17. *On the* Traces *of a* Great Ice-sheet *in the* Southern Part *of the* Lake District, *and in* North Wales. By D. Mackintosh, Esq., F.G.S. (Read January 7, 1874.)

(Abridged.)

[Plate XX.]

[After a few introductory remarks on *roches moutonnées*, the distinction between primary and subsequent striæ, &c., the author proceeds to consider the main subject of his paper as follows.]

A tabular statement of facts will, I think, clearly show that the primary or most persistent glaciation of the south-central part of the Lake District, must have been produced by an ice-flow capable of ignoring the drainage of the country to a much greater extent than could have resulted from any system of confluent glaciers strictly so called.

	Primary glaciation.
Far Easdale (near Grasmere), rocks generally smoothed from between	N.N.W. and N.W.
Entrance to Far Easdale (east side), striæ from	N.W.
East of Easdale House, striæ from about	N. 10° W.
Near Sourmilk waterfall, striæ from	N.W.
Near Blind Tarn moss (crossing the outlet), striæ from	N. 30° W.
On summit of the rock and bog tableland between Easdale and Great Langdale up to at least 1700 feet above sea, *roches moutonnées* smoothed from about	N.N.W.
Striæ on ditto from	N.N.W.
A short distance north of High Close, striæ from	N. 40° W.
Top of High Close col, striæ from	N.
East of Chapel Stile (Great Langdale), striæ from	N. 30° W.
North of Elterwater Village, rocks smoothed and striated from	N. 26° W.
Bottom of Great Langdale west of Elterwater Village and south-west of Chapel Stile School, rocks smoothed and striated from	N.W.
On roadside (up hill) from Elterwater Village to Dale End, striæ from	N. 40° W.
Higher up on same road, striæ from	N. 40° W.
North of Little Langdale Tarn, striæ from	N.W.
Between Little Langdale Tarn and Blea Tarn, striæ from	N. 30° W. and N.W.
Near the Parsonage (Grasmere), striæ from about	N.W.
East of Town End (Grasmere), striæ from	N.N.W.
Roches moutonnées between Town End and Whitemoss quarry, smoothed from about	N.W.
At Whitemoss quarry, striæ from about	N.W.
Rydal valley (about 1 m. north of Wordsworth's house), striæ from	N. 10° W.
Near Ambleside (on Grasmere road), striæ from	N. 20° W.
Near Ambleside Church, striæ from about	N. 15° W.
Rocks on north side of Loughrigg Fell, smoothed from about	N.N.W.

	Primary glaciation.
Loughrigg Tarn and the neighbourhood, striæ from about	N.N.W. and N. by W.
In one place crossed by striæ from about N.W.	
North side of Brathay valley (between Loughrigg Tarn and Clappersgate), striæ from	N.W.
Crossed by striæ from a little N. of W.	
Near Pull (on road from Clappersgate to Hawkstead), striæ from about	N. 27° W.
Quarry near Mr. Atkinson's house (north-west of Windermere), striæ from	N. 30° W.
Crossed by later striæ from N. 10° W.	
Windermere churchyard, broad grooves from	N. 25° W.
Crossed by sharp striæ from N. 10° W.	
Near Mr. Pritt's house, Bowness, striæ from	N. 30° W.
In front of a house called the Ferns, Windermere, striæ from between	N. 20° and N. 30° W.
Near Rev. Mr. Stock's house, Bowness, striæ (possibly secondary) from	N. 10° W.
Near Crossings (Windermere) broad grooves, from between	N. 20° and 23° W
Crossed by striæ from about W. 35° N., and a few grooves from about N. 33° W.	
About halfway between Windermere and the Lake, striæ from	N. 33° W.
Orrest Head (Windermere), smoothed from about	N.N.W.
Top of a high ridge called School Knott (near Windermere), crossed by great grooves from	N. 33° W.
Near Ings (east of Windermere) a number of large *roches moutonnées* smoothed from about	N.N.W.
Broad grooves and striæ on ditto, from between	N. 20° and 30° W.
Rocks at a considerable height on west side of Troutbeck valley, smoothed from about	N.N.W.
Watershed between Style End (Kentmere) and Long Sleddale, striæ from	N.
West of Stavely Parsonage, primary glaciation from about	N.W.
Crossed by large grooves from nearly	W.
Near entrance to Tilberthwaite valley (about High Yewdale, Coniston), rocks extensively smoothed up hill from about	N.
North side of Church Beck valley about halfway between Coniston and Copper-works, rocks extensively grooved obliquely down hill from about	N.
Crossed by striæ running in direction of valley or from N.N.W.	
Near Copper-works, striæ (covered with stratified sand and gravel) from	N.N.W.
Between Copper-works and Paddy End, striæ from	N. 30° W.
At mouth of Reddale valley above Copper-works, striæ from	N.W.
On steep slope above Copper-works, rocks extensively striated down hill from about	N. 10° W.
Roches moutonnées on nearly opposite slope, smoothed up hill from about	N.
Between Duddon Bridge and Seathwaite Church, *roches moutonnées* with parallel undulations and striæ coinciding in direction, from about	N.N.E.

