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SIR,

Morphology and development of medial moraines: comments on the paper by R. J. Small and M. J. Clark

Whilst concurring with R. J. Small and M. J. Clark's (1974) analysis of the development of the medial moraines of the lower Glacier de Tsidjiore Nouve, I am a little disturbed that they should attribute a particular model of medial moraine development to Loomis's (1970) proposal for the form of that developed on Kaskawulsh Glacier, Yukon. Small and Clark write that "Loomis's explanation cannot be applied to the moraines of the Glacier de Tsidjiore Nouve without some modification". I suggest that Loomis's "model" be regarded with considerable trepidation—if, as Loomis (1970, p. 15) suggests, ablation and the development of an ice core constitute the major factors determining moraine morphology, the observation that the width of the medial moraine "remains relatively constant down-valley for many kilometers" seems a trifle odd. Certainly, beyond 1 500 m down-glacier the seven distinct debris bands, of which the medial moraine is composed, lose their coherency—this is to be expected. However, the maintenance of a distinct debris–ice boundary, defining the lateral limits of the medial moraine, is difficult to equate with the supposed dominance of ablation. Moreover, coincidence of maximum elevation with minimum width (approximately 1.4 km down-glacier from the confluence of the two ice streams) would seem to suggest some other factor at work; one cannot avoid concluding that lateral compression between the two ice streams, not ablation, is the prime factor in the determination of moraine morphology. It is significant that the features described as being representative of the efficacy of ablation ("meltwater-associated features" (Loomis, 1970, p. 23)) and the 31 ablation-stake sites, from which correlation between till thickness and mean daily ablation rates were derived, are all located at the confluence of the two ice streams where under no circumstances can the morphology be said to be representative of that developed on the median line down-glacier; here "the dominant topographic form is not a ridge but rather a large elliptical depression measuring 180×130 m^2 across the top and dropping 33 m to a conical bottom" (Loomis, 1970, p. 16).

Despite the existence of prominent topographic troughs on the two sides of the moraine band, control of the morphology of the moraine by lateral longitudinal melt-water streams is unlikely. Troughs need not necessarily be associated with such stream activity (though occupied for the greater part of their length by melt water); the quantity of debris moved by streams in the case of such a mechanism operating would, in the case of Kaskawulsh Glacier, where considerable quantities of debris could be expected to be removed by the thermal erosion activity of such water, undoubtedly lead to the initiation of differential ablation processes; marked topographical features in contrast to the present troughs could be expected to develop—for which, at present, no evidence is forthcoming. One cannot accept Loomis's (1970, p. 36) conclusion that "moraine relief is due entirely to differential ablation processes". This seems to be at odds with his later statement (p. 38) that "relief on the moraine increases down-glacier as the moraine band narrows, the debris bands thicken and ablation rates decrease". Instead, it would appear that differential ablation is subsidiary to lateral compression between the two ice streams in the control of medial moraine morphology; pronounced longitudinally trending furrows in the thick basalt and shale bands near the centre of the medial moraine seem at odds with Loomis's later refutation of the efficacy of lateral compression in determining the primary dominant characteristics of medial moraine morphology, ablation only attaining this role in the immediate confluence zone; elsewhere its

effects are superimposed on the forms created by lateral compression between the north and central ice arms.

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SIR,

Morphology and development of medial moraines: reply to comments by N. Eyles

We have read with interest N. Eyles's (1976) comments on our analysis of the moraines of the Glacier de Tsidjiore Nouve, and also his criticisms of Loomis's (1970) interpretation of Kaskawulsh Glacier. We do not share his detailed field knowledge of the latter and are unable to judge the validity of his observations. We chose Loomis's account of the Kaskawulsh Glacier moraine as an appropriate basic "model" simply because there is little else in the literature. Certainly, we would not regard it, or our own modified version, as in any way definitive. There is much field observation yet to be carried out; we think we are aware of most factors involved, but are far from assigning to these factors quantitative values, even in individual cases such as that of the Glacier de Tsidjiore Nouve.

To begin with a specific comment, we would certainly accept Mr Eyles's point that lateral compression *can* play some role in determining moraine morphology—though we very much doubt, on many grounds, whether it can be of greater importance than differential ablation. Certainly, an hypothesis of lateral compression does not seem applicable to the Glacier de Tsidjiore Nouve, the moraines of which cannot be related to merging ice streams; rather the glacier undergoes slight *broadening* in the zone at the foot of the Pigne d'Arolla ice fall where the moraines begin to emerge. On a nearby glacier (Glacier de Haut Arolla) there are two medial moraines, which differ not only in form, scale and mode of origin from those of the Glacier de Tsidjiore Nouve but also from each other. The larger, more westerly of the two moraines begins below the peak of La Vierge, on either side of which are ice streams; these merge, to form the Glacier de Haut Arolla, at the head of a deep and well-defined glacial trough. In such a situation lateral compression seems possible but the evidence is somewhat equivocal. Down-glacier from La Vierge the medial moraine grows steadily and continuously in height over a distance of about 3 km; towards the snout it becomes very pronounced, partly as a result of thermal erosion of adjacent bare ice by concentrated melt-water streams. Thus there are significant differences from the Loomis "model" and that proposed by us for the Glacier de Tsidjiore Nouve. A very important point is that, on the Glacier de Haut Arolla, the till cover of the moraine becomes progressively thicker down-glacier; although the moraine widens somewhat, owing to lateral sliding of till down marginal slopes, effective till dispersal is counteracted by some opposing tendency. Whilst lateral compression may play some part, this can only prevent a greater lateral dispersion than in fact occurs. To account for a moraine that is actually widening, however slowly, and at the same time experiencing a greater concentration of till cover, three obvious explanations exist. First, there has been a systematic decline in the supply of rock debris to the head of the moraine, lasting several decades; secondly, *longitudinal* concentration has resulted from compressional flow towards the glacier snout; and thirdly, the amount of englacial debris exposed at the ice surface by ablation, or raised along shear planes, increases notably on the lower part of the glacier. The last two explanations seem the more likely in this and other similar instances.