# CORRESPONDENCE

The Editor,
*Journal of Glaciology*

SIR,

*Isotopic fractionation at the base of polar and sub-polar glaciers*

In their paper, Boulton and Spring (1986) use the well-known Rayleigh model to interpret the oxygen-isotopic composition of basal ice from Byrd Station and to discuss a possible application for other oxygen-isotopic profiles from polar glaciers. There are some limitations to the use of their approach that I would like to point out.

1. While the fractionation at the water–ice interface is always given by the equilibrium fractionation coefficient (1.003 for $^{18}O$), the amount of observed fractionation is dependent on the freezing rate. This is due to the fact that the water close to the ice interface is more or less depleted in heavy isotopes. The controlling factor is the ratio between the diffusion coefficient of $H_2{}^{18}O$ in water and the freezing rate. As pointed out by Posey and Smith (1957), the consequence is that the ice is more or less enriched in $^{18}O$. The observed separation will be different from the true value. The isotopic range between the value at a certain percentage of freezing – that is for the authors at a certain value of discharge reduction – and the value of the initial water is thus not fixed unless diffusion phenomena and freezing kinetics are considered. It would only be fixed if water is always completely homogenized during freezing. This limiting case would give a Rayleigh distribution for an infinitely low freezing rate. Of course, this is probably never realized in Nature. The Jouzel and Souchez (1982) approach was concerned with a co-isotopic study – both D/H and $^{18}O/^{16}O$ – and put forward the concept of the slope of the freezing process on a $\delta D$–$\delta^{18}O$ diagram. This slope is not dependent on the freezing rate but the relative positions of the points representing a certain percentage of freezing. If we refer to figures 2 and 3 of the paper by Souchez and Jouzel (1984), the apparent fractionation co-efficients can be very different from equilibrium values in freezing experiments but the slope $(\alpha - 1)/(\beta - 1)$ is the same. This phenomenon has to be taken into account for a precise interpretation of the isotopic composition of basal ice.

2. If an open system is considered, then another difficulty arises. Souchez and De Groote (1985) showed that the freezing slope increases if initial water is mixed with iso-topically more negative water in the course of freezing. Thus, the range of values for a single isotopic ratio between the value at a certain percentage of freezing and the value of the initial water will be different if there is some mixing or if there is none. By a study of a single isotopic ratio, it is not possible to tell whether the isotopic profile in basal ice is only due to fractionation by freezing without any mixing. Obviously, a co-isotopic study of basal ice from Byrd Station would be of great value. I am aware that the $\delta D$ values of basal ice from Byrd Station are probably not available.

I am not sure that, at the present day, a theory can predict that the difference between subglacial water and the basal part of normal ice at Byrd Station would be $5.4^0/_{00}$ and that the difference between $\delta^{18}O$ values for subglacial water and the glacier sole with which it is in contact would be $3^0/_{00}$ for the two reasons given above. One cannot exclude the possibility that the slight difference obtained by the authors is purely coincidental, as other combinations of factors would allow one to reach the same result. I do not yet see a means of testing this further with a single iso-topic approach.

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*9 February 1987*

## REFERENCES

Boulton, G.S., *and* Spring, U. 1986. Isotopic fractionation at the base of polar and sub-polar glaciers. *Journal of Glaciology*, Vol. 32, No. 112, p. 475-85.

Jouzel, J., *and* Souchez, R.A. 1982. Melting-refreezing at the glacier sole and the isotopic composition of the ice. *Journal of Glaciology*, Vol. 28, No. 98, p. 35-42.

Posey, J.C., *and* Smith, H.A. 1957. The equilibrium distribution of light and heavy waters in a freezing mixture. *Journal of the American Chemical Association*, Vol. 79, No. 1, p. 555-57.

Souchez, R.A., *and* Groote, J.M. de. 1985. $\delta D$–$\delta^{18}O$ relationships in ice formed by subglacial freezing: paleoclimatic implications. *Journal of Glaciology*, Vol. 31, No. 109, p. 229-32.

