Upon Glaciers, Moraines, and Erratic Blocks; being the Address delivered at the opening of the Helvetic Natural History Society, at Neuchatel, on the 24th of July 1837, *by its President,* M. L. Agassiz.

Gentlemen,—It is now a considerable period since the Neuchatel members of our Society have longed for the time when they could invite their associates throughout Switzerland, to congregate amongst them. Circumstances, however, over which they had no control, and more especially the erection of the building in which we are now assembled, and which is intended for the reception of the various scientific collections, have compelled them to delay this honour till they could proffer it without inconvenience to their guests, and till they could submit to their inspection a part at least of their museum. Even now, in spite of the extraordinary exertions of the indefatigable keeper of our museum, but a small portion of the specimens are yet displayed; they have likewise been arranged with haste; and the workmen have scarcely quitted the premises. We therefore need your indulgence, but trust you will not the less doubt the satisfaction with which we receive you, and the high gratification it affords us. From our hearts we gladly bid you welcome!

On such an occasion as the present, we are naturally led to inquire, What is the bond which connects the different sciences that are prosecuted by our Society? I do not hesitate to affirm that one grand idea pervades all the exertions directed to the extension of the limits of these sciences;—it is a belief in progressive development throughout creation, of a transformation extending through different states which are dependent upon each other;—it is the conception of an intelligible connection, concerning which our task is to ascertain the relations of all the phenomena which come under our observation. In this view we may regard Astronomy, engaged with the formation of the celestial spheres; Chemistry, investigating the molecular actions which bodies exert upon each other; Natural Philosophy, appreciating the nature of those forces whose actions are

tained; Natural History, considering the phases of life throughout animated nature; and, finally, Geology, which ventures to comprehend the history of our globe, to decipher its oldest records, and to represent them as one grand whole, whose various revolutions have invariably tended to one great result.

From the progress of these, there will, no doubt, one day appear a noble result, something worthy of *Man*, which will introduce the cultivation of the natural sciences within the circle and sympathies of social life, more powerfully than all the advantages which they bestow upon industry and the arts, however prodigious these may be.

Our society has not been a stranger to the movement here alluded to, and the names of its members appear honourably by the side of those masters in science who have united with us in our labours. This very day's meeting, better perhaps than any other, may prove that my assertion is not at all exaggerated. You, gentlemen, know that our small society has served as a model to those vast associations in Germany, England, and France, which can boast of so many illustrious names; and if the labours which it has undertaken have appeared less brilliant than those accomplished by greater societies, it has at least given the first impulse to more than one interesting undertaking.

Still more recently, two of our members have, by their researches, given rise to discussions of the deepest importance, and the result of which will resound far and near. The locality in which we have now met, leads me again to introduce to your notice a subject whose solution will be found in the examination of the slopes of our Jura. I mean to speak of glaciers, moraines, and erratic blocks.

Every one in Switzerland is familiar with the glaciers, and knows that their margins are bounded by dykes of roundish blocks which are called *moraines*, and which are continually pushed forwards, or abandoned, by the glaciers, as these advance or retire. The inhabitants of the Jura especially are acquainted with another phenomenon which is striking among our mountains,—I mean that of *erratic blocks*, or those masses of granite and other primitive rocks, which are found chiefly on the southern slopes of the Jura. It is not, however, so gene-

rally known that other moraines exist besides those which, at the present day, skirt the edges of the glaciers. Messrs Venetz and Charpentier were the first to introduce these to notice, and they have observed them chiefly in the lower valleys of the Alps. One point regarding these remains still to be discussed; it is the connexion which it has been endeavoured to establish between these erratic blocks, and the glaciers which formed the nucleus or matrix, so to speak, of the great moraines, the traces of which are still found upon the northern shores of the Lake of Geneva. It is to this point I now intend to request your attention.

The *facts*, at all events, which have been observed by Messrs Venetz and Charpentier * have been gained for science; and it is also important to proclaim their extreme accuracy, for upon this naturally depends the validity of whatever conclusions may be legitimately deduced from them.

At distances, more or less considerable, from the existing glaciers, we find, at different elevations, moraines which are perfectly similar to those which still encircle the glaciers. They are equally concentric, and form walls which follow the sinuosities of the sides of the valleys. Every where many stages of them may be discovered, the most elevated of which may be found some hundreds of feet above the bottom of the upper valleys of the Alps, where glaciers now no longer exist. In descending into the *lower* valleys, we still encounter them, at the successive elevations of twelve and fifteen hundred feet, and even at eighteen hundred feet; there are also some, which are quite distinct, at a height of two thousand feet above the bed of the Rhone, in the neighbourhood of Saint-Maurice in the Valais. They may be followed even to the margin of the Lake of Geneva. Some very elevated ones exist above Vevey, and in the environs of Lausanne, which correspond with those on the southern side of the lake.

