Bulletin of Glaciological Research 22 (2005) *109-119*

Overview of Glaciological Research Project in Patagonia 2003

Masamu ANIYA[1], Kazuhide SATOW[2], Pedro SKVARCA[3], Ryo ANMA[1], Tatsuto AOKI[4], Takanobu SAWAGAKI[5], Tomonori TANIKAWA[6], Renji NARUSE[7], Neil GLASSER[8] and Stephan HARRISON[9]

1 Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki 305-8572, Japan
2 Nagaoka National College of Technology, Nagaoka 940-8532, Japan
3 Instituto Antártico Argentino, Serrito 1248, C1010AAZ Buenos Aires, Argentina
4 Department of Geography, Kanazawa University, Kanazawa 920-1192, Japan
5 Graduate School of Environmental Earth Sciences, Hokkaido University, Sapporo 060-0810, Japan
6 Graduate Student, Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki 305-8572, Japan
7 Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819, Japan
8 Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth, Aberystwyth, UK
9 Oxford University Centre for the Environment, Mansfield Road, Oxford, UK

(Received October 6, 2004; Revised manuscript received October 29, 2004)

Abstract

Glaciological Research Project in Patagonia 2003 is the first year of the three-year project entitled "Holocene Environmental Changes in Patagonia Icefield, South America" funded by the Ministry of Education, Science, Sports and Culture, Japan. In this report, we outlined the aim of the project and purposes of the 2003 activities. Three field parties were sent to Patagonia; (1) geomorphological and glaciological group to Glaciar Exploradores, the Northern Patagonia Icefield, (2) glaciological group to Glaciar Perito Moreno, the Southern Patagonia Icefield, and (3) geological group to the volcanic field and alpine glaciers of Patagonia. Activities of the each group are described and some preliminary results are summarized.

1. Introduction

Glaciological Research Project in Patagonia 2003 (hereafter GRPP03) was the first year of the three-year project entitled "Holocene Environmental Changes in Patagonia Icefield, South America." The main objectives of this project are to:
(1) establish the Holocene glacial chronology of the Hielo Patagónico Norte (HPN),
(2) continue monitoring of variation of the HPN outlet glaciers,
(3) elucidate calving mechanism of Patagonian glaciers, and
(4) establish paleomagnetic characteristics recorded in the Middle Miocene-Holocene igneous rocks and sediments.

The research themes in 2003 consisted of three major topics; (1) geomorphological and glaciological research at Glaciar Exploradores, HPN (Hielo Patagónico Norte or Northern Patagonia Icefield); (2) glaciological investigation at Glaciar Perito Moreno, HPS (Hielo Patagónico Sur, or Southern Patagonia Icefield); and (3) preliminary geomorphological investigation of the Patagonian volcanic field, and of South Andean alpine glaciers. Figure 1 shows the area of our interest.

2. Study area

2.1. Glaciar Exploradores, HPN

The HPN is located around 47°S and 73°30′W with an area of about 4200 km^2 in 1974 (Aniya, 1988, Fig. 2). It has the highest mountain in Patagonia, Monte San Valentin (3910 m) at the northeastern corner of the Icefield. The icefield has 28 outlet glaciers, of which 21 major glaciers have been studied for their variations since 1944 to 1999 (Aniya, 2001). Of these, Glaciar Soler has been extensively studied by the GRPPs since 1983 (*e.g.*, Nakajima, 1985, 1987; Aniya and Naruse, 2001). This time Glaciar Exploradores, located at the northeast corner of the icefield on the north flank of Monte San Valentin, was chosen for geomorphological and glaciological studies. The glacier has an area of about 95 km^2 with a length of 20.3 km and the AAR was 0.66 in 1974 (Aniya, 1988). The glacier is nourished on the north flank of Monte San

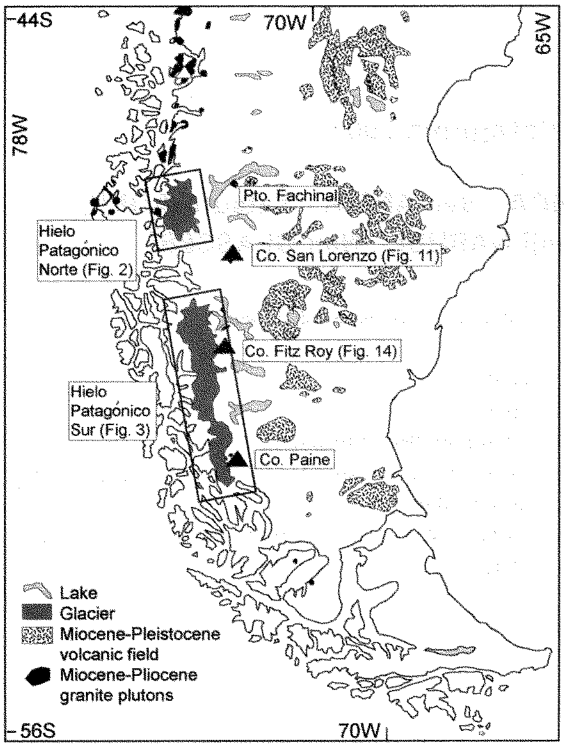

Fig. 1. Map of the southern part of South America - Patagonia. Major areas of interest in this paper indicated.

