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

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

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.

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

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[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.

that they were converted into rocks as hard and crystalline as many of the Palæozoic masses. It is strange to reflect that the enduring materials out of which so many of the mountains, cliffs, and pinnacles of the Alps have been formed are of no higher geological antiquity than the London Clay and other soft Eocene deposits of the south of England. After the paroxysm of elevation had ended, one or more large lakes were formed along the northern base of the mountains. In these hollows the Swiss molasse accumulated to a depth of more than 6000 feet—a great pile of slowly formed gravels, sands, and clays. That the sea gained occasional access to the region is shown by the interpolation of bands containing marine organisms, as already stated (*ante*, p. 363). Not improbably a gradual subsidence of the region was going on during the formation of the molasse. But towards the close of the Miocene period another great epoch of mountain-making was ushered in. The lakes disappeared, and their thick sediments were thrust up into large, broken, mountain masses. The Righi, Rossberg, and other prominent heights along the northern flank of the Alps are formed of these upturned lacustrine deposits. Since that great movement no paroxysm seems to have affected the Alpine region. Ceaseless changes, indeed, have been in progress, but they have been due not so much to subterranean causes as to those subaerial forces which are still so active.

The gradual evolution of a continent during a long succession of geological periods has been admirably worked out for North America by Dana, King, Hayden, Newberry, Powell, Dawson, and others. The general character of the structure is extreme simplicity, as compared with that of the Old World. In the Rocky Mountain region, for example, while the Palæozoic formations lie unconformably upon the Archæan gneiss, there is, according to King, a regular conformable sequence from the Lower Silurian to the Jurassic rocks. During the enormous interval of time represented by these massive formations what is now the axis of the continent remained undisturbed save by a gentle and protracted subsidence. In the great depression thus produced all the Palæozoic and a great part of the Mesozoic rocks were accumulated. At the close of the Jurassic period the first great upheavals took place. Two lofty ranges of mountains,—the Sierra Nevada (now with summits more than 14,000 feet high), and the Wahsatch,—400 miles apart, were pushed up from the great subsiding area. These movements were followed by a prolonged subsidence, during which Cretaceous sediments accumulated over the Rocky Mountain region to a depth of 9000 feet or more. Then came another vast uplift, whereby the Cretaceous sediments were elevated into the crest of the mountains, and a parallel coast-range was formed fronting the Pacific. Intense metamorphism of the Cretaceous rocks is stated to have taken place. During the Tertiary ages the Rocky Mountains were permanently raised above the sea, and gradually elevated to their present height. Vast lakes existed among them, in which, as in the Miocene basins of the Alps, enormous masses of sediment accumulated. The slopes of the land were clothed with an abundant vegetation, in which, as already stated (*ante*, p. 365), we may trace the ancestors of many of the living trees of North America. One of the most striking features in the later phases of this history was the outpouring of great floods of trachyte and other lavas from many points and fissures over a vast space of the Rocky Mountains. In the Snake River region these lavas have a depth of 700 to 1000 feet, over an area 300 miles in breadth.

These examples show that the elevation of mountains has been occasional and, so to speak, paroxysmal. Long intervals elapsed when a slow subsidence took place, but at last a point was reached when the descending crust, unable any longer to withstand the accumulated lateral pressure, was forced to find relief by rising into mountain ridges. With this effort the elevatory movements ceased. They were followed either by a stationary period, or more usually by a renewal of the gradual depression, until eventually relief was again obtained by upheaval, sometimes along new lines, but often on those which had previously been used.

We see also how, by such enormous compression, the rocks should have acquired a cleavage structure (*ante*, p. 306). Soft clays have been squeezed and folded till they have become hard fissile slates. So intense have been the corrugation and compression that the strata have undergone a chemical rearrangement of their particles; they have been "metamorphosed" or changed into schists and gneisses, if indeed some portions of them have not been actually fused and intruded into the surrounding masses as igneous rocks.

The consideration of these changes enables us to realize why the strata of a great mountain chain should rise into steeper folds as they are traced away from the plains, until they are found at last folded back upon themselves, and the older are made to overlie the younger. Instead of overlying the central and more ancient masses of the range, they seem really to dip into and under them, so that a section across the region might convey the impression of a great syncline instead of a great and complicated anticline. This fan-shaped arrangement of the rocks may be observed even in the single mountains of a great chain. Mount Blanc is a familiar example.

