two lines if attaining as much. They were always of a fine uniform yellow colour, the body very flexible and of variable shape; and they invested themselves with such muddy particles as came in contact with them.

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## *Remarks on Glaciers.* By M. Agassiz.*

In laying before you, gentlemen, a few details regarding glaciers, and the phenomena attending them, I design to confine myself exclusively to matter of fact. I shall submit to you the principal observations which have been made on this interesting subject; to these I shall add a few others which I believe to be new; and finally, bring to your recollection some which have been known from the time of Saussure, but probably forgotten, because he did not connect them with the phenomena of glaciers, on which they really depend.

A glacier is a mass of ice hanging on the sides of an Alpine ridge, or enclosed in one of its valleys, and which is moving *continually* down the declivity. I say continually, for the glacier is always descending; if the extremity should at any time seem to retire, this implies nothing more than that the portion of the ice, melted by the heat of summer, is more considerable than that which the glacier brings along with it in its progress.

This movement of the ice, which many refused for a long while to admit, is now known and acknowledged by every observer; but there is a great contrariety of opinion respecting the cause which produces it. The opinion generally received from the time of Saussure, is, that the descent of a glacier is nothing more than a slipping upon itself, occasioned by its own weight. But there are many reasons for doubting the accuracy of this explanation. The motion appears to be much more properly ascribed to the expansion of the ice resulting from the congelation of the water which has filtered into it and penetrated its cavities. The ice of glaciers, it must be observed, has not the continuous texture of ordinary ice; it is composed of a multitude of fragments, which have been improperly

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* Read to a meeting of the Geological Society of France.

called crystals by Hugi. We may easily convince ourselves of this by breaking a portion, or infusing a coloured liquid which penetrates into the fissures separating the fragments, and allows us to distinguish their form and size. It is easy to perceive that their size diminishes in proportion as we ascend either from the bottom of the glacier towards the surface, or from its lower to its upper part or origin. Here they may be seen reduced to mere granules, so that the ice, losing more and more its transparency and compactness, insensibly passes (nearly at a uniform elevation among the Alps) into the state of a coarse snow which is known to the mountaineers by the term *firn* or *haut névé.* A glacier is, therefore, a spongy mass, continually imbibing atmospheric waters, as well as those produced by the melting of its surface, and which infiltrate into the capillary fissures which the ice presents throughout its whole thickness, and particularly at the portion nearest the surface where it is less compact. The temperature of this water being always near the freezing point, it is converted into ice by the least sinking of the temperature, and tends to dilate the glacier in every direction. But as it is restrained on two sides by the flanks of the valley, and above by the weight of the superior masses, the whole act of dilatation, aided besides by that of gravitation, tends to urge it down the declivity to the only side which offers a free passage. This explanation being once admitted, it follows that the more frequently the alternations of freezing and melting take place, or the variations of the temperature are above and near zero, the more rapid will be the advance of the glacier subjected to them. Thus it happens that winter, when the entire mass is frozen in an equal manner, is the season when it is in a state of rest.

The progress of the glacier is not uniform throughout the whole thickness of the mass; but if we suppose it divided into beds parallel to its surface, each of these beds or layers will advance with greater rapidity in proportion as it is nearer the surface, or, in other words, as it is more exposed to the influence of atmospheric changes. It will be perceived that this difference in quickness will become more obvious in the upper beds, because there must be added to the quickness, proper to each of them, that of all the beds inferior to it; so that if the bed at the bottom move with the quickness of 1, the second with the quickness of 2, the third of 3, and so on, the quickness of the third, for example, will be $3+2+1$ or 6.

A glacier, when seen in a vertical section, often exhibits a series of beds of variable thickness, sufficiently distinct in the upper part, less evident in the middle, and more or less obliterated below, according as the mass, from being exposed to moisture, has been more or less completely converted into transparent ice. These beds diminish in thickness from the top downwards, no doubt by an effect of the *tassement*, and represent the additional beds which the glacier receives every year. (Upper glacier of the Grindelwald, Trient, &c.)

In regard to external form, a glacier usually presents a more or less convex surface, particularly at the lower extremity. This form results from the reflection of the heat from the sides of the valley, which accelerates the melting of the ice at the edges of the glacier. When the ground on which the glacier moves, is but little inclined and free from inequalities, the surface continues regular, and the mass is not divided. But if it has some obstacle to surmount in its progress, or if the ground present one of those sudden changes of level so frequent among the Alps, the mass splits transversely into irregular leaves, moving on their lower edge as around an axis, and separated by wide crevices, which close again when the ground becomes less steep, just as the waves of a torrent again become calm after a fall. A glacier, in fact, is a river of ice stereotyped, with its cascades, rapids, storms, and calms; the superficial mass moving more quickly, and the lateral portions being influenced by the form of the bed in which it moves.