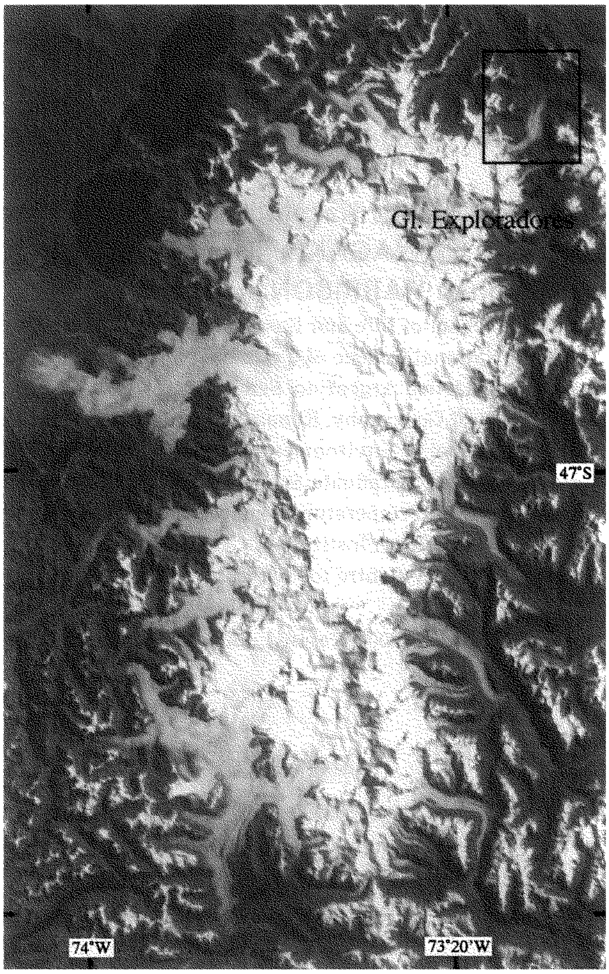

Fig. 2. Landsat ETM image of the HPN (March 8, 2001), indicating the location of Glaciar Exploradores.

Valentin with two branches. There is a big, conspicuous, elongated continuous moraine in front of the present glacier snout. This is the only terminal moraine formed by Glaciar Exploradores that can be recognized in the valley of Río Exploradores (Harrison *et al.*, 2004). If we can date the age of this moraine, we may be able to establish a part of the Holocene glacial chronology of the HPN, because there are similar moraines at other glaciers such as Grosse, Reicher, Gualas, Nef, Colonia to name but a few. Also no glaciological study has been carried out at Glaciar Exploradores, despite relatively easy access from Pto. Tranquilo.

2.2. *Glaciar Perito Moreno, HPS*

Glaciar Perito Moreno is located in the HPS, on the eastern side in Argentina at 53°30′S and 73°00′W. It has an area of 258 km^2 and a length of 30 km with an AAR of 0.73 in 1986 (Aniya *et al.*, 1996, Fig. 3). The GRPPs have been studying this glacier since 1990 and have accumulated a wealth of glaciological and meteorological information (*e.g.*, Naruse and Aniya, 1992; Aniya *et al.*, 1992; Aniya and Skvarca, 1992; Naruse *et al.*, 1992; Naruse and Aniya, 1995; Naruse *et al.*, 1995a; 1995b; Takeuchi *et al.*, 1996; del Valle *et al.*, 1995; Skvarca and Naruse, 1997), as well as few studies by others (*e.g.*, Warren, 1994; Rott *et al.*, 1998; Michel and Rignot, 1999). Glaciar Perito Moreno has been known for the repeated advances and consequent damming up of lake "Brazo Rico-Sur" to the south (Mercer, 1962; 1968) and the glacier has been fairly stable since the 1940s despite the general trend of glacier recession in Patagonia (Aniya and Skvarca, 1992; Aniya *et al.*, 1997). In 2003, the glacier had advanced, thereby damming up Brazo Rico-Sur for the first time since 1988. The ice-dam was eventually ruptured on March 13, 2004.

2.3. *The Patagonian volcanic fields and glaciers at Cerro San Lorenzo and Cerro Fitz Roy*

The Miocene-Pleistocene volcanic rocks (Fig. 1; Kay *et al.*, 1993) of the Patagonian volcanic field cover vast area behind the Andean arc system. We visited most Mesetas aligned along the longitude 70°W in Figure 1.

Andean alpine glaciers are developed on the top of Miocene plutons distributed along back-arc plutonic chain behind the Andes and the Hielos Patagónicos Norte and Sur. Among them, famous mountains such as Cerro (Co.; Mount, Mt) San Lorenzo (6.6 Ma; Suarez and De la Cruz, 2001), Co. Fitz Roy (18 Ma; Kay *et al.*, 1993) and Torres del Paine (12∼13 Ma; Halpern, 1973) massifs are included (Fig. 1). Co. San Lorenzo (3,706 m) is located on the border between Chile and

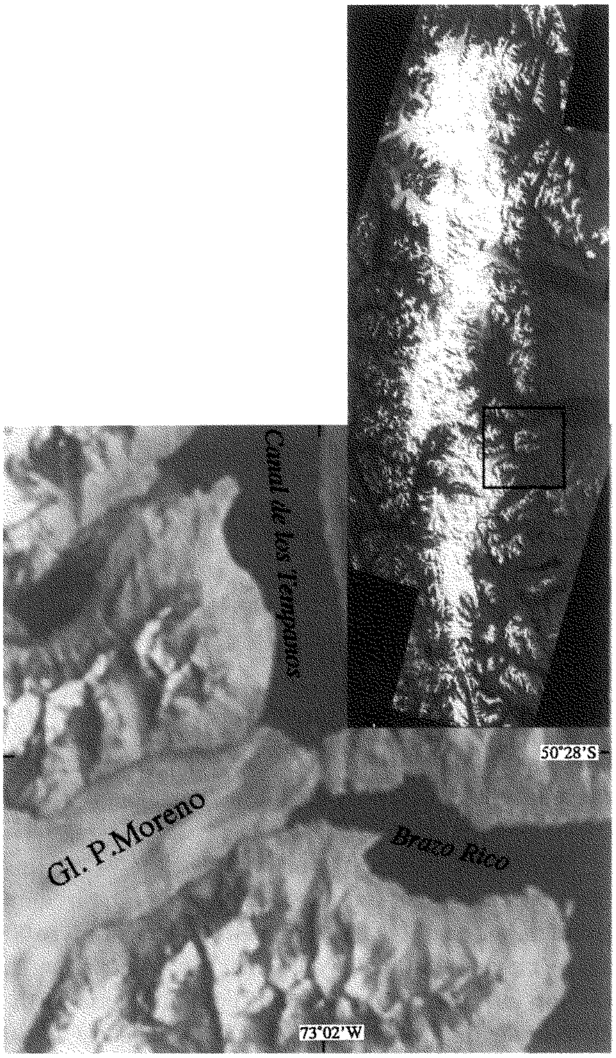

Fig. 3. Landsat TM image of Glaciar Perito Moreno (January 14, 1986). Inset: Landsat ETM mosaic of the HPS (March 11, 2001), indicating the location of Glaciar Perito Moreno.

