Bulletin of Glacier Research 4 (1987) *133 – 140*

Flow and surface structure of Tyndall Glacier, the Southern Patagonia Icefield

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(Received December 9, 1986 ; Revised manuscript received January 16, 1987)

Abstract

Glacial flow was measured for three days from November 30 to December 2, 1985, along a transverse line extending halfway across the 8-km-wide upper ablation area of Tyndall Glacier, one of the outlets of the Southern Patagonia Icefield. The flow velocity of 0.1 m/d observed near the left lateral margin increased with the distance away from it to 1.9 m/d near the medial moraine which constituted the central axis of the glacier. Characteristics of the surface structure and the recent glacier variation were also discussed from the results of the field observations and analyses of air photographs taken in 1944/5, 1975 and 1985.

1. Introduction

The Southern Patagonia Icefield (Hielo Patagónico Sur) stretches for 350 km from 48°20′S to 51°30′S. The area of the icefield is 13,500 km^2, with its mean elevation at 1500 m - 2000 m. From the icefield a number of outlet glaciers discharge toward all directions.

Explorations of the Southern Icefield and its outlet glaciers were started from the end of the 19 th century. However, very little glaciological work has been done. Marangunić (1964) obtained some glaciological and meteorological information from the accumulation area of the icefield. Moreno Glacier which caused ice-damming and subsequent flooding due to its collapse has been studied extensively (*e. g.* Nichols and Miller, 1952 ; Lliboutry, 1953 ; Liss, 1970). Very active advances and retreats, resembling a surge phenomenon, of Pio XI (or Brüggen) Glacier were analyzed and reported by Lliboutry (1956), Mercer (1964) and Iwata (1983). Inoue (1983) made a preliminary heat balance measurement on HPS-10 Glacier in 1969. Peña and Escobar (1983) examined catastrophic runoff from Dickson Glacier in the Paine region. Reconnaissance surveys of glaciology were made at Jorge Montt Glacier (Enomoto and Abe, 1983), and at Grey and Amalia Glaciers (Naruse and Casassa, 1985). Lliboutry (1986) studied the satellite imagery of the Chilean Andes, in particular, of the southern Patagonia area.

With respect to research on glacial flow, also few data have been obtained in southern Patagonia. A flow velocity of 450 m/a was deduced from air photographs at the middle part of Grey Glacier (Lliboutry, 1956), and 745 m/a was estimated at the front of Pio XI Glacier and 70 m/a near the front of Colonia Glacier (Marangunić, 1964).

Detailed study on the dynamics of Patagonian glaciers has been required to make clear the characteristics of mass balance and variation of glaciers. Accurate measurements of ice flow were carried out in late November and early December, 1985, by means of a traverse survey at Tyndall Glacier in the southern part of the Southern Patagonia Icefield. The present report gives the results of the survey and some glaciological features and variations of Tyndall Glacier.

2. Characteristics of the surface structure of Tyndall Glacier

Tyndall Glacier flows southward from the Southern Icefield (see Fig. 1) ; the terminus of the glacier is