If these moraines are not generally noticed, this is owing to the fact, that they are much more elevated than are any of the common routes, and that those occurring in the lower districts have generally been much disturbed by descending torrents.

It is not at all a difficult matter to distinguish these ancient

* See this Journal, vol. xxi. p. 210, and vol. xxii. p. 27.

moraines from the dykes which are formed by the overflow of water, and from the masses of debris, more or less extensive, which are produced by avalanches. The dykes are very irregular, and extend only to small distances, when they gradually become level; the masses of debris from avalanches again assume the shape of very flattened cones, debouching from the valleys, and gradually losing themselves in the plains; whilst the moraines are continuous and parallel dykes or walls, which extend along the two sides of the valleys, and are formed of rounded blocks, that have been evidently triturated, so to speak, *in situ*, one against the other, as actually happens at the margin of the modern glaciers, which occur in long and narrow valleys. The blocks of avalanches, on the contrary, are angular; those of the dykes formed by torrents may, indeed be rounded, when, for example, they are derived from broken up moraines, but then they extend themselves in irregular plane surfaces or sheets; and when they are derived from recent avalanches, they are equally angular, unless in their progress they meet with ancient moraines, which they carry along with them, and mix with their own constituent parts.

That we may be convinced of the accuracy of these facts, all that is necessary is to traverse the valley of Chamouni, there tracing the moraines which approach nearest to the glaciers, or to mount perpendicularly upon the sides of the valley of the Rhone, between Saint-Maurice and Martigny, on the left bank, above the Pissevache, near the hamlet of Chaux-Fleurie (Tsaufria), or on the opposite bank, ascending from the village of Morcles to the baths at Lavey. The rubbish of the late *débâcles* of the Dent du Midi, the immense avalanches whose traces are every where seen, and the numerous dykes formed by the Rhone, will, moreover, enable us justly to appreciate the difference which exists in those various phenomena produced by such different causes.

Lateral valleys, it should be remarked, exhibit the same phenomena, which may be seen by ascending the course of the Avençon, as far as the glacier of Paneyrossaz.

In perambulating these valleys, nothing has exited my attention more than a peculiar polished appearance which those rocks present on which glaciers have moved, an appearance

which may be observed not less distinctly in all the valleys the flanks of which are crowned with ancient moraines, at whatsoever distance they may now be from the existing glaciers. In fact the whole sides of the valley of the Rhone are thus polished, to the very shores of the Lake of Geneva, more than a day's journey from the glaciers, and in all places where the rocks are so hard as to have resisted the influence of the atmosphere.

The *explanation* which M. de Charpentier has given of these facts, viz. that they are clearly produced by great masses of ice which, at a former time, had filled the bottom of all the Alpine valleys, does not appear to embrace the whole question, and the Jura exhibits a series of phenomena which lead to additional conclusions.

That I may more satisfactorily discuss what I mean to advance on this subject, I shall first make some remarks on those polished surfaces which are to be found over the whole of the southern slope of the Jura, and which are designated *laves* by our mountaineers, as we are informed by M. Leopold de Buch, the individual who, of all geologists, was the first deeply to study the Neuchatel Jura, and who has most successfully investigated the subject which now engages our attention.

The southern slope of the Jura, which fronts the Alps, exhibits these *laves* to its very summits, from the shores of the lake Bienne even to beyond Orbe, limits within which I have myself ascertained their existence.* They are polished surfaces completely independent of the stratification of the beds and of the direction of the mountain-chain of the Jura; they extend over the whole surface, following its undulations, and are equally marked upon the Neocomian and the Jurassic rocks; they penetrate into the depressions which form the little valleys, and elevate themselves on the most isolated ridges, presenting a polish not less uniform than that of a mirror, especially where the rocks have been recently exposed, that is to say, cleared of the earth, gravel, and sand which generally cover them. These surfaces are sometimes plane, sometimes undulated, and often even traversed by furrows more or less deep and tortuous, or with longitudinal very rounded elevations, but which never follow the direction of the slope of the mountain; on the contrary, like the gibbosities, these furrows are oblique and longitudinal, a direction which excludes every idea of a stream of water being the cause of these erosions. Another curious fact, which is quite inconsistent with the action of water as their cause, is, that these polished surfaces are uniform, even where the rock is composed of fragments of different degrees of hardness, and the shells which it contains are sliced as in an artificially polished slab of marble. We likewise remark, upon the surfaces which are at all fresh, a number of fine lines or scratches, similar to those produced by a diamond on glass, and which in general follow the direction of the oblique furrows.

* They extend much further, as we learn by a letter from M. Schimper, received July 25, and inserted in the Transactions of the Society, p. 38.