Another piece of geological structure is sometimes brought vividly before us by the examination of these regions of disturbance. Not only have the rocks been crumpled and inverted; they have likewise been traversed by great dislocations. Those on one side of a fissure have been pushed bodily over those on the other side, or they have experienced a vertical displacement of hundreds or even thousands of feet. As a rule, however, dislocations are more easily traced, if they are not also larger and more numerous, among the low grounds than among the mountains. One of the most remarkable and important faults in Europe is that which bounds the southern edge of the Belgian coal-field. It can be traced across Belgium, has recently been detected in the Boulonnais (*ante*, p. 350, *note*), and may not improbably run beneath the Secondary and Tertiary rocks of the south of England. It is a remarkable fact that faults which have a vertical displacement of many thousands of feet produce little or no effect upon the surface. The great Belgian fault, for example, is crossed by the valleys of the Meuse, and other northerly-flowing streams. Yet so indistinctly is it marked in the Meuse valley that no one would suspect its existence from any peculiarity in the general form of the ground, and even an experienced geologist, until he had learned the structure of the district, would scarcely detect any fault at all.

With the fractures along mountain chains we may connect the hot springs so frequently to be met with in these regions. But the most important connexion with the heated interior is that established by volcanic vents. The theory of secular contraction, while affording a rational explanation of the origin of the great terrestrial ridges, serves at the same time to show why volcanoes should so frequently rise along these ridges (*ante*, p. 254). The elevation of the crust, by diminishing the pressure on the parts beneath the upraised tracts, permits them to assume a liquid condition, and to rise within reach of the surface when, driven upwards by the expansion of superheated vapours, they are ejected in the form of lava or ashes.

It appears therefore that the present contours of the earth's surface must be due in large measure to the effects of the contraction of a cooling globe. The crust has been repeatedly corrugated, sometimes suffering sudden and paroxysmal shocks, at other times undergoing slow and long-continued upheaval and depression.

But these subterranean movements form only one phase of the operations by which the outlines of the land have been produced. They have ridged up the solid crust above the sea-level, and have thus given rise to land, but the land as we now see it has acquired its features from the prolonged and varied action of the epigene agents upon rocks of very varied heights and powers of resistance.

It is evident that, as a whole, the land suffers ceaseless erosion from the time that it appears above water. It is likewise clear, from the nature of the materials composing most of the rocks of the land, that they have been derived from old denudations of the same kind. And thus, side by side with the various upheavals and subsidences, there has been a continuous removal of materials from the land, and an equally persistent deposit of these materials under water, and consequent growth of new rocks.

This degradation of the surface may be aptly compared to a process of sculpturing, which begins as soon as the land emerges from the sea, and never ceases so long as any portion of the land remains above water. The implements employed by nature in this great work are those epigene forces whose operations have already been described. Each of them, like a special kind of graving tool, produces its own characteristic impress on the land. The work of rain, of frost, of rivers, of glaciers, can be readily discriminated, though they all combine harmoniously towards the achievement of their one common task. Hence the present contours of the land must depend partly (1) on the vigour with which the several epigene agents perform their work of erosion, (2) on the original configuration of the ground, and the influence it may have had in guiding the operations of these agents, and (3) on the varying structure and powers of resistance possessed by the rocks.

1. Taking a broad view of denudation, we may conveniently group together the action of air, frost, springs, rivers, glaciers, and the other agents which wear down the surface of the land, under the one common designation of subaerial, and that of the sea as marine. The general results of subaerial action are—to furrow and channel the land, to erode valleys, to sharpen and splinter the ridges of mountains, and thus, while roughening, to lower the general surface and carry out the detritus to the sea. The action of the sea, on the other hand, is to plane down the land to the level at which the influence of breakers and ground-swell ceases to have any erosive effect; the flat platform, so often visible between tide-marks on a rocky exposed coast-line, is an impressive illustration of the tendency of marine denudation. The combined result of subaerial and marine action, if unimpeded by any subterranean movement, would evidently be to reduce the land to one general level under the sea. For, except in that upper marginal zone where the waves and tidal currents play, the waters of the ocean protect the solid rocks which they cover. And the rocks indeed can find no permanent protection anywhere else. But to reduce a large area of land such as a continent to the condition of a submarine plain, would require a longer period of time than seems to have elapsed between two epochs of upheaval. Traces of ancient plains of marine denudation are to be met with in Scandinavia and in Scotland, on but a comparatively small scale, as if there had been time for only a narrow platform to be formed before the next paroxysm of contraction and uplift completely renovated the geography of the region.