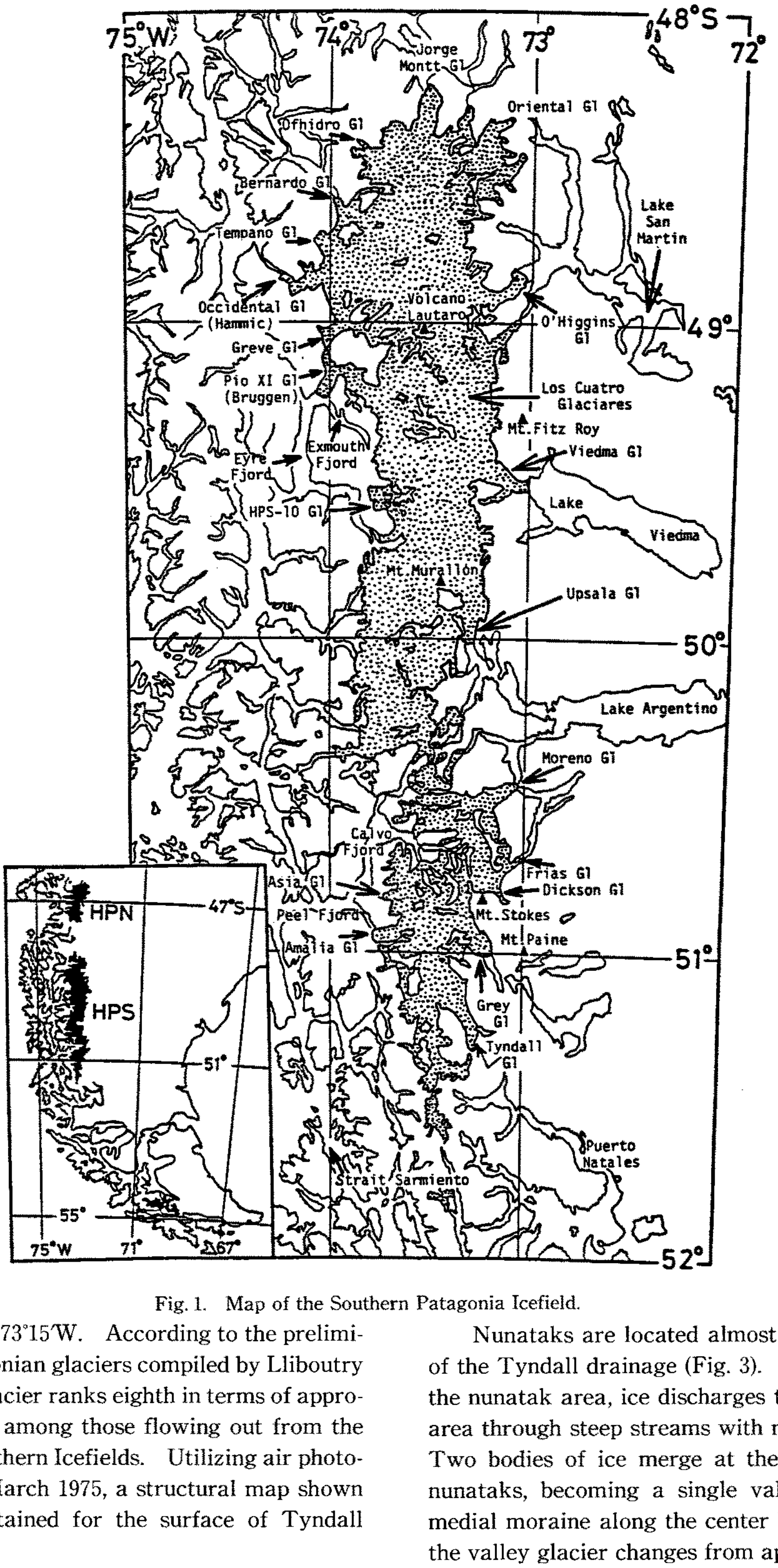

Fig. 1. Map of the Southern Patagonia Icefield.

located at 51°15'S, 73°15'W. According to the preliminary list of Patagonian glaciers compiled by Lliboutry (1956), Tyndall Glacier ranks eighth in terms of approximate dimension among those flowing out from the Northern and Southern Icefields. Utilizing air photographs taken in March 1975, a structural map shown in Fig. 2 was obtained for the surface of Tyndall Glacier.

Nunataks are located almost at the central part of the Tyndall drainage (Fig. 3). From both sides of the nunatak area, ice discharges toward the ablation area through steep streams with numerous crevasses. Two bodies of ice merge at the lowest end of the nunataks, becoming a single valley glacier with a medial moraine along the center line. The width of the valley glacier changes from approximately 10 km