The localities in which these appearances may most readily be perceived in the environs of Neuchatel, are the Mail, on the side of the lake, at the surface of the *Neocomian* formation, and at the Plan, at the spot where the old road joins the new one. The most remarkable, however, are at some distance from the town, as, for example, above Landeron, on the surface of the *Portland* rock, at the confines of the vineyard and the forest, in the neighbourhood of Saint-Aubin and above Concise.

In some localities great excavations may be observed, and even something very like walls, which could only have been produced by the cascades which descend between the fissures of the ice. To any one who has examined in the Alps the bottoms of the ancient glaciers, it appears manifest that it is the ice which has produced these polished surfaces, as, for example, those in the valley of the Rhone, to which we have above alluded. It is worthy of remark, that these surfaces are never found at the bottoms of the small longitudinal valleys which are formed by the abrupt faces of the different zones of beds which compose our chains, nor even upon the escarpment of those of such mural walls as look towards the mountain, whilst I have noticed them on many steeps which look towards the Alps, as, for example, along the new road between Saint-Aubin and the Castle of Vauxmarcus.

It is of no less importance to point out the differences which exist between these *laves* and the other polished surfaces with which they may be confounded, but which resemble them only in a few particulars. I allude to the polished surfaces which

are produced by faults, or by the sliding of strata upon one another. The former of these, penetrating vertically or obliquely across many strata, are not visible except when one of the sides of the ruptured rock is sunk; they are, moreover, never seen over a somewhat extended surface, as are the laves: the latter, or sliding strata, sometimes present surfaces which are pretty extensive, when the beds above the slide have been removed; but then the grooves or furrows produced by the sliding are in the direction of the slope, which is by no means one of their characters on the surface of the *laves*. Surfaces which are polished by the action of water also possess a peculiar character, whether produced by running streams or by more considerable masses of water contained in a lake, &c. In the former case the sinuous furrows always descend; whilst the furrows and the gibbosities of the *laves* ascend and descend with the accidental surface of the polished rock. In the latter case, the waters, agitated near the shore by the winds, and raised above their habitual level, always regain their equilibrium, and thus form unequal furrows, more or less deep, which usually follow the line of the greatest inclination, at all events when there are no local peculiarities to impart to them a different direction. This occurs when the waters of the lake are high or low, in spring-time and autumn. All these differences may be studied in the immediate neighbourhood of this city, by comparing the polished surfaces of the *Mail* with the erosions produced by the lake in the prolongation of the same beds, or with the sinuosities which have been produced by the Seyon in its ravines. I may add, that the polished surfaces produced by the action of water are never so smooth as these *laves*, or as the surfaces polished by the glaciers. When the water is charged with sand or mud, the same effects are produced, with this modification, that they are not quite so marked. I have not hitherto had occasion particularly to study the effects produced by great masses of water charged with ice; I believe, however, they are much the same as those produced by simple water. One thing is clear, viz. that in the beds of our rivers, and at the margins of our lakes, both of these effects are produced; and it is moreover evident, that floating ice can produce no action at the under surface of the water that supports

it. It follows, therefore, that it is only the movement of great masses of ice immediately upon solid masses, which can produce effects similar to the polish which we remark upon the margins of the retreating glaciers. This last phenomenon perfectly resembles that which is exhibited by the *laves* of the Jura.

By this similarity alone we might be led, in application to this phenomenon, to conclude, that like causes have produced like effects. But there is another class of considerations which more directly lead us to associate these two phenomena, and which will compel even those who would resort to different agencies, to regard them under one and the same point of view.

We have witnessed moraines on the very margin of the lake of Geneva, and on both banks, at the same elevation; we have thereby the certainty that there was a time when the lake was frozen to the bottom, and when this ice was elevated to a considerable height above its present level.

But we also know that all the moraines which remain *in situ* are such as the glaciers leave in retiring. Since the epoch, then, which I have just mentioned, or in which the glaciers still debouched in the lower Swiss valleys, they have gone on diminishing and retiring into the more elevated and higher valleys.

Here, then, a question naturally suggests itself, Have those glaciers which have extended to the greatest distances, descended from the summit of the Alps? or was there a time when the ice was naturally formed beyond the limits within which we now see it confined, reaching even to the Jura, and possibly beyond it?

The level of the moraines on the shores of the Lake of Geneva, viz. 2500 feet above the sea, and the nature of the polished surfaces on the Jura, would lead to this conclusion. We have, moreover, only to mark on a chart of the levels the heights of the moraines which debouch in the different localities of the alpine chains, to be convinced that ice at one time covered the whole of the plain of Switzerland, and reached the slope of the Jura. *

* M. Rod. Blanchet, who has been engaged upon this subject, has some

In truth, the difference of level between the elevation of the moraines on the border of the lake of Geneva, of those in the neighbourhood of Vevey, and on the side of Savoy, and that of the polished surfaces which are observed above the margin of the lake of Neuchatel, and onwards to the very summit of Chaumont, is such that the sheet of ice which filled the space comprised within these limits, must have had a certain inclination, since the level of the lake of Neuchatel is only 1344 feet above the level of the sea, that of the zone of Pierre-à-Bot, along which the greatest number of boulders is found, is 2150 feet, and the summit of Chaumont itself is only 3619 feet above the level of the sea.

