is not redder than the purple rocks in the hill above, from which it has apparently descended. It is arranged over the mass in horizontal layers; it is clearly of subsequent and drifted origin. The Roman works which are brought into daylight by the open cutting are exceedingly curious in their character and condition as mining operations. I subjoin a rough sketch of the mass and its overburden at the Buitron mine.

For further notice of these deposits, I beg to refer the reader to Mr. A. H. Green's paper in the *Quarterly Journal of Science*, 1868, vol. v., p. 468, and the authorities there quoted, especially Mr. J. L. Thomas's admirable pamphlet on the mines of Rio Tinto, London, 1865.

III.—On Changes of Climate during the Glacial Epoch.

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Third Paper.

(*Continued from the January Number, p.* 31.)

In my first paper[1] I gave the sequence of the Scottish Drift under three groups; but in order to compare these deposits more satisfactorily with the drifts of other countries, it is necessary to subdivide them more closely. Briefly tabulated, the order of succession of the Scottish Drifts, beginning with the oldest, is as follows:

Scottish Glacial Deposits.

1. Till with intercalated and subjacent deposits; Boulder-earth and clay	Intense glacial conditions (general ice-sheet), with intervening periods marked by milder climates. The Boulder-earth and clay being partly of land-ice and partly of marine formation, indicates the decrease of the ice-sheets in the later cold periods.
2. Moraine rubbish	Retreat of great glaciers.
3. Kames of sand and gravel	Little or no floating ice; period of subsidence.
4.[2] Brick clays, etc., with arctic and boreal shells; Erratics	Advance of glaciers; period of floating-ice; climate not so intensely cold as during accumulation of Till; re-elevation of the land.
5. Valley moraines.....	Final retreat of the glaciers.

Before proceeding to compare this sequence with that of Scandinavia and Northern Europe generally it will not be amiss to refer in this place to the succession established by the Swiss geologists. According to Mühlberg,[3] the Glacial drifts of the Canton of Aargau are as follows:

Swiss Glacial Deposits.

1. Grundmoräne or moraines profondes	Intense glacial conditions; northern limits of the ice unknown.

[1] See Geol. Mag. Vol. VIII., Dec. 1871, p. 545.

[2] To avoid confusion I have in this table omitted the "high-level beaches," which mark the pauses in the re-elevation of the land. They are referred to in my second paper. I have of course left unmentioned the more recent raised beaches, etc. It is with the Glacial beds proper that I am dealing.

[3] Ueber die erratischen Bildungen im Aargau, etc.; See Nature, vol. ii., p. 310. Mühlberg's results agree with those obtained by M. Morlot, see Edinb. New Phil. Journal, 1855, p. 14, and Antiquity of Man, p. 320.

2. and 3. Moraine rubbish...	Retreat of the great glaciers; erosion of river terraces.
4. Moraines overlaying the older glacial deposits	New advance of glaciers.
5. Newer moraines.....	Periodic retreat of glaciers.

The ground moraines are undoubtedly the exact equivalents of our Till. The Scottish drifts marked 2 and 3 correspond to the moraine rubbish of the Swiss section—the difference between the Scottish and Swiss deposits being only what we should expect when we remember the different conditions under which they were separately deposited. The subsidence that drowned a large part of Scotland produced the Kames, which are made up partly of the old moraines (2) and partly of the Till and Boulder-earth or clay (1). In the Swiss section, No. 4 is the terrestrial equivalent of the shelly clays and erratics of the Scottish series. No. 5 is precisely the same both in Scotland and Switzerland. It will be observed that in the ground moraines of the latter country no inter-Glacial beds, such as characterize the Scottish Till, have been observed. But when we consider how great the chances are against inter-Glacial deposits being preserved, the absence of these from the Swiss *Grundmoräne* need not surprise us. It is quite possible, however, that they may exist, although they have not yet been detected.[1] The Scottish Till was studied for many years before its intercalated deposits attracted any attention. Is it too much to say that it may be even so with the Swiss *Grundmoräne?*

The succession of the drifts in Scandinavia also agrees generally with that observed in Scotland, and there is nothing in the descriptions given of the "northern drift" of Russia, Germany, and Denmark which does not fit in to the sequence tabulated above. Putting together the results arrived at by several observers, as Sefström, Berzelius, Murchison, Forchhammer, Lyell, Erdmann, and others, we get the following:

Scandinavian Glacial Deposits.

