Derbyshire sheets of contemporaneous lava, locally termed "toadstone," are interpolated in the Carboniferous Limestone.

The fauna of the Carboniferous Limestone of England is abundant and characteristic. Numerous foraminifers occur, *Saccamina Carteri* being often very characteristic. The corals are numerous, embracing upwards of 30 genera and about 100 species. These include both simple cup corals, as *Zaphrentis*, *Clisiophyllum*, and compound forms, like *Alveolites* and *Phillipsastræa*. Crinoids are individually in enormous numbers, many beds of limestone appearing to consist of little else than their fragmentary stems and cups; *Actinocrinus*, *Platycrinus*, *Poteriocrinus*, *Cyathocrinus*, are common genera. Three species of sea-urchins are known. Of the trilobites, so characteristic of the older Palæozoic rocks, the last lingering forms are here found in three small genera —*Brachymetopus*, *Phillipsia*, and *Griffithides*. Polyzoa abound, some portions of the limestone being almost entirely composed of them, the genera *Fenestella*, *Sulcoretepora*, *Vincularia*, *Polypora*, *Diastopora*, and *Glauconome* being frequent. The brachiopods comprise 18 genera and 160 species, some of the most common forms being *Productus*, *Spirifer*, *Rhynchonella*, *Athyris*, *Chonetes*, *Orthis*, *Lingula*, and *Discina*. But the higher mollusks now begin to preponderate over the brachiopods. The lamellibranchs number 49 genera and 334 species, including forms of *Aviculopecten*, *Leda*, *Nucula*, *Sanguinolites*, *Leptodomus*, *Schizodus*, *Edmondia*, *Modiola*, and *Conocardium*. The gasteropods amount to 206 species belonging to 29 genera, among which *Euomphalus*, *Natica*, *Pleurotomaria*, *Macrocheilus*, and *Loxonema* are frequent. The genus *Bellerophon* is represented by 23 species, among which *B. Urei* and *B. decussatus* are frequent. The cephalopods number 148 species, belonging among other genera to *Orthoceras*, *Nautilus*, *Dibites*, and *Goniatites*. About 100 genera of fishes, chiefly from teeth and spines, have been described, as *Psammodus*, *Cochliodus*, *Cladodus*, *Petalodus*, *Rhizodus*, *Ctenoptychius*, &c. Some of these were no doubt placoids which lived solely in the sea, but many, if not all of the ganoids, probably migrated between salt and fresh water; at least their remains are found in Scotland in strata full of land-plants, cyprids, and other indications of estuarine or fluviatile conditions.

The Carboniferous Limestone series of Scotland presents a striking contrast to that of the typical formation in England. It consists mainly of sandstones, shales, fire-clays, and coal-seams, with a few comparatively thin seams of encrinal limestone. Its lower portions include the chief limestone bands. The thickest of these seams, known as the Hurlet or main limestone, is usually about 6 feet in thickness, but in the north of Ayrshire swells out to 100 feet, which is the most massive bed of limestone in any part of the Scottish Carboniferous system. It lies upon a seam of coal, and is in some places associated with pyritous shales, which have been largely worked as a source of alum. This superposition of a bed of marine limestone on a seam of coal is of frequent occurrence in the Carboniferous Limestone series of Scotland. Above the group of Lower Limestones comes a thick mass of strata containing many valuable coal-seams and ironstones. Some of these strata are full of terrestrial plants (*Lepidodendron*, *Sigillaria*, *Stigmaria*, *Sphenopteris*, *Alethopteris*); others, particularly the ironstones, contain marine shells, such as *Lingula*, *Discina*, *Leda*, *Myalina*, *Euomphalus*. Numerous remains of fishes have been obtained, more especially from some of the ironstones and coals (*Gyracanthus formosus* and other placoid fin-spines, *Megalichthys Hibberti*, *Rhizodus Hibberti*, with species of *Elonichthys*, *Acanthodes*, *Ctenoptychius*, &c.). Remains of labyrinthodonts have also been found in this group of strata, and have been detected even down in the Burdie House limestone. The highest division of the Carboniferous Limestone series consists of a group of sandstones and shales, with a few coal-seams, and three, sometimes more, bands of marine limestone. Although these limestones are each seldom more than 3 or 4 feet thick, they have a wonderful persistence throughout the coal-fields of central Scotland. As already mentioned, they can be traced over an area of at least 1000 square miles, and they probably extended originally over a considerably greater region. The Hurlet limestone with its underlying coal can also be followed across a similar extent of country. Hence it is evident that during certain epochs of the Carboniferous period a singular uniformity of conditions prevailed over a large region of deposit in the centre of Scotland.

The difference between the lithological characters of the Carboniferous Limestone series, in its typical development, as a great marine formation, and in its arenaceous and argillaceous prolongation into the north of England and Scotland, has long been a familiar example of the nature and application of the evidence furnished by strata as to former geographical conditions. It shows that the deeper and clearer water of the Carboniferous sea spread over the site of Yorkshire, Derbyshire, and Lancashire; that the land lay to the north; and that, while the whole area was undergoing subsidence, the maximum movement took place over the area of deeper water. It was from the northern land that the sand and mud were derived, but the sediment during the time of the Carboniferous Limestone seems to have sunk to the bottom before it could reach the great basin in which foraminifers, corals, crinoids, and mollusks were building up the great calcareous deposit. Yet the thin limestone bands, which run so persistently among the Lower Carboniferous rocks in Scotland, prove that there were occasional episodes during which the sediment ceased to arrive, and when the same species of shells, corals, and crinoids spread northwards towards the land, forming for a time over the sea-bottom a continuous sheet of calcareous ooze like that of the deeper water further south. These intervals of limestone growth no doubt point to times of more rapid submergence, perhaps also to other geographical changes whereby the sediment was for a time prevented from spreading so far.

