XI. *On* Boulder Clay. By Rev. Henry W. Crosskey, F.G.S., Vice-President.

(Read 9th January, 1868.)

Under the general term, Boulder Clay, many deposits produced at various periods during the great glacial epoch, and by different causes, have been loosely included. It is necessary to distinguish between these various "Boulder Clays," before observers in separate localities will be able to understand each other's language, and before any satisfactory theories can be established regarding the methods of their formation.

The old motto for statesmen dealing with barbarous tribes on the frontiers of an empire was, "Divide and command;" and this must also be the motto for students of the apparently confused accumulations of glacial deposits. We must divide to command.

I. The oldest boulder clay I at present believe to be represented by that which underlies the shell clay of the West of Scotland.

It is only in the lower districts, however, that the shell clay rests upon it, while it reaches to a height in Scotland (1,500 feet or more) far beyond that at which any shells have yet been discovered. Its thickness extends from a mere covering of the rock, to the depth of even 300 feet, and is excessively variable.

It is closely compact, as though subjected to immense pressure, and difficult to work even with the pick-axe.

Although occasionally containing patches of sand, of greater or less extent, it has no stratification. The included stones are in large numbers, polished and striated, and have not been broken by the process through which they have passed. Even thin and brittle pieces of shell are found finely striated.

These polished and striated surfaces are so freshly preserved that the stones could not have been rolled on a beach subsequently to their production. Any trituration would at once destroy the fineness of the glaciated surfaces.

The included stones are chiefly traceable to the heights nearest the locality in which the special bed is found, although a certain proportion have travelled from distances in the direction along which a glacier would naturally have moved, according to the general conformation of the country.

This boulder clay, we suggest, belongs to the period when the cold of the glacial epoch reached its intensest point.

It preceded the development of the arctic fauna, now fossil in our glacial clays, since the shell beds again and again most decisively rest upon it.

The highest point at which arctic shells are found in Scotland is 510 feet (Airdrie); from that point downwards at various levels to half-tide mark and beneath the sea.

The boulder clay, however, is found destitute of shells to the height of at least 1,600 feet, in every hollow and nook, on mountain flanks, through Scotland.

The only cases of fossiliferous boulder clays are those which I shall presently describe under the second type of boulder clay, and which form cliffs upon the shore, and never extend to any distance inland.

It is difficult to explain these facts in connection with the marine origin of the older boulder clay.

Upon the higher grounds it occupies frequently large hollows; these hollows might possibly have existed beneath an ice sheet, and the clay have been accumulated within them, and subjected to great pressure.

At lower levels the boulder clay is largely developed, both in the plains themselves, and on the flanks of the hills bordering wide valleys, and may thus have been formed beneath the glacier near its termination at the sea.

Whatever explanation if its origin, however, may be given, there seems, so far as present investigations extend (and I admit that all present investigations are more or less tentative), to be evidence for the existence of a boulder clay. (1) Older than the fossiliferous glacial deposits. (2) Extending to greater heights than those to which the proof of any *recent* elevation in Scotland yet extends. (3) Unsubjected to any action of the tidal wave upon the shore. (4) And connected with the more remote and extreme arctic conditions.

II. There is a boulder clay very similar in physical composition to the one just described, but containing fragments of broken shells and many Entomostraca and Foraminifera.

I have examined this along the Irish coast, at the base of the Hill of Houth, and many other localities; on the Scotch coast; on the English coast near Sunderland; in Yorkshire, and along the banks of the Mersey.

The shells this boulder clay contains are essentially arctic in

character, but they are very fragmentary, and even single valves are seldom found whole. This feature is in strange contrast with the state in which fossils are found in the great shell beds, resting upon the boulder clay in the Clyde districts. In these shell beds specimens are characteristically found with united valves, and in their natural position.

I have not yet observed this clay in any other situation than within easy reach of the shore, and I am inclined to regard this fossiliferous boulder clay as peculiar to the seaward terminations of the general deposit.

