Journal of Glaciology, Vol. 23, No. 89, 1979

ABSTRACTS OF PAPERS ACCEPTED FOR THE SYMPOSIUM BUT NOT PRESENTED

THE ORIGIN OF DRUMLINS AS AN ICE–ROCK INTERFACE PROBLEM

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ABSTRACT. The origin of drumlins has long been one of the most intriguing, yet unsolved problems in glacial geology. It seems that until the mechanism responsible for drumlin formation is fully understood some of the key glaciological problems related to the glacier bed will remain obscure.

Drumlins are clearly formed at the ice–rock interface. The following are the most characteristic features which must be taken into account when explaining their origin.

1. They are, at least partly, built of depositional material (till) but they show distinct traces of powerful erosional and shaping action of moving ice.
2. They usually appear in swarms but their position in relation to each neighbouring form is not incidental; a certain, more-or-less constant distance between the longer axes of forms, typical to every field or its major part, is the rule.
3. They were formed during the last stage of glaciation, shortly before the glacier's complete decay, therefore during the time when most glacial processes seem to slow down.

In spite of the great number of theories for drumlin formation, none is able to explain the above-mentioned characteristic features.

Among the more widely accepted theories of drumlin formation is one put forward by Smalley and Unwin (1968), who suggested that till in the glacier floor, after the pressure there reaches a certain (not closely defined) level, undergoes so-called "dilatation", and that this is an essential factor for the formation of drumlins. If the pressure is higher than the suggested range, the glacier would sweep everything in front of it, but, with a lower pressure applied a continuous deformation of till is impossible (Smalley and Unwin, 1968, p. 379). However, it is not clear if "dilatation" always takes place in the glacier substratum when the suggested pressure range is reached. The experiments described by Smalley and Unwin seem to suggest that "dilatation" ought to be expected in material like till when pressure and also deformation rises from lower to higher values. It is by no means quite certain whether "dilatation" takes place with the same intensity when pressure in the glacier floor reaches the critical value and remains at it for a longer period of time, or when the pressure has changed from a higher to a lower value.

It is likely that "dilatation", even if it does exist at the glacier bottom may change the mechanical properties of the deformed till in the glacier bed only slightly, and probably it is far too weak a process to create drumlins.

* This paper was not presented because of the accident which occurred to its author in the Antarctic. At the time of the Symposium he was seriously ill in hospital, and he died shortly afterwards. An obituary has been printed in *Journal of Glaciology*, Vol. 22, No. 87, 1979, p. 408–09.

It is postulated that it is possible to explain the origin of drumlins if we assume that it is the temperature and not the pressure changes which are the cause of the differences in till properties at the glacier substratum (Baranowski, 1977).

It has been found, both in laboratory experiments and in natural conditions at the bottom of some sub-polar glaciers, that changes of the thermal regime of water-saturated till from warm to cold produce a sudden and drastic transformation of the mechanical properties of till. It seems that in the flow law: $\dot{\epsilon} = A\sigma^n$, the value of A for an ice–till mixture is even more temperature-dependent than for pure ice. Also the value of the power index n, which for pure glacier ice is about 3, although basically temperature independent, will be much lower than that for till–water mixtures and probably higher than that for frozen till.

Thus, in the warm thermal regime, a layer of till at the glacier bottom was being continuously deformed along the whole substratum in a uniform way proportional to the rate of motion of the overlying glacier. At that time the glacier did not show any particularly strong erosive activity, and there conditions did not favour the development of drumlins. However, with the appearance of the cold thermal stage, due either to climatic changes or changes in the glacier thickness, the hitherto relatively plastic till-rich floor layer became several times more resistant to deformations brought about by the movement of the glacier, although it is probable that in the initial phase of thermal changes in the substratum only certain portions of the floor ice and till have been retained. If, however, a portion of till stopped suddenly in the glacier sole, the glacier, with a diminished cross-sectional area, must have flowed more intensively in other parts along that cross-section, by-passing the obstacle and modelling it strongly. Even if the proximal part of the obstacle were destroyed, the remaining part could last until the end of the glaciation ready in the form of a drumlin.

The formation of a drumlin must have resulted in an increase of the ice flow on both sides of the form so that the next part of material was arrested at the glacier–rock interface with more difficulty there than a little further off on both sides of the drumlin, beyond the zone of intense deformation. Thus, it can be assumed, that the distances between the neighbouring forms measured in a direction perpendicular to the ice flow were proportional to the heights of the drumlins and so to the thickness of the till layer in the glacier floor. This mechanism could not result in an entirely random distribution of drumlin forms within a field, although their distribution could not have been mathematically regular either.

It is suggested that at least three simultaneously existing conditions are necessary to cause the formation of drumlins:

(a) the presence of till at the sole or at the floor of the glacier,
(b) a change of the thermal regime from warm to cold,
(c) ice flow in the bottom layer of the glacier.

The relative rareness of drumlins compared with other ground-moraine forms of the Pleistocene ice sheets most probably indicates, that a simultaneous occurrence of these conditions in the marginal zone of ice sheets must have been also quite rare.

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