Souchez, R.A., *and* Jouzel, J. 1984. On the isotopic composition in $\delta D$ and $\delta^{18}O$ of water and ice during freezing. *Journal of Glaciology*, Vol. 30, No. 106, p. 369-72.

SIR,

*Winter-talus ridges, nivation ridges, and pro-talus ramparts*

In a previous letter to the *Journal of Glaciology*, D.R. Butler (1986) drew attention to the apparent primacy of R.A. Daly (1912) in describing "winter-talus ridges", features that are now usually referred to as pro-talus ramparts. Butler also suggested a return to Daly's original terminology. His letter raises a number of interesting issues.

First, R.A. Daly was apparently *not* the first person to provide a written description of pro-talus ramparts, though he may well have inferred their mode of formation independently. It is often difficult to establish primacy in scientific explanation, but it is clear from a number of accounts that certain geologists and geographers working in the British Isles were aware that ridges could accumulate at the foot of perennial or even possibly late-lying snow beds several years before Daly's description was published. For example, in an account of the various types of moraine found in the English Lake District, Ward (1873, p. 426) described a separate category consisting of

> "mounds of scree material formed at the base of a slope, by the sliding of fragments over an incline of snow lying at the base of crags",

and noted that he was indebted for this suggestion to

> "Mr Drew, late of Cashmere ... he having seen mounds of this kind at the foot of snow slopes among the Himalayas".

A quarter of a century later, Marr and Adie (1898, p. 56) described a possible example of what would now be termed



https://doi.org/10.3189/S0022143000008789 Published online by Cambridge University Press

a pro-talus rampart in Snowdonia, North Wales. On the concentric ridges of the moraine damming Llyn du'r Arddu, a small tarn north-west of the main Snowdon Ridge, they noted that on most of the moraine ridges

> "rest *sub-angular* perched blocks, whilst the innermost crescent of the drift dam consists of *angular* blocks, as though some at least of this material was rather of the nature of snow-slope detritus than true moraine".

Even more explicit is a remarkable account of recent pro-talus rampart development on the north face of Ben Nevis, the highest mountain in Scotland, where Gatty (1906, p. 491) observed in Coire na Ciste

> "a little tarn ... enclosed by a semi-circular embankment rising some 6 or 8 feet above the water level. This dam is built up stones of all sizes, from pebbles to blocks 4 feet across. Some of these had plainly fallen last spring ... . The way in which the dam is forming is this: in the spring a tongue of snow projects over the site of the tarn, and terminates against the dam; blocks wedged off the cliffs by the winter's frost roll or slide down and come to rest at the foot of the snow-shoot, and so build up the dam".

Gatty's account also included two photographs of this feature, and he went on to note that

> "Several instances of old semicircular embankments of identical formation are to be found amongst the hills of the English Lake District; these almost certainly all date back to glacial times".

He also mentioned another recent example in the Alps (p. 492). The above examples reveal that Daly's (1912) account of pro-talus ramparts was by no means the first to appear, though it may well represent the first documentation of North American examples.

Secondly, it seems debatable as to whether Daly's term "winter-talus ridge" is more appropriate than "pro-talus rampart". Not only has the latter term become firmly entrenched in the literature on the topic, but also it seems more accurate, on three counts. First, recent work on actively accumulating ramparts in northern Norway (Ballantyne, in press) has shown that rampart accumulation takes place in summer rather than winter, as these ramparts are entirely covered by snow in winter so that debris from the cliffs up-slope overshoots the rampart crests. In such circumstances, the term "winter-talus ridge" seems inappropriate. Secondly, "rampart" is in some circumstances at least more accurate than "ridge", as some examples do not possess a proximal slope (e.g. Ballantyne and Kirkbride, 1986, p. 662). Finally, all examples known to the author or documented in the literature lie at or near the foot of a talus slope, which suggests that "pro-talus" is an apt descriptor; that illustrated by Daly (1912, pl. 57) is a fine example of this.