This being the case then, we are not only entitled to attribute to the action of ice all the polished surfaces we find on the slope of the Jura, but also to regard these surfaces as a certain index of the wider limits which the ice had at a former period both over the Jura and the Alps.

M. Charpentier imagines, that these masses of ice were glaciers which were formed on the summit of the Alps, and which had descended into the plain, and had then been elevated to the heights in which we now find their traces, forcing before them the blocks which are now reposing on the Jura. There is a striking fact, however, which is in opposition to this explanation: it is, that the Jura blocks are usually less rounded and even of a larger size than those which are found in the moraines at the margin of the existing glaciers.* If our blocks had been thus rolled in front of a glacier from the Alps as far as the Jura,

time ago remarked, that the summit of the Pèlerin, the mountain which overhangs Vevey, fronting the opening into the Vallais, and elevated 3301 French feet above the sea, and which is composed of a coarse-grained conglomerate, is polished near the top, at a spot where there is no water even to form a little rivulet, and no path, or any other polishing cause which can be adduced. It is therefore to a height of 3300 feet at least, that we may carry the elevation of that ice which filled the basin of the Lake of Geneva, the surface of which lake is now at an elevation of 1145 feet. On the summit of the Pèlerin is the *resting-place* of the ice whose level was 3300 feet above the level of the sea. We have no data, however, to indicate what was its thickness at this place.

* These facts do not at all agree with what M. Elie de Beaumont has described respecting the valley of the Durance.

they must generally have been rounded and smaller, and there must also have been immense moraines reposing on the Jura, which, however, have no existence.*

The prevailing opinion attributes the transport of these blocks to vast currents of water, or to floating ice.

The greatest difficulties which exist in this theory, and we shall mention but a few of them, are first to give a sufficient explanation of the origin of these currents, and of the rapidity it is necessary to assign them, in order that they might be able to transport such enormous masses; if, at the same time, it be admitted, as every thing seems to indicate, that they have been transported *after* the elevation of the Alps. For in this case these currents must have started from the *crests* which separate the valleys, because the phenomenon of the blocks presents itself in all the Alpine valleys, and on both slopes of the chain; that is to say, to meet the exigencies of the case they must have been projected from all these crests† with an impetuosity which would not permit the blocks to fall below the level in which they are found in the Jura and the Alpine valleys where now there are no glaciers, for even the existence of the great moraines is denied, in order that the deposition of their blocks may be attributed to the same streams. But how is it possible that currents of water of several leagues in length (I here speak of the lateral valleys which debouch into the principal ones) could have con-

* I have no intention of describing the distribution of the erratic blocks which occur on the slopes of the Jura, inasmuch as they are generally known since the publication of the researches of Messrs Léop. de Buch, of Escher de la Linth, and of De Luc on the subject. I shall only remark, that their accumulation in different places does not at all agree with the theories which have been proposed to explain their transport. Thus the greatest accumulations, so far as I know, are found at an inconsiderable distance from each other, near the summit of Mont Auber, and at the bottom of Noiraigue, which are at very different levels, and are not in an ascending line whose summit would be Chasseron. On the contrary, upon the border of the several steeps of the Jura they are most markedly seen, and more particularly on the line which the depression of the upper beds of the *Portland* Rock produces along the whole length of the Neuchatel Jura, between the Castle of Neuveville, Fontaine-André, Pierre-à-Bot, Troirod, Châtillon, Fresens, Mutruz, &c.

† Any system of banking up or of breaking up, which can be imagined, will never explain so many facts common to so many valleys.

veyed such immense blocks to an elevation of more than a thousand feet? Moreover, the fact that the blocks of the different valleys are not similar, and that they are spread, fan-shaped, to a certain distance round the Alps, excludes the idea of that extreme rapidity which has been ascribed to the currents for the simple purpose of explaining this transport, without considering that it must, at the same time, have produced effects, a trace of which is no where to be found. This fact, then, most completely excludes the idea of *a grand diluvial current* passing over all Switzerland in any direction whatsoever. If, again, it were before the elevation of the Alps it is supposed the phenomenon occurred, I ask, how has it happened that the lines of these blocks formed in the Alps have not been dislocated by the uprising? For in this case the continuous and parallel dykes of blocks which may be seen *upon both flanks* of the whole of the Alpine valleys, and which follow them in all their windings, whatever may be their direction and tortuosity, will remain inexplicable, the water proceeding in a rectilinear course in the different windings of the bed in which it flowed, whilst the ice alone acted with the same energy upon every point of the basins which it filled.

