XLV.—*Geological Notes on the Excavations at the Leith Dock Extension, 1897.* By J. G. GOODCHILD, H.M. Geol. Survey, F.G.S.; Curator of the Collections of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art.¹

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A LARGE area contiguous to the Old Docks at Leith has lately been enclosed for the purpose of extending the accommodation for shipping there. This enclosed area has been drained, and excavations are now being made there to a depth of about 25 feet below low-water mark. The strata exposed consist almost entirely of superficial deposits. The uppermost of these are well-bedded and rather fine-grained quartzose sands, which are interstratified at irregular vertical intervals with thin bands of loam. There is very little false-bedding seen. A few impersistent bands of fine gravel occur in places. None of these strata exhibit any signs of such disturbances as might arise from the impact of floating masses of ice. Towards their base these beds are somewhat more loamy. Their total thickness varies with the form of the beds next below, but it nowhere much exceeds 15 feet.

The included organic remains consist chiefly of mollusca, of which nearly fifty species have been noticed. Their facies is identical with that of the mollusca occurring on sandy bottoms, within the laminarian zone on the East of Scotland in general. They occur in variable quantities on different platforms, most commonly, however, within the upper few feet; but the same assemblage of species prevails throughout. Many of the shells occur in their natural positions of growth; while a fairly large proportion may have been washed up from the lower laminarian zones during storms, or have been transported on seaweed; and others, again, which are of a peculiarly littoral type, may have worked downward from the shore-line under the influence of gravitation. Some interesting biological problems were suggested by an examination of these organic remains. An account of these by the present writer, including a list of the mollusca

¹ In accordance with instructions received from the Council of the Geological Society of Edinburgh, Mr James Currie and the writer of this undertook to report on the excavations referred to in the title of this communication. After one joint visit, Mr Currie requested the present writer to report alone.

observed, and some remarks upon the early history of the marine invertebrate fauna of the Forth, appear in the Transactions of the Royal Physical Society, vol. xiii., to which reference should be made by those who may desire further details, especially in regard to the mollusca.

There is nothing in either the nature of these sands or their organic contents to show that they have any claim to a high antiquity. For aught one can say to the contrary, the whole of the deposit might have been formed within the last few hundred years.

These sands lie abruptly, and without the slightest trace of a passage, upon beds of glacial origin, to be presently referred to in more detail. The abruptness of the change is, doubtless, to be attributed to the fact that there have been several uprisings of the land since the close of the Glacial Period, each of which, by increasing the gradient of the river bed, and thereby accelerating the flow of the water for the time being, has led to the removal at successive periods of the several deposits previously laid down.

At the bottom of all the superficial deposits there occur, here and there, some small exposures of Lower Carboniferous sandstones and shales, which it is very likely may pertain to the Granton Sandstones and the overlying Wardie Shales. A small exposure of oil-shale, similar in general appearance to that occurring in the Wardie Shales in the Craiglockhart Cutting, on the north side of the Suburban Railway Station, was touched in some of the deeper excavations.

The boulder clay is probably the stratum of chief interest in the present excavation. In its general aspect this deposit does not differ very materially from the till of the lowland areas of the Lothians in general. A dark grey sandy clay, tough and extremely difficult to work when freshly exposed, filled almost everywhere with a pell-mell assemblage of stones of all kinds, shapes, and size (in the proportion, roughly, of 40 per cent. stones to 60 per cent. matrix), massive nearly everywhere, or, at the most, shewing only obscure traces of bedding, locally diversified by irregular nests and pockets of gravel mixed with clay like the bulk of the mass—in all these particulars the boulder clay at Leith agrees well with the normal till of the land areas adjoining.

In one or two important respects, however, this boulder clay does differ from the normal till. This latter rock, in the basin of the Forth especially, usually contains, nearly uniformly distributed throughout at least its lower parts, a fairly high percentage of well-glaciated stones; and usually also it includes but a small percentage of stones upon which more or less