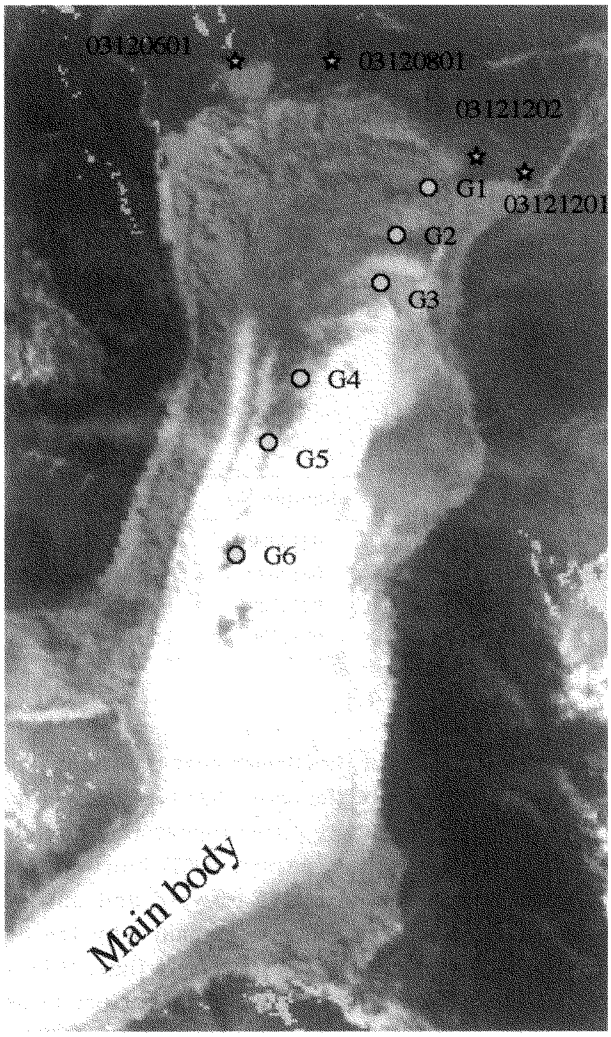

Fig. 4. Landsat ETM image of Glaciar Exploradores (April 2, 2003), on which sampling points for ^{14}C dating materials and GPS points for glacier flow measurements are indicated.

Argentina at latitude 47.6° S, to the southeast of the HPN, and Co. Fitz Roy (3,405 m) is located on the eastern edge of the HPS at latitude 49.3° S, to the north of Glaciar Viedma, the second largest glacier in Patagonia.

3. Fieldwork

3.1. Glacier Exploradores and the HPN

Schedule: November 28-December 13, 2003

Member: M. Aniya, T. Aoki, T. Sawagaki, T. Tanikawa and G. Barcaza

Activities: Measurements of glacier flow, collection of materials for ^{14}C dating, and measurements of glacier surface albedo and roughness.

The weather in November and December 2003 was exceptionally bad in the HPN area and of two weeks in the field we had only two days without rain. We could never see Monte San Valentin (3910 m), the highest mountain in Patagonia, although the campsite was one of the best spot for viewing the mountain. The location of BC was not convenient, because we had to cross a branch of the outlet stream, about 20 m wide and knee-thigh deep, to go to glacier every time.

(1) Glacier flow

Initially we planned to carry out the measurement of glacier flows with a GPS and an Electronic Distance Meter (EDM) in the ablation area of the glacier. However, we could not use the EDM. The primary reason was that the glacier was too big to establish control points on lateral moraines on either side of the glacier (about 2.7 km wide), and going to lateral moraines required crossing marginal streams/pond, which was practically impossible.

Instead of using stakes, we chose prominent boulders for the differential GPS measurement, and established six GPS stations from near the debris covered snout to dirt mounds on clean ice about 7 km upstream (Fig. 4). Preliminary results of these measurements are shown in Table 1. The notable results are

Table. 1. Flow speed of Glaciar Exploradores (movements by differential GPS).

Point	Horizontal (m)	Vertical (m)	Azimuth (degree)	Number of days	Daily movement	
					H (cm)	V (cm)
G1	0.58	1.31	E 28.7	9	6.5	14.5
G2	0.73	0.99	E 10.0	9	8.1	11
G3	0.83	1.2	E 7.9	9	9.3	13.3
G4	0.68	−0.08	W 40.0	8	8.5	−0.9
G5	0.67	−0.19	W 3.5	8	8.4	−2.3
G6	0.91	−0.18	W 10.5	8	11.4	−2.2

Table 2. ^{14}C Dating Results.

Sample No.	Material	Year (calibrated)	
03120601	wood	1900 BP±50	(Beta 188284)
03120801	organic sediment	122.6 BP±0.2 pMC	(Beta 188285)
03121201	organic sediment	108.9 BP±0.7 pMC	(Beta 188283)
03121202	leaves	115.3 BP±0.3 pMC	(Beta 188282)

upward movement of the glacier near the snout. The debris-covered area of the snout has been slowly decaying, thereby becoming pitted topography and has been considered dead ice (Aniya, 2001): however, our measurements revealed active forward and upward movements. These movements explain why the debris-covered part has existed for a long time, at least since 1946. While in the field, we made cursory measurements of ablation, which was about 20 cm or more in a few days. If the glacier were not active in upward movement, the surface would have lowered rapidly with this rate of melting during summer.

