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The geographical evolution of Europe

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THE SCOTTISH GEOGRAPHICAL MAGAZINE.

THE GEOGRAPHICAL EVOLUTION OF EUROPE.

Read before the Society, at Edinburgh, 9th March 1886.

BY PROFESSOR JAMES GEIKIE, LL.D., F.R.S.

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It is one of the commonplaces of geology that the Present is built up out of the ruins of the Past. Every rock beneath our feet has its story of change to tell us. Mountains, valleys, and plains, continents and islands, have passed through vicissitudes innumerable, and bear within them the evidence of a gradual development or evolution. Looking back through the vista of the past one sees the dry lands gradually separating from the ocean, and gathering together into continental masses according to a definite plan. It is this slow growth, this august evolution, carried on through countless æons, which most impresses the student of physical geology. The earth seems for the time as if endowed with life, and like a plant or animal to pass through its successive stages of development until it culminates in the present beautiful world. This conception is one of comparatively recent growth in the history of geological science. Hutton, the father of physical geology, had indeed clearly perceived that the dry lands of the globe were largely composed of the *débris* of former land-surfaces—that there had been alternate elevations and depressions of the earth's crust, causing now sea and now land to predominate over given areas. But the facts known in his day could not possibly have suggested those modern ideas of geographical evolution, which are the outcome of the multifarious observation and research of later years. It is to Professor Dana, the eminent American geologist, that we are indebted for the first clear enunciation of the views which I am now about to illustrate. According to him the great oceanic basins and conti-

mental ridges are of primeval antiquity—their origin is older than that of our oldest sedimentary formations. It is not maintained that the present lands have always continued above the level of the sea. On the contrary, it can be proved that many oscillations of level have taken place within each continental area, by which the extent and outline of the land have been modified again and again. Notwithstanding such changes, however, the great continental ridges would appear to have persisted from the earliest geological times as dominant elevations of the earth's crust. Some portions of these, as Dana remarks, may have been submerged for thousands of feet, but the continents have never changed places with the oceans.

I shall presently indicate the nature of the evidence by which it is sought to prove the vast age of our continental masses, but before doing so it will be well to give an outline of the facts which go to show that the oceanic depressions of the globe are likewise of primeval antiquity.

The memorable voyage of the *Challenger* has done much to increase our knowledge of the deep seas and the accumulations forming therein. The researches of the scientific staff of the expedition, and more particularly those of Mr. Murray, have indeed given a new impulse to the study of the larger questions of physical geology, and have lent strong support to the doctrine of the permanence of the oceanic basins and continental ridges. One of the most important facts brought before our attention by Mr. Murray is the absence of any land-derived materials from the sediments now gathering in the deeper abysses of the ocean. The coasts of continents and continental islands are strewn, as every one knows, with the wreck of the land—with gravel, sand, and mud, derived from the demolition of our rocks and soils. The coarser *débris* accumulates upon beaches and in shallow littoral waters, while the finer materials are swept further out to sea by tidal and other currents—the sediment being gradually sifted as it is borne outwards into deeper water, until only the finest mud and silt remain to be swept forward. As the floor of the ocean shelves down to greater depths the transporting power of currents gradually lessens, and finally land-derived sediment ceases to appear. Such terrigenous materials may be said to extend from the littoral zone down to depths of 2000 feet and more, and to a distance of 60 to 300 miles from shore. They are confined, therefore, to a comparatively narrow belt round the margins of continents and islands. And thus there are vast regions of the oceanic depressions over which no terrigenous or land-derived materials are accumulating. Instead of these we meet with a remarkable red clay and various kinds of ooze, made up largely of the shells of foraminifera, pelagic mollusca, and radiolarians, and the frustules of diatoms. The red clay is the most widely distributed of abysmal deposits. Indeed, it seems to form a certain proportion of all the deep-sea organic oozes, and may be said, therefore, to exist everywhere in the abysmal regions of the oceanic basins. It is extremely fine-grained, and owes its deep brown or red colour to the presence of the oxides of manganese and iron. Scattered through the deposit occur particles of

