hazard. The flash point of aqueous ethanol is lower than that of butyl acetate, which is considered safe only in view of the low temperatures at which it will be used. Table 1 shows the flash point of ethanol and aqueous ethanol. The data were determined in a commercial testing laboratory or taken from the literature. Butyl-acetate and fuel-oil data are added for comparison. One mitigating factor is that only 20–70% solutions of ethanol will be employed, but the flame point for 50% or greater concentrations is below the temperature of the heater element in the warm-up hut.

Table 1. Flash point of ethyl alcohol and aqueous solutions (in comparison with other fluids)

Per cent alcohol	*Flash point* °C
100	10
50	22
30	28
(Butyl acetate)	29
(Fuel oil)	~66

The manufacture cost of ethanol is about half that of butyl acetate but the major advantage comes in the transportation cost to the remote drill sites (about \$3–4 kg^{-1}), amounting to tens of thousands of dollars per borehole. Nominally, 50% solutions would be required and the snow will not require any (or very little) added heat because of the corrosive nature of ethanol towards snow to be used to dilute the alcohol.

In summary, aqueous ethanol is decidedly cheaper and easier to employ than either butyl acetate or fuel oil, and may be a useful ice-core drilling fluid in warm (≥ −25°C boreholes and where density overturn is not a problem, i.e. in holes of moderate depth with temperature gradients of ≤2°C per 100 m. The viscosity properties of aqueous ethanol are vastly superior to those of ethylene-glycol solutions, even at −55°C, and workable for shallow- to moderate-depth (<1000 m) boreholes. It is, unquestionably, an environmentally sound choice. The drawback is its flammability when enriched above 30% but its paramount weakness is the potential for contamination in parts per trillion analyses.

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SIR,

Ablation thresholds and ash thickness

In their paper on the mode of formation of ablation hollows, Rhodes and others (1987) presented some useful ideas on a small scale, but nevertheless an interesting problem. Ablation hollows, often called ablation polygons or sun cups (Matthes, 1934; Jahn and Klapa, 1968) are common features which form more or less regular networks of hollows and interconnecting ridges, on the surface of compacted "spring" snow. In resolving some of the conflicting observations in the literature, Rhodes and others explained how these hollows can form under conditions in which ablation is forced either by direct solar radiation or by turbulent heat transfer. To achieve this, the role of dirt is considered, in terms of the opposing

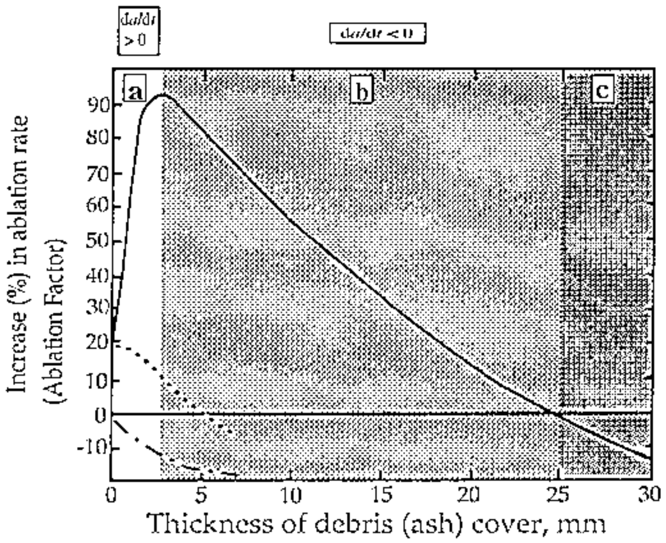

Fig. 1. The change in ablation rate of different (Mount St. Helens) ash thicknesses at experimental plots on South Cascade Glacier, Washington, August 1980. Dotted lines are theoretical representations of conditions of reduced solar radiation. (Adapted from Driedger (1981) and Rhodes and others (1987).) ($\mathrm{d}a/\mathrm{d}t$ = increase in ablation.)

effects arising from its properties of thermal insulation and low albedo.