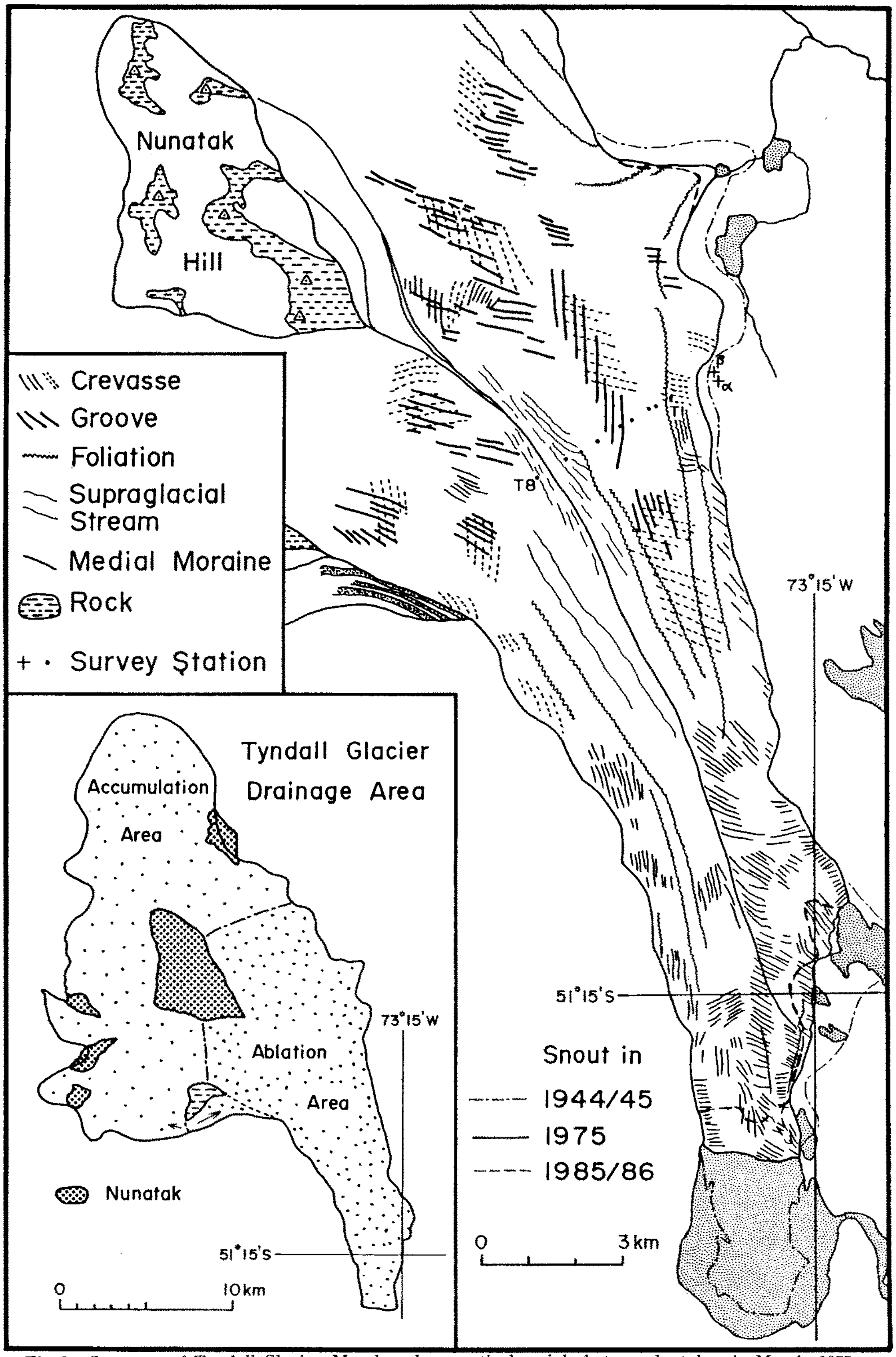

Fig. 2. Structure of Tyndall Glacier. Map based on vertical aerial photographs taken in March, 1975. Crevasses and other features are shown only where no snow covered the glacier surface.

Fig. 3. Photograph of nunataks located at the central part of Tyndall Glacier. Taken from near station T3.

in the upper reach to 3.5 km in the lower reach ; the length of the valley glacier is about 20 km long. The drainage boundaries in the icefield were delimited by stereoscopic analyses of vertical aerial photographs and the total area was measured to be 355 km^2. By examining the surface condition appearing on photographs, the position of the equilibrium line was inferred as shown in the inset of Fig. 2, and the accumulation and ablation areas were estimated at 210 km^2 and 145 km^2, respectively.

Generally a number of crevasses are distributed over the glacier surface. In the crevasse-free areas, supraglacial water streams were developed. The surface structure of foliations was recognized, but no ogives were observed. "Grooves" (called by Aniya and Naruse, 1987), which stretch parallel to each other and run across the crevasses at angles of about several tens of degrees, were also found in many areas. The grooves were approximately a few meters deep and about 10 m wide. This structure may be considered as a relic of old crevasses which have been deformed due to velocity gradient in the glacier surface flow and melting of surface ice.