various minerals of volcanic origin, together with lapilli and fragments of pumice, *i.e.* volcanic *ejectamenta*. Such materials may have been thrown out from terrestrial volcanoes and carried by the winds or floated by currents until they became water-logged and sank; or they may to some extent be the relics of submarine eruptions. Whatever may have been their immediate source, they are unquestionably of volcanic origin, and are not associated with any truly terrigenous sediment. The red clay is evidently the result of the chemical action of sea-water on volcanic products; and many facts conspire to show that its formation is an extremely slow process. Thus, remains of vertebrates, consisting of the ear-bones of whales, beaks of ziphius, and teeth of sharks are often plentifully present, and there is no reason to suppose, as MM. Murray and Renard point out, that the parts of the ocean where these remains occur are more frequented by whales and sharks than other regions where similar relics are rarely or never dredged up. Of these remains some have all the appearance of having lain upon the sea-bottom for a very long time, for they belong to extinct species, and are either partially coated or entirely surrounded with thick layers of manganese-iron. In the same red clay occur small metallic spherules which are of cosmic origin—in other words, meteoric dust. The accumulation of all these substances in such relatively great abundance shows us that the oceanic basins have remained unchanged for a vast period of time, and assures us that the formation of the abysmal red clay is extremely slow.

When we come to examine the rocks which enter into the framework of our continents, we find that these may be roughly classed under these heads:—

1st, Terrestrial and Aqueous Rocks.

2d, Igneous or Volcanic Rocks.

3d, Crystalline Schists.

By far the largest areas of land are composed of rocks belonging to the first class. These consist chiefly of the more or less indurated sediments of ancient rivers, lakes, and seas—namely, conglomerate, sandstone, shale, limestone, etc. And now and again, interstratified with such aqueous beds, we meet with rocks of terrestrial origin, such as lignite, coal, and the *débris* of former glacial action. Now, most of our aqueous rocks have been accumulated in the sea, and thus we arrive at the conclusion that the present continental areas have from time to time been largely submerged—that the sea has frequently covered what are now the dry lands of the globe. But one remarkable fact stands out, and it is this: Nowhere amongst the sedimentary rocks of the earth's crust do we meet with any ancient sediments which can be likened to the red clay now slowly accumulating in the deeper abysses of the ocean. There are no rocks of abysmal origin. Many of our limestones have undoubtedly formed in deep, clear water, but none of these is abysmal. Portions of Europe may now and again have been submerged for several thousand feet, but no part of this or any other continent, so far as we yet know, has within geological time been depressed to depths comparable to those

of the present oceanic basins. Nay, by far the larger portions of our marine formations have accumulated in comparatively shallow water—sandstones and shales (sand and mud) being by far the most common kinds of rock that we encounter. In short, aqueous strata have, as a rule, been deposited at no great depth and at no great distance from dry land; the rocks are built up mostly of terrigenous material; and even the purer limestones and chalks, which we may suppose accumulated in seas of moderate depth, not infrequently contain some terrestrial relic which has been drifted out to sea, and afford other evidence to show that the nearest land was never very far away. Followed along their outcrop such rocks sooner or later become mixed and interbedded with ordinary sedimentary matter. Thus, for example, the thick carboniferous limestone of Wales and the Midlands of England must have accumulated in the clear water of a moderately deep sea. But when this limestone is traced north into Northumberland it begins to receive intercalations of sandstone and shale, which become more and more important, until in Scotland they form by much the larger portion of the series—the enormous thick limestones of the south being represented by only a few inconsiderable beds, included, along with seams of ironstone and coal, in a thick succession of sandstones and shales.

Of the igneous rocks and the crystalline schists I need not speak at present, but I shall have something to say about them before I have done.

Having learned that no truly abysmal rocks enter into the composition of our continents, of what kind of rocks, we may ask, are the islands composed? Well, some of those islands are built up of precisely the same materials as we find in the continents. This is the case with most islands which are not separated from continental areas by profoundly deep seas. Thus our own islands with their numerous satellites are geologically one with the adjacent continent. Their present separation is a mere accident. Were the European area, with the adjacent sea-bed, to be elevated for a few hundred feet we should find that Britain and Ireland form geologically part and parcel of the continent. And the same is the case with Nova Zembla and Spitzbergen in the north, and with the Mediterranean islands in the south. There is another large class of islands, however, which are characterised by the total absence of any of those sedimentary rocks of which, as I have just said, our continents and continental islands are chiefly built up. The islands referred to are scattered over the bosom of the great ocean, and are surrounded by profoundly deep water. Some are apparently composed entirely of coral, others are of volcanic origin, and yet others are formed partly of volcanic rock and partly of coral. Thus we have two distinct kinds of island:—

1st, Islands which have at one time evidently been connected with adjacent continents, and which are therefore termed *continental islands*; and

2d, *Oceanic islands*, which rise, as it were, from profound depths in the sea, and which have never formed part of the continents.