1. Stony clay, sand and gravel	Intense glacial conditions; general ice-sheet.
2 ? (Moraines)	Retreat of confluent glaciers or ice-sheet.[2]
3. Ösar or Åsar of sand and gravel...	Little or no floating ice; period of subsidence.
4. Clays, etc., with arctic and boreal shells. Erratics	Advance of glaciers; period of floating ice; climate arctic, but not so cold as (1). Re-elevation of the land.
5. Moraines.....	Retreat of the glaciers.

I have not been able to satisfy myself as regards the position of the "sand and gravel" of No. 1, and therefore cannot say whether it points to inter-Glacial mild periods, like those of which we find such

[1] In a subsequent paper I shall return to the consideration of the inter-Glacial periods of the Swiss geologists, noticing especially the remarkable results obtained by Prof. Heer, see his Urwelt der Schweitz, p. 484, et seq.

[2] From the descriptions given of some of the ösar or åsar, I strongly suspect that the equivalent of No 2 in the Scottish section occurs in Sweden; but without a personal examination one can hardly be sure of this. MM. Durocher and Martins distinguish two kinds of ösar—the one containing scratched stones and sometimes shells of Arctic species, and being often made up of very coarse materials; the other being more sandy and showing shells of Baltic species. The former may possibly represent some portion of the Scotch Boulder-earth and clay.

decided evidence in the Scottish Till. The "stony clay" is undoubtedly the same deposit as our Till; but it is possible that some of the "sand and angular gravel," associated with the "Rullesteensler" of Scandinavian geologists, may represent No. 2 of the Scottish section. The ösar or åsar agree precisely with our Kames. They are composed of water-worn detritus, gravel or sand, or both. Sometimes the ingredients are fine, sometimes very coarse. Murchison describes large tracts of northern Russia as covered with wide expanses of undulating sandhills; and these occur also in Northern Germany and in Denmark. Occasionally shells are obtained in this drift; those of the Danish drift being of the same species as now occupy the adjoining seas. The same would seem to be the case with some of the Swedish åsar. Sir C. Lyell mentions the occurrence of a ridge of gravel near Upsala which showed a bed of marl made up of the remains of "the mussel, cockle, and other marine shells of living species, intermixed with some proper to freshwater." Several huge erratics lay upon the top of this ridge. All the observers agree that the dispersion of the large angular erratics took place after the accumulation of the ösar, for everywhere the big blocks rest upon these hills of pebbles and sand, an appearance which is common to Russia, Germany, and Denmark, no less than to Scandinavia. Here, then, the phenomena are precisely the same as we meet with in Scotland, and the conclusion seems irresistible that the åsar were accumulated during a temperate condition of things, and while the land was sinking, and that the erratics only began to be dispersed from the Scandinavian mountains when the subsidence had become considerable, and the glaciers consequent upon an increase of cold had entered the sea. The clays with Arctic shells (No. 4) are the representatives of the Scottish shelly clays; and, like them, give evidence of floating ice. The moraines (No. 5) are, of course, much larger than their Scottish equivalents, but they tell exactly the same story.

The Glacial deposits of North America give a similar succession, with the addition of some interesting details. And as these throw considerable light upon the character of those changes that followed upon the withdrawal of the great ice-sheets, I shall refer somewhat more fully to the American drifts than I have done to the Glacial deposits of Europe.