evident traces of glacial wear cannot be detected. Moreover, the normal till of the Basin of the Forth has not yet been proved to contain any stones which have clearly not been derived from areas either within the watershed or from the country lying to the west of that. The boulder clay at Leith, on the other hand, is variable in this respect—some parts yielding a considerable number of well-glaciated stones congregated together, and with only a very small percentage not shewing more or less evident traces of glacial wear; while in other parts of the boulder clay there is a singular rarity of such glaciated material—a large percentage being angular and more or less unworn in aspect. Furthermore, although fully 90 per cent. may well have come from areas within the basin of the Forth, or, at any rate, from some part of the region over which the Ice Sheet is known to have moved, other stones occur whose origin cannot be pointed out with any approach to certainty. Amongst the rocks of doubtful origin, there were at one spot many angular blocks of a peculiar saccharoidal sandstone, some creamy white, and superficially resembling statuary marble, others of a similar texture but of a bright red colour. These are identical in appearance with some rocks associated with the Caledonian Old Red not far from Montrose. With these occurred a boulder of andesitic lava like, it is true, one of the forms common in the Ochils, but containing agates of the type most commonly found near Montrose, and not known in the Ochils. It will naturally occur to most people at first to regard these as possibly having been derived from the Ochils, instead of from a source outside of the Forth; but in the same boulder clay occurred at least three examples of gneiss, which I carefully examined on the spot. One of these was nearly identical with the epidositic gneiss of *Iona*, a rock which owes its special characteristics largely to hydrometamorphism which has taken place immediately below the base of the overlying Torridonians. No rock at all like this is known to occur anywhere within the area traversed at any time by the Forth branch of the ice sheet. There was also a block of augen gneiss, and another of granulitic garnetiferous gneiss. None of these shewed any signs of having been derived at secondhand from an older conglomerate such as occurs at the base of the Caledonian Old Red. I also picked out one small chip of a Chalk Flint. If these came, as I suppose, from areas outside the Forth Basin, there is an additional reason for referring the rocks mentioned above to sources outside of the Forth also. The great majority of the other boulders were of Dolerite, and were mostly of the type occurring at Queensferry and Cramond. Schists, andesites from the Ochils, and other rocks that may well have been derived from the areas

around the head waters of the Forth, are, as might be expected, by no means rare.

As is usually the case with the maritime boulder clays occurring below the level of the Forth, the surface of that at Leith is locally encumbered with large blocks, which occur, sporadically, between the boulder clay proper and the base of the recent sands above. These are probably due to the scouring action of the river water upon the boulder clay when it happened to form the surface deposit at the bottom of the Forth. The clay has been slowly washed away and the larger stones left behind, exactly as occurs in exposures of boulder clay on the shore now, as, for example, between Leith and Portobello. Those who are inclined to regard the boulder clay at Leith as a true till deposited directly from land ice will perhaps be disposed to explain the presence of some of these surface boulders as due to the action of floating ice after the formation of the till, properly so called, had ceased, and to refer to them as evidence of submergence.

No trace whatever of any form of life could be detected in the boulder clay at Leith—perhaps for the reason given by Mr Peach when this paper was read, that the water in which the boulder clay was dropped was too muddy and perhaps too cold to be congenial to most forms of life.

As regards the origin of the boulder clay under notice, it is not easy to express any definite opinion which would be generally recognised as of value. Were it not for the presence in this clay of stones which seem to me necessarily to have been derived from sources at a distance from any part of Scotland traversed by the Forth branch of the Ice Sheet, I should certainly have been disposed to regard that at Leith as simply an glacial deposit representing the mud, silt, and stones, melted out of the stony and dirty ice, in direct contact with the ground upon which the boulder clay now lies. But, after all, there could not be much difference of importance between a deposit of stones and mud resulting from the melting of dirty ice which was floating in a few fathoms of water and the till which was sedimented from land ice of the same kind directly upon the surface of the rock. I am certainly inclined to regard the former as having been the cause in the present instance, because that explanation will permit of our accounting for the occurrence in the boulder clay of stones that have come *up* the Forth, and are associated with others (the great majority) which have come down that river valley.

If the Leith boulder clay be regarded as due to the liberation

of stones and mud from floating ice after the climax of the Glacial Period had passed, and the land was standing at a level lower by a hundred or two hundred feet than it has at present, we can readily understand how rafts of coast ice, drifting southward along the east coast of Scotland, might occasionally stray up the Forth under the influence of the winds or currents, and drop their stony and muddy burdens along with the materials melted out of the ice of local origin. A boulder clay formed under these conditions would thus be simply the deeper-water equivalents of the deposits forming the Hundred Foot beach. These deposits, as is well known, testify by both their contents and the local disturbance their strata have undergone, to the occasional presence near the shore of masses of floating ice, which now and then capsized or foundered with their stony burdens quite close to the shore.

It is not pretended that there is anything novel in these views; on the contrary, they are almost word for word repetitions of what has been many times said by others. But as there is in existence even yet an active body of writers on glacial matters who appear to think that the Scottish school of glacialists do not recognise the fact, that, besides much that is the product of land ice, there are also deposits of glacial origin which have been formed subaqueously, it is as well to raise one's voice once again upon this subject. We need only point to such deposits as those at Elie, Errol, Berwick-on-Tweed, to say nothing of the newer glacial beds of the Clyde Valley, as examples of deposits which are, and always have been, universally recognised as having originated in this manner. The fact that some geologists regard certain other deposits as having originated as the *moraine profonde* of the Ice Sheet, or that the majority of other geologists now regard as sediments, melted *in situ* out of the dirty parts of that ice in contact with the ground, as I suggested in 1874,¹ does not preclude us from recognising the possible subaqueous origin of certain deposits elsewhere (such as parts of the boulder clays of East Anglia), whose structure and composition can be more satisfactorily accounted for on the theory that they were deposited from floating ice during a period of submergence, instead of resembling the till in having had an englacial origin from land ice.

¹ Goodchild, "On Drift," Geol. Mag., November 1874.