North Staffordshire

NATURALISTS' FIELD CLUB

AND

ARCHÆOLOGICAL SOCIETY.

ON GLACIAL THEORIES, PAST & PRESENT,

AND THEIR

APPLICATION TO STAFFORDSHIRE.

BY

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Of H.M. Geological Survey.

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[*Read January 22nd, 1895.*]

Two sentences used in a Geological debate, by my old chief, the late Sir Andrew Ramsay, have lingered in my memory. Speaking against the views of a speaker said, "he has forgotten more than he ever knew," and added, "all that he has told us that is true is not new, and I fear all that is new, is not true," this criticism, applied to an individual, is often equally applicable to groups of individuals forming 'schools of thought,' and the history of Glaciology, is a remarkable example of that fact. A very recent work, published indëed only last month, "The Annals of British Geology 1893," by my friend the Revd. Professor Blake, M.A., tells us that "another new periodical has started during the year devoted to Glacial Geology, called 'The Glacialists' Magazine.' It is the organ of the Glacialists' Association, and is edited by its Secretary Mr P. F. Kendall. Its supporters belong to what is called the New School, in that subject, but its contributors are sought from amongst the supporters of both schools, the object being to give a fair meaning to all sides." In this statement, I believe there is given a very true and just view of the objects of the Glacialists' Association, who number in their ranks nearly every member of the Geological Section of the North Staffordshire Field Naturalists' Society, if for "New School" we read "old," and *vice versâ.* This I trust to establish in the course of the following address.

In the "Illustrations of the Huttonian Theory" in 1802, Professor Playfair pointed out that glaciers had been the means of carrying erratic blocks, and 1806 he further inferred that those on the Jura had been thence transported from the Alps from an ancient extension of the glaciers now existing in that range of mountains, and in 1816 he stated that no power could have transported the great angular erratics of Switzerland, but glaciers which formerly extended far down its valleys. On the Continent this view was adopted by M. Venetz in 1821 (Bibliothèque Universelle de Geneve, tom. xxi., p. 77, and further in 1833 (Denkschriften der Schweizerischen Gesellschaft, 1 Band Zurich), by M. de Charpentier in 1835, "Notice sur le cause probable du Transport des block erratiques de la Suisse," (Annales des Mines 3 me Series, tom. vol. viii.), and in 1841, in his "Essai sur les Glaciers, et sur le Terrain Erratique de Bassin du Rhone" (Lausanne).

In 1828 Mr Charles Maclaren in the *Scotsman* described the glaciation of boulders *in situ* occurring in the railway cuttings near Edinburgh. "In examining some of the blocks of larger size" he says "we find the *upper surface* and two of the sides finely dressed, while the lower surface and the two ends are either much less dressed, or actually rough and angular. It is remarkable that in such stones, though lying at a distance from each other, we find the direction of these fine groovings, which constitute dressing generally to correspond, and to point in a direction E. and W. . . . Some of the larger blocks are polished on the upper and not on the under side. This evidently shows that the clay did not close round them at once, and that after the part below was firm, the current above bearing other clay and stones with it, was still in motion." This current the author ascribed to water.

The important generalizations of Playfair first received the powerful support of Agassiz in 1837, in an address before the Helvetic Society of Natural Sciences, at Neufchatel, and his more extended researches "Etudes sur les Glaciers" in 1840, in which year he visited the British Isles, to which he extended his views, and gave a summary of his results to the Geological Society of London ; showing distinct centres of dispersion of erratic blocks, by glacier ice in the Ben Nevis area of Northern Scotland, the Grampians and Ayrshire in Southern Scotland, and the hills of Northumberland and the mountains of Westmoreland, Cumberland, Wales, and Antrim, Wicklow, and the West of Ireland, each district he pointed out has its peculiar débris, hence it is plain, "that the cause of transport must be sought for in the centre of the mountain ranges and not from a point without the district." (Proc. Geol. Soc. Lond. Vol. III, p. 328, 1840).

It is of great interest to note that in the short communication of Agassiz giving the summary of the results he arrived at, that the researches of the following 55 years have only filled in the details. In the same volume of the Proceedings of the Geological Society Dr. Buckland in November 1840 communicated to the Society, of which he was then President, a "Memoir on the Evidence of Glaciers in Scotland, and the north of England," he stated that after examining the actual glaciers of the Alps, he adopted Professor Agassiz's views in October 18th, 1838, as to the glacial origin of the polished, striated, and furrowed surfaces, as well as the transport of erratic boulders on the Jura, near Neufchatel, and in the Grindelwald on his return to North Britain he informed Mr Agassiz that the same phenomena were observable in Scotland, and that they were such as he attributed to 'diluvial action,' in 1811; as did he also the smoothed rocks, grooves and striæ seen in 1824, on a visit to the east of Ben Nevis, with the then Mr Lyell, but about the same time, Sir George Mackenzie pointed out to Dr. Buckland a high ridge of gravel, laid obliquely across a valley near the base of Ben Nevis, in a manner inexplicable by any action of water, which in 1840 Dr. Buckland on reflection recognised as 'a moraine,' and he ascribed the Scottish parallel terraces to lakes damned by glaciers.