The objections which may be made to the theory of currents are all applicable, to a certain extent, to the theory advanced by several naturalists of their being conveyed by icebergs. It is no difficult matter to transport, in imagination, upon these floating islands great angular blocks even to the Jura; but the other particulars of this great phenomenon are not thereby better explained than by the help of the currents, were we even to admit with M. Elie de Beaumont that the water which fed them proceeded from the glaciers as the source.

Another objection of the greatest weight, made by M. Schimper to this theory is, the present state of the lakes of the great Swiss valley. If the blocks have been carried by the currents from the Alps to the Jura, these currents must naturally have passed over the lakes and the longitudinal and transverse valleys which occur between the two chains. How then has it happened that these lakes and valleys were not filled up, and how are we to explain the angular escarpments of their margins? However violent, rapid, and deep, these currents may be supposed, and were we even to imagine, contrary to every physical law, that they could have conveyed blocks of granite of the size of 50,000 cubic feet, as is that of Pierre-à-Bot, still they must have had their impetuosity diminished some time, and then the remains must have filled up some of the inequalities. Notwithstanding, there are no blocks to be found between the Alps and the Jura.

If, according to another hypothesis, the great boulders are conceived to have proceeded more gradually amongst great masses of mud and rubbish, so thick as actually to carry them along, how has it happened that these masses have not extinguished all the inequalities of Switzerland? How has it happened that the blocks alone should have been deposited after their arrival on the Jura, and the masses of mud which had been able to convey them so far, should then have flowed away, so as to leave them in their places?

There are still additional considerations which oppose themselves to the admission of any of these currents.

The erratic blocks of the Jura every where repose on polished surfaces, all those at least which have not been carried beyond the crests of our mountains, and which have not fallen to the bottom of our longitudinal valleys, as may be seen throughout the valley of the Creux du Vent. But they do not repose *immediately* upon these polished surfaces. Wherever the rounded pebbles which accompany the great blocks have not been removed by subsequent influences, it is remarked that small blocks, in other words pebbles of different sizes, form a bed of some inches, and sometimes even of many feet, *upon* which the great angular blocks repose. These pebbles are also much rounded, even polished, and are heaped up in such a way that the larger are above the smaller, and that these last often pass below into a fine sand, lying immediately over the polished surfaces. This order of superposition which is constant, is opposed to all idea of a transport by currents; for in this latter case the order of the superposition of the pebbles would have been precisely reversed. The presence of a fine sand at the surface of the polished surfaces, proves, beyond dispute, that no powerful cause could have been in operation, and that no important catastrophe could have affected the surface of

the Jura, since the epoch of the transport of these alpine rocks, or, in other words, that the polished surfaces have not been dislocated or disturbed since the transport of the blocks. But as these surfaces form a large part of the northern bank of the lakes of Neuchâtel and Bienne, they prove, so far as they are concerned, that the Swiss lakes had previously existed; and the continuity of the moraines, upon the opposite banks of the Lake of Geneva, proves that this basin likewise was anterior to the transport, since it has preceded the formation of the moraines, as we shall very soon see.

In considering the intimate connection between the different facts which we have just been describing, it is manifest that every explication which does not *account at the same time* for the polish of the surface of the soil, for the superposition and the rounded form of the pebbles, for the sand reposing immediately upon the polished surfaces, and also for the angular form of the great superficial blocks, is an explication which is quite inadmissible as accounting for the erratic blocks of the Jura; and these objections forcibly apply to all the hypotheses respecting the transport of blocks with which I am acquainted.

I shall now proceed to that explanation of the phenomena which I consider the most plausible; and which is the result of my own views, together with those of M. Schimper, upon the subject. In glancing at many general questions which are connected with the explanation, I have no intention of expatiating upon them. I wish simply to demonstrate that the subject now before us has a relation to the most interesting and important geological inquiries.

The study of fossils has for some time led to very unexpected results, especially since it has assumed a physiological character; that is to say, since it has been recognised, that a progressive development exists in the whole range of those organized beings which have formerly peopled the earth; and since epochs of renewal have been recognised throughout the whole. Those individuals who have admitted this progression ought not now to entertain any fears in prosecuting these consequences to their legitimate limits; and the idea of a uniform and constant diminution of the earth's temperature, such as is

now sometimes admitted, is so contrary to every physiological idea, that it must be strenuously repelled, to make way for another, viz. that there has been a diminution of temperature, which has been accidental in relation to the development of the organized beings that have appeared and disappeared one after the other at determinate epochs, maintaining itself at a particular mean temperature during a given era, and diminishing at certain fixed epochs.