Instead of trying to estimate how much work is done by each of the subaerial agents in eroding the land, we gain a much more impressive idea of the reality and magnitude of their work as a whole by treating their operations as one great process, the effects of which can be actually measured. The true gauge of the present yearly waste of the surface of the land is furnished by the amount of mineral matter carried every year into the sea by rivers. This mineral matter is partly in mechanical suspension, partly in chemical solution, and is to no small extent pushed in the form of shingle and sand along the bottoms of the streams. Some data respecting its amount have been already given (*ante*, pp. 274, 278). If we take the ratios furnished by the Mississippi as a fair average, which, from the vast area and varied climatal and geographical characters of the region drained by that river, they probably are, then we learn that $\frac{1}{6000}$th of a foot is worn away from the general surface of the land every year. At this rate, if the present erosion could be sustained, the whole American continent, of which, according to Humboldt, the mean height is 748 feet, would be worn down to the sea-level in about $4\frac{1}{2}$ millions of years—a comparatively short period in geological chronology. It is obvious, however, that the denudation is not equally distributed over the whole surface of the land. If $\frac{1}{6000}$th of a foot is the mean rate from the whole surface, then some parts, including the more level grounds, must lose very much less than that amount, while other parts, such as the slopes and valleys, must lose very much more. The proportions between these extremes must continually vary throughout every country, according to angle of declivity, nature of surface, amount and distribution of rainfall, and whether the rain is spread over the year or concentrated into a short period.

The proportion between the area covered by the more level ground of a country, where the rate of deundation is least, and that of the declivities, valleys, and stream channels, where that rate is greatest, may be assumed as nine to one. The extent of the annual waste may be further taken to be nine times greater over the latter than over the former, so that, while the more level parts of the surface have been lowered 1 foot, the valleys have lost 9 feet. Taking the mean rates of waste over the whole area to be $\frac{1}{6000}$th of a foot per annum we find that on these data the annual loss amounts to $\frac{5}{6}$ths of a foot from the flatter grounds and 5 feet from the valleys in 6000 years. This is equal to a loss of 1 foot from the former in 10,800 years and from the later in 1200 years, or to $\frac{1}{12}$th of an inch from the one in 75 and from the other in $8\frac{1}{2}$ years. At this rate of erosion, a valley 1000 feet deep may be excavated in 1,200,000 years. These estimates are only approximations to the truth, but they are valuable in directing attention to the real efficacy of the apparently insignificant subaerial denudation now in progress. Any other estimates of the relative amount of material worn away from the different parts of the surface may be taken, but the mean annual loss from the whole area, as ascertained by the river discharge, remains unaffected. If we represent too large an amount as removed from the valleys we diminish the loss from the open country, or if we make the contingent derived from the latter too great we lessen that from the former.

2. From this reasoning it follows that, apart altogether from irregularities of surface due to inequalities of upheaval, every area of land exposed to ordinary subaerial action must, in the end, be channeled into a system of valleys. Even a smooth featureless tract elevated uniformly above the sea would eventually be widely and deeply eroded. Nor would this require a long geological period, for, at the present rate of waste in the Mississippi basin, valleys 800 feet might be carved out in a million years. Undoubtedly the original features superinduced by subterranean action would guide and modify the operations of running water, though their influence would certainly wane as the features themselves slowly disappeared. In no case probably would the aboriginal contour remain through a succession of geological periods. Traces of it might still be discernible, but they would be well-nigh effaced by the new outlines produced by the superficial agents. In the vast tablelands of Colorado and the other western territories of the United States an impressive picture is visible of the results of mere subaerial erosion on undisturbed and nearly level strata. Systems of stream-courses and valleys, river gorges unexampled elsewhere in the world for depth and length, vast winding lines of escarpment, like ranges of sea-cliffs, terraced slopes rising from plateau to plateau, huge buttresses and solitary stacks standing like islands out of the plains, great mountain masses towering into picturesque peaks and pinnacles cleft by innumerable gullies, yet everywhere marked by the parallel bars of the horizontal strata out of which they have been carved—these are the orderly symmetrical characteristics of a country where the scenery is due entirely to the action of subaerial agents on the one hand and the varying resistance of perfectly regular stratified rocks on the other. The Alps, on the contrary, present an