The fauna and flora of the former class agree with those of the neighbouring continents, although some modifications are met with, especially when the insulation has been of long standing. When such has been the case the species of plants and animals may be almost entirely distinct. Nevertheless, such ancient continental islands agree with those which have been separated in more recent geological times, in containing both indigenous amphibians and mammals. Oceanic islands, on the other hand, contain no indigenous mammals or amphibians, their life consisting chiefly of insects and birds, and usually some reptiles,—just such a fauna as might have been introduced by the influence of winds and oceanic currents carrying driftwood.

Such facts, as have now been briefly summarised, point clearly to the conclusion that the oceanic basins and continental areas are of primeval antiquity. All the geological facts go to prove that abysmal waters have never prevailed over the regions now occupied by dry land; nor is there any evidence to show that continental land-masses ever existed in what are now the deepest portions of the ocean. The islets dotted over the surface of the Pacific and the other great seas are not the relics of a vast submerged continent. They are either the tops of submarine volcanic mountains, or they are coral structures founded upon the shoulders of degraded volcanoes and mountain-chains, and built up to the surface by the indefatigable labours of the humble polyp. We come then to the general conclusion that oceanic basins and intervening continental ridges are great primeval wrinkles in the earth's crust—that they are due to the sinking down of that crust upon the cooling and contracting nucleus. These vast wrinkles had come into existence long before the formation of our oldest geological strata. All our rocks may, in short, be looked upon as forming a mere superficial skin covering and concealing the crystalline materials which no doubt formed the original surface of the earth's crust.

Having premised so much, let me now turn to consider the geological history of our own continent, and endeavour to trace out the various stages in its evolution. Of course I can only do so in a very brief and general manner; it is impossible to go into details. We shall find, however, that the history of the evolution of Europe, even when sketched in meagre outline, is one full of instruction for students of physical geography, and that it amply bears out the view of the permanency of the greater features of the earth's surface.

The oldest rocks that we know of are the crystalline schists and gneiss, belonging to what is called the Archæan system. The origin of these rocks is still a matter of controversy—some holding them to be in large part the chemical precipitates of a primeval ocean, others maintaining that they are altered or metamorphosed rocks of diverse origin, a large proportion having consisted originally of aqueous or sedimentary rocks, such as sandstone and shale; while not a few are supposed to have been originally eruptive igneous rocks. According to the first of these views, therefore, the Archæan rocks represent the earliest sediments deposited

over the continental ridges. It is supposed that here and there those ridges rose above the surface of what may have been a boiling or highly-heated ocean, from whose waters copious chemical precipitations took place, while gravel and shingle gathered around the shores of the primeval lands. According to the opposing view, however, the Archæan rocks were probably accumulated under normal conditions. They consist for the most part, it is contended, of sediment washed down from some ancient land-surface, and distributed over the floor of an old sea, just as sediments are being transported and deposited in our own day. Their present crystalline character is attributed to subsequent changes, superinduced by heat and pressure, at a time when the strata in question were deeply buried under later formations, which have since been washed away. Probably this latter view, with some modification, will eventually prevail; but the origin of the Archæan rocks is a question which need not concern us at present. All I shall say about them is simply this—that they are *bedded*; that they must have been laid down originally in approximately horizontal layers; and that since the time of their formation, they have been tilted up, squeezed, crushed, and convoluted in the most remarkable manner. Whatever may have been their origin, geologists are agreed that the earliest land-surfaces, of the former existence of which we can be quite certain, were composed of Archæan rocks. And this brings us to the beginning of reliable geological history.

All subsequent geological time—that, namely, of which we have any record preserved in the fossiliferous strata—is divided into four great eras, namely the Palæozoic, the Mesozoic, the Cainozoic, and the Post-Tertiary eras, each of which embraces various periods, as follows:—

Post-Tertiary	{	Recent.
		Pleistocene.
		Pliocene.
Tertiary or	{	Miocene.
Cainozoic		Oligocene.
		Eocene.
Secondary or	{	Cretaceous.
Mesozoic		Jurassic.
		Triassic.
		Permian.
Primary or	{	Carboniferous.
Palæozoic		Devonian and Old Red Sandstone.
		Silurian.
		Cambrian.
Archæan,		Fundamental Gneiss.

