The glaciation of the Edinburgh and Lothians area

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The Quaternary landforms and deposits of this area have a long record of scientific study. The earlier 19th century work is dominated by accounts of the superficial deposits and bedrock markings which were explained in terms of diluvial or marine processes. Nevertheless, many of the original field observations and reports stand the test of time, and they remain valuable and pertinent contributions to the literature, most notably those of Maclaren (1828) and Milne Home (1840). In the years following the visit of Agassiz to Scotland in 1840 (see Agassiz Rock), the glacial theory gradually became established.

In an early keynote paper Milne Home (1840) described in some detail the superficial deposits of the Edinburgh and Lothians area, erecting an eight-unit stratigraphic succession. Boulder clay, sometimes resting on a layer of sand and gravel, was overlain by a sequence of sands, gravels and clays. Although he explained the full sequence in terms of marine inundation, his carefully set out field observations represent a landmark in Scottish Quaternary stratigraphy. Later, Nicol (1844) and Chambers (1853) quoted extensively from Milne Home's succession, Chambers adding further observations of his own in support. In the first editions of the Geological Survey Memoirs for the Edinburgh and East Lothian areas, Geikie (in Howell and Geikie, 1861) and Young (in Howell *et al.,* 1866) presented broadly similar successions to those of Milne Home: boulder clay overlain by sands and gravels and brick clays, then succeeded by raised beach deposits.

Fleming (1847, 1859) described essentially the same succession as Milne Home, but classified the deposits using different terminology. At one locality he noted an upper boulder clay resting on sand (Fleming, 1859, p. 75).

The existence of more than one till in the area was possibly first recognized by Maclaren (1828; see also Maclaren, 1838, 1866). He described the following sequence of deposits in sections along the Dalkeith railway:

3. Bedded sands.

2. Upper boulder clay; redder, looser texture and with fewer and more angular stones than the lower boulder clay.

1. Lower boulder clay; stiff, blackish and bluish clay interspersed with boulders and stones.

This sequence is similar to that at Hewan Bank (see below) and has recently been widely recognized throughout the Edinburgh area in the regional stratigraphic scheme of Kirby (1966, 1968, 1969b). Maclaren's valuable early observations, however, have largely been neglected by subsequent workers.

Maclaren (1828, 1838) originally interpreted the deposits as the product of ocean currents or a succession of great waves in the style of Hall (1815). Later, as a confirmed glacialist, he proposed that the lower boulder clay was formed as a glacial deposit, but, surprisingly, suggested that the upper one was formed by icebergs and ocean currents. However, in the preface to the second edition of his book (Maclaren, 1866) he does note that his interpretations of the surface deposits of the area were not fully recast with his revised views on glaciation. Significantly, Maclaren (1866) inferred that the two compositionally different boulder clays were formed in one uninterrupted depositional event.

J. Geikie (1877, p. 72) first introduced the idea of the interaction of more than one ice mass in the southern part of the Midland Valley. He suggested the presence of ice from separate sources in the Highlands and Southern Uplands in what he termed 'the debatable ground'. As part of his evidence he cited the intermingling of stones of both northern and southern origins in the till of the Esk Valley in Midlothian and noted the occurrence of Highland erratics as far south as Tynehead. Subsequently, Somervail (1879) inferred two directions of erratic transport in the Pentland Hills: from south-west to north-east and from north-west to south-east. This idea of shifts in ice-movement direction later assumed considerable importance in 20th century investigations of till clast fabric and till lithology patterns.

In the second edition of the Geological Survey Memoir, Peach *et al.* (1910a) envisaged a composite ice-sheet from sources in the Highlands and Southern Uplands moving eastwards across the Edinburgh area. They emphasized that variations in the character of the till were related to variations in the underlying bedrock. However, they made no references to multiple till sequences nor the previous accounts of them.

Peach *et al.* (1910a) considered that the thick sequences of sand and gravel above the till in the Midlothian basin were deposited when the southern ice had receded, but drainage was still obstructed by ice to the north. Significantly, they noted that the gravels largely comprised grey-wacke pebbles derived from the Silurian rocks to the south.

Campbell (1951) identified three separate boulder clays in the Esk Valley in the Pentland Hills. The lithological character of the deposits suggested that the lowest one was associated with ice moving east-north-east, the middle one with local ice in the Pentland Hills and the uppermost one with ice moving east-south-east. Eckford (1952), however, considered that the yellow colour of the middle till could reflect weathering, whereas the other two could be explained by changes in direction of flow of the dominant ice mass. Eckford in fact described two tills from the southern part of the Pentland Hills, but suggested that both were associated with the same ice-sheet, the lower one being a basal lodgement till, the upper one being formed by ablation of englacial and supraglacial debris. On lithological grounds Eckford considered that the last ice invasion of the area was from the Southern Uplands and was represented by extensive sand and gravel deposits overlying the Highland drift.