The lowest Glacial deposit recognized by Canadian and American geologists is "unstratified boulder-clay," or "unmodified drift." In some places this deposit is found to overlie beds of sand, gravel, and clay, and these beds have occasionally yielded vegetable remains. Dr. Dawson cites[1] the case of "a hardened peaty bed which appears under the Boulder-clay on the north-west arm of the River of Inhabitants in Cape Breton." "It contains many small roots and branches apparently of coniferous trees allied to the spruces." In an interesting paper by Mr. C. Whittlesey (*Smithsonian Contributions*), reference will also be found to the occurrence below and in the "unmodified drift" of decayed leaves and the remains of the Mas-

[1] Acadian Geology, p. 63.

todon and Elephant. Generally speaking, however, the "unmodified drift" appears to rest directly upon the rocks, which are polished and striated below it. But over wide regions in Labrador, Canada, and the New England States, the lowest member of the drift series is entirely absent; either because it never was deposited, or else, having been laid down, it has subsequently been removed by denudation. Dr. A. S. Packard says, "Nowhere did I see on the coast of Labrador any deposits of the original Glacial clay or unmodified drift. Upon the sea-shore it has been remodelled into a stratified clay, and the boulders it once contained now form terraced beaches."[1] Professor Hind, however, mentions its occurrence capped by sand and forming banks "rising seventy feet above the level of the Moisie River, twenty miles from its mouth." Thick masses of it are encountered in Maine, where it presents precisely the same character as in Scotland—a tough, unstratified clay, crammed with angular and subangular, smoothed, and striated stones. In the State of New York it is described as "sometimes loose but frequently partially aggregated by argillaceous matter that renders a pick necessary to dig it."[2] Mr. Whittlesey also makes frequent reference to the occurrence in Michigan and Ohio of a deposit which he calls "Hardpan," a firmly-compacted "mixture of clay, sand, and gravel, or fragments of rocks in a confused or imperfectly stratified condition."[3] This deposit I conjecture to be the same as our "Till." In the regions described by Mr. Whittlesey it is always associated with freshwater beds, and is included by him among the Glacial drifts.

The same geologist describes the occurrence of freshwater beds, below glacial clay with boulders and sand and gravel. The freshwater beds contained remains of white cedar, pine, spruce, willow, and other varieties not yet determined, and passed down into laminated clays and "hardpan." He gives several sections to show the character of these beds, of which the following is an example:

ARTESIAN WELL, COLUMBIA, OHIO.

Surface 215 feet above Lake Erie and 780 feet above tide.

1. Soil	4	feet.
2. Sand gravel and boulders	10	„
3. Coarse sand	2	„
4. Blue clay and boulders	4	„
5. Fine quicksand	2	„
6. Blue clay, inclosing a log	17	„
7. Hardpan	3	„
8. Quicksand	1	„
9. Hardpan to cliff limestone	37	„
	80	„

Sometimes the vegetable remains in the freshwater beds are so plentiful as to vitiate the water-supply. With the above section it is interesting to compare the "journals" of borings made through

[1] On the Glacial Phenomena of Labrador and Maine.
[2] Geology of New York, part iv., p. 160 (Prof. W. Mather).
[3] Smithsonian Contributions to Knowledge, vol. xv.

the drifts in the neighbourhood of Glasgow. Mr. J. Bennie gives,[1] amongst a number of others, a section of the "surface" at Blairdardie, which is as follows:—

1.	Surface soil	4½ feet.
2.	Blue clay	9 „
3.	Hard stony clay (Till)	69 „
4.	Sand with a few shells	3 „
5.	Stony clay and boulders (Till)	46½ „
6.	Mud and running sand (quicksand)	11 „
7.	Hard clay, boulders, and broken rock (Till)	27 „
		170 „

Mr. Whittlesey figures a section taken quite close to Lake Michigan, which shows the following succession. (The thicknesses are not given.)

Red clay and red hardpan.
Yellow sandy clay.
White and purple clay, mixed colours in part.
Gravel.
Blue laminated clay passing down into purple hardpan [apparently very thick].

