



# LXX. On the question, whether there are any evidences of the former existence of glaciers in North Wales

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To cite this article: J.E. Bowman F.L.S. F.G.S. (1841) LXX. On the question, whether there are any evidences of the former existence of glaciers in North Wales , Philosophical Magazine Series 3, 19:126, 469-479, DOI: [10.1080/14786444108650468](https://doi.org/10.1080/14786444108650468)

To link to this article: <http://dx.doi.org/10.1080/14786444108650468>



Published online: 01 Jun 2009.



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opinions which to my mind are but the necessary consequences and developments of the great path which Lavoisier marked out for modern chemistry ; allow me, I say, to express myself as he did with regard to his fellow-labourers and his friends.

If in my lessons, if in this summing up, I have chanced to adopt without mentioning them the experiments or the opinions of M. Boussingault, it is that the habit of communicating to each other our ideas, our observations, our manner of viewing things, has established between us a community of opinions, in which we ourselves even afterwards find it difficult to distinguish what belongs to each of us.

In resting these opinions and their consequences on his name and on his authority, in telling you that we work actively, sometimes together, and sometimes apart, in order to verify and to develop all these facts, all these results by experiment, I do but evince my anxious desire to justify the interest which you have this year taken in my labours.

For this I beg to thank you. It has given me courage to undertake a long course of researches ; if anything useful to the progress of humanity should result from them, let all the honour of it redound to the intelligent good will with which you have constantly surrounded me, and for which I shall ever be profoundly grateful.

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LXX. *On the question, Whether there are any evidences of the former existence of Glaciers in North Wales ?* By J. E. BOWMAN, F.L.S. & F.G.S. \*

THE recent discovery of traces of ancient glaciers in Scotland and the north of England, rendered it probable that similar appearances would be found in North Wales, where, though situated in a somewhat lower latitude, the slight increase of temperature is fully counteracted by the greater altitude of the central mountain group. The geographical situation of all these parts of our island with respect to the sea, and the geological periods of their elevation may be considered to be so nearly the same, that if glaciers can be satisfactorily proved to have once existed in one, there seems no reason to doubt their occurrence in the rest, even admitting them to have had a much more local origin and limited range than Prof. Agassiz has supposed. If we compare the mountains of Britain with those of Switzerland, where the most un-

\* Communicated by the Author.

doubted evidence of the former greater extent of glaciers may be gradually traced from the warm valleys of the Alps up to the actual feet of existing glaciers, the greater altitudes of the mountains and increased distance from the modifying influence of the sea, will be found more than adequate to compensate for their being situated ten degrees nearer to the equator. In this view it is therefore possible, assuming the theory of Prof. Agassiz of a general reduction of temperature in ancient times over the whole northern hemisphere, that Switzerland might be covered with ice and snow, while Britain might be comparatively free from them. But this reasoning, though plausible on a cursory glance, falls to the ground, if we accept the theory of this distinguished philosopher, that the glacial period occurred antecedent to the elevation of the Alps. There is abundance of direct geological evidence to prove that they have been raised, at least much higher than before, since the deposition and consolidation of the tertiary strata; and as it is scarcely less certain that the primary mountains of Britain were raised at a much earlier period, it seems to follow from their altitude and higher latitude, that the surrounding region must have been the seat of more intense cold than Switzerland, *then* without high mountains and situated in a much warmer climate.

Having spent a portion of the late summer in endeavouring to trace the geological sequence of the schistose rocks of North Wales, I have been naturally led into some high and unfrequented tracts where it seemed probable, if anywhere, that evidence of glaciers would be found. I have examined many of the main and lateral valleys on the east and south flanks of the Snowdon group, of the Arenigs, and of the north end of Berwyn chain, as well as of the moorland hills of Denbighshire, between Cerrig y Druidion and Llanrwst; also those which intersect the wild and barren hills that occupy the country between the great Holyhead road and Bala, and form the dividing ridge between Merionethshire and Denbighshire. These valleys descend from the highest mountains of North Wales, and are the troughs through which the numerous tributaries of the Dee, the Clwyd, and the Conway, are carried into the lower parts of the country. Many of them, from their smooth uniform slopes and easy inclinations, seem calculated to give rise to, and to retain those appearances which glaciers usually create and leave behind them. In none of them, however, have I found any features which appeared to me to have been produced by glaciers; none at least have retained that outward form or shape which seemed to justify me in referring them to such an origin.