3. Recent variations of the glacier

Tyndall Glacier has been retreating lately. Utilizing the trimetrogon photographs taken in 1944/45, the vertical photographs taken in March 1975, at scales ranging from 1 : 85,000 to 1 : 90,000, and the oblique photographs taken on December 31, 1985, the glacier termini were located and compared (Fig. 2).

From 1945 to 1975 (30 summers) the southern terminus was found to have retreated up to about 3.5 km (120 m/a), and the southeastern terminus retreated about 1.7 km (57 m/a), while at the left margin about 20 km from the terminus where two lobes are spilling into side valleys, the retreat was 500–900 m (17–30 m/a). Between 1975 and 1985 (10.5 summers), the retreat was about 900 m (85 m/a) at the southern terminus, whereas it was a maximum of 900 m (85 m/a) at the southeastern terminus (Fig. 4). At the left margin, the northern lobe has retreated up to 500 m (48 m/a), while there seems to be no change at the southern lobe. The retreat rates were, therefore, slightly faster during the earlier period since 1945 at the main terminus (southern one), while at the offshoot terminus (southeastern one) and side lobes, rates were variable.

4. Distribution of flow velocities

Measurements of the glacier flow were made in the upper part of the ablation area along the dotted line shown in Fig. 2. The surveyed area was gently sloping with few crevasses. Two control points (α and β) were established on the left bank of the glacier, with the base-line distance of 196.0 m. Eight stakes

Fig. 4. Oblique air photograph of the southeastern terminus and the central nunataks of Tyndall Glacier. Taken on December 31, 1985.

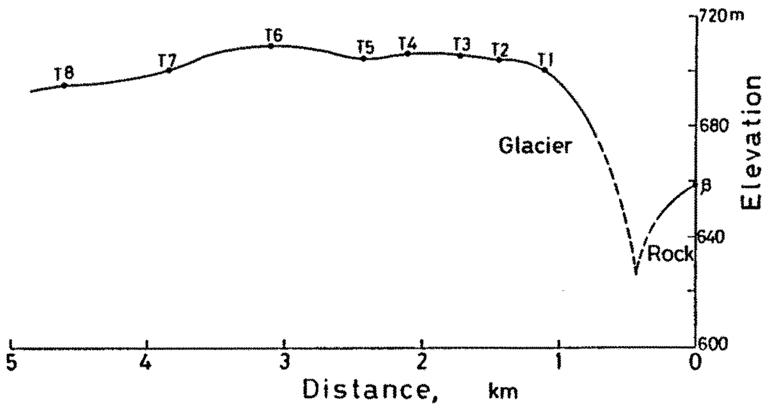

Fig. 5. Surface profile along the survey line in the upper part of the ablation area of Tyndall Glacier.

with red flags, T1 through T8, were set up half-way across the 8-km-wide glacier from the left bank.

The method of measurement was a traverse survey. At each station on the glacier, the horizontal and vertical angles between neighbouring stations and the distance to the next station were measured both with an electronic distance meter (Topcon EDM-Theodolite Guppy GTS-2 : a minimum reading of angle is 10 seconds). The first survey was carried out on November 30 and the second on December 2, 1985.

A cross-sectional profile along the traverse line is illustrated in Fig. 5. Elevations of all stations were determined on the basis of 659 m a. s. l. at Station β, which was estimated from a barometric elevation difference from that on Lake Grey. The profile shows a convex upward, which is the general feature of the ablation area of glaciers. The surface elevation has a maximum near Station T6, from which the elevation decreases gradually toward the right margin of the glacier.

The obtained horizontal velocities of the ice flow are shown by arrows in Fig. 6. The velocity increased rapidly from 0.1 m/d at T1 near the left margin to 1.9 m/d at T8 on the center line of the