As the development of individual life is always accompanied with that of heat, since its continuance establishes a certain equilibrium of longer or shorter duration, and since its extinction produces an icy coldness, I conceive I deduce only legitimate inferences, when I conclude that the same phenomena occurred upon the globe: that the earth, when it was formed, acquired a certain very elevated temperature, which progressively diminished during the different geological formations; that during the continuance of each of them, the temperature has not been more variable than that of our globe since it has been occupied by its present inhabitants, but that it has been at the epochs of the disappearance of these inhabitants that a fall in the temperature has taken place, and that this fall has been beneath the temperature which prevailed in the subsequent epoch, and which re-appeared with the development of the newly animated creatures which were called into existence.

If this theory be correct, and the facility with which it explains so many phenomena which have hitherto been deemed inexplicable, induces me to believe that it is; then it must follow that there has been, at the epoch which preceded the elevation of the Alps and the appearance of the existing animated world, a fall of temperature far below that which prevails in our days. It is to this fall of temperature that we must attribute the formation of those immense masses of ice, which must universally have covered the surface, where we find these erratic blocks along with rocks which are polished as are ours. It is also, unquestionably, this extreme cold which has enveloped the Siberian mammoths in ice, has congealed all our lakes, and accumulated the ice as high as the ridges of our Jura, which existed before the elevation of the Alps.

This accumulation of ice above all the hydrographic basins of Switzerland may easily be supposed, on reflecting that when lakes are once frozen to the level of their emerging current, the running waters no longer drain off, and those of the atmosphere, augmented by the vapours of the southern regions, which, under the circumstances, abundantly precipitate themselves towards the north, must have most rapidly augmented the extent, and raised the level even to the height which has already been established by the foregoing facts. The winter of Siberia was for a time established upon a soil previously covered with luxuriant vegetation, and peopled with great Mammalia, whose fellows in our day inhabit the warm regions of India and Africa. Death enveloped nature in its winding-sheet, and the cold reaching its extremest limit, gave to this mass of ice, at the maximum of tension, the greatest hardness it could acquire. When any one has frequently witnessed the congelation of a lake, he can then form a conception of the vast resistance of ice in this condition, and to what immense distances hard bodies which are thrown upon its surface may glide in consequence of even a feeble impulse.

The appearance of the Alps, the result of the greatest convulsion which has modified the surface of our globe, found its surface covered with ice, at least from the North Pole to the shores of the Mediterranean and Caspian Seas. This upheaving, by raising, breaking, and cleaving in a thousand ways, the rocks which compose the prodigious mass that now forms the Alps, at the same time necessarily raised the ice which covered them; and the debris detached from so many deep upbreakings and ruptures, naturally spreading themselves over the inclined surface of the mass of ice which had been supported by them, slid along the declivity to the spots where they were arrested, without being worn or rounded, since they experienced no friction against each other, and even when arrested came in contact with a surface so smooth; or after being stopped, they were conveyed to the margin, or to the clefts of this immense sheet of ice, by that action and those movements which characterise congealed water when it is subjected to changes of temperature, in the same manner as the blocks of rock which fall upon glaciers, approach their edges in

consequence of the continual movements which the ice experiences, in alternately melting and congealing at the different hours of the day and seasons of the year. These effects ought to be described in detail; but as they are partly known I shall not dwell upon them.* I shall only remark, that the power of the action, so far as the ice is concerned, is immense; for these masses, continually moving upon each other, and on the surface, bruise and grind down every thing moveable, and polish the solid surfaces on which they repose; at the same time that they push before them all that they encounter, with a force which is irresistible. It is to these movements we must attribute the strange superposition of rolled pebbles, and of sand which immediately repose upon the polished surfaces; and it is unquestionably to the grating of this sand upon these surfaces that the fine lines which we find are owing, and which would never have existed if the sands had been acted upon by a current of water: for neither our torrents, nor the stormy waters of our lakes, produce any thing like this upon the very same rocks. As to the longitudinal direction of these fine lines, and of the furrows which are observed upon the polished surfaces, it ought to be observed that they must have resulted from the much greater facility which the ice had in dilating itself in the direction of the great Swiss valley, than transversely, confined as it was between the Jura and the Alps; the phenomenon itself commencing only with the retreat of the ice, at the time that the Alps appeared. I have not the slightest doubt that the greater number of the phenomena which have been attributed to vast diluvial currents, and in particular those which M. Seefstrom has recently made known, have been produced by ice.