There are, however, various appearances scattered here and there through the districts I have named, which, if they have not originated in glaciers, bear a sufficient resemblance to require a close examination. It is more important to make this examination than may at first sight appear, in order to guard those who have not witnessed the actual effects of glacial action from attributing every accumulation of gravel or streaked rock to such an origin. Though satisfied myself, from personal observation, that existing glaciers form moraines on their sides and at their feet, and abrade the rocks over which they move, so as to scratch and polish their surfaces, it has constantly been my practice to see, in the first place, if the analogous appearances I have met with in North Wales were not capable, on taking into account all the local circumstances, of satisfactory explanation by some obvious existing cause; conceiving it to be improper hastily to refer to the operation of ice, effects which would admit of an equally easy explanation from the transporting or erosive power of water.

Of true lateral moraines ranging along the slopes of the valleys more or less horizontally, and formed either of stones or gravel, no instance has fallen under my observation. I passed through many valleys, where, from the gradual rise of the sides and the laminar or schistose structure of the rock, the detritus from above had lodged and accumulated into a talus, or formed continuous inclined planes of great uniformity, which were often covered with herbage. This was strikingly seen in the valley above Penmachno, but I could not discover any trace of lateral moraines, nor of terminal ones, about the outlet of the valley into the great trough of the Conway. In the neighbouring valley of the infant Conway, between Yspytty and Pentre Voelas, where the river first runs parallel with the great Holyhead road, the slopes are covered on both sides by a succession of rounded wavy knolls or swellings, which are very striking in such a barren and rugged district, from their smoothness and rich verdure, a character by which they may be recognised at a considerable distance. Near the lower end of the valley, on the east side, several of them are detached, and are about fifty yards diameter and twenty or thirty yards high; but they usually run into one another and are of no regular shape, except that they all slope towards the stream, so that they look like great undulating and projecting breastworks and bastions thrown up for military defence. Some of these mounds cover an area of 100 acres, and are two or three hundred feet high, looking like little hills, but without any regularity or uniformity in the grouping, their bases running into one another and sloping towards

the middle of the valley on both sides. One only near the little stream of the Clettwr and above the road, seemed, when seen from a distance, to have a pretty level top; but I observed none with steep sides or escarpments, as though they had been eroded or cut down by a current. The road from Pentre Voelas to Ysptyty winds among them, the higher ones being above it to the S.E., the rest inclining towards the valley below. Similar mounds mask the rocky slope on the opposite bank of the Conway as high as half a mile above Ysptyty, becoming gradually lower and thinner till they disappear altogether. In a north-west direction they extend from Pentre Voelas to the opening of the valley of the Machno, and may often be seen on both sides the great road in the less precipitous parts of the gorge, though more frequently and more distinctly on the left bank of the river. From partial openings into several of them, I saw they were formed of local drift or gravel from the neighbouring dark schistose rocks, without any large boulders. In one of them, near the great road, there was a streaked or bedded character, the layers being formed of pebbles of different sizes, as though they had been left by a current which had varied in intensity. It appeared to me that these hills were not composed throughout of this gravelly drift, but that this material only formed a coat or covering upon the previously existing prominences of the lower Silurian schist of the district, sufficiently thick to conceal the rocky nucleus and to give it a smooth rounded outline. Neither could I attribute their shape to any form or modification of lateral moraine; and I was of opinion, that even should any one contend that they had originated in a glacier, it would be necessary to admit they must have been subsequently modified by water. It is not easy to understand how so large a mass of diluvium could have been accumulated in this particular locality. Seeing that the river Conway, soon after passing through it, has to make its way along a narrow gorge, and that from the precipitous form of the rocks on each side, it must always have flowed in the same channel, I was at first inclined to suppose that some obstruction might have filled this gorge and pounded up the river and the detritus it had brought down from the higher lands. But on examination of their relative levels, it appeared that the gravelly hills above the road east of Ysptyty were higher than the surface of a lake so dammed up, and consequently they could not have originated from such a cause. It is singular that in no other neighbouring valley of similar character, were there any accumulations of the same material, and further observation will be necessary to explain their origin.

