The Ancient Rhone Glacier. By James Heelis.

Most of us who have read and thought about the condition of the Rhone Glacier at the time when it is supposed to have extended to the flanks of the Jura, have speculated upon the conditions under which this enormous development of the glacial action, with which we are more or less familiar in its modern form, took place. I propose to put forward in this paper some of the facts which seem to me to have an important bearing upon the question, but I shall avoid drawing any conclusions from what I state, leaving those to be deduced by others who have wider knowledge of physical phenomena than I possess.

Monsieur Charpentier in his 'Essai sur les Glaciers et sur le Terrain Erratique du Bassin du Rhône,' published in 1841, gives a map of the country in which erratic blocks from the Rhone valley have been recognised. The area shown by him in this map, below the upper end of the lake of Geneva, is 884 square miles; but the map is not strictly to scale, and he makes the moraine come down nearly to the present level of the lake at Yvoire. Probably, he there noticed traces of a lower moraine than that which bounded the south side of the glacier when having its greatest extent. Indeed, Monsieur Alphonse Favre * has observed moraine matter much higher than that recorded by Monsieur Charpentier in the Rhone basin, in the neighbourhood of Geneva. By measurements taken on the Federal map, I find that the area of Monsieur Charpentier's glacier from the gorge between the Dent du Midi and the Dent de Morcles was about 1,000 square miles or 3,000,000,000 square yards. According to him, the glacier extended from that gorge to the head of the lake of Geneva, the south side of which it followed to Yvoire, whence it crossed the lake, and abutted on to the side of the Jura, attaining on the Chasseral a height of 2,015 ft. above the Lake of Neuchatel, and extending as far as Soleure.† The other, or right-hand side, swept round the mountains of the Canton Fribourg to Guggesberg in the Sensethal. I have spoken of Monsieur Charpentier's map, because, though his work is one of the earliest in date, it contains the most complete discussion of the subject which I have met with: but I do not wish to imply that subsequent observations have not confirmed those made by him, for several writers have published notes to the same effect.

Now, if the theory of the former extension of the Rhone Glacier is to be accepted, probably no better mode of measuring its size can be found than by tracing the position of erratic blocks which can be recognised as coming from the upper valleys of the Rhone; but it is to be noted that such a mode of measurement will not give the maximum size of the glacier: the blocks borne by the ice from the Rhone valley would not be transferred to the ice from the valley of the Dranse, for instance; they would, when meeting an opposing glacier,

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* *Recherches Géologiques dans la Savoie*, vol. i. pp. 125-6.

† *Essai sur les Glaciers*, p. 160.

be rolled inwards on to the glacier to which they properly belonged. I make the observation that it may not be supposed that I have made no allowance for the contributions of ice from large districts, such as Chablais and the Saanethal (large in themselves, but not large when compared with that part of Valais lying above the gorge). As, however, it is important for the purposes of this paper to establish that the portion of the glacier with which I propose to deal was supplied with and maintained by ice, which had passed through the gorge at St. Maurice, I will briefly indicate the nature of the evidence, and will cite a few cases; but a full discussion of the question would exceed the reasonable limits of a paper for this Journal.

At p. 90 of the first volume of this Journal, in a review of Sir Charles Lyell's 'Antiquity of Man,' the case is shortly summed up as follows: 'Monsieur Guzot has shown that the Alpine erratics, instead of being scattered at random over the Jura and the great plain of Switzerland, are arranged in a certain and determined order, strictly analogous to that which ought to prevail if they had once constituted the lateral, medial, and terminal moraines of great glaciers.'