Upon the elevation of the Alps, the surface of the earth would be reheated, and the caloric disengaged on every side would produce the melting of the ice, which would gradually retire into its present domain. Clefts would first be formed in those places where the ice was thinnest, that is to say, on the summits of the mountains and the hills which were covered by

* M. Schimper has written a most interesting work upon the effects of ice, to which I should have been most happy to refer if it had been published.

it, afterwards upon the most saliant parts of the plain; valleys of drainage would then be excavated at the bottom of these clefts, in localities where no current of water could flow without being inclosed within congealed walls; and when the ice had completely disappeared, the great angular blocks which had covered its surface, or had fallen into the clefts, would be found upon a bed of small rounded pebbles, under which is usually found a layer of sand. In melting from the surface, the ice must necessarily have continued longest in the depressions of the country, in the little longitudinal valleys which are formed by the different zones of the strata of the Jura, and at the bottom of the lakes; and it is undoubtedly to this circumstance we are to attribute the extraordinary position occupied by so many of these blocks, which are perched up, scarcely in equilibrium, upon the highest points of rocks; and also their constant absence in the hollows, where they are not found, except at least where fresh momentary expansions of the ice were able to precipitate them.

So long as the level of the ice on the Jura had not fallen below the line of Pierre-à-Bot, the blocks which were yet spread over its whole surface, might continue their descent towards the Jura; but so soon as the ice became thin over the plain of Switzerland, it must have very speedily disappeared, and have only left portions in the deep valleys, and in the basins of the lakes, that is to say, it must have been soon confined to the lower valleys of the Alps.

In reflecting upon what must necessarily have occurred upon this disappearance of the ice, we are naturally led to think that the transport of the rolled pebbles of the valley of the Rhine, and the deposition of *Löss*, must have been among its first effects; and this is confirmed by the facts, that these pebbles are the same with those which we found along with our blocks, and that the *Löss* is evidently the result of the detritus of the *molasse*. The frequent *débâcles* of the ice could only at that time convey blocks upon the masses of ice to great distances, or carry them farther in their current.

The melting and maceration of the ice and its repeated congelation in cold weather have produced many other geological effects, which it is difficult to account for as produced by any

other causes. Without again recurring to the valleys of drainage or erosion, I may mention those deep furrows which are not fissures, and which have above them plains of great extent; also those small lakes which are sometimes formed near the edges of the glaciers, and which so affect the small stones that are accumulated at their margins, as to impress upon them the appearance of stratification; or again, the analogous phenomena which are observed upon the limits of different stations where the immense sheets of ice have successively stopped in their retreat; and likewise the dispersion of the bones of the Mammalia at the diluvian epoch, without their being at all rolled or broken, and in short, a number of other particulars which have no interest except when we embrace the whole of the question.

From this moment the surface of the earth must have been afresh subjected to the influence of the regular succession of the seasons. Then appeared the first spring time of the animals and plants which flourish in our days. The ice had retired to the foot of the Alps, and from their summits it began to receive fresh reinforcements. Speedily it reached its last retreats, where it is ever oscillating, sometimes gaining in extent, and forcing the blocks before it, and sometimes again retiring within narrower and narrower limits. At each step of ground they abandoned they left behind them, as the existing retreating glaciers now do, some of those long dykes of blocks which still exist in the Alpine valleys. Soon, too, the lakes themselves would melt, the waters would assume their present courses, the valleys of the Alps would be drained, and there remained no more ice, the product of former congelation, except on the summits of snow-clad mountains.

It would be a great mistake, therefore, to confound the glaciers which descend from the summits of the Alps with the phenomena of the epoch of that extensive ice which had preceded their existence.

The phenomena of the dispersion of erratic blocks, then, ought not any longer to be regarded in any other light than as one of the circumstances which have accompanied the vast changes occasioned by the fall of the temperatures of our globe previous to the commencement of our epoch.

The admission of an epoch of cold, which was so intense as to cover the earth to such distances from the poles with so vast a mass of ice as we have been contemplating, is a supposition which appears in direct contradiction with those well known facts, which shew a considerable cooling of the earth since the most remote period. Nothing, however, has proved that this refrigeration has been constant, and that it has occurred without oscillations. On the contrary, whoever has been in the habit of studying nature in a physiological point of view, will be much more disposed to admit that the temperature of the earth has been maintained, without any considerable oscillations, to a certain degree, during the whole period of any geological epoch, as is occurring in our own epoch, since it has diminished suddenly and considerably at the termination of each epoch, a change accompanied by the disappearance of the organized beings which characterized it, that it may rise again with the appearance of a new creation at the commencement of the following epoch, although at a lower degree of mean temperature than the preceding one, so that the diminution of the temperature of the globe may be expressed by the following line:—

Thus, the epoch of extreme cold which preceded the present creation, has only been a passing oscillation of the temperature of the globe, somewhat more considerable than the periodic refrigeration to which the valleys of our Alps are subject. It was attended by the disappearance of the animals of the diluvian epoch of geologists, as the mammoths of Siberia still attest, and preceded the uprising of the Alps, and the appearance of the animated nature of our day, as is proved by the moraines, and the presence of fish in our lakes. There was thus a complete separation between the existing creation and those which have preceded it; and, if the living species sometimes resemble in our apprehension those which are hid in the bowels of the earth, it nevertheless cannot be affirmed that they have regularly descended from them in the way of primogeniture, or, what is the same thing, that they are identical species.