The next class of appearances I have met with in North Wales resembling those produced by glacier action, are the striæ or scratches on the surfaces of rocks. Of these I have found several decided and strongly marked instances; and as they are due to various causes, and can in some cases be demonstrated *not* to have been connected with glaciers, it may be useful to describe them somewhat in detail.

The first I met with occurs in the Upper Silurian rocks on the right bank of the Dee, in the immediate neighbourhood of Llangollen. Here the true stratification is easily ascertained, since it is not affected by any cleavage, though the rock has a system of joints which divide the beds diagonally to the planes of the surface into irregular rhombs. The beds are nearly horizontal, having an average dip to the S.S.E. of about five or six degrees; and they rise to the height of from 300 to 400 feet, without any apparent dislocation or change in the direction of the dip. At the base of this precipitous hill, and in a little quarry, the outcrop of the beds is seen in various places; their surfaces are generally smooth and uniformly plane, occasionally slightly undulated. I observed the level surface of one of them to be streaked or traced with strong and perfectly parallel grooves or furrows, some as fine as though they were made by the point of a pin, and others the eighth of an inch wide, promiscuously and closely ranged alongside others of intermediate dimensions. The whole surface was occupied by these grooves and their intermediate ridges, and had the appearance of having been planed with a tool with a snapped or indented edge. Some of the broader furrows were truncated and terminated abruptly, and one or more narrower ones seemed to be connected with and to issue from them. The range or bearing of the striæ was N.N.W. and S.S.E., and the breadth of surface exposed was from twenty-five to thirty yards, every part of which was channeled in the manner described. It was at once evident, from the general appearance of the quarry, that this bed had never been exposed or disturbed from those above or below it, since it was closely and conformably overlaid by the mass above, the whole having a slight inclination to the S.S.E. The furrows were also evidently continued inwards upon the yet undisturbed portions; but to remove all doubt upon this head, I employed a quarryman to cut away the superincumbent bed more than a foot inwards from the face, where they were found to be equally clear and strong. The specimens I obtained were from this part, and had never before been exposed since the original deposition of the beds. The under surface of the superincumbent bed was moreover similarly though more faintly streaked;

in some places so obscurely, that it would not have been perceived to be so on casual inspection; but in others, very clearly. There was another bed lying about a foot lower in the series, similarly though less distinctly striated; and the striæ had exactly the same direction.

