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Ice flow and surface lowering of Tyndall Glacier, southern Patagonia

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Abstract

Horizontal surface velocities of ice-flow were obtained at Tyndall Glacier, Patagonia, during a period from December 7 to 15 in 1990. The velocities along a transverse line varied from 0.07 m/d near the left margin to 0.51 m/d at a point 2.5 km from the margin. Velocities at each point increased by about 0.1 m/d during several days. This is interpreted to be due to the accelerated basal sliding of the glacier.

The surface elevation of the glacier was measured along a transverse line stretching over 5 km from the left margin, and the elevations were compared with those obtained in December 1985. The glacier surface has lowered by about 20 m, that is at a rate of about 4.0 m/a during the five-year period.

1. Introduction

The Southern Patagonia Icefield (Hielo Patagónico Sur) stretches for 350 km from 48°30'S to 51°30'S with an area of 13000 km^2. In spite of its potential importance to the global environment, fluctuations of Patagonian glaciers have not been monitored systematically. Furthermore, glaciological and meteorological data in the Patagonia region are too scarce to study the relationship between glacier fluctuations and climatic changes.

For this reason, in the austral summer of 1990, glaciological, meteorological and geomorphological investigations were carried out at Tyndall Glacier in the Southern Patagonia Icefield. Tyndall Glacier flows southward from the icefield and terminates in a proglacial lake (see Fig. 1). The length and area of the glacier are estimated to be about 40 km and 355 km^2, respectively (Naruse *et al.*, 1987). A massif of nunataks is located near the equilibrium line in the Tyndall drainage basin. A medial moraine is well developed from the nunataks to the glacier snout. The width of the valley glacier (ablation area) is about 10 km in the upper part and about 3.5 km in the lower part.

In December 1985, measurements of the surface flow were made along a transverse profile in the upper part of the ablation area, approximately 13 km from the snout (Naruse *et al.*, 1987). Measurements of surface elevation, ice-flow and radio-echo soundings were carried out in December 1990 almost along the same transverse line. This report presents the results of flow velocity measurements and surface lowering from 1985 to 1990 at Tyndall Glacier.

2. Methods

A control station α and an azimuth point β were established on bare-rock at the left bank of the glacier. An electronic distance meter (EDM : TOPCON ET-2, minimum reading 1") was set at the control station. A mobile team drilled holes on the glacier surface and placed stakes, at the top of which a reflector was set up for the EDM measurement. From the control station, distance, vertical angle and azimuth were measured for each survey point up to a