Viewed as a whole, therefore, the Carboniferous Limestone series of Northumberland and Scotland contains the records of a long-continued but intermittent process of subsidence. The numerous coal-seams with their underclays were undoubtedly surfaces of vegetation that grew in rank luxuriance on the wide marine mud-flats, and mark pauses in the subsidence. Perhaps we may infer the relative length of these pauses by the comparative thicknesses of the coal-seams. The overlying and intervening sandstones and shales indicate a renewal of the downward movement, and the gradual infilling of the depressed area with sediment, until the water once more shoaled, and the vegetation from adjacent swamps spread over the muddy flats as before. The occasional limestones serve to indicate the epochs of more prolonged or more rapid subsidence, when marine life was enabled to flourish over the site of the submerged forests. But that the sea, even though tenanted in these northern parts by a limestone-making fauna, was not so clear and well suited for the development of animal life during some of these submergences as it was further south, seems to be proved by the paucity and dwarfed forms of the fossils in the thin limestones, as well as by the admixture of clay in the stone.

In Ireland the Carboniferous Limestone swells out to a vast thickness, and covers a large part of the island. It attains a maximum in the west and south-west, where, according to Kinahan,[1] it consists in Limerick of the following subdivisions:—

		Feet.
Upper (Burren) Limestone	Bedded limestone	240
	Cherty zone	20
Upper (Calp) Limestone	Limestones and shales	1000
	Cherty zone	40
Lower Limestone	*Fenestella* limestone	1900
	Lower cherty zone	20
	Lower shaly limestones	280
Lower Limestone Shale		100
		3600

[1] *Geology of Ireland*, p. 72.

The chert bands which form such marked horizons among these limestones are counterparts of others found abundantly in the Carboniferous Limestone of England and Scotland. They have been recently studied by Hull and Hardman, who have found them full of siliceous replacements of calcareous foraminifers, crinoids, &c., and who regard them as due to a chemical alteration on the floor of the Carboniferous sea. Portions of the limestone have a dolomitic character, and sometimes are oolitic. Great sheets of melaphyre, felstone, and tuff, representing volcanic eruptions of contemporaneous date, are interpolated in the Carboniferous Limestone of Limerick and other parts of Ireland. As the limestone is traced northwards it shows a similar change to that which takes place in the north of England, becoming more and more split up with sandstone, shale, and coal-seams, until, at Ballycastle, it presents exactly the characters of the coal-bearing part of the formation in Scotland.

Millstone Grit.—This name is given to a group of sandstones and grits, with shales and clays, which runs persistently through the centre of the Carboniferous system from South Wales into the middle of Scotland. In South Wales it has a depth of 400 to 1000 feet; in the Bristol coal-field, of about 1200 feet. Traced northwards it is found to be intercalated with shales, fire-clays, and thin coals, and, like the lower members of the Carboniferous system, to swell out to enormous dimensions in the Pennine region. In North Staffordshire, according to Mr Hull, it attains a thickness of 4000 feet, which in Lancashire increases to 5500 feet. These massive accumulations of sediment were deposited on the north side of a barrier of Silurian and Cambrian rocks, which, during all the earlier part of the Carboniferous period, seems to have extended across central England, and which was not submerged until part of the Coal-measures had been laid down. North of this great area of deposit the Millstone Grit thins away to not more than 400 or 500 feet. It continues a comparatively insignificant formation in Scotland, attaining its greatest thickness in Lanarkshire and Stirlingshire, where it is known as the Moor Rock. In Ayrshire it does not exist, unless its place be represented by a few beds of sandstone at the base of the Coal-measures.

The Millstone Grit is generally barren of fossils. When they occur they are either plants like those in the coal-bearing strata above and below, or marine organisms of Carboniferous Limestone species. In Northumberland, indeed, it contains a band of limestone undistinguishable from some of those in the Yoredale group and Scaur limestone.

Coal-Measures.—This division of the Carboniferous system consists of numerous alternations of grey, white, yellow, sometimes reddish sandstone, dark-grey and black shales, clay-ironstones, fire-clays, and coal-seams. In South Wales it attains a maximum depth of about 12,000 feet; in the Bristol coal-field it is 5050 feet. But in these districts, as in the rest of the Carboniferous areas of Britain, we cannot be sure that all the Coal-measures originally deposited now remain, for they are always unconformably covered by later formations. In some localities, indeed, the denudation must have been very great, for the next overlying system of deposits (Permian) is found resting even on the Carboniferous Limestone. In North Staffordshire the depth of the Coal-measures is about 5000 feet, which in South Lancashire increases to 8000. These great masses of strata diminish as we trace them eastwards and northwards. In Derbyshire they are about 2500 feet thick, in Northumberland and Durham about 2000 feet, and about the same thickness on the west side of the island in the Whitehaven coal-field. In Scotland they attain a maximum of about 2000 feet.

The Coal-measures are susceptible of local subdivisions indicative of different and variable conditions of deposit. The following tables show the more important of these:—

Glamorganshire.

Upper series, more than 3400 feet	Sandstones, shales, &c., with 26 coal-seams.
Pennant Grit, 3246 feet	Hard thick-bedded sandstones &c., 15 coal-seams.
Lower series, 450 to 850 feet	Shales, ironstones, and 34 coal-seams.
	Millstone Grit.

South Lancashire.

Upper, 1680 to 2000 feet	Shales, *Spirorbis* limestone, ironstone, sandstone, and thin coal-seams.
Middle, 3000 to 4000	A great series of strata, with numerous valuable coals.
Lower or Gannister, 1400 to 2000 feet	Flags, shales, and three or four thin coals, with floors of "gannister."
	Millstone Grit.

Central Scotland.

150 feet and upwards	Red sandstones and clays, with occasional thin coals and *Spirorbis* limestone.
Upwards of 2000 feet in Lanarkshire	Sandstones, shales, and fire-clays, with ironstones and coals.
	Moor-rock or Millstone Grit.