(2) Solar radiation, glacier surface albedo and glacier surface roughness

We carried out measurements of solar radiation and glacier surface albedo by albedometer in the middle of white expanse of the ablation area. Since the weather had been unusually bad when we were in the field, the measurements were not ideal. The broadband albedo in the solar spectral region (300–3000 nm) was measured using albedometer (EKO Instruments Trading Co., Ltd, Japan). The broadband albedo was sampled every 1 second and 10-second averaged values were stored in a data logger. To keep the observational condition uniform, we analyzed only data closest to the local solar noon (13: 00–14: 00 LT). The albedo was approximately 0.74 under the cloudy sky (cloud cover 7/8). This is relatively low as compared to new snow, which may be accounted for by wet snow (granular snow) on the glacier surface with scattered tiny-debris cover.

The roughness of glacier surface was estimated for the radar backscatter, by measuring two traverse lines with a handy altimeter and a range finder in the middle of the ablation area. The width and length of crevasse were about 7 m and 22 m, respectively, under the assumption of the hemispheroid form of crevasses.

(3) Moraines

We have collected four samples for ^{14}C dating from the moraines; one piece of wood and three organic materials (Fig. 4). The results are listed in Table 2. The organic samples were collected from the under the top surface of moraine (cliff) or sediments in the depression in the moraine surface. A piece of wood (03120601) was recovered from the proximal side of the western part of the prominent moraine (Fig. 4). The lake in front of this moraine has been slowly expanding since 1974. There is a cluster of wood pieces embedded about 5 m above the present lake level. Apparently these wood pieces were entrapped in debris on glacier and carried down here. Therefore the age of this piece of wood indicates the lower limit of the moraine formation, which is 1900 BP±50 (calibrated). The three organic samples yielded modern ages. From these data, we only know that the prominent, elongated continuous moraine was formed some time after 1900 BP or about 50 AD. Within this time constraint, two or three glaciations have been recognized in the HPN (Aniya and Naruse, 1999; Glasser *et al.*, 2002). Therefore, before we can assign the certain age to this moraine in order to establish the glacial chronology of the HPN, we have to collect some more data.

(4) Environmental change - recent warming?

While walking around the big, prominent moraine, we observed a few interesting phenomena. We saw several spots at the base of proximal side of the moraine, where water was seeping out/flowing out, thereby forming a pond (Fig. 5). Submerged trees (diameter at breast height, up to 20 cm or so) are common

Fig. 5. Pond formed and fed by recent core-ice melting and convex slope above the pond. Note: submerged trees in the pond. The convex slope is the result of bulging caused by flowage due to core-ice melting. Many trees on this slope have tilted (Photo Dec. 6, 2003). Location, near the sampling point 03120801 of Fig. 4.

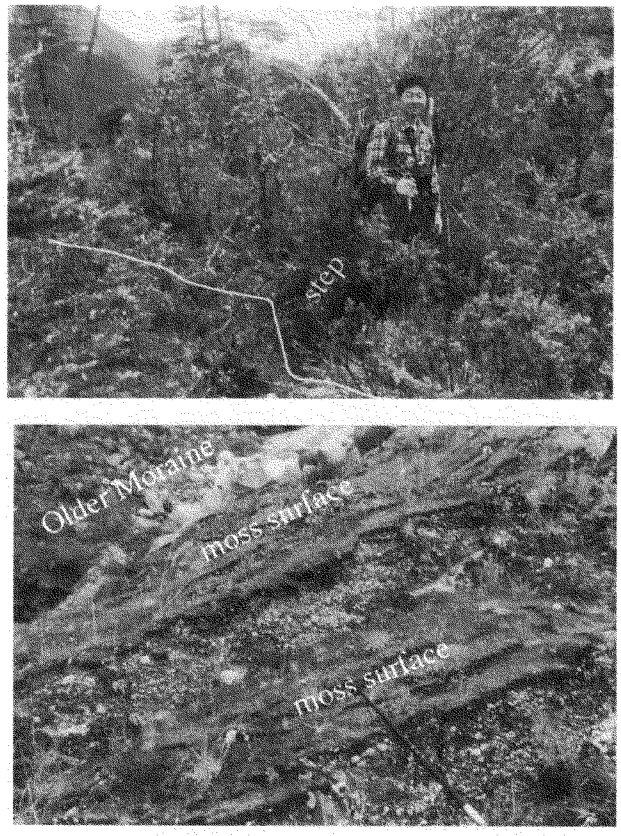

Fig. 6. Surface deformation due to recent core-ice melting. Top: Vegetated surface with soil about 20–30 cm thick. White line indicates surface. The height of the step about 50 cm (Dec. 8, by Aniya). Location, near the sampling point 03120601 of Fig. 4. Bottom: stepped surface covered with moss, right next to the older moraine (probably of LIA) (Dec. 1, by Aniya). A stick as scale. Location, near G1 of Fig. 4.

in such ponds. Normally, above such spot/pond is located uneven, convex slope with cracks and small cliffs (a few cm or more) with tilted trees, which are characteristics of a typical ice-cored slope. At one spot, we saw the exposure of core-ice at the base of the big moraine. Between this prominent moraine and the debris-covered snout, there are many moraines covered with trees and/or grasses. To support trees, soil must have developed, which requires some stability of the surface. However, we saw quite a few moraines that are covered with large/dense trees, yet whose surface has gotten cracked open and became soggy due to core-ice melting (Fig. 6). The thickness of top soil layer is about 20 cm or more, suggesting that for a long time, the environment had been stable so that soil developed and trees have grown; however, core-ice has started melting recently, probably due to temperature rise.

