p-forms from the Isle of Mull

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Synopsis

Large numbers of well preserved p-forms occur along the southern shore of Loch na Keal on the Isle of Mull. The main forms are curved and sinuous channels up to 20 m long, 3 m wide and 1·5 m deep, but bowls, sichelwannen and other forms are also present. Field measurement of the orientation of 142 channels shows that they are consistently orientated parallel to the direction of ice movement as indicated by striae, and striae are present on the floors and sides of many of the channels. The mode of origin of the p-forms is discussed and it is concluded that meltwater erosion by corrasion and/or cavitation is the most likely process with active ice later moving through them. It may be significant that the p-forms occur along the former boundary zone between mainland and Mull ice.

Introduction

The term p-forms was introduced by Dahl (1965) to describe plastically moulded forms on glaciated bedrock surfaces. The forms, which include winding channels, bowls, potholes and sichelwannen have been described from Scandinavia, the Alps and N. America in a large number of papers (e.g. Andrews 1883; Ljungner 1930; Hjulstrom 1935; Ebers 1961; Dahl 1965; Gjessing 1965, 1978; Bernard 1971a, 1971b, 1972; Boulton 1974) but in marked contrast in Britain there is an almost complete absence of research on p-forms. Their origin is controversial, the three most favoured mechanisms being the movement of water-soaked till, glacial abrasion and meltwater moving under high velocities. Since the origin of many of the forms is uncertain, the term p-forms has come to be used as a general one for small-scale, smooth erosional forms associated with glaciation whatever their precise origin.

The author knows of only one British locality where considerable numbers of different types of p-forms exist. This is around Scarisdale on the Isle of Mull where J. E. Richey in the Geological Survey Memoir for Mull (Bailey *et al.* 1924, p. 396) describes "a remarkable series of little striated hollows and winding grooves". Although many of the features occur in the present or former intertidal zone where it is known that wave action can produce bowls and channels similar to p-forms (e.g. Bernard 1971b; Sollid 1975), the Mull features are believed to be associated with glaciation because of the presence of parallel striae inside many of the channels (e.g. see Plate 3), the consistent orientation of the channels irrespective of variations in the

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trend of the coastline (see below), and the presence of examples of similar forms up to altitudes of over 300 m (Bailey *et al.* 1924). Thus, although it is possible that some shallow bowls and channels are the product of recent marine or fluvial erosion, it is believed that the vast majority of the Mull features were formed when ice covered the area, and their size and shape conforms to numerous literature descriptions of p-forms (e.g. Embleton and King 1975).

Since such features appear to be rare in Britain, the aim of this paper is to provide a more detailed description of the Mull features and to discuss their origin. It seems unlikely that this is the only British locality where numbers of p-forms exist and it is hoped that this paper will arouse interest in this neglected aspect of glacial geomorphology in Britain.

The study area

The Mull p-forms occur along a 4 km stretch of coast on the south side of Loch na Keal between Knock at the head of the loch and Rubha na Moine, about half-way along the loch. (Fig. 1).

They are best developed between low water mark and a few metres above high water mark, in part at least because of the absence of masking soil and vegetation. The bedrock is basalt, lava steps forming the hillsides above the loch and extending down to present sea-level. There are thus flat rock areas all along this coastal zone though near Scarisdale Wood the coastal platform is very narrow. Particularly near the Scarisdale River, Lateglacial and Flandrian raised beach gravels mantle the bedrock below an altitude of about 35 m O.D. (Bailey *et al.* 1924). Loch na Keal itself is a 2–3 km wide sea loch with a maximum depth of about 25 m in its upper part, though it deepens to over 40 m towards its mouth. The nearshore gradient on the coastline where the p-forms are found is believed to be low since a series of skerries known as Scarisdale Rocks are revealed several hundred metres offshore at low tide (Fig. 1).

Ice movements and glacial erosion

The most detailed work on ice movements over the Isle of Mull was carried out by Bailey *et al.* (1924). From studies of erratics and striae they proposed the pattern of ice movement shown in the inset of Fig. 1 with a "sanctuary" over the Mull mountains where no mainland erratics were found. They suggested that a Mull ice cap deflected ice moving westwards and southwestwards from the west Highlands. The northern limit of the Mull sanctuary runs approximately along the south shore of Loch na Keal (Fig. 1 inset). The study area lies outside the limits of the Loch Lomond Readvance (Gray and Brooks 1972) and was therefore last glaciated by the Late Devensian ice sheet (Sissons 1976).