The numerous beds of compressed vegetation form the most remarkable feature of the Coal-measures. Each of them is usually underlaid by a seam of fire-clay, representing the soil on which the plants grew. Hence they mark successive terrestrial surfaces, which, after enduring for a longer or shorter period, were carried down beneath the water and covered over with sand and silt. There is no modern formation that affords a close parallel to that of the ancient coal-growths. The nearest analogy is furnished by the mangrove swamps alluded to already on p. 290. These masses of arborescent vegetation grow out into the sea as a belt or fringe on low shores, and form a matted soil which adds to the breadth of the land. Their roots spread in the salt water where marine organisms are abundant. The coal-growths no doubt also flourished in salt or at least brackish water; for such shells as *Aviculopecten*, *Anthracosia*, and *Goniatites* are found lying on the coal or in the shales attached to it.

The vegetation of the Carboniferous period must have been luxuriant and varied. Upwards of 500 species of plants have been obtained from the Carboniferous rocks of Britain, yet these must represent but a small portion of the original flora.

The most abundant forms were ferns and lycopods. Numerous reed-like plants likewise played a conspicuous part in the general vegetation of the low grounds, while apparently on the drier and more elevated tracts (for their remains are less frequently met with) large coniferous trees flourished. The ferns strikingly resemble many modern forms. Among the more frequent genera were *Sphenopteris*, *Pecopteris*, *Alethopteris*, *Neuropteris*, and *Cyclopteris*. The lycopodiaceous plants attained the size of forest trees. Among the more typical forms were many species of *Lepidodendron*, the stems and seed-cones of which are scattered through the Carboniferous strata. Some of the coal-seams are largely composed of the spores of these plants. *Sigillaria*, regarded by some as allied to the cycads, by others as more akin to the lycopods, is represented by numerous species. The roots known as *Stigmaria* abound in most fire-clays, showing how largely the coal consists of trees having roots of this kind. The *Equisetaceæ* show themselves in the form of numerous *Calamites* which, though resembling in general aspect our modern horse-tails, differed in many points of structure, and notably in their gigantic size. Coniferous trees occur chiefly in the form of stems and branches. They include the genera *Dadoxylon*, *Araucarioxylon*, and *Pinites*. Small nut-like fruits (*Trigonocarpum*) abound in some beds, and are now believed to be the fruits of yew-like conifers. The presence of monocotyledonous plants is proved by the *Pothocites* referred to above (p. 347)

The animal remains of the Coal-measures are comparatively few. In certain bands, particularly of ironstone, numerous mollusca occur, and similar forms are to be occasionally met with in the shales.

Among the more frequent species are *Anthracomya modiolaris*, *Anthracosia ovalis*, *A. robusta*, *A. acuta*, *Anthracopteron Brownianus*, *Aviculopecten papyraceus*, and *Goniatites Listeri*. But at the top of the Middle Coal-measures, near Manchester, a band of true marine shells occurs, including *Clenodonta*, *Nautilus*, *Discites*, *Goniatites*, and *Orthoceras*. The little *Spirorbis carbonarius* abounds in some shales. The crustaceans are chiefly represented by *Beyrichia* and *Estheria*, but large eurypterid forms likewise occur. Fishes occur frequently, remains of the larger kinds usually appearing as scales, teeth, fin-spines, or bones, while the smaller ganoids are often preserved entire. Common species are *Megalichthys Hibberti* (?), *Rhizodus granulatus*, *Celacanthus leptarus*, *Palæoniscus Egertoni*, *Pleuracanthus gibbosus*. The British Carboniferous rocks have yielded 13 genera of labyrinthodonts (*Anthracosaurus*, *Loxomma*, *Ophiderpeton*, *Pholiderpeton*, *Pteroplax*, *Urocordylus*, &c.). These were probably fluviatile animals of predaceous habits, living on fish, crustacea, and other organisms of the fresh or salt waters of the coal lagoons. The larger forms are believed to have measured 7 or 8 feet in length; some of the smaller examples, though adult and perfect, do not exceed as many inches.[1] That the woods of the Carboniferous period were not devoid of insect life is known from the discovery of some beetles and neuropters at Coalbrookdale.

CONTINENTAL EUROPE.—As in Britain so on the Continent the Carboniferous system occupies many detached areas or basins—the result partly of original deposition, partly of denudation, and partly of the spread and overlap of more recent formations. There can be no doubt that the English Carboniferous Limestone once extended continuously eastward across the north of France, along the base of the Ardennes, through Belgium, and across the present valley of the Rhine into Westphalia. From the western headlands of Ireland this calcareous formation can thus be traced eastward for a distance of 750 English miles into the heart of Europe. It then begins to pass into a series of shales and sandstones, which no doubt represent the same proximity to shore as the similar strata in the north of England and Scotland. In Silesia, and still much further eastwards in central and southern Russia, representatives of the Carboniferous Limestone appear, but interstratified, as in Scotland, with coal-bearing strata. Traces of the same blending of marine and terrestrial conditions are found also in the north of Spain. But over central France, and eastwards through Bohemia and Moravia into the region of the Carpathians, the Coal-measures rest directly upon the older formations, most commonly upon gneiss and other crystalline rocks. It would appear that these tracts had remained above water during the time of the Carboniferous Limestone, but were gradually depressed during that of the Coal-measures.