Finally, recent studes of actively accumulating pro-talus ramparts suggest that traditional definitions of such features require revision. Butler (1986) adopted the genetic definition:

> "A 'pro-talus rampart' is a ridge or ramp of debris that forms where clasts fall from a cliff face, slide, or roll across the surface of a perennial snow bank of somewhat standard dimensions, and accumulate at its base".

Similar definitions have been proposed by several authors in the past, including the present writer (Ballantyne, 1986; Ballantyne and Kirkbride, 1986). As noted by Johnson (1983), however, the validity of this mode of accumulation tends to have been assumed rather than demonstrated, as most accounts of protalus ramparts concern relict (usually late Pleistocene) examples. Recent work on actively accumulating ramparts in Japan and Norway indicates that other processes such as debris flow (Ono and Watanabe, 1986), reworking of till deposits from up-slope (Harris, 1986), and slush avalanches (Ballantyne, in press) also contribute substantially to the accumulation of at least some ramparts, and account for the presence of abundant fines within these ramparts. A more general definition seems to be required, such as:

> "a ridge or ramp of predominantly coarse detritus, usually located at or near the foot of a talus slope, that formed through the accumulation of debris along the down-slope margins of a snow bed".

Whether *perennial* snow or firn is necessarily involved seems uncertain, though Gatty's (1906) account seems to suggest that some examples may have formed in association with seasonal snow beds. Further research is necessary to clarify this point.

I am grateful to D. Unwin of the University of Leicester for drawing my attention to the early accounts of pro-talus ramparts by Ward (1873) and Marr and Adie (1898).

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*15 February 1987*

REFERENCES

Ballantyne, C.K. 1986. Protalus rampart development and the limits of former glaciers in the vicinity of Baosbheinn, Wester Ross. *Scottish Journal of Geology*, Vol. 22, No. 1, p. 13-25.

Ballantyne, C.K. In press. Some observations on the morphology and sedimentology of two active protalus ramparts, Lyngen, northern Norway. *Arctic and Alpine Research.*

Ballantyne, C.K., *and* Kirkbride, M.P. 1986. The characteristics and significance of some lateglacial protalus ramparts in upland Britain. *Earth Surface Processes and Landforms*, Vol. 11, No. 6, p. 659-71.

Butler, D.R. 1986. Winter-talus ridges, nivation ridges and pro-talus ramparts. *Journal of Glaciology*, Vol. 32, No. 112, p. 543.

Daly, R.A. 1912. Geology of the North American Cordillera at the forty-ninth parallel. *Geological Survey of Canada. Memoir*, No. 38.

Gatty, V.H. 1906. The glacial aspect of Ben Nevis. *Geographical Journal*, Vol. 27, No. 5, p. 487-92.

Harris, C. 1986. Some observations concerning the morphology and sedimentology of a protalus rampart, Okstindan, Norway. *Earth Surface Processes and Landforms*, Vol. 11, No. 6, p. 673-76.

Johnson, P.G. 1983. Rock glaciers. A case for a change in nomenclature. *Geografiska Annaler*, Vol. 65A, Nos. 1–2, p. 27-34.

Marr, J.E., *and* Adie, R.H. 1898. The lakes of Snowdon. *Geological Magazine*, Decade 4, Vol. 5, p. 51-61.

Ono, Y., *and* Watanabe, T. 1986. A protalus rampart related to alpine debris flows in the Kuranosuke cirque, northern Japanese alps. *Geografiska Annaler*, Vol. 68A, No. 3, p. 213-23.

Ward, C. 1873. The glaciation of the northern part of the Lake District. *Quarterly Journal of the Geological Society of London*, Vol. 29, p. 422-41.

SIR,

*Early description of pro-talus ramparts*

Butler (1986) rightly pointed out that Daly (1912), early in the present century, drew attention to the distinctive alpine land form that Bryan (1934) subsequently named "*protalus rampart*". However, Daly was not the first to describe and discuss the origin of these features. Cross and Howe (1905, p. 25) described pro-talus ramparts in the San Juan Mountains of Colorado which were forming at the front of snow banks, mainly at the base of north-facing cliffs, and referred to them as "snowbank accumulations". In