The State geologists of Illinois[2] give the following section of the drift afforded by a shaft sunk in the city of Bloomington:

1.	Surface soil and brown clay	10 feet.
2.	Blue clay	40 „
3.	Gravelly hardpan	60 „
4.	Black mould, with pieces of wood, etc.	13 „
5.	Hardpan and clay	89 „
6.	Black mould, etc.	6 „
7.	Blue clay	34 „
8.	Quicksand, buff and drab in colour, and containing fossil shells	2 „
9.	Clay shale (Coal-measures)	
		254 „

I have referred to these American sections because, as it seems to me, they are in all probability the equivalents of the inter-Glacial deposits of the Scottish Till. It is quite clear from Mr. Whittlesey's paper that the freshwater beds with organic remains are of older date than the mounds of sand and gravel and erratic blocks which overlie the unmodified drift; and Mr. Whittlesey himself believes the plants to represent the flora that characterized North America during or previous to the Glacial epoch. Dr. J. S. Newberry, referring to these and similar phenomena, says, "It has long been known that, in many parts of the valley of the Mississippi, wells penetrating twenty, thirty, or more feet, the superficial formations of drifted materials, clays and sands, with gravels and boulders brought from the far north, encounter sticks, logs, stumps, and sometimes a distinct carbonaceous soil." These vegetable remains, he continues, "form a distinct line of demarcation between the older and newer drift deposits. In or above the horizon of this ancient soil have been found numerous animal remains, *Elephas, Mastodon, Castoroides* (the great extinct beaver), and some others."[3]

[1] On the Surface Geology of the District round Glasgow, etc. Glasgow Geol. Trans. vol. iii., part i.

[2] See Geology of Illinois, vol. iv., p. 179. The "shells" are of fresh-water species.

[3] See Nature, June 22, 1871, p. 155.

The withdrawal of the great ice-sheet was marked, as in Switzerland, by the accumulation of immense piles of moraine rubbish, which are partially re-arranged or "modified," as Professor Hitchcock has it, "by the action of water."[1] It is thus difficult sometimes to distinguish true moraine drift from the re-assorted marine drift,—the one, in short, seems to shade into the other. This, however, does not mean that the deposition of the moraines and their re-assortment by the sea took place at one and the same time. The ice may have melted away from all the low grounds of New England and shrunk back to the valleys among the White Mountains before subsidence of the land began.

In reading descriptions of the mounds of gravel and sand which cover large tracts of country in the New England and the North-western States and also in Canada, one cannot fail to notice how closely all the appearances coincide with those we are familiar with in this country. Professor Hitchcock, describing the drifts of New England, says, they "form ridges and hills of almost every possible shape. It is not common to find straight ridges for a considerable distance. But the most common and most remarkable aspect assumed by these elevations is that of a collection of tortuous ridges and rounded and even conical hills with correspondent depressions between them."[2] This description would apply word for word to some of the larger areas of Kames in Scotland. The American mounds and cones are almost invariably composed of well water-worn materials, usually gravel and sand; and they are, moreover, not infrequently false-bedded. Occasionally boulders are found inside these mounds, but this is certainly quite exceptional, and such included stones are usually more or less rounded. Now and again a mound appears to be composed of coarse shingle and rounded boulders. But when boulders occur in mounds of sand and fine gravel, they seem to be confined chiefly to the upper parts of the deposits.[3]

Immense numbers of large erratics cumber the surface of the ground in many parts of New England, the North-western States, Canada, and Labrador, and are scattered over the tops and slopes of the mounds and ridges of sand and gravel. Even much further north the same phenomena are so striking as to arrest the attention of the traveller who is not strictly a geologist. I was much interested some years ago in reading the accounts given of the "barren grounds" of North America by various writers who had visited these inhospitable regions. Sandhills and huge erratics appear to be as common there as in the countries further south. Captain Back, who followed the course of the Great Fish River (Back's River) down to the Arctic Sea, gives a very graphic account of the isolated cones and

[1] Smithsonian Contributions. Illustrations of Surface Geology, etc.

[2] Trans. of the Assoc. of Amer. Geol. and Natur. 1840-1842, p. 191.

[3] See Report on the Geology of the Lake Superior Land District, p. 235. Also Geology of New York, part iii., p. 121, where Lardner Vanuxem says, "With some exceptions they (erratics) are generally found upon the surface, frequently upon the tops of hills or on their sides, appearing in almost all their localities as if but recently dropped," etc.

