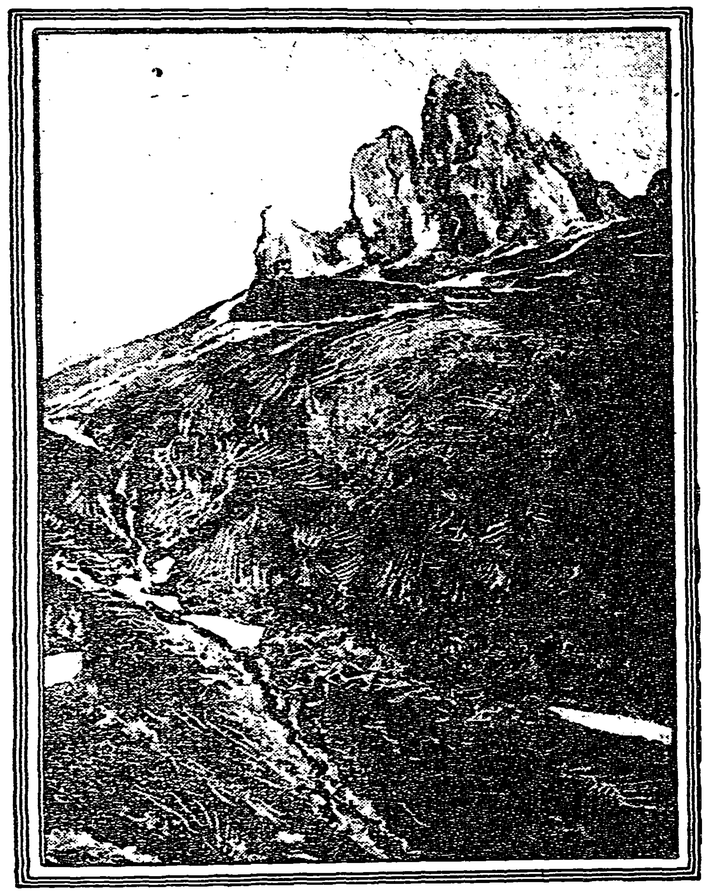
THE ALPS WILL SOME DAY BE LEVELED, SAYS GEOLOGIST

Once Drowned in the Sea, They Will Again Be Brought Low---Already Four-fifths Washed Away, Their Dissolution Is Predicted by James Geikie, F. R. S., of Edinburgh University.

By James Geikie, LL.D., D.C.L., F.R.S. Dean of the Faculty of Science, Edinburgh University, and Author of Works on Geology.

THE basement rocks of the Alps represent the southern seacoast tract of an ancient land which had come into existence during the closing stages of the Palaeozoic era. That land was throughout more or less mountainous in character and extended far north into what is now Middle Europe. It was bounded on the south by a much more extensive Mediterranean than that of our day. Coming into existence in the age succeeding the formation of the world's coal beds it persisted as a continental area for a very prolonged period, during which it suffered excessive wearing away. Its chains and ranges were thus gradually reduced and degraded, and over wide tracts became replaced by undulating low grounds. Here and there, however, more or less prominent heights survived—the stumps and torsos, as it were, of the old mountains. Before the complete reduction of the land could be accomplished a movement of sinking ensued. This depression affected the Alpine region especially, but was likewise experienced throughout extensive



The Great Spannort.

areas of Middle Europe. Slowly the reduced Alpine land sank—its more prominent heights enduring for a long time as gradually diminishing islands. The sinking movement, although now and again interrupted, may be said to have prevailed throughout the whole course of the protracted era of the second strata of rocks above the most ancient formations. Immense deposits of sediment had thus ample time to accumulate over the slowly subsiding seafloor. When the dawn of the tertiary era, or that in which later forms of life appear, approached, the ancient Alpine land, next oldest of geologic forms, had all but vanished—only a few small islands remaining, and by and by these too sank in the broadening Mediterranean.