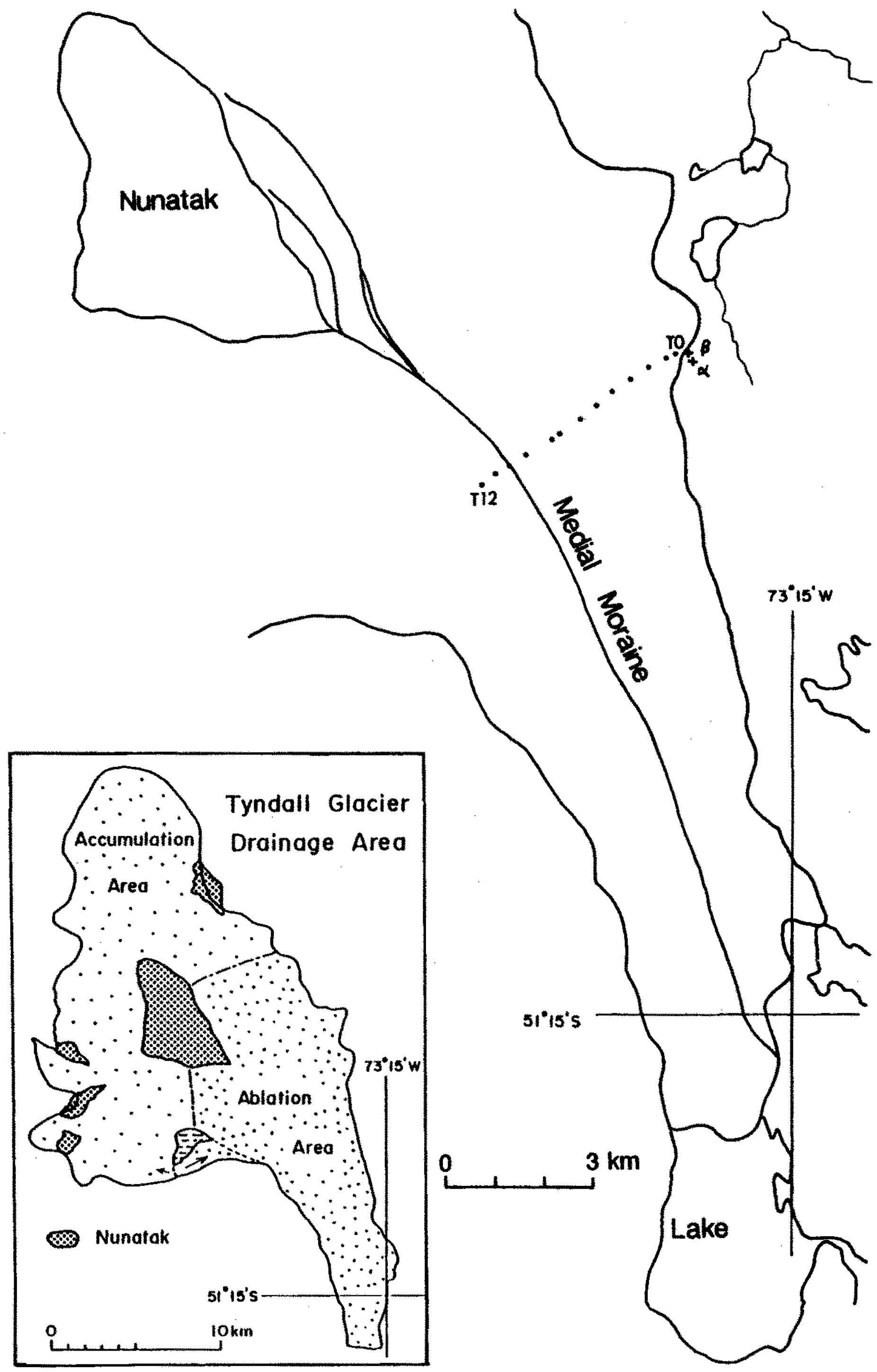

Fig. 1. Map of Tyndall Glacier (modified after Naruse et al., 1987). Surface level measurements were carried at the dotted points on the glacier.