It was therefore abundantly clear that these grooved striæ could not have been produced by glacial action, or indeed by any cause operating after the original deposition or consolidation of the beds; inasmuch as they are nearly at *right angles* to the course of the river, and therefore to the *direction* of a glacier, and especially as they are found under beds in close contact, that have never suffered any partial or relative disturbance *inter se*\*. Since, however, they exist on two surfaces in contact, and somewhat resemble those polished portions of rocks well known by the name of Slickensides, which are believed to be the effect of friction on two surfaces rubbed against each other, it is worth while to examine whether they might not have been produced by a similar action. As already stated, the appearance of the quarry and precipice above the road shows that the rock has been tilted aside *en masse*, and has not been affected by any partial or subsequent dislocation; and the nearly horizontal position of the beds renders it extremely improbable, if not impossible, that they could have been so rubbed against each other as to produce the furrows in question. The appearance called Slickensides is found on the perpendicular or slanting sides of fissures and veins, and is caused by the unequal and repeated motion of the two surfaces against each other. But in proportion as the direction of these sides varies from the slanting to the horizontal position, this kind of action diminishes, from the increasing difficulty of maintaining motion on the horizontal plane. Great lateral pressure, from the gravity of an upheaved mass, may suddenly and for once act horizontally; but a succession of alternating throes or paroxysms can only be propagated from below; from any other point, motion would soon be overcome by the *vis inertiae* of the mass. It is easy to understand how the upper portion of a stratified rock may slide off its base when but gently inclined; but it is scarcely credible that any possible circumstances could cause it, in such a position, to be moved backwards and forwards long enough to produce the grooved appearance impressed upon the bed in question.

\* It is scarcely necessary to say that they differ essentially from the furrows which traverse the mountains of Scandinavia, as described by Seffström (see the last Part of Taylor's Scientific Memoirs); and from the furrowed and polished rocks of Fontainebleau, as noticed by Durocher in the Phil. Mag. for Nov. 1841.

Again, an examination of the striæ in hand specimens will show that some of the more delicate lines diverge from the general parallelism, and unite with the contiguous ones without suffering interruption from the intervening furrows. In some parts of the surface there are groups of faint transverse elevations and depressions which run across many contiguous striæ with a gentle curve; and in others the grooving is not confined to a single plane, but seems to penetrate beneath the surface, and to pervade several laminæ inwards. None of these appearances could have been produced by a hard body sliding along its surface in right lines, as in slickensides; and I regret my inability to offer any satisfactory explanation. The only conjecture I can make is, whether, as these striæ lie in the direction of the magnetic meridian, they may not have been produced by some electric or magnetic power acting upon the chemical ingredients of the bed or upon its surface, and causing them to assume a polaric direction while yet in a soft or semi-indurated state. They belong to a class of phenomena hitherto little noticed and still less understood, but which are nevertheless of great interest and worthy of especial attention, from the important bearing they have on questions of physical geology, about which we are at present almost totally in the dark, but which may one day throw light on the original structure of our globe.

I come now to describe a still more curious case of striated surface, found on a system of rocks lying geologically far below that just mentioned, and which, though unfossiliferous, will range with the Lower Silurian formation. It occurs in the bed of a little mountain stream named Clettwr, that falls into the Conway a mile or two below Ysptyty, having cut its way through the great mounds of gravel already described in that vicinity and exposed the solid rock beneath. The rock is a very hard blue schist, in thick compact beds, with a dip of  $15^{\circ}$  N.N.E. and an obscure cleavage dipping  $48^{\circ}$  N.E., which has but partially obliterated the bedding. The true stratification is indicated by many thin streaked laminæ which appear as lines in the section, and are quite parallel with the undulated surface of the bed about to be described. This surface is somewhat glossy and very strongly marked with a system of wavy lines that preserve a general parallelism, but run into one another, and do not long preserve their individual and separate character. The surface may be more correctly said to be corrugated and undulated than grooved, for the striated lines do not possess the perfect parallelism and continuity of those near Llangollen, though they maintain an uniformity of character, are persistent over every part of the surface that was exposed,