The movement of ice parallel to the trend of Loch na Keal is confirmed by the present author's measurements of the orientatons of striae and grooves that occur on

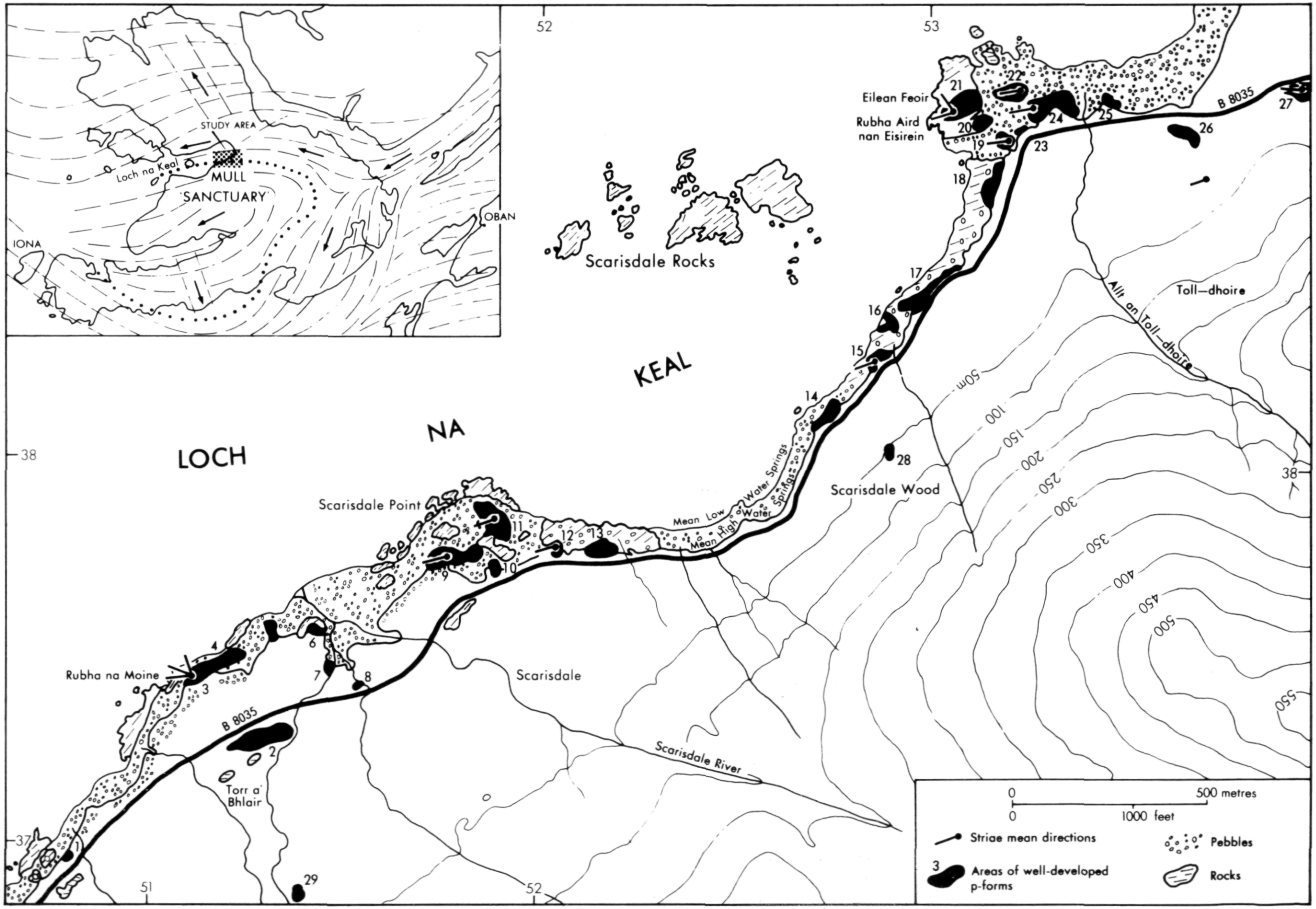

FIG. 1. Localities in the study area with well-developed p-forms. Inset map shows the pattern of ice-movement over Mull with arrows indicating directions of movement and with the extent of the Mull 'sanctuary' shown by dots (after Bailey *et al.* 1924).