McCall and Goodlet (1952) studied indicator stones (erratics indicative of a particular litho-logical source), especially felsites, in various Midlothian deposits and concluded that the lower boulder clay of the area (which they did not differentiate) was the product of Highland ice.

Tulloch and Walton (1958) reached a similar conclusion to Peach *et* al. (1910a) that the composition of the till in the area of the Midlothian Coalfield closely reflected the character of the local bedrock. This view was again echoed by Mitchell and Mykura (1962). The latter summarized the glacial sequence in the Edinburgh area as:

3. Southern Uplands Readvance Boulder Clay and Gravel.

2. 'Middle' Sands and Gravels.

1. Basal Boulder Clay.

The available evidence suggested that a single ice-sheet flowed eastwards across the area. From erratics of distinctive lithology they inferred that most of this ice originated in the western Highlands but coalesced in the southern part of the Edinburgh area with ice from the Southern Uplands. Like Eckford (1952), they found no definite evidence that the two tills were deposited by separate ice-sheets, or even different phases of a single ice-sheet. Significantly, also, they found no evidence of three tills as recorded by Campbell (1951). During the retreat of the Highland ice, the extensive suite of 'Middle' sands and gravels was deposited.

Charlesworth (1926b) introduced the idea of a Lammermuir–Stranraer 'moraine' formed during the retreat phase of the last ice-sheet. In its eastern part, he correlated the 'moraine' with the extensive deposits of sand and gravel along the northern flanks of the Lammermuir and Moorfoot Hills. The 'moraine' was formed by a readvance of Highland ice from the north. Sissons (1961c), however, showed that the sand and gravel deposits were not ice-marginal moraines but were rather 'dead'-ice features formed diachronously. Moreover, several lines of evidence in the area to the west strongly suggested that the last ice movement was from the south and southwest, not from the north (McCall and Goodlet, 1952; Bailey and Eckford, 1956; Sissons, 1958b, 1961c).

Kirby (1966, 1968, 1969a, 1969b, 1969c) carried out a detailed investigation of the glacial deposits in the Lothians area. On the basis of stratigraphy, fabric analyses and stone counts he recognized a sequence of:

5. Roslin Till

4. Sand

3. Intermediate Till

2. Sand

1. Basal Till

The Basal Till occurs widely above bedrock throughout the area, from sea level up to about 250 m in the Esk basin. The Intermediate Till is best developed at the southern end of the basin on higher ground, but appears to be absent as a separate unit near the coast. At a number of localities the two tills are superimposed, and the Intermediate Till occupies an analogous position to the reddish-brown till in the Pentland Hills, recorded by Eckford (1952) and Mitchell and Mykura (1962). Indeed the stratigraphy described by Kirby is basically that noted first by Maclaren in 1828. Kirby also recorded a similar strati-graphy for East Lothian (see Keith Water).

From its lithology and fabric, Kirby inferred that the Basal Till was deposited by ice moving from the west, as noted by many of the early workers in the area (see above) and also more recently by Burke (1968); the Intermediate Till was deposited by ice from the south. Since both tills graded up into their own meltwater deposits, Kirby envisaged two temporally separate stages of ice movement, with ice from Highland sources being succeeded by ice from the Southern Uplands. Locally, however, he also identified complex sequences of till and glaciofluvial sediments formed during a single phase of glaciation (Kirby, 1969c) (see also Young, 1966).

Several authors have referred to washed tills in the Lothians area, usually comprising a sandy clay overlying the more typical tills (for example, Geikie, 1863a; Burke, 1968, Kirby, 1968). Kirby considered them to be subglacial deposits; Burke, the result of washing in the immediate post-glacial period.

In addition to the Basal and Intermediate tills of Kirby, a third and later till unit has been identified in the Midlothian area. Peach *et al.* (1910a) first referred to a reddish-brown boulder clay overlying sands and gravels in the Eskbank and Newton Grange areas, but did not attach any particular significance to it. Later, Anderson (1940) described between 3 and 10 ft (0.9–3.0 m) of what he called 'Upper Boulder Clay' overlying considerable thicknesses of sand and gravel in a number of sandpits around Roslin. Anderson also recorded clay-filled fissures in the sands and gravels, interpreting them as frost cracks. Additional examples of the latter were subsequently reported by Common and Galloway (1958). Anderson considered the Upper Boulder Clay to represent a readvance of ice. He did not specify Highland ice as Mitchell and Mykura (1962) stated, although it might be a logical inference from the indicator stones that he recorded.

