OBSERVATIONS ON THE RECENT GLACIAL DRIFT OF THE ALPS.

By T. C. Chamberlin, A. M., Ph. D., State Geologist.

The drift formation of our state forms an important feature of its geology, and, owing to some peculiarities of its development, perhaps more than ordinary interest attaches to it. I therefore zealously embraced the opportunity which a visit to Switzerland afforded of observing the drift deposits formed by the glaciers of the Alps.

Observations were made upon the deposits of the Bossons, Bois or Mer de Glace, Findelin, Gorner, Viesch, Aletsch, Rhone, Unter Aar, and the upper and lower Grindewald glaciers, and, casually, as many more.

It was my endeavor to use the limited time at my command to as great an advantage as possible by confining my attention to those features which are most analogous to our drift; the more so, because it is most difficult to gather exact and definite descriptions of this phase of glacial phenomena from most accessible writings on the subject, and naturally enough so, because the glaciers themselves and their surface moraines present so much more conspicuous and absorbing objects of interest.

My observations will, therefore, have value, if they have value at all, not because of their fullness and completeness, for they do not approach to that, but because they were made from this standpoint, and because they have been brought to the standard of the same mental meter with our own deposits; and whether that meter be standard or otherwise, it is hoped that, with some corrections for mental temperature, it has measured alike in both cases.

It is essential, at the outset, to clearly discriminate between the products that arise under those conditions which are peculiar to Alpine situations and those that are more specifically due to glacial agency without regard to special local circumstances; and hence a few explanatory words, antecedent to the observations themselves, may be appropriate.

In the majority of cases, Alpine glaciers occupy narrow steep valleys which afford them little opportunity to deploy as they undoubtedly would in more open ground, where they might present phenomena analogous to those of continental or arctic glaciers; but in some cases, they terminate, or have recently done so, in broader and less sloping portions of their channels, and thus furnish some very valuable hints as to the probable action of broad glaciers on less sloping floors.

Alpine glaciers derive the material of their deposits from two general sources, and their debris is correspondingly divided into two general classes, 1st, that which falls upon them from above, and 2d, that which they abrade from the rocks over which, or against which they move. The first class is borne passively *on* the ice stream, while the second is pushed or rolled along *beneath* it. The first is due to the accident of the glacier's position, the second is the direct result of its own action. The first class is only present when the glacier originates among towering peaks or flows along precipitous slopes; the latter presumably is always present. At the edges of the glacier the two classes often mingle, and undoubtedly some of the surface debris finds its way to the bottom through crevasses and moulins, so that the material carried along beneath the glacier is greater than it would be but for the surface burden; but, for the purposes of our study, this is unimportant. It is imperative, however, that we distinguish between the superficial and basal debris, as the former can have little or no representative in so plane a region as that covered by our drift, and can therefore throw no light upon its origin. This distinction is very easily made, for the most part, in the case of the Alpine glaciers mentioned; for the surface material is almost wholly unworn and angular, while the basal portion is usually abraded and rounded in greater or less measure.

The surface material forms in lines along the sides of the ice stream, where it has fallen from above, constituting lateral moraines; and where two streams unite, two of these lateral moraines are brought together and form a line along the middle of the joint stream, constituting a medial moraine.

To the rock rubbish borne along beneath the glacier, the term ground moraine, or *moraine profonde*, is applied.

So far, all is clear. So long as the glacier itself is present bearing lateral moraines on its sides, medial moraines on its surface and a ground moraine at its base, there is no room for confusion. But this detrital material at length reaches the end of the glacier and is deposited; and here arises something of confusion in the deposit itself, and something of confusion of ideas respecting it, or at least, a want of accurate and precise use of terms. The phrase terminal moraine is used to designate accumulations formed at the extremity of the glacier. But, setting aside the terminal deposits arising from the dropping of the lateral moraines, which remain somewhat distinct, it is evident that the medial moraine will be dropped upon the ground moraine at the foot of the glacier, and that this will occur under three conditions that ought to be distinguished. First, the foot of the glacier may be retreating, as is the case at present, because the melting is more active than the onward flow of the ice. Under these circumstances, the withdrawal of the ice leaves the medial moraines as a ridge, or line of debris, lying on the sheet-like ground moraine, and their relations remain essentially the same as before, save that the glacier has vanished from between them. In this instance the terms medial and ground moraines may still be used appropriately to designate them.