It will be seen from the above statement of facts that the primary ice-marks embrace an area extending from near Style End

and Stavely (Kentmere), on the east, to nearly as far west as Stickle Tarn and the Coniston Old Man *—and from Far Easdale on the north to as far south as Bowness and Church-beck valley, Coniston. In the neighbourhood of Windermere they average about N. 27° W., and run generally up hill. About Ambleside their average direction is nearly the same. Around Grasmere they average about N. 40° W. To the north-west and west of Grasmere, in the upland valleys and on high ridges, they average about N. 30° W. South of Grasmere and in Great Langdale they average about N. 35° W. In the Coniston district they average a little W. of N.

In the neighbourhood of Windermere and Bowness, the ice, besides moving generally up hill, must have ascended and passed over Orrest Head (700 feet above the sea), crossed a high ridge called School Knott (760 feet) at right angles †, and the upland valley between Windermere and Stavely at nearly right angles. North-west and west of Ambleside it must have obliquely crossed Rydal water, and a high, if not the highest part of Loughrigg Fell (1100 feet). East of Grasmere it would appear to have smoothed the side of Rydal Fell up nearly to the summit; but, so far as yet known, the ice must chiefly have ignored the configuration of the ground in a district extending for some miles to the north-west, west, and south-west of Grasmere. From the north slope of Far Easdale, it must have obliquely crossed the dale, smoothed the rocks on its south side up hill, then crossed a high ridge, descended into Easdale, smoothed the rocks obliquely across the dale, marched from the bottom of the dale (900 feet) up hill to the top of a ridge more than 1700 feet above the sea. This ridge consists of hard volcanic breccia and other felspathic rocks; the summit is a narrow tableland consisting of alternate rock-basins and bosses; the rock-basins are partly filled with peat and water; and many of the bosses are *roches moutonnées*. Nowhere in the Lake District have I seen such a striking series of mammillated rocks: they have been considerably roughened by the weather; but the regular curvilinearity of their forms has been perfectly preserved. From the appearance of the surface of the great tableland on the north-west (which reaches a height of between 2300 and 2500 feet), and the rounded rocky eminences on its southern border, it can scarcely be doubted that the ice went over it; but I did not examine the ground further west than Stickle Tarn. From the top of the ridge just described the ice must have gone down into great Langdale, smoothing the sides of the projecting rocks which faced it or looked up hill, and leaving the down sides cliffed or jagged. Numerous examples of this smoothing of the sides of the rocks which offered the greatest

* The parallel undulations and striæ of Duddon valley, though probably primary, as they coincide in direction with the valley, may at present be left out of consideration.

† The ice-flow which crossed School Knott must have come from at least as far as Rydal (a distance of about 7 or 8 miles), and moved the greater part of the way over longitudinally level ground, and the latter part up hill.