Whilst their major conclusions are valid, they seem to have partially misinterpreted the message of Driedger's (1981) "enhancement of ablation" maximum (Fig. 1). Rhodes and others (1987) divided the empirical Driedger curve into two regimes: the rising limb, $t < 3$ mm, where $\mathrm{d}a/\mathrm{d}t > 0$, and the falling limb, $t > 3$ mm, where $\mathrm{d}a/\mathrm{d}t < 0$ (a = ablation factor, t = ash thickness). They went on to consider the maximum point of ablation as a "threshold thickness". This concept is particularly important, as we shall see, because of the frequently verified mechanism (Ball's (1954) normal trajectory theory (Fig. 2)), which demonstrates that dirt migrates to the summits of ridges as the ablation topography develops and the snow surface is lowered. If the hollows and ridges are to be sustained, the ablation rate at the ridge must clearly be less than that at the hollow. Under conditions dominated by solar radiation, the low-albedo dirt/ash on the ridge will be a strong influence; dirt concentration leads to increased ablation at the ridges, relative to the hollows, setting up a negative feed-back mechanism, thereby preventing their formation. In their interpretation, Rhodes and others (1987) suggested that no negative feed-back would occur under direct sunlight "if the snow is covered with a layer of dirt thicker than the threshold value (c. 3 mm) ... and the irregularity (ridge) can continue to grow". Here, the use of the term "covered" is significant; their interpretation is correct under conditions of total dirt cover but only where thickness on the ridge exceeds thickness on the hollow *and* both thicknesses exceed the 3 mm maximum. Conditions of total dirt cover are not common, arising only from volcanic-ash or dust-storm events. Examination of ablation hollows and of published photographs and diagrams (e.g. Jahn and Klapa, 1968) reveals that debris cover in the hollow areas is minimal. As dirt normally arises at the snow surface by exhumation of irregularly buried mineral and organic material, this is not surprising. The development of an ablation topography becomes more complex, however, when the dirt cover is continuous, but its thickness on the ridge corresponds to the falling (R.H.) limb and the hollow thickness (thinned by normal trajectory theory) lies on the rising (L.H.) limb. This scenario was not discussed by Rhodes and others (1987), but it is possible that conditions favouring topographic development can be transferred into conditions favouring topographic decay simply by the thinning of the hollows' dirt from the falling to the rising limb.

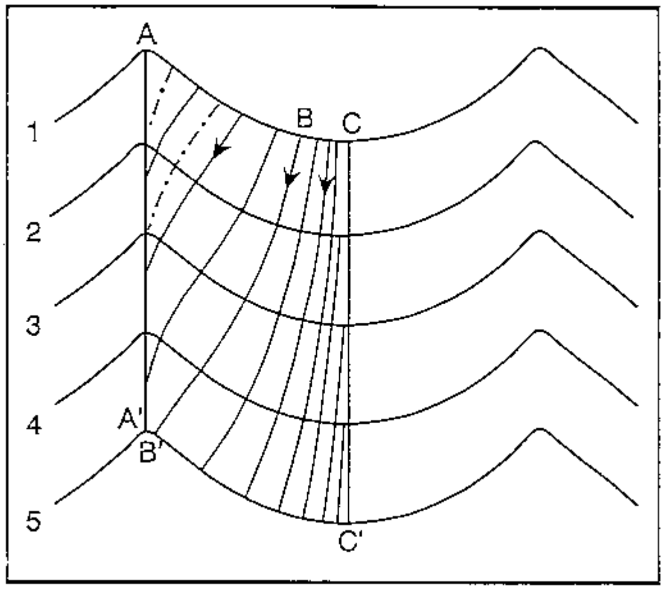

Fig. 2. Diagram illustrating how dirt initially uniformly distributed through snow is concentrated at the ridges of polygons as ablation proceeds. Curves 1–5 represent the successive positions of the lowered snow surface. Dirt initially at B is later located at B′; similarly for A and C. (Both the figure and the caption from Ball (1954, fig. 1).)

Under the relatively common conditions of dirt-free hollows, Driedger's (1981) curve can be differently divided into two regimes relating to hollow–ridge enhancement and decay. This dividing-thickness threshold does not correspond to the ablation-rate maximum but is at the point where the increase in ablation rate, relative to no dirt cover, is zero (t = 25 mm). Ridge ablation will exceed hollow ablation, beyond the maximum, although beyond this point the relative ridge ablation will decline with increasing thickness.