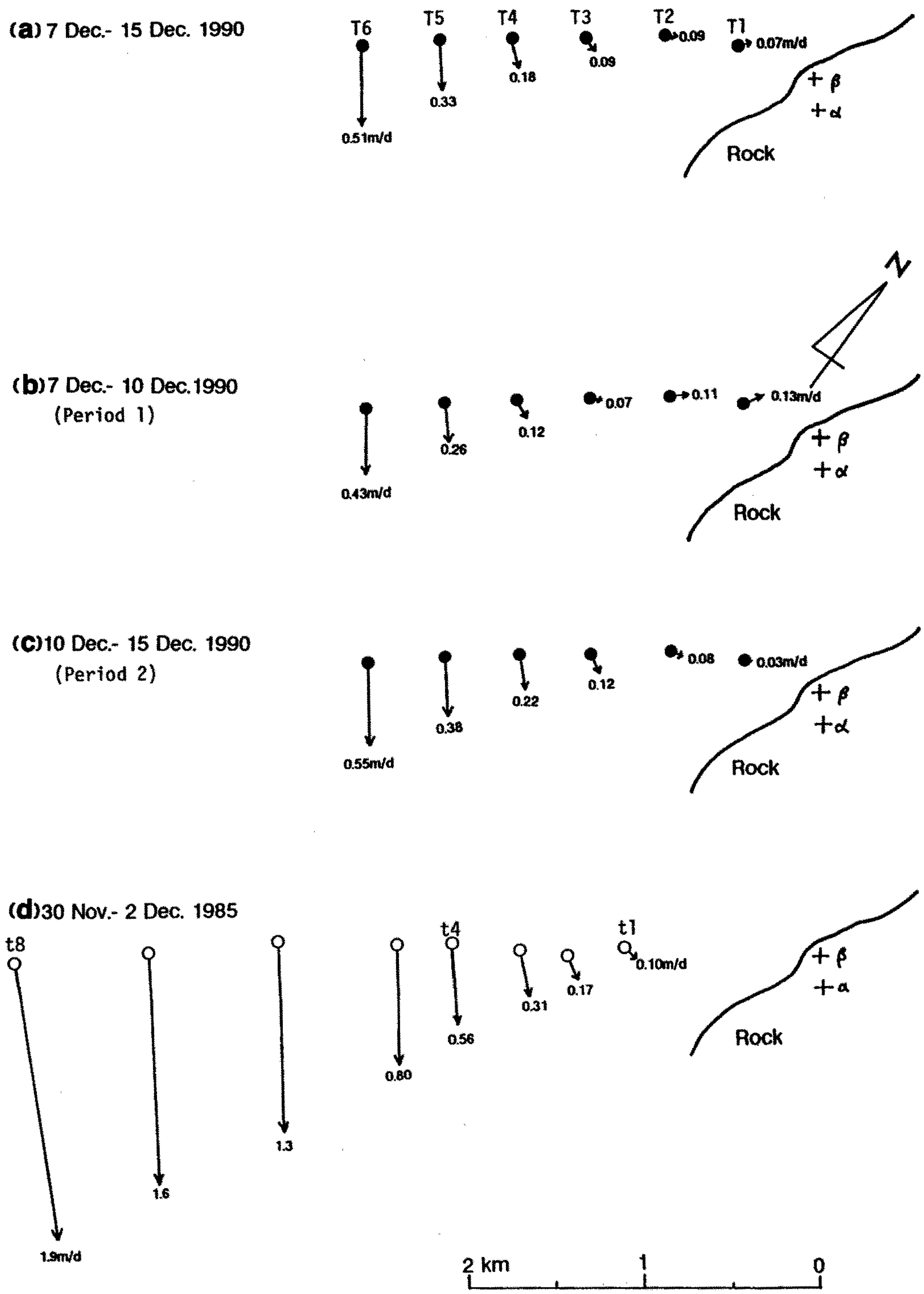

Fig. 2. Distribution of mean surface flow velocities during different periods.

distance of 2.5 km from the left margin. Three dimensional coordinates of the point can be determined from these measurements. Repeated measurements of some survey points enabled us to calculate surface ice-flow velocities. These measurements were performed at six points on December 7, 10 and 15 in 1990. A traverse survey of the surface elevation was also carried out on December 13, to a point 5 km from the left margin of the glacier (Fig. 1).

3. Results and discussion

3.1. Ice flow

The mean ice-flow velocities during eight days (December 7 – 15) were obtained at six points (T1–T6). As expected, velocity increased gradually from 0.07 m/d near the margin to 0.51 m/d at a point 2.5 km from the margin (Fig. 2 (a)). A remarkable difference in flow directions can be recognized between stations T1-T3 and T4-T6. The former stations flow toward the lateral margin while the latter flows almost parallel to the margin. The transverse profile of glacier surface is convex upward (see Fig. 3), and the direction of the maximum surface slope is approximately northeast in the region near the lateral margin (see Fig. 4). So that the directions of ice-flow at T1-T3 can be regarded as almost coinciding with those of the glacier surface. The bedrock profile derived from radio-echo soundings also shows considerable variations in the region from T2 to T4, namely ice thicknesses are small (less than 250 m) at T1 and T2 and large (more than 450 m) in the area from T4 to T7 (Casassa, 1992).

Fig. 2 (b) and (c) show the mean velocities during three days from December 7 to 10 (period-1) and during five days from December 10 to 15 (period-2),