Leaving the Archæan, we find that the next oldest strata are those which were accumulated during the Cambrian period, to which succeeded the Silurian, the Devonian and Old Red Sandstone, the Carboniferous,

and the Permian periods—all represented by great thicknesses of strata, which overspread wide regions.

Now, at the beginning of the Cambrian period, we have evidence to show that the primeval continental ridge was still largely under water, the dry land being massed chiefly in the north. At that distant date a broad land-surface extended from the Outer Hebrides north-eastwards through Scandinavia, Finland, and Northern Russia. How much further north and north-west of the present limits of Europe that ancient land may have spread we cannot tell, but it probably occupied wide regions which are now submerged in the shallow waters of the Arctic Ocean. In the north of Scotland a large inland sea or lake existed in Cambrian times, and there is some evidence to suggest that similar lacustrine conditions may have obtained in the Welsh area at the beginning of the period. South of the northern land lay a shallow sea covering all Middle and Southern Europe. That sea, however, was dotted here and there with a few islands of Archæan rocks, occupying the site of what are now some of the hills of Middle Germany, such as the Riesengebirge, the Erzgebirge, the Fichtelgebirge, etc., and possibly some of the Archæan districts of France and the Iberian peninsula.

The succeeding period was one of eminently marine conditions, the wide distribution of Silurian strata showing that during the accumulation of these, enormous tracts of our continent were overflowed by the sea. None of these deposits, however, is of truly oceanic origin. They appear for the most part to have been laid down in shallow seas, which here and there may have been moderately deep. During the formation of the Lower Silurian the whole of the British area, with the exception perhaps of some of the Archæan tracts of the north-west, seems to have been under water. The submergence had commenced in Cambrian times, and was continued up to the close of the Lower Silurian period. During this long-continued period of submergence volcanic activity manifested itself at various points—our country being represented at that time by groups of volcanic islands, scattered over the site of what is now Wales, and extending westward into the Irish region, and northward into the districts of Cumberland and South Ayrshire. Towards the close of the Lower Silurian period considerable earth-movements took place, which had the effect of increasing the amount of dry land, the most continuous mass or masses of which still occupied the northern and north-western part of our continent. In the beginning of Upper Silurian times a broad sea covered the major portion of Middle and probably all Southern Europe. Numerous islands, however, would seem to have existed in such regions as Wales; and the various tracts of older Palæozoic and Archæan rocks of South Germany. Many of these islands, however, were partially and some entirely submerged before the close of Silurian times.

The next great period—that, namely, which witnessed the accumulation of the Devonian and Old Red Sandstone strata—was in some respects strongly contrasted to the preceding period. The Silurian rocks, as I

have said, are eminently marine. The Old Red Sandstones, on the other hand, appear to have been accumulated chiefly in great lakes or inland seas, and they betoken therefore the former existence of extensive lands, while the contemporaneous Devonian strata are of marine origin. Towards the close of the Upper Silurian period, then, we know that considerable upheavals ensued in Western and North-western Europe, and wide stretches of the Silurian sea-bottom were converted into dry land. The geographical distribution of the Devonian in Europe, and the relation of that system to the Silurian, show that the Devonian sea did not cover so broad an expanse as that of the Upper Silurian. The sea had shallowed, and the area of dry land had increased when the Devonian strata began to accumulate. In trying to realise the conditions that obtained during the formation of the Devonian and Old Red Sandstone, we may picture to ourselves a time when the Atlantic extended eastwards over the south of England and the north-east of France, and occupied the major portion of Central Europe, sweeping north-east into Russia, and how much further we cannot tell. North of that sea stretched a wide land-surface, in the hollows of which lay great lakes or inland seas, which seem now and again to have had communication with the open ocean. It was in these lakes that the Old Red Sandstone was accumulated, while the Devonian or marine rocks were formed in the wide waters lying to the south. Submarine volcanoes were active at that time in Germany; and similarly in Scotland numerous volcanoes existed, such as those of the Sidlaw Hills and the Cheviots.

