The Powfoot Boulder Pavement

Michael Brookfield, Jon Merritt and Andrew McMillan

A striated boulder pavement is intermittently exposed at low tide on Priestside Bank following the removal of intertidal sands and clays during changes in course of the estuarine channel of the River Eden within the Solway Firth. The main locality is located on a boulder scar [NY 125 645], 500 m south of the shoreline at Nethertown, just north of a large, prominent boulder on the foreshore (Merritt and Phillips, this volume, fig.1). Striated boulders also may be found on Powfoot Scar [NY 145 650] and Howgarth Scar [NY 136 643], to the east

The pavement, where undisturbed, consists of a single layer of interlocking bullet- and flatiron-shaped boulders up to 50 cm in length (Figure 1). The clasts are composed predominantly of wacke sandstone (95%) with some red Triassic sandstone (5%) and sparse granodiorite derived from Criffell, some 15 km to the west. The flatirons have smoothed and striated upper surfaces and both the long axes of the boulders and the striations show a consistent WNW-ESE alignment, but with no unambiguous directional indicators. They are, however, parallel to the general ESE ice flow deduced from drumlins to the east of the River Annan on the Scottish side of the Solway Firth (BGS, 2005, 2006; Livingstone et al., 2008, flow set LT4). The pavement is only locally developed and passes laterally into patches of pebbles both overlying, and interbedded with coarse, well-sorted, reddish brown sand; elsewhere, it is replaced by scattered pebbles lying on till.

The pavement rests on compact diamicton and is overlain locally by a unit of similar till that is exposed along the high tide mark, north of the main pavement location. The diamicton underlying the pavement is exposed where boulders have been removed or dislodged by recent marine erosion. It is a pale reddish brown (10R 5/4 - Munsell Rock Color Chart on wet material), pebbly silty clay diamicton with well dispersed clasts (<20%) dominated by Lower Palaeozoic wackes. A pebble count at the main locality gave: wackes (95%), red Triassic sandstones (4%), with less than 1% of Carboniferous conglomerate, and, significantly, with no granodiorite. The clasts are dominantly subangular to subrounded and many are bullet- or flatiron-shaped, polished and scratched. There are a few large wacke erratics up to 1 metre diameter on the Powfoot foreshore.

Discussion

Striated boulder pavements are flat, tightly packed mosaics of ice-smoothed and striated boulders, one clast thick, with faceted upper surfaces commonly exhibiting orientated striations, lying within or between tills (Hansom, 1983, Eyles, 1988). They are a class of armoured surface produced when coarser particles are concentrated by the removal of intervening finer material (Benn and Evans, 1998). Striated boulder pavements are considered to form either at the base of grounded ice sheets or in intertidal areas in cold climates; they have been recorded from both Quaternary (Eyles, 1988; McCabe and Haynes, 1996) and older glacial deposits (Visser and Hall, 1985; Lucio and Rocha-Campos, 2000).

Subglacial boulder pavements may be created by:

a) preferential lodgement of boulders against bed obstructions beneath a wet-based glacier (Boulton, 1978); the clasts form a ‘traffic jam’ with their long axes parallel to flow and may show an up-glacier imbrication. Such subglacial boulder pavements have limited areal extent and should be dominated by bullet shaped striated clasts typical of transport at the glacier base.

b) a deforming bed at the base of a glacier in which case clasts may either be similar in lithology to the overlying till, having settled through the deforming bed (Hicock, 1991; Clark, 1991), or similar in lithology to the underlying sediment following ‘excavational deformation’ (Boulton, 1996). Such pavements commonly pass laterally into lines of widely spaced clasts with flattened and striated upper surfaces, then into either pebble-rich bands without striated surfaces or sharp unconformities separating distinct units of till.

c) basal glacier meltwater erosion and concentration of clasts from underlying till or other sediments (Shaw, 1988), in which case a wide variety of clast morphologies may be present.

Intertidal, periglacial boulder pavements originate as gently undulating boulder lag surfaces produced by wave and current winnowing of till in relatively shallow seas, followed by abrasion and transport by a grounded ice shelf (Eyles, 1994). Intertidal ice has been observed freezing downwards to encase boulders on subarctic flats as the ice cover is raised and grounded repeatedly (Rosen, 1979; McCann et al., 1981). However, the boulders typically show very divergent scratch alignments and clasts have neither the preferred alignment nor the characteristic bullet shape of clasts transported at a glacier base (Eyles, 1988). Repeated abrasion by debris within ice blocks grounded across the intertidal zone at low tide produces flattened upper surfaces and short, randomly orientated striations on the pavement clasts (Eyles, 1994), dissimilar to the unidirectional striations produced beneath a glacier.