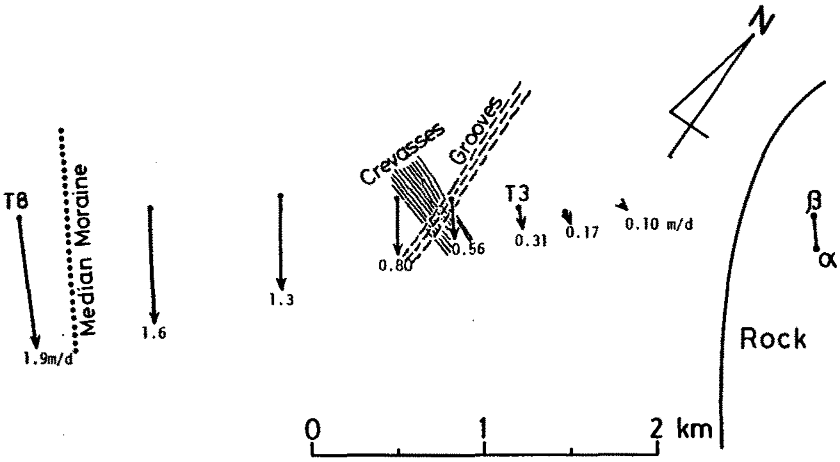

Fig. 6. Distribution of horizontal vectors of the surface flow velocity at Tyndall Glacier.

glacier. Although no measurements were made in the right half of the glacier, the velocity at T7-T8 near the medial moraine is considered to be the maximum value along this transverse line.

If we would make a rough estimate under the assumption of a constant flow velocity throughout the year, the velocity near the center line of the glacier corresponds to 700 m/a. This value is almost the same order of magnitude as 300-500 m/a for the upper part of the ablation area of Soler Glacier in the Northern Patagonia Icefield (Naruse, 1987).

Mean daily ablation rates during the 2 days were obtained as 2.5 to 3.0 cm/d along the survey line.

5. Concluding remarks

Velocities of ice flow were obtained by the ground survey in Tyndall Glacier. Generally it is difficult to carry out a triangulation survey in such a large glacier as Tyndall, since angle measurements for a marker of stake with flag are usually restricted within several kilometers even under the condition of good visibility. A traverse survey should be a more suitable method. However, much effort is needed to keep a tripod upright on the ice surface during the measurement.

Also made were preliminary measurements of water temperature of streams and ponds, and a geomorphological reconnaissance survey around Tyndall Glacier in November-December 1985. The results will contribute to future studies in this region.

Acknowledgments

We are grateful to Mr. Raul Anabalón of Dirección General de Aguas, Chile, Mr. José Alarcón of CONAF in Parque Nacional Torres del Paine, Mr. Luis Oyarzún and Mr. Mauricio Menéndez of the Andean Club in Punta Arenas for their assistance in the field survey.

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Appendix

Flow and ablation of HPS-10 Glacier

Preliminary surveys of ice flow and ablation were made at HPS-10 Glacier in January 1969 by the scientific expedition of the Kyoto University Exploring Club 1968-69, in which one of the authors (Inoue) participated. HPS-10 Glacier is located at the western side of the middle part of the Southern Patagonia Icefield (see Fig. 1) ; it discharges from the icefield toward a proglacial lake at the terminus, as shown in Fig. 7. A simple theodolite was set up on the left bank of the glacier and the base line was fixed across the glacier about 2 km upstream from the terminus, where the glacier width is about 1 km. Five stakes for the glacier flow and ablation measurements were set along the base line. The distances of the devia-

