therium, and other mammals. The second group (Sarmatian stage) consists of brackish-water beds showing the partial uprise of the bottom of the Vienna basin. It contains *Cerithium*, *Paludina*, *Rissoa*, with bones of dolphins, seals, turtles, and fish. The two uppermost divisions (Congeria stage and Belvedere stage), referred to the Pliocene series, are fresh-water formations, showing the final freshening and disappearance of the Miocene sea in the south-east of Europe.

In Styria and Carinthia the lower Aquitanian or Mediterranean stage bears witness in its plants and lignites to the proximity of land during its formation, while its shells are of fresh and brackish water genera. It has subsequently been upheaved, and the later Miocene strata lie unconformably on its edges. The subterranean movements east of the Alps culminated in the outpouring of enormous sheets of trachyte, andesite, propylite, and basalt in Hungary and along the flanks of the Carpathian chain into Transylvania. In Croatia the older Miocene marls, with their abundant land-plants, insects, &c., contain two beds of sulphur (the upper 4 to 16 inches thick, the under 10 to 15 inches), which have been worked at Radoboj. At Hrastreigg, Buchberg, and elsewhere, coal is worked in the Aquitanian stage in a bed sometimes 65 feet thick. In Transylvania, and along the base of the Carpathian mountains, extensive masses of rock-salt and gypsum are interstratified in the Tertiary formations. The largest of these, that of Parajd, has a maximum length of about 2500 yards, a breadth of 1800 yards, and a depth nearly 200 yards, and is estimated to contain 3500 millions of cubic feet of salt.

Greenland.—One of the most remarkable geological discoveries of recent times has been that of Miocene plant beds in North Greenland. Heer has described a flora extending at least up to 70° N. lat., containing 137 species, of which 46 are found also in the central European Miocene basins. More than half of the plants are trees, including 30 species of conifers (*Sequoia*, *Thujopsis*, *Salisburia*, &c.), besides beeches, oaks, planes, poplars, maples, walnuts, limes, magnolias, and many more. These plants grew on the spot, for their fruits in various stages of growth have been obtained from the beds. From Spitzbergen (78° 56′ N. lat.) 136 species of fossil plants have been named by Heer. But the latest English Arctic expedition brought to light a bed of coal, black and lustrous like one of the Palæozoic fuels, from 81° 45′ lat. It is from 25 to 30 feet thick, and is covered by black shales and sandstones full of land-plants. Heer notices 26 species, 18 of which had already been found in the Arctic Miocene zone. As in Spitzbergen, the conifers are most numerous (pines, firs, spruces, and cypresses), but there occur also the arctic poplar, two species of birch, two of hazel, an elm, and a viburnum. In addition to these terrestrial trees and shrubs the stagnant waters of the time bore water-lilies, while their banks were clothed with reeds and sedges. When we remember that this vegetation grew luxuriantly within 8° 15′ of the North Pole, in a region which is now in darkness for half of the year, and is almost continuously buried under snow and ice, we can realize the difficulty of the problem in the distribution of climate which these facts present to the geologist.

Pliocene.

Great Britain.—The Miocene period seems to have passed away without any notable portion of the British Islands being depressed under the sea. Save the great outpouring of lava in the north-west, and the rise of hundreds of "dykes" of basalt along cracks of the crust in the north of England and throughout Scotland, the area of Britain seems to have remained as a part of the mainland of Europe, little affected by the subterranean movements which, as we have seen, were so potent among the Alps and in eastern Europe. At length the south-eastern counties began to subside, and on their submerged surface some sandbanks and shelly deposits were laid down, very much as similar accumulations now take place at the bottom of the North Sea. These formations are termed the Crag, and are subdivided, according to their proportion of living species of shells, into the following groups:—

Chillesford beds	Chillesford Clay	1 to 8 ft.
	Chillesford Sand with shells	5 ,, 8 ,,
Norwich (fluvio-marine, mammaliferous) Crag		5 ,, 10 ,,
Red Crag		25 ,,
White (Suffolk, coralline) Crag		40 ,, 60 ,,

The White Crag consists of shelly sands and marls. It contains 316 species of shells, of which 84 per cent. are still living. Among these are *Terebratula grandis*, *Lingula Dumortieri*, *Pecten opercularis*, *Pholadomya histerna*, *Pyrula reticulata*. The name coralline was given to the formation from the immense number of coral-like polyzoa which it contains, no fewer than 130 species having been described. The Red Crag is also a thin and local formation, consisting of a dark-red or brown ferruginous shelly sand. Of its mollusks, 92 per cent are believed to be still living species, and, out of 25 species of corals, 14 are still natives of British seas. Some of the typical shells of this subdivision are *Trophon antiquum* (*Fusus contrarius*), *Voluta Lamberti*, *Purpura tetragona*, *Pecten opercularis*, *Pectunculus glycimeris*, and *Cyprina rustica*. Numerous mammalian remains have been obtained from these sands, including bones of *Mastodon Arvernensis* and *M. tapiroides*, *Elephas meridionalis*, *Rhinoceros Schleiermacheri*, *Tapirus priscus*, *Sus antiquus*, *Equus plicideus*, *Hipparion*, *Hyæna antiqua*, *Felis pardoides*, and *Cervus anoceros*. The Norwich or Fluvio-marine or Mammaliferous Crag consists of a few feet of shelly sand and gravel, containing, so far as known, 139 species of shells, of which 93 per cent. are still living. About 20 of the species are land or fresh-water shells. The name of mammaliferous was given from the large number of bones, chiefly of extinct species of elephant, recovered from this deposit. These fossils comprise *Mastodon Arvernensis*, *Elephas meridionalis*, *E. antiquus*, a hippopotamus, horse, and deer, likewise the living species of otter and beaver. One interesting feature in this formation is the decided mixture in it of *northern* species of shells, such as *Rhynchonella psittacea*, *Scalaria Grœnlandica*, and *Astarte borealis*. These may be regarded as the forerunners of the great invasion of Arctic plants and animals which, in the beginning of the Quaternary ages, came southward into Europe, together with the severe climate of the north. The Chillesford beds occur likewise as a thin local deposit in Suffolk and Norfolk. Of the shells which they contain, about two-thirds still live in Arctic waters. It is evident that, in these fragmentary accumulations of the Crag series, we have merely the remnants of some thin sheets of shelly sands and gravels laid down in the shallow waters of the North Sea, while that great lowering of the European climate was beginning which culminated in the succeeding or Glacial period.

Continental Europe.—Marine strata, sometimes of considerable thickness, were laid down over different portions of the European area during the Pliocene period. The most extensive of these occur in Italy and Sicily; in the latter island they have since been upheaved to a height of 3000 feet above the sea. They have likewise been raised into the chain of heights flanking the Apennine Mountains, where they are known as the Subapennine series. In the shore waters and estuaries of that ancient Italy some of the same huge mammals lived as were contemporaneously denizens of England,—the Auvergne mastodon, *Rhinoceros Etruscus*, *Elephas meridionalis*, *Hippopotamus major*, with bears and hyænas.