Secondly, the foot of the glacier may be stationary, in which case the material of the ground moraine, pushed along beneath, will accumulate at the glacier's margin in the form of a ridge, and the medial moraines will pile up in heaps on this. To call this simply a terminal moraine is not to speak very discriminately; for, in addition to the complexity of its own formation, it is liable to be confused with that which arises under the third condition, viz.: that in which the foot of the glacier is advancing.

In this case the glacier is not only discharging material from its surface and bearing it along its base, but it is plowing up that previously deposited in its pathway.[1] The result of this is the formation of a ridge at the foot of the ice plow, as in the previous case, but of more irregular character in respect, at once, to material, structure, and surface configuration. This is a terminal

[1] A portion is also overridden by the glacier.

moraine in a more significant sense than the preceding, in that it was not simply accumulated at the foot of the glacier, but was formed by its mechanical agency; and in that it marks the termination of a given glacial advance.

It would appear to be much in the interest of precision of thought and expression to confine the phrase "terminal moraine" to accumulations produced by a glacial advance, and to employ some other term, as peripheral moraine, for ridge-like accumulations due to halts in the retreat of the glacier; while the term "ground moraine" should include the wide-spread, sheet-like deposits of retreating glaciers. Our classification of morainic accumulations would then stand:

I. SUPERFICIAL MORAINES.

(*a*) *Due to local environment and passive glacial agency.*

(*b*) *Characterized by angular material.*

1. Lateral moraines.
2. Medial moraines.

II. BASAL MORAINES.

(*a*) *Independent of local environment and due to active glacial agency.*

(*b*) *Characterized by worn material.*

1. Ground moraines (sheet-like).
2. Peripheral moraines.
3. Terminal moraines.

Besides the glacial accumulations, we have constantly to deal with the associated torrential and other aqueous deposits formed by the abundant glacial waters, but these may usually be distinguished by structural characters.

The following observations relate to individual features of drift phenomena, and will be found more or less disconnected, and the paragraphs are arranged without much reference to logical sequence of thought:

1. The Rhone glacier surpasses all others visited in its instructiveness in relation to drift deposits. After a course of nearly 15 miles, it descends precipitously, like a gigantic frozen cascade, into a valley of the Rhone, where it finds a broader area and

more gentle slope. Here its foot spreads out into a flat semicircular form not altogether unlike an equine hoof.

The first point of special interest to be noticed is that the crevasses in this flat portion diverge in curving lines from the axis of the glacier toward the expanded margin. This I believe to be correlated with a divergent motion of the ice by which the expanded foot was formed; and in this I find a close analogy to the divergent motion of the ice of our own ancient Green Bay glacier, as shown in my recent report. The valley of the Rhone just below this is covered with drift, so that the striations, which it might be presumed to have made in its recently more expanded condition, are concealed, but at the foot of the Glacier de Bois, in the Chamouni valley, a divergence in striation amounting to about 75° was observed.

2. The Rhone glacier is now retreating at a somewhat rapid rate. With commendable regard for the interests of science and the profit of transient students, the successive positions occupied by the retreating foot of the glacier, each year since 1874, have been marked by lines of tarred bowlders and cairns. The method and rate of retreat is thus mapped out on the face of the valley itself. It will be sufficiently near for our purposes to say that the average retreat since 1874, has been about fifty paces per year. It therefore presents a fine opportunity to observe the deposition of a receding glacier, and, as it bears but little detritus on its surface, its abandoned ground moraine is well exposed for study. However, certain portions of the plain have been swept by glacial floods, which have somewhat modified the deposit, and care should be taken not to confuse the two deposits. A little close observation will show that in the portions recently abandoned by the glacier, and that have not been washed by the issuing waters, the bowlders frequently bear, perched upon their tops and slopes, sand, pebbles, and small fragments of rock. It is hence evident that they have never been swept by even the gentlest stream, and that no assorting or modifying action of any kind has been brought to bear upon them since they were abandoned by the ice. Furthermore, we may go to the foot of the glacier and see them slowly issuing, thus crowned, directly from the ice.