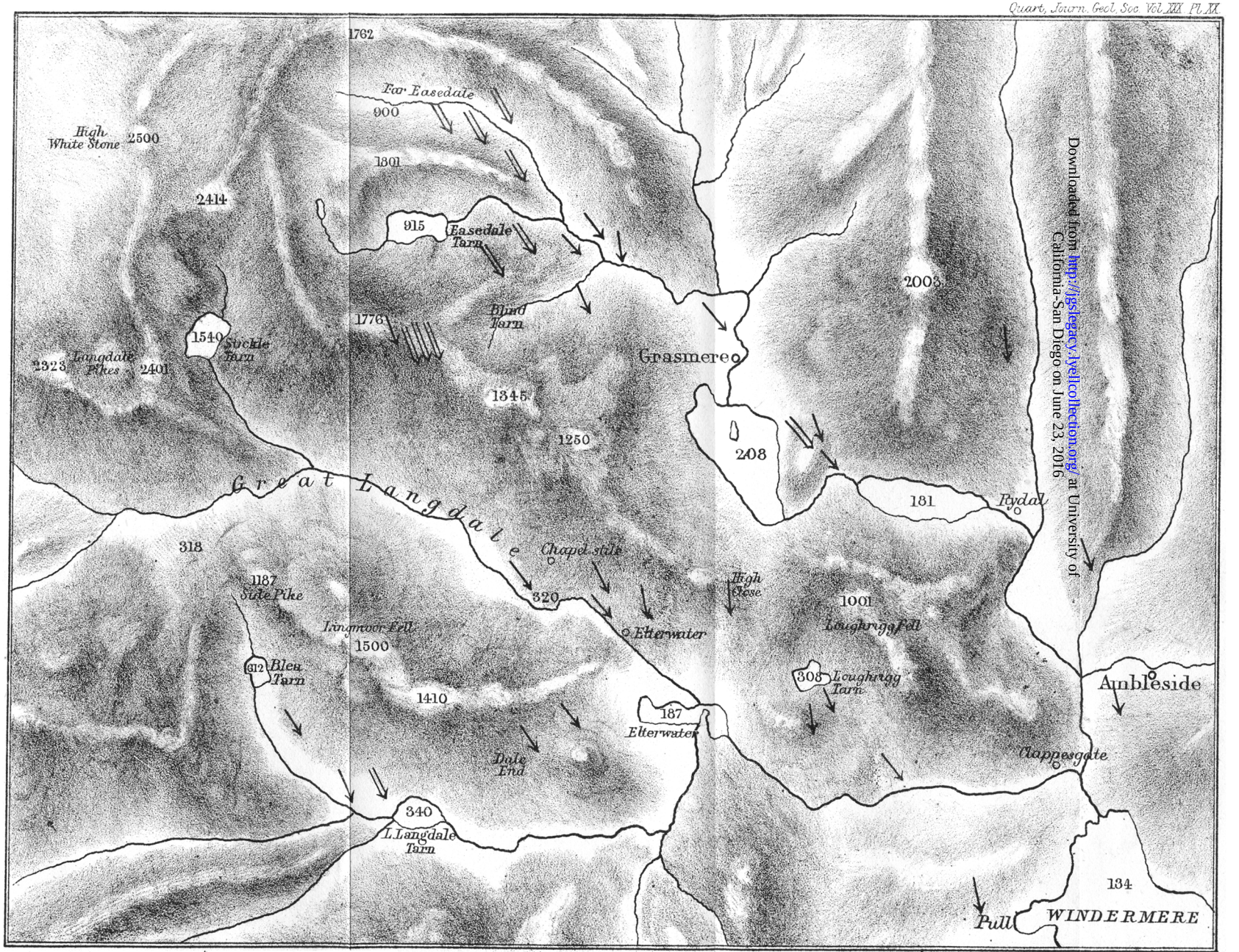
resistance to the descending ice, may be seen on the north side of Great Langdale from High Close westwards; many of them were pointed out to me by E. B. Wheatley Balme, Esq., of High Close. The ice in obliquely crossing Great Langdale (about 300 feet) in one place nearly coincided in direction, without altering its course, with a bend in the valley. A greater number of distinctly striated *roches moutonnées* may be seen in the lower part of Great Langdale than perhaps anywhere else in the Lake District: they extend to the base of the ridge called Lingmoor on the south side of Great Langdale; and the eastern part of this ridge is striated in such a manner as to leave no doubt that the ice passed over it. In some places further west there are indications of the ice having ascended the north side of the highest part of Lingmoor (about 1500 feet), and glaciated Side Pike, nearly 1200 feet; but the rocks are much dilapidated and their bases scree-strewn. On the south side of Lingmoor the striæ and *roches moutonnées* clearly point to ice having descended from its summit; so that it may safely be inferred that the ice-flow crossed over Lingmoor from Great into Little Langdale. In the Coniston-Old-Man area we meet with phenomena which cannot be very satisfactorily explained without supposing that the ice-sheet continued its march not only across Little Langdale, but (after a westerly deflection of its course) up the northern slopes of the Coniston Fells, over ground at least 2000 feet above the sea, down into Church-beck valley (600 feet) *, and up the side of the ridge on the south, beyond which I have not traced the ice-marks. As, however, it is barely possible, though not probable, that the ice which accomplished such feats among the Coniston Fells may have belonged to an ice-dome rising to a great height above the northern part of the Fells, and sloping down towards Little Langdale, we may principally direct our attention to the Easdale and Langdale ice-sheet until the Coniston mountains have been more extensively examined, especially to the north and north-west of the Copper-works.