The Carboniferous system contains the record of a long and complex series of geographical changes, but the chief points of importance in the present rapid review may be very briefly summed up. In the earlier part of the period marine conditions prevailed. Thus we find evidence to show that the sea extended further north than it did during the preceding Devonian period. During the formation of the mountain limestone, a deep sea covered the major portion of Ireland and England, but shallowed off as it entered the Scottish area. A few rocky islets were all that represented Ireland and England at that time. Passing eastwards, the Carboniferous sea appears to have covered the low grounds of Middle Europe and enormous tracts in Russia. The deepest part of the sea lay over the Anglo-Hibernian and Franco-Belgian areas; towards the east it became shallower. Probably the same sea swept over all Southern Europe, but many islands may have diversified its surface, as in Brittany and Central France, in Spain and Portugal, and in the various areas of older Palæozoic and Archæan rocks in Central and South-east Europe. In the later stages of the Carboniferous period, the limits of the sea were much circumscribed, and wide continental conditions supervened. Enormous marshes, jungles, and forests now overspread the newly-formed lands. Another feature of the Carboniferous was the great number of volcanoes—submarine and subaërial—which were particularly abundant in Scotland, especially during the earlier stages of the period.

The rocks of the Permian period seem to have been deposited chiefly

in closed basins. When, owing to the movement of elevation or upheaval which took place in late Carboniferous times, the carboniferous limestone sea had been drained away from extensive areas in Central Europe, wide stretches of sea still covered certain considerable tracts. These, however, as time went on, were eventually cut off from the main ocean and converted into great salt lakes. Such inland seas overspread much of the low-lying tracts of Britain and Middle Germany, and they also extended over a broad space in the north-east of Russia. It was in these seas that the Permian strata were accumulated. The period, it may be added, was marked by the appearance of volcanic action in Scotland and Germany.

So far, then, as our present knowledge goes, that part of the European continent which was the earliest to be evolved lay towards the north-west and north. All through the Palæozoic era a land-surface would seem to have endured in that direction—a land-surface from the denudation or wearing down of which the marine sedimentary formations of the bordering regions were derived. But when we reflect on the great thickness and horizontal extent of those sediments, we can hardly doubt that the primeval land must have had a much wider range towards the north and north-west than is the case with modern Europe. The lands from which the older Palæozoic marine sediments of the British Islands and Scandinavia were obtained must, for the most part, be now submerged. In later Palæozoic times land began to extend in the Spanish peninsula, Northern France, and Middle Europe, the denudation of which doubtless furnished materials for the elaboration of the contemporaneous strata of those regions. Southern Europe is so largely composed of Mesozoic and Cainozoic rocks, that we can say very little as to the condition of that area in Palæozoic times, but the probabilities are that it continued for the most part under marine conditions. In few words, then, we may conclude that while after Archæan times dry land prevailed in the north and north-west, marine conditions predominated further south. Ever and anon, however, the sea vanished from wide regions in Central Europe, and was replaced by terrestrial and lacustrine conditions. Further, as none of the Palæozoic marine strata indicates a deep ocean, but all consist for the most part of accumulations formed at moderate depths, it follows that there must have been general subsidence of our area to allow of their successive deposition—a subsidence, however, which was frequently interrupted by long pauses, and sometimes by movements in the opposite direction.

The first period of the Mesozoic era, namely, the Triassic, was characterised by much the same kind of conditions as obtained towards the close of Palæozoic times. A large inland sea then covered a considerable portion of England, and seems to have extended north into the south of Scotland, and across the area of the Irish Sea into the north-east of Ireland. Another inland sea extended westward from the Thüringerwald across the Vosges into France, and stretched northwards

from the confines of Switzerland over what are now the low grounds of Holland and Northern Germany. In this ancient sea the Harz Mountains formed a rocky island. While terrestrial and lacustrine conditions thus obtained in Central and Northern Europe, an open sea existed in the more southerly regions of the continent. Towards the close of the period submergence ensued in the English and German areas, and the salt lakes became connected with the open sea.

During the Jurassic period the regions now occupied in Britain and Ireland by the older rocks appear to have been chiefly dry land. Scotland and Ireland, for the most part, stood above the sea-level, while nearly all England was under water—the hills of Cumberland and Westmoreland, the Pennine chain, Wales, the heights of Devon and Cornwall, and a ridge of Palæozoic rocks which underlies London being the chief lands in South Britain. The same sea overflowed an extensive portion of what is now the continent. The older rocks in the north-west and north-east of France, and the central plateau of the same country, formed dry land; all the rest of that country was submerged. In like manner the sea covered much of Eastern Spain. In Middle Europe it overflowed nearly all the low grounds of North Germany, and extended far east into the heart of Russia. It occupied the site of the Jura Mountains, and passed eastward into Bohemia, while on the south side of the Alps it spread over a large part of Italy, extending eastwards so as to submerge a broad area in Austro-Hungary and the Turkish provinces. Thus the northern latitudes of Europe continued to be the site of the chief land-masses, what are now the central and southern portions of the continent being a great archipelago with numerous islands, large and small.