The empirical curve represents the maximum possible increase of ablation rate under the weather conditions considered. The additional theoretical curves (Rhodes and others, 1987, fig. 1), in which solar radiation is of reduced significance, indicate either little or no enhancement of dirt-covered or clean-snow ablation rates. From these curves and from the theoretical assumptions of Rhodes and others (1987), the growth of clean-hollow ablation topography under a (ridge) debris cover of <25 mm thickness, in a regime dominated by solar radiation, is problematic. That these features do grow in this regime is evident. It would appear that some other, as yet undetermined, factor must be involved in both the inception and development of these features. This conclusion seems to suggest that the growth of ablation topography is favoured by systems dominated by turbulent heat transfer. Until all factors influencing their development are understood, this conclusion should be treated with caution. Furthermore, disregarding the assumption of constant debris cover in relation to the Driedger curve (an assumption implicit, although unstated by Rhodes and others) allows the dynamical development of the ablation topography. Consideration of this possibility suggests that future work should be directed towards detailed and regularly repeated surface mapping of the topography, a strategy that has not been employed in published field studies.

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SIR,

Thrust of Glaciar Torre over itself

I recently had the opportunity of examining two aerial coverages of the FitzRoy area (southern Patagonia) made in 1966 and 1981, respectively, and an accurate topographic map at a scale of 1 : 50 000. This work was done for the Argentine and Chilean commission in charge of fixing the frontier between both countries and is still classified. The most interesting point is that Glaciar Torre, which I observed and named at the very beginning of my glaciological observations (Lliboutry, 1953), has suffered dramatic and unusual changes. I am kindly authorized by the Argentine authorities to report on them to the glaciological community.

This glacier forms on the eastern side of the small granodioritic range that runs north–south from Cerro Pollone (2570 m) to Cerro Torre (3102 m) (see Fig. 1). The snow limit when the aerial surveys were made, at the end of the summer, was at about 1400 m. The ablation zone flows over 6 km, with a small surface slope (7%), in a deep valley between the range above and a parallel one, which starts from Monte FitzRoy (3405.5 m) southward. Glaciar Torre is squeezed by Glaciar Adela on its right (west) side, and, when the valley turns eastward, also by Glaciar Grande. Therefore, only a very narrow ice stream coming from Glaciar Torre reaches Laguna Torre (665.8 m). The corresponding calving front, on the north side of Laguna Torre, had receded by 700 ± 50 m between 1952 and 1981.

In 1952, the surface of Glaciar Torre was clean, except for an area covered by debris from a rockfall. Since the tongue of debris was already visible on a Trimetrogon photograph from 1945, the surface velocity of the glacier could be determined. In the middle of the glacier, the surface velocity was 86–100 m a^{-1}.

In 1966, Glacier Torre was covered with debris over a distance of 6.15 km, up to an altitude of 1170 m. Whether this debris from rockfalls had been embedded in the glacier some time or not is a matter of conjecture, and therefore I do not call it "ablation moraine". Upstream, Glaciar Torre formed a clean tongue, which had pushed the debris, setting up a perfect overglacial push moraine. An overthrust is unquestionable. There was a gap of about 30 m between the terminus of the superimposed upper glacier and in its middle the push moraine. It proved that overthrusting had ended and it also allowed me to observe the existence of some debris-laden ice at the sole of the superimposed glacier.

From 1966 to 1981, the push moraine had moved about 700 m, between the same points as the 1945–52 rockfall. It had not changed in form and had apparently not increased in size. Thus, this motion is due only to the motion of the glacier below. It follows that the surface velocity of Glaciar Torre has halved between both periods, 1945–52 and 1966–81.

In 1966, 900 m downstream from the overglacial push moraine, there was a hollow, about 500 m long and 200 m wide, whose bottom was flat and clear of debris. It might have been the remnant of an older overthrust but, more probably, it was formed by differential ablation. In 1981, this hollow had become much smaller and had moved about 450 m downstream. Thus, the surface velocity there was 30 m a^{-1}. This value corresponds more or less to the velocity along the axis of a half-cylindrical temperate valley glacier with a radius of 300 m, a uniform bottom shear stress of 1 bar and no sliding on the bed. (These assumptions are consistent with a slope of about 7%.)

The provisional conclusion is that, in 1945–52, sliding accounted for about one-half of the surface velocity. Some year between 1952 and 1966, sliding ceased in the lower part, causing an overthrust of the still-sliding upper part. Next, sliding ceased everywhere.