"chains of sandhills" which he saw in several places stretching far away on either side from the river valley. He tells us that "the ridges and cones of sand were not only of great height but singularly crowned with immense boulders, grey with lichen, which assuredly would have been considered as having been placed by design, had not the impossibility of moving such enormous masses proved incontestably that it was Nature's work." This was in 66° N. lat. In another place "the country was formed of gently undulating hills, whose surfaces were covered with large fragments of rock and a coarse gravelly soil."[1] In the "barren grounds" to the west of the bleak country traversed by Back sandhills and huge erratics are equally abundant.[2]

Thus in Northern America, as in the northern latitudes of Europe, we find the ground covered throughout wide areas with groups of kames, eskers, ösar, ridges, mounds, or cones of sand and gravel; and these peculiar hillocks are everywhere dotted over with large erratics in such a way as to show that the sand and gravel must have been deposited and heaped up before the erratic blocks were dropped. And, from the rare occurrence of boulders embedded in the sand and gravel, it is only reasonable to infer that at the time the sand and gravel were deposited there could not have been much ice floating about. It is true that piles and mounds of coarse unstratified débris and boulders are occasionally found associated with the re-assorted drift; but these, according to Professor Agassiz and several other American geologists, are moraines and not the droppings of icebergs. The mounds of well water-worn sand and gravel are singularly free of boulders, except on the outside.

After wide-spread accumulations of sand and gravel had gathered upon the bed of the sea, the climate of the northern hemisphere, which had been moderate during the period of subsidence, again became cold. Fleets of icebergs and ice-rafts set sail from every coast that remained above the sea, and dropped their burdens as they journeyed on. But the bed of the sea was now rising, and a great number of old beaches mark out the successive pauses in the re-elevation of the land. Professor Hitchcock describes many in his paper already referred to. The highest beach he mentions is one in the White Mountains, at a height of 2449 feet above the sea. An-

[1] Narrative of Arctic Land Expedition to the Mouth of the Great Fish River, etc., pp. 140, 346. I cannot refrain from quoting a passage which the geologist will at once recognize as a faithful picture of a highly glaciated land-surface. The scene described by Back was just on the skirts of the barren grounds. "There was not the stern beauty of Alpine scenery, and still less the fair variety of hill and dale, forest and glade, which makes the charm of a European landscape. There was nothing to catch or detain the lingering eye, which wandered on without a check over endless lines of round-backed rocks, whose sides were rent into indescribably eccentric forms. It was like a stormy ocean suddenly petrified. Except a few tawny and pale green lichens there was nothing to relieve the horror of the scene; for the fire had scathed it, and the gray and black stems of the mountain pine which lay prostrate in mournful confusion seemed like the blackened corpses of departed vegetation" (p. 178).

[2] See Sir J. Franklin's "First Journey to the Shores of the Polar Sea;" and his "Second Journey;" also Sir J. Richardson's "Journal of a Boat Voyage through Rupert's Land."

other on the Hoosac Mountain (Massachusetts) reaches an elevation of 2022 feet. In the valley of the Connecticut river a raised beach occurs at 1082 feet above the sea. Many of the raised beaches are strewed with huge boulders, as if these had been stranded by rafts of ice.[1]

During the re-elevation of the land beds of clay accumulated off the coast, and became gradually stocked with shells of an arctic type. These are the "Leda clays" of Labrador and Maine, so ably described by Dr. Dawson, Dr. Packard, and others. It can hardly be doubted that they are the equivalents of the Scottish and Scandinavian shelly clays. The fossils which they contain are very decidedly Arctic in the lower beds, but in the upper beds they give evidence of a gradually ameliorating climate.

