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.

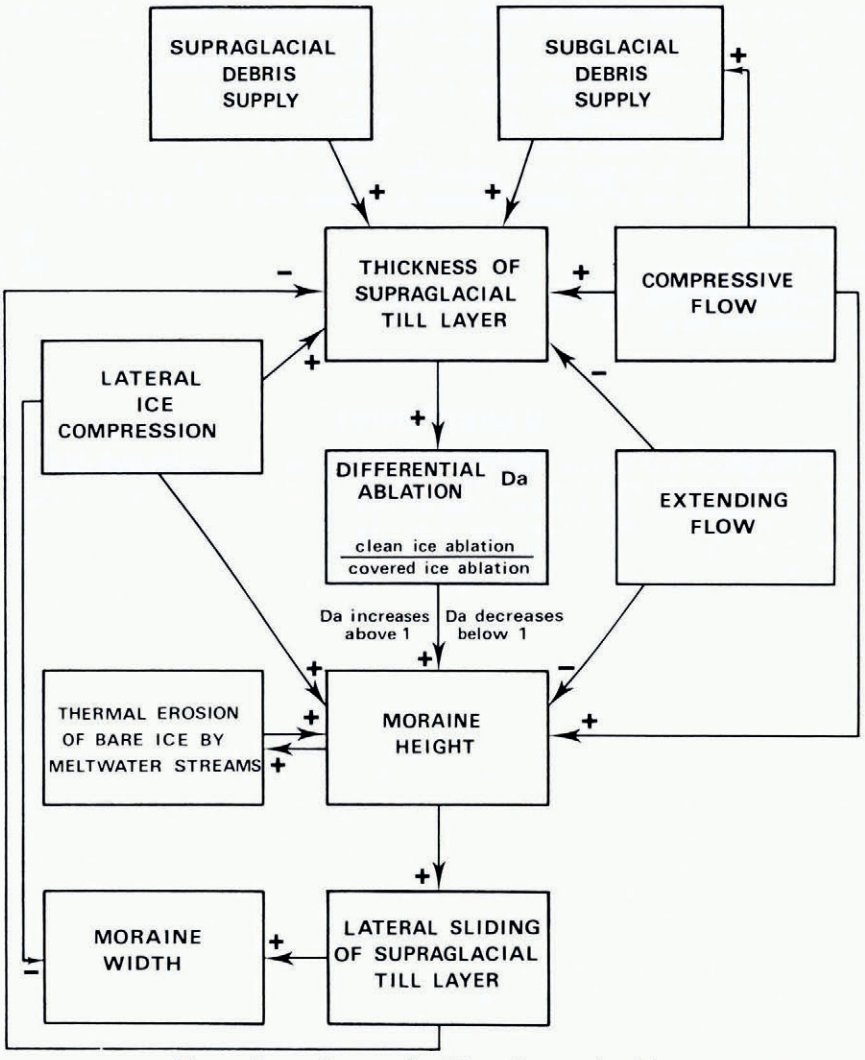

Fig. 1. Systems diagram of medial moraine growth and decay.

The occurrence of compressional (and extending) flow is a factor that must be included in any definitive model of moraine development. Although not referred to in our paper, extending flow probably aids the decline of the Glacier de Tsidjiore Nouve medial moraines, particularly the subsidiary moraine which is influenced by the pronounced curvature of the glacier tongue to the right. On both the main and subsidiary moraines, numerous transverse crevasses occur below the points of maximum relief; over the past 3 years, since our field survey of 1971, these have shown signs of progressive widening. Such crevasses are direct evidence of tension, induced by extending flow; furthermore, they lead to ingestion of surface till, which will subsequently be exposed again by surface ablation farther down-glacier. Refinement of our model for these moraines is therefore evidently needed. It is not merely a question, as figures 4 and 5 (Small and Clark, 1974) imply of a "fixed" quantity of englacial detritus being exposed by ablation and then being spread by lateral sliding in the waning section, but of debris being re-cycled, perhaps several times, in such a way that the expectable rate of decline of moraine height is not attained.

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It is clear that a definitive model of medial moraine development should take account of many influences; in particular instances some of these may be present (e.g. lateral compression, extending flow), in others not. A systems diagram showing the operation of these influences is given in Figure 1. On this it is emphasized that as the differential ablation ratio exceeds 1 (i.e. ablation over clean ice is greater than that over moraine-covered ice) moraine height will be increased. However, where the differential ablation ratio decreases below 1 moraine decline sets in; the only other factor seemingly capable of decreasing moraine height is extending flow—and it is difficult to see this is more than a relatively minor factor in terms of its *direct* reduction of moraine height by ice attenuation.

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SIR,

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

I have been working on medial moraines with particular reference to their sedimentology for the past two field seasons. Last year's operations were based on Austerdalsbreen, Jostedal, Norway: a similar glacial environment to that described by Drs Small and Clark in their paper. Their basic model of medial moraine formation, with its reliance on a lower limit of englacial debris controlling moraine morphology, can be corroborated by the Norwegian example. This is what I have called elsewhere (Eyles, in press) an "ablation-dominant" model of moraine formation.

To invoke lateral compression between merging ice streams of large valley glaciers as contributing to resultant medial moraine morphology is appealing. Ice structures found in this area are, superficially, akin to boudinage in rock (see Anderton, 1970). Certainly, a similar mechanism may explain peculiarities of moraine from down-glacier; increasing height occurring concomitant with decreasing width, for instance. The latter, as Drs Small and Clark will confirm, is opposite to that developed on the lower Glacier de Tsidjiore Nouve, Valais, and from that described from Austerdalsbre, Norway, where medial moraine form is typical of an "ablation-dominant" model of moraine formation (Eyles, in press). Such a model is certainly dependent upon a lower limit of englacial debris controlling moraine morphology (Small and Clark, 1974).

However, as Drs Small and Clark suggest, the effect of lateral compression is in all probability indirect. Longitudinal attenuation of debris quantity down-glacier from confluence areas *may* contribute to the narrowing of moraines commonly observed in such areas. This factor is currently under investigation on Berendon Glacier, British Columbia. Any substantive statement must of course await field results. By virtue of the absence of any well-developed lower limits of englacial debris, important subglacial debris components may be added to the moraine, in the terminal area. Exciting techniques for discriminating sub-components of glacial debris systems (englacial, subglacial and supraglacial sediments) are currently being scrutinized within the framework of medial-moraine sedimentology.

One other point of concern is that of the significance of debris added to medial moraines by ogive bands. On Austerdalsbreen, substantial contribution to moraine debris made by a well-developed ogive suite is lacking; debris of the dirty summer ogive bands is diffuse only. An immature beading of the