(5) Aerial survey

We planned to make two aerial surveys: circumferential flight of the HPN to take snout photos of the outlet glaciers to update the variation (Aniya, 1987; 1992; 2001; Wada and Aniya, 1995; Aniya and Wakao, 1997) and vertical photographs of Glaciers Soler and Exploradores. However, due to the exceptionally bad weather in December, we could barely fly once for oblique photographs of the outlet glaciers. Although the vertical photographs of Glaciar Exploradores were important for detailed topographic mapping of the glacier for fieldwork and we established some ground control points (GCPs), we had to give up this time.

Based on the results and experience of the December 2003 fieldwork, we discussed about the fieldwork in 2004/2005, in which we plan to include hydrometeorological observations and ice-radar thickness measurements. In the course of discussion, we came up with the idea of going there during austral winter (July-August) to avoid excessive melt water in the glacier for ice-radar measurements. Also Aniya has been contemplating for some time an aerial survey of the HPN in winter, because he has postulated that winter precipitation may not be as important/dominant as normally thought to nourish and maintain the HPN glacier (Aniya, unpublished).

Consequently, Aniya went back to Patagonia in July 2004 for aerial survey and reconnaissance of Glaciar Exploradores in winter. He flew on July 25 in one of the two best weather conditions in 20 years of his aerial survey experience, with no wind at all. The result was what Aniya anticipated for the HPN winter condition, that is, not much snow in general, although there are regional differences. Those glaciers located on the north and west sides of the HPN were mostly snow-free on the lower part of glaciers (Glaciers Exploradores, Grosse, Reicher, Gualas, San Rafael, San Quintin, Benito, HPN1, HPN2, HPN3). Even proglacial lakes are not frozen, as well as some supraglacial lakes on these glaciers. In particular, the valley of Río Exploradores looks as green as in summer, without snow at all.

The roads to Glaciar Exploradores were mostly snow/ice-free and we visited the glacier on July 26–27. The temperature during the night was only −2℃ due to cloud cover. Previous evening the temperature dropped to −5℃ before becoming cloudy. So the temperature we would experience is probably in the neighborhood of −10 to −15℃ when the sky is clear. The scenery is almost as green as in summer: only difference was that plant "Nalcas" were dead and rotten among evergreen plants such as "Nothofagus" and "Calafate", offering easy passage through dense bush. The glacier surface on which we walked around in December 2003 was completely snow-free and as dirty as and strewn with debris just as in summer (Fig. 7). Proglacial and supraglacial ponds are not frozen, except for very small ones, and water was flowing.

With running water readily available and without snow and winds, fieldwork in winter at Glaciar Exploradores seems very feasible. The big advantage of winter fieldwork is the weather, *i. e.*, there is a spell of sunny days without winds at all, although the temperature during the night may be low, between storms. With the sunshine during the daytime, fieldwork should be no problem with proper attire.

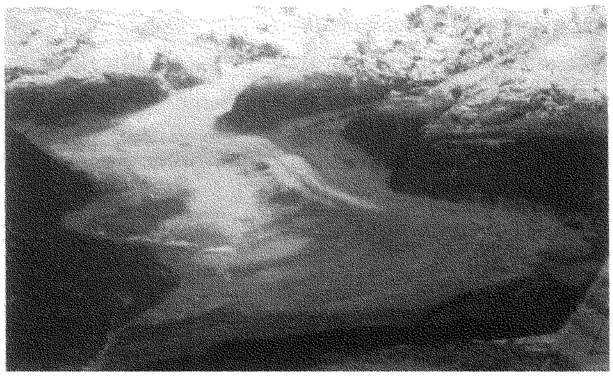

Fig. 7. Winter aerial view of Glaciar Exploradores (July 25, 2004, by Aniya). No snow at all on the ablation area of the glacier. The elevation of the glacier surface in the photograph is about 240–400 m a.m.s.l.

3.2. Glacier Perito Moreno, HPS

Schedule: November 27-December 19, 2003

Members: K. Satow, P. Skvarca, R. Naruse, E. Isenko and C. M. Paterlini

Activities: measurements of glacier flow, glacier profile, bathymetry of lake and sediment thickness, and supraglacial stream investigation.

We have conducted the following measurements and observations at Glaciar Perito Moreno of the HPS, in an attempt to shed light on the calving mechanism. While we were in the field, one of the most interesting phenomena at Glaciar Perito Moreno was occurring, that is, damming up of the lake to the south, Brazo Rico-Sur (Fig. 8). This provided us with a rare opportunity to observe and measure the glacial processes such as flow speed and calving during the damming-up.

(1) Glacier flow

Glacier flow speed at the terminus was measured with an EDM every day or two, and also with taking a stereo-pair of photos twice a day. We also measured the height of seracs above the lake surface near the terminus. During the observation period, the average flow speed was 2.3 $\mathrm{md^{-1}}$ at the terminus, with the frontal height of about 52 m. The flow speed at upstream where the glacier enters into the lake was measured to be 5 $\mathrm{md^{-1}}$. Comparing with those measurements in 1999 (Naruse *et al.*, 2001), the flow speed in 2003 was faster, although the glacier height above the lake surface was about the same.

Fig. 8. Glaciar Perito Moreno, showing the ice dam that had separated Brazo Rico-Sur (far side) from Canal de los Témpanos (near side). (Nov. 28, 2003, by Satow).