In the north of France and Belgium the British type of the Carboniferous system is well shown. At the base lies a group of green, grey, and reddish shales and yellow sandstones, precisely similar in lithological character to parts of the Calciferous Sandstones of Scotland. They are well seen in some recent railway cuttings to the north of Boulogne, and also in the valley of the Meuse above Namur, lying upon the Psammites de Condroz or Upper Devonian beds. They are succeeded by the Carboniferous Limestone, which is subdivided into eight formations, having an aggregate thickness of 800 metres, and each characterized by its own assemblage of fossils. The horizon of the Millstone Grit is marked by the occurrence of certain alum-schists. The Coal-measures of this area have been referred to in the article COAL.[2]

The Saarbruck coal-field furnishes a good example of that type of the Carboniferous system where the lower marine series is absent. It lies unconformably on Devonian rocks, and attains a thickness of more than 10,000 feet.[3] It is divided into the following groups of strata:—

2. Upper series, consisting at the top of red sandstones, below which come shales, sandstones, &c., with a few coal-seams—*Anthracosia*, *Estheria*.
1. Lower series, consisting of an upper group of red conglomerates, sandstones, clays, resting upon the great coal-bearing division. Abundant plants, with labyrinthodonts and insect remains.

Geinitz, drawing attention to the distribution of plants in the Saxon Coal-measures, remarks that a certain order can be observed in their appearance. He divides the strata accordingly into three zones, each marked by a characteristic assemblage of plants, and he believes that the classification can be applied in other countries.

3. The Fern Zone, marked by the profusion of its ferns (*Sphenopteris*, *Hymenophyllites*, *Schizopteris*, *Odontopteris*, *Neuropteris*, *Cyclopteris*, *Alethopteris*, *Caulopteris*). This is underlaid by
2. The Sigillaria Zone, containing many species of *Sigillaria*, also *Lepidodendron*, *Calamites*, *Asterophyllites*, and a few ferns.
1. The Lycopod Zone, abounding in *Sagenaria Veltheimiana*, with *Sphenopteris distans*, *Calamites transitionis*, &c.

The lowest of these zones (1) is compared by Geinitz with the Culm, that is, the sandy, shaly, and coal-bearing representative of the Carboniferous Limestone. To the east of the Rhine valley, as already mentioned, the true Carboniferous Limestone loses its normal character and assumes that of the Culm—a series of shales, sandstones, greywackes, and conglomerates, in which the abundant fauna of the limestone is reduced to a few mollusks (*Productus antiquus*, *P. latissimus*, *P. semireticulatus*, *Posidonomya Becheri*, *Goniatites sphæricus*, *Orthoceras striatulum*, &c.). The *Posidonomya* particularly characterizes certain dark shales known as Posidonia schists. About 50 species of plants have been obtained from the Culm, typical species being *Calamites transitionis*, *Sagenaria Veltheimiana*, *Stigmaria ficoides*, *Sphenopteris distans*, *Cyclopteris tenuifolia*. This flora bears a strong resemblance to that of the Calciferous Sandstones of Scotland.

NORTH AMERICA.—Rocks corresponding in geological position and the general aspect of their organic contents with the Carboniferous system of Europe are said to cover an area of more than 200,000 square miles in the United States and British North America. The following table shows the subdivisions which have been established among them:—

Carboniferous.	Coal-measures,—a series of sandstones, shales, ironstones, coals, &c., varying from 100 feet in the interior continental area to 4000 feet in Pennsylvania, and more than 8000 feet in Nova Scotia. The plant remains include forms of *Lepidodendron*, *Sigillaria*, *Stigmaria*, *Calamites*, ferns, and coniferous leaves and fruits. The animal forms embrace in the marine bands species of *Spirifer*, *Productus*, *Bellerophon*, *Nautilus*, &c. Among the shales and carbonaceous beds numerous traces of insect life have been obtained, comprising species related to the may-fly and cockroach. Spiders, scorpions, centipedes, limuloid crabs, and land snails like the modern *Pupa* have also been met with. The fish remains comprise teeth and ichthyodorulites of placoid genera, and a number of ganoids (*Eurylepis*, *Prodictes*, *Celacanthus*, *Megalichthys*, *Rhizodus*, &c.). Several labyrinthodonts occur, and true reptiles are represented by one saurian genus found in Nova Scotia, the *Eosaurus*.
	Millstone Grit,—a group of arenaceous and sometimes conglomeratic strata, with occasional coal-seams, only 25 feet thick in some parts of New York, but swelling out to 1500 feet in Pennsylvania.	
Sub-Carboniferous.	Chester group.—Limestones, shales and sandstones, sometimes 600 feet.	
	St Louis group.—Limestones with shale, in places 250 feet.	
	Keokuk group.—Limestone with chert layers and nodules.	
	Burlington group.—Limestone, in places with chert and hornstone, 25 to 200 feet.	
	Kinderhook group.—Sandstones, shales, and thin limestones, 100 to 200 feet, resting on the Devonian black shale.	

The sub-Carboniferous groups are mainly marine limestones, but contain here and there remains of the characteristic Carboniferous land vegetation. Crinoids of many forms abound in the limestones. A remarkable polyzoon, *Archimedes*, occurs in some of the bands. The brachiopods are chiefly represented by species of *Spirifer* and *Productus*; the lamellibranchs by *Myalina*, *Schizodus*, *Aviculopecten*, *Nucula*, *Pinna*, and others, the cephalopods by *Orthoceras*, *Nautilus*, *Goniatites*, *Gyroceras*, &c. The European genus of trilobite, *Phillipsia*, occurs. Numerous teeth and fin-spines of selachian fishes give a further point of resemblance to the European Carboniferous Limestone. Some of the rippled rain-pitted beds contain amphibian footprints—the earliest American forms yet known.

[1] Miall, *Brit. Assoc. Rep.*, 1873, p. 246.
[2] In the article COAL, vol. vi. p. 56, the coal basin of Hardinghem is said to be of Carboniferous Limestone age. This, which appeared to be the most probable view of a very obscure point, has been proved to be a mistake, as the strata are actually Coal-measures inverted in position, the same disturbance being characteristic of the south side of the basin of the Pas-de-Calais for a considerable distance. This is now so generally recognized that borings for coal in that basin through the Tertiary and Cretaceous formations are not necessarily stopped on reaching Devonian strata, as coal-seams have been discovered vertically below the older strata at considerable depths, *e.g.*, at Anschy en Boks. In another pit, at Courrières, the fact that the measures on the upper levels are inverted in position has been recently proved by the sinkings traversing the same seams in reverse order, *i.e.*, in their normal position in the lower workings. These facts have an important bearing on the question of the probable extension of the Coal-measures in the south-east of England. The discovery (in 1878) of Devonian strata at the moderate depth of 1400 feet in the centre of London, at Messrs Meux's brewery, is another interesting fact that bears out the views previously put forward by Mr Godwin Austen. (H. B.)