The Jurassic rocks, attaining as they do a thickness of several thousand feet, point to very considerable subsidence. The movement, however, was not continuous, but ever and anon was interrupted by pauses. Taken as a whole, the strata appear to have accumulated in a comparatively shallow sea, which, however, was sufficiently deep in places to allow of the growth, in clear water, of coral reefs.

Towards the close of the Jurassic period a movement of elevation ensued, which caused the sea to retreat from wide areas, and thus, when the Cretaceous period began, the British region was chiefly dry land. Middle Europe would seem also to have participated in this upward movement. Eventually, however, subsidence again ensued. Most of what are now the low grounds of Britain were submerged, the sea stretching eastwards over a vast region in Middle Europe, as far as the slopes of the Urals. The deepest part of this sea, however, was in the west, and lay over England and Northern France. Further east, in what are now Saxony and Bohemia, the waters were shallow, and gradually became silted up. In the Mediterranean basin a wide open sea existed, covering large sections of Eastern Spain and Southern France, overflowing the site of the Jura Mountains, drowning most of the Alpine lands, the Italian peninsula, the eastern borders of the Adriatic, and Greece. In short,

there are good grounds for believing that the Cretaceous Mediterranean was not only much broader than the present sea, but that it extended into Asia, overwhelming vast regions there, and communicated with the Indian Ocean.

Summing up what we know of the principal geographical changes that took place during the Mesozoic era, we are impressed with the fact that, all through those changes, a wide land-surface persisted in the north and north-west of the European area, just as was the case in Palæozoic times. The highest grounds were the Urals and the uplands of Scandinavia and Britain. In Middle Europe the Pyrenees and the Alps were as yet inconsiderable heights, the loftiest lands being those of the Harz, the Riesengebirge, and other regions of Palæozoic and Archæan rocks. The lower parts of England and the great plains of Central Europe were sometimes submerged in the waters of a more or less continuous sea; but ever and anon elevation ensued, and the sea was divided, as it were, into a series of great lakes. In the south of Europe a Mediterranean Sea would appear to have endured all through the Mesozoic era—a Mediterranean of considerably greater extent, however, than the present. Thus we see that the main features of our continent were already clearly outlined before the close of the Cretaceous period. The continental area then, as now, consisted of a wide belt of high ground in the north, extending roughly from south-west to north-east; south of this a vast stretch of low grounds, sweeping from west to east up to the foot of the Urals, and bounded on the south by an irregular zone of elevated land having approximately the same trend; still further south, the maritime tracts of the Mediterranean basin. During periods of depression the low grounds of Central Europe were invaded by the sea, and the Mediterranean at the same time extended north over many regions which are now dry land. It is in these two low-lying tracts, therefore, and the country immediately adjoining them, that the Mesozoic strata of Europe are chiefly developed.

A general movement of upheaval supervened at the close of the Cretaceous period, and the sea which, during that period, overflowed so much of Middle Europe had largely disappeared before the beginning of Eocene times. The southern portions of the continent, however, were still mostly under water, while great bays and arms of the sea extended northwards now and again into Central Europe. On to the close of the Miocene period, indeed, Southern and South-eastern Europe consisted of a series of irregular straggling islands and peninsulas washed by the waters of a genial sea. Towards the close of early Cainozoic times, the Alps, which had hitherto been of small importance, were greatly upheaved, as were also the Pyrenees and the Carpathians. The floor of the Eocene sea in the Alpine region was ridged up for many thousands of feet, its deposits being folded, twisted, inverted, and metamorphosed. Another great elevation of the same area was effected after the Miocene period, the accumulations of that period now forming considerable mountains along the northern flanks of the Alpine chain. Notwithstanding these gigantic

elevations in South-Central Europe—perhaps in consequence of them,—the low-lying tracts of what is now Southern Europe continued to be largely submerged, and even the middle regions of the continent were now and again occupied by broad lakes which sometimes communicated with the sea. In Miocene times, for example, an arm of the Mediterranean extended up the Rhone valley, and stretched across the north of Switzerland to the basin of the Danube. After the elevation of the Miocene strata these inland stretches of sea disappeared, but the Mediterranean still overflowed wider areas in Southern Europe than it does in our day. Eventually, however, in late Pliocene times, the bed of that sea experienced considerable elevation, newer Pliocene strata occurring in Sicily up to a height of 3000 feet at least. It was probably at or about that period that the Black Sea and the Sea of Asov retreated from the wide low grounds of Southern Russia, and that the inland seas and lakes of Austria-Hungary finally vanished.