the often glacially smoothed rock outcrops in the study area, although occasionally cross striae have been measured, e.g. at sites 3 and 21. Up-ice faces are often abraded, as in the case of three rock hillocks at Rubha Aird nan Eisirein (sites 19, 20 and 21) which have the shape of small rock drumlins. Friction cracks (Embleton and King, 1975, pp. 187–91) are not common in the study area but at site 21 a trail of 10–12 fractured crescentic gouges occurs along a shallow groove orientated at N65°E (Pl. 1).

Description of the p-forms

The p-forms found in the study area are mainly curved and sinuous channels, although bowls, sichelwannen and some other forms also occur. Figure 1 shows areas where the densest concentrations of p-forms occur but examples may be encountered on other rock outcrops throughout the study area. Sites 4 and 14 carry the most impressive suites of features and detailed maps of parts of these sites are shown in Figures 2 and 3. These maps were constructed by setting up 5 m square string grids over the areas. Site 4 and many other sites, are completely covered at high-tide and a visit to the area is best undertaken at low water levels.

As first remarked by Richey (Bailey *et al.* 1924, p. 396) the features have been cut irrespective of geological structure. A few channels or parts of channels are developed along joints but the vast majority are not.

Channels. Although channels are by far the most abundant p-form type in the study area, they are very variable in both size and morphology. The largest channel is at site 22 and is about 3 m wide and has steep walls well over 1 m high, though its floor is masked by mud and boulders. It consists of a single curve *c.* 12 m long, with an undercut outer wall and smooth inner wall both of which are covered with glacial striae that follow the curvature of the channel. Another large channel occurs at 19 and is one of a number that begin in bowls. This bowl is over 3 m wide but it leads into a channel that tapers down to *c.* 15 cm towards the end of its 18 m length. At the other extreme some channels are only 1 cm or so deep and under 10 cm wide. Occasionally, individual channels can be traced for over 20 m. Examples are AA at site 4 (Fig. 3) and a sinuous channel near the northern extremity of site 3.

Channel sides vary from very gently sloping to vertical or even undercut. A particularly good example of undercutting is Q at site 14 (Fig. 2 and Plate 2) where the depth of undercutting is up to 5 cm, but the deepest undercut is at 22 where a 10 cm deep undercut occurs. Asymmetrical cross-profiles are common with the south (inland) slopes usually being steeper and higher. Examples are D, O and F at site 4 (Fig. 3), which are virtually one-sided channels. On the other hand the steepest slope is not always the highest. Channel C at site 14 for example (Fig. 2) has a well striated 1 m high southern slope dipping at 30–40° whereas the northern slope is only 30–40 cm high but dips at up to 70°. Previous work on p-forms has laid some emphasis on the distinction between sharp and rounded edged channels in classifying