Of the discussion that followed the reading of this paper, my Colleague Mr H. B. Woodward, is in possession of an interesting note made by his father, the late Dr. S. P. Woodward, at that time sub-curator of the Society which states:—"The then Mr Murchison admitted the scratches, but refused to believe them of glacial origin, which he referred to diluvial action. Professor Agassiz said that Murchison admitted that if a little bit was granted the whole was granted. In Switzerland the glacial action can be seen by all, and we can argue from what is proved, to what is to be proved. Below the Glacier de l'Aar, the grooves descend 22 miles below its present termination. When glaciers traverse soft rocks like the Lias, the grooves are only seen, when the glacier has just retreated, and are removed by atmospheric action in summer, and annually renewed in winter. M. Agassiz stated that he had been under many hundred feet under the glacier of Monte Rosa, and found the quartzoze sand forming a bed beneath, and acting like emery upon the rocks. Mr (afterwards) Sir Charles Lyell spoke of the size of

Moraines, and their retreating in Switzerland half a mile in a summer, which on the return of the glacier in severe winters are driven successively on by the downward motion of the glacier. Mr Greenough stated travelled rocks in Germany must have crossed the Baltic, and in Switzerland must have crossed Lake Geneva, and asked whether Prof. Agassiz supposed that the lake was filled with a glacier 3000 feet thick, to which Agassiz replied "at least." Dr. Whewell dissented from Lyell's views. Dr. Buckland resigning for the occasion the chair to Mr Greenough and made a strong reply to opponents, stating that "those who dared to question the orthodoxy of the scratches and grooves, and polished surfaces of the glacial mountains (when they should come to be d——d) the pain of *eternal* itch, without the privilege of scratching!"

M. Agassiz followed up his remarks on the Geological Society, by a paper in October 1842, a paper communicated to the *Edinburgh New Philosophical Journal*, he showed that the whole of this country had been the home of glaciers, which descended every valley from the hills above, scoring, smoothing, and scratching the rocks beneath, and carrying on their surface erratic blocks from the rocks above far up the valley, and was the first to express the opinion that the whole of Britain was covered by an ice-sheet, which passed over hill and dale, as is now the case in Greenland, and that it was only towards the close of the Glacial Epoch, that this ice-sheet so far dwindled away as to consist of isolated valley-glaciers such as now exist in Norway and Switzerland. He pointed out that the north polar ice advanced as far south, as does the south polar ice advance north, or to 50° from the pole. He describes the period of ice-sheet as being followed by a period of retreat, during which glaciers occurred locally in the valleys.

From this traverse it will be seen that between 1802 when Playfair first expounded the true cause of the dispersal of Erratics in Switzerland, and 1840, the whole of the leading Swiss Geologists, adopted his explanation, and one of their most distinguished members applied the theory, with a considerable amount of detail to explain the glacial phenomena of the whole of the British Isles. Before following the progress of Playfair's views in the British Isles, it is here necessary to refer to the rival *floating ice* theory of the transport of Erratic blocks. It appears to have been first made in Germany, and originated with Professor Wrede of Berlin, who imagined that drift covered area of the countries on the Baltic was once a sea-bottom, which became dry, with the ice-borne blocks of rock upon it, through a slow change in the centre of the earth's gravity, his views were published in 1810 by De Luc, in the "Geological Travels" of that writer, and were adopted a year later by Dr. Buckland, who thus explained the Scottish Drift. In 1812 Sir James Hall (Trans. Royal Soc. of Edinburgh, vol. vii, p. 157), ascribed the distribution of Erratic blocks in northern Europe to floating ice aided by earthquake waves of translation. In 1824 Dr. Buckland and Sir Charles Lyell together visited Ben Nevis, and inspected the grooves and striæ and referred them to diluvial action and floating ice. In 1828 Mr Charles Maclaren described the glaciation of boulders found in the railway cuttings in Edinburgh, and ascribed them to the action of currents of water. In 1832 Sir Charles Lyell referred the northern erratics to floating ice-bergs, which deposited them on a sea-bottom since uplifted, these views he maintained in one of his last publications, in which he wrote "marine shells demonstrate the submergence of large areas in Scandinavia, and the British Isles," (Students' Elements of Geology, 1871, p. 147), but so far back as 1841 admitted that Agassiz's theory applied to Scotland accounted for facts difficult to explain on the drifted ice theory.

Before Dr. Buckland's views were changed by his contact with Agassiz, the late Mr. Joshua Trimmer had anticipated most of the views of the latter in his Practical Geology and Mineralogy. London ; John W. Parker, 1841 ; at p. 392 he states : "The conchiferous gravel accompanying northern boulders in Carnarvonshire and other parts of North Wales, and in Lancashire, Cheshire and Shropshire ; also in Ireland, on the coasts of the counties of Dublin and Wicklow, is classed by some of our most eminent geologists (Murchison, Lyell and Phillips) with raised beaches ; but we have ventured to exclude it from the list, being convinced by long and careful examination of it, that it affords no proof of submergence, and of the action of ordinary marine currents, but many of rapid accumulation on the surface of the land." And further, in describing the Northern Drift, he states (page 393 op. cit.) : "The mass of the detritus is less water-worn than that of a river or a beach, and is generally heaped confusedly together, without any indications of regular stratification, and without reference to the size, magnitude, or specific gravity of the component materials ; fragments derived from various quarters, large and small, rounded and angular, being imbedded in clay, or fine sediment, in which huge boulders are enveloped, sometimes in positions into which they could not have settled by the force of gravity. These deposits are however, occasionally stratified, or even finely laminated; for the stratification is persistent over small spaces only; the same bed is rarely continuous for 300 yards; the most finely laminated portions pass on the same plane into the unstratified, and have never yet furnished an instance of a layer of shells, in different states of growth, following laminæ of stratification, not a bivalve shell with the two valves united. They are destitute with two exceptions, which will be noticed hereafter, and which admit of easy explanation, of lithodomous perforations, on the calcareous pebbles, and of marine incrustations, on those which are not calcareous, neither have incrustations or perforations been found on the rocks beneath them; but their surface is marked by scratches, grooves and indentations, named by Sir James Hill "dressings." On the surface of the rocks exhibits indications of an ancient weathering, older than the transported matter. These indications consist of a rubbly mass of angular fragments, are most strikingly exhibited in the soft slate rocks traversed by numerous horizontal joints. The upper part of such rocks is bent, and broken beneath the incumbent diluvium; some of the angular fragments are dispersed through it, but they frequently form a layer between the rock and the transported matter, it having been lifted up bodily and enveloped in it."