Conclusions

The Powfoot boulder pavement has characteristics of both subglacial and intertidal boulder pavements. On the one hand, the aligned clasts (dominated by flatiron and bullet shapes) and consistent striation directions strongly suggest a subglacial origin. On the other hand the local close packing and rapid passage into dispersed pebbles both underlying and overlying well-sorted sands may indicate an intertidal origin. It is possible that estuarine wave action first concentrated boulders from the underlying till, accounting for the variability of the pavement and its apparent passage into pebbles overlying beach deposits. A wet-based glacier flowing from the WNW subsequently moulded the boulders into the present polished and unidirectionally striated mosaic, accounting for the numerous bullet and flatiron clasts together with the strong pebble and striae alignment.

It is important to test the hypothesis outlined above, because either a simple intertidal origin or an intertidal followed by subglacial origin for the pavement raises questions regarding the established sea level history of the region (Wells, 1999). For example, fragmentary Late-glacial raised beaches occur up to about 11m above OD within the area to the north-west of the pavement that would have been affected by such a readvance of ice (Haggart, 1999; BGS, 2005; McMillan et al., 2010b), necessitating a significant sea level rise following the readvance. The simplest explanation is that the pavement formed subglacially beneath wet-based ice that readvanced ESE across previously deposited till and glaciofluvial deposits during the ‘Powfoot Oscillation’ (Merritt, 2010, this volume). The presence of granodiorite boulders from Criffell in the till overlying the pavement, but not below it, is compatible with such a late-stage readvance of ice splaying out into the Solway Firth from Nithsdale and Annandale (Figure 2).

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Figures

1. View of the glaciated pavement. A: general view looking NW with main pavement outcrop arrowed; B: view of dominant flatiron- and bullet-shaped clasts. C: close-up of striated flatirons.

2. Speculative reconstruction of the readvance of Scottish ice into the Solway Lowlands following the Last Glacial Maximum (after Stone et al., 2010), showing the approximate position of the ice front during the Scottish Readvance and subsequent Powfoot Oscillation. P, Plumpe Farm; PF, Powfoot.

