(2) Usually the water from the rock glaciers drains underground due to the presence of boulder material.

(3) The rivers fed from rock glaciers are clearer and have more stable run-off than rivers fed from snow or ice.

In the Alps Schweizer (1968, p. 98–105) indicates a significant amount of water coming out of a rock glacier in Braissekar (Sestrière). I would be very glad to know whether such phenomena have been observed in other places, and would appreciate receiving information regarding the ways in which water, snow, ice, ground ice, segregated ice, or interstitial ice, can become incorporated or eliminated from the body of the two types of rock glaciers.

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REFERENCES

Barsch, D. 1969. Studien und Messungen an Blockgletschern in Macun, Unterengadin. *Zeitschrift für Geomorphologie*, Supplementbd. 8, p. 11–30.

Brown, W. H. 1925. A probable fossil glacier. *Journal of Geology*, Vol. 33, No. 5, p. 464–66.

Di Colbertaldo, D. 1946. I Ghiacciai del Canin a del Montasio nel 1946 ad il loro regreso durante l'ultimo ventennio. *Società Monte Lussari, Pubblicazioni Scientifiche*, No. 1.

Grötzbach, E. 1965. Beobachtungen an Blockströmen im afganischen Hindukusch und in den Ostalpen. *Mitteilungen der Geographischen Gesellschaft in München*, Bd. 50, p. 175–201.

Johnson, P. G. 1974. Mass movement of ablation complexes and their relationship to rock glaciers. *Geografiska Annaler*, Vol. 56A, Nos. 1–2, p. 93–101.

Lliboutry, L. A. 1953. Internal moraines and rock glaciers. *Journal of Glaciology*, Vol. 2, No. 14, p. 296. [Letter.]

Lliboutry, L. A. 1961. Les glaciers enterrés et leur rôle morphologique. *Union Géodésique et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Assemblée générale de Helsinki, 25–7—6–8 1960. Commission des Neiges et Glaces*, p. 272–80.

Outcalt, S. I., *and* Benedict, J. B. 1965. Photo-interpretation of two types of rock glacier in the Colorado Front Range, U.S.A. *Journal of Glaciology*, Vol. 5, No. 42, p. 849–56.

Potter, N. 1972. Ice-cored rock glacier, Galena Creek, northern Absaroka Mountains, Wyoming. *Geological Society of America. Bulletin*, Vol. 83, No. 10, p. 3025–57.

Schweizer, G. 1968. Der Formenschatz der Spät- und Postglazials in der Hohen Seealpen. Aktualgeomorphologische Studien im oberen Tinéetal. *Zeitschrift für Geomorphologie*, Supplementbd. 6, p. 98–105.

Spencer, A. C. 1900. A peculiar form of talus. *Science*, Vol. 11, No. 266, p. 188.

SIR, *Ice-movement direction from drumlin morphology: comments on the paper by C. P. Gravenor*

A recent paper by Gravenor (1974) raises two points concerning drumlins, first by the use of the term "stoss" in this context and secondly the position of the steep end. Over the years stoss has become synonymous with steep—see, for instance, Gravenor (1953), Blake (1956) and Chapman (1970); *the actual meaning of stoss in relation to streamlined forms, however, is proximal—it does not mean or imply steep.* (Consideration of the general usage of "lee" lends etymological support to this.)

It is, as Gravenor states, generally taken for granted that the stoss is the steeper end and generally points towards the up-stream ice-movement direction; he also states (p. 51) "the acceptance of this general observation is critical in deciphering the ice-movement directions in the Yarmouth area". It must be pointed out that this is only a general observation, not an invariable law. Gravenor therefore assumes that, as the steep end of the Yarmouth drumlins in most cases (55%) is to the south, the ice that moulded them was from this direction—a direction opposite to that suggested by the erratics and till-fabric analysis. He therefore has to postulate two separate glacial episodes: one to account for the erratics and fabric, the other to account for the position of the steep end.