Mr. Trimmer illustrates this by a section of the Tyn-y-fridd quarry, near Bangor, taken between 1829 and 1830. He goes on to state that "the general direction of the diluvial currents, by which this heterogeneous mass was distributed over the British Isles, has been from north-west to south-east, modified, however, by the local configuration of the surface. "The 'Till' of the south-west of Scotland . . . contains boulders of rocks, which can be traced to a more northern region, and some blocks of Scottish rocks have crossed the Solway Firth. The local nature of the gravel below the openings of the valleys which descend from the Grampians, appears quite compatible with the action of a great current traversing that range, as will be shewn hereafter, when adverting to the same phenomena in parts of the Cambrian Mountains."

Our author goes on to state that "the dispersion of the granitic, syenitic and porphyritic detritus of the mountains of Cumberland southwards as far as Worcestershire, and eastwards to the mouth of the Humber, is highly instructive. The phenomena have been studied by numerous observers, the scattered masses are easily identified with their parent rocks, and the district from which they are derived is small and well defined. Boulders from these mountains have been driven eastwards across the limestone ridge of Ortn and the Vale of Eden, a pre-existing valley filled with New Red Sandstone. They have crossed the Pennine Chain, but only at one point, and that the lowest pass opening directly to the west, about 1400 feet above the sea, nearly level with the present summits of the mountains whence they were derived, and 900 feet above the Vale of Eden. The summit of Stainmoor attained, they have rolled down the eastern slope of the Pennine Chain, have traversed the Vale of Tees to Redcar, and the Vale of York to the Humber. The oolitic and chalk ranges of the moorlands and the wolds have opposed obstacles to their passage eastward, similar to that presented by the Pennine Chain, though on a smaller scale, and these obstacles have been surmounted in a similar manner at their lowest points; so that blocks of granite from Shap Fells are found near Scarborough and Flamborough Head. Detritus from the Cumberland mountains has likewise been borne eastward to the mouth of the Tyne, along the depression caused by the Tynedale fault, or the northern termination of the Pennine Chain, though the streams flowing in that direction are quite unconnected with the mountains from which the detritus was derived.

"Parallel to the course of the Pennine Chain, a small portion of the Cumbrian erratic blocks have gone northwards along the Vale of Eden to Carlisle, and an immense quantity . . . crossed the drainage of the Lune, Ribble, Wyre, Weaver, Mersey and Dee . . . spreading into the valleys of the Severn and Trent. Blocks of large size are found as far south as Bridgenorth, from which point they decrease in size and quantity, and pass off into coarse gravel composed of the same materials, which gradually dies off into the fine gravel and silt of the Vale of Gloucester."

Mr. Trimmer describes large errattic blocks accompanied by shells as occurring "from the banks of the Ribble to Bridgenorth," both in the valleys and the hill slopes of the Wrekin. He combats Murchison's view that a strait of the sea separated Wales from the

Cotteswolds, in which it deposited the boulders, and raises the following objections :—

1. That the blocks are rounded and waterworn.

2. That the blocks diminish in size and number from north to south.

3. That the northern drift cannot be "a marine deposit, slowly formed, such as would be found in the bed of any of our existing straits, if laid dry by movements of elevation, for it contains neither marine incrustations, nor drilled pebbles, boulders, or rocks, nor layers of shells, nor groups of particular species, nor bivalve shells with the two valves united."

Mr. Trimmer describes detrital deposits with Cumbrian fragments and marine shells, as occuring along the banks of the Dee, from Chester, by Holywell, and St. Asaph to Abergele, and thence to the Conway, the Northern Granites diminishing westward, only eight occurrences taking place between the Menai Straits and the Snowdonian chain, and marine shells at 4 localities in the same area, one of which is the Shelly deposit, or Moel Tryfaen. He points out that it has "none of the characteristics already enumerated of a beach, or sea bottom. It rests on a layer about 2 feet thick of angular fragments of the subjacent rock, and the erratic material and the shells are exceedingly local; only 1500 feet distant the former is rare, the latter absent." He points out that the ancient talus, composed of angular fragments of the rock beneath, occurs at Aberdaron Bay, overlaid by loam with erratic boulders, which clearly proves that the latter deposit was not slowly formed "beneath the sea." He considered the huge boulders, derived from the Snowdonian Chain, to have been carried to the head of Cardigan Bay, and states that this circumstance appears inexplicable on the hypothesis of gradual submarine formation, but in accordance with that of great currents from the north traversing pre-existing land.