The ground moraine here consists mainly of rounded and scratched bowlders, gravel and sand, with but little clay, and only a small proportion of angular blocks that cannot be traced distinctly to the medial or lateral moraines. The surface contour is slightly, though not conspicuously, ridged. The more abrupt side of these little ridges is toward the glacier and their trend is in the main approximately parallel to the edge of the glacier, though sometimes notably oblique. This relationship suggested that they might be due to annual oscillations of the glacial margin. There is also discernable a feeble tendency of the material to arrange itself in heaps and ridges parallel to the lines of movement of the ice.

3. If we now approach the foot of the glacier, we shall find this moranic sheet of detritus passing without notable change or interruption beneath the ice. The appearance is as though a stationary mass of ice had formed on the surface of a bed of bowlders and gravel and was now quietly melting away. More critical examination would, of course, show that any given particle of ice was advancing. The edge of the glacier is thin and sloping and we may walk directly up on it. The edge seems to rest lightly upon the drift below. This last is not a mass of debris frozen together, or imbedded in the base of the ice — although individual bowlders are — but an independent underlying bed of bowlders, and finer material and open interspaces. These observations of course relate to the immediate edge of the ice. Some of the crevasses enable us to see a short distance farther in, where the same condition prevails. An artificial tunnel, styled an ice grotto, shows the same through a break in the ice.

The marginal portion of the glacier rests, so far as could be ascertained, not upon the bed rock, but upon its own basal moraine. How thick this bottom accumulation was, I had no means of ascertaining, but from the configuration of the valley, I should judge it was considerable.

4. The surface contour of the ground moraine seems to some extent to take shape beneath the glacier. At one point I observed a diminutive hillock, about six feet high, half enclosed in the edge of the ice, which was here nearly vertical. The appearance was

as though the ice, in its withdrawal, had half disclosed a mound lying beneath it. This, though a mere mound, was about equal in height to the adjacent heaps that had been left by the glacier.

5. At other points, near the center of the valley, the ice may be seen resting directly upon well assorted, stratified sand and gravel. Level sheets of fine detrital matter extend without disturbance of continuity or surface beneath the edge of the glacier. The assortment and stratification of this material was apparently accomplished by sub-glacial streams, which seem afterwards to have found other avenues, when the ice occupied their place, either by settling down from above, or advancing from behind. The singular fact is that the stratified sands should not have been disturbed. It is very likely true that these fragile formations near the edge of the glacier are heated by conduction from the warm earth surrounding, and by transmission through the comparatively thin ice above, and that they are thus enabled to protect themselves from the forcible action of the ice, by melting it as fast as, in its slow motion. it is pressed upon them.

6. If we now turn to the sides of the valley, we shall see that up to a certain height they are mainly bare of vegetation and present a fresher and less weathered surface than the slopes above, as though the glacier had recently stood at that hight. If we glance down the valley, we shall see that the upper margin of this surface descends curvingly, much like the contour of the present foot of the glacier. If we descend the valley to the point where this reaches the plain, we shall find the ground moraine rising into a low, irregular ridge, which stretches in a broken curve across the valley. The material of this ridge is essentially the same as that of the ground moraine, save that there is noticeably more sand and gravel in proportion to the coarse material, and the whole is more thoroughly rounded. These remarks relate to the surface material. The superficial contour, however, assumes quite a different and distinctive aspect. Although but a diminutive ridge itself, not perhaps exceeding twenty feet in height, its surface contour, instead of presenting a simple curving outline, exhibits a complex series of still more diminutive ridges, hills and hummocks, of irregular outline and arrangement, accom-

panied by correspondingly irregular depressions, some of which are filled with water and form miniature lakelets. The irregular outline and little islands of one of these made it almost a Lilliputian Minnetonka. Bowlders are abundant in all positions on and in the ridge, as shown by the sections exposed by the outflowing streams, which also exhibit the confused unstratified condition of the interior. Locally, there are small patches of stratified material. This ridge is most abrupt on the outside, or that away from the glacier, while on the inside it graduates, without any distinct line of definition, into the bowlder sheet above described.

This ridge presents a striking similitude to our Wisconsin Kettle moraine, and I think it may be safely said to be a miniature representative of the same phenomena.

This is a true terminal moraine, according to our definition, formed by an advance of the Rhone glacier.

7. A few rods — perhaps 20 — below this there is another moraine of like character, but of older date, as shown by the grass and shrubs that have grown upon it, as well as by its position and less angular contour. It is narrower and more simple in form than the preceding, and like it, is interrupted by level passes, the channels of former streams.