In many cases the stoss is the steeper end but this is not invariable. Charlesworth (1924) noted that there was some divergence of opinion on the position of the blunt and higher end of the drumlin and that in general this was towards the stoss end of the mound. Hollingworth (1931) noted that the steeper end was usually the stoss, although in the Carlisle area there was an apparent reversal of "this general

rule". Blake (1956) noted that most of the drumlins of the Lake Melville area of Labrador had their steeper ends to the west so the ice that formed them was from that direction, but that some were steeper to the east; and, on the assumption that the steep end is the stoss, he stated that adjacent drumlins appeared to have been formed from different directions. Trenhaile's (1971) analysis of 6 000–7 000 mapped drumlins in southern Ontario showed that 19% had lee steeper than stoss, and in 2% of these the lee was considerably steeper. Glückert (1973, p. 9) mentioned that it did rarely happen that the highest widest part of the drumlin was at the distal end. Detailed field mapping by Rose in the Glasgow area and Letzer in Westmorland shows that the stoss is, on average, the steeper end in 73% of a sample of drumlins from the Glasgow area and 62% of the sample from Westmorland, leaving a comparatively high proportion of drumlins with either indeterminate steep ends or steeper lee ends. More specifically, in the area around Lenzie, north of Glasgow, 35% of the drumlins have their highest point at the lee end, and figures of 42% and 35% are recorded for North Soulby and Ravenstonedale in Westmorland, respectively (Rose and Letzer, 1975). The Yarmouth field described by Gravenor also has a high combined percentage (45%) of non-"typical" drumlins, as does the Petersborough field he has also investigated in which he recognizes that 69% are not "normal".

It is interesting to note that, when drumlins have been mapped in the field rather than solely from air photographs and/or topographic maps, it becomes obvious that they vary considerably in shape and "perfection"; the reliability of methods of mapping not involving detailed field investigation must therefore be treated with caution. Alden (1905) noted 91 variations in shape; Aronow (1959) found that only 20 out of 160 drumlins mapped are the "perfect" shape—the majority fall into his "rather nondescript" group. Charlesworth's (1927, 1957, vol. 1, p. 395) comments that non-"perfect" drumlins are either not true drumlins, or reflect complexity of ice flow or erroneous flow determination, would seem to be over-generalizations. He drew the analogy, as have many writers, with dunes as examples of adjustment to flow; it should be pointed out that anti-dunes also occur. Since so many drumlins do not have the "perfect" shape, it is perhaps not a safe criterion upon which solely to base provenance of ice; it is necessary to consider other evidence also.

With the knowledge that stoss means ice proximal and should not imply steep, that the lee end is occasionally the steeper, and that drumlins are very variable in shape, it cannot be assumed that where a steeper end is distinguishable it is the stoss end. If it were accepted that Gravenor's Yarmouth drumlins were in the apparently minority class of those having a less steep stoss end it is not then necessary to postulate two glacial events to account for the disparity between the fabric analysis and the position of the blunt end. It could be argued that the Yarmouth field is unusual in having a large percentage of steeper-lee-end drumlins and it is therefore more likely that there were two events; but it could be that the data represent a small sample from a larger field, and therefore has the inherent faults of a small sample, or perhaps detailed field mapping elsewhere will show that such an occurrence is much less rare than hitherto suspected.

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REFERENCES

Alden, W. C. 1905. The drumlins of southeastern Wisconsin. *U.S. Geological Survey. Bulletin* No. 273.
Aronow, S. 1959. Drumlins and related streamline features in the Warwick–Tokio area, North Dakota. *American Journal of Science*, Vol. 257, No. 3, p. 191–203.
Blake, W., *jr.* 1956. Landforms and topography of the Lake Melville area, Labrador, Newfoundland. *Geographical Bulletin* (Ottawa), No. 9, p. 75–100.
Chapman, R. J. 1970. The Late-Weichselian glaciations of the Erne Basin. *Irish Geography*, Vol. 6, No. 2, p. 153–61.
Charlesworth, J. K. 1924. The glacial geology of the north-west of Ireland. *Proceedings of the Royal Irish Academy*, Ser. B, Vol. 36, No. 12, p. 174–314.
Charlesworth, J. K. 1927. The post-glacial erosion theory of drumlins. *Geological Magazine*, Vol. 64, No. 4, p. 157–61.
Charlesworth, J. K. 1957. *The Quaternary era, with special reference to its glaciation.* London, Edward Arnold (Publishers) Ltd.
Glückert, G. 1973. Two large drumlin fields in central Finland. *Fennia*, 120.
Gravenor, C. P. 1953. The origin of drumlins. *American Journal of Science*, Vol. 251, No. 9, p. 674–81.