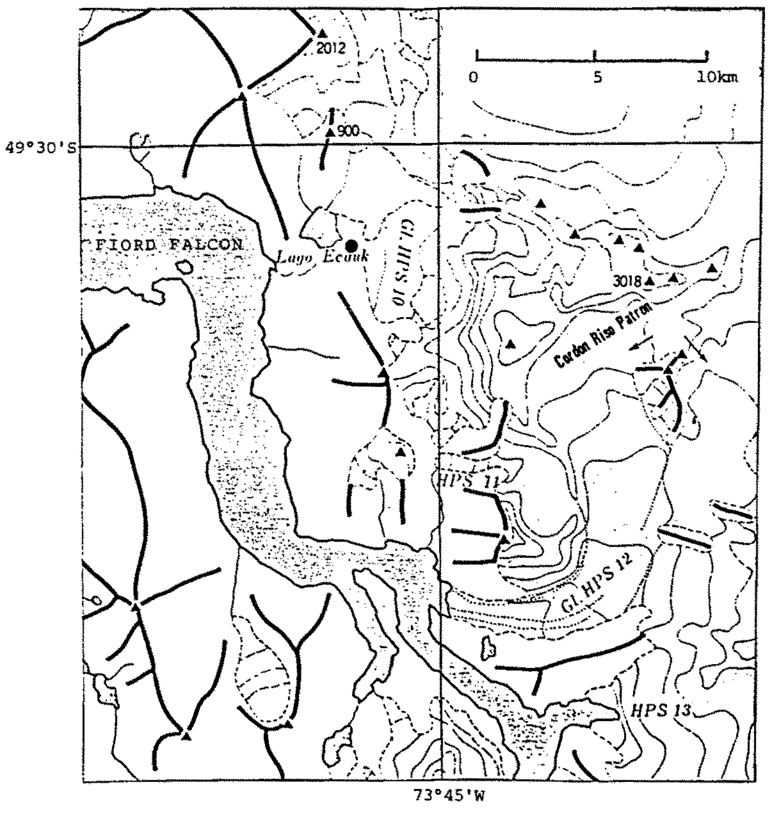

Fig. 7. Map of HPS-10 Glacier (reproduced from the maps of Andes Patagonicos sheet No. 4, 1976, compiled by S. Iwata). A solid circle shows the theodolite position.

tions from the base line were measured after five days. The results are shown in Table 1.

Table 1. Results of flow and ablation measurements of HPS-10 Glacier during the five days from January 22 to 27, 1969. "Distance" indicates position of the stakes measured from the theodolite position on the left bank.

Stake	Distance (m)	Flow speed (m/d)	Ablation rate (cm/d)
A	132	0.24	5.6
B	188	0.30	4.4
C	313	0.43	4.0
D	435	0.59	5.2
E	634	0.55	6.0

Resumen

Flujo y estructura de superficie del Glaciar Tyndall, Hielo Patagónico Sur (HPS)

Entre fines de Noviembre y principios de Diciembre de 1985 se llevó a cabo mediciones de flujo en el Glaciar Tyndall, el cual fluye hacia el sur en la parte meridional del Hielo Patagónico Sur (HPS) (ver Fig. 1) ; el frente del glaciar está ubicado a 51°15′ S, 73°15′ W. La zona de drenaje en el campo de hielo fue delimitada por medio del análisis estereoscópico de fotografías aéreas verticales, resultando en un área total de 355 km^2. Se supuso que la posición de la línea de equilibrio fue aquella mostrada en el recuadro de la Fig. 2, y se estimó áreas de acumulación y ablación de 210 km^2 y 145 km^2, respectivamente.

Ultimamente el Glaciar Tyndall ha estado retrocediendo. La posición del frente del glaciar fue ubicada y comparada por medio de fotografías aéreas tomadas en 1944/45, 1975 y 1985 (Fig. 2). Se encontró que desde 1945 a 1975 el frente meridional ha retrocedido unos 3,5 km (120 m/a), mientras que a unos 20 km del frente el retroceso del margen izquierdo fue de 500 -900 m (17-30 m/a). El retroceso entre 1975 y 1985 fue de 900 m (85 m/a) en el frente meridional, mientras que en el margen izquierdo se ha observado un máximo retroceso de 500 m (48 m/a).

Se realizó mediciones de flujo glaciar en la parte superior del área de ablación, a lo largo de la línea punteada que se muestra en la Fig. 2. El área estudiada tenía una pendiente suave con pocas grietas. Se estableció dos puntos de control en el margen izquierdo del glaciar, instalándose ocho balizas, T1 a T8, hasta la línea central del glaciar que tiene un ancho total de 8 km. Se realizó una poligonal de enlace, midiendo en cada estación los ángulos horizontales y verticales hacia las estaciones vecinas y por medio de un distanciómetro electrónico se midió la distancia a la siguiente estación.

En la Fig. 5 se muestra el perfil transversal del glaciar. La cota en superficie alcanza un valor máximo cerca de la estación T6, desde donde decrece gradualmente hacia el margen derecho del glaciar.

La velocidad horizontal obtenida se indica por medio de flechas en la Fig. 6. Dicha velocidad aumentó rápidamente desde 0,1 m/d en T1 cerca del margen izquierdo hasta 1,9 m/d en T8 sobre la línea central del glaciar. A pesar que no se realizó mediciones en la mitad izquierda del glaciar, se consideró que la velocidad en T7-T8 cerca de la morrena medial representa el valor máximo a lo largo de esta línea transversal.

También se presentan en el Apéndice los resultados de estudios preliminares de flujo de hielo y ablación realizados en Enero de 1969, en el frente del Glaciar HPS-10, ubicado en el margen occidental de la sección media del HPS (Tabla 1, Apéndice).