PERMIAN.

BRITAIN.—In England the Coal-measures are unconformably overlaid by a series of red sandstones, conglomerates, breccias, and marls, which at one time were grouped in one great formation as the New Red Sandstone, in contradistinction to the *Old* Red Sandstone lying below the Carboniferous system. They were likewise known as the Poikilitic series, from their mottled or variegated colours. They are now divided into two systems or groups of formations, the lower half being included in the Palæozoic series under the name of Permian (after Perm, a Russian province where they are well displayed), and the upper half being relegated to the Secondary series, and termed Trias.

The Permian system in England consists of the following subdivisions:—

		W. of England.	E. of England.
3. Upper...	Red sandstones, clays, and gypsum	600 ft.	50–100 ft.
2. Middle..	Magnesian limestone	10–30 ,,	600 ,,
	Marl slate		
1. Lower...	Red and variegated sandstone	3000 ,,	100–250 ,,
	Reddish-brown and purple sandstones and marls, with calcareous conglomerates and breccias of volcanic rocks		

From the thicknesses here given, it is evident that the Permian rocks have a very different development on the two sides of England. On the east side, from the coast of Northumberland southwards to the plains of the Trent, they consist chiefly of a great central mass of limestone. But on the west side of the Pennine Chain, and extending southwards into the central counties, the calcareous zone disappears, and we have a great accumulation of red, arenaceous, and gravelly rocks.

Lower.—This subdivision attains its greatest development in the vale of the Eden, where it consists of brick-red sandstones, with some beds of calcareous conglomerate or breccia, locally known as "brockram," derived from the waste of the Carboniferous Limestone. These red rocks extend across the Solway into the valleys of the Nith and Annan, in the south of Scotland, where they lie unconformably on the Lower Silurian rocks. Their breccias consist of fragments of the adjacent Silurian greywackes and shales, but near Dumfries some calcareous breccias or "brockrams" occur. These brecciated masses have evidently accumulated in small lakes or narrow fjords. Much further south, in Staffordshire, and in the districts of the Clent and Abberley Hills, the brecciated conglomerates in the Permian series attain a thickness of 400 feet. They have been shown by Ramsay to consist in large measure of volcanic rocks, grits, slates, and limestones, which can be identified with rocks on the borders of Wales. Some of the stones are 3 feet in diameter and show distinct striation. The same writer has pointed out that these Permian drift-beds cannot be distinguished by any essential character from modern glacial drifts, and he has no doubt that they were ice-borne, and, consequently, that there was a glacial period during the accumulation of the Lower Permian deposits of the centre of England.

Like red rocks in general the Lower Permian beds are almost barren of organic remains. Such as occur are indicative chiefly of terrestrial surfaces. Plant remains occasionally appear, such as *Cauleripites* (supposed to be of marine growth), *Lepidodendron dilatatum*, *Calamites*, *Sternbergia*, and fragments of coniferous wood. The cranium of a labyrinthodont (*Dasyceps*) has been obtained from the Lower Permian rocks at Kenilworth. Footprints referred to members of the same extinct order have been observed abundantly on the surfaces of the sandstones of Dumfriesshire, and also in the vale of the Eden.

Middle.—This subdivision is the chief repository of fossils in the Permian system. Its strata are not red, but consist of a lower zone of hard brown shale with occasional thin limestone bands (Marl Slate) and an upper thick mass of dolomite (Magnesian Limestone). The latter is the chief feature in the Permian development of the east of England. It corresponds with the Zechstein of Germany, as the Marl Slate does with the Kupfer-schiefer. It is a very variable rock in its lithological characters, being sometimes dull, earthy, fine-grained, and fossiliferous, in other places quite crystalline, and composed of globular, reniform, botryoidal, or other irregular concretions of crystalline and frequently internally radiated dolomite. Though the Magnesian Limestone runs as a thick persistent zone down the east of England it is represented on the Lancashire and Cheshire side by bright red and variegated sandstone covered by a thin group of red marls, with numerous thin courses of limestone, containing *Schizodus*, *Bakevellia*, and other characteristic fossils of the Magnesian Limestone.

The middle Permian division has yielded about 100 species belonging to 46 genera of fossils—a singularly poor fauna when contrasted with that of the Carboniferous system below. The brachiopods (9 genera, 21 species) include *Productus horridus*, *Camarophoria multiplicata*, *C. Schlotheimi*, *Strophalosia Goldfussi*, *Lingula Credneri*, and *Terebratula elongata*. The lamellibranchs number 16 genera and 31 species, among which *Schizodus Schlotheimi*, *Bakevellia tumida*, *B. antiqua*, *B. ceratophaga*, *Mytilus squamosus*, and *Arca striata* are characteristic. The univalves are represented by 11 genera and 26 species, including *Pleurotomaria* and *Turbo* as common genera. Fishes have been obtained chiefly in the marl slate to the number of 21 species belonging to 8 genera, of which *Palæoniscus* is the chief. These small ganoids are closely related to some which haunted the lagoons of the Carboniferous period.

Upper.—Murchison and Harkness have classed as Upper Permian certain red sandstones with thin partings of red shale, and an underlying band of red and green marls and gypsum. These rocks, seen at St Bees, near Whitehaven, resting on a magnesian limestone, have not yet yielded any fossils.

CONTINENTAL EUROPE.—The two types of the Permian system presented by the east and west sides of England reappear in different areas on the mainland of Europe. The eastern or Durham type is found in enormous masses of strata flanking the Harz Mountains, also in Thüringia, in Saxony, and in Bohemia. The western or Salopian type is found over many thousands of square miles in the north and east of Russia.