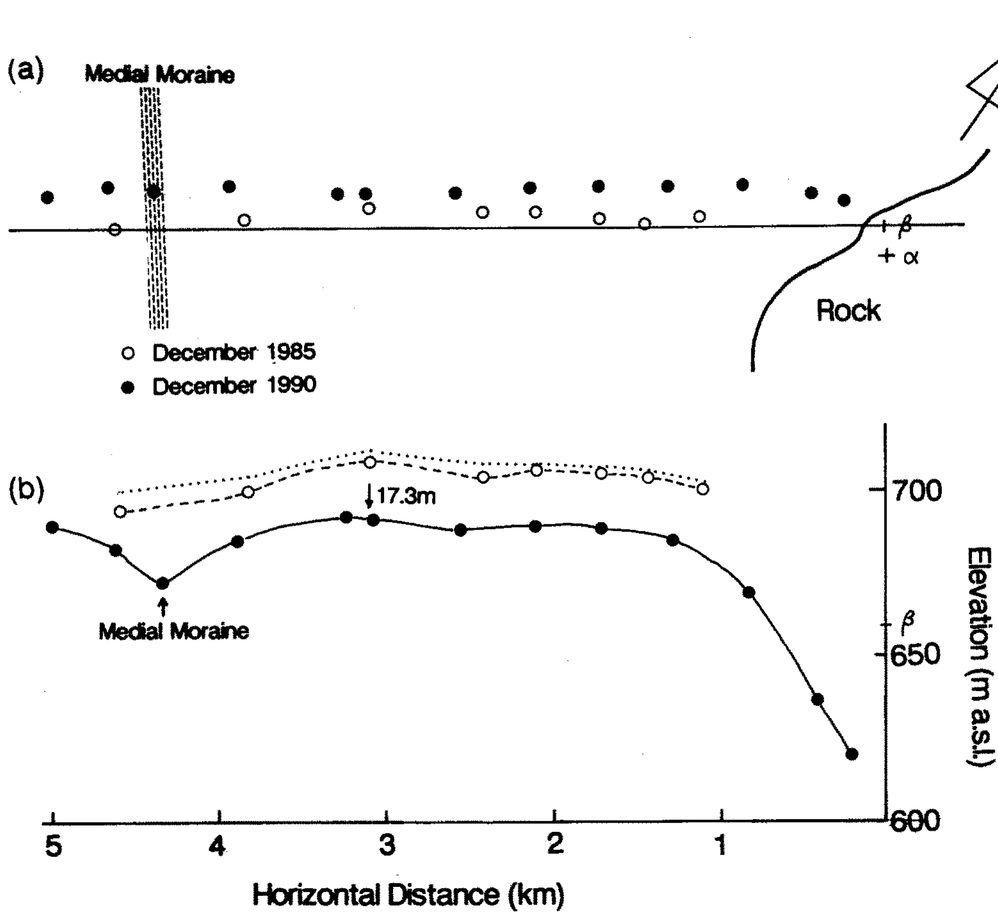

Fig. 3. (a) A plan view of survey points in 1985 and 1990. (b) Comparison of the surface profiles between 1985 and 1990 along survey lines. The dotted line shows an adjusted profile of the 1985 survey line (see text).

respectively. Velocities at T4-T6 showed an increase of 0.10 to 0.12 m/d from period-1 to period-2. The condition of the glacier surface was different between the two periods. In period-1 the glacier surface was still covered with newly deposited snow, while in period-2 the snow had melted away and ablation of bare-ice started. Therefore, in period-2 abundant melt water supposedly reached the bottom of the glacier, causing an increased basal sliding.

Fig. 2 (d) shows the mean surface velocities in 1985 with an interval of two days from November 30 to December 2 (Naruse *et al.*, 1987). The velocities indicate larger values than those in 1990, which may be attributed to the difference in basal sliding velocity. In the survey period in 1985 the water channels within and beneath the glacier may have already developed, whereas in 1990 they had just started to develop since it was still cold in the early summer. At present, it is difficult to estimate the mean annual flow velocity, as we have no information on its seasonal variation.

3.2. Surface lowering of the glacier from 1985 to 1990

The surface elevation of the glacier was obtained at eight points in 1985 (Naruse *et al.*, 1987) and at 13 points in 1990. Cross profiles of each year are shown in Fig. 3 (b). A direct comparison yielded a mean difference of 17.3 m between the two profiles. However, since the traverse line in 1990 is located slightly upglacier as shown in Fig. 3 (a), we adjusted the 1985 profile based on the surface slope. Assuming the mean surface slope at the survey line to range from 6/1000 to 30/1000 as derived from the topographic map (Fig. 4), we corrected the surface height of the 1985 survey line to the height along the 1990 survey line, which is shown in Fig. 3 (b) by a dotted line. A surface lowering of 20 m was obtained for the five-year period from 1985 to 1990, which results in at a rate of 4.0 m/a.