Gravenor, C. P. 1974. The Yarmouth drumlin field, Nova Scotia, Canada. *Journal of Glaciology*, Vol. 13, No. 67, p. 45–54.
Hollingworth, S. E. 1931. The glaciation of western Edenside and adjoining areas and the drumlins of Edenside and the Solway Basin. *Quarterly Journal of the Geological Society of London*, Vol. 87, Pt. 2, p. 281–359.
Rose, J., *and* Letzer, J. M. 1975. Drumlin measurements: a note on the reliability of data derived from topographic maps. *Geological Magazine*, Vol. 112, No. 4, p. 361–71.
Trenhaile, A. S. 1971. Drumlins: their distribution, orientation and morphology. *Canadian Geographer*, Vol. 15, No. 2, p. 113–26.

SIR, *Ice-movement direction from drumlin morphology: reply to comments by W. Everett*

In Everett's letter she has correctly pointed out that the term "stoss" as it applies to the up-stream end of a drumlin is not synonymous with "steep". In describing the shape of a drumlin, however, it is important not only to determine the position of the steep end but also to consider the shape of the drumlin. For this reason, in my paper on the Yarmouth drumlin field (Gravenor, 1974, p. 51) the word stoss is defined as follows: "unless otherwise specified, the word 'stoss' is used to mean the more steeply inclined wider end of the drumlin and the high point on the drumlin is closer to the steep end than the more shallowly inclined tapered 'tail' of the drumlin". In accordance with this definition, 55% of the drumlins in the Yarmouth field have stoss ends which are steeper and wider than the lee ends.

If drumlins are to be used to determine the direction of ice movement, it is important to define both the shape of the drumlins as well as the slope of the ends. This fact has been recognized by many researchers and excellent summaries on the importance of shape can be found in Embleton and King (1968, p. 322–27), Chorley (1959) and Doornkamp and King (1971, p. 298–304). In this regard, Doornkamp and King (1971, p. 302) have analysed the significance of the Chorley K-value and concluded "The variation of the K-values is a measure of the stress of the ice on the drumlin. The rounded end of the drumlin faces the direction from which the greatest pressure came".

It is unfortunate that Everett has stated "It is, as Gravenor states, generally taken for granted that the stoss is the steeper end and generally points towards the up-stream ice-movement direction". In fact, I said (Gravenor, 1974, p. 51) "It is generally taken for granted that the stoss end of drumlins points towards the up-stream ice-movement direction". To the casual reader, these two statements may appear synonymous. It must be kept in mind, however, that my use of the word stoss in the paper on the Yarmouth drumlin field implies both shape and slope.

Nevertheless, it is worthwhile to examine the evidence that Everett has presented in an attempt to demonstrate that the steep end of drumlins is an unreliable indicator of ice-movement direction. From the published data referred to by Everett, it would appear that there is little evidence to suggest that a drumlin field exists where the bulk of the drumlins have a steeper lee end. For example, Everett has referred to Trenhaile's analysis of about 6 000–7 000 drumlins in Ontario and states "Trenhaile's (1971) analysis of 6 000–7 000 mapped drumlins in southern Ontario showed that 19% had lee steeper than stoss, and in 2% of these the lee was considerably steeper". This is a distortion of Trenhaile's findings as illustrated by the following quote from Trenhaile's paper: "One of the fundamental characteristics of the drumlin form is a stoss slope considerably steeper than the lee slope. An analysis was made to investigate both the order of these slopes and also any possible tendency towards the maintenance of a constant ratio between them. Data were obtained by field mapping using an Abney level for the localities on the six drumlin fields mentioned previously.

"The mean ratio for stoss–lee slopes was 1 : 28/1 : 38, although 19% of the sampled drumlins exhibited lee slopes steeper than the stoss slopes. There did not appear to be any evident pattern or spatial concentration of these atypical drumlins."

In summary, if drumlins are to be used for the determination of ice-movement direction, it is important to define not only the slope of the ends but also the shape. With regard to one of these parameters—slope—it has yet to be demonstrated conclusively that a drumlin field exists in which the bulk of the drumlins have steeper lee than stoss ends.

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