The German geologists, recognizing the remarkable two-fold character of its rocks, have called this system "Dyas," and have proposed to retain the term Permian to express the more simple type, such as is found in Russia and western England. They group the members of their Dyas as follows:—

Zechstein Group.	Anhydrite, gypsum, rock-salt, marl, dolomite, fetid shale and limestone. The amorphous gypsum is the chief member of this group; the limestone is sometimes full of bitumen.
	Crystalline granular (*Rauchwacke*) and fine sandy (*Asche*) dolomite (6 to 65 feet).
	Zechstein, an argillaceous thin-bedded compact limestone 15 to 30 (sometimes even 90) feet thick.
	Kupfer-schiefer—a black bituminous shale not more than about 2 feet thick.
	Zechstein, conglomerate, and calcareous sandstone.
Rothliegende Group.	Upper.—Conglomerates (quartz-porphyry conglomerate) and sandstone, with associated melaphyres and tuffs.
	Middle.—Red clays, shales, and fine shaly sandstones, with bands of quartz-conglomerate and earthy limestone. Melaphyre and porphyrite masses intercalated.
	Lower.—Shaly sandstones, shales (with bituminous bands), and conglomerates.

The name "Rothliegende" or "Rothtodtliegende" (red-layer or red-dead-layer) was given by the miners because their ores disappeared in the red rocks below the copper-bearing Kupfer-schiefer. The coarse conglomerates have been referred by Ramsay to a glacial origin, like those of the Abberley Hills. One of the most interesting features of the formation is the evidence of the contemporaneous

outpouring of great sheets of quartz-porphyry, granite-porphyry, porphyrite, and melaphyre, with abundant interstratifications of various tuffs, not infrequently enclosing organic remains. From the very nature of its component materials, the Rothliegende is comparatively barren of fossils, a few ferns, calamites, and remains of coniferous trees are found in it, particularly towards the base, where indeed they form, in the Mansfeld district, a coal-seam about 5 feet thick.

The plants, all of terrestrial growth, on the whole resemble generically the Carboniferous flora, but seem to be nearly all specifically distinct. They include forms of *Calamites* (*C. gigas*), *Asterophyllites*, and ferns of the genera *Sphenopteris*, *Alethopteris*, *Neuropteris*, *Odontopteris*, with well-preserved silicified stems of tree-ferns (*Psaronius*, *Tubicaulis*). The conifer *Walchia* (*W. piniformis*) is specially characteristic. Fish remains occur sparingly (*Amblypterus*, *Palæoniscus*, *Acanthodes*), and traces of labyrinthodonts (*Archegosaurus Decheni*) have been met with.

The Zechstein group is characterized by a suite of fossils like those of the Middle Permian of England. The Kupfer-schiefer contains numerous fish (*Palæoniscus Freieslebeni*, *Platysomus gibbosus*, &c.) and remains of plants (coniferous leaves and fruits and sea-weeds). This deposit is believed to have been laid down in some enclosed sea-basin, the waters of which, probably from the rise of mineral springs connected with some of the volcanic foci of the time, were so charged with metallic salts in solution as to become unfit for the continued existence of animal life. The dead fish, plants, &c., by their decay, gave rise to reduction and precipitation of these salts as sulphides, which thereupon enclosed and replaced the organic forms, and permeated the mud at the bottom. This old sea-floor is now the widely extended band of copper-slate which has so long and so extensively been worked along the flanks of the Harz. After the formation of the Kupfer-schiefer the area must have been once more covered by clearer water, for the Zechstein contains a number of organisms of which *Productus horridus*, *Spirifer undulatus*, *Strophalosia Goldfussi*, *Schizodus obscurus*, and *Fenestella retiformis* are common. Renewed unfavourable conditions are indicated by the dolomite, gypsum, and rock-salt which succeed. Professor Ramsay, reasoning upon such phenomena as developed in England, has connected them with the abundant labyrinthodont footprints and other evidences of shores and land, as well as the small number and dwarfed forms of the shells in the Magnesian Limestone, and has speculated on the occurrence of a long continental period in Europe, during one epoch of which a number of salt inland seas existed wherein the Permian rocks were accumulated. He compares these deposits to what may be supposed to be forming now in parts of the Caspian Sea.

North America.—The Permian system is hardly represented at all in this part of the globe. In Kansas certain red and green clays, sandstones, limestones, conglomerates, and beds of gypsum lie conformably on the Carboniferous syste , and contain a few genera and species of molluscs (*Bakewellia*, *Myalina*, &c,), which occur in the European Permian rocks.

III. SECONDARY OR MESOZOIC.

Triassic.

It has been already mentioned that the great mass of red rocks, which in England overlie the Carboniferous system, were formerly classed together as New Red Sandstone, but are now ranged in two systems. We have considered the lower of these under the name of Permian. The general facies of organic remains in that division is still decidedly Palæozoic. Its brachiopods and its plants connect it with the Carboniferous rocks below. Hence it is placed at the close of the long series of Palæozoic formations. When, however, we enter the upper division of the red rocks, though the general lithological characters remain very much as in the lower group, the fossils bring before us the advent of the great Mesozoic flora and fauna. This group therefore is put at the base of the Mesozoic or Secondary series. It is called Trias, because in Germany it consists of three well-marked subdivisions. But the old name, New Red Sandstone, is familiarly retained for it by many geologists in England. The term Trias, like Dyas, is unfortunately chosen, for it elevates a mere local character into an importance which it does not deserve. The threefold subdivision, though so distinct in Germany, disappears elsewhere.