Mr. Trimmer then goes on to state: "But the strongest evidence of the accumulation of this transported detritus *on the surface of dry land* [the italics are mine] is to be found in the Cefn Caves in the Vale of Clwyd, situated in a district overspread with detritus from Cumberland, and at a point which connects the erratic gravel of the eastern and western sides of the Cambrian Chain." He points out that the bottom of the cave consists of mud, with round pebbles, pieces of wood and bones of mammalia, including hyæna, bear and rhinoceros occurring on a lower level than the entrance of the cave, asdescribed by Dr. E. Stanley, Bishop of Norwich (Proc. Geol. Soc., vol. I. p. 402). Marks of teeth occur on the bones, and the pebbles resemble those of the existing river, as does the finely laminated silt, pointing to the cave being inhabited when the river flowed at a higher level, being 100 feet above the present Clwyd; these deposits were sealed by stalagmite; proves the cave was sub-aerial at the time. Above the stalagmite occurred a second bone bearing bed, consisting of calcareous loam, with local angular fragments of limestone. Referring to the latter deposit, Mr. Trimmer states: "It may perhaps be referred to the waters of the river, pent back by the advance of the current, the close of which introduced the marine remains through fissures in the roof. The difference between the present levels of the mouth of the cave and the river may be explained by erosion both before and since the marine inundation, or it may be attributed to a movement of elevation, or to a combination of the two, erosion acting slowly while the surface was stationary, and with rapidity during the elevatory process."

Mr Trimmer points out that detrital deposit of lead, formerly worked at Talargoch, Prestatyn, is analagous to the tin works of Cornwall, the lead occurs on the bottom of the deposit, with broken shell fragment, drilled and rounded limestone pebbles, bone of stags, and many angular blocks.

Trimmer describing the supposed raised beaches of the West of Ireland, says the *two perforated pebbles* discovered in Glenismaule, "must be considered as drifted from the sea, with the fragments of marine shells rather than on proofs of elevation." Speaking of central and south-eastern England he says, "It is probable . . . that many of the mammaliferous deposits hitherto called diluvial, are in reality lacustrine and fluviatile beds, containing land and fresh-water shells, and *covered by diluvial detritus*." [The Italics are his].

He adds, "The investigation of diluvial phenomena of those regions best known to Geologists, can as yet scarcely be said to be commenced; for a general explanation of them can only be safely based on a much more extensive accumulation of facts than we at present possess. The solution of the question, as far as regards the British Islands, would be a great point gained; but that cannot be expected for a great many years, while so few labourers appear disposed to apply themselves to this branch of inquiry, which at present is not a favourable subject with some of our leading Geologists. It can only be effected by the combined exertion of many local observers.

Mr Trimmer in a postscript, written probably in 1841, says that with the publication of papers by Agassiz, Buckland and Lyell, "the Diluvial theory enters a new phase. That sheets of ice and glaciers are believed to have overspread the country like those in Greenland." He points out that "he long contended to Mr Murchison and Mr Lyell that erratic blocks accompanying marine shells in Wales, Lancashire, Cheshire, Shropshire, and Ireland, were not deposited by melting icebergs on the floor of a sea, which after remaining submerged during a long course of ages, was converted into dry land by movements of elevation; but that were spread by marine currents of extraordinary energy and short duration over the surface of pre-existing land, and I have no objection to add over land covered with ice," and he adds "the descriptions of Dr. Buckland and Mr Lyell of phenomena which they attribute to glacial action in Scotland and Cumberland, forcibly remind me of similar phenomena observed by me in Wales, some of which seem difficult of explanation by aqueous action, the polished, rounded, and striated surface of the rocks,—the direction of the striæ dependent on that of the valleys, and the inclination of the surface—the general subterposition of the till or boulder clay to the stratified deposits composed of the same erratic materials . . . the local characters of the deposits in the central parts of the Chain varying with the nature of the rocks in each valley . . . the mounds of debris derived from neighbouring precipices which could not have reached their present situations without having passed over deep lakes.

Mr. Trimmer in a later paper "On the Erratic Tertiaries of the Pennine Chain between Congleton and Macclesfield" (2 J. G. S. 1851. vol. vii. p. 201), describes comminuted shell fragments at a sandpit, 3 miles north of Macclesfield, on the Stockport road; in gravelly clay in railway cutting, 2 miles south of Macclesfield; in North Rode Railway Cutting, 4 miles south; and from a pit near the Dan Viaduct, 6 miles south. At North Rode the fragments were in gravel patches in 11 feet of Boulder Clay, and some occurred in the clay itself, in a neighbouring well, where it reached 10 feet, and overlaid gravel. He states the Macclesfield canal is taken on the upper surface of the Boulder Clay, through a valley, between a ridge of

Drift Sand and the Carboniferous hills; at Bullgate the canal descends, by 12 locks, 120 feet, and runs for a mile first along reconstructed gravel, then reddish sand, resting in places on the Red Marl, and then on dark Coal Measure slabs. He gives a good figure of the Drift Sand mounds at Capesthorne and Cheney Gate, between Congleton and Alderley Edge.

It is a curious fact that Darwin threw the whole weight of his great authority and travelled experience in support of the submergence theory, fresh from the channels which divides Tierra del Fuego, and the strait of Magellan separating it from the mainland of America with the very numerous indentations in channels found between the straits of Magellan and the Penas, into which glaciers often descend and float off in ice-bergs; he visited Snowdonia and recognized the traces of ancient glaciers, but considered the distributed boulders, which he recognized as local, were distributed by the tide during a period of submergence, to which he referred the sands and gravels of the Carnarvonshire mountains, [Philosophical Magazine 1842, vol. xxi, p. 180] and the high level erratics of England and Scotland, and considered the amount to have been not less than 1,300 feet. It is of interest to note that Darwin's dictum of the submergence of the British Isles to an extent of 1,300 feet, was published two years after Agassiz had correctly shown that the phenomena were due glacier-ice transport, Darwin's views were adopted by Lyell, whose books exercised the most powerful influence at work in British Geology between 1830 and 1875, the year of his death.