Eastwards we obtain evidence of the gradual exclusion of the sea from the areas of the European continent which it had covered during the Miocene period. The Congeria stage (above referred to) of the Vienna basin brings before us the picture of an isolated gulf gradually freshening by the inpouring of rivers like the modern Caspian, but with bays nearly cut off from the main body of water, and undergoing so copious an evaporation without counterbalancing inflow that their salt was deposited over the bottom as in the Karaboghaz of the Caspian (*ante*, p. 279).

Tertiary Series of North America.

Tertiary formations of marine origin extend in a strip of low land along the Atlantic border of the United States. from the coast of New Jersey southward round the margin of the Gulf of Mexico, whence they run up the valley of the Mississippi to beyond the mouth of the Ohio. On the western sea-board they also occur in the coast ranges of California and Oregon, where they sometimes have a thickness of 3000 or 4000 feet, and reach a height of 3000 feet above the sea. Over the Rocky Mountain region Tertiary strata cover an extensive area, but are chiefly of fresh-water origin, though containing marine interstratifications. The following are the subdivisicns into which they have been grouped, together with their supposed European equivalents:—

4. Sumter series = Pliocene.
3. Yorktown ,, = Miocene, with perhaps part of Pliocene.
2. Alabama ,, = Middle and Upper Eocene.
1. Lignitic ,, = Lower Eocene.

1. *Lignitic*.—As already mentioned, it is still matter of dispute whether this formation should not be included wholly or in large measure in the Cretaceous system below. It consists mainly of lacustrine strata, with occasional brackish water and marine bands. Its name is derived from the beds of fossil fuel which it contains. The mollusca in some of the shell-bearing beds comprise species of *Inoceramus*, *Anchura*, *Gyrodes*, *Cardium*, *Cyrena*, *Melampus*, *Ostrea*, and *Anomia*. Other strata contain the modern lacustrine and fluviatile genera *Physa*, *Valvata*, *Cyrena*, *Corbula*, and *Unio*. An abundant terrestrial flora has been disinterred from the Lignitic strata. It resembles in many respects the present flora of North America, comprising as it does species of oak, poplar, maple, elm, dogwood, beech, hickory, ilex, plane, fig, cinnamon, laurel, magnolia, smilax, thuja, sequoia, and several palms. A few of the species are common to the Middle Tertiary flora of Europe, and a number of them have been met with in the Tertiary beds of the Arctic regions. Some of the seams of vegetable matter are true bituminous coals and even anthracites.

It was stated in the account of the North American Cretaceous rocks that considerable difference of opinion exists as to the line to be drawn between these rocks and those of Tertiary age. According to Cope, the Vertebrate remains of the Lignitic series bind it indissolubly to the Mesozoic formations. Lesquereux, on the other hand, insists that the vegetation is unequivocally Tertiary. The former writer, admitting the force of the evidence furnished by the fossil plants, concludes, that "there is no alternative but to accept the result that a Tertiary flora was contemporaneous with a Cretaceous fauna, establishing an uninterrupted succession of life across what is generally regarded as one of the greatest breaks in geologic time." The Lignitic series was disturbed along the Rocky Mountain region before the deposition of the succeeding Tertiary formations, for these lie uncomformably upon it. So great have been the changes in some regions that the strata have assumed the character of hard slates like those of Palæozoic date, if indeed they have not become in California thoroughly crystalline masses.

2. *Alabama Group*.—The strata included in this group are believed to represent the Middle and Upper Eocene of Europe. As their name implies, they are well developed in the State of Alabama, where they consist of two sub-groups,—(1) the Clayborne beds—clays, marls, limestones, lignite, and sands, and (2) the Vicksburg beds—lignitic clays, limestones, and marls,—the whole attaining a thickness of nearly 250 feet. But the strata thicken into South Carolina. Towards the west the marine fossils give place to leaf-beds and lignites. In the Green River basin the strata attain a thickness of more than 2000 feet, lying on the disturbed Lignitic group, and containing beds of coal, with remains of fish and of tapiroid pachyderms. The fossils of the Alabama group in the eastern States comprise numerous sharks, some of which are specifically, and more are generically, the same as some of the English Eocene forms, such as *Lamna elegans*, and *Carcharodon megalodon*; also bones of several crocodiles and snakes. In the lacustrine and fluviatile deposits of the west there have been found also the remains of several birds, and a large number of mammals, including marsupials, numerous representatives of the tapirs, with double pairs of nasal horns, an early form of horse (*Orohippus*) not larger than a fox, and with four toes in the fore foot, rodents, insectivores, bats, carnivores, and a number of forms allied to the living lemurs and marmosets. The richness of this fauna is remarkable, particularly in the mammals.

3. *Yorktown Group*.—Under this name are classed strata of sand and clay, which extend over a large area in the seaward part of the eastern States. Their organic remains (comprising mollusks, with remains of sharks, seals, walruses, whales, &c.) show them to have been chiefly laid down in a shallow sea in Miocene time. Westward, in the Upper Missouri region, and across the Rocky Mountains into California and Oregon, strata assigned to the same geological period were laid down in great lakes, and attain thicknesses of 1000 to 4000 or 5000 feet. The organic remains of these ancient lakes embrace examples of three-toed horses (*Anchitherium*), of horned tapir-like animals (*Titanotherium*), of forms related to the hog, rhinoceros, camel, lama, deer, musk-ox, hare, squirrel, beaver, hyæna, wolf, panther, and tiger. The intermediate types indicated by Cuvier among the Paris Tertiary beds have been greatly increased from the American Tertiary groups by the researches of Marsh and Leidy.

4. *Sumter Group* or *Pliocene*.—In the Carolina States beds of loam, clay, or sand, lying in hollows of the older Tertiary deposits, and containing from 40 to 60 per cent. of living marine shells, are referred to the Pliocene age. In the Upper Missouri region, the Yorktown group is overlaid by other fresh-water beds, which are believed to be Pliocene. These strata contain land and fresh-water shells, probably of existing species. But their most remarkable organic remains are the mammalia, which continue the wonderful series in the strata underneath. Dana thus summarizes the facts:—"Leidy has determined a large number of Pliocene mammals, all now extinct. They include three species of camel (*Procamelus*); a rhinoceros as large as the Indian species; a mastodon smaller than *M. Americanus*, L., of the Quaternary; an elephant (*E. Americanus*), occurring also in the Quaternary; four or five species of the horse family, one of which was closely like the modern horse; a species of deer (*Cervus Warreni*, L.); others near the musk-deer of Asia; species of *Merychyus*, allied to *Oreodon* (a genius intermediate between deer, camel, and hog); a wolf larger than any living species; a small fox; a tiger (*Felis augustus*, L.) as large as the Bengal tiger, besides other carnivores; a small beaver; a porcupine. The collection of animals has a strikingly Oriental character, except in the preponderance of herbivores."