Great Britain.—Triassic rocks occupy a large area of the low plains in the centre of England, ranging thence northwards along the flanks of the Carboniferous tracts to Lancaster Bay, and southwards by the head of the Bristol Channel to the south-east coast of Devonshire. They have been arranged in the following subdivisions:—

Rhætic	Penarth beds.—Red, green, and grey marls, and "White Lias."	
Upper Trias or Keuper.	New Red Marl.—Red and grey shales and marls, with beds of rock-salt and gypsum (*Estheria* and *Foraminifera*).	
	Lower Keuper Sandstone.—Thinly laminated micaceous sandstones and marls (waterstones) passing downwards into white, brown, or reddish sandstones, with a base of calcareous conglomerate or breccia.	
Middle	Wanting in England (Muschelkalk of Germany).	
Lower Trias or Bunter.	Upper Mottled Sandstone.—Soft bright-red and variegated sandstones, without pebbles.	
	Pebble beds.—Harder reddish-brown sandstones with quartzose pebbles, passing into conglomerate; with a base of calcareous breccia.	
	Lower Mottled Sandstone.—Soft bright-red and variegated sandstone, without pebbles.	

like the Permian red rocks below, the sandstones and marls of the Triassic series are almost barren of organic remains. Hence the subdivisions in the foregoing table are based on mineral characters, and could not therefore be relied on as a guide in districts outside of the English area. Indeed, extraordinary differences in the development of the different members of the series occur, even within that area, as may be seen from the subjoined table, which shows the variations in thickness from north-west to south-east:—

		Lancashire and W. Cheshire.	Stafford-shire.	Leicester-shire and Warwick-shire.
		Fct.	Feet.	Feet.
Keuper.	Red marl	3000	800	700
	Lower Keuper sandstone	450	200	150
Bunter.	Upper mottled sandstone	500	50–200	absent
	Pebble beds	500–750	100–300	0–100
	Lower mottled sandstone	200–500	0–100	absent

Hence we observe that, while towards the north-west the Triassic rocks attain a maximum depth of 5200 feet, they rapidly come down to a fifth or a sixth of that thickness as they pass towards the south-east. Recent borings in the south-eastern counties show that the Triassic rocks are there absent altogether. It is evident that the source of supply of the sediment lay towards the north. This is further borne out by the character of the pebble-beds. These are coarsest towards the north, and, besides local materials, contain abundant rolled pebbles of quartz which have evidently been derived from some previous conglomerate, probably from some of the Old Red Sandstone masses now removed or concealed The Trias everywhere rests unconformably on the rocks underneath it, so that, although the general physical conditions as regards climate, geography, and sedimentation, which prevailed in the Permian period still continued, great terrestrial movements had, in the meanwhile, taken place, whereby the Permian sediments were upraised and exposed to denudation. Hence the Trias rests now on Permian, now on Carboniferous, and sometimes even on Cambrian rocks. Moreover, the upper parts of the Triassic series overlap the lower, so that the Keuper groups come to rest directly on Permian or Carboniferous rocks.

One of the most interesting features in the English Trias is the occurrence of beds of rock-salt which have long been profitably worked. The uppermost subdivision of the Keuper, consisting of red marls, has a wide distribution, for it can be traced from the coast of Lancashire to the Bristol Channel, and covers a larger area of surface in the central counties than the rest of the Trias and the whole of the Permian sandstones combined. Even as far south as the

coast of Devonshire, it contains casts of the cubical spaces once occupied by crystals of common salt. But in Cheshire the salt occurs in two or more beds, of which the lower is sometimes upwards of 100 feet thick. It is a crystalline substance, usually tinged yellow or red from intermixture of clay and peroxide of iron, but is tolerably pure in the best part of the beds, where the proportion of chloride of sodium is as much as 98 per cent. Through the bright red marls with which the salt is interstratified there run bands of gypsum, somewhat irregular in their mode of occurrence, sometimes reaching a thickness of 40 feet and upwards. Thin seams of rock-salt likewise occur among the red marls. These facts point to the concentration and evaporation of salt lakes or inland seas.

The organic remains of the Trias are comparatively few, as the conditions for at least animal life must have been extremely unfavourable in the waters of the ancient Dead Sea wherein these red rocks were accumulated. The land possessed a vegetation which, from the few fragments yet known, seems to have consisted in large measure of cypress-like coniferous trees (*Voltzia*, *Walchia*), with calamites on the lower more marshy grounds. The red marl group contains in some of its layers numerous valves of the little crustacean *Estheria minuta*, and a solitary species of lamellibranch, *Pullastra arenicola*. A number of teeth, spines, and sometimes entire skeletons of fish have been obtained (*Dipteronotus cyphus*, *Palæoniscus superstes*, *Hybodus Keuperi*, *Acrodus minimus*, *Sphenonchus minimus*, *Lophodus*, &c.). The bones, and still more frequently the footprints, of labyrinthodont and even of saurian reptiles occur in the Keuper beds—*Labyrinthodon* (4 species), *Cladyodon Lloydii*, *Hyperodapedon*, *Palæosaurus*, *Teratosaurus*, *Thecodontosaurus*, *Rhyncosaurus*, and footprints of *Cheirotherium*. The remains of a small marsupial (*Microlestes*) have likewise been discovered.

Rhætic.—At the top of the Red Marl certain thin-bedded strata form a gradation upwards into the base of the Jurassic system. As their colours are grey and blue, and contrast with the red marls on which they repose conformably, they were formerly classed without hesitation in the Jurassic series. Egerton, however, showed that, from the character of their included fish remains, they had more palæontological affinity with the Trias than with the Lias. Subsequent research, particularly among the Rhætic Alps and elsewhere on the Continent, brought to light a great series of strata of intermediate characters between the Trias and Lias. These results led to renewed examination of the so-called beds of passage in England, which were found to be truly representative of the massive formations of the Tyrolese and Swiss Alps. They are therefore now classed as Rhætic, and considered as the uppermost member of the Trias, but offering evidence of the gradual approach of the physical geography and characteristic fauna and flora of the Jurassic period.

