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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The accuracy of references in the text and in this list is the responsibility of the author, to whom queries should be addressed.

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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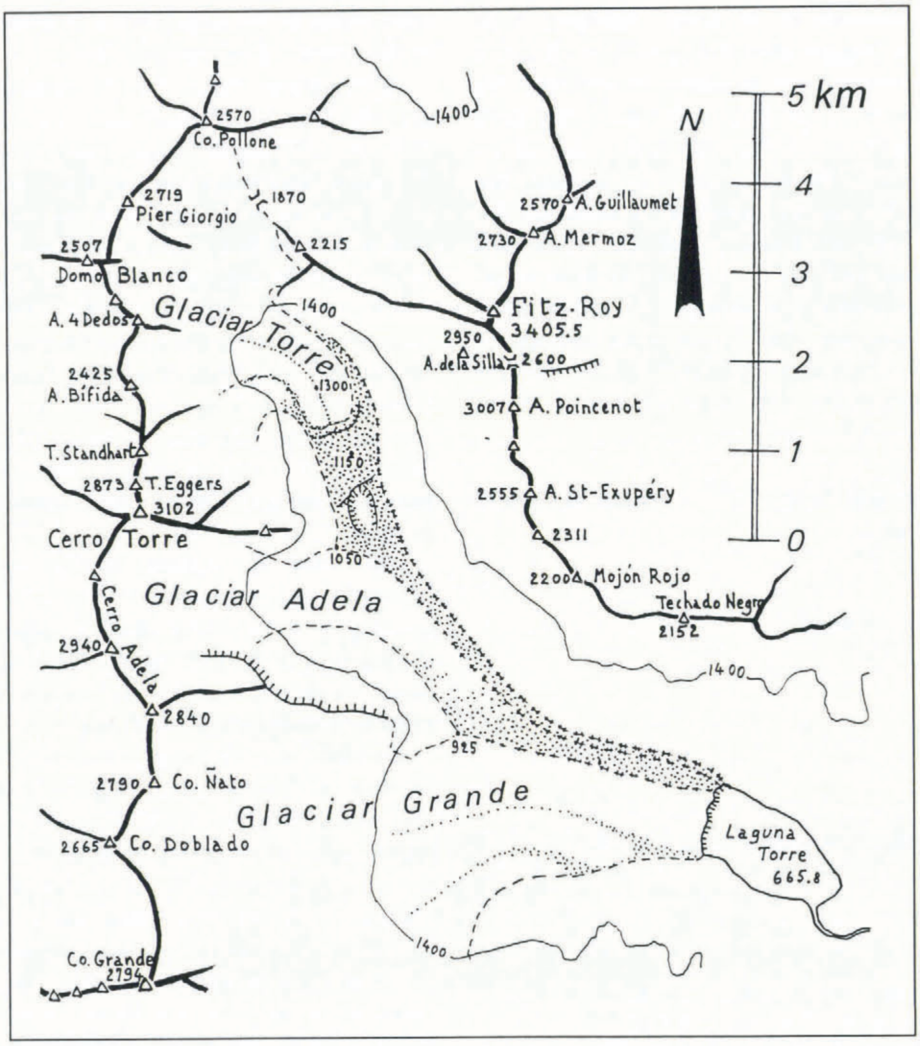

Fig. 1. Glaciar Torre as in 1961. Altitudes of surrounding peaks are more accurate than in Lliboutry (1953) and 20–35 m lower. (The length of my base line was overestimated.)

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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