their words, the "snowbanks would form highways down which rocks loosened by frost would travel from the cliffs to the floors of the amphitheaters, and the effect would be to deposit waste at a greater distance from the cliffs than ordinary talus, and to protect a zone at the very foot of the cliffs from excessive talus accumulations." Howe (1909, p. 35-36, fig. 3) subsequently described them in more detail and illustrated their inferred origin by a diagram that is both clearer and more informative than the one which Daly (1912, fig. 41) later published. In this report, they were referred to as "snowbank deposits". Although Daly referenced several U.S. Geological Survey publications in his memoir, he did not cite Howe's observations; apparently that work was unavailable to him at the time of his writing. The Cross and Howe folio was published 7 years before Daly's report appeared, but he may not have seen the brief description it contained.

In addition to Cross and Howe's description of pro-talus ramparts, I have come across an even earlier discussion of these land forms in a paper that apparently escaped the attention of geologists working in the American west during the early years of this century. In describing the varied surficial deposits of the upper Indus River basin in the regions of Gilgit, Baltistan, and Ladakh, Drew (1873, p. 445) described different forms of talus along the valley walls and provided a description of what is clearly a pro-talus rampart:

> "sometimes it happens that a talus of snow forms first, in much such position and form as the stone-heap itself might acquire; and then upon this snow-heap rolls down the loosened stuff, which therefore finds rest only at the foot, round the edge, of the snow-talus; the melting of this in summer leaves a heap of stones which may be of considerable height, though it is not very likely to increase by additions in successive seasons. Such circumstances as these should be borne in mind when one meets with isolated heaps, not far from the mountain-side, which might otherwise be taken for moraine-heaps ... the heap at the foot of the snow talus is not unlikely to take the form of part of a ring abutting at its ends against the mountain, and thus enclosing a hollow ...".

This description, which antedates Daly's by more than a third of a century, may constitute the earliest mention of these alpine land forms by a geologist.

Butler (1986) argued that Daly's term "winter-talus ridge" takes precedence over the term "protalus rampart" later introduced by Bryan. One could argue equally well that Cross and Howe's term "snowbank accumulation" (or Howe's subsequent "snowbank deposit") should take precedence over Daly's term. However, I find neither of these terms very satisfactory, for they are imprecise and ambiguous. Daly's term can also be faulted, for it implies that the talus ridge forms in winter. Although this may be true in some cases, I know of no definitive studies showing that sliderock production and accumulation at the toe of a snow bank occurs exclusively, or even predominantly, during the winter season. Some studies have shown that release of rock debris from mountain slopes reaches maximum frequency during mid- to late spring (May–June) when rapid thawing of frost-rived cliff faces takes place (Rapp, 1960); in polar latitudes, such activity may peak during the summer (e.g. Åkerman, 1984). Rock debris generated during the height of the accumulation season tends to become buried within the growing snow bank and would be unlikely to slide or roll down the unconsolidated snow surface to its toe. Bryan's term "protalus rampart" avoids these problems, for it is a descriptive, non-genetic designation. Until more is learned about how and when these land forms develop under different geographic conditions, the widely used term proposed by Bryan remains a viable and preferred one.

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*25 February 1987*

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SIR,

*Concerning early descriptions of pro-talus ramparts*

I should like to thank S.C. Porter (1987) and C.K. Ballantyne (1987) for their interesting letters concerning pro-talus ramparts, written in response to my previous comments (Butler, 1986). They make several points in their letters, and I should like to comment on some of these issues.

First, it was certainly not my intention to ignore or denigrate the contributions of geologists and geographers working in the British Isles, cited by Ballantyne (1987). I did not allude to those works because they do not describe pro-talus ramparts. Ballantyne cites three papers which he interprets as providing earlier written descriptions of pro-talus ramparts than that of Daly (1912). Ward (1873, p. 426) indeed did hypothesize a type of "moraine-like mound", based on a suggestion from "Mr. Drew, late from Cashmere", but did not actually provide any field description of such a feature in the Lake District. Furthermore, Ward's descriptive mounds (note that he did not use the term ridge or rampart) could easily be interpreted as attributable to snow-avalanche impact (Corner, 1980). Ward's brief comment cannot be construed as describing a pro-talus rampart.

The comments of Marr and Adie (1898) are also sufficiently vague as to preclude the establishment of primacy. Their statement that the angular blocks resting upon the sub-angular blocks of a moraine were "rather of the nature of snow-slope detritus" may again refer to avalanche-deposited materials. It is also clear that the feature in question was a moraine, which had undergone minor post-glacial modification.