In this way the drowned ancient Alpine country was at last completely buried under a varying thickness of sediments—mostly of the sea. The submergence appears to have been greatest in the south and least in the north, but what are now the central parts of the Swiss Alps would seem to have been as deeply depressed as any. Owing to the irregular depths of the seas of the third geologic era and the period of later life-forms the sediments naturally attained their greatest thickness over what had been the low lying tracts of the drowned land, and thinned away across the heights which had for so long a period survived as islands.

Thus the conditions that obtained over the Alpine area just before the great crustal movements of the era of later life-forms began were simply these: an ancient much reduced mountain-land submerged and covered throughout by a vast succession of horizontal beds—reaching in some places a thickness of 10,000 or 15,000 feet. The buried land is built up chiefly of crystalline masses and some strata formed during the period of excessive vegetation, while the overlying bedded series range in age from the early part of the third geologic era down to that of later life forms. Geologists have no means of computing the time required for the accumulation of that most impressive succession of formations. But when we think of the many geographical and climatic changes—of the extensive evolution of life-forms—the successive appearance and disappearance of aggregates of plants and animals—that took place between the close of the next most ancient of land-forms and the dawn of the era of later life, we are forced to admit that many millions of years must have been consumed in merely bringing together the materials for the construction of the present Alps upon the site of the ancient Alpine land.

"Folded Mountains."

These Alps may well be taken as a type of what are known as folded mountains—a class which includes all the greatest chains and ranges of the globe—the Himalayas, the Rockies, the Andes, and many less conspicuous heights. All these owe their origin to movements of compression whereby their rock-masses have been buckled up, dislocated, and displaced. The movements referred to are doubtless due to the wrinkling of the earth's crust over the slowly cooling and contracting interior. The crust having already cooled cannot contract to the same extent, and therefore as it subsides it is compelled to accommodate itself to the shrinking nucleus by folding and breaking. The relief to compression may be expressed either by the crust—that is, by the bulging upward of extensive areas, accompanied not infrequently by much subordinate warping, flexing, and folding of a more or less gentle or moderate character. Cases of this kind are termed "regional uplifts." In other cases, however, the crust yields along some distinct zone of great length, it may be, but of relatively narrow width. Under such conditions compression usually results in the formation of more or less numerous steeply inclined folds and in the displacement on a level of great rock-sheets. The general character of the rock-folds and displacements in these "axial uplifts" naturally varies according to the degree of crustal compression. When the pressure sidewise has not been excessive the folds may be more or less symmetrical in form, and relatively inconsiderable horizontal displacements may occur. But when crustal compression has been most vigorous the resulting flexures, folds, and rock-displacements are correspondingly pronounced and often astonishingly complicated.