Dr. Packard seems, if I follow him rightly, to be of opinion that the Leda clay is older than the ösar, and Principal Dawson inclines, but with some hesitation, to the same belief. It may appear presumptuous in me to differ from these authorities, yet after carefully considering what they have written, I venture to think that the evidence in support of their conclusions is hardly satisfactory. The shelly clays (like those of Scotland) are sometimes covered with deposits of sand and gravel (Saxicava Sands), but there is no proof that these beds are necessarily of the same age as the ösar of the interior of America. In America, as with us, the shelly clays are confined to the maritime regions, and I have found no mention made of ösar or mounds and ridges of sand and gravel overlying them. When it is remembered also that erratics everywhere cap the sand and gravel ridges of the interior, and occur abundantly in the fossiliferous clays of the maritime regions,[2] while they may be said to be absent from the interior of the ösar, we can hardly, I think, escape from these conclusions,—first, that the accumulation of the ösar took place under a milder condition of climate than characterized the deposition of the shelly clays; and, second, that of the two deposits the ösar must be the older. But of course it is quite possible that some of the ösar adjoining the maritime regions may have been formed contemporaneously with the Leda clay, with which some of the old sea-beaches, at all events, must be synchronous. If, therefore, we refer the accumulation of the American ösar to the period of subsidence, and the deposition of the "Leda clay" to the following period of re-elevation, we shall have for North

[1] There is some uncertainty as to the height reached by the sea during the period of subsidence that followed upon the retirement of the ice-sheet. Perched blocks are not always safe guides, as these may sometimes have been stranded along the sides of mountains by glaciers. In many, or rather in most cases, however, they would appear to have been carried by rafts of ice and dropped into their present positions. They seem to give evidence, therefore, that the land subsided to at least 2500 feet below the present level of the sea. But Dr. Packard thinks that some of the high-level terraces described by Hitchcock are not of marine but freshwater origin, and that they are relics of glacial lakes. In this case these terraces would resemble the parallel roads of Glenroy.

[2] So much so indeed as to entitle them to be called "Boulder-clays." They are more or less distinctly stratified, however. (*Packard.*)

America exactly the same succession as we have in Scotland and Scandinavia.

In the valleys of the White Mountains and in those of the Rocky Mountains a number of terminal moraines mark the sites of local glaciers which gradually crept up the valleys and vanished as the cold of the Glacial epoch passed away.

For purposes of comparison I shall now throw into a tabular form the general results obtained from a review of what our friends in America have done in the matter of Glacial geology. This table will show how closely the succession of the drift deposits tallies with that of the equivalent beds in Northern Europe.

NORTH AMERICAN GLACIAL DEPOSITS.

1. Unmodified drift with subjacent and intercalated beds[1]	Intense glacial conditions (general ice-sheet), with intervening periods marked by milder conditions.
2. Moraines.....	Withdrawal of ice-sheet from low grounds.
3. Ösar or ridges of sand and gravel	Little floating-ice; period of subsidence.
4. Leda clay, etc. Erratics	Advance of glaciers; period of floating-ice; climate Arctic, but not so intensely glacial as during accumulation of "unmodified drift"; land slowly rising.
5. Valley Moraines	Final retreat of the glaciers.

It is unnecessary for my purpose that I should refer to the details of the more recent superficial accumulations of North America; it is enough merely to remind geologists that in none of the post-Glacial or recent deposits of North America have any traces been found of a warmer climate than the present. On the contrary, every proof is afforded us that from the close of the Glacial epoch there has been a gradual amelioration of climate down to our times.

In my next paper I shall endeavour to correlate the English and Irish drifts with those of Scotland.

IV.—HEER'S FLORA FOSSILIS ARCTICA.

Communicated by ROBERT H. SCOTT, F.R.S., etc.

IN vol. ii. of his Flora Fossilis Arctica, Professor Oswald Heer has treated of the Fossil Flora of Bear Island, and shown that it belongs to the Lower Carboniferous Formation, of which it forms the lowest beds (named by him the "Ursa" beds), close to the junction with the Devonian. The Yellow Sandstone of Kiltorcan in Ireland, the Grauwacke of the Vosges, and the southern part of the Black Forest, and of St. John in Canada, belong to the same group. In the summer of 1870 two young Swedish naturalists (Wilander and Nathorst) discovered this same formation in the Klaas Billen Bay of the Eisfiord in Spitzbergen, and brought home fine specimens of *Lepidodendron Veltheimianum*, and *Stigmaria ficoides*. It has also been found in West Greenland, for Prof. Nordenskiold tells us

[1] I would remind the reader of what I have said in the text concerning the evidence for these intercalated beds.