This fact (if as a fact it is finally established by further researches) may throw considerable light upon its origin.

This fossiliferous boulder clay may represent the debris accumulated on its progress downwards from the mountain by the descending glacier, and deposited by it, as it pushed itself beneath the sea on reaching the shore.

While this boulder clay possesses the general physical characteristics of the boulder clay first described—containing the usual stirated and polished stones, and being compact and unworkable—these characteristics may perhaps fairly be described as not quite so intense in their development in many cases, although often its only distinguishing mark is the presence of shell fragments.

Its peculiar position in cliffs near the shore, the occurrence of fossils, and its general composition, seem to sustain the theory that it marks the point where the debris of great glaciers was pressed to the bottom of the sea at the final point of their descent.

Without reference, however, to the method of its formation, as a matter of fact there exists a boulder clay. (1) Fossiliferous—the included shells being arctic in character, but fragmentary. (2) chiefly developed in the neighbourhood of the shore in the form of sea cliffs. (3) Physically the same as that which underlies the shell clay of the Clyde district, although sometimes distinguishable by a diminution in the intensity of its characteristics.

III. The type of a third clay, which may in its extreme form be termed a boulder clay, may be seen near Lag, Arran, overlying the older boulder clay. It is very hard and compact; the shells are better preserved than in the second boulder clay; but the embedded stones are not so well striated, and have been more or less worn since their first glaciation. Patches of sand and sandy clay are common.

This clay I am disposed to regard as the wash of the last described boulder clay upon a somewhat exposed coast. The angular blocks have been jumbled together, and their striations half obliterated, and their polish somewhat worn off, while the clay has been washed and rewashed around them, and a rude and rough habitat formed for the scanty development of some forms of molluscan life.

IV. An upper boulder clay belonging to the period of retreating glaciers, and an ameliorated climate, is very distinguishable. (1) It is far less compact than any clay yet described. (2) The included stones have very feeble polish, and only faint reminiscences survive of their former striations. They have evidently been much worn in many cases, and in others have not been subjected to any extreme glaciating force. (3) It is not fossiliferous.

The older boulder clay, and this younger boulder clay may sometimes be seen resting upon each other. At Chapel Hall, Airdrie, a good example of this occurs. The line of separation in a well dug by Mr. Russell in his garden, might even be detected by the eye, and it was in a deposit occurring between the two that fossils were found.

Sometimes a shell bed may been seen in sections intervening between the older and the newer boulder clay. This may be admirably studied in the beds before alluded to near Lag, Arran.[1]

In regular and ascending order may be seen the older boulder clay—1 of this paper; unfossiliferous and typical.

The fossiliferous clay—3 of this paper; with a scattering of striated stones; a wash from an older bed, indicating depression.

Younger boulder clay—4 of this paper; unfossiliferous, loose and sandy, with feebly striated stones; the most recent bed which can be attributed to ice action.

If there be any truth whatever in these divisions of "boulder clay," it is evident that to speak of a fossil as found in boulder clay, or under boulder clay, is a most vague and indefinite phrase.

A shell may be said to occur *in* the boulder clay, and may have been found in the second, third, or fourth, of the beds discriminated in this paper; or a shell may be said to occur *under* the boulder clay, and may have been found under the first or the fourth.

A fossil really belonging to the age of the Paisley clay may thus

[1] *See* a joint account of these beds by Dr. Bryce and the writer, "Geology of Arran."—P. 166, 2nd edition.

be ascribed to a more remote or a more recent era, to the great confusion of any attempt to understand either variations of climate or distribution of species during the glacial epoch.

The classification of boulder clays in this paper is given as a suggestion rather than in any way as an established arrangement, with the view of urging upon the members of the Society the necessity for more extended investigations.

XII.—*On* Modern Denudation. By Archibald Geikie, F.R.S., Director of the Geological Survey of Scotland.

(Read 26th March, 1868.)

CONTENTS.