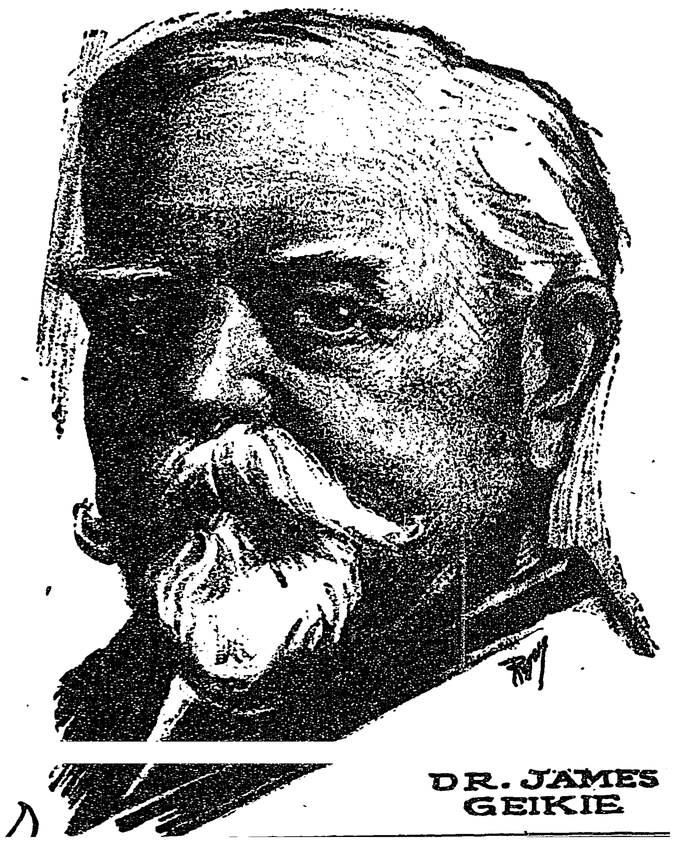
In great mountain uplifts folds often occur on a gigantic scale, and could only have been caused by intense tangential pressure. It is, therefore, not surprising that in their case excessive rock-displacement should frequently have taken place—sheets of rock, thousands of feet in thickness, and of vast extent, having been forced to move along approximately horizontal levels or up gentle inclines for distances of many miles. But rock-displacements on this grand scale have not always been preceded by folding. Frequently the rocks subjected to great pressure along the surface have yielded without any preliminary doubling or buckling up, and enormous slices or sheets have been driven successively for miles one over another. Thus, partly by the rupturing of extensive reclining folds and partly by direct displacement along horizontal or inclined planes, the oldest rocks in a mountain region frequently overlie the youngest—both kinds of crustal deformation having resulted from an irresistible thrust in some particular direction.

The great crustal movement to which the present Alps owe their origin followed a general northerly direction. It is, of course, hard to say to what extent the area undergoing compression was affected during the earlier stages of the movement. The probabilities are, however, that the first notable result of pressure would be the elevation of the sea-floor, and the appearance of a broad flat land extending over what is now the Alpine area. Even at that early stage a certain amount of warping of the new land surface may have taken place—the ground possibly rising and falling in long gentle waves or undulations. At considerable depths from the surface, however, crustal deformation would be more pronounced. The folds, at first symmetrical, would become gradually deformed and distorted or asymmetrical: the crowns of the saddlebacks ing over more and more in the direction of movement, until they assumed a recumbent position and finally yielded to pressure along the surface. Great rock-sheets of various thickness and tent would then begin to move up gentle inclines or to creep along approximately horizontal "thrust-planes." Meanwhile, the deeper parts of the folds—the synclines or so-called "roots"—tarrying behind, would tend under continued pressure to assume steep and vertical positions.

Several series of complex folds and overthrust rock-sheets were developed successively in the northern, in the central, and, finally, in the southern zones of the Alpine area—each complex following, and eventually overtaking, and to some extent overlapping its predecessor. While the removal of these several sheets was in progress the downward bends of the original folds—the deep-seated "roots," although relatively stationary, were becoming ever more compressed and steeper, so as to occupy less space, and the interval separating one sheaf of "roots" from another necessarily diminished in proportion.

Mountains Traveled Into Place.

When rock-sheet after rock-sheet was being driven forward, the existing lofty mountain ranges had not as yet made their appearance. There may well have been a general bulging upward of the whole compressed area, but the dominating massifs of our day—Mont Blanc, the Aiguilles Rouges, the Gotthard, and Aar massifs—had not as yet shown themselves—their elevation belongs to a later phase of the great crustal movement. The invasion of the northern zone by exotic rock-sheets, therefore, was not opposed by any insuperable mountain barrier. When the removal of successive rock-sheets had been completed, the ancient palaeozoic land lay deeply buried in Switzerland—the earliest traveled rock-sheets being covered and concealed by their successors. If it took millions of years to bring together materials for the construction of the Alps, long aeons were required for the process of building—for piling up rock-sheet upon rock-sheet. Crustal movement had begun before the close of eocene times, was continued throughout the subsequent oligocene and miocene periods, and had apparently not quite ceased before the advent of prehistoric man, if indeed it has even now completely died away. In a word, the movement of compression must have extended over several millions of years.