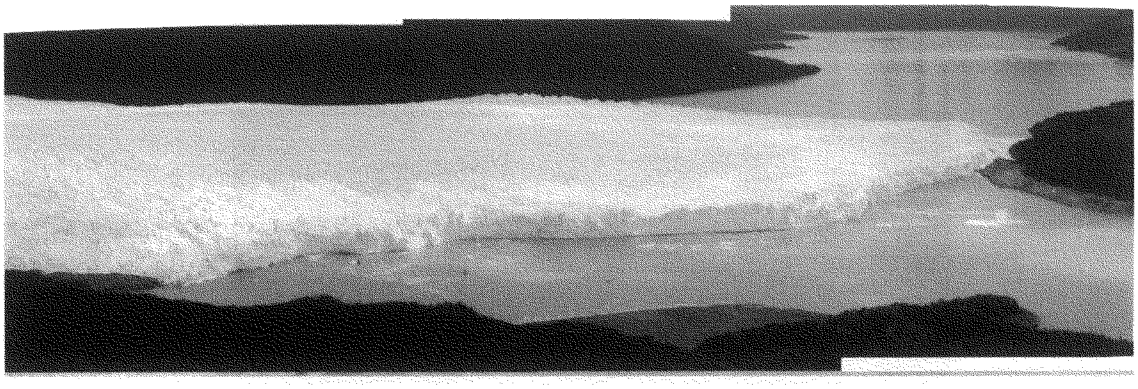

Fig. 9. Calving front of Glaciar Perito Moreno, showing that the tip of ice has reached the opposite bank, thereby blocking water flow between two lakes. Near side lake is Brazo Rico-Sur, and the far side is Canal de los Témpanos. Normally water flows from Brazo Rico-Sur to Canal de los Témpanos. (Dec. 13, 2003, by Skvarca).

(2) Calving events

We set up a water-level (pressure) gauge in the lake that recorded every 2 seconds, from which we estimated the frequency and magnitude of calving events. During the observation period, the average number of daily calving was 25, which is much more than 7 of the 1999 observation (Iizuka *et al.,* 2001). However, again, there seems no correlation between the number of daily calving events or hourly calving events and temperature variations. Comparing with the 1999 data, flow speed was slightly faster and the number of calving events was much more, which may be interpreted as the effect of increased buoyancy or reflecting change in the glacier flow system.

(3) Cross-profile of glacier surface

At the mid-section of the glacier, we measured a cross-profile of the glacier surface with an EDM (which is going to be analyzed soon). We have repeatedly measured the profile since 1990 (Naruse *et al.,* 1995a; Skvarca and Naruse, 1997), and found out that the period1990–1999 was very stable without thickening or thinning. However, between 1999 and 2002, the glacier was found to be thickening (Skvarca *et al.,* 2004). From 2002 to 2003, the glacier was almost steady. We think that the thickening trend in the middle reach between 1999–2002 may have effected the advance in 2003 for damming up of Brazo Rico-Sur; however, more detailed mechanism must be clarified.

(4) Supraglacial hydrology

At the mid-section and terminus of the glacier, we mapped the distribution of supraglacial streams, and measured water flow-speed and temperature, and the depth of moulins.

(5) Meteorology

At the terminus and the mid-section, we measured temperature and solar radiation with a data logger.

(6) Bathymetry and sounding of lake sediments

In order to study the past evolution of Glaciar Perito Moreno, a survey of thickness distribution of sediments was made at Brazo Rico in December 2003. Measurements were carried out continuously almost all over the lake from a semi-rigid rubber boat, using a high-resolution seismic reflection system (EPC Boomer). The total survey distance reached about 100 km, and the thickness of sediments ranges from 5 m to 30 m. A mean depth of Brazo Rico near the glacier front was found to be around 100 m. Warren (1994) reported the depth about 170 m by spot measurements, and the difference is probably due to the difference in measuring sites.

(7) Water-level of lake "Brazo Rico-Sur"

Since the austral spring 2003, the glacier front has reached the opposite bank, thereby blocking the water flow from Brazo Rico-Sur to Canal de los Témpanos, causing water-level rise. By December 14, 2003, the water level had risen by 4.2 m.

Damming up process in 2003 is as follows (Skvarca *et al.,* unpublished). The tunnel in the glacier front, through which water had been drained from Brazo Rico-Sur to Canal de los Témpanos, has closed off probably in September/October 2003, thereby completely separating Brazo Rico-Sur from Canal de los Témpanos (Fig. 9). The water level continued to rise by several cm per day until March 11 when the water level reached the highest at 9.3 m above the normal. The area of Brazo Rico-Sur expanded from 125 km^2 to 170 km^2 with the width of 2.5 km and a length of 48 km. Then water started to drain through cracks in the glacier or subglacial water channels, and on March 13, the frontal part of the ice-dam (several tens of meters high and several tens of meters wide) almost instantaneously collapsed, thereby discharging about 10^9 m^3 of water into Canal de los Témpanos.

3.3. *Patagonian volcanic field and Cerro San Lorenzo and Cerro Fitz Roy*

Schedule: February 26-March 28, 2004

Members: R. Anma, A. Veloso, R. Endo, S. Yamamoto, and S. Ike

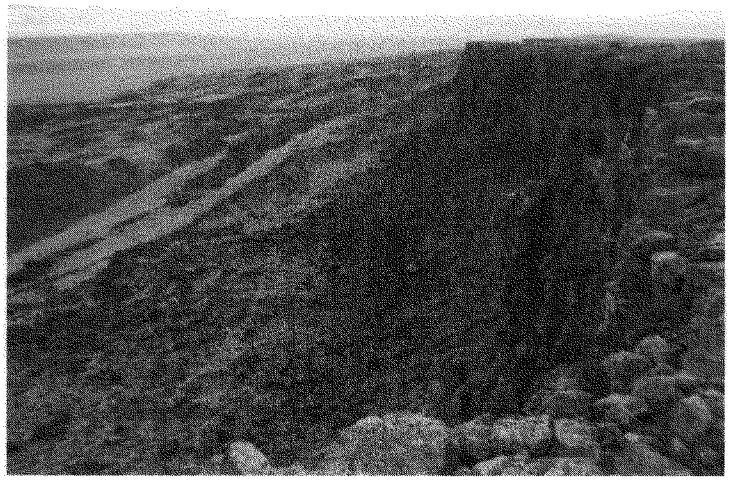

Fig. 10. View of a ridge system that encircles Meseta near Tamel Aike at 48.7° S (Mar. 18, 2004, by Anma).