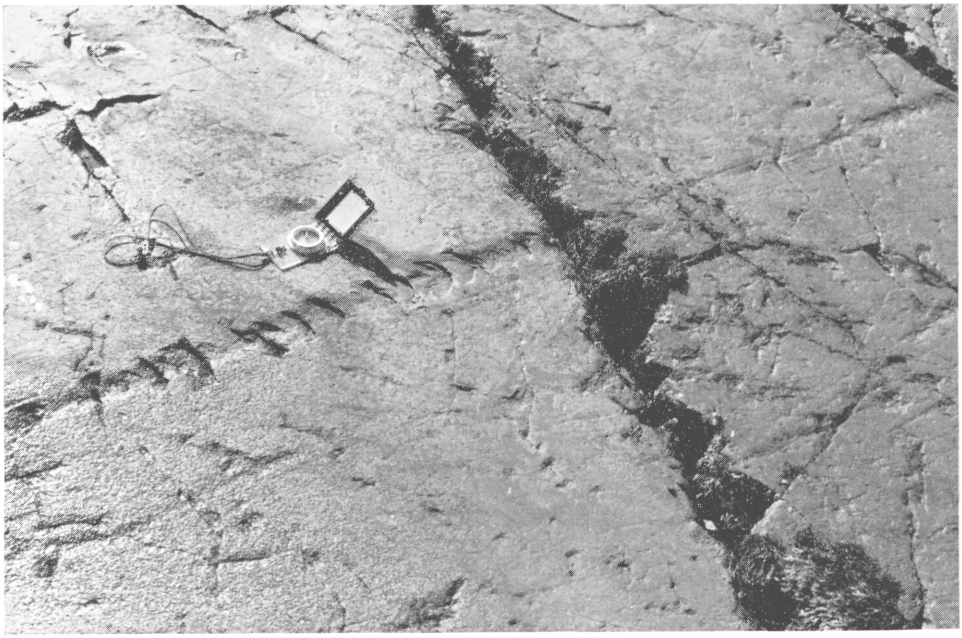

Plate 1

Crescentric gouge trail occurring along a shallow groove at site 21. Ice moved from left to right, i.e. the gouges are concave up-ice.

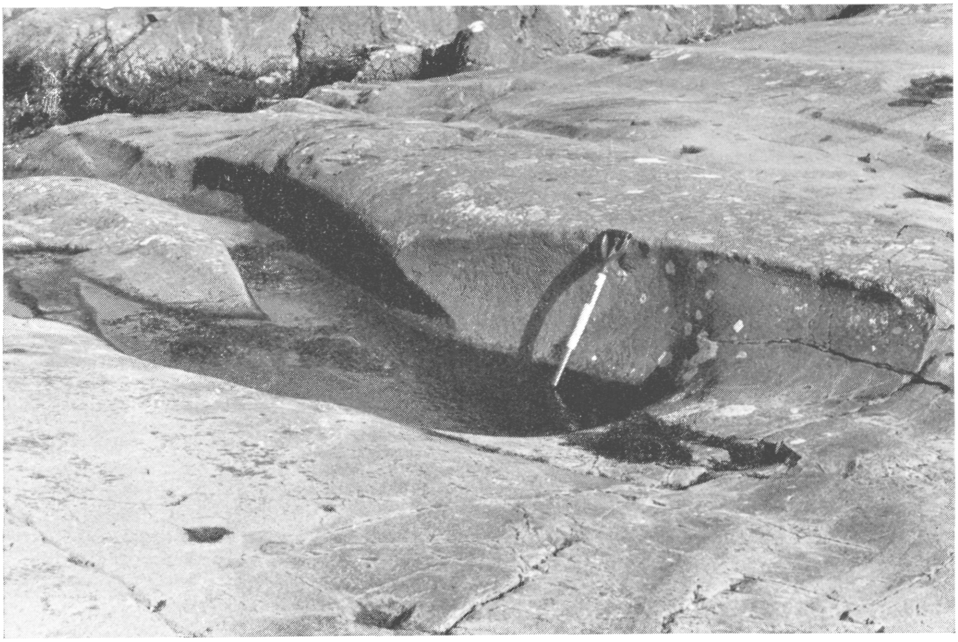

Plate 2

Feature Q at site 14 (Fig. 2) illustrating two-phase erosion, undercut sides and an overdeepened floor.

Plate 3

Channel M at site 14 (Fig. 2). Channel H (a "one-sided" example) is top centre and Channel C with its striated south face is top right.