The description of Gatty (1906) is, as Ballantyne states, "a remarkable account". It is, however, a remarkable account of glacial moraines, not pro-talus ramparts. Both of Gatty's (1906, p. 490, 491) photographs refer to the land forms in question as *morainic dams* (an item omitted in Ballantyne's letter). A reading of Gatty's description, as well as interpretations of the photographs, reveals that the ridges in question are weathered, stable glacial moraines. A veneer of some isolated, recently deposited clasts on the surface of a moraine does not make the moraine a pro-talus rampart.

The papers cited by Porter (1987) certainly do describe features later called pro-talus ramparts, and I thank him for calling them to my attention. I should be pleased to hear of other early descriptions of these land forms, and hope to hear from readers of the *Journal*.



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Secondly, I have no dispute with Ballantyne or Porter concerning the entrenchment of the term "pro-talus rampart" in the literature. My advocacy of Daly's (1912) term "winter-talus ridge" was based primarily on its primacy over the later terms "nivation ridge" and "pro-talus rampart". In the light of Porter's examples from the historical literature, this is no longer an issue. Ballantyne's (in press) forthcoming paper, as well as the process studies cited by Porter, clearly shed doubt on the genetic accuracy of Daly's term.

Finally, I completely agree with Ballantyne (1987) that the traditional definition of the term "pro-talus rampart" will eventually require revision and, in the light of Porter's comments, that the term "pro-talus rampart" remains a viable and preferred one. The definition I presented (Butler, 1986) was simply a summary of currently utilized working definitions. The works of Harris (1986) and Ono and Watanabe (1986), works not published at the time my previous letter was written, indeed illustrate the problems with a morphogenetic definition based solely on one form of genesis. I am not, however, at this time prepared to adopt Ballantyne's (1987) "more general definition", particularly in the light of recent studies which attribute glacial origins to features previously described as owing their genesis to pro-talus processes (e.g. Gardner and others, 1983, p. 171). As pointed out by Madole (1972, p. 122), "the polygenetic origin of talus makes it both the most complex and ill-defined facies", and as Porter states, much work obviously remains to be done before a thoroughly accurate definition will be available.

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SIR,

*A computer program for glacier-surface plain-strain analysis*

Established methods of determining surface strain on glaciers involve slow and cumbersome data analysis. We have prepared a simple program in BASIC, for use on micro-computers, which performs the analysis without the pitfalls of graphical manipulation and manual calculation, facilitating quicker, easier, and more accurate strain resolution.

Various methods have been used to determine strain-rates from the movement of markers on a glacier surface (Nye, 1959; Meier, 1960; Hambrey and Müller, 1978). The method outlined by Hambrey and Müller, (1978), and used subsequently by Hambrey and others (1980), determines strain from the deformation of triangular arrays of surface markers and the use of a Mohr circle construction. The procedure has been described more fully by Ramsay (1967), in a geological context, and it is on this description that glaciological work has hitherto drawn. However, this method involves a combination of calculation and geometrical construction which is time consuming, imprecise relative to field measurements, and prone to error.

We have reduced the procedure to a mathematical solution, and, in turn, to a computer program which takes raw field data as input, and presents as output the orientation and magnitude of the principal strain and elongation rates, the shear strain-rate, and the change in surface area. The program is written in BBC BASIC, but is sufficiently simple to be easily adapted to other programming languages.

Strain-rates within a prescribed area are determined from the deformation of a triangular array of stakes on the glacier surface. The data required are the lengths of each side of the triangle before and after deformation and the time interval between measurements. The method of resolving such data which Ramsay (1967) described can be divided into three stages. First, the angular and hence the absolute shear strains can be geometrically determined from the changing shape of the strain triangle during deformation. Secondly, strain and elongation parameters are calculated from the shear strain and from changes in the lengths of the triangle sides during deformation. Thirdly, these parameters are applied in a geometric Mohr circle construction which gives the magnitude and orientation of the principal strains effecting the deformation. The purely numerical solution to the procedure follows the same three steps but avoids the inaccuracy inherent in the graphical method. However, the lengthy set of calculations involved is more conveniently carried out computationally than by hand.

The graphical, numerical, and computer solutions have been described in more detail by Williams and Knight (1987). Copies of this paper, including a full listing of the program, are available from the Editor of the Discussion Paper series, Dr J.H. Farrington, Department of Geography, University of Aberdeen, Aberdeen AB9 2UF, Scotland.

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