The overthrust of a fast-sliding glacier over its lower "dead" tip has already been observed at least in one case (Lliboutry and others, 1977). It would be the extreme

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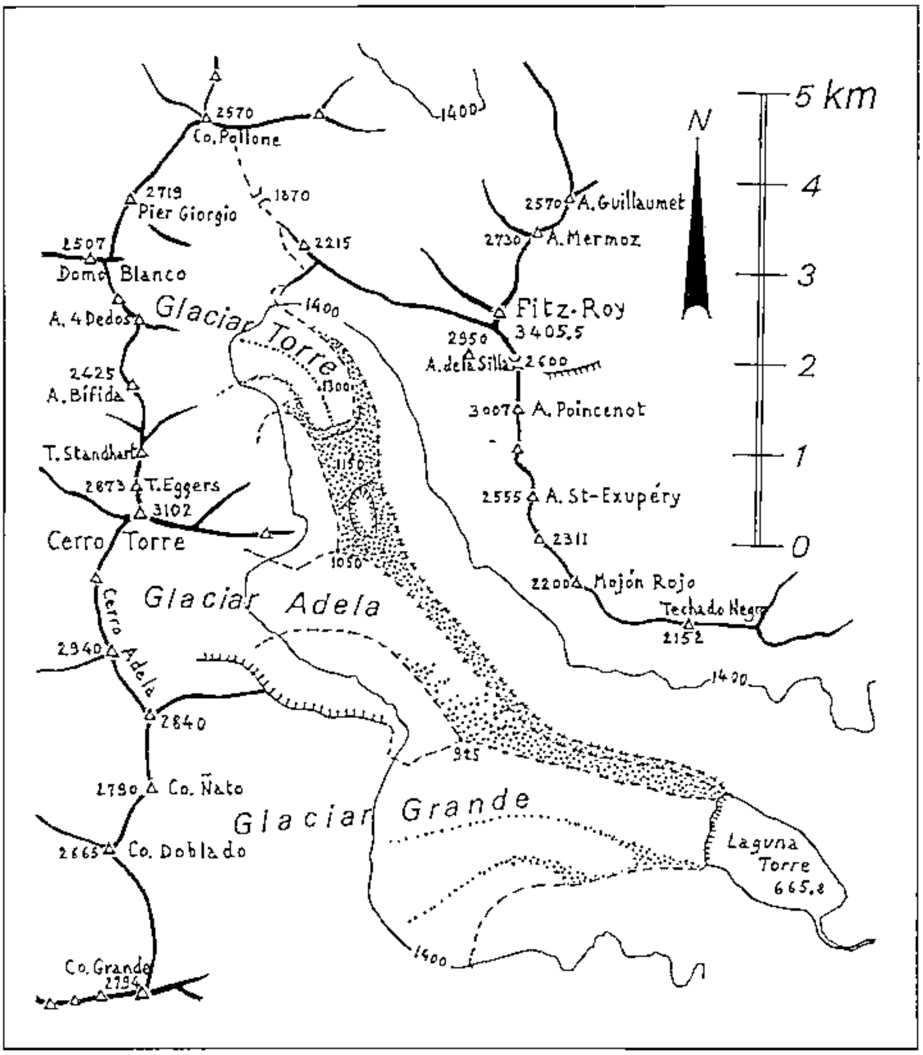

Fig. 1. Glaciar Torre as in 1961. Altitudes of surrounding peaks are more accurate than in Lliboutry (1953) and 20–35 m lower. (The length of my base line was overestimated.)

case of a more frequent phenomenon: the existence of an internal fault (or very thin shear layer) within a glacier subject to a large longitudinal compression. In 1969, at glacier de Saint-Sorlin (French Alps), near Col des Quirlies (2998 m), at a site where the firn line stood many years with lowest balances, a corer became inexplicably jammed at 15 m depth (Gillet, unpublished). In 1973, vertical wires were inserted down to 120 m in glacier du Tacul (middle part of Mer de Glace, also an area without crevasses, and where the large longitudinal compression is documented.) Two years later, when boring began again along these "Ariadne clues" for an inclinometric survey, the wires were cut at 65, 75 and 85 m depth, respectively, showing the presence of an almost horizontal fault or thin shear layer (Reynaud, unpublished).

I shall be happy to know whether similar facts have been observed elsewhere, on entirely temperate glaciers. I do not refer to dipping superficial small faults (Lliboutry, 1958a), to overthrusts at a frontal cliff (Lliboutry, 1958b) or to the well-known overthrusts at the bottoms or edges of cold ice sheets. Overthrusts contradict the crucial assumption made in modeling that the mass of a temperate glacier is everywhere a continuous medium, hence that the ice discharge through a cross-section is a continuous function of the abscissa.

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