flagstones. Other red sandstones, however, supervene in the higher parts of the system. The total depth of the series in Caithness has been estimated at upwards of 16,000 feet.

Murchison was the first to attempt the correlation of the Caithness flagstones with the Old Red Sandstone of the rest of Britain. Founding upon the absence from these northern rocks of the characteristic cephalaspidean fishes of the admitted Lower Old Red Sandstone of the south of Scotland and of Wales and Shropshire, upon the presence of numerous genera of fishes not known to occur in the true Lower Old Red Sandstone, and upon the discovery of a *Pterygotus* in the basement red sandy group of strata, he concluded that the massive flagstone series of Caithness could not be classed with the Lower Old Red Sandstone, but must be of younger date. He supposed the red sandstones, conglomerates, and shales at the base, with their *Pterygotus*, to represent the true Lower Old Red Sandstone, while the great flagstone series with its distinctive fishes was made into a middle division answering in some of its ichthyolitic contents to the Middle Devonian rocks of the Continent. This view has been accepted everywhere by geologists. Recently, however, it has been called in question by Professor Geikie, who gives reasons for maintaining the Caithness flagstones to be Lower Old Red Sandstone, and for denying the existence of any middle division. He shows that the discrepance in organic contents between the Caithness and the Arbroath flags is by no means so strong as Murchison supposed, but that several species are common to both. In particular, he finds that the characteristically Lower Old Red Sandstone and Upper Silurian crustacean genus *Pterygotus* occurs, not merely in the basement zone of the Caithness flags, but also high up in the series. The genera *Acanthodes* and *Diplacanthus* are abundant both in Caithness and in Forfarshire. *Parexus incurvus* occurs in the northern as well as the southern basin. It is contended that the palæontological distinctions are not greater than the striking lithological differences between the strata of the two regions would account for, or than the contrast between the ichthyic faunas of contiguous water-basins at the present time.

Somewhere about 60 species of fishes have been obtained from the Old Red Sandstone of the north of Scotland. Among these the genera *Acanthodes*, *Asterolepis*, *Cheiracanthus*, *Cheirolepis*, *Coccosteus*, *Diplacanthus*, *Diplopterus*, *Dipterus*, *Glyptolepis*, *Osteolepis*, and *Pterichthys* are specially characteristic. Some of the shales are crowded with the little ostracod crustacean *Estheria membranacea*. Land-plants abound, especially in the higher groups of the flagstones, where forms of *Psilophyton*, *Lepidodendron*, *Stigmaria*, *Sigillaria*, *Calamite*, and *Cyclopteris*, as well as other genera, occur. In the Shetland Islands traces of abundant contemporaneous volcanic rocks have been observed, which, with the exception of two trifling examples in the region of the Moray Firth, are the only known instances of volcanic action in the Lower Old Red Sandstone of the north of Scotland. In the other two Scottish basins, those of the Cheviot Hills and of Lorne, volcanic action continued long vigorous, and produced thick piles of lava like those of the central basin above referred to.

The Upper Old Red Sandstone consists in Scotland of red sandstones, clays or marls, conglomerates, and breccias, the sandstones sometimes becoming yellow or even white. These strata, wherever their stratigraphical relations can be distinctly traced, lie unconformably upon the lower division of the system, and pass up conformably into the Carboniferous rocks above. If they are studied from the side of the underlying formation, they seem naturally to form part of the Old Red Sandstone, since they agree with it in general lithological character and also in containing some distinctively Old Red Sandstone genera of fishes, such as *Pterichthys* and *Holoptychius*. But, approached from the upper or Carboniferous direction, they appear rather to form the natural sandy base of that system into which they insensibly graduate. On the whole, they are remarkably barren of organic remains, though in one locality—Dura Den in Fife—they have yielded a number of genera and species of fishes, crowded profusely through the pale sandstone as if the individuals had been suddenly killed and rapidly covered over with sediment. Among the characteristic organisms of the Scottish Upper Old Red Sandstone are *Pterichthys major*, *Holoptychius nobilissimus*, *H. Andersoni*, *Glyptopomus*, *Glyptolæmus*, and *Phaneropleuron*.