instructive example of the kind of scenery that arises where a mass of high ground has resulted from the intense corrugation and upheaval of a complicated series of stratified and crystalline rocks, subsequently for a vast period carved by rain, frost, springs, and glaciers. We see how, on the outer flanks of those mountains among the ridges of the Jura, the strata begin to undulate in long wave-like ridges, and how, as we enter the main chain, the undulations assume a more gigantic tumultuous character, until, along the central heights, the mountains lift themselves towards the sky like the storm-swept crests of vast earth billows. The whole aspect of the ground suggests intense commotion. Where the strata appear along the cliffs or slopes they may often be seen twisted and crumpled on the most gigantic scale. Out of this complicated mass of material the subaerial forces have been ceaselessly at work since its first elevation. They have cut out valleys, sometimes along the original depressions, sometimes down the slopes. They have eroded lake-basins, dug out corries or *cirques*, notched and furrowed the ridges, splintered the crests, and have left no part of the original surface unmodified. But they have not effaced all traces of the convulsions by which the Alps were upheaved.

3. The details of the sculpture of the land have mainly depended on the nature of the materials on which nature's erosive tools have been employed. The joints by which all rocks are traversed have served as dominant lines along which the rain has filtered, and the springs have risen, and the frost wedges have been driven. On the high bare scarps of a high mountain the inner structure of the mass is laid open, and there the system of joints is seen to have determined the lines of crest, the vertical walls of cliff and precipice, the forms of buttress and recess, the position of cleft and chasm, the outline of spire and pinnacle. On the lower slopes, even under the tapestry of verdure which nature delights to hang where she can over her naked rocks, we may detect the same pervading influence of the joints upon the forms assumed by ravines and crags. Each kind of rock, too, gives rise to its own characteristic form of scenery. The massive crystalline rocks, such as granite, yield each in its own fashion to the resistless attacks of the denuding forces. They are broadly marked off from the stratified rocks in which the parallel bands of the bedding form a leading feature in every cliff and bare mountain slope. Among the latter rocks also very distinctive types of surface may be observed. A range of sandstone hills, for example, presents a marked contrast to one of limestone.

In the physiography of any region, the mountains are the dominant features. A true mountain chain consists of rocks which have been crumpled and pushed up in the manner already described. But ranges of hills almost mountainous in their bulk may be formed by the gradual erosion of valleys out of a mass of original high ground. In this way some ancient tablelands, those of Norway and of the Highlands of Scotland, for example, have been so channeled by deep fjords and glens that they now consist of massive rugged hills, either isolated or connected along the flanks. The forms of the valleys thus eroded have been governed partly by the structure and composition of the rocks, and partly by the relative potency of the different denuding agents. Where the influence of rain and frost has been slight, and the streams, supplied from distant sources, have had sufficient declivity, deep, narrow, precipitous ravines or gorges have been excavated. The cañons of the Colorado are a magnificent example of this result. Where, on the other hand, ordinary atmospheric action has been more rapid, the sides of the river channels have been attacked, and open sloping glens and valleys have been hollowed out. A gorge or defile is usually due to the action of a waterfall, which, beginning with some abrupt declivity or precipice in the course of the river when it first commenced to flow, or caused by some hard rock crossing the channel, has eaten its way backward, as already explained (p. 276).