V. POST-TERTIARY OR QUATERNARY.

Under this division are included the various superficial deposits in which all the mollusca are of still living species. It is usually subdivided into two series—(1) an older group of deposits in which many of the mammals are of extinct species,—to this group the names of Pleistocene, Post-Pliocene, or Diluvial have been given; and (2) a later series, wherein the mammals are all of still living species, to which the name of Recent or Alluvial has been assigned. These subdivisions, however, are confessedly very artificial, and it is often exceedingly difficult to draw any line between them.

In Europe and North America a tolerably sharp demarcation can usually be made between the Pliocene formations and those now to be described. The Crag deposits of the south-east of England show traces of a gradual lowering of the temperature during later Pliocene times. This change of climate continued to augment until at last thoroughly arctic conditions prevailed, under which the oldest of the Post-Tertiary or Pleistocene deposits were accumulated.

It is hardly possible to arrange these deposits in a strict chronological order, because we have no means of deciding, in many cases, their relative antiquity. The following table is rather an enumeration of the more important of them than an arrangement in their exact sequence:—

Recent	River alluvia, peat mosses, lake deposits, blown sand, marine deposits, raised beaches.
Pleistocene or Glacial.	Brick-earth, valley-gravels, old marine terraces, cavern-deposits.
	Moraine-stuff, Kame or Esker series, Clyde-beds, Upper Boulder clays, Interglacial beds, Lower Till, ice-worn rock-surfaces.
	Pre-glacial forests and land surfac

Pleistocene or Glacial.

Under the name of the Glacial Period or Ice Age, a remarkable geological episode in the history of the northern hemisphere is denoted. We have seen in the foregoing section on the Crag deposits that there is evidence of a gradual refrigeration of the climate at the close of the Tertiary ages. This change of temperature affected the higher latitudes alike of the Old and the New World. It reached such a height that the whole of the north of Europe was buried under snow and ice, extending southwards even as far as Saxony. The Alps and Pyrenees were loaded with vast snow-fields, from which enormous glaciers descended into the plains, overriding ranges of minor hills on their way. The greater portion of Britain was similarly ice-covered.

The effect of the movement of the ice was necessarily to remove the soils and superficial deposits of the land surface. Hence in the areas of country so affected, the ground having been scraped and smoothed, the glacial accumulations laid down upon it rest abruptly, and without any connexion, on whatever underlies them. Considerable local differences may be observed in the nature and succession of the different deposits of the glacial period, as they are traced from district to district. It is hardly possible to determine, in some cases, whether certain portions of the series are coeval or belong to different epochs. But the following are the leading facts which have been established for the North-European area. First, there was a gradual increase of the cold, though with warm intervals, until the conditions of modern North Greenland extended as far south as Middlesex, Wales, the south-west of Ireland, and 50° N. lat. in central Europe. This was the culmination of the Glacial period. Then followed a considerable depression of the land and the spread of cold arctic water over the submerged tracts, with abundant floating ice; next came a re-elevation, with renewed augmentation of the snow-fields and glaciers. Very gradually, and after intervals of increase and diminution, the ice retired towards the north, and with it the arctic flora and fauna that had peopled the European plains. The existing snow-fields and glaciers of the Pyrenees, Switzerland, and Norway are remnants of the great ice-sheets of the glacial period, while the arctic plants of the mountains are relics of the northern vegetation which was universal from Norway to Spain.

Ice-worn Rocks.—Beginning at the base of the deposits from which this interesting history is compiled, we find the solid rocks over the whole of northern Europe to present the characteristic smoothed flowing outlines which can be produced only by the grinding action of land-ice (*ante*, p. 282). Where they have been long exposed, this peculiar surface is apt to be effaced by the disintegrating action of the weather, though it retains its hold with extraordinary pertinacity. Along the fjords of Norway and the sea-lochs of the west of Scotland, it may be seen slipping into the water, smooth, bare, polished, and grooved as if the ice had only recently retreated. But where the protecting cover of clay or other superficial deposits has been newly removed, the peculiar ice-worn surface is as fresh as that by the side of a modern glacier. Observations of the directions of the striæ have shown that on the whole these markings diverge from the main masses of high ground. In Scandinavia they run westwards and south-westwards on the Norwegian coasts, and eastwards or south-eastwards across the lower grounds of Sweden. When the ice descended into the basin of the Baltic and the plains of northern Germany, it moved southwards and south-westwards, but seems to have slightly changed its direction in different areas and at different times. Its movements can be made out partly from the striæ on the solid rock, but more generally from the glacial drift which it has left behind. Thus it can be shown to have moved down the Baltic into the North Sea. At Berlin its movement must have been from east to west. But at Leipsic, as recently ascertained by Credner, it came from N.N.W. to S.S.E., being doubtless shed off in that direction by the high grounds of the Harz mountains. Its southern limit can be traced with tolerable clearness from Jevennaar in Holland eastwards across the Rhine valley, along the base of the Westphalian hills, round the projecting promontory of the Harz, and then southwards through Saxony to the roots of the Erzgebirge. Passing next south-eastwards along the flanks of the Riesen and Sudeten chain, it sweeps across Poland into Russia, circling round by Kieff, and northwards by Nijni Novgorod towards the Urals.

It has been estimated that, excluding Finland, Scandinavia, and the British Isles, the ice must have covered not less than 1,700,000 square kilometres of the present lowlands of Europe. Its influence on the solid rocks over which it passed has not been everywhere equal. Over much of the north German plain, indeed, the rocks are concealed under drift. But in the more undulating hilly ground, particularly in the north and north-west, the ice has effected the most extraordinary abrasion. It is hardly possible, indeed, to describe adequately in words these regions of most intense glaciation. The old gneiss of Norway and Sutherlandshire, for example, has been so eroded, smoothed, and polished, that it stands up in endless rounded hummocks, many of them still smooth and flowing like dolphins' backs, with little pools, tarns, and larger lakes lying between them. Seen from a height the ground appears like a billowy sea of cold grey stone. The lakes, every one of them lying in a hollow of erosion, seem scattered broadcast over the landscape. So enduring is the rock, that even after the lapse of so long an interval, it retains its ice-worn aspect almost as unimpaired as if the work of the glacier had been done only a few generations since.