An interesting fact deserves mention here as a corollary to what has been stated above regarding the survival for some time of an Upper Silurian fauna outside the area of the British Old Red Sandstone lakes. In the Upper Old Red Sandstone of the basin of the Firth of Clyde, *Pterichthys major* and *Holoptychius* occur at the Heads of Ayr, while a band of marine limestone lying in the heart of the red sandstone series in Arran is crowded with ordinary Carboniferous Limestone shells, such as *Productus giganteus*, *P. semireticulatus*, *P. punctatus*, *Chonetes Hardrensis*, *Spirifer lineatus*, &c. None of these fossils has been detected in the great series of red sandstones overlying the limestone. They do not reappear till the limestones at the base of the Carboniferous series; yet the organisms must have been living during all that long interval outside

of the Upper Old Red Sandstone area. Not only so, but they must have been in existence long before the formation of the thick Arran limestone, though it was only during the comparatively brief interval represented by that limestone that geographical changes permitted them to enter the Old Red Sandstone basin and settle for a while on its floor. Thus we see that while, on the one hand, the older parts of the Lower Old Red Sandstone were coeval with an Upper Silurian fauna which, having disappeared from the area of Britain, survived outside of that area, on the other hand, the higher parts of the Upper Old Red Sandstone were contemporaneous with a Carboniferous Limestone fauna which, having appeared beyond the British area, was ready to spread over it as soon as the conditions became favourable for the invasion. It is, of course, obvious that such an abundant and varied fauna as that of the Carboniferous Limestone cannot have come suddenly into existence at the period marked by the base of that formation. It must have had a long previous existence outside the present area of the deposits. But it is seldom that we obtain such clear evidence of the fact as in these instances from the Scottish Old Red Sandstone.

In the north of Scotland, on the lowlands bordering the Moray Firth, and again in the island of Hoy, one of the Orkney group, yellow and red sandstones, sometimes containing characteristic Upper Old Red Sandstone fishes, are found lying unconformably upon the Caithness flags. In these northern tracts the same relation is thus traceable as in the central counties between the two divisions of the system.

Turning southward across the border districts, we trace the red sandstones and conglomerates of the Upper Old Red Sandstone lying unconformably on Silurian rocks and Lower Old Red Sandstone. Some of the brecciated conglomerates have much resemblance to glacial detritus, and it has been suggested that they have been connected with contemporaneous ice-action. Such are the breccias of the Lammermuir Hills, and those which show themselves here and there from under the overlying mass of Carboniferous strata which flanks the Silurian hills of Cumberland and Westmoreland. Red conglomerates and sandstones appear interruptedly at the base of the Carboniferous rocks even as far as Flintshire and Anglesea. They are commonly classed as Old Red Sandstone, but merely from their position and lithological character. No organic remains have been found in them. They may therefore, in part at least, be taken as the basement beds of the Carboniferous system.

In Devonshire, at Barnstaple, Pilton, Marwood, and Baggy Point, certain sandstones, shales, and limestones (already referred to in the account of the Devonian rocks) graduate upward into the base of the Carboniferous system, and appear to represent the Upper Old Red Sandstone of the rest of Britain. They contain land plants and also many marine fossils, some of which are common Carboniferous forms. They thus indicate a transition into the geographical conditions of the Carboniferous period, as is still more clearly illustrated by the corresponding strata in Scotland.

NORTH AMERICA.—The Devonian system, as developed in the northern States, and eastern Canada and Nova Scotia, presents much geological interest in the union which it contains of the same two distinct petrographical and biological types found in Europe. If we trace the range of these rocks along the Alleghany chain through Pennsylvania into New York, we find them to contain a characteristic suite of marine organisms comparable with those of the Devonian system of Europe. But on the eastern side of the great range of Silurian hills in the north-eastern States, we encounter in New Brunswick and Nova Scotia a succession of red and yellow sandstones, limestones, and shales nearly devoid of marine organisms, yet full of land-plants, and with occasional traces of fish remains.