and were also found at intervals of a few yards, wherever I removed the overlying strata. Their direction is E.S.E. and W.N.W., or  $45^{\circ}$  W. of the magnetic meridian, and at right angles with the direction of the valley. But the most singular feature of this bed is a second system of closer, finer, and more regular lines which cross the larger undulations at an angle of about  $70^{\circ}$ , traversing their intermediate hollows as well as their crests and sides, thus covering the whole surface, and giving it a reticulated appearance very difficult to describe. Now and then, at irregular intervals, there is an occasional thicker line; or perhaps it would be more correct to say that the interval between the fine lines is greater in these places than usual. This double system of lines seems to originate in a thin plate of somewhat different material, about the eighth of an inch thick, and interstratified with the schist; for the lines cover both its upper and under surface, and the still thinner laminæ of which this plate is composed, are seen by their darker and lighter shades, to be undulated also throughout its whole thickness. This plate easily separates from the contiguous thicker beds, and when removed, is found to have left a sharp and perfect impression of both sets of lines on each of the surfaces with which it was in contact. Not only so, but the wavy lines have affected and penetrated the thicker beds, rendering them more glossy, and giving to the split of the cleavage a corresponding undulation which gradually dies away at the depth of one-third or half an inch beneath the surface. This is the more singular, as the cleavage planes cut the surface at an angle of  $15^{\circ}$  with the corrugated lines, and throw the undulations out of their regular course. There is another somewhat similar marking on the surface of a second bed in the same brook, about a foot higher in the series, and in the same direction or line of strike. Here the lines are broader and have been deeper; but being in the direct course of the stream, they are much obliterated by the water passing over them, and I did not bring away a specimen.

The reasoning already employed to show that the striæ on the Upper Silurian bed near Llangollen could not have been formed by a glacier, nor by slickensides action, is in a great measure applicable to those now under consideration; it applies to them, if possible, with greater force, since the double series of intersecting lines offers the most decisive evidence that they could not have been produced by either. In speculating as to their real origin, I will only add to the suggestion before thrown out, that when this class of phænomena shall be better understood, the specimen in the bed of the Clettwr may possibly throw some light on the obscure subject of cleavage.

A slight notice of a different kind of striæ on the Welsh rocks, arising from another cause and capable of easy explanation, will be sufficient. At the north end of Trefriw, in the vale of Llanrwst, by the side of the road to Conway, large surfaces of the true beds of Lower Silurian rocks are laid bare in several different places; they have an average dip of about  $18^{\circ}$  to the E.S.E., and form smooth and regular inclined planes. This arises from wayboards of softer shale, or from slight adhesion of the beds. On one of these inclined planes to the north of the little quay, are many nearly parallel lines or striæ, running in the direction of the valley, which are very liable to be mistaken for those produced by glaciers grating upon their bed. But on close examination I found them to be only the ends or sections of one of the series of joints which pervaded the bed and divided it nearly at right angles to its surface. The very general occurrence of joints symmetrically arranged in the Silurian rocks, makes it necessary to guard against deception arising from this cause. I will only add, under this head, a short notice of one or two patches of rocks by the side of the Holyhead road, where it overlooks the great chasm opening into Glyn Lledr, a mile east of the Waterloo Bridge, which have the appearance of being somewhat striated and polished. But the surfaces are also irregularly undulated, and the dip is to the south, or diagonal to the direction of the trough of the Conway; and there is a very steep hill immediately above them, down which, if these striæ were produced by glaciers, the icy mass must have descended, a supposition which inspection shows to be impossible. Besides, the slopes of the great opening from Glyn Lledr are very favourable for the formation and preservation of lateral moraines, of which I could observe no traces. And it may be remarked generally, that as both lateral and terminal moraines are more frequently formed on the outskirts of glaciers than striæ on the rocks beneath, and are from their situation and the nature of the material, more likely to be preserved as monuments to after ages, their occurrence in North Wales, either accompanied by striated rocks, or alone in other parts of the country, would have added to the probability of their common origin; while their entire absence from localities so favourable for their production, makes it necessary to exercise the greater caution, in referring to glacial action the other phænomena described in this paper.