Some idea of the massiveness of the ice-sheet is obtainable from a consideration of the way in which the striæ run across important hill ranges, and athwart what might seem to be their natural direction. Whilst there was a general southward movement from the great snow-fields of Scandinavia, the high grounds of Britain were important enough to have their own independent ice, which, as the striæ show, radiated outward, some of it passing westwards into the Atlantic and some of it eastward into the North Sea. So thick must it have been as it moved off the Scottish Highlands that it went across the broad plains of Perthshire, filling them up to a depth of at least 2000 feet, and passing across the range of the Ochil Hills, which at a distance of 12 miles runs parallel with the Highland mountains, and reaches a height of 2352 feet. In such cases it has been observed that the striæ along the lower slopes of the hill barrier run either parallel with the trend of the ground or slant up obliquely, while those on the summits may cross the ridge at right angles to its course. This shows that there must have been a differential movement in the great ice-sheet, the lower parts, as in a river, becoming embayed, and being forced to move in a direction sometimes even at a right angle to that of the general advance. On the lower grounds, also, the striæ, converging from different sides, unite at last in one general trend as the various ice-sheets must have done, as they descended from the high grounds on either side and coalesced into one common mass. This is well seen in the great central valley of Scotland. Still more marked is the deflexion of the striæ in Caithness and the Orkney and Shetland Islands. In these districts the general direction of the striation is from S.S.E., which, in Caithness, is nearly at right angles to what might have been anticipated. This deflexion has been attributed to the coalescence of the ice from Norway and from the northern Highlands in the basin of the North Sea, and its subsequent progress along the resultant line into the Atlantic. But it may have been due to the fan-shaped spreading out of the vast mass of ice descending into the Moray Firth; for the striæ on the south side of that inlet run E. by S., and at last S.E., on the north-east of Aberdeenshire, showing that the ice, on the one hand, turned southwards into the North Sea, until it met the N.E. stream from Kincardineshire and the valleys of the Dee and Don, while, on the other, it moved northward so as no doubt to join the Scandinavian sheet, and march with it into the Atlantic. The basin of the North Sea must have been choked up with ice in its northern parts, if not entirely. At that time England and the north-west of France were united, so that any portion of the North Sea basin not invaded by land-ice must have formed a lake,

with its outlet by the hollow through which the Strait of Dover has since been opened. It has been suggested that during such a condition of things the widespread fresh-water deposit termed Loess was formed, which covers so large a space in the lower plains of the Rhine and the north of Belgium, and appears in the valleys of the south-east of England.

The ice is computed to have been at least between 6000 and 7000 feet thick in Norway, measured from the present sea-level. From the height at which its transported debris has been observed on the Harz, it is believed to have been at least 1470 feet thick there, and to have gradually risen in elevation as one vast plateau, like that which at the present time covers the interior of Greenland. Among the Alps it attained almost incredible dimensions. The present snowfields and glaciers of these mountains, large though they are, form no more than the mere shrunken remnants of the great mantle of snow and ice which then overspread Switzerland. In the Bernese Oberland, for example, the valleys were filled to the brim with ice, which, moving northwards, crossed the great plain, and actually overrode a part of the Jura mountains. Huge fragments of granite and other rocks from the central chain of the Alps are found high on the slopes of that range of heights.

Boulder-clay or Till.—Under this name is included the debris which accumulated and was pushed onward under the ice-sheet, the "grund-moräne" or "moraine profonde" (*ante*, p. 282). All over the low grounds of North Germany, Denmark, and Holland lies a stony or earthy clay passing into sand or gravel, in which, together with locally derived debris, there is a greater or less proportion of fragments from the north. Some of the rocks of Scandinavia, Finland, and the Upper Baltic are of so distinctive a kind that they can be recognized in small pieces in the boulder-clay. Thus the peculiar syenite of Laurwig in the south of Norway has been recognized abundantly in the drift of Denmark; it occurs in that of Hamburg, and in the boulder-clay of the Holderness cliffs in Yorkshire. The well-known Rhomben-porphyr of southern Norway has likewise been recognized at Holderness. Fragments of the Silurian rocks from Gothland, or from the Russian islands Dago or Oesel, have been met with as far as the north of Holland. These transported fragments, so abundant within the line of demarcation just traced, are an impressive testimony to the movements of the northern ice-sheet and floating ice.

The boulder-clay is not spread as a uniform sheet over the ground, but varies greatly in thickness and in irregularity of surface. Round the mountainous centres of dispersion it is apt to occur in long ridges or "drums" which run in the general direction of the rock-striation.

In those areas which served as independent centres of dispersion for the ice-sheet, the boulder-clay partakes largely of the local character of the rocks of each district where it occurs. Thus in Scotland the clay varies in colour and composition as it is traced from district to district. Over the Carboniferous rocks it is dark, over the red sandstones it is red, over the Silurian rocks it is fawn-coloured. The great majority of the stones also are of local origin, not always from the immediately adjacent rocks, but from points within a distance of a few miles. Evidence of transport, however, can be gathered from the stones, for they are found in almost every case to include a proportion of fragments which have come from beyond the district. The direction indicated by the percentage of travelled stones is always the same for each region. Thus, in the lower part of the valley of the Firth of Forth, while most of the fragments are from the surrounding Carboniferous formations, from 5 to 20 per cent. is found to have come eastward from the Old Red Sandstone range of the Ochil Hills—a distance of 25 or 30 miles, while 2 to 5 per cent. are pieces of the Highland rocks, which must have come from the high grounds at least 50 miles to the north-west. The evidence of dispersion revealed by the stones in the boulder-clay harmonizes with that of the striæ on the rocks. Every main mass of elevated ground in Britain seems to have caused the ice to move outward from it for a certain distance, until the stream coalesced with that descending from some other height. In Scotland the ice was massive enough to move out into the basin of the North Sea (then doubtless in great part usurped by the glaciers) until it met that which was streaming down from Scandinavia. Hence no Scandinavian blocks have ever been found in Scotland. But the Norwegian ice which crept southwards across Denmark, may once have extended across the North Sea to the Yorkshire coast, if the Scandinavian stones of Holderness were not carried on floating ice.

The stones in the boulder-clay have a characteristic form and surface. They are usually oblong, have one or more flat sides or "soles," are smoothed or polished, and have their edges worn round. Where they consist of a fine-grained enduring rock, they are almost invariably found to be striated, the striæ running with the long axis of the stone. These markings are precisely similar to those on the solid rocks underneath the boulder clay, and like them have manifestly been produced by the friction of stones and grains of sand as the whole mass of debris was being steadily pushed on in one given direction by the resistless advance of the ice (*ante*, p. 282).

Interglacial Beds.—The boulder-clay is not one uniform mass of material. In a limited section, indeed, it usually appears as an unstratified mass of stiff stony clay. But it is found on further examination to be split up with various inconstant and local interstratifications. Beds of sand, gravel, fine clay, and peaty layers occur in this way in different platforms in the boulder clay. In Scotland and elsewhere these interpolated beds bear witness to intervals when the ice retired from the area, and the land, so far as uncovered, was clothed with vegetation and traversed by herds of the hairy mammoth, reindeer, and musk-ox. Hence the long glacial period must have been interrupted by episodes probably of considerable duration when a milder climate prevailed. Such an alternation of conditions is explained on the hypothesis discussed in previous pages (*ante*, pp. 218–220).