The Cainozoic era is distinguished in Europe for its volcanic phenomena. The grandest eruptions were those of Oligocene times. To that date belong the basalts of Antrim, Mull, Skye, the Farøe Islands, and the older series of volcanic rocks in Iceland. These basalts speak to us of prodigious fissure eruptions, when molten rock welled up along the lines of great cracks in the earth's crust, flooding wide regions, and building up enormous plateaus, of which we now behold the merest fragments. The ancient volcanoes of Central France, those of the Eifel country, and many other places in Germany, and the volcanic rocks of Hungary, are all of Cainozoic age; while, in the south of Europe, Etna, Vesuvius, and other Italian volcanoes date their origin to the later stages of the same great era.

Thus before the beginning of Pleistocene times all the main features of Europe had come into existence. Since the close of the Pliocene period there have been many great revolutions of climate; several very considerable oscillations of the sea-level have taken place, and the land has been subjected to powerful and long-continued erosion. But the greater contours of the surface which began to appear in Palæozoic times, and which in Mesozoic times were more strongly pronounced, had been fully evolved by the close of the Pliocene period. The most remarkable geographical changes which have taken place since then have been successive elevations and depressions, in consequence of which the area of our continent has been alternately increased and diminished. At a time well within the human period our own islands have been united to themselves and the continent, and the dry land has extended north-west and north, so as to include Spitzbergen, the Farøe Islands, and perhaps Iceland. On the other hand, our islands have been within a recent period largely submerged.

The general conclusion, then, to which we are led by a review of the greater geographical changes through which the European continent has passed, is simply this—that the substructure upon which all our sedimentary strata repose is of primeval antiquity. Our dry lands are built

up of rocks which have been accumulated over the surface of a great wrinkle of the earth's crust. There have been endless movements of elevation and depression, causing minor deformations, as it were, of that wrinkle, and inducing constant changes in the distribution of land and water; but no part of the continental ridge has ever been depressed to an abysmal depth. The ridge has endured through all geological time. We can see also that the land has been evolved according to a definite plan. Certain marked features begin to appear very early in Palæozoic times, and become more and more pronounced as the ages roll on. All the countless oscillations of level, all the myriad changes in the distribution of land and water, all the earthquake disturbances and volcanic eruptions, —in a word, all the complex mutations to which the geological record bears witness,—have had for their end the completion of one grand design.

A study of the geological structure of Europe—an examination of the manner in which the highly folded and disturbed strata are developed—throws no small light upon the origin of the larger or dominant features of our continent. The most highly convoluted rocks are those of Archæan and Palæozoic age, and these are developed chiefly in the north-western and western parts of the continent. Highly contorted strata likewise appear in all the mountain-chains of Central Europe—some of the rocks being of Palæozoic, while others are of Mesozoic and Cainozoic age. Leaving these mountains for the moment out of account, we find that it is along the western and north-western sea-board where we encounter the widest regions of highly disturbed rocks. The Highlands of Scandinavia and Britain are composed, for the most part, of highly flexed and convoluted rocks, which speak to titanic movements of the crust; and similar much crushed and tilted rock-masses occur in North-west France, in Portugal, and Western Spain. But when we follow the highly folded Palæozoic strata of Scandinavia into the low grounds of the great plains, they gradually flatten out, until in Russia they occur in undisturbed horizontal positions. Over thousands of square miles in that country the Palæozoic rocks are just as little altered and disturbed as strata pertaining to Mesozoic and Cainozoic times.

These facts can have but one meaning. Could we smooth out all the puckerings, creases, foldings, and flexures which characterise the Archæan and Palæozoic rocks of Western and North-western Europe, it is certain that these strata would stretch for many miles out into the Atlantic. Obviously they have been compressed and crumpled up by some force acting upon them from the west. Now, if it be true that the basin of the Atlantic is of primeval origin, then it is obvious that the sinking down of the crust within that area would exert enormous pressure upon the borders of our continental area. As cooling and contracting of the nucleus continued, subsidence would go on under the oceanic basin, depression taking place either slowly and gradually, during protracted periods, or now and again more or less suddenly. But whether gradually or suddenly effected, the result of the subsidence would be the same upon the borders of our

continent; the strata along the whole western and north-western margins of the European ridge would necessarily be flexed and disturbed. Away to the east, however, the strata, not being subject to the like pressure, would be left in their original horizontal positions.