Carruthers (1941, 1942), however, considered that the frost wedges described by Anderson were post-glacial and that the till–sand contact was not typical of readvancing ice, but rather was the product of subglacial meltout during a single event (Carruthers, 1939). Anderson (1941, 1942) countered by arguing that there was no trace of the fissures in the boulder clay.

Contrary to Anderson's results, McCall and Goodlet (1952) found no rocks of Highland origin in what they now called the 'Roslin Upper Boulder Clay', but there was abundant felsite which they referred to the Tinto Hill outcrop. They therefore concluded that the boulder clay was laid down during a readvance of Southern Uplands ice after the retreat of the main Highland ice which deposited the lower till of the area.

Kirby (1966, 1968) proposed the term 'Roslin Till' for this third till after the area where it was best exposed. He noted that it was only identified there because it overlay thick glaciofluvial deposits (cf. Tulloch and Walton, 1958). Elsewhere it was visually indistinguishable from the underlying till. However, Kirby put forward a variety of evidence to show that the Roslin Till represented a distinctive readvance of ice. His main arguments included the presence of frost wedges and deformation in the top of the sands below the Rosin Till and variations in lithological content between the Roslin Till and the two earlier tills. Mechanical analysis and fabrics excluded the possibility of the Roslin Till being an ablation moraine (Kirby, 1969b, 1969c). The fabric also suggested that it was not a solifluction deposit and, although its orientation was similar to that of the underlying intermediate till, the lithologies of the two units were quite distinctive. On the basis of the fabrics and stone counts he inferred that after a phase of glaciation by Highland ice, ice from the Southern Uplands entered the area from the south. From geomorphological evidence (Kirby, 1969c), he suggested that the ice then bifurcated near the present watershed at Kingside. One lobe retreated southwards (Sissons, 1958b, 1963b). The northern lobe receded northwards downslope into Midlothian and, during a subsequent readvance of this lobe, the Roslin Till was deposited on top of some of the earlier deglaciation features.

Subsequently, Martin (1981) has reassessed the status of the Roslin Till and presented a revised interpretation of the glacial stratigraphy. From sedimentological studies and comparisons with contemporary glacial environments, he concluded that there is no basis for regarding the Roslin Till as a separate stratigraphic unit. The sequence of glacial deposits in Midlothian shows considerable lateral and vertical variation and is clearly analogous to that seen along present-day glacier margins, for example in Iceland, where outwash, flow till and subaerial fan depositional environments are all closely related. Thus the till overlying the sands and gravels of the Roslin area has been interpreted by Martin as part of a complex sequence of diachronous debris flows draped over sediments deposited at receding ice margins. Martin considered features such as the till-filled cracks in the sand and gravel to reflect loading pressures rather than ice wedging. Martin also questioned whether the two lower tills are temporally discrete, and suggested rather that they represent a single complex meltout sequence such as described by Young (1966) and Kirby (1969a). He argued that the clast fabrics were not sufficient evidence to assign the tills to separate glacial episodes. Variations in flow conditions in a single glacier could produce clast fabrics both normal and parallel to the ice flow. Also, the observed lateral variations in clast composition could be explained by variations in solid geology, whereas the vertical variations could reflect the reverse order of lithologies traversed by the glacier (cf. Boulton, 1970).

Martin therefore proposed a single Late Devensian ice-sheet derived from the west, but with a flow component from the south to account for the transport of the Southern Upland erratics into the Lothian basin. This ice-sheet deposited a heterogeneous lodgement till, possibly with a melt-out component, with sand and gravel deposits formed as diachronously off-lapping wedges during the recession and marginal stagnation of the ice; the latter deposits were then buried by debris flows. Such a pattern accords with observed associations of depositional environments at modern glacier margins (Boulton, 1972b; Lawson, 1979). These observations demonstrate that the tripartite sequences comprising sands and gravels between tills, conventionally interpreted in terms of multiple glaciation, can quite normally relate to a single phase of ice retreat (Boulton, 1972b). Similarly, reappraisal of lodgement till complexes (Eyles *et al.,* 1982) has shown that observed variations in their sedimentary characteristics can be satisfactorily explained in terms of a single glacial episode. For example, till deposition may be interrupted by phases of erosion or deposition of subglacial meltwater sediments, and lateral migration of basal flow-lines may produce the unconformable superimposition of lodgement till units derived from different source areas.

References