11th May 1876.

D. MILNE HOME, Esq., LL.D., *President*, in the Chair.

The following Communication was read :—

On the Glacial Phenomena of Scotland ; with special Reference to the recent Works of Dr Croll and Mr James Geikie. By
ALEXANDER SOMERVAIL.

(*Abstract.*)

At the very outset it might be preferable at once to define the object of the present paper, in order to prevent any misconception as to its aim, or needless discussion that might otherwise arise. Besides minor points it seeks to deal with the nature of the lower drift deposits ; to show that the so-called " interglacial periods " have no substantial existence ; and that the conditions under which the lower drift deposits have been formed were not of that severe and rigorous kind that has of late been so vigorously advocated. That the objects here indicated are attained and confirmed by the subsequent reasoning, I myself do not profess dogmatically to believe, although for the present they are my stronger convictions. This chapter in the world's geological history, more than any other, is so problematic and perplexing, that even the most careful observers of its puzzling phenomena are frequently inclined to halt between sometimes more than two opinions.

That the superficial accumulations falling under the term *glacial drift* have been the product of ice in one or other of its forms no geologist will any more doubt than he would call in question the stratified rocks being other than the result of the deposition of sediment in water ; but under what precise forms of ice the drift deposits have been formed, and brought together in their present arrangement, is a question only to be gradually answered with patient observation and correct deduction, so varied and complicated are all the phenomena of the drift deposits. Another great question is evolved out of the former : What is the cause or causes that gave rise to conditions so widely different from what we now enjoy, that should have brought about all the rigorous climatic severity of the Glacial period, covering our country with ice in one or other of its forms, and furnishing the agents by which the whole phenomena of the boulder clay and its associated deposits are alone explicable ? The answer to this latter question very much depends on what

we consider the exact conditions of the Glacial period to have been. Certain conditions might be quite readily explained on geographical grounds which are patent to human experience and observation. Other conditions might only be explainable on astronomical grounds aided by inductive argument. If the geographical theory, which is the more simple and ascertainable, failed to yield a satisfactory explanation, then we would be justified in having recourse to the astronomical for a solution of the problem. The whole subject has of late been discussed under a variety of forms and from numerous points of view, and most extensively so by Mr James Geikie, in his recently published work "The Great Ice Age." So bold and startling are both his assertions and conclusions that it will not be uninteresting very briefly to examine the evidences on which they are based.

The terms *till* and *boulder clay*, which have been long, and are still, used by geologists as synonyms, have now been separated by Mr Geikie into two distinct systems or formations,—the till being described by him as the older, or lower, the boulder clay as the upper, or more recent. Both of these systems or divisions contain intercalated or interstratified deposits of gravel, sand, clay, and occasionally beds of peat, which are regarded by Dr Croll and Mr Geikie as marking interglacial periods. Each of those interglacial periods, of which there were many, occurred at nearly regular intervals, and lasted for some thousands of years, glacial and interglacial conditions alternating. In order to account for all the complicated phenomena of the Glacial period, the accumulation of till and boulder clay, the grooved and polished surfaces on which it rests, and the directions in which the groovings trend, Mr Geikie, no half-hearted ice theorist, calls in the aid of an agent capable for the work, a stupendous *mer de glace*, a great ice sheet covering up the whole country, and in some parts attaining a thickness of more than 3000 feet. Indeed, so high of late has this ice mania run, that some of the American geologists, with a genius not uncharacteristic, have demanded for the explanation of their phenomena a sheet of ice of not less than 12,000 feet in thickness in some portions of that country. This great *mer de glace*, covering Scotland, is made, in its descent from the Highland districts, to overflow all the higher hill ranges, such as the Ochils, with as much ease as a stream would overflow a stone in its bed. As this ice sheet reached the coast, it displaced the sea in all its shallower parts to such an extent that the ice from our northern Highlands is described as coalescing with that coming from Scandinavia on what now forms the bed of the present North Sea. Another mighty stream of ice is made to flow from our western seaboard and over-ride the Hebrides, while smaller streams are described as coming from the Welsh and Cambrian mountains, and uniting with