The marine or Devonian type has been grouped in the following subdivisions by the geologists of New York:—

Upper Devonian.	Catskill Red Sandstone. Chemung group. Portage group. Genesee group. Hamilton group. Marcellus group.
Lower Devonian.	Corniferous or Upper Helderberg group. Schoharie Grit. Cauda-galli Grit.

In the Lower Devonian series traces of terrestrial plants (*Psilophyton*, *Cauleopteris*, &c.) have been detected even as far west as Ohio. Corals (cyathophylloid forms, with *Favosites*, *Syringopora*, &c.) abound, especially in the Corniferous Limestone, which is perhaps the most remarkable mass of coral-rock in the American Palæozoic series. Among the brachiopods are species of *Pentamerus*, *Stricklandinia*, *Rhynchonella*, and others, with the characteristic European form *Spirifer cultrijugatus*, and the world-wide *Atrypa reticularis*. The trilobites include the genera *Dalmanites*, *Proëtus*, and *Phacops*. The earliest known traces of American fishes occur in the Corniferous group. They consist of ichthyodorulites, and teeth of cestraciont and hybodont placoids, and plates, bones, and teeth of some peculiar ganoids (*Macropetalichthys*, *Onychodus*).

In the Hamilton formation (embracing the Marcellus shale, the Hamilton beds, and the Genesee shale) remains of land-plants occur, but much less abundantly than among the rocks of New Brunswick. Brachiopods are especially abundant among the sandy beds in the centre of the formation. They comprise, as in Europe, many broad-winged spirifers (*S. mucronatus*, &c.), with species of *Productus*, *Chonetes*, *Athyris*, &c. The earliest American goniatites have been noticed in these beds. Newberry has described a gigantic fish (*Dinichthys*) from the Black Shale of Ohio.

The Portage and Chemung groups have yielded land-plants and tucoids, also some crinoids, numerous broad-winged spirifers, with *Aviculæ*, and a few other lamellibranchs. These strata consist in the New York region of shales and laminated sandstones, which attain a maximum thickness there of upwards of 2000 feet, but die out entirely towards the interior. They are covered by a mass of red sandstones and conglomerates—the Catskill group, which is 2000 or 3000 feet deep in the Catskill Mountains, and thickens along the Appalachian region to 5000 or 6000 feet. Those red arenaceous rocks bear a striking similarity in their lithological and biological characters to the Upper Old Red Sandstone of Europe. As a whole they are unfossiliferous, but they have yielded some ferns like those of the Upper Old Red Sandstone of Ireland and Scotland (*Cyclopteris*), and some characteristic genera of fish, as *Holoptychius* and *Bothriolepis*.