About 30 rods below this is a third, still less continuous, a good illustration of an interrupted, half destroyed moraine.

8. Between these three moraines are level gravel flats of fluviatile origin, and doubtless stratified.

9. On the south side of the Rhone, the middle moraine breaks up into an area of scattered mounds or "knobby drift."

10. On that side also, at the foot of the acclivity, where the solar action is less effective than elsewhere, a considerable mass of ice has been left by the retreating glacier, and this is much covered by sand, gravel and coarse detrital matter. As the ice melts, it deposits its burden of rock-rubbish in an irregular, hummocky fashion, somewhat resembling that of the moraine above described, but without the ridgey characteristics of the latter. It is mainly interesting as illustrating the form of deposition of a superficial glacial accumulation where the ice lets it down by melt-

ing from beneath, instead of casting it over its extremity in the usual method.

11. The south side of the Rhone also presents a fine exhibit of fluviatile silt, sand and gravel flats, and shows the pre-eminent tendency of glacial streams to wander widely, back and forth, across their valleys, when the slope is moderate, owing to the unusual rapidity with which they fill up their channels by the large burden of glacial mud, sand and gravel that they carry, or roll along their beds. They thus rapidly accumulate broad stratified sheets. I suspect that some deposits formed in this way during the Quaternary age have been mistaken for lacustrine formations, owing to their breadth and extent.

12. None of the other glaciers visited terminate in a manner equally favorable to the observations sought, but some of them present particular features of equal interest. The terminal moraines of the Grindenwald glaciers are even more instructive by way of comparison with our drift moraines, because of the closer proximity of the successive ridges, and greater similarity of the material, it being a limestone bowlder clay, with some metamorphic erratics included, and some assorted detritus. Some of the moraine ridges are a pronounced bowlder clay, while others are largely composed of bowlders or gravel. On the inner moraine of the upper Grindenwald glacier, there is much fine gravel and sand in heaps and miniature ridges, presenting a very interesting phenomenon. The outer range is more massive than those of the Rhone glacier, and is very strikingly similar to the Wisconsin Kettle moraine in its superficial expression. The corresponding moraines of the lower Grindelwald glacier show the same features very neatly, and those of the Bois and other glaciers display like characteristics.

13. So far as my observations went, the nature of the rock over which the glaciers passed was more influential in determining the proportion of clay, sand, gravel and bowlders, than I had supposed. Where the rock was mainly granitic, the amount of clay was proportionately small, the detritus being mainly coarse sand, gravel and bowlders. This was doubtless due to the difficulty of reducing the hard constituents of granite to powder. Where the

glacial channel lay through schistose rocks, or limestone, there was a notable larger proportion of clay, and some of the moraines were a typical bowlder clay. These observations throw unexpected light on the drift of our state, where there is a very marked difference between the glacial deposits of the limestone and granitic districts in respect to the physical condition of the material.

14. In former times, the Alpine glaciers were greatly expanded and stretched entirely across the lake region to the foot of the Jura mountains, on the French border. In this expanded condition, they most nearly, though still quite inadequately, represent the nature of American Quaternary glaciers. The Juras and much of the intermediate region are composed of limestone strata. To the west of Lake Neuchatel the sheet of drift extends up the mountain slope nearly 3,000 feet above the lake surface, when it terminates on the declivity in a rude, imperfect terrace of undulatory surface. This, where I observed it, is composed of bowlder clay, usually quite gravelly, and associated with gravel beds. It was my hope to find the margin of this great *moraine profonde* at some point on a comparatively level tract, where its development would not be cramped or coerced by encompassing barriers, but both at this point and in the vicinity of Gex, west of Geneva — the only two points where I was able to examine it — I found it pushed high up on the steep side of the mountains, and could, therefore, only conjecture what its form and structure would have been on plains similar to those of the Mississippi valley; indeed we can hardly assume that its material would have remained precisely the same, since in more level regions it might have been influenced in a greater degree by glacial waters. As it was, it may be characterized as a gravelly bowlder clay, with accompanying gravel beds.