the Scotch and Irish ice on the bottom of the Irish Sea. As this mighty mass descended from higher to lower levels the whole surface of the country was grooved and polished in the direction of its movement, the clay and debris forming beneath it by its grinding action giving rise to the deposits termed the till. For the formation of the boulder-clay, which Mr Geikie, as we have already pointed out, regards as a distinct deposit accumulation, a slightly different explanation is given. It is described as being formed not under the ice, like the till, but at its termination in or near the sea, during which period the ice-sheet was thinner or more broken up into separate glaciers. When we come to examine the causes by which Mr Geikie seeks to explain the origin of his great *mer de glace*, we have to acknowledge his perfect consistency. He dismisses the geographical theory as altogether untenable. Along with Dr Croll and others, Mr Geikie is convinced that the astronomical theory will answer all the requirements for a successful exposition of the problem; and that those peculiar oscillatory movements of the ecliptic and those of the earth's axial inclination known as the precession of the equinoxes, would, under given conditions, such as our hemisphere's winter occurring in aphelion during a period of maximum eccentricity of the ecliptic, cause such a diminution of solar heat during the winter solstice as to bring about all the rigorous severity of climate required for the formation of the great *mer de glace* of the Glacial epoch. That such conditions would flow or result from the astronomical changes indicated is open to the gravest doubt. The whole argument is an induction of *a priori* reasoning furnishing nothing substantial by which to test its validity.

In order to show wherein I differ from the conclusions arrived at by Dr Croll and Mr Geikie, let us approach the inquiry with some degree of system, and consider—

1. The thickness of the ice sheet.
2. The direction of its movement.
3. The evidence of perched blocks.
4. The till or boulder-clay.
5. Interglacial periods.
6. Climatic conditions during the formation of the boulder clay.
7. General conclusions.

1. *The Thickness of the Ice-Sheet.*—The first thought that suggests itself, when reflecting on the mighty incubus of ice which is affirmed to have gathered over our country to a depth of more than 3000 feet, is the question: Is the area of Scotland of sufficient extent to admit of the accumulation of such an enormous mass? I unhesitatingly answer, No. Perpetual movement from a higher to a lower level by virtue of the law of

gravitation or regulation, or a combination of both, would in an area so small prevent the ice forming to such a thickness, independently of the hot summer of perihelion. We are referred by Mr Geikie to Greenland as an illustration; but Greenland is of almost continental dimensions compared with Britain, and even there we possess no evidence that the ice-sheet attains a thickness of anything like 3000 feet. It cannot be argued that during the Glacial period Britain had a much greater altitude than at present, and consequently a much larger gathering area, as we have the best of evidence that, during the very formation of the till, the land was then at least 500 feet lower than at present. Fully aware of the difficulty of explaining this immense covering of ice, Messrs Croll and Geikie attempt a solution by another difficulty yet harder of explanation. They make a great glacier descend from the Scandinavian mountains, filling the bed of the North Sea until it reached our coast, and forming a barrier to the progress of the Scottish ice, which accumulated to the thickness mentioned. If this great glacier, born among the Scandinavian mountains, marched with such resistless power until it reached and pushed aside the glaciers of Scotland, why did it not overflow the country? Indeed, that this glacier ever reached our shores at all, or even strayed very far from home, is extremely doubtful.

Although Mr Geikie infers from the striæ which occur on our Highland mountains at a height of 3500 feet, that the ice must have had a corresponding thickness, we affirm that there is no necessary connection between the altitude of the striæ and the thickness of the ice which produced them. Even in cases where the striæ do not conform to the slope like those observed by Mr Jamieson at great heights, they may be explained on the more natural ground of a submergence of the land during a period when ice-floes and bergs drifted over its surface. This submergence, unlike the thickness of the ice, is no mere hypothesis, as we have absolute proof to an extent of nearly 1500 feet, while certain other facts would indicate a much greater submergence.

2. *The Direction of its Movement.*—Independently of the assertions made regarding the direction of the ice movement, we possess substantial evidence from the trend of the striæ that the ice conformed to and flowed in a line with the great valleys, nay, that as a general rule the striations wherever they occur are in harmony with the present drainage of the country. That the ice from the Grampians, as asserted by both Messrs Croll and Geikie, should have filled up the great valley of Strathearn and flowed over the tops of the Ochils and Pentlands, is a baseless hypothesis. The existence of till on the tops of both these ranges is incorrect. On the summits, a peaty soil certainly occurs,

formed partly by the decomposition of vegetable and mineral matter, in which are included numerous fragments of rock of both local and Highland origin; but to term this accumulation till or boulder clay is an abuse of language; and to infer from the loose and imbedded pieces of mica schist that the Highland ice overflowed these hills is a most unwarrantable conclusion. The striations mentioned by Dr Croll as occurring on the top of Allermuir, very unfortunately for him and Mr Geikie, trend in the wrong direction, and are opposed to the idea of an ice-sheet coming from the Grampians sweeping over the Pentland range.*