In December 1842, in a remarkable paper read at the Manchester Geological Society, the late Mr E. W. Binney, F.R.S., laid the foundation of our knowledge of the Glacial Drift of Lancashire and Cheshire. In it he was perhaps the first to point out the great value to all classes of society of a correct knowledge of those extensive superficial deposits, which were formerly termed "Diluvium," and which he states in 1842 are now better known by the name of "Drift." He describes the Drift as being capable of division into local and foreign. The *local* consists of angular fragments over the coal-measures, and loose sand over the New Red Sandstone, with occasionally a well-rounded erratic forced in amongst the local specimens. He adds "all are mingled together without any order of deposition, and appear as though they had been produced by the upheaving of the strata, or as if some heavy body had passed over and crushed and displaced them." He clearly points out that the country is so smothered with Drift that the underlying rocks are only seen or known in steep escarpments, the great lines of drainage, or in artifical sections. That they rise to from 1000 to 1200 feet above the sea, at Blackmoss above Ramsbottom in Walmersley, and at Pike Lowe near Manchester, and he suggests that it passed through the Pennine chain, through the valley of Todmorden to Hebden Bridge, by the summit valley, above Littleborough, only 610 feet above the sea. He points that Drift is often preserved on flat and hollowed surfaces of rock at high levels, when it is absent on sloping surfaces at lower levels.

The foreign Drift he divides as follows, beginning with the oldest :—

1. Stratified and unstratified gravel and sand containing well-rounded pebbles of ancient rocks, occurring between Manchester and Bolton.

2. Thick deposit of Till, known in the towns as 'brickearth,' and in the country as 'marl,' mixed with variable quantities of sand and carbonate of lime, drys in the open air, with vertical cleavage, with blue fans. Included fragments range from the bulk of a pea to blocks of 6 tons, lying mingled together pell mell; 50 per cent. of the rocks are older than the mountain limestone, and include Scotch porphyries, Ravenglass, and other granites, and the old rocks of the Lake District, some blocks are rounded on one or more sides, some are angular, some are scored with striæ. At Ormskirk the late Mr afterwards Professor Harkness found it to be 150 feet thick, and between Manchester and the Pennine chain it is usually 75 feet.

3. Beds of stratified fine rolled gravels and 'forest sand' often containing beds of loam and clay, at High Broughton, and Kersal Moor, it contains much drifted coal, and at the latter locality large masses of 'till,' and blocks of granite of many tons weight. At Hazelgrove it is course and unstratified, but generally it contains shells which are "for the most part broken."

4. Stratified and unstratified gravel and sand at the bottoms of valleys adjoining rivers, the pebbles being well-rounded and divided from Nos. 1, 2 and 3. In the valley of the Irwell at Bolton, and at Manchester it reaches 60 feet in thickness, it has been deposited during the erosion of the present valleys, but produced by far greater currents of water, and under very different circumstances to what we now see going on in them. In fact the present volumes of water are quite inadequate to produce the phenomena which are now exhibited.

In 1845 and 1848 Mr Smith of Jordan Hill observed parallel striæ, on the upper surfaces of imbedded stones on the shore of Gareloch near Glasgow, and in 1852 the late Hugh Miller wrote "There occurs deep down in the clay, at several points on one coast, what I have ventured to term *pavements*—for such is their appearance—composed of boulder stones laid as in a common pavement, with their smooth surface upwards, . . . grooved and rutted. As decidedly as the greenstone causeway of our streets bear evidence in their scratched and furrowed surfaces of the heavily laden carts and waggons that have passed over them, are those pavements of the boulder clay charged with evidences that great moving masses had also dragged their ponderous weight over them. But the agent was evidently the same as that which grooved and polished the rocks beneath" . . . he refers them "to pauses in the formation of the boulder clay."

Mr Tiddeman in 1872 fully recognized that the glacial phenomena of North Lancashire was due to an ice-sheet, and he speaks of its "resistless force working in an undeviated course over hill and dale across the ordinary drainage-channels of the country . . . to the wreck and ruin of all opposing obstacles."

The ingenious theory that erratics occurred in Britain at high levels, were left by massive icebergs during a period of depression, which left their stores at higher and higher levels, as the land subsided, was early rejected by the Scandinavian geologists who came to the opinion that another origin was possible and Mr Törnebohm, of the Geological Survey of Sweden, pointed out that erratic blocks had been left at 4,500 feet, derived from localities no higher than 1,800 feet, and he believed this to be due to land-ice, but the process by which this was affected was pointed out by Prof. James Geikie, F.R.S.E., in 1873, who founded his observations on a letter of the late Principal Forbes to Professor Jameson, written 12th December 1846, that stones on the surface of the ice are due to the ablation of the ice which tends to reject all impurities in its mass, and stones are forced up through the mass of ice, from points on the bottom of the glacier to points on the surface of the glacier below, higher than the level of the point of origin. The facts were previously noticed by Principal Forbes, but his explanation of the method by which they got them, is bound up with the theory of 'viscous flow,' believed by some to be upset by the subsequent researches of Dr. Tyndall. Professor Geikie pointed out that if a boulder reappears at a point

80 or 100 feet above its point of origin, it cannot be due to melting of ice alone and evaporation, for as the level of the ice is maintained, it must be due to new supplies pouring in from higher levels. If the line of ejection of the boulder was the same as the slope of the valley, the boulder would never be seen at the surface, and only reappear at the foot of the glacial at its terminal front. The line of ejection will be always less than the gradient of the valley, and will vary from almost horizontal where obstacles to the flow of the glaciers are great, and even rise upwards when the obstacles are very formidable, to down grades, where the bottom of the valley is uniform.