15. In the beautiful valley of Ruz, west of Neuchatel, I found excellent exhibits of the morainic bowlder clay. If an excavation seen on the east side of this valley were placed side by side with any one of a large number that can be found in Wisconsin, no one but a skilled lithologist or paleontologist could determine to which locality they severally belonged, so striking is the physical similarity of the two formations. Indeed the resemblance of

the rock forming the detrital material is so close that, were the Swiss hill transplanted to certain localities in Eastern Wisconsin, probably no geologist would ever detect the imposition, unless fossils, of which I saw none, were found in it.

16. In company with our genial vice consul at Geneva, Dr. Delavan, I had the pleasure of visiting the celebrated Jardin, in the Chamouni region. A four hours walk up the *Mer de Glace* and over the *Glacier de Talèfre* brought us to an island of sub-triangular outline, completely encompassed by a sheet of snow and ice; and around which clustered an amphitheater of mountain pinnacles. It derives its name, "The Garden," from the fact that, although more than nine thousand feet above the sea, and surrounded on all sides by perpetual snow and ice, a handsome flora of grasses and bright, beautiful, little flowers bloom on its southward sloping side. But, putting aside this interesting phenomenon, and restraining the sentiments, which the magnificent surroundings and the grand views of Mount Blanc and the glaciers below inspire, I can only, in this connection, remark upon the point of chief geological interest to us, viz.: the likeness to our driftless area which this glacier-girt island presents. Let me say, however, at the outset, that the Jardin is not a driftless area. It was formerly covered by an ice sheet and contains erratics on its surface. But at present, though the glacier originates much higher up the slope, it divides and passes around the Jardin and again unites below it, leaving it, so far as present action is concerned, a non-glaciated area, surrounded on all sides by active glaciation.

Its likeness to our driftless area, however, ceases here. It is walled in, as is appropriate to a garden, by a steep sharp moraine, thrust up by the ice in moving around it. On the border of our driftless area, the glacial debris thins out very gradually and disappears in an obscure margin. The Jardin differs also, in that it appears to owe its immunity from present glacial action more to its own prominence than to the effects of adjacent depressions. The driftless area of Wisconsin does not lie, like it, on the summit of a protuberance, but on its lee side. The ice of the glacial period surmounted the Archæan heights, south of Lake Superior, in Wisconsin and Michigan, and descended the southern slope a

distance of about one hundred miles, where it terminated on the declivity, and its waters continued on across the driftless area, leaving gravel terraces along their course. We must, therefore, seek elsewhere for an adequate illustration of the essential principles involved.

At the foot of the Viesch glacier, the ice stream divides and the branches pass through valleys on either side of a ridge, though the ice at the point of branching is higher than the ridge. Formerly the branches extended much further, and probably united below the ridge. This would be an approach to an illustration of the phenomena in question, but, unless the ice moved over the ridge, and terminated on its slope, it would fail of an essential element.

The right hand branch of this glacier is antagonized by a prominence, and the greater portion of the ice passes through lower channels on either hand; and these subordinate streams approach each other below, leaving an island, or nearly so, on the slope. Above this island the ice terminates on the declivity. On one side the slope is so steep that the ice breaks away and rolls to the bottom, marring the perfection of the illustration, but not destroying its force. The ice, while not really split in twain, is so far thinned by the combined action of the prominence and the adjacent depressions, as to be unable to maintain itself against the wasting to which it is subjected. If the slope were somewhat less precipitous the illustration would be more complete.

Near the termination of the upper Grindenwald glacier, there has recently been a similar instance of an island in a glacial stream with higher ice on either side and above it. In this case, the slope was so great that a portion of the ice above the island became loosened and rolled down to the ice below. The amount which thus passed over was less than an equivalent of the melting capacity of the area of the island, so that, had not the cohesion of the ice been overcome, it would have been melted on the upper margin of the island.

In all the foregoing instances, the areas have formerly been glaciated, and thus differ from the Wisconsin driftless area. They have force, however, as illustrating, in a miniature and imperfect

fashion, the fact that, not only may a glacial stream be parted and an island be formed by a prominence projecting through the ice and wedging it aside, or by valleys leading it around; but also that there may be such a combination of prominence and depression as — while not entirely parting the stream — to so thin the ice passing over the prominence, that it shall be wasted and disappear before it can join the main currents diverted on either side; so that there shall be a non-glaciated area, not on the summit of the prominence, but on its lower slope, and these I conceive to be the essential phenomena and elucidation of the Wisconsin driftless area.