The Rhætic beds extend as a continuous though very thin band at the top of the Trias, from the coast of Yorkshire across England to Lyme Regis on the Dorsetshire shores. They occur in scattered patches even up as far as Carlisle, and westwards on both sides of the Bristol Channel. Their thickness, on the average, is probably not more than 50 feet, though it rarely increases to 150 feet. They consist of thin-bedded grey and dark shales and clays, with bands of light-coloured limestone. One of their most important subdivisions is the so-called Bone-bed—a pyritous, micaceous, and occasionally rippled sandstone, sometimes in several bands, abounding in fish bones, teeth, coprolites, and other organic remains. The grey marly beds in the lower portion of the series have yielded remains of the *Microlestes Rhæticus*. Among the reptilian fossils are some precursors of the great forms which distinguished the Jurassic period (*Ichthyosaurus* and *Plesiosaurus*). The fishes include *Acrodus minimus*, *Ceratodus altus*, *Hybodus minor*, *Nemacanthus monilifer*, &c. Some of the lamellibranchs are specially characteristic; such are *Cardium Rhæticum*, *Avicula contorta*, *Pecten Valoniensis*, and *Pullastra arenicola*.

Professor Ramsay has drawn attention to the probable geographical changes recorded by the Triassic rocks of England. Connecting them with the earlier and similar Permian sandstones and marls he points out that the great Continental period which began with the Old Red Sandstone closed with the New Red Marl, and was characterized by the existence of great lakes, many of which must have been salt, and by the abundance of labyrinthodont life. The Triassic rocks were, doubtless, laid down in one of these salt lakes round the margins of which the labyrinthodonts left their footprints on the soft sand. In the Rhætic series we see how these inland basins were gradually invaded by the sea, which brought into the region of Britain the rich fauna of the Jurassic period.

Continental Europe.—The Trias is the most compactly distributed of all the geological formations of Europe. Its main area extends as a great basin from Basel down to the plains of Hanover, traversed along its centre by the course of the Rhine, and stretching from the flanks of the old high grounds of Saxony and Bohemia on the east across the Vosges mountains into France. This must have been a great inland sea, out of which the Harz mountains, and the high grounds of the Eifel, Hundsruck, and Taunus probably rose as islands. It may have extended up to the base of the Alps, for enormous masses of Triassic rocks now form part of these mountains. Traces of what were probably other basins occur eastward in the Carpathian district, along the southern front of the Alps, in the west and south of France, and over the eastern half of the Spanish peninsula. But these areas have been considerably obscured, sometimes by dislocation and denudation, sometimes by the overlap of more recent formations.

In the great German Triassic basin the deposits are as shown in the subjoined table.

Keuper.	Upper or Rhætic.—Grey sandy clays and fine-grained sandstones, containing *Equisetum*, *Asplenites*, and cycads (*Zamites*, *Pterophyllum*), sometimes forming thin seams of coal—*Cardium Rhæticum*, *Avicula contorta*, *Estheria minuta*, *Nothosaurus*, *Termatosaurus*, *Belodon*, and *Microlestes antiquus*.	
	Middle (Bunte Keupermergel, Gypskeuper).—Bright red and mottled marls, with beds of gypsum and rock-salt. In some places where sandstones appear they contain numerous plants (*Equisetum columnare*, *Taniopteris vittata*, *Pterophyllum*, &c.), and labyrinthodont and fish remains. 300 to 1000 feet.	
	Lower (Lettenkohle, Kohlenkeuper).—Grey sandstones and dark marls and clays, with abundant plants, sometimes forming thin seams of an earthy hardly workable coal (Lettenkohle). The plants include, besides those above mentioned, the conifers *Araucarozylon Thuringicum*, *Voltzia heterophylla*, &c Some of the shales are crowded with small ostracod crustacea (*Estheria minuta*). Remains of fish (*Ceratodus*) and of the *Mastodonsaurus Jægeri* have been obtained. About 230 feet.	
Muschelkalk.	Upper Limestone in thick beds with argillaceous partings.—It abounds in organic remains among which *Ceratites nodosus*, *Nautilus bidorsatus*, *Lima striata*, *Myophoria vulgaris*, *Trigonodus Sandbergeri*, *Terebratula vulgaris*, and *Encrinus liliiformis* are specially characteristic. It is a thoroughly marine formation, sometimes almost wholly made up of crinoid stems. 200 to 400 feet.	
	Middle Limestone and Anhydrite, consisting of dolomites with anhydrite, gypsum, and rock-salt. Nearly devoid of organic remains, though bones and teeth of saurians have been found. 200 to 400 feet.	
	Lower Limestone, consisting of limestones and dolomites, but on the whole poor in fossils, save in the limestone bands, some of which are full of *Terebratula vulgaris* and *Encrinus liliiformis*. 160 to 500 feet.	
Bunter.	Upper (Röth).—Red and green marls, with gypsum in the lower part. 250 to 300 feet.	
	Middle.—Coarse-grained sandstones, sometimes incoherent, with waxboards of *Estheria* shale.	
	Lower.—Fine reddish argillaceous sandstone, often micaceous and fissile, with occasional interstratifications of dolomite and of the marly oolitic limestone called "Rogenstein."	
	The Bunter division is usually barren of organic remains. The plants already known include *Equisetum arenaceum*, one or two ferns, and a few conifers (*Albertia* and *Voltzia*). The lamellibranch *Myophoria costata* is found in the upper division all over Germany. Numerous footprints occur on the sandstones, and the bones of labyrinthodonts as well as of fish have been obtained.	

The Trias attains an enormous development in the eastern Alps, where it bears evidence of having been accumulated under very different conditions from those of the Trias in Germany. The great thickness of its limestones, and their unequivocally marine organisms, show that it must have accumulated in opener water, which remained clear and comparatively free from inroads of sandy and muddy sediment. It possesses, moreover, a high interest as being a massive formation of marine origin formed between Permian