Turning now to the eastern side of the ancient Laurentian and Silurian ridge, which, stretching southwards from Canada, separated in later Palæozoic time the great interior basin from the Atlantic slopes, we find the Devonian rocks of New York, Pennsylvania, and the interior represented in New Brunswick and Nova Scotia by a totally different series of deposits. The contrast strikingly recalls that presented by the Old Red Sandstone of the north of Scotland and the Devonian rocks of North Germany. On the south side of the St Lawrence the coast of Gaspé shows rocks of the Quebec group unconformably overlaid by grey limestones with green and red shales, attaining, according to Logan, a total thickness of about 2000 feet,[1] and replete in some bands with Upper Silurian fossils. They are conformably followed by a vast arenaceous series of deposits termed the Gaspé Sandstones, to which the careful measurements of Logan and his colleagues of the Canadian Geological Survey assign a depth of 7036 feet. This formation consists of grey and drab-coloured sandstones, with occasional grey shales and bands of massive conglomerate. Similar rocks reappear along the southern coast of New Brunswick, where they attain a depth of 9500 feet, and again on the opposite side of the Bay of Fundy. The researches chiefly of Dr J. W. Dawson have shown that these strata contain an abundant terrestrial flora—the oldest of which any relics have yet been recovered, for the few Upper Silurian land-plants at present known hardly deserve to be reckoned as a known flora. In his recent census he enumerates no fewer than 118 species of land-plants. They are almost all acrogens, the lycopods and ferns being largely predominant. Among the distinctive forms the following may be mentioned—*Psilophyton*, *Arthrostigma*, *Leptophleum*, and *Prototaxites*. Forty-nine ferns are given, including the genera *Cyclopteris*, *Neuropteris*, *Sphenopteris*, and some tree-ferns (*Psaronius*, *Caulopteris*). Lepidodendroid and sigillaroid plants abound, as well as calamites. Higher forms of vegetation are represented by a few conifers (*Dadoxylon*, *Ormoxylon*, *Prototaxites*, &c.). From a locality on Lake Erie, Dr Dawson describes a fragment of dicotyledonous wood, not unlike that of some modern trees—the most ancient

[1] *Geology of Canada*, p. 393.

fragment of an angiospermous exogen yet discovered. So abundant are these vegetable remains that in some layers they actually form thin seams of coal.

The interest of these remains of the most venerable American forests is heightened by the discovery of the fact that they were not without the hum of insect life. The most ancient known relics of insect forms have been recovered from the Devonian strata of New Brunswick. They are all neuropterous wings, and have been referred by Mr Scudder of Boston to four species combining a remarkable union of characters now found in distinct orders of insects. In one fragment he observed a structure which he could only compare to the stridulating organ of some male *Orthoptera*. Another wing indicates the existence of a gigantic *Ephemera*, with a spread of wing extending to 5 inches. In the shallow pools of the period some small crustaceans lived, the remains of which have been partially preserved. Among these is a minute, shrimp-like *Eurypterus*, and a more highly organized form named *Amphipeltis*. That the sea had at least occasional access to the inland basins into which this abundant terrestrial vegetation was washed is proved by the occurrence of marine organisms, such as a small annelid (*Spirorbis*) adhering to the leaves of the plants, and (in Gaspé and Nova Scotia) by the occasional appearance of brachiopods, especially *Lingula*, *Spirifer*, and *Chonetes*.[1]

Carboniferous.

This great system of rocks has received its name from the seams of coal which form one of its distinguishing features both in Europe and in North America. In Europe it is most completely developed in the British Islands. Elsewhere on that continent it occurs in patches, either lying in hollows of older rocks, or exposed by the removal of overlying formations.

Great Britain.—The area within which the Carboniferous rocks of Britain occur is sufficiently extensive to contain more than one type of the system, and thus to cast much light on the varied geographical conditions under which these rocks were accumulated. In prosecuting the study of this part of British geology, it is soon discovered, and it is essential to bear in mind, that, during the Carboniferous period, the land whence the chief supplies of sediment were derived rose mainly to the north and north-west, as it seems to have done from very early geological time. While therefore the centre and south of England lay under clear water of moderate depth, the north of the country and the south of Scotland were covered by shallow water, which was continually receiving sand and mud from the adjacent northern land. Hence vertical sections of the Carboniferous formations of Britain differ greatly according to the districts in which they are taken. The subjoined table may be regarded as expressing the typical subdivisions which can be recognized, with modifications, in all parts of the country.