Source of the Easdale and Langdale Ice-sheet.—Several years ago I noticed that the northern part of the Lake District must have been mainly glaciated from the south; and Mr. Ward has brought his S. and N. ice-marks to within two miles of where my N. and S. ice-marks begin, as may be seen from his map (Quart. Journ. Geol. Soc. vol. xxix. pl. xv.). It is impossible that a strip of ice not two miles in breadth could have originated two ice-flows in opposite directions, and both of them many miles in length. The northern ice-flow may have taken place at a later period than the southern; but however this may have been, I think it may be regarded as certain that the southerly ice-flow could not have performed the feats above specified without being backed up on the north by an ice-dome rising to a great height and covering many square miles of country to the north of Far Easdale. Until the central part of the Lake District

* At intervals along the whole of the northern slope of Church-beck valley N. and S. primary striæ may be seen running obliquely down hill. The instance noticed in the tabular statement is perhaps the best-defined.

has been carefully searched for ice-marks further west and east (but especially further east) than the area treated of in this paper, it might be going too far to invoke an ice-flow assailing the Lake District from without, and overriding an area extending west and east from the Duddon valley to Kentmere, if not to the West Riding of Yorkshire, and as far south at least as Morecambe Bay.

Traces of an Ice-sheet in North Wales.—The state of the basin of the Irish Sea between the Lake District and North Wales, at the time of the greatest development of the ice, cannot be well ascertained without a wider induction of facts than we at present possess. The north-western side of Snowdonia has been principally glaciated from the S.E. and S. or in the direction of the lower valleys. In the high-level valleys, as long ago shown by Professor Ramsay, there are striæ which indicate a thickness of ice sufficient to have enabled it to cross minor ridges and hollows, and to move along the sides of hills at great altitudes. During recent visits to North Wales I saw many glaciated surfaces between the Vale of Conway and Capel Curig, the striæ varying from between S.W. and W.S.W., and indicating an ice-flow capable of ignoring hills and valleys. In the great Ogwen Pass, near a farm-house called Wern-go-ischaf, I found an extensive rock-surface striated at right angles to the pass (or nearly N. and S.) which a small glacier coming down from above did not seem capable of explaining, especially as the lines did not coincide in direction with the small lateral valleys on the right and left. To the south of the Snowdonian range of mountains I happened to alight on a number of phenomena which clearly indicated the southerly movement of a great ice-sheet capable of ignoring or crossing deep valleys, and which probably had its source in an ice-dome covering the peak of Snowdon and the surrounding heights, and levelling the area between Snowdon and Moel-wyn. The group of mountains of which Moel-wyn is the principal, furnishes evidences of the former existence of such an ice-sheet. On the southern side of Bwlch-cwm-orthin (which separates the head of Cwm Croesor from Cwm Orthin) away from any valley, and at a height of more than 1800 feet above the sea, I found a number of rock-surfaces, smoothed, mammillated, and striated from about W. 30° N. There is a possibility of these surfaces having been glaciated by floating ice; but when viewed in connexion with *roches moutonnées* at a lower level, soon to be noticed, I think it is more probable that the agent was land-ice of a thickness sufficient to fill up and override the upper part of