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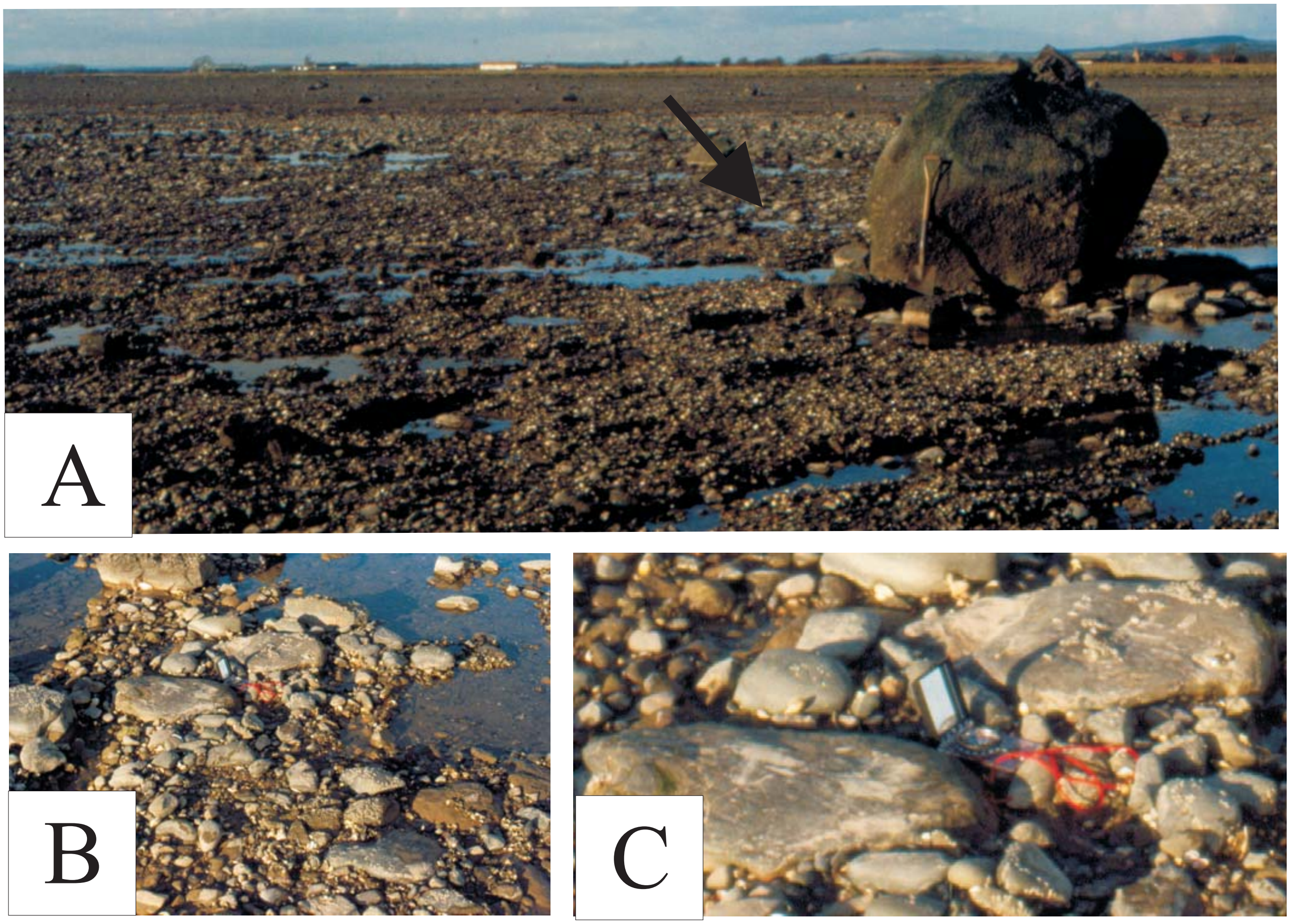
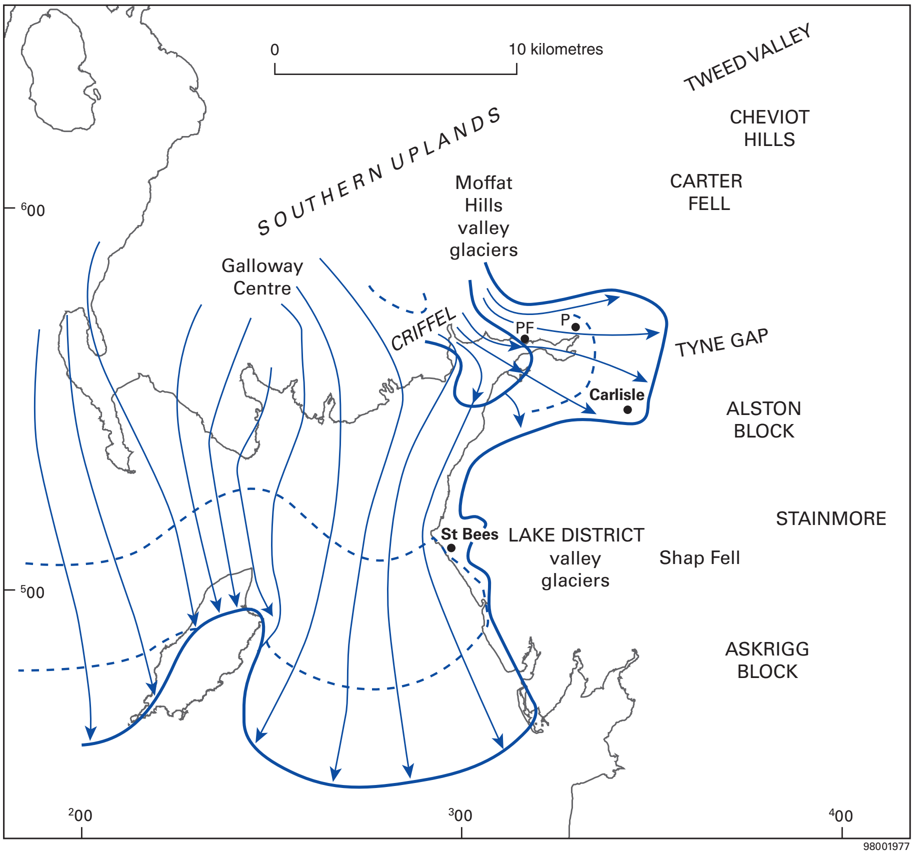


Fig 2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Moffat Hills valley glaciers
CARTER FELL
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Galloway Centre
CRIFFEL
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Carlisle
ALSTON BLOCK
STAINMORE
St Bees
LAKE DISTRICT valley glaciers
Shap Fell
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