Coal-measures	Red and grey sandstones, clays, and sometimes breccias, with occasional seams and streaks of coal and spirorbis limestone (*Cythere inflata*, *Spirorbis carbonarius*).
	Middle or chief coal-bearing series of yellow sandstones, clays, and shales, with numerous workable coals (*Anthracosia*, *Anthracomya*, *Beyrichia*, *Estheria*, *Spirorbis*, &c.).
	Gannister beds, flagstones, scales, and thin coals, with hard siliceous (gannister) pavements (*Orthoceras*, *Goniatites*, *Posidonia*, *Aviculopecten*, *Lingula*, &c.).
Millstone Grit	Grits, flagstones, and shales, with thin seams of coal.
Carboniferous Limestone series	Yoredale group of shales and grits passing down into dark shales and limestones (*Goniatites*, *Aviculopecten*, *Posidonomya*, *Lingula*, *Discina*, &c.).
	Thick limestone in south and centre of England and Ireland, passing northwards into sandstones, shales, and coals (abundant corals, polyzoans, brachiopods, lamellibranchs, &c.).
	Lower Limestone Shale of south and centre of England (marine fossils like those of overlying limestone), passing northward into the Calciferous Sandstone group of Scotland (marine, estuarine, and terrestrial organisms).

[1] Dawson's *Acadian Geology*, chaps. xxi. and xxii.

In the article Coal (vol. vi. p. 49) an account has been given of the principal coal-fields of the world; likewise a diagram (p. 48) representing the chief subdivisions of the Carboniferous system in Britain, as the rocks are traced from north to south.

Base of the System.—In the south-west of England, and in South Wales, the Carboniferous system passes down conformably into the Old Red Sandstone. The passage beds consist of yellow, green, and reddish sandstones, of green, grey, red, blue, and variegated marls and shales, sometimes full of terrestrial plants. They are well exposed on the Pembrokeshire coasts, marine fossils being there found even among the argillaceous beds at the top of the Red Sandstone series. They occur with a thickness of about 500 feet in the gorge of the Avon near Bristol, but show less than half that depth about the Forest of Dean. At their base there lies a bone-bed containing abundant palatal teeth. Not far above this horizon plant-bearing strata are found. Hence these rocks bring before us a mingling of terrestrial and marine conditions. In Yorkshire, near Lowther Castle, Brough, and in Ravenstonedale, alternations of red sandstones, shales, and clays, containing *Stigmaria* and other plants, occur in the lower part of the Carboniferous Limestone. Along the eastern edge of the Silurian hills of the Lake district the Old Red Sandstone appears here and there, and passes up through a succession of red and grey sandstones, and green and red shales and marls, with plants, into the base of the Carboniferous Limestone.

It is in Scotland, however, that this peculiar type of the basement Carboniferous rocks is best seen. In that country the lowest subdivision of the Carboniferous system, known as the Calciferous Sandstones, consists of red, white, and yellow sandstones, blue, grey, green, and red marls or clays, blue and black shales, thin coals, seams of limestone and cement-stone, and abundant volcanic rocks. The red sandstones lie at the base, and pass down into the Upper Old Red Sandstone, in which, as has been already pointed out (*ante*, p. 344), true Upper Old Red Sandstone fishes are found, while there occur also bands of limestone full of true Carboniferous Limestone corals and brachiopods. Hence it is evident that the Carboniferous Limestone fauna had already appeared outside the British area before the close of the Old Red Sandstone period. It was when the peculiar geographical conditions which prevailed during that period finally ceased, and the sea began to spread over the ancient lakes and land of Britain, that the abundant Carboniferous fauna invaded the area. The Calciferous Sandstones of Scotland may therefore represent a portion of the Carboniferous Limestone of England.