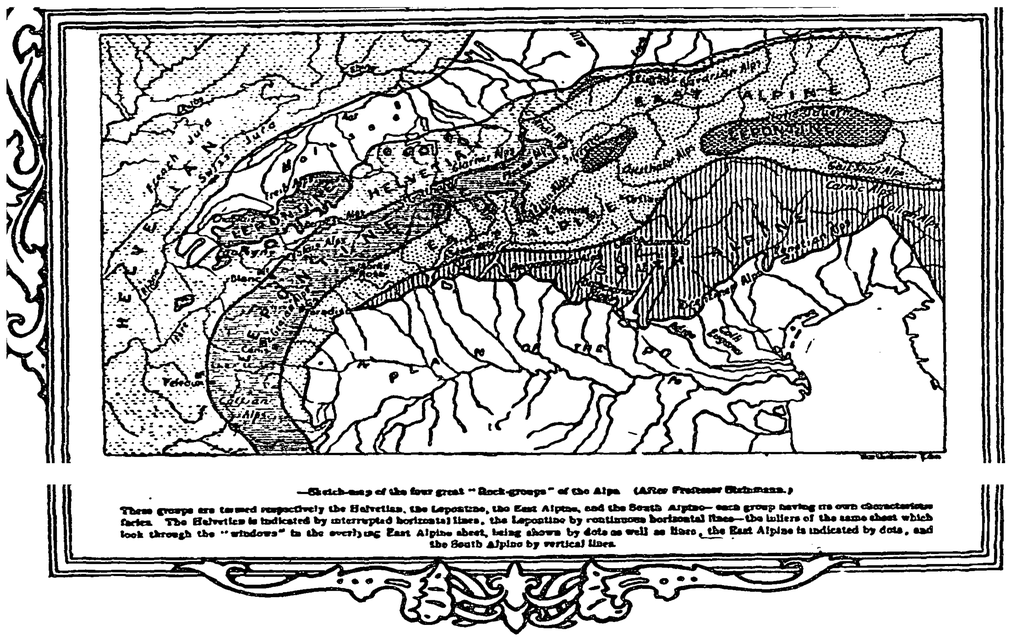


DR. JAMES GEIKIE

We come now to a very interesting episode in the history of the Alps. When the last of the foreign rock-sheets had ceased to move, North Switzerland appears to have been represented by an elevated tract extending in a northeast and southwest direction. Soon after the dawn of the present geological formations an inland sea covered the site of the present Jura Mountains, and laved the north front of the Alpine area, where it maintained its position for a prolonged period. This is proved by the simple fact that thick masses of sediment had time to gather over the floor of the sea that preceded the fourth geologic age—all of them derived from the denudation of the Alpine area. Torrential streams and rivers swept down to the sea vast quantities of shingle and gravel, and doubtless waves ate their way into the land, and thus played a part in the work of degradation and accumulation.