Monsieur Charpentier mentions a large erratic, found at Steinhof near Soleure, composed of talcose granite which he asserts came from the Binnenthal. The Pierre à Bot found near Neuchatel is composed of granite, supposed to have been carried from the neighbourhood of Martigny. A block found at Mont la Ville is recognised as being of granite, from the Val Ferret. Another block called the Pierre de Condy, found near the village of Provence, is referred by Monsieur Charpentier to the talcose granite of the Binnenthal.* Monsieur Favre recognises in the moraine matter found on the Chasseron, the peculiar formation of the Valorsine.†

These examples might be increased in number, but I must leave those who are interested in the subject to refer to the authors I have named, and to others who have written upon the same subject, and will only add that the area of 1,000 square miles, which I have adopted for the purposes of this paper, does not include any part of the glacier between the gorge at St. Maurice and the present head of the lake, nor any part lying west of a line from the mouth of the Dranse to Mont de Bière in the Jura range.

Monsieur Charpentier,‡ followed by Monsieur Favre, places the moraine of the old glacier on the sides of the Dent du Midi and the Dent de Morcles, at a height above the Rhone of 3,000 Swiss feet, which is equal to 1,066 yards. By measurements on the Federal map, I find that the valley between the slopes of those two mountains is 1,944 yards broad; from the bottom of the valley to the contour line of 1,066 yards is 1,515 yards measured horizontally on the west side, and 1,390 yards on the east side. The open space through which the glacier, 1,066 yards high, had to force itself is consequently about 3,630,000 square yards. If, as I have endeavoured to show was the

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* *Essai sur les Glaciers*, p. 126.
† *Recherches Géologiques*, vol. i. p. 114.
‡ *Essai sur les Glaciers*, p. 158.

case, the whole of the ice necessary to feed and maintain the glacier, 1,000 square miles in extent, on the plane of Switzerland passed through the gorge, then for every yard in thickness annually evaporated or melted from the glacier, 84 in. of ice must have passed daily through the perpendicular section of the gorge. The calculation is simple:

$$1{,}000 \times 1{,}760 \times 1{,}760 \text{ cub. yds.} \div 3{\cdot}630000 \times 365 \text{ sq. yds.} = 2{\cdot}3379 \text{ yds.}$$
$$= 84 \text{ inches.}$$

We know, from the observations of Professors Forbes and Tyndall and others, that glaciers as we now find them move more rapidly in the centre than at the sides, at the top than at the bottom. What must have been the speed of the centre of this glacier at its surface?

To compare this speed with what we are accustomed to, I will direct attention to the 'Alpine Journal,' vol. i. p. 332, where Mr. Cowell records the finding of the relics of the guides lost on Mont Blanc. The accident occurred on August 20, 1820; the relics were first found in the summer of 1863. The distance from the place of the accident to where the relics were found was 8,513 yards; that is, they had advanced less than 200 yards per annum, or about 20 in. a day on an average; and this on a slope of 23° or 1 in 2·356.

What is the slope of the Rhone Glacier? The following table has been taken from the Federal map, but of course the distances are only approximate ones.

	Distance in Miles	Altitude. Feet	Difference. Feet	1 in
From Rhone Glacier		5,751		
To Oberwald	3½	4,455	1,296	14
„ Obergestelen	2	4,393	62	170
„ Ulrichen	1½	4,373	20	396
„ Munster	2½	4,363	10	1,320
„ Niederwald	4½	4,052	311	76
„ Fiesch	4½	3,458	594	40
„ Lax	2½	3,425	33	400
„ Mörel	5	2,494	931	28
„ Brieg	5	2,214	280	94
„ Vispach	5½	2,155	59	501
„ Turtmann	8	2,080	75	563
„ Sierre	8½	1,863	217	207
„ Sion	10	1,636	227	233
„ Saxon	10½	1,542	94	590
„ Martigny	6	1,505	37	856
„ St. Maurice	9	1,368	137	347
„ Bex	2	1,342	26	406
„ Villeneuve	11	1,230	112	518

Or, to break the table up into sections:—

From Rhone Glacier to Brieg 31 miles 3,537 ft. fall or 1 in 46.
„ Brieg „ Villeneuve 70½ „ 984 „ „ 1 in 378.

Taking the whole length of the valley, the fall from Rhone Glacier to Villeneuve is 1 in 118.