Evidences of Submergence.—After the ice had attained its greatest development, the land, which perhaps in north-western Europe stood at a higher level above the sea than it has done since, began to subside. The ice-fields were carried down below the sea-level, where they broke up and cumbered the sea with floating bergs. The heaps of loose debris which had gathered under the ice, being now exposed to waves, ground-swell, and marine currents, were thereby more or less washed down and reassorted. Coast-ice, no doubt, still formed along the shores, and was broken up into moving floes, as happens every year now in northern Greenland. The proofs of this phase of the long glacial period are contained in the sands, gravels, erratic blocks, and stratified clays which overlie the coarse older till. It is difficult to determine the extent of the submergence, for when the land rose the more elevated portions continued to be the seats of glaciers, which, moving over the surface, destroyed the deposits which would otherwise have remained as witnesses of the presence of the sea. The most satisfactory evidence is undoubtedly that supplied by beds of marine shells. These have been observed on Moel Tryfan, in North Wales, at a height of no less than 1350 feet, but as the same kind of deposits in which they occur extend to a much greater height, the submergence probably considerably exceeded the limit at which the shells occur. In Cheshire beds of shells have been met with at a height of

1200 feet. In Scotland the highest level from which they have yet been obtained is 524 feet; and in this instance they lie in one of the interstratifications in the boulder-clay. The coast of Scotland is fringed by a succession of raised beaches which, up to that at 100 feet above the present mean tide-level, are often remarkably fresh. The 100-feet terrace forms a wide plateau in the estuary of the Forth, and the 50-feet terrace is as conspicuous on the Clyde. The elevation of the land has brought up within tide-marks some of the clays deposited over the sea-floor during the time of the submergence. In the Clyde basin and some of the western fjords these clays (Clyde beds) are full of shells. Comparing the species with those of the adjacent seas, we find them to be more boreal in character; nearly the whole of the species still live in Scottish seas, though a few are extremely rare. Some of the more characteristic northern shells in these deposits are *Pecten Islandicus*, *Tellina calcarea*, *Leda truncata*, *L. lanceolata*, *Saxicava rugosa*, *Panopœa Norvegica*, *Trophon clathratum*, and *Natica clausa*.

That ice continued to float about in these waters is shown by the striated stones contained in the fine clays, and by the remarkably contorted structure which these clays occasionally display. Sections may be seen where, upon perfectly undisturbed horizontal strata of clay and sand, other similar strata have been violently crumpled, while horizontal beds lie directly upon them. These contortions must have been produced by the horizontal pressure of some heavy body moving upon the originally flat beds. No doubt the agent was ice in the form of large stranding masses which were driven aground in the fjords or shallow waters where the clays accumulated. Another indication of the presence of floating ice is furnished by large boulders scattered over the country, and lying sometimes on the stratified sands and gravels, though no doubt many of the so-called erratics belong to the time of the chief glaciation.

One of the most puzzling members of the Drift is the series of sands and gravels which cover the low grounds in many places, and rise up to heights of 1000 feet and more. These deposits are sometimes spread out in undulating sheets, which, in the lower districts, seem to merge insensibly into the marine terraces and raised beaches. But they are also very commonly disposed in remarkable mounds and in ridges which run across valleys, along hill-sides, and even over watersheds. These ridges are known in Scotland as kames, in Ireland as eskers, and in Scandinavia as osar. They consist sometimes of coarse gravel or earthy detritus, but more usually of clean, well-stratified sand and gravel, the stratification towards the surface corresponding with the external slopes of the ground, in such a manner as to prove that the ridges are original forms of deposit, and not the result of the irregular erosion of a general bed of sand and gravel. Some writers have compared these features to the submarine banks formed in the pathway of tidal currents near the shore. Others have supposed them rather to be of terrestrial origin, due to the melting of the great snow-fields and glaciers, and the consequent discharge of large quantities of water over the country. But no very satisfactory explanation has yet been given.

Re-emergence.—Later Glaciers.—When the land began to rise again, the temperature all over central and northern Europe was still severe. Vast sheets of ice still held sway over the mountains, and continued to descend into the lower tracts and to go out to sea. To this period are ascribed certain terraces or "parallel-roads" which run along the sides of valleys in the Scottish Highlands. It is believed that the mass of ice descending from some of the loftier snow-fields of this time was so great as to accumulate in front of lateral valleys, and to so choke them up as to cause the water to accumulate in them and flow out in an opposite direction by the *col* at the head. In these natural reservoirs the level at which the water stood for a time was marked by a horizontal ledge or platform due partly to erosion of the hill-side and partly to the arrest of the descending debris when it entered the water.

Every group of mountains nourished its own glaciers; even small islands, such as Arran in Scotland, had their snowfields, whence glaciers crept down into the valleys and shed their moraines. It would appear indeed that some of the northern glaciers of Scotland continued to reach the sea-level even when the land had risen to within 50 feet or less of its present elevation. On the east side of Sutherlandshire the moraines descend to the 50-feet raised beach; on the west side of the same county they come down still lower. The higher mountains of Europe still show the descendants of these later glaciers, but the ice has retreated from the lower elevations. In the Vosges the glaciers have long disappeared, but their moraines remain still fresh. In Wales, Cumberland, and the southern uplands and Highlands of Scotland, moraines, perched blocks, and *roches moutonnées* attest the abundance and persistence of the last glaciers. It is sometimes possible to trace the stages in the gradual retreat of the ice towards its parent snow-fields, for the crescent-shaped moraine mounds lie one behind another until they finally die out about the head of the valley, near what must have been the edge of the snow-field.

We know as yet very little of the fauna and flora of the land during the Glacial Period in Europe. The vegetation was doubtless in great measure the same as that of arctic Norway at the present day. The animals included the musk-ox, lemming, rein-deer, and other still living arctic forms, but included some which have become extinct, such as the hairy mammoth and woolly rhinoceros. During the milder inter-glacial periods denizens of warmer regions found their way northwards into Europe. Thus the hippopotamus haunted the rivers of the south of England. By degrees, as the climate ameliorated, the arctic vegetation was finally extirpated from the lower grounds of central and western Europe, and plants loving a milder temperature, which had doubtless been natives of Europe before the period of great cold, were enabled to reoccupy the sites whence they had been driven. On the higher mountains, where the climate is still not wholly uncongenial for them, colonies of this once general arctic flora still survive. The arctic animals have also been driven away to their northern homes, or have become wholly extinct. And thus, as imperceptibly as it began, the long and varied Ice Age came to an end as it merged into the next succeeding geological period.

Recent or Human Period.

That long succession of ages to which the name of the Glacial Period has been given shaded without abrupt change of any kind into what is termed the Human or Recent Period. Indeed it may be said with truth that the Glacial Period still exists in Europe. The snow-fields and glaciers have disappeared from Britain, but they still linger among the Pyrenees, remain in larger mass among the Alps, and spread over wide areas in northern Scandinavia. This dovetailing or overlapping of geological periods has been the rule from the beginning of time, the apparently abrupt transitions in the geological record being due to imperfections in the chronicle.