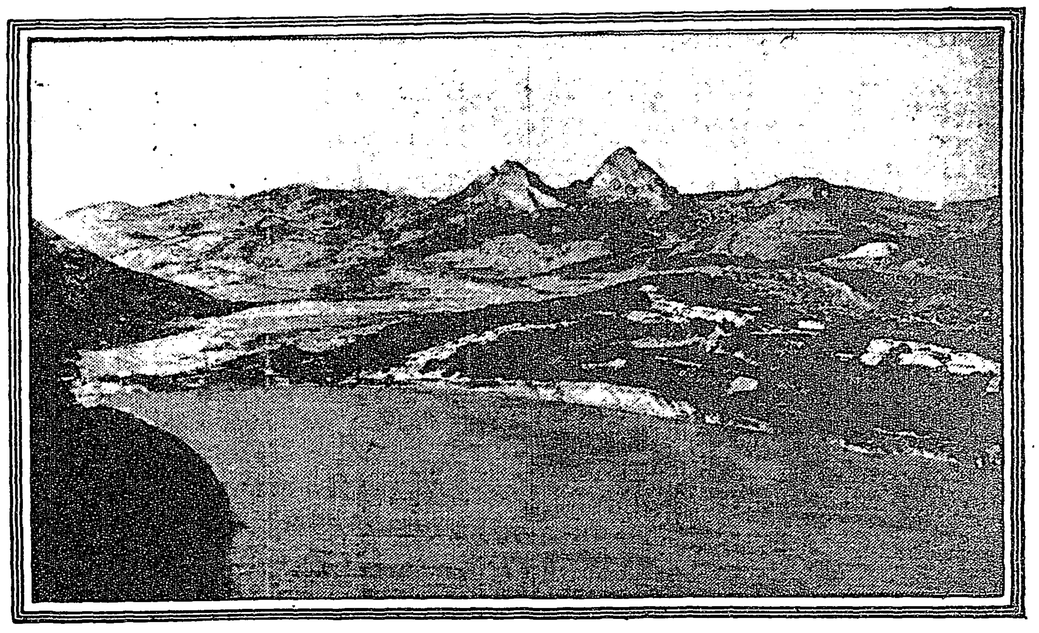
During the second phase of deformation the fundamental crystalline rocks found relief from renewed compression partly by folding, but chiefly by rising vertically. In a word, the grand massifs of Aar-Gotthard, of the Aiguilles Rouges, and Mont Blanc slowly bulged upward. At the same time the irresistible thrust that caused these upheavals affected all the regions lying to the north and northwest.

Long before this stage, however, the upper rock-sheets in northeast Switzerland had been largely denuded away, leaving the underlying Helvetian sheets exposed over an extensive area. Now strongly compressed, these sheets rose in a series of gigantic folds. It was at this particular stage that the folded



—Sketch-map of the four great "Rock-groups" of the Alps. (After Professor Heim.)

These groups are named respectively the Helvetian, the Lepontine, the East Alpine, and the South Alpine—each group having its own characteristic facies. The Helvetics is indicated by interrupted horizontal lines, the Lepontine by continuous horizontal lines—the hillers of the same sheet which look through the "windows" in the overlying East Alpine sheet, being shown by dots as well as lines, the East Alpine is indicated by dots, and the South Alpine by vertical lines.



The Great and Little Mythen and Rote Fluh.

These mountains have no roots, but consist of exotic Jurassic and cretaceous rocks which rest upon the much younger Flysch. The mountains are simply gigantic "erratics"—isolated fragments of the Lepontine rock sheets.

ranges of the Jura came into existence. The upheaval of these mountains, in a word, was of the same age with that of the lofty limestone ranges of the Säntis.

The upheaval of the basal crystalline rocks lifted them into a region where waste in the atmosphere is always carried on most actively, and their destruction must therefore have been rapidly effected. Not improbably, indeed, they may have been removed long before the massifs had reached their greatest elevation. A few relics, however, may still be seen capping the rocks that split and cleave of the massif or dominant ridge of the Aar—such, for example, as the acute peaks of the Great Spannort (10,500 feet) and the Little Spannort (10,300 feet) overlooking the Engelberg Valley.

Certain isolated hills and mountains, and even continuous ranges, occur in North Switzerland, which, like the erratics of the "Flysch," are of alien origin. Their immigrant character is demonstrated by the simple fact that they are "mountains without roots"—they have no original connection with the pavement rocks on which they rest, for the latter are much younger than the masses above them. Between the valley of the Rhine and Lake Thun, for example, and particularly in the neighborhood of the Lake of Lucerne, there are certain prominent hills and mountains, such as the Mythen, Mördergrube, Bouchserhorn, Stanserhorn, and the Giswiler Stock (west of the Lungern See)—heights of 6,000 feet or more, all of which are built up of rocks quite foreign to that region. They are in fact immigrants—lonely fragments of the great Lepontine sheets of rocks of the third series which, during the earlier phase of the mountain-making process, were thrust forward from the south, and came to rest at last upon the much younger strata formed in the fourth geologic age of North Switzerland. Such outlying remnants of the traveled rock-sheets or "decken" are called by Swiss geologists "klippen," for which we have no satisfactory equivalent in English, unless we may substitute the geographical term "drongs," as used in Shetland—pillar-like rocks standing separate from a line of cliffs.