The late Professor Forbes believed that "curves of ejection" correspond with those of "forced separation," and that both were the action of the *frontal resistance* which produces the *frontal dip* of the veined structure. Tyndall subsequently showed that the ribboned structure is due to pressure, but it has *not* been disproved that Forbes was wrong in his view of a filamentary sliding of the ice particles, and in the molecular theory of James Croll that there is a motion of ice particles parallel to the direction of the blue veins in glaciers. But be this as it may, the fact remains that stones introduced into the body of a glacier whether from above or below, tend to rise upwards in the ice as the glacier flows on its way.

In 1874 Mr R. L. Jack of the Geological Survey of Scotland, in his "Notes on a Till or Boulder clay with broken shells in the Lower valley of the river Endrick, near Loch Lomand, and its relation to certain other glacial deposits," [Trans. Geol. Soc., Glasgow, vol. v, part 1, page 5.] stated that at the height of the glacial period the Irish Sea and the North Sea were both filled up with true land-ice, so that probably every form of marine life, except perhaps a few minute and hardy Foraminefera and Entomostraca, was banished for a time from our shores, at least as far as the Bristol Channel. Referring to a description of the Lower Boulder clay of Blackpool, given by myself in 1870 (Q.J.G.S. vol. xxvi), he says it is easy by "his description to identify it with the lower till of Scotland, the striæ of North Lancashire run from north to south, the Lake District having sent off an ice sheet which would be compelled by the pressure of Scotch and Irish ice to hug the coast." And to a similar origin he refers the Dawpool (Cheshire) Boulder clay described by the late Mr Mackintosh, F.G.S. (Q.J.G.S. vol. xxviii, p. 388).

In 1875 Mr J. G. Goodchild [Q.J.G.S., Feb. 1875] referred the stratified sands and gravels, and the laminated or "gutta-percha" clays of the Eden valley and Yorkshire Dale District, to deposits left by fresh water, flowing under an ice-sheet, and following up previous suggestions of Sir Andrew Ramsay, believes ice-currents at high levels travelled across lower ice-currents in the valleys beneath, which were thus bridged over often at right angles to each other, the maximum height being 2,200 to 2,400 feet above the present sea level. And he points out, little the country has changed in Post-glacial times, and considers present surface due to former great ice-sheet.

In 1875 Mr Thomas Belt stated that during the advance of the ice-sheet, no till or *ground moraine* was formed below it, nor the smoothing and scratching of the surfaces of the solid rocks were then effected, and that the till was deposited beneath the ice when it melted back, and its pressure being gradually lessened. Meeting objections of the Rev. Professor Bonney, F.R.S., he points out that erosion of rocks and deposition of till were not contemporaneous, the one belonging to the period of advance, the other to the period of retreat of the ice. Mr Belt was of opinion that the principal glaciations of America was effected by land ice, but that it was followed by a period of floating ice, due not to the submergence of the land below the sea, but that owing to the production of immense lakes of fresh water, formed by the damming up of continental drainage. He was of opinion that the Greenland ice reached the western coast of Europe, passing across Iceland, and overflowed Caithness, and he believed that it further filled up the English Channel, and caused the formation of the fresh-water high and low-level gravels, the beds of the Rhine, and the floated boulders of Devonshire, Somersetshire, and Wales.

The expression *boulder-pavement* was invented by the late Hugh Miller, but he states his attention was first drawn to them by the late Mr Robert Chambers, who also describes them [Edin. Phil. Jour. vol. liv, 1852-3] and states that there is here a surface of the boulder-clay deep down in the entire bed, which to all appearance had been precisely in the same circumstances as the past rock-surface had previously.

In 1859 Professor O. N. Stoddard of Miami University described 141 boulders uncovered in an American railroad, he points out that the agency of running water, icebergs driven by waves and currents, all inadequate to explain the facts. He states that Icebergs might plough up the bottom and scatter the fragments but could not retain them in place. It seems necessary to admit that they were firmly frozen into the clay, and thus held in position while some overlying mass slowly ground off their exposed surfaces. [American Journal of Science, vol. xxviii, p. 227].

Messrs Milne Holme and Mr John Henderson have given attention, in publications of the Boulder Committee of the Royal Society of Edinburgh, to the minutiæ of boulder-glaciation, noting not merely the direction of the stone, but their limitation, or the reverse—to its upper sides, the direction of its longer axis and pointed end.

Mr Hugh Miller of the Geological Survey in a paper on Boulder Glaciation [Trans. Royal Physical Soc.] shows that the random character of the Boulder clay with "its indiscriminate assemblage of materialsof all sorts and sizes," is more apparent than real, and that Geologists have been somewhat in error in considering it structureless. He quotes Robert Dick working and writing all alone at Thurso, who says "it differs from every other thing on the earth's surface. It is not a conglomerate. It would never, though consolidated, form a bed similar to conglomerate. It is not a production of the mosaic deluge. It is not strictly speaking a production of the sea. It is not the sweeping of a sea shore. No! nothing of the kind. No mosaic deluge could have produced these deep beds of dark stony clay. No ocean waves alone, by the friction of ten thousand rocky strata, could have done it. No! tens and hundreds of millions of steam-mills, grinding stones night and day for a thousand years, could not have done it. No sea casts up anything like it. It is a distinct, genuine production, fairly entitled to a plan by itself."

"The boulder-clay" says Professor Hull "is entirely structureless." Sir Archibald Geikie says, "save with rare exceptions, its boulders are not arranged in any determinate manner." Professor Green says, "Typical till is a tough dense clay . . . stuck as full as it can hold of stones of all sizes, which are not arranged in any order but look as if they had been forcibly rammed in anyhow."