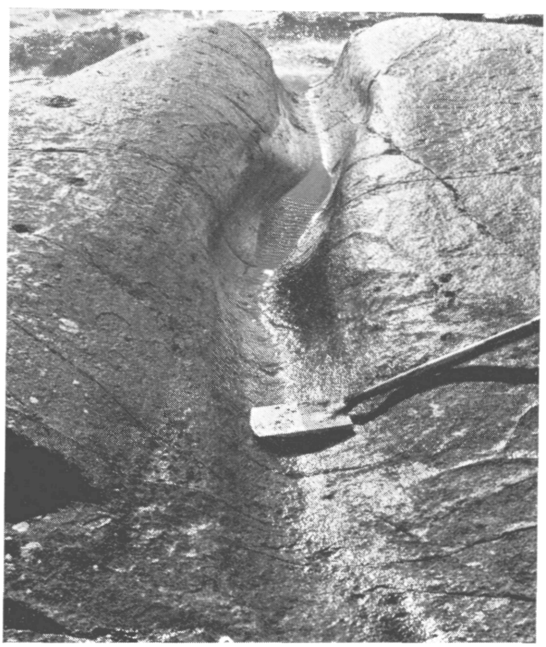

Plate 4

Channel P at site 14 (Fig.2).

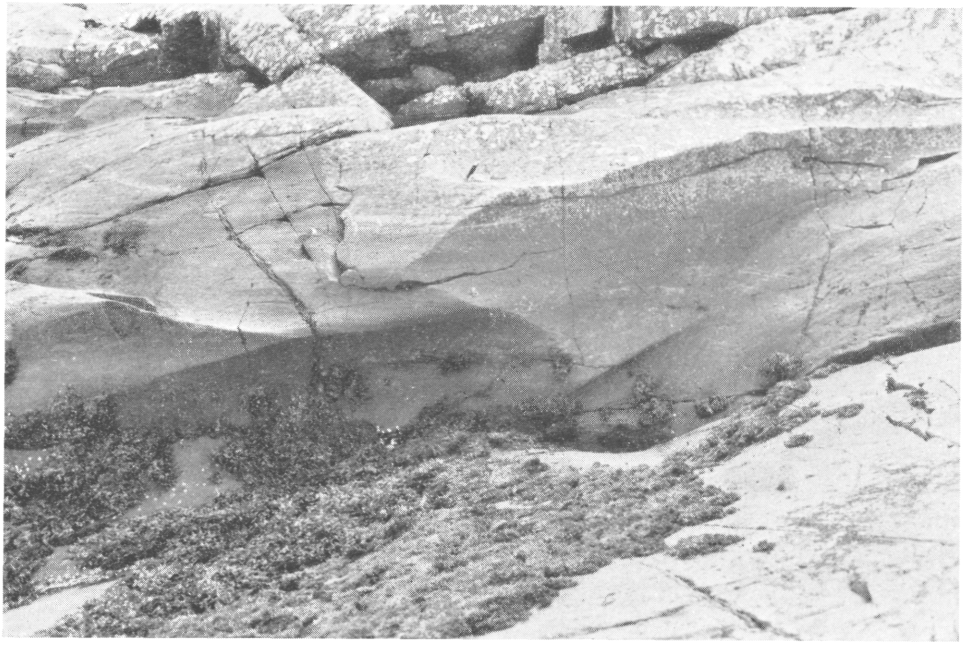

Plate 5
Faceting at site 22. Ice moved from left to right.

Plate 6
Channels and bowls at site 13. The mapping board is about 35cm long.