I met with but one example of rock with a rounded or domed surface, to which Saussure has given the name of "*roches moutonnées*," and this was in a locality where it seemed so much more natural to refer it to a cause still in operation,

that it was not necessary to call in the aid of glaciers. The spot is well known to tourists as one of the wildest and most alpine in North Wales, where the torrents from Llyn Ogwen and Llyn Idwal, on issuing from their respective lakes, are precipitated over the rocky barrier that forms the head of Nant Francon. Standing on the bridge between these two torrents, the rocks on both sides, that form, as it were, the crest of this barrier, and obstruct the free passage of the water, seem to have a smooth or rounded form that is evidently not natural. That in the stream of the Ogwen is the largest and the most regularly domed; and the side next the bridge having been recently cut away in the direction of the cleavage, their planes form a perpendicular face, on which the true lines of stratification may be traced with sufficient distinctness. The dip is towards the S.E. at an angle of about  $40^{\circ}$ , thus proving the rounded top to have no connexion with either of the divisional planes just named, or with the intersecting joints, which, as usual, have flat surfaces. Though rounded, the surface is not polished, but has a dull and weathered appearance, the effect of abrasion rather than of friction, on the hard hornstone porphyry, of which the rock is composed.\* These rounded bosses of rock are at present some feet higher than the level of the respective torrents that wash their bases; but it is not difficult to believe that a period has existed when they were covered by the torrent, and that in the lapse of ages, the stones and ice it has carried along with it, having given them this rounded form, have continually deepened the channel, till the domed surfaces have been left projecting in their present situation.

Such are the principal appearances I have observed in North Wales, which approximate to the effects produced by existing glaciers upon the rocks and debris by which they are surrounded. The phenomena of moraines interested me much in Switzerland; and the recollections of their singular features would, I think, have enabled me to detect any traces of similar remains in the mountainous district under consideration. I would not, however, be understood as meaning to deny their existence in it altogether; for there are still so many obscure valleys that I have not visited, at least since the discovery of the remains of glaciers in Britain, that it would be presumptuous to speak dogmatically upon so obscure a subject. My object has been to confine myself to what I have

\* Several varieties of hornstone porphyry are seen near this spot; and on the ascent to Cwm Idwal a thick perpendicular vein of hornstone schist is exposed, and is thrown by a dislocation on the opposite side of the road west of the bridge. It is extracted for whetstones.

seen during the late summer, to describe appearances with accuracy, and refer them to their real causes, independently of any theory. Believing that glaciers once existed in Scotland and in the north of England, I thought it probable traces of them might be found in Wales also; and I have shown that not a few appearances there, may, on a hasty survey, be referred to such an origin. But believing, after deliberate examination, that these have either been produced by other adequate causes, or *could not* have been due to glacier action, I have felt myself bound honestly to state the conclusions I have arrived at, being satisfied from some experience, that to allow the observation or the judgement to be warped by preconceived theory, however plausible, or to decide on partial insufficient evidence, must be ultimately injurious to the cause of truth.

Manchester, Oct. 18, 1841.

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LXXI. *Calculation of Logarithms by means of Algebraic Fractions.* By the Rev. R. MURPHY, M.A.\*

THE logarithms here used are Napierian, which may be readily converted into logarithms of any other system, simply multiplying them by the modulus.

Take the coefficients of a binomial raised to any positive and integer power  $n$ , and the same number of the coefficients of a binomial raised to the next superior negative power,  $-(n+1)$ ; multiply both sets, term by term, multiply the products by the successive powers of a number as  $1, t, t^2, \dots t^n$ , and connecting all the terms thus formed by the sign  $+$ , this sum is the denominator of the fraction.

Multiply the last term but one of this denominator by  $\frac{2}{n}$ , the last but two by  $\frac{2}{n} + \frac{2}{n-1}$ , the last but three by  $\frac{2}{n} + \frac{2}{n-1} + \frac{2}{n-2}$ , and so on; connect the products with the sign  $+$ , the sum thus obtained is the numerator of the fraction.

The fraction thus formed is to be added to  $\log t$  in order to obtain  $\log(t+1)$ .

The sum is always deficient.

Call the above denominator  $P_n$  and put  $T = 4t(t+1)$ , the

\* Communicated by the Author.