Mr Hugh Miller points out that Northumbrian glaciation occurs under three heads :—

1. General glaciation from the west, crossing the watershed.
2. Valley glaciation, when the ice held the valley.
3. Glaciation from the north, along the sea board.

All large boulders are not striated, but those that are, are invariably in the direction of the striæ of the rock surfaces beneath, and rock striæ and boulder striæ occur at all levels from the watershed down to the coast, the highest of the former up to 1,500 feet above the sea, of the latter up to 1,400 feet. The high level drift is generally raw material and striated boulders are seen, but when the till is well worked up, in the open and level country, the ice has had a steady *purchase* or mechanical advantage over the surface over which it moved, and then boulder striation is seen at its maximum, as in the low grounds, near Edinburgh. Mr. Miller points out the *adjustment* of graciated boulders, "resembles that of small *roches moutonñes*. The side facing the ice is apt to be tilted towards it, or to be ground down into a smooth slope, with flowing outlines. The averted or shattered size retains more or less of its mightiness." "The angle of the abraided slope varies . . . between 7 and 30 degrees. The long axis of the stone is often directed in the line of glaciation, and the pointed end is frequently, but by no means always towards the ice." The striæ on the boulders are often ⅛th of an inch thick and half-an-inch wide.

Professor Boyd Dawkins in 1874, in the first edition of "Cave Hunting" clearly pointed out that the glacial period does not separate one life-era from another, and described caveman as associated with the same group of mammalia, as the palæolithic man, whose implements are found in the old river gravels, but though certain forms of implements are the same, there is a marked difference in the two sets. Professor James Geikie, L.L.D., refers the implement bearing gravels of England to "an interglacial period." At Kent's Hole Professor Dawkins states the cave earth with the cave type of implement overlies the fluvial deposit with the fluviatile type.

Sir Archibald Geikie has shown that the mammoth lived in Scotland before the Boulder clay was deposited. Professor James Geikie considered that the mixture of northern and southern forms of animals is due to destruction of osseous deposits by streams, but Professor Boyd Dawkins pointed out that the former are always in the same mineral condition.

At the Victoria cave, near Settle, Yorkshire, 1,450 feet above the sea, and at Cae Gwyn cave Flintshire at 400 feet, occur laminated clays overlying bone-earth; in 1873 Mr Tiddeman referred the laminated clay in the former to the action of water in a quiet hollow beneath an ice-sheet, which dammed up the mouth of the cave; the Boulder clay with Silurian scratched stones passing along the beds containing the oldest mammals. [Geol. Mag., vol. x. p. 15]. The flint implements of the Cae Gwyn caves* are stated by Sir John Evans to resemble those found in Kent's cavern as regards the wrought flint flakes, and to a well-worked flint scraper found in the French caves of the Reindeer period; the animals were:—Lion, Hyæna, Bear, Red Deer, Reindeer, Horse and Rhinoceros, of which 400 teeth were found.

My colleague, Mr Dakyns, M.A., was the first to point out that if the dispersion of Shap Fell Granite took place by submergence, they would have been equally distributed over all adjoining areas up to 1,400 feet above the sea, and the granite itself would have been covered instead of which the boulders are confined to a narrow strip of country.

Professor Henry Carvill Lewis, M.A., F.G.S. gave his first communication in this country at the British Association at Aberdeen in 1885, showing that the tapering end of a glaciated surface was the end first in contact with the ice as had been long held by the Irish Geologists, but disputed by one section of the Scotch. At Birmingham in 1886, and still further at the British Association's meeting in 1887, he clearly showed that the great Boulder clay of the north of England was a terminal moraine. The interesting volume of his notes, published by Longmans last year fill up many interesting gaps in his views, especially as to the position to which he assigns the terminal moraine, as shown especially in map No. 3, where it is indicated as passing east of Macclesfield and through Stoke-upon-Trent. He describes Lake District erratics between Stoke and Trentham, and refers the hills above Longton to the fringe of the ice-sheet, in which he was correct. I met Prof. Carvill Lewis at this time, and was greatly impressed with his ability, but unfortunately I was so long wedded to the views then in vogue, that I did not recognize the value of the evidence he put before me, "the eye only seeing what the heart wishes for," as has been lately said in Parliamentary Committee, with my friend Mr Percy Kendall, F.G.S., of the

*The Cae Gwyn Cave was discovered by Dr. Hicks, F.R.S., and it and the adjacent Tremerchion Cave explored by a Committee of the British Association, under the direction of Dr. Hicks and the late Mr. Bouverie Luxmoor, F.G.S. The caves are on the east side of the Vale of Clwyd, and opposite those of Cefn, previously noticed.

Victoria University, this was not the case, and he at once grasped the bearing of Lewis studies in America, in unravelling the intricate Drift phenomena of the neighbourhood of Stockport, which led to so much local interest that "the Glacialists' Association" was formed by a group of the Stockport Natural History Society, the latter alas ! is now extinct, but the Association is most vigorous, spending the last days of the old year and the first days of the new examining the Drift phenomena around Birmingham, under the able guidance of Professor Lapworth and Mr Jerome Harrison, and at a meeting at Masons' College of the Association, I rejoiced to find the Midland Geologists assembled to meet us, cordially supporting the *restoration* of the old views. These undoubtedly would have not advanced so rapidly but for a second impulse from the United States, when the Rev. Professor G. Frederick Wright, D.D. visited this country in 1891 and examined the country around Stockport under Mr Kendall's guidance, and between Macclesfield and Buxton, under the auspices of the Glacialists' Association. This visit led to Mr Kendall's contribution to Professor Wright's "Man and the Glacial Period," in the International Series, which gives the best general account of the north of England glaciation yet published.