Fig. 4 represents a part of a 1 : 25,000 topographic map showing the area around the survey points. The

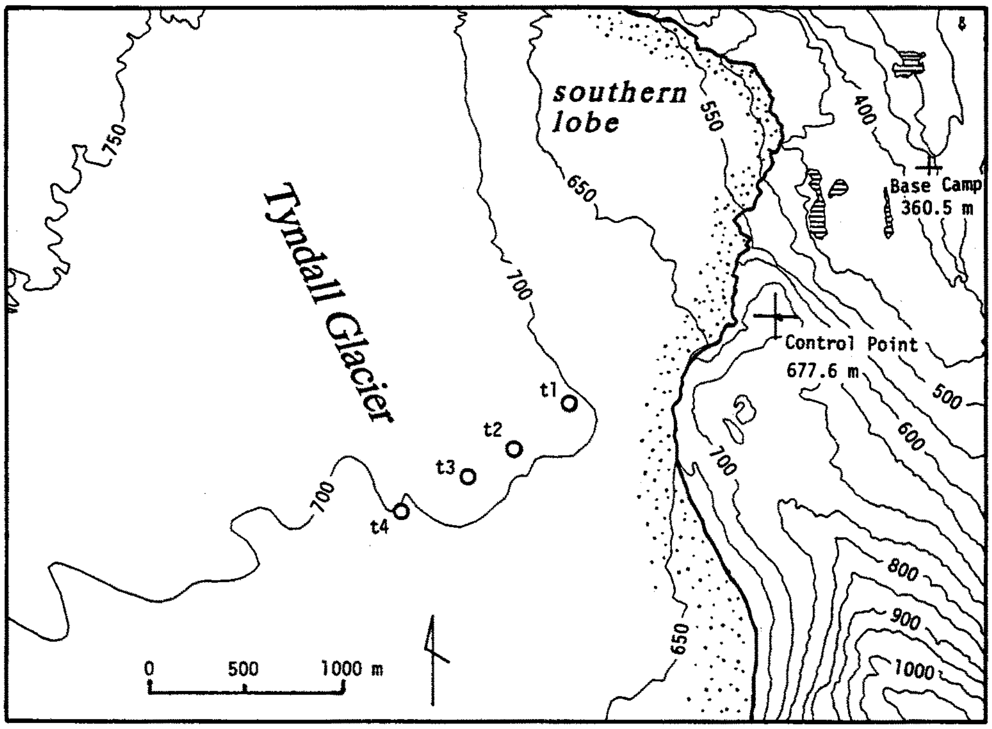

Fig. 4. Topographic map originally at a 1 : 25,000 scale produced from vertical aerial photographs taken in March 1975 by the Chilean Air Force. Digital mapping at contour intervals of 10, 25 and 50 m was done with a Zeiss planicomp P3. Contour lines are shown with an interval of 50 m. Control points were taken from the 1 : 100,000 topographic map "Rio Serrano" published by Instituto Geográfico Militar, Chile (1986). Some survey points in 1985 are shown by open circles.

map was produced for the present Patagonia project with a contour line interval of 50 m based on vertical aerial photographs taken in March 1975. Survey points from t1 to t4 in 1985 were plotted on Fig. 4, and the elevation of each point was roughly estimated from the contour lines. By comparing the elevations in 1975 with those in 1985, we obtained a surface lowering of about 19 m (1.7 m/a in average) from 1975 to 1985. This rate of lowering is less than one half of that from 1985 to 1990.

At Soler Glacier in the Northern Patagonia Icefield, Aniya and Naruse (1987) showed that the surface of the ablation area lowered at a rate of 5.2 m/a from 1983 to 1985. This rate is much larger than the rate of 1.0 to 1.8 m/a obtained near the snout of Soler Glacier for the period from 1944 to 1984 (Aniya and Enomoto, 1986). Based on the data compiled by IAHS/UNESCO (1988), six glaciers in the Alps were found to show thinning from the 1940s to the 1980s at rates from 0.1 m/a to 0.3 m/a as an average for the whole glacier. However, the maximum thinning of these six glaciers in the Alps for altitude intervals of 50 to 100 m was 0.5 m/a to 4.1 m/a. Aniya and Enomoto (1986) summarized thinning rate of three alpine glaciers in France, New Zealand and Canada show values that range from 2 m/a to 4.5 m/a. The thinning rate of Tyndall and Soler glaciers lies in the upper range of the values of other alpine glaciers of the world.

If a glacier is in a steady state, the surface level should be constant with time, because in an ablation area the emergence flow of ice (upward relative to the glacier surface) compensates for the ablation of surface ice. The surface lowering results from an increase in ablation rate and/or a decrease in the emergence ice flow. Because the surface lowering or thinning of ice causes a decrease in ice-flow velocity so that it reduces the ice flux discharge, this phenomenon should strongly affect the mass balance and the condition of a glacier.

In order to clarify the cause of thinning of a glacier, more detailed studies on the mass balance, the heat balance and the dynamics of Patagonian glaciers are needed.

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