So we have, by way of comparison, the present Glacier des Bossons, with a slope of 1 in 2½, travelling at the rate of 20 in. a day; the old

Rhone Glacier, with a bed of 1 in 378, travelling at four times that speed, on the supposition that only 1 yard per annum is melted or evaporated from its lower surface. I shall now give reasons for believing that that supposition is far below the truth.

Monsieur Escher von der Linth made experiments on the Aletsch Glacier for the purpose of ascertaining the surface-melting of the glacier. On July 8, 1841, he inserted stakes in holes 3 ft. in depth. On August 16, forty seven days after, all the stakes had fallen and no trace was to be found of the holes.* This experiment, however, is not quite satisfactory, for there is nothing to show that Monsieur Escher visited the stakes daily, so that they might have fallen some days previous to his visit on August 16; and secondly, the experiment was made at the hottest part of the year, when the glacier was free from snow. But at any rate we are entitled to say that, in forty-seven days of summer, at least 1 yard of ice was melted off the surface of the Aletsch Glacier. Probably the preceding and the succeeding forty-seven days were equally effective, or in rather more than one-third of a year, the summer one-third, 3 yards of ice would be melted. Is it very bold to suppose that the remaining two-thirds of the year would supply an additional 2 yards, or that the total melting for the year may be estimated at 5 yards?

Dr. Haughton, in his paper on 'Sunheat and Radiation,' † read before the Royal Geographical Society of Ireland, gives a formula for calculating the amount of heat received annually from the sun in any degree of latitude, in terms of the amount of ice which that heat would melt. From the formula I calculate that the number of feet of ice melted in latitude 46·40 (which is about the centre of the ancient Rhone Glacier below the gorge) is 70 ft. . From this must be deducted the radiation equivalent calculated from the northern hemisphere by Dr. Haughton, which is 35·475 ft.; consequently, upon this hypothesis, the actual available heat is about 34·5 ft., or $11\frac{1}{2}$ yards. But the rays reflected from a white glacier would be more than those from an earth surface, his radiation constant being for the average characters of exposed surface, and in addition some part of the residue has to be considered as producing meteorological effects. If we make a liberal allowance for these two sources of error, we approximate to the 5 yards of actual melting, which we have arrived at from an entirely different line of discussion. But 5 yards of ice per annum, melted from the old Rhone Glacier below the gorge, would require an average speed of 400 in. per diem, or more than 11 yards for the speed of the glacier through the gorge, in order to maintain the old glacier in the dimensions to which it is said to have attained.

I have hitherto considered only the glacier below the gorge. I will now deal with the source of supply of the enormous amount of ice which was required to maintain it in the condition to which it is said to have attained.

Monsieur Favre, in his 'Recherches Géologiques dans la Savoie,' ‡ gives

* Quoted in Tyndall, *Glaciers of the Alps* (1860), p. 271.
† *Journal of the Royal Geological Society of Ireland*, 1877–78.
‡ Vol. i. pp. 9, 10.

as the mean height of the river near Geneva 131 c.m. of Monsieur Burnier's scale, which is equivalent to 108·47 c.m. of the limnimètre. He also gives a list of measurements of volume water passing down at various times and in various states of the river. It is not possible to find any rule from the examples given, but taking the average I find that for a height on the limnimètre scale of 108·47 c.m. 358 cub. m. of water would pass per second. From this I deduct ten per cent. for the contributions of the Dranse and other rivers below the gorge, which, taking into consideration the evaporation from the lake, seems to me liberal, and I get 320 cub. m., or 416 cub. yards, for the flow per second down the Rhone at St. Maurice.

The area of Valais is about 2,070 square miles. Some portion of this is below the point I am considering, while another small part belongs to a different watershed. As a set-off against this, I may remind readers of this paper that some geologists consider that the Glacier d'Argentière, at the time of the great extension of the Rhone Glacier, blocked the upper end of the Chamonix valley, so as to turn the drainage of that part into the Rhone basin.

Four hundred and sixteen cub. yards of water per second passing St. Maurice would be equivalent to a rainfall of about 2 yards over the whole of the watershed. Really it implies a heavier rainfall, for what is discharged by the river is only the surplus fall, and gives us no idea as to what is evaporated, and again precipitated in the district.