Now it can be shown that the mountains of Scandinavia and the British Islands are much older than the Alps, the Pyrenees, and many other conspicuous ranges in Central and Southern Europe. Our mountains and those of Scandinavia are the mere wrecks of their former selves. Originally they may have rivalled—they probably exceeded—the Alps in height and extent. It is most likely, indeed, that the areas of Palæozoic rocks in France, Portugal, and Spain also attained mountainous elevations. But the principal upheaval of the western margins of our continent was practically completed before the close of the Palæozoic period, and since that time those elevated regions have been subjected to prodigious erosion, the later formations being in large measure composed of their *débris*. I do not, of course, wish it to be understood that there has been no upheaval affecting Western Europe since Palæozoic times. The tilted position of many of our Mesozoic strata clearly proves the contrary. But undoubtedly the main disturbances which produced the folding, fracturing, and contortion of the Palæozoic strata of Western Europe took place before the close of the Palæozoic period. The mountains of Britain and Scandinavia are amongst the oldest in Europe.

When we come to inquire into the origin of the mountains of Central Europe, we have little difficulty in detecting the chief factors in their formation. An examination of the Pyrenees, the Alps, and other hill-ranges having the same general trend shows us that they consist of flexed and convoluted rocks. They are, in short, mountains of elevation, ridged up by tangential thrusts. Of this we need not have the slightest doubt. If, for example, we approach the Alps from the low grounds of France, we observe the strata as we come towards the Jura beginning to undulate—the undulations becoming more and more marked, and passing into sharp folds and plications, until, in the Alps, the beds become twisted, convoluted, and bent back upon themselves in the wildest confusion. Now, speaking in general terms, we may say that similar facts confront us in connection with every true mountain-range in Central Europe. Let it be noted, further, that all those ranges have the same trend, which we may take to be approximately east and west, or nearly at right angles to the trend of the Palæozoic high grounds of Western and North-western Europe. Looked at broadly, our continental ridge may be said to be traversed from west to east by two broad depressions or troughs, separated by the intervening belt of higher grounds just referred to. The former of these troughs corresponds to the great Central Plain, which passes through the south of England, North-east France, the Low Countries, and Denmark, whence it sweeps east though Germany, and expands into the wide low grounds of Russia. The southerly trough or depression embraces the maritime tracts of the Mediterranean and the regions which that sea

covers. Such, then, are the dominant features of our continent, to which all others are of subordinate importance. Now it cannot be doubted that the two great troughs are belts of subsidence in the continental ridge itself. And their existence explains the origin of the mountain-ranges which separate them. We know that the northern trough is of extreme antiquity; it is older, at all events, than the Silurian period. Even at that distant date its southern limits were marked out by ridges of Archæan rocks, which seem to have formed islands in what is now Middle Germany, and probably also in Switzerland and Central France. The appearance of those Archæan rocks in Central Europe was doubtless due to a ridging up of the crust induced by those parallel movements of subsidence which produced the northern and southern troughs. The northern trough was probably always the shallower depression of the two, for we have evidence to show that, again and again in Mesozoic and later times, the seas which overflowed what are now the Central Plains of Europe were of less considerable depth than that which occupied the Mediterranean trough. As time rolled on, therefore, the northern trough eventually became silted up; but so low even now is the level of that trough that a very slight depression would cause the sea to inundate most extensive regions in Middle Europe.

In Cainozoic times, as we have seen, the last great elevation of the Alps was effected, an elevation which can hardly have been due to any other cause than the more or less abrupt depression of the earth's crust under the Mediterranean basin. The area of that sea is now much less considerable than it was in Tertiary times—a change due in part to silting up, but chiefly perhaps to the sinking down of its bed to profounder depths.

Thus we may conclude that from a very early period—a period antedating the formation of our oldest fossiliferous strata—the physical structure of our continent had already been planned. The dominant features of the primeval continental ridge are those which have endured through all geological time. They are the lines along which the beautiful lands in which we dwell have been constructed. Tilted and convoluted, broken and crushed by myriad earth-movements—scarred, furrowed, worn and degraded by the frosts, the rains, the rivers, and the seas of countless ages,—the rocks of our continent are yet eloquent of design. Where the ignorant sees nothing save confusion and discord, the thoughtful student beholds everywhere the evidence of a well-ordered evolution. Such is the conclusion to which we are led by all geological research.