The Tattered Alps.

Owing to the extraordinary washing away of the Alps it will readily be believed that the several traveled rock-sheets are now in a very tattered condition. The Helvetian, whose "roots" appear in the valleys of the Vorder Rhine and the Rhone, has been cleared away from the Aar massif, but puts in a strong appearance north of that massif, where it constitutes the border ranges of the Limestone Alps, stretching from Säntis and Churfirsten southwest to the Lake of Lucerne, Lake Thun, and the Diablerets. The Lepontine, the "roots" of which occur chiefly south of the Gotthard massif, formerly covered the Helvetian extensively, but has since vanished from wide areas. Its most conspicuous remnants in North Switzerland form the "Voralps" of Chablais and the Stockhorn, and the pre-Alps of the Bernese Oberland up to the foot of the Diablerets and the Wildstrubel. East of the Lake of Thun it is represented by the Klippen or Drongs already described. Its most extensive exposure, however, occurs further south, and comprises the mountains of Graubünden that border on the Vorder Rhine, the Alps of Valais, the Graian Alps, &c. Overlaid on the south by the East Alpine sheet, it continues eastward under that sheet for an unknown distance. Its prolongation in that direction, however, is proved by the notable fact that in Lower Engadine it peers through a great aperture, or "window" as it is called, in the overlying East Alpine sheet. In the region of the Hohe Tauern a similar but much larger "window" has been opened in the same far-spreading sheet, through which look out the Lepontine masses of the Gros Glockner and its giant associates.

From the foregoing brief account of the essential characters of Alpine architecture it may be gathered that the occurrence of older overlying younger rocks is much the most notable. "Inversion," as it is termed, is the outstanding feature in the structure of the mountains.

The great inversions are everywhere explained by overfolding and horizontal movement in one general direction, and on a much grander scale than was at first suspected. This conception of Alpine structure so boldly outlined by Marcel Bertrand is applicable to every part of the great chain which has been critically examined.

While overfolding and extensive thrust-planes are the most characteristic features of Alpine architecture, it must not be forgotten that compression resulted also in the bulging up or general elevation of the entire Alpine area. Many years ago Prof. Heim was of opinion that if all the Alpine folds could be smoothed out, and the beds could regain their original undisturbed position, they would necessarily extend over a much wider area; the two points Zürich and Como, for example, would be further apart by some 74½ to 93 miles. This estimate, he now thinks, is considerably under the mark. According to him the Alpine area before compression was a flat land, measuring probably 372½ to 745 miles. Instead of this broad, low-lying tract, we have now a lofty mountain chain averaging not more than 93 miles in width!

Action of the Waters.

Denudation must have commenced with the first appearance of the Alpine area as dry land, and doubtless continued without pause throughout the whole period of mountain growth. Thus, long before the final phase of crustal compression had been inaugurated, a prodigious amount of erosion or wearing away must have been effected. The molasse of the fourth period, with its great masses of shingle, gravel, and sand, is sufficient evidence of that. And if denudation was in active progress during the first phase of crustal deformation, we may feel sure that the final phase was in like manner accompanied throughout by never-ceasing erosion.

What the direction of its drainage system may have been when the Alpine area appeared above the level of the sea formed in the fourth geologic age can only be conjectured. The land probably at first showed a somewhat level or flat surface. Even at that incipient stage, however, there may have been a slight bulge at the axis sufficient to form an east-and-west or a northeast and southwest watershed. If that were so, then transverse streams and rivers would be the earliest to appear. When the crustal movement had been in progress for some time, the larger lengthwise folds must have wrinkled the surface and influenced the drainage. It is not improbable, therefore, that at a very early stage in the development of the Alps both crosswise and longitudinal rivers had come into existence.