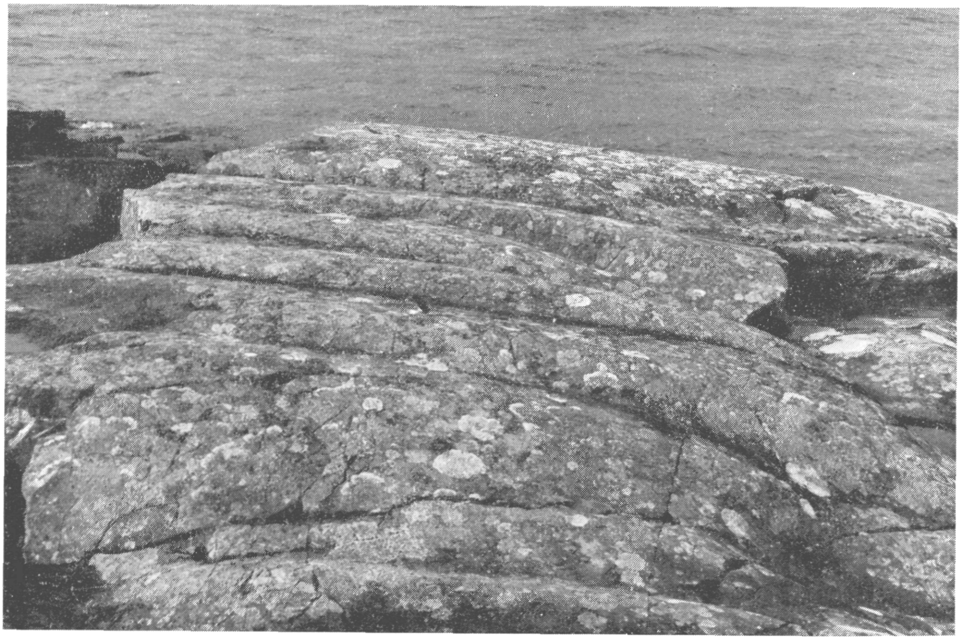

Plate 7

Parallel channels at site 17, giving the rock surface a "furrowed" appearance. Ice moved from right to left.

Plate 8

Sichelwanne at site 2. Note the striae oblique to the horn in the upper left.

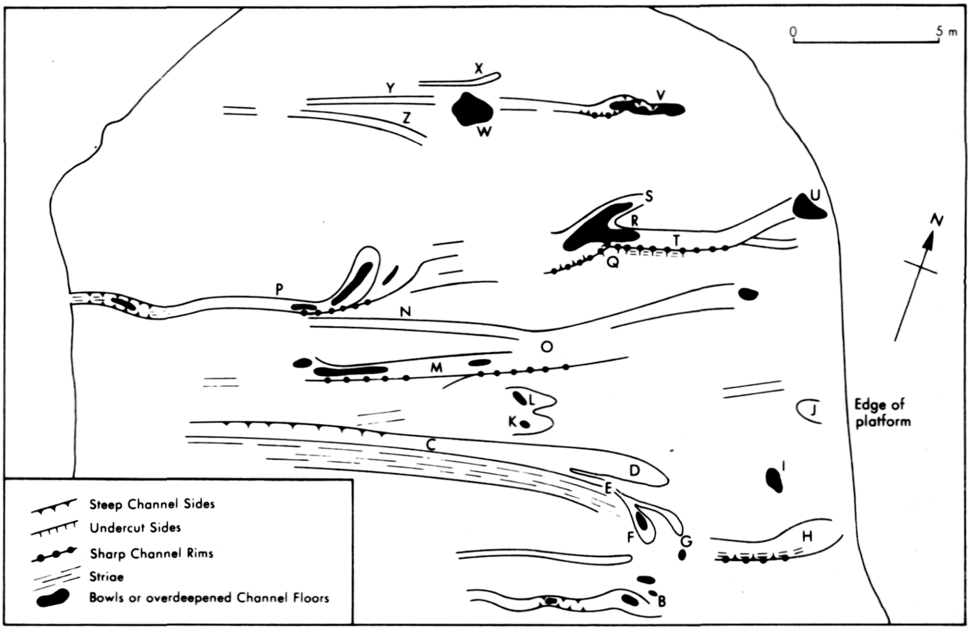

FIG. 2. Map of the p-forms on part of site 14.