The question has often been asked whether man was coeval with the Ice Age. To give an answer, we must know within what limits the term Ice Age is used, and to what particular country or district the question refers. For it is evident that even to-day man is contemporary with the Ice Age in the Alpine valleys and in Finmark. There can

be no doubt that he inhabited Europe after the greatest extension of the ice, but while the rivers were still larger than now from the melting snow, and flowed at higher levels.

The proofs of the existence of man in former geological periods are not to be sought for in the occurrence of his own bodily remains, as in the case of other animals. His bones are indeed now and then to be found, but in the vast majority of cases his former presence is revealed by the implements he has left behind him, formed of stone, metal, or bone. Many years ago the archæologists of Denmark, adopting the subdivisions of the Latin poets, classified the prehistoric traces of man in three great divisions—those of (1) the Stone Age, (2) the Bronze Age, and (3) the Iron Age. There can be no doubt that, on the whole, this has been the general order of succession. Men used stone and bone before they had discovered the use of metal. Nevertheless, the use of stone long survived the introduction of bronze and iron. In fact, in many European countries where metal has been known for many centuries, there are districts where stone implements are still employed, or where they were in use until quite recently. It is obvious also that, as there are still barbarous tribes unacquainted with the fabrication of metal, the Stone Age is not yet extinct in many parts of the world. In this instance we again see how geological periods run into each other. The nature or shape of the implement cannot therefore be always a very satisfactory proof of antiquity. We must judge of it by the circumstances under which it was found. From the fact that in north-western Europe the ruder kind of stone weapons occurs in what are certainly the older deposits, while others of more highly finished workmanship are found in later accumulations, the Stone Age has been subdivided into an early or Palæolithic and a later or Neolithic epoch. There can be no doubt, however, that the later was in great measure coeval with the age of bronze, and even to some extent of iron.

The deposits which contain the history of the human period are cavern-loam, river-alluvia, lake-bottoms, peat-mosses, sand-dunes, and other superficial accumulations.

Most calcareous districts abound in underground tunnels and caverns which have been dissolved by the passage of water from the surface (*ante*, p. 271). In a large number of cases these cavities have communicated with the outer surface, so that terrestrial animals, including man himself, have made use of them as places of retreat, or have fallen or been washed into them. The floors of some of them are covered with loam or cave-earth, resulting from the deposit of the silt carried in the water which formerly flowed through them. Very commonly also, a deposit of stalagmite has formed from the drip of the roof. Hence any organic remains which may have found their way to these floors have been sealed up and admirably preserved.

Above the present levels of the rivers there lie platforms or terraces of alluvium, sometimes to a height of 80 or 100 feet. These deposits are fragments of the river gravels and loams laid down when the streams flowed at that elevation, and therefore before the valleys were widened and deepened to their present form. River action is at the best but slow. To erode the valleys to so great a depth beneath the level of the upper alluvia, must have demanded a period of many centuries. There can therefore be no doubt of the high antiquity of these deposits. They have yielded the remains of many mammals, some of them extinct, together with the flint flakes made by man. From the nature and structure of some of the high-lying gravels, there can be little doubt that they were formed at a time when the rivers were larger than now, and were liable to be frozen and to be obstructed by large accumulations of ice. We are thus able to connect the formations of the human period with some of the later phases of the Ice Age in the west of Europe.

From the evidence of caverns and river-alluvia of Britain, Germany, and France, Dawkins enumerates about fifty mammals as among the chief inhabitants of Europe during the early human period. They include many of the animals still found wild in Europe, Asia, or Africa, such as the marmot, hare, beaver, lemming, leopard, lynx, wild cat, otter, brown bear, wolf, fox, African elephant, musk sheep, chamois, wild boar, horse, reindeer, and hippopotamus. It will be observed what a remarkable mixture there is in this list of forms now found in alpine or arctic regions, on the one hand, with others only now to be seen in warm latitudes. Probably there continued to be great alternations of climate and changes in the distribution of food, so that migrations successively from opposite quarters took place into central and western Europe. But among the denizens of these regions were some that have been long extinct, such as the mammoth, *Elephas antiquus*, *Machairodus latidens*, the woolly rhinoceros, the Irish elk, and others. That man was the contemporary of these extinct forms is shown both by the association of his flint weapons with their remains, and by the discovery of a tusk of the mammoth with an admirable outline of the animal carved upon it. This valuable relic, with bones of the reindeer and stag admirably sculptured into likenesses of these animals, was found in one of the caves of Perigord in central France.

From the beds of lakes, and from peat-mosses, evidences of more advanced civilization have been obtained. In Switzerland and elsewhere, remains of wooden pile-dwellings have been observed during times when the water has been low. Associated with these are weapons and implements of stone, in other cases of bronze and of iron, pottery, rude kinds of cloth, seeds of different cereals, and bones of domesticated animals. The dog, swine, goat, horned sheep, and other familiar animals appear as the companions of man. But there is evidence that some of the creatures which he tamed to his use were not natives of Europe, but had their original stocks in central Asia, and that some of his grains must likewise have been introduced. Hence we have glimpses into some of the early human migrations from that eastern centre whence so many successive waves of population have invaded Europe.

The later chronicles of the geologist merge insensibly into those of the archæologist. The latter claims as his field whatever belongs to the history of man on the globe; the former includes the history of man in that larger history of the earth of which a brief outline has been given in the foregoing pages.

Post-Tertiary Series in North America.

The general succession of events in post-Tertiary times appears to have been nearly the same over the northern hemisphere both in the New and the Old World. In North America we have the same sharply-defined line between the older post-Tertiary deposits and previous formations, due to the glacial conditions which, overspreading these regions, in great measure destroyed the superficial accumulations of the immediately preceding eras. The Quaternary or post-Tertiary formations are grouped by American geologists in the following subdivisions:—

4. Recent and Prehistoric	Peat, alluvium, blown sand, "alkali" deposits, geyser deposits, cave deposits, artificial mounds.
3. Terrace	River-terraces, loess. Raised beaches.
2. Champlain ...	*Saxicava* sand, Champlain clays, *Leda* clay.
1. Glacial	**Boulder clays, unstratified clays, sands, and gravels.**

1. *Glacial.*—As in Europe, the glacial deposits increase in thickness and variety from south to north. The southern limit of the unstratified drift lies somewhere in the neighbourhood of the 39th parallel of north latitude, and the deposit ranges from the Atlantic westward to the meridian of 98°. It spreads, therefore, across British North America, and is found over a considerable area of the north-eastern States. It rises to a height of 5800 feet among

the White Mountains. The absence of any true boulder-drift on the Rocky Mountain slopes, where it might have been looked for, is remarkable.