Cwm Croesor before it found its way to the irregular plateau on which the glaciated rocks occur. Between Cwm Croesor and Beddgellert mammillated rocks may be almost everywhere observed; but the greatest display occurs immediately to the south of the bare and craggy felstone ridge called Yr Arddu; I believe they are unequalled in any part of Wales or, perhaps, in the Lake District. Their regularly rounded and approximately dome-shaped forms, not exceptionally, but as a general rule, furnish an unquestionable evidence of a great flow of land-ice, as icebergs would have tended to flatten and plane



F Dangerfield lith. 22, Bedford St Covent Garden.

MAP OF PART OF THE LAKE DISTRICT.

Roches moutonnées Striæ

down projecting rocks, though, under exceptionally favourable circumstances, they might have left rocks more or less rounded. These *roches moutonnées* are not in a valley, but on an irregular plateau. They occur at various heights, and must have been smoothed by ice which moved independently of the drainage of the country. Indeed the ice by which many of them were smoothed must have come over Yr Arddu. They are so much smoothed that it is often difficult to tell the precise direction from which the ice came; but taken in connexion with a number of striæ, the direction would appear to have been approximately N. The ice may have radiated from the Snowdonian dome south-easterly towards Bwlch-cwm-orthin and southerly towards Yr Arddu. East of Moel Wyn the mouth of Cwm Orthin is magnificently mammillated, as long ago mentioned by Professor Ramsay; and a survey of the surface-configuration would, I think, lead to the conclusion that the mammillation was principally caused by a great ice-sheet and not by a corry glacier.

The above remarks on the primary glaciation of a part of North Wales are intended as supplementary to those on the Lake District, and not as exhaustive of the subject.

[The author concludes with observations on the correlation of the drifts of the Lake District with those of North Wales, the relation between lake-basins, drifts, and moraines, the commencement of the great submergence while the land was deeply covered with ice, &c., &c.]

EXPLANATION OF PLATE XX.

Map intended to show the positions and directions of the primary striæ and rock-smoothing in connexion with the surface-configuration of the principal area described in the paper.

Discussion.

Mr. Ward was inclined to regard the scratches in the Lake-district described as due to the confluence of several glaciers, so as to form a large mass of ice, the pressure of which enabled it to travel over the ridges separating the valleys, especially at their lower ends. If the phenomena could be explained in this manner, he thought it needless to invoke the existence of a large general ice-sheet. If such a thing had existed, it must have brought some of the rocks from the north and deposited them in the district; and this was not the case.

Mr. D. C. Davies thought that the author had left some circumstances out of view, especially the difference of dates of the striæ on the Welsh mountains, which had been cut at different times during the elevation and depression of the land. He instanced the occurrence of fragments of Scotch granite in gravels at an elevation of from 1500 to 2000 feet above the sea.

Prof. RAMSAY observed that some years ago he had attempted to show that Anglesea had been glaciated by ice that had come from the north in the Cumberland district, and attributed this circumstance to the preponderance of this northern ice over that from the Snowdon range, which was, as it were, set aside by it. He was inclined to think that the Menai Straits, the direction of which coincided with the main lines of glaciation in Anglesea, might be due to the same cause.