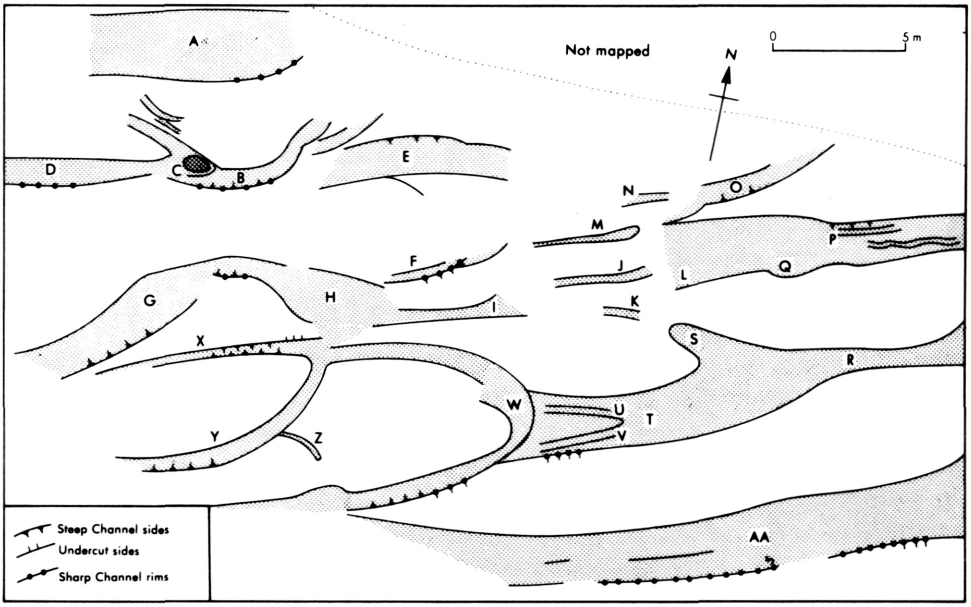

FIG. 3. Map of the p-forms on part of site 4.

the forms (e.g. Dahl 1965). In this study most channels have rounded edges but there are several places where sharp edges occur (Figs. 2 and 3, Plates 2 and 3) often accompanied by undercutting. However, even where sharp edges do occur, they almost always grade into rounded edges or are accompanied by rounded edges on the opposite side of the channel.

In plan some channels are winding (e.g. P, Fig. 2 and Plate 4), others describe single curves, while still others are almost straight (e.g. M, Fig. 2 and Plate 3). Some of the straight channels are shallow with rounded edges and may be equivalent to the "groove-like channels" of other workers (Dahl 1965; Bernard 1971a). Channels sometimes curve round the flanks of abraded hillocks though some run over the crests of hillocks, regardless of morphology (e.g. X, Fig. 3). Sometimes more than one phase of erosion is evident, as at site 22 where a number of facets have been produced (Plate 5), the lowest of which is the wall of an undercut channel. Another good example of more than one phase of erosion occurs at Q (Fig. 2 and Plate 2), while the best example of a channel cut into the floor of a larger one occurs at site 15. Channels may bifurcate (e.g. Plate 6) or join (e.g. F and G, Fig. 2) and many of their floors have overdeepended sections where there is often standing water (e.g. Fig. 2 and Plates 2–4). They are often best developed where they run up the stoss sides of abraded bedrock outcrops and they sometimes terminate abruptly at the down-ice side of a glaciated pavement (e.g. Plate 7). In most cases, however, it is not possible to be certain whether this is due to glacial plucking shortly after their formation or to subsequent marine erosion of rock blocks.

The orientations of 142 channels have been measured. Because of the sinuosity of many of the channels, overall directions were measured and single curved channels were omitted. The general pattern, however, is clear, 96% of the channels being orientated between 50° and 90° E of N, i.e. consistent with the trend of Loch na Keal and the main striae direction (see Figs. 1–3). Anomalous channels occur, for example, at site 13 where two channels are orientated at *c.* N35°E (Plate 6.) Where a number of channels with similar orientations occur close together, the rock may take on a furrowed appearance (e.g. at site 17, Plate 7 and at site 22).

Bowls. Bowls, which generally have gently sloping sides and rounded edges, are common in the study area but contrary to previous descriptions (e.g. Dahl 1965; Bernard 1971a) they occur on flat surfaces. It has already been remarked that some channels begin in bowls (e.g. D, F and G, Fig. 2) while bowl sections also occur along channels. Elsewhere individual bowls may occur (e.g. I and J, Fig. 2), while sometimes large numbers of bowls occur, giving the rock surface an extremely irregular appearance. One example is at site 24 where large numbers of shallow bowls and channels occur on a flat rock surface. The largest bowl occurs at site 11 and is *c.* 10 m long, 3·5 m wide and 1 m deep, but this is exceptional and most are little more than 1 m in diameter and only a few centimeters deep.