Lakes may have been formed in several ways. 1. By subterranean movements as, for example, during those which gave rise to mountain chains. But these hollows, unless continually deepened by subsequent movements of a similar nature would be filled up by the sediment continually washed into them from the adjoining slopes. The numerous lakes in such a mountain system as the Alps cannot be due merely to this cause, unless we suppose the upheaval of the mountains to have been geologically quite recent, or that subsidence must take place continuously or periodically below each independent basin. But there is evidence that the upheaval of the lakes is not of recent date, while the idea of perpetuating lakes by continual subsidence would demand, not in the Alps merely, but all over the northern hemisphere where lakes are so abundant, an amount of subterranean movement of which, if it really existed, there would assuredly be plenty of other evidence. 2. By irregularities in the deposition of superficial accumulations prior to the elevation of the land or during the disappearance of the ice-sheet. The numerous tarns and lakes enclosed within mounds and ridges of drift-clay and gravel are examples. 3. By the acccumulation of a barrier across the channel of a stream and the consequent ponding back of the water. This may be done, for instance, by a landslip, by the advance of a glacier across a valley, or by the throwing up of a bank by the sea across the mouth of a river. 4. By erosion. The only agent capable of excavating hollows out of the solid rock such as might form lake-basins is glacier-ice (*ante*, p. 282). It is a remarkable fact, of which the significance may now be seen, that the innumerable lake-basins of the northern hemisphere lie on surfaces of intensely ice-worn rock. The striæ can be seen on the smoother rock-surfaces slipping into the water on all sides. These striæ were produced by ice moving over the rock. If the ice could, as the striæ prove, descend into the rock-basins and mount up the farther side, smoothing and striating the rock as it went, it could erode the basins. It is hardly possible to convey in words an adequate conception of the enormous extent to which the north of Europe and North America has had its surface ground down by ice. The ordinary rough surfaces produced by atmospheric disintegration have been replaced by a peculiar flowing contour which is traceable even to below the sea-level.

In the general subaerial denudation of a country, innumerable minor features are worked out as the structure of the rocks controls the operations of the eroding agents. Thus, among comparatively undisturbed strata, a hard bed resting upon others of a softer kind is apt to form along its outcrop a line of cliff or escarpment. Though a long range of such cliffs resembles a coast that has been worn by the sea, it may be entirely due to mere atmospheric waste. Again, the more resisting portions of a rock may be seen projecting as crags or knolls. An igneous mass will stand out as a bold hill from amidst the more decomposable strata through which it has risen. These features, often so marked on the lower grounds, attain their most conspicuous development among the higher and barer parts of the mountains, where subaerial disintegration is most rapid. The torrents tear out deep gullies from the sides of the declivities. Corries are scooped out on the one hand, and naked precipices are left on the other. The harder bands of rock project as massive ribs down the slopes, shoot up into prominent *aiguilles*, or give to the summits the notched saw-like outlines they so often present.

Tablelands may sometimes arise from the abrasion of hard rocks and the production of a level plain by the action of the sea, or rather of that action combined with the previous degradation of the land by subaerial waste. But most of the great tablelands of the globe seem to be platforms of little-disturbed strata which have been upraised bodily to a considerable elevation. No sooner, however, are they placed in that position than they are attacked by running water, and begin to be hollowed out into systems of valleys. As the valleys sink, the platforms between them grow into narrower and more definite ridges, until eventually the level tableland is converted into a complicated network of hills and valleys, wherein, nevertheless, the key to the whole arrangement is furnished by a knowledge of the disposition and effects of the flow of water. The examples of this process brought to light in Colorado, Wyoming, Nevada, and the other western territories, by Newberry, King, Hayden, Powell, and other explorers, are among the most striking monuments of geological operations in the world.

The materials worn from the surface of the higher are spread out over the lower grounds. We have already traced how streams at once begin to drop their freight of sediment when, by the lessening of their declivity, their carrying power is diminished (p. 276–7). The great plains of the earth's surface are due to this deposit of gravel, sand, and loam. They are thus monuments at once of the destructive and reproductive processes which have been in progress unceasingly since the first land rose above the sea and the first shower of rain fell. Every pebble and particle of their soil, once part of the distant mountains, has travelled slowly and fitfully downward. Again and again have these materials been shifted, ever moving downward and sea-ward. For centuries, perhaps, they have taken their share in the fertility of the plains and have ministered to the necessities of flower and tree, of the bird of the air, the beast of the field, and of man himself. But their destiny is still the great ocean. In that bourne alone can they find undisturbed repose, and there, slowly accumulating in massive beds, they will remain until, in the course of ages, renewed upheaval shall raise them into future land, there once more to pass through the same cycle of change. (A. GE.)

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