Underneath the boulder-clay the solid rocks, as in Europe, are often well striated. The direction of the striæ is generally southward, varying to south-east and south-west according to the form of the ground. In recent years extensive ice-worn rock-surfaces have been observed among the Rocky Mountains by Hayden, King, and others, proving that these elevations formerly possessed their glaciers, if they were not buried under the great ice-sheet.

The drift bears witness to a general southerly transport of material, and, in conjunction with the striated rocks, shows that the great ice-sheet moved from north to south at least as far as about the latitude of Washington. Logan mentions that in some parts of Canada the glacial drift and boulders run in ridges north and south, thus corresponding with the general direction of transport, like the "drums" in Britain. As in Europe, the coarse boulder-clay at the base of the Quaternary deposits is essentially unfossiliferous.

2. *Champlain.*—Under this name American geologists class the sands, gravels, and clays which overlie the lower boulder-drift. These deposits include coarse unstratified gravels, as well as finely-stratified clays. In eastern Canada they are well developed, and show the following subdivisions :—

Upper.	St Maurice and Sorel sands; *Saxicava* sand of Montreal; upper sand and gravel of Beauport; upper Champlain clay and sand of Vermont.
Lower.	*Leda* clay of the St Lawrence and Ottawa; lower shell-sand of Beauport; lower Champlain clay of Vermont.

The lower subdivisions consist chiefly of clays, which rise to a height of 600 feet above the sea. They have some interstratified beds of siliceous sand, but few boulders. They contain marine organisms, such as *Leda truncata, Saxicava rugosa, Tellina Grœnlandica*, bones of seals, whales, &c. On the banks of the Ottawa, in Gloucester, the clays contain numerous nodules which have been formed round organic bodies, particularly the fish *Mallotus villosus* or capeling of the Lower St Lawrence. Dawson also obtained numerous remains of terrestrial marsh plants, grasses, carices, mosses, and algæ. This writer states that about 100 species of marine invertebrates have been obtained from the clays of the St Lawrence valley. All except four or five species in the older part of the deposits are shells of the boreal or Arctic regions of the Atlantic; and about half are found also in the glacial clays of Britain. The great majority are now living in the Gulf of St Lawrence and neighbouring coasts, especially off Labrador.[1]

3. *Terrace.*—This division includes the terraced deposits of alluvial material so marked along the river valleys and lake margins in the northern part of the United States and in Canada, and found also in some degree along the sea-coast. These deposits occur in successive platforms or terraces, marking the contraction in volume of the lakes and rivers, consequent, probably, upon intermittent upheavals of the land. They are well developed round the great lakes. Thus in the basin of Lake Huron deposits of fine sand and clay containing fresh-water shells rise to a height of 40 feet or more above the present level of the water, and run back from the shore sometimes for 20 miles. Regular terraces, corresponding to former water-levels of the lake, run for miles along the shores at heights of 120, 150, and 200 feet. Shingle beaches and mounds or ridges, exactly like those now in course of formation along the exposed shores of Lake Huron, can be recognized at heights of 60, 70, and 100 feet. Unfossiliferous terraces occur abundantly on the margin of Lake Superior. At one point mentioned by Logan, no fewer than seven of these ancient beaches occur at intervals up to a height of 331 feet above the present level of the lake.[2] Most of the rivers are bordered with lines of terraces, as in the well-known example of the Connecticut valley described by Hitchcock. The rivers are believed to have had their maximum volume at the beginning of the Terrace epoch, swollen doubtless by the melting of the still existing ice-sheets and snow-fields. Their work consisted partly in depositing fine alluvium or loess over their flood-plains, partly in scouring their channels out of the Champlain formations. Greater elevation towards the interior, by augmenting their slope, increased their excavating power.

Terraces of marine origin likewise occur both on the coast and far inland. On the coast of Maine they occur at heights of 150 to 200 feet, round Lake Champlain at least as high as 300 feet, and at Montreal nearly 500 feet above the present level of the sea. In the absence of organic remains, however, it is not always possible to distinguish between terraces of marine origin marking former sea-margins, and those left by the retirement of rivers and lakes. In the Bay of Fundy evidence has been cited by Dawson to prove subsidence, for he has observed there a submerged forest of pine and beech lying 25 feet below high-water mark.[3]

4. *Recent and Prehistoric.*—The deposits in this group are essentially the same with those in Europe; and, as in that continent so in America, no definite lines can be drawn within which they should be confined. They cannot be sharply separated from the Terrace series, on the one hand, nor from modern accumulations, on the other. Besides the marshes, peat-bogs, and other organic deposits which belong to an early period in the human occupation of America, some of the younger alluvia of the river-valleys and lakes can no doubt claim a high antiquity, though they have not supplied the same copious evidence of early man which gives so much interest to the corresponding European formations. Heaps of shells of edible species occur on the coasts of Nova Scotia, Maine, &c. The large mounds of artificial origin in the Mississippi valley have excited much attention.

PART VII.—PHYSIOGRAPHICAL GEOLOGY.

In the investigation of the geological history of any country, two questions present themselves. We have first to consider the nature and arrangement of the rocks which underlie the surface, and to ascertain from them what has been the march of events, what changes in geography have successively taken place, and what races of plants and animals have come and gone. The gradual geological evolution of the earth has been sketched in the foregoing part of this article. But besides the history of the solid rocks beneath the surface of the land, there is that of the surface itself. Mountains and plains, valleys and ravines, cliffs, peaks, passes, lakes, and the many other features of a country demand attention. By what processes have these varied outlines been impressed upon the surface of the globe? Are they of different ages, and if so, how can their history be ascertained?

The branch of geological inquiry which endeavours to answer these questions has been termed Physiography or Physiographical Geology. Its investigations evidently demand an acquaintance with Stratigraphical Geology. We must be able to trace out the former geographical conditions of the globe before we can adequately reason on the origin of those now existing. Hence the consideration of this branch of the subject has necessarily been reserved for this concluding section.

The stratified formations, of which the succession and history have been traced in the previous pages, were chiefly laid down on the sea-floor in wide horizontal or gently inclined sheets. They have since been upraised into land; their horizontality has been in great part destroyed; and they have been enormously wasted by denuding agents. In considering therefore how they have acquired their present external forms, we have to deal with the effects of two kinds of forces, one acting from below, the other on the surface.

These stratified rocks were, on the whole, deposited in shallow water, and have been repeatedly upraised and denuded, so that the younger have been formed out of the waste of the older. They have their modern counterparts, not in the deposits of the great ocean-basins, but in those of comparatively shallow seas. The inference to be drawn from these facts is that the present continental regions, through many local oscillations, have existed as terrestrial ridges from a remote geological antiquity, and that the ocean basins in like manner have, on the whole, retained their identity. When the geologist asks himself how the present distribution of sea and land is to be accounted for, he finds that the answer to the question goes back to early Palæozoic times, whence he can in some cases trace the gradual growth of a continent downward through the long cycles of geological time. But there still remains the problem to account for the original wrinkling of the surface of the globe, whereby the present great ridges and hollows were produced.