Sichelwannen. In many studies of p-forms sichelwannen have been described as the dominant type (e.g. Dahl 1965; Bernard 1971a) but in the study area they are of minor importance to channels. In some cases sichelwannen-type features are produced by the splitting of a channel into two oppositely curving sections. There are, however, also some examples where two horns curve away from a bowl that is cut deeper than the possible feeding channel. One example of this is W in Fig. 3 while another is shown in Plate 8. The latter is at site 2 and is only 2 m in horn-horn length. Two larger sichelwannen have been discovered in the study area, both of which have insignificant feeding channels. One is at 18 and is 6 m in horn-horn length and the other is at site 3/4 and is *c.* 11 m in horn-horn length. The latter begins in a bowl 3 m in diameter from which the horns curve down-ice. The northerly horn can be traced for *c.* 23 m, though it is partly floored by soil and grass. Sichelwannen of such large dimensions do not appear to have been described in the literature. All the sichelwannen found are concave down-ice and are useful indicators of direction of ice movement.

Other Forms. The only convincing cavetto-type feature in the study area is at site 27. It is 3 m long and has a sharp edge along the full length of its up-slope side. Nearby, as well as at site 16, there are examples of shallow scoops 0·5–1·0 m in diameter. These forms resemble the "mussel gouges" described in some previous studies (e.g. Bernard 1971a).

Discussion

The three most favoured theories of p-form formation are (i) glacial abrasion (e.g. Boulton 1974) (ii) movement of water-soaked till (Gjessing 1965) and (iii) meltwater moving under high velocities (e.g. Dahl 1965). It now seems clear that they can be formed in various ways (Sugden and John 1976), for although most authors have favoured cavitation and/or corrasion by debris in meltwater streams (e.g. Ljunger 1930; Hjulstrom 1935; Ebers 1961; Dahl 1965; Bernard 1972), others have named similar forms "glacial grooves" without any discussion of their origin. Sugden and John (1976, p. 174), for example, believed that glacial grooves "may be slightly sinuous with soft flowing outlines". However even the spectacular winding grooves in Glacial Grooves State Park on Kelleys Island in Lake Erie "were once stream courses" which deflected basal glacier ice (Goldthwait 1979, p. 304).

Many features of the Mull p-forms accord with a meltwater flow origin. These include their winding forms, sometimes with curves with radii of a few centimetres, their undercut lips often with sharp edges, the examples of sharp-edged facets, and the asymmetric cross profiles of several of the channels. None of the p-forms explained in the literature by glacial abrasion or movement of till have all these characteristics. On the other hand some features produced by these agents are absent from the Mull forms. For example there are no lee-side transverse trenches, explained by Gjessing (1965) by the squeezing of till independent of the direction of ice movement, and there is no second order grooving, described by Goldthwait (1979) as having been abraded onto the floors of his megagrooves. The most likely origin of the Mull p-forms is therefore meltwater flow.

A problem arises however in explaining the striated floors of some of the Mull channels. Dahl (1965, p. 138) thought that the fine striation in the forms he studied "can be connected with glacifluvial corrasion", but, as Gjessing (1965) pointed out, such striae would be expected to be rather irregular due to turbulent flow and to be restricted to the channel beds. On Mull the striae in the channels are usually reasonably continuous and sub-parallel and they occur well up the channel sides and even along some overhanging sections. Ebers (1961) argued that the presence of such consistent striae in p-forms suggested that active ice must have moved through them subsequent to their formation by meltwater streams. On Mull there is evidence that such a two-phase history occurred for there are examples of striae trending slightly obliquely to channels. The most convincing example is shown in Plate 8 in the upper left part of which striae can be seen trending obliquely to the trend of the horn of the sichelwanne.

It is not clear why p-forms should have formed in this particular locality, but it may be more than coincidence that they occur along the former boundary zone between Mull and mainland ice (see Fig. 1 inset) and that individual channels are orientated parallel to this boundary. Thus one explanation is that meltwater flow was concentrated along the junction between the two ice masses. Only when further p-form localities have been identified and detailed studies made of them will it be possible to generalize about the sites and conditions favourable to p-form formation. Our present knowledge of the distribution of p-forms is inadequate as is our knowledge of the subglacial processes that may form them. The literature is full of subjective assessments of the theories but before further progress can be made answers are required to a number of questions. Can ice flow in small-scale meanders? Is moving till able to erode channels with sharp edges? Can high-velocity heavily debris-laden meltwater produce consistent linear striations?

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