Over the greater part of the south and centre of Scotland the lower red sandstones are surmounted by a series of contemporaneous volcanic rocks. Successive sheets of porphyrites and tuffs form long ranges of hills from Arran and Bute on the west to the mouth of the estuary of the Forth on the east, and from the Campsie Fells on the north to the heights of Liddesdale and the English border. These volcanic sheets sometimes reach a thickness of 1500 feet. That they belong to the Carboniferous system is shown by the occurrence of shales and sandstones (with Carboniferous plants) at their base. They show that the early part of the Carboniferous period in Scotland was marked by a prodigious volcanic activity, which, on its cessation, was followed by the prolonged subsidence required for the accumulation of the Carboniferous system. The rocks succeeding the volcanic zone are termed the cement-stone group. In Berwickshire and the west of Scotland they consist of thin bedded white, yellow, and green sandstones, grey, green, blue, and red clays and shales, with thin bands of a pale argillaceous limestone or cement-stone. Seams of gypsum occasionally appear. These strata are, on the whole, singularly barren of organic remains. They seem to have been laid down with great slowness, and without disturbance, in enclosed basins, which were not well fitted for the support of animal life, though fragmentary plants serve to show that the adjoining slopes were covered with vegetation.

In the basin of the Firth of Forth, however, the group presents a different lithological aspect and is abundantly fossiliferous. It there usually consists of yellow, grey, and white sandstones, with blue and black shales, clay-ironstones, limestones, "cement-stones," and occasional seams of coal. The sandstones form excellent building stones, the city of Edinburgh having been built of them. Some of the shales are so bituminous as to yield, on distillation, from 30 to 40 gallons of crude petroleum to the ton of shale; they are consequently largely worked for the manufacture of mineral oils. The limestones are usually dull, yellow, and close grained, in seams seldom more than a few inches thick, and graduate by addition of carbonate of iron into cement-stone; but occasionally they swell out into thick lenticular masses like the well-known limestone of Burdie House, so long noted for its remarkable fossil fishes. This limestone appears to be mainly made up of the crowded cases of a small ostracod crustacean (*Leperditia Okeni*, var. *Scoto-Burdigalensis*). The coal-seams are few and commonly too thin to be workable, though one of them, known as the Houston coal, has been mined to some extent in Linlithgowshire. The fossils of the cement-stone group indicate an alternation of fresh or brackish-water and marine conditions. They include numerous plants, of which the most abundant are *Sphenopteris affinis*, *Lepidodendron* (two or three species), *Lepidostrobus variabilis*, *Araucarioxylon*. Some of the shales near Edinburgh have afforded a few specimens of a true monocotyledon allied to the modern Pothos (*Pothocites Grantoni*). Ostracod crustaceans, chiefly the *Leperditia* above mentioned, crowd many of the shales. With these are usually associated abundant traces of the presence of fish, either in the form of coprolites or of scales, bones, plates, and teeth. The following are characteristic species: *Elonichthys striolatus*, *E. Robisoni*, *Rhadinichthys ornatissimus*, *Nematoptychius Greenockii*, *Eurynotus crenatus*, *Rhizodus Hibberti*, *Megalichthys* sp., *Gyracanthus tuberculatus*, *Ctenoptychius pectinatus*. At intervals throughout the group marine horizons occur, usually as shale bands marked by the presence of such distinctively Carboniferous Limestone species as *Spirorbis carbonarius*, *Discina nitida*, *Lingula squamiformis*, *Bellerophon decussatus*, and *Orthoceras cylindraceum*.

One of the most interesting features in the cement-stone group of the basin of the Firth of Forth is the prodigious number and variety of the associated volcanic masses, and the proofs which they exhibit that, at the time when that group of strata was accumulating, the region of shallow lagoons, islets, and coal-growths was dotted over with innumerable active volcanic vents. The eruptions continued into the time of the Carboniferous Limestone, but ceased before the deposition of the Millstone Grit. The lavas are chiefly varieties of basalt-rocks, sometimes coarsely crystalline and even granitoid in texture, and graduating through intermediate stages to true close-grained compact basalts, which neither externally nor in microscopic structure differ from basalt of Tertiary date