Activities: Sampling rocks and sediments and reconnaissance of moraines of some alpine glaciers.

(1) Geomorphological investigation of the Patagonian volcanic field

The Patagonian volcanic field, rather flat with deeply eroded Mesetas, provides an excellent opportunity to observe cross sections of piles of lava flows and allows sequential sampling of oriented samples for analyses. The younger Pliocene-Pleistocene volcanic rocks form a horizontal thin sheet of less than 4 m thick. They have filled in the area of topographic low. In contrast, the older Miocene volcanic rocks are distributed in higher elevations, forming almost horizontal terrace of the Mesetas (Fig. 10). They comprise a pile of lava flows that reaches 40 m in total thickness, with each less than 10 m in thickness. The base of these lava flows is exclusively covered with loose conglomerate and/or sand. Such loose sediments were observed throughout this area and may be of ice-sheet related deposit. Further systematic investigation will be necessary to clarify the origin. No esker or sandur-like structure was recognized during this reconnaissance. It is noteworthy that a thick pile of Miocene lava flows is normally faulted and slid (Fig. 10) or toppled along edges of the Meseta due to deep incision by the drainage system, and forms a series of ridge systems that fringe the Meseta. We collected oriented rock samples only from the cliff walls or top of the terraces to avoid the effect of later block rotation due to gravity sliding.

(2) Alpine glaciers and moraines of Cerro San Lorenzo and Cerro Fitz Roy

Figure 11 is based on the geological map by Welkner *et al.* (2002). We traveled along Río Tanquilo and Río San Lorenzo. The valley head of Río San Lorenzo is covered by a small glacier (indicated by GSL in Fig. 11), which has a series of terminal moraines with a glacial lake and ablation valleys (Fig. 12). At least, two lateral moraines are recognizable from this photograph. In addition, we crossed several small mo-

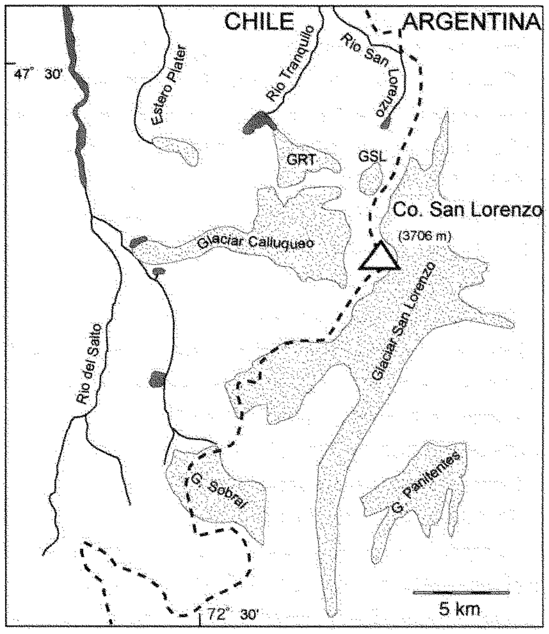

Fig. 11. Map showing the distribution of glaciers around Co. San Lorenzo. Broken line, national boundary: Dark pattern, lake.

raine ridges in the field to reach the foot of the eastern ridge of Co. San Lorenzo (3706 m). Detailed mapping of such small topographical features may lead us to further understanding of behavior of alpine glaciers, which is sensitive to small-scale environmental changes. In the valley of Río Tanquilo, three levels of lateral moraines can be recognized (Fig. 13). The lowest lateral moraine is clearly visible in the upstream to the right (south), while the highest lateral moraine is traceable in the middle part of Figure 13 and continues to the left, which is interrupted by a landslide. The trim line of the intermediate lateral moraine can be recognized, although weak, in the middle of the highest moraine slope; but is obliterated by fan deposits in the center. Ages of these moraines are not yet known.

Figure 14 was drawn based on a trekking map

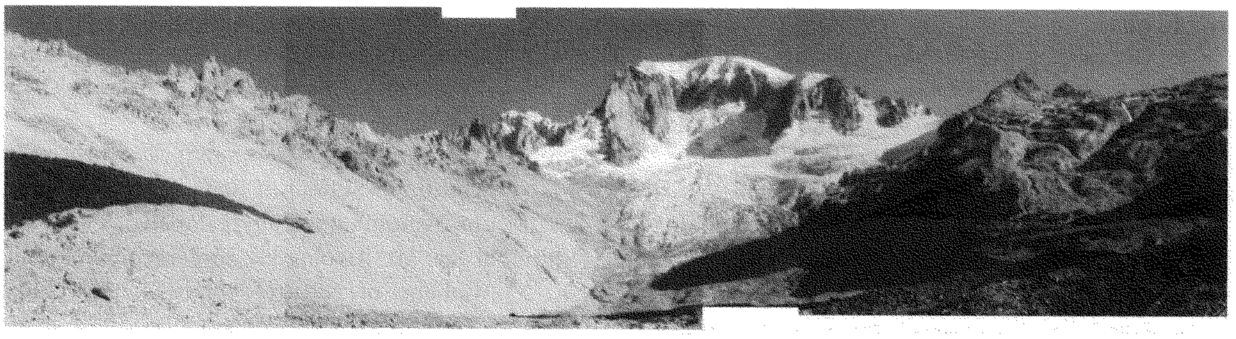

Fig. 12. Co. San Lorenzo seen from Río San Lorenzo, in which lateral moraines are recognizable (Mar. 11, 2004, by Anma).