By prosecuting these views, we may anticipate the time will come when we shall be able to determine the geological period at which the sun began to exercise an influence upon the surface of the globe, so considerable as to produce the differences which now exist between the different zones, without these effects being neutralized by the influence of the internal heat, from which the earth must for a time have enjoyed a very uniform temperature over all its surface.

This theory, I fear, will not be adopted by a number of our geologists, who have settled and confirmed opinions on the point; but I anticipate it will be with this question, as with many others which assail old and established views. At all events, whatever opposition it may experience, it will remain true that the numerous new facts relating to the transport of blocks which I have pointed out, and which may be studied so easily in the valley of the Rhone and the environs of Neuchatel, have brought the discussion into wholly different ground from that on which it has hitherto been debated.

When M. de Buch for the first time affirmed, in opposition to the formidable school of Werner, that granite is of Plutonic origin, and that the mountains had been uplifted, What did the Neptunists say? At first he sustained his position alone; and it has only been by his defending it with the innate powers of genius, that he has made it triumph. It is happy for us, that in scientific discussions, numerical majorities at first have never decided any question.

The form into which I have thrown these observations will, I trust, banish all discussion on the subject at the present moment; and as, at the same time, I cannot hope that I have convinced every one of the truth of my views who have heard them for the first time, I propose the Geological Section as the most suitable for any discussion which may follow. I shall then make it my business to meet any objections which may be started; and, for the sake of truth, I earnestly solicit them.

Upon Glaciers, Moraines, and Erratic Blocks; being the Address delivered at the opening of the Helvetic Natural History Society, at Neuchatel, on the 24th of July 1837, *by its President,* M. L. Agassiz.

Gentlemen,—It is now a considerable period since the Neuchatel members of our Society have longed for the time when they could invite their associates throughout Switzerland, to congregate amongst them. Circumstances, however, over which they had no control, and more especially the erection of the building in which we are now assembled, and which is intended for the reception of the various scientific collections, have compelled them to delay this honour till they could proffer it without inconvenience to their guests, and till they could submit to their inspection a part at least of their museum. Even now, in spite of the extraordinary exertions of the indefatigable keeper of our museum, but a small portion of the specimens are yet displayed; they have likewise been arranged with haste; and the workmen have scarcely quitted the premises. We therefore need your indulgence, but trust you will not the less doubt the satisfaction with which we receive you, and the high gratification it affords us. From our hearts we gladly bid you welcome!

On such an occasion as the present, we are naturally led to inquire, What is the bond which connects the different sciences that are prosecuted by our Society? I do not hesitate to affirm that one grand idea pervades all the exertions directed to the extension of the limits of these sciences;—it is a belief of a progressive development throughout creation, of a transformation extending through different states which are dependent upon each other;—it is the conception of an intelligible creation, concerning which our task is to ascertain the relations in all the phenomena which come under our observation. In this view we may regard Astronomy, engaged with the formation of the celestial spheres; Chemistry, investigating the different actions which bodies exert upon each other; Natural Philosophy, appreciating the nature of those forces whose actions are ascertained; Natural History, considering the phases of life throughout animated nature; and, finally, Geology, which ventures to comprehend the history of our globe, to decipher its oldest records, and to represent them as one grand whole, whose various revolutions have invariably tended to one great result.

From the progress of these, there will, no doubt, one day appear a noble result, something worthy of *Man*, which will introduce the cultivation of the natural sciences within the circle and sympathies of social life, more powerfully than all the advantages which they bestow upon industry and the arts, however prodigious these may be.

Our society has not been a stranger to the movement here alluded to, and the names of its members appear honourably by the side of those masters in science who have united with us in our labours. This very day's meeting, better perhaps than any other, may prove that my assertion is not at all exaggerated. You, gentlemen, know that our small society has served as a model to those vast associations in Germany, England, and France, which can boast of so many illustrious names; and if the labours which it has undertaken have appeared less brilliant than those accomplished by greater societies, it has at least given the first impulse to more than one interesting undertaking.

Still more recently, two of our members have, by their researches, given rise to discussions of the deepest importance, and the result of which will resound far and near. The locality in which we have now met, leads me again to introduce to your notice a subject whose solution will be found in the examination of the slopes of our Jura. I mean to speak of glaciers, moraines, and erratic blocks.

Every one in Switzerland is familiar with the glaciers, and knows that their margins are bounded by dykes of roundish blocks which are called *moraines*, and which are continually pushed forwards, or abandoned, by the glaciers, as these advance or retire. The inhabitants of the Jura especially are acquainted with another phenomenon which is striking among our mountains,—I mean that of *erratic blocks*, or those masses of granite and other primitive rocks, which are found chiefly on the southern slopes of the Jura. It is not, however, so gene-