The basement group of the Carboniferous system in Ireland is evidently a prolongation of the Scottish cement-stone group. In the south of this island, however, a very distinct and peculiar development of the Lower Carboniferous rocks is to be remarked. Between the top of the Old Red Sandstone and the base of the Carboniferous Limestone there occurs in the county of Cork an enormous mass (fully 5000 feet) of black and dark-grey shales, impure limestones, and grey and green grits and true cleaved slates. To these rocks the name of Carboniferous Slate was given by Griffith. They contain numerous Carboniferous Limestone species of brachiopods, echinoderms, &c., as well as traces of land-plants in the grit bands. Great though their thickness is in Cork, they rapidly change their lithological character, and diminish in mass as they are traced away from that district. In the almost incredibly short space of 15 miles, the whole of the 5000 feet of Carboniferous Slate of Bantry Bay have disappeared, and at Kenmare the Old Red Sandstone is followed immediately and conformably by the Limestone with its underlying shale. Mr Jukes held that the Carboniferous Slate is the equivalent of part of the Devonian rocks of Devon and Cornwall.

Carboniferous Limestone.—The Lower Limestone shale is overlaid conformably by a thick mass of limestone, one of the most distinctive members of the British Carboniferous system. On referring to a geological map of England it will be seen that from Northumberland southwards to the low plains in the centre of England there runs a ridge of high ground, formed by a great anticline, along which the Carboniferous Limestone appears at intervals from underneath higher members of the system. In this northern Carboniferous area, of which the axis is known as the Pennine Chain, the limestone attains its maximum development. In one portion of the district it reaches a depth of 4000 feet, and yet its actual base is nowhere seen. This Pennine region appears to have been the area of maximum depression during the early part of the Carboniferous period in Britain. Traced towards the south-west, the limestone diminishes to sometimes not more than 500 feet in South Wales. Northwards, losing its character as a massive calcareous formation, it is split up by intercalations of sandstone, shale, coal, &c., until actual limestone becomes a very subordinate member of the series in central Scotland.

In the Carboniferous areas of the south-west of England and South Wales, the limits of the Carboniferous Limestone are well defined by the Limestone Shale below, and by the Farewell Rock or Millstone Grit above. In the Pennine area, however, the massive limestone is succeeded by a series of shales, limestones, and sandstones, known as the Yoredale group. These cover a large area and attain a great thickness. In North Staffordshire they are 2300 feet, which, added to the 4000 feet of limestone below, gives a depth of 6300 feet for the whole Carboniferous Limestone series of that region. In Lancashire the Yoredale rocks attain still more stupendous dimensions, Mr Hull having found them to be no less than 4500 feet thick. Both the lower or main (Scaur) limestone and the Yoredale group pass northwards into sandstones and shales, with coal-seams, and diminish in thickness. It is not impossible, as already suggested, that the cement-stone group of the Calciferous Sandstones of Scotland may represent, not only the thin Lower Limestone shale, but also some of the older parts of the English Carboniferous Limestone.

Where typically developed, the Carboniferous Limestone is a massive well-bedded limestone, chiefly light bluish-grey in colour, varying from a compact homogeneous to a distinctly crystalline texture, and rising into ranges of hills, whence its original name "Mountain Limestone." It contains occasional scattered irregular nodules and nodular beds of dark chert. It is abundantly fossiliferous. The fossils commonly stand out on weathered surfaces of the rock, but microscopic investigation shows that even those portions of the mass which appear most structureless consist of the crowded remains of marine organisms. The limestone may be regarded as derived entirely from the organic debris of a sea-floor. Diversities of colour and lithological character occur, whereby the bedding of the thick calcareous mass can be distinctly seen. Here and there a more marked crystalline structure has been superinduced; but the most distinct examples of metamorphic change are those where the rock has been converted into what is termed "dun-stone." This alteration is frequent in the mining districts of Yorkshire and the neighbouring counties. It consists in the dolomitization of the rock along either the lines of bedding or the joints. Thus changed, it becomes a yellowish or brown crystalline dolomite, which runs vertically through the mass of the limestone along some definite joint, in courses of 20 or 30 fathoms in width. Such a metamorphism must have been effected by water percolating along the line of the joint, and affecting the rock for some distance on either side. In