3. *The Evidence of Perched Blocks.*—Like the striations occurring at great heights, the boulders, or perched blocks, have been made to yield evidence of the great thickness and direction of the ice movement. The boulders perched at great altitudes are referred by Mr Geikie to the period of the boulder-clay, and their transit is said to be due to great glaciers. Doubtless many huge boulders occurring both in the boulder-clay and resting on the surface of the country at low levels may have been brought to their present sites or near them by glaciers, but these found at very great heights and of remote origin like many of those occurring on or near the tops of our highest hills must have had a different mode of transport, and are in all likelihood due to floating ice during the submergence of our land, which we actually know to have taken place at least during one period of the Glacial epoch. It is worthy of remark that the perched blocks are not referred by Mr Geikie to the age of his till—when, according to him, the ice-sheet was thickest—but to his boulder-clay period, a subsequent epoch when the ice was much thinner and more broken up into separate glaciers. How in this period of thinner ice and consequently smaller glaciers enormous blocks were carried to heights where they now occur is a kind of mystery.

4. *The Till and Boulder Clay.*—I have already pointed out that Mr Geikie divides the lower drift deposits into till and boulder-clay. With this division I am humbly inclined to differ. Wherever I have examined the glacial drift I have never been able to detect any substantial difference that would lead to such a conclusion. The boulder-clay, as far as my own observations extend, frequently alters with the locality. Indeed, in whatever aspect we regard it, it is extremely variable, altering rapidly both in thickness, composition, and boulders. In our own neighbourhood, along the shores of the Firth of Forth, where most excellent opportunities are afforded for the study of the drift deposits, no such distinctions are traceable. In some localities, however, the boulder-clay has a parting into two or more distinct beds, which might be spoken of as upper and

* Striæ observed by Mr John Henderson ran N.E. by E. and S.W. by W.

lower, but even then those terms could only have a local application, as in many districts the boulder-clay forms a consecutive mass from bottom to top. To accept, then, the classification of Mr Geikie would be to repeat the lower drift deposits twice over, and render their complications doubly complicated. We cannot help thinking that those two divisions have been conveniently made by Mr Geikie to suit his own theories,—the till to accord with his ice-sheet, and the boulder-clay with his subsequent glaciation of the country. All Mr Geikie's distinctions between till and boulder-clay are of the most conventional kind, which will not hold good over any extent of area; consequently we think that the old term till, or boulder-clay, it matters little which, should retain its former meaning.*

5. *Interglacial Periods.*—We come now to examine the evidences on which the so-called interglacial periods are based. In accordance with the theory of the precession of the equinoxes, as calculated by Dr Croll and accepted by Mr Geikie, several interglacial periods, each lasting for thousands of years, intervened during the accumulation of the till, or boulder-clay. The proofs on which those interglacial periods are based are the intercalated beds of gravel, sand, clay, and peat, which occur in the drift, and the organic remains which those stratified deposits contain. The great ice sheet passes away, and is followed by a period of warmth greater than now, during which the land was occupied by a by no means scant flora and fauna. Those conditions, however, in their turn disappeared, and the great *mer de glace*, with all its barrenness and desolation, once more reigned supreme. This alternation of glacial and interglacial conditions is repeated again and again, but we are not informed how often. That those so-called interglacial periods have no substantial existence we will now attempt to show. In whatever part of the country we examine the till, or boulder-clay, we discover it to be most variable in all its characters. Those intercalated beds on which the interglacial periods are founded are sometimes entirely absent even in localities where it reaches a very considerable thickness. In some districts the intercalated deposits are thin, irregular, and patchy in the extreme. At other times they are thicker but thinning rapidly out, occupying basins or hollows in the till. Frequently, however, they are regularly interbedded with the boulder-clay, both alternating several times. I can give no better examples of the extreme variability of both boulder-clay and intercalated deposits than that given by Mr James Bennie from 250 separate bores, which I now quote.

* Since this paper was read, Mr Geikie has, in the second edition of his work, relinquished the use of the terms till and boulder-clay as referring to distinct deposits, and now regards the terms as synonymous.