In the year 1881, when writing my work "on the Water Supply of England and Wales," I prepared a map, which was published in that volume, showing the natural grouping of the river basins of England and Wales, I was then struck with the close coincidence between the natural boundaries or watersheds separating these basins, and a large number of the County boundaries.

An inspection of this map by Sir John T. Brunner, M.P., led him to ask me to prepare a map on a large scale from which a photographic reduction was made, to show the relations of county areas to river basins, for the joint control of rivers under the Rivers Pollution Act of 1888. A comparison of the map I made at his request, which was distributed by him 1893, to the County Councils of England and Wales, with the map prepared by the late Hewett Cottrell Watson, to illustrate his llfe long labours on the Topographical botany of Britain, more especially the northern and north-central counties of England and the northern counties of Wales, remarkable coincidences occur, and still more remarkable differences will be noted, both of which I believe are capable of explanation, on the assumption that since the era of existing plants and animals a portion of these areas have been covered by an ice-sheet, but is not capable of explanation on the hypothesis of a submergence during the glacial period, as the water would cover the whole area, up to 1250 or 1300 feet, and all area below that level would have their plant life killed, and an identical flora might fairly be expected to replace it, from an unsubmerged area, on the re-elevation of the land. The following is a comparison of the maps in county groups :—

DeRance's River Basins.		Watson's Botanical Provinces.	
River Till (Northumberland)		Cheviotland,	
Northumberland & Durham		Northumberland & Durham	
Yorkshire, North Riding, West Riding		N.W. York, & Mid West York	
Yorkshire, West Riding (Aire and Don)		S.W. York	
Lincoln . . .		East Trent	
Notts.	Trent Group	Notts.	West Trent
Leicester		Leicester	
Derby		Derby	
Stafford		(not included)	
Cumberland & Westmoreland		Lakes	
Lancashire & Cheshire		Lancashire & Cheshire	
(not included) . . .		Stafford	North Severn
Salop		Salop	
Montgomery . . .		(not included, placed in North Wales group)	

Studying Mr Watson's Provinces, No. xxv., which consists of Cumberland, Westmoreland, Lancashire north of the Sands, the whole of this it is worthy of note, is an area of independent glaciation, large glaciers spreading out from the central watershed seawards and passing eastwards, at two points, when gaps in the Pennine chain permitted the ice to escape in that direction, the Scotch ice hugged the coast of this area, and no Scotch rocks occur in the Drift in the Lake mountains, and there is no reason to believe that the northern ice over-rode that elevated area, but Scotch rocks occur plentifully in the Boulder clay fringing the coast. It would be of considerable interest to ascertain if the plants of "the Boulder clay fringe," from the Solway Firth to the mouth of the River Kent are more in accord with the flora of the Boulder clay area, marking that occupied by the ice-sheet than that of the "Lakes Province" which they margin.

The eastern limit of the ice-sheet in Lancashire and Cheshire may be taken at, or about the 1,250 feet contour, or level of that amount above ordnance, the mean level of the sea; the Pennine chain for the most part rises above that level and was free from an ice-sheet, though traces of local glaciers occur in some of the deep Dales of Yorkshire lying to the east. The County boundary forms the margin of Mr Watson's Provinces between Lancashire and west Yorkshire, reference to my map of river basins in county groups shows a considerable area of the Ribble and other basins, which naturally should form part of Lancashire, lying as they do west of the Pennine chains; and it would be of interest to see whether Mr Watson's Lancashire Province was not more sub-divided than he imagined, and in reality follows the river-basin into the next county, that the ice-sheet did so there is no doubt, as Scotch erratics have already been traced as far east as Whalley and Padiham.

Mr Watson makes a similar distinct province of N. Wales, including Montgomery with the other five northern counties and the Isle of Anglesea. Studying this district from a Glacialist's point of view, the six counties in question like the English Lakes, form an area of independent local glaciation, and the central area was never over-ridden by the Scotch ice, which covered only a narrow fringe circling the coast, when it was met and held back by the Cambrian ice; its trail can be traced by the Scotch and Lake district erratics occuring in the Boulder clay of Wrexham on the Dee, Mold on the Alyn, Holywell, Prestatyn, Abergele, Llandulas, Colwyn Bay, and Llandudno on the North Welsh coast, and Denbigh in the Vale of Clywd, and its maximum height was attained at Moel Tryfaen, where the shell bearing gravels rise to 1,350 feet above the sea; it is worthy of note that so far back as 1840, Joshua Trimmer not only described these shells but pointed out the mingling or rather meeting of the northern Drift and the Welsh Drift in the Vale of Clywd.

As before similarly stated in regard to the north west of England, it will be considerable interest to ascertain whether Mr Watson's North Wales province is capable of further sub-division, i.e., the coast area of Flint and Carnarvon, and the coast area of Denbigh at one end of the county and the Dee valley at the other end, and the Isle of Anglesea, once overlaid by Scotch and Lake district ice, as distinct from the Welsh mountains, whose native ice held their fastness uninvaded. It is due to local glaciation that Montgomery was not like the next north Severn Basin county, Shropshire invaded by the northern ice, the presence of which can also readily be traced in North Stafford where several lobes protruded through the Biddulph and Rushton Spencer valleys, and passing across the Pennine chain at Kidsgrove and Golden Hill, into the Trent basin, with the effect that the plant life, as shown by Mr Watson, ranges with the Drift covered Shropshire area rather than the Driftless adjacent Trent counties.