The destructive action of atmospheric agents on the mountain summits from which glaciers descend, and on the crests and declivities which border the valleys in which they move, the fall of avalanches, and the motion of the ice itself, are continually detaching, along the whole basin of the glacier, fragments of rock of every size, which roll into the place which the glacier occupies, and rest upon its surface. These debris, thus deposited on and carried along with the glacier in its progress, give rise to several remarkable phenomena. The largest of these fragments, by protecting the part of the ice which they cover from the action of the sun's rays and from rain, and also from evaporation (which is often considerable, being occasioned by warm or dry winds), become, by the sinking of the rest of the surface, gradually insulated on the summit of a large pedestal or pillar of ice. This support, suffering in its turn from the action of the same agents, soon gives way; the block rolls down, and forms another pyramid at some distance. It is these that are called the *tables des glaciers*, of which fine examples are afforded by the glaciers of the Aar. If these fragments do not exceed an inch in diameter, a phenomenon of a different description takes place. Absorbing the solar rays, by their property as opaque bodies, more rapidly than the ice, their entire mass (not the surface merely, as in large blocks) becomes raised to a high temperature. Instead, therefore, of protecting the ice beneath them, they cause it to melt, and form holes which often penetrate to a great depth; they even pierce the glacier from one side to the other; for as long as a constant cause of heat remains at the upper orifice, the water which fills them is warmed above zero, then descends by virtue of its maximum of density to the inferior beds, where it continues to perforate the ice by slowly melting it. When we add to these phenomena the small currents of water running in every direction, uniting into torrents, and throwing themselves in cascades into the larger crevices which open or close by turns, we shall be enabled to form an idea of the perpetual movement going forward of the surface of a glacier.

These blocks, scattered over the glacier, thus move along with it, and at last reaching its edges, and being continually thrown off, they accumulate and form masses of debris more or less considerable, which are named *moraines* among the Alps. These moraines are either *lateral*, disposed along the glacier parallel to its sides; or *terminal*, bounding its lower extremity, and usually describing a semicircle; or finally, *median*, forming long tracks on the surface of the interior of the glacier itself. These latter are occasioned by a union of the two lateral moraines of two glaciers descending two different gorges, and uniting in the same valley. The two glaciers never become blended, as might be supposed; each preserves its own direction and rate of progress, the line of separation being the two lateral moraines, which touch each other in such a manner as to form only one. However, when the progress of the two glaciers is very unequal, something like a division of the moraine takes place, and we then see two or three parallel tracks, as in the glacier of the Aar. These median moraines produce the phenomena of *tables des glaciers* on a large scale. Being placed at first in the depression formed by the union of the two convex surfaces of the contiguous glaciers, and protecting the ice which they cover from evaporation, they are soon elevated on a base of ice, usually in the shape of an ass's back, which, however, disappears where the moraine spreads out towards its extremity. (Glacier of the Aar.)

Let us now examine what is the action of the ice on the surface which it traverses. Here, also, we find fragments of rocks, which, by being pressed and ground, as if between the stones of a mill, are comminuted, or arrive, in the form of rounded pebbles, at the lower part, where they form the base on which the extremity of the glacier, and also the terminal moraine itself, usually rest. While moving along a rocky alterable surface, the ice, by modifying it, produces various phenomena, the principal of which are the following:

It levels it by the friction, and polishes it sometimes as perfectly as could be done by the marble-cutter, cutting the fossil bodies and concretions which it meets in its progress, and exercising its action equally upon the bottom of the bed and its sides.

It rounds off all the angles and inequalities of the ground, giving them a mammiform appearance, or transforming them into protuberances with rounded surfaces. (Granites of the Grimsel, *lapiaz* of the Valais.)

When the ground admits, it scoops out broad furrows, from an inch to a foot in diameter, the length of which is in the direction of the movement of the ice, and of these the surface is equally polished, and the angles rubbed off. Here, also, might be mentioned spoon-shaped depressions, resembling the commencement of a furrow which has not been continued, occasioned by certain movements of the ice, for which it is difficult to account. They might be called the cuts of a chisel in the flat surface of the rock.

Particles of the hardest sand, which are always found between the ice and the rock, such as small crystals of quartz, &c., produce the same effect as so many diamonds, by forming lines on these polished surfaces, which are thus covered with a multitude of rectilinear striæ parallel to each other. These striæ have no dependence on the structure of the rock; they do not follow its cleavage; they are seen to cut in two the crystals they traverse; they are always in lines of great inclination, and follow the direction which the form of the subjacent ground has given to the ice, whether in its regular progress or accidental deviations. They cannot be attributed therefore, as has been done by Deluc, to rapid currents of water, nor to muddy currents filled with fragments of rocks, as some other observers are inclined to believe. The *débâcle* of the Dent du Midi, which presented a fine example of a current of this nature, has not left any trace of this kind in any part of its course.