20 of those borings have 1 boulder-clay with beds of stratified gravel and sand beneath.

25 have 2 boulder clays with stratified beds between.

10 have 3 " " "

1 has 4 " " "

2 have 5 " " "

1 has 6 " " "

According to the last bore, containing the six boulder-clays and interstratified deposits, it would furnish evidence for no fewer than six glacial periods and five interglacial periods, if we were to accept the theory of Dr Croll and Mr Geikie. Do the six boulder-clays mentioned in the bore represent six glacial periods,—six separate times that the great ice sheet covered up the country? Do the five intercalated deposits represent five interglacial periods,—five times of great warmth and subtropical conditions? No, certainly not. There is, I think, overwhelming evidence that to found interglacial periods, each of several thousand years of duration, on those inconstant, variable, irregular, and patchy deposits is strikingly and palpably absurd. It is a most remarkable fact that many of the so-called interglacial beds have yielded abundance of marine shells which show a much colder set of conditions than those actually inhabiting our present seas. Thus, in spite of the alleged warmth and high temperature, the whole evidence furnished by the mollusca obtained from the intercalated deposits is decidedly in favour of conditions approaching to an Arctic type. Had the so-called interglacial beds contained such genera as *Terebra*, *Conus*, *Oliva*, or *Voluta*, the evidence for warmer conditions would have been worth consideration; but when we find such genera and species as *Astarte borealis*, *Tellina calcarea*, *Leda pernula*, and many others which now are only to be found in the Arctic seas, occurring in the interglacial deposits, then those warm or subtropical periods disappear "like the baseless fabric of a vision." The interglacial periods being the necessary outcome or consequence of the astronomical theory, as elaborated by Dr Croll, the stratified deposits occurring in the till have been eagerly seized upon and compelled to do service in its behalf; so that we cannot escape the conviction that the whole reasoning moves in a most pernicious circle.

6. *Climatic Conditions under which the Boulder-Clay was Formed.*—We can now no longer regard the boulder-clay as a non-fossiliferous deposit. In the true till, or boulder-clay, but more especially in its intercalated or stratified beds, numerous remains both of plants and animals occur, which yield a material assistance in generalizing on the climatic conditions under which the drift deposits were formed. It is true that in the unstratified till few remains have been found, yet nevertheless these few are

significant, especially when we consider that the boulder-clay has been formed under circumstances which would in a great measure preclude the occurrence of organisms. From the true till, or boulder clay, then, have been obtained in different localities the remains of the mammoth and reindeer, also portions of such trees as the oak, pine, and birch. That abundance of other animals and plants existed during the period there is no doubt whatever, for whenever we alight on the stratified drift we have evidence of their existence. Besides the forms already mentioned, the stratified beds have yielded remains of the ox, the horse, and the elk. Plants have also been obtained both of exogenous and endogenous structure, and although few in species, yet apparently of sufficient individual abundance as to form beds of peat marking the sites of small lakes which existed during the period. Thus we are in possession of absolute evidence that a flora and fauna, however scant, really existed during the very formation of the boulder clay. Like the marine shells the scant flora and fauna would indicate something like Arctic conditions; but not such severe conditions as a *mer de glace* 3000 feet thick, covering the country and pushing itself far out to sea. Under such conditions no life of any kind whatever could have existed, only the unconscious life of the physical forces.

From the evidence furnished by the presence of both plant and animal remains in the true till, or boulder-clay, also their presence in its stratified beds, with the occasional occurrence of layers of peat, I think we should be warranted in drawing something like the following conclusions regarding the climatic conditions which existed during the formation of the boulder-clay:—

All the higher parts of the country would appear to have been covered with snow and ice to a considerable depth. The great valleys were filled with glaciers which reached the sea. Large tracts of the coast were entirely free from ice and covered with the flora and tenanted by the fauna already referred to, and doubtless by many more of whose existence we have not as yet discovered any record. Over certain tracts small lakes existed; formed by the melting of the terminal portion of the glaciers further inland, whilst in and around those lakes sufficient vegetation grew to form the layers of peat which we sometimes find inclosed in the boulder-clay, of which the bed described by Mr Henderson as occurring at Redhall quarry* is an excellent example. Very probably the inland ice sometimes approached nearer to the coast and at other times retreated further inland; indeed, this seems evident from the frequent occurrence of interstratified beds. As the ice descended to lower levels, its moraine matter would give rise to the boulder-clay. As it shrunk back into the country the water from its