The following figures are taken from the 'Bulletin de la Société Vaudoise des Sciences Naturelles,' 2nd series, vol. xvii., and will afford some means of comparison between the actual precipitation and the calculated one. The rainfall is probably greater in the Upper Rhone Valley than at the places named:

Year	Place	Rain	Snow
1879	Chateau d'Œx . . .	1,214·7 m.m.	181 c.m.
1880	„ „ . . .	1,116·5 „	87 „
1880	Cuves	1,394·4 „	48·7 „

I have not been able to refer to the St. Bernard observations, which would have given a more satisfactory means of comparison. The same amount of water passing down the Rhone at St. Maurice would, if turned into ice with the same sectional area I have already mentioned, require a speed of 10 yards per diem through the entire section of the glacier.

These two speeds of 11 yards and 10 yards per diem, obtained by totally different means, must not, however, have too great importance attached to them; for throughout the discussion the data are very uncertain; and in the last mode of viewing the question it must not be overlooked that some part of the rainfall or snowfall probably passed off as water and not as ice.

I hope, however, that what I have written will again draw attention to a subject which is by no means exhausted; indeed, I should say that we have hardly touched the fringe of it. A glacier speed of

10 yards per day is a thing unknown either in Switzerland, Greenland, or elsewhere, and we may well hesitate before we accept it as a possible solution of the difficulties presented for our consideration by geologists.

On the other hand, if any importance is to be attached to the various calculations to which I have drawn attention, it is possible to believe that not a very great change in the meteorological conditions of Switzerland would suffice to maintain a glacier of the required dimensions when once formed. Few people would have supposed that the waters of the Rhine as they now flow would suffice, if turned into ice, to supply an annual melting of five yards upon a glacier 1,000 square miles in extent.

NOTE BY THE EDITOR.

The velocity at the gorge of St. Maurice of the ancient Rhone glacier admits of an easy explanation. It is a well-known fact in glacier motion that, if we consider the molecules of ice in any vertical line in a glacier, each molecule shears over the one immediately below it, the actual velocity being the least at the bottom, where the ice is in contact with the bed of the glacier, and increasing continuously towards the surface, where the velocity is the greatest. It follows that the surface velocity at any given point and the mean velocity of any given section must, *cæteris paribus*, increase with the thickness of the glacier. The ancient glacier of the Rhone was 3,000 feet thick in the gorge of St. Maurice. There is no glacier at present existing in the Alps at all approaching this thickness. There would consequently be great reason for surprise if the velocity of the ancient Rhone glacier, where it passed through the gorge, was not very much in excess of any rate of motion observable in Alpine glaciers at the present day.

The most recent observations of the glaciers of the Arctic regions confirm in a striking manner what we know must have been the case with the ancient glacier of the Rhone. In the *Quarterly Journal of the Geological Society*, vol. xxxiii., 1877, page 142, is a paper by Amund Helland, of Christiania, descriptive of certain phenomena of the glaciers of Greenland. Among the glaciers described in this paper is that of the Fjord of Jacobshavn, where M. Helland determined the summer velocity of a series of points on the surface, at distances varying from 400 to over 1,000 metres from the edge. The greatest mean daily velocity observed was 19·77 metres, or very nearly 65 feet, and this on a glacier with a slope of only half a degree, or 1 in 115. The thickness of the glacier could only be estimated approximately from the height above the water of the icebergs which 'calve' from it, and probably did not exceed 1,500 feet.

DR. R. v. LENDENFELD'S EXPLORATIONS IN THE SOUTHERN ALPS OF NEW ZEALAND.

By W. S. Green.

A short notice of Dr. R. von Lendenfeld's expedition to the great Tasman glacier may be found in the 'Alpine Journal.' * Details of his expedition have since come to hand, and he has been good enough to send a set of the photographs which he took to the Alpine Club. The

* Vol. xi. p. 301.