Finally, we perceive, on surfaces which the ice has left, other furrows, not rectilinear but undulated, often running into each other, and generally following the line of the greatest declivity. These are called *Carrenfelder* in some parts of the Alps. These furrows are evidently owing to the erosion of waters circulating beneath the glace, and gradually scooping out a bed down the declivity. Other erosions are likewise observed, exactly resembling those produced by a cascade in the place where it falls, and which probably have no other origin.

All these actions of the ice are somewhat modified by the nature of the rock on which they are exercised. Granite becomes rounded in large masses, and broad convex surfaces of a pretty uniform description. The masses in limestone are smaller, and acquire the most perfect polish. It alone presents beautiful surfaces, resembling those of a slab of marble from the hands of the workman. Gneiss and the schists are more furrowed, although often in a direction transverse to their beds.

These phenomena, at once well known and easily observed, afford us the means of ascertaining the former existence of glaciers at a remote period, in places where they do not now occur. When a glacier advances, it rolls before it all the blocks accumulated at its extremity, and which form around it a more or less semicircular mound. But many glaciers, on parting from the moraine which borders their extremity, present several others, concentric to the first and of a like structure; of these, the most remote is necessarily the most ancient, and the intermediate ones mark so many epochs of the successive recedence of the glacier. It is thus that Saussure formerly detected moraines in the valley of Chamouni, although they were partly covered by vegetation. From the extremity of the glacier des Bois or of the Mer de Glace, we can, in fact, enumerate seven concentric moraines, as far as the village of Tines, which is built on the last and largest, at the height of more than 200 feet. Ascending towards the Col de Balme, ten or eleven others are distinguishable, although many causes are continually in operation to obliterate them. These collections of rolled stones undoubtedly indicate the ancient extent of the glaciers. We see, in the particular case alluded to, that the valley of Chamouni was occupied by an immense glacier, receiving in its course those of Argentière and of Tour, and moving towards the Col de Balme, in order, probably, to debouche in the Valais by the Col de la Tête-Noire.

Polished and rounded surfaces, with furrows and striæ still remaining, particularly on hard rocks, notwithstanding the destructive influence of the atmosphere, serve even now as guides to the site of ancient glaciers, in places where they would never have been supposed to exist. Saussure, whose eye nothing escaped, had long since remarked them on the extensive polished rock of St Bernard (see vol. ii. p. 451. 4to ed.), as well as in other places, but he failed in divining the causes of these appearances. They are seen to exist beneath the ice, within the moraines; they also appear on the outside on the ground, and on the declivities and sides of the valleys, accompanied, often to a great height, with old lateral moraines. It is thus that we can follow the striæ beneath the ice of the Aar almost without interruption as far as the Hospice de la Grimsel, around which all the granite is deeply striated. They likewise appear throughout the whole valley of Hasli, particularly on the beautiful rounded surfaces of the Helle-Platte, below Handeck. M. Braun, an engineer, has noticed them at Leissingen, on the left bank of the lake of Thun ; M. A. Guyot, at Oberwald, in the upper Valais. The whole of the lower Valais is, in like manner, the bed of a glacier, of which the lateral moraines may be distinguished at a pretty considerable height above the valley. I have taken care to indicate these on the map (that of Keller) as I have determined them from Martigny to Lausanne. Polished surfaces, striæ, and all the phenomena produced by the action of ice, appear more beautiful and distinct on the Jura range than in any other place, accompanied likewise with Alpine blocks disposed in two zones, one above the other, the second rising to a point upwards of 2000 feet above the level of the plain. The identity of these polished surfaces and striæ with those observed among the calcareous rocks of the Alps—for example, below the glacier of Rosenlaui in the Bernese Oberland,—the distribution of rolled blocks on the sides of this chain, and their relations to the Alpine moraines, leave no doubt as to the former existence of a layer of ice which covered all the great Swiss valley, and moved towards the north-east, in the direction of the declivity. This icy covering would be no doubt circumstanced somewhat differently from a glacier enclosed within a narrow Alpine valley, but the principal characters, notwithstanding, must have been the same.

From the whole of these phenomena, and the circumstance of analogous striæ having been observed in Sweden by M. Sefstroem, I conclude, that at a certain epoch the whole of Europe was covered with ice : that this epoch marks the date of the disappearance of the large mammifera which have been discovered among the ice of northern regions ; that it must have preceded the elevation of the Alps ; but that the recedence of the ice, the polished surfaces, the moraines, and the dispersion of the boulders to the very summits of high mountains, must all have been posterior to the elevation of the Alps to their present level.