* Society's Trans. vol. ii. p. 393 (woodcut of section at quarry).

melting terminus would carry mud, sand, and gravel, and stratify them over the moraine deposits already formed. This alternating process might take place again and again, giving rise to something like the boring with the six boulder-clays with the interstratified deposits between. Besides the country being covered with ice, with some glaciers terminating inland and some terminating in the sea, the adjoining seas would be filled with icebergs, some local, some foreign to the locality, driven by currents from a distance to our warmer latitude, which in stranding would contort our already formed beds of boulder-clay, and add to their heterogeneity and confusion by leaving their loads of strange debris as they melted away. Under those different yet simultaneous conditions, a partial covering of ice, with glaciers reaching the sea, and others terminating inland, together with the droppings of icebergs from a distance, a most complicated and heterogeneous set of boulder-clays and interstratified deposits would be formed, answering in every respect our variable drift, and meeting every difficulty it presents.

7. *General Conclusion.*—Throughout the paper I have shown, or at least attempted to show, that the division of the lower drift deposits into till and boulder clay, each having a different age and origin, is quite unwarranted; that the so-called interglacial periods have actually no existence whatever, being only the outcome of the astronomical theory; and that the climatic conditions prevailing during the Glacial epoch were much less severe than has of late been represented. In speculating on the causes which gave rise to the Glacial period, we find the astronomical theory, as propounded by Dr Croll, beset with many difficulties. When tested and balanced with the geographical theory, it is open to more decided objections. The climatic changes produced by altitude, arrangement, and distribution of sea and land is a tangible reality, but the climatic changes produced by astronomical mutation is only an inductive conclusion. The former is an objective certainty, the latter a subjective inference. I do not assert that astronomical causes may not have had some influence in the production of climatic change in the past; but to forsake altogether causes which fall under human observation and experience, for hypothetical astronomical results, is to forsake the true philosophical principles on which the whole structure of geological science has been so successfully built, viz., the application to the seen and known forces around us for the explanation of the past.

On the other hand, I freely admit that it would be unwise entirely to overlook and ignore the aid of the astronomical mutations referred to as causes combining with geographical relations of sea and land in the production of climatic change, especially when difficulties present themselves which are hard of explana-

tion on geographical grounds alone. Such a difficulty is presented by the climatic conditions which prevailed in England during the deposition of the Eocene formation, the whole fauna and flora of which have truly a tropical aspect. A still greater difficulty is presented by the occurrence of the usual coal-measure plants in latitude 75° in Melville Island. Also by the occurrence of numerous plants and true timber trees like the oak, beech, poplar, and plane-tree in deposits of Miocene age as far north as Spitzbergen, in latitude 78° . Much, however, of these seemingly anomalous climatic conditions disappear when we reflect that the present geographical arrangement of land, unassisted by any astronomical aid, is of such a nature as to give rise to most extraordinary variations of temperature in widely different latitudes, so much so that one of the mean annual isothermal lines reaches as high as 80° , and descends as low as nearly 60° north latitude.

It is very evident that the astronomical theory, as elaborated at present by Dr Croll, involves so many difficulties as to completely destroy itself. It demands every few thousand years (a mere unit in geological time) a glacial period which by its severity of conditions would have completely annihilated all the ordinary stratified interglacial deposits, and would have left nothing but an immense thickness of successive boulder-clays. In consistency with this theory a glacial period in every formation from the Laurentian upwards would by no means suffice; in some we would require them by the score. Again, in none of the formations do we meet with sudden or even gradual transitions in the fossil contents which would indicate a change from Arctic to sub-tropical forms, or, in other words, a change from glacial to interglacial life. The geographical theory, on the other hand, by no means precludes the occurrence of glacial periods at various times in the history of the world. Such evidence as we at present possess would greatly confirm the opinion that they have been of not unfrequent occurrence, although the intervals are apparently irregular; but this might be expected from the nature of the causes by which they were produced. We are therefore, for the present, convinced that the more insight we gain into the nature of the drift deposits, and the more we become acquainted with the flora and fauna of the Glacial period, the more shall we be able to dispense with the 3000 feet of ice which are affirmed to have covered our country, and the better able to explain the climatic conditions of the Glacial period on geographical grounds.