When we are speculating on the effect produced at the surface by crustal deformation, we must remember that the complicated rock structures everywhere conspicuous in the Alps originated under an enormous thickness of strata. Flexures and folds of the kind could therefore have had only a moderate influence on the configuration of the surface. No doubt deep-seated rocks must frequently have snapped under stress and strain, causing tremors, jarrings, and earthquakes, so that rock-falls and landslips at the surface may often have occurred, and brought about multiform local modifications of the drainage. It is highly probable, moreover, that crustal compression may again and again have expressed itself at the surface by elevations of a more or less pronounced kind, which would bring into existence many younger streams and rivers. There is no evidence, however, to suggest that the subterranean processes referred to ever resulted in wholesale revolution of the Alpine drainage system.

As torrents, streams, and rivers cut their way down into an uprising massif, larger and larger surfaces of rock became exposed to subaerial action. The shattered débris detached from cliff and mountain slope, slowly or more rapidly enters the drainage system, gradually becoming reduced, and eventually is swept away as gravel, sand, and mud beyond the limits of the mountain area. In this manner profound and broad valleys are excavated, and these continue to be deepened and widened all the time that mountain-making goes on. In short, the rate of erosion keeps pace with or may even exceed the rate of rock-folding and uplift, and thus mountain range after mountain range may be successively sawn across by the primary rivers of a region undergoing crustal compression. The Indus, for example, has neither been dammed back nor deflected by the secondary and more recently formed ranges of the Himalaya, but has cut its way down through these mountains as fast as they rose. The same phenomenon confronts us in North Switzerland, where the Rhine traverses the young Helvetian folds on its way to the Lake of Constance. While folded mountains, therefore, cannot be developed across the valleys of active rivers, their growth outside of these valleys is not prevented by the other agents of erosion on the surfaces, however much the latter may modify their configuration.

The protracted process of crustal deformation must from time to time have brought new streams and rivers into existence, and these would forthwith enter into competition, so to say, with others of earlier origin. Some streams, owing to various circumstances, such as steeper regular rise and larger volume, are more energetic workers than others in their vicinity. A transverse stream, for example, may cut its way back toward its water-parting, and eventually breach the ridge in which it rises, and thus open a way into a longitudinal valley occupying a higher level. The river in the latter may consequently be captured and diverted into a transverse course. Many captures of the kind have been effected throughout the Alpine lands, and not improbably most of the erratic courses pursued by the streams and rivers have originated in such ways. To the action of the streams must be added that of the enormous glaciers of the Ice Age, which, partly by profound erosion and partly by accumulation of heaps of rocks and materials left by glacial streams, have produced many remarkable changes in the drainage system of the Alps. The history of the evolution of Alpine valleys would require a volume to itself to do it justice.

When it is recognized that the existing mountains represent only a fourth or a fifth part of the original land mass it needs but little imagination to conceive of a time when the entire region must be reduced to its base-level. Should no renewed crustal compression supervene all that vast array of stupendous heights must gradually crumble down and be ultimately replaced by a gently undulating plain. The process of decay, everywhere conspicuous, will go on apace until, with the gradual lowering of the surface, the rate of waste will diminish, but nevertheless degradation will never cease. The rivers and their multitudinous tributaries must continue to deepen and widen their valleys, and to cut back into their watersheds, and thus the mountain-ridges that separate the valleys will gradually lose in height and width. All the beautiful lakes will disappear at an early stage. At present they form the base-levels of the drainage-areas in which they lie—they are the receptacles of the waste-materials of the mountains, and must be relatively soon silted up. Thereafter the loosened fragments of the Alps will make their way by the great rivers to the sea, which will then have become the base-level. Slowly but surely the plain-tracks of rivers and streams will travel up the valleys—slowly but surely the heights of the land must be reduced, until the entire Alpine area is finally resolved into a rolling plain.

The lowering of the land continues, and will not cease, even should occasional uplifts recur, until the region is either submerged or worn down to its base level.

The New York Times
Published: October 27, 1912