It is now generally agreed that these inequalities have been produced by unequal contraction of the earth's mass, the interior contracting more than the outer crust, which must therefore have accommodated itself to this diminution of diameter by undergoing corrugation. But there seems to have been some original distribution of materials in the globe that initiated the depressions on the areas which they have retained. It has been already pointed out (*ante*, p. 223) that the matter underlying the oceans is more dense than that beneath the continents, and that, partly at least, to this cause must the present position of the oceans be attributed. The early and persistent subsidence of these areas, with the consequent increase of density, seems to have determined the main contours of the earth's surface.

[1] *Acadian Geology*, p. 76. [2] *Geology of Canada*, p. 910.
[3] *Acadian Geology*, p. 28.

From what has been stated in part iv., the reader will understand that rocks which were originally horizontal, or nearly so, have been crumpled over tracts thousands of square miles in extent, so as to occupy now a superficial area greatly less than that which they originally covered. It is evident that they have been horizontally compressed, and that this result can only have been achieved as a consequence of the subsidence of such a curved surface as that of our globe. The difficulty of explaining these corrugations on the hypothesis of the contraction of a solid globe is undoubtedly great. Mr O. Fisher, indeed, believes that the present inequalities of contour on the earth's surface are from sixty-six to eleven and a half times as great as they would have been had they resulted from the contraction of a solid globe; and he has suggested that the earth need not have become solid throughout simultaneously, and consequently may have been considerably larger than it is now at the time when a solid crust was first formed.[1]

The geological phenomena long ago led to a belief in the liquidity of the earth's interior. Since this belief has been so weightily opposed by the physical arguments already adduced (*ante*, p. 225), geologists have endeavoured to modify it in such a way as, if possible, to satisfy the requirements of physics, while at the same time providing an adequate explanation of the corrugation of the earth's crust. Mr Hopkins, Professor Dana, Professor Shaler, and Mr Fisher have, on different grounds, advocated the existence of a fluid or viscous substratum beneath the crust, the contraction and consolidation of which produce the corrugations of the rocks and of the surface. "The increase of temperature," says Mr Fisher, "though rapid near the surface, becomes less and less as we descend, so that, if the earth were once wholly melted, the temperature near the centre is not very greatly above what it is at a depth which, compared to the earth's radius, is small. Consequently, if it requires great pressure to solidify the materials at such a temperature, it is probable that the melting temperature may be reached before the pressure is sufficient to solidify." The crust, of course, must be able to sustain itself on the corrugated surface of the supposed viscous layer without breaking up and sinking. The same writer has even suggested that the observed amount of corrugation is more than can be accounted for even on this hypothesis, and that the shrinkage may have been due not merely to cooling, but to the escape of water from the interior in the form of the superheated steam of volcanic vents.[2] More recently Herr Siemens has been led, from observations made in May 1878 at Vesuvius, to conclude that vast quantities of hydrogen gas, or combustible compounds of hydrogen, exist in the earth's interior, and that these, rising and exploding in the funnels of volcanoes, give rise to the detonations and clouds of steam.[3]

Leaving the vexed question of the condition of the earth's interior, the hypothesis of secular cooling and contraction furnishes a natural explanation of the origin of the dominant elevations and depressions of the surface, and of the intense crumpling which the rocks in many regions have undergone. Taking 0·09 as the coefficient of contraction for a supposed stratum 500 miles thick, lying beneath 25 miles of crust, and passing from a fused into a solid state, Mr Fisher found that every 100 miles measured along a great circle on the surface would have been one mile larger before the contraction, and that this might produce a triangular elevation of "25 square miles on a base of 100 miles, which would give a range of mountains half a mile high. If only 50 miles out of the hundred were disturbed, the range would be a mile high, and so on."[4]

The effects of this lateral pressure may show themselves either in broad dome-like elevations, or in narrower and loftier ridges of mountain. The structure of the crust is so complex, and the resistance offered by it to the pressure is consequently so varied, that abundant cause is furnished for almost any diversity in the forms and distribution of the wrinkles into which it is thrown. It is evident, however, that the folds have tended to follow a linear direction. In North America, from early geological times, they have kept on the whole on the lines of meridians. In the Old World, on the contrary, they have chosen diverse trends, but the last great crumplings—those of the Alps, Caucasus, and the great mountain ranges of central Asia—have risen along parallels of latitude.

Mountain chains must therefore be regarded as evidence of the shrinkage of the earth's mass. They may be the result of one movement, or of a long succession of such movements. Formed on lines of weakness in the crust, they have again and again given relief from the strain of compression by undergoing fresh crumpling and upheaval. The successive stages of uplift are usually not difficult to trace. The chief guide is supplied by unconformability, as explained on p. 318. Let us suppose, for example, that a mountain range consists of upraised Lower Silurian rocks, upon the upturned and denuded edges of which the Carboniferous Limestone lies transgressively. The original upheaval of that range must have taken place at the period of geological time represented by the interval between the Lower Silurian and the Carboniferous Limestone formations. If, in following the range along its course, we found at last the Carboniferous Limestone also highly inclined and covered unconformably by the Upper Coal-measures, we should know that a second uplift of that portion of the ground had taken place between the time of the Limestone and that of the Upper Coal-measures. By this simple and obvious kind of evidence the relative ages of different mountain chains may be compared. In most great mountain-chains, however, the rocks have been so intensely crumpled, and even inverted, that much labour may be required before their true relations can be determined.

The Alps offer an instructive example of a great mountain chain formed by repeated movements during a long succession of geological periods. As has been already stated, the central portions of the chain consist of gneiss, schists, granite, and other crystalline rocks, partly referable to the Archæan series, but many of which appear to be metamorphosed formations of Palæozoic, Secondary, and even of older Tertiary age.

It would appear therefore that the first outlines of the Alps were traced out even in Archæan times, and that after submergence, and the deposit of Palæozoic formations along their flanks, if not over most of their site, they were re-elevated into land. From the relations of the Mesozoic rocks to each other, we may infer that several renewed uplifts after successive denudations took place before the beginning of the Tertiary formations. A large part of the range was, as we have seen, submerged during the Eocene period under the waters of that wide sea which spread across the centre of the Old World, and in which the Nummulitic Limestone and Flysch were deposited. But about the close of that period the grand upheaval took place to which the present magnitude of the mountains is chiefly due. The older Tertiary rocks, previously horizontal under the sea, were raised up into land, crumpled, dislocated, inverted, together with all the older formations of the chain. So intense was the compression to which the Eocene clays and sands were subjected

[1] *Cambridge Phil. Trans.*, vol. xii. pt. ii., 1875.
[2] *Phil. Mag.*, October 1875.
[3] *Monatsbericht der K. preuss. Akad. Wissenschaft*, 1878, p. 558.
[4] *Cambridge Phil. Trans.*, vol. xi. pt. iii.