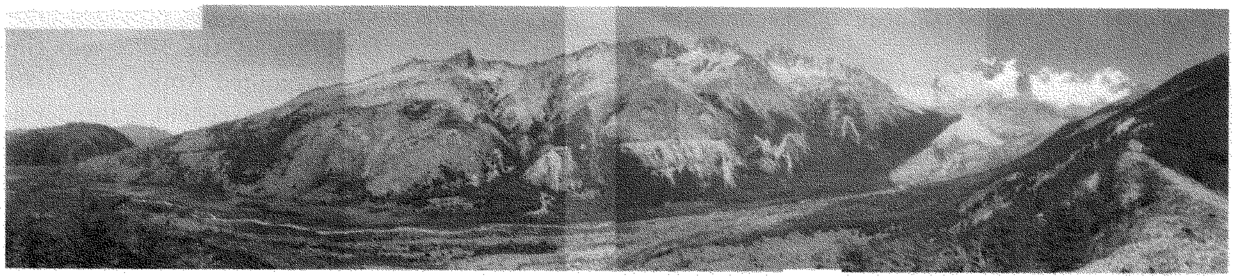

Fig. 13. Lateral moraines developed along Río Tranquilo. A huge landslide interrupts the highest Lateral moraine that continues from right to left of the photograph. The foot of this landslide is covered by fan deposit in the center (Mar. 9, 2004, by Anma).

(Zagier & Urruty publications, 2004). Co. Fitz Roy (3405 m) is composed of a Miocene pluton intruded into basement rocks of the Jurassic age. The regional glacial chronology of this area since the Late-glacial period is summarized by Wenzens and Wenzens (1997). We visited Lago Torre and also approached Co. Fitz Roy from Río Electrico. In the Río Electrico area, a brief observation was made on a small glacier (GE in Fig. 14) of Co. Guillaumet. The glaciers Torre and Grande merge and flow into Lago Torre to the south of Co. Fitz Roy, around which two closely-spaced terminal moraines were clearly observed. The younger moraine forms Lago Torre. In between, ablation moraines in the shape of small cones are scattered. Ages of these moraines are not known.

(3) Lacustrine deposit around Lago General Carrera

We took a short visit to an outcrop of lacustrine sediments deposited around Lago General Carrera near Puerto (Pto.) Fachinal (see Fig. 1). Medium to fine-grained sand and silt were deposited here, forming rhythmic layers. Oriented samples were collected from this outcrop. No microfossils were found by brief microscopic observations.

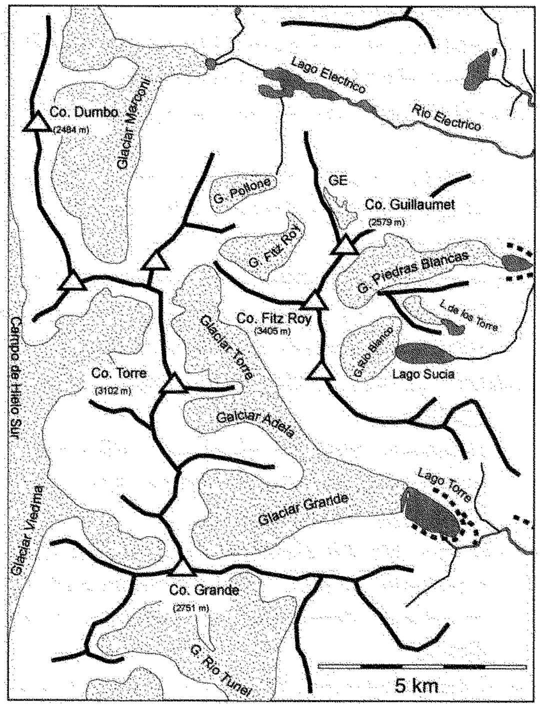

Fig. 14. Map showing the distribution of glaciers around Co. Fitz Roy.

4. List of members in Glaciological Research Project in Patagonia in 2003

The affiliation and title are those at the time of participation

Principal Investigator

Masamu Aniya, Dr. (Geomorphologist), Professor
Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan

Co-Investigator
Takanori Nakano, Dr. (Geologist), Associate professor
Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
Ryo Anma, Dr. (Geologist), Assistant professor
Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
Tatsuto Aoki, Dr. (Geomorphologist), Associate professor
Department of Geography, Kanazawa University, Kanazawa, Japan
Kazuhide Sato, Dr. (Glaciologist), Professor
Nagaoka National College of Technology, Nagaoka, Japan
Takanobu Sawagaki, Dr. (Geomorphologist), Research assistant
Graduate School of Environmental Earth Sciences, Hokkaido University, Sapporo, Japan
Pedro Skvarca, Lic. (Glaciologist), Head of Glaciology Division
Instituto Antártico Argentino, Buenos Aires, Argentina
Neil Glasser, Dr. (Glacial Geomorphologist), Senior lecturer
Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth, Aberystwyth, UK
Stephan Harrison, Dr. (Geomorphologist), Senior researcher
Oxford University Centre for the Environment, Mansfield Road, Oxford, UK
Field Members
Renji Naruse, Dr. (Glaciologist), Associate professor
Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan
Tomonori Tanikawa, Mr. (Glaciologist), Doctoral student
Graduate Student, Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
Evgeni Isenko, Mr. (Glaciologist), Doctoral student
Graduate School of Environmental Earth Sciences, Hokkaido University, Sapporo, Japan
Carlos Marcelo Paterlini, Mr. (Geographer), Ingeniero Geodesta y Geofisico, Comisión National del Limite Exterior de la Plataforma Continental
Gonzalo Barcaza, Mr. (Geographer)
self-employed, Santiago, Chile
Ryota Endo, Mr. (Geologist), Doctoral student
Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
Andrés Eugenio Veloso, Mr. (Geologist), Doctoral student
Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan
Shinji Yamamoto, Mr. (Geologist), Doctoral student
Graduate School of Science, Tokyo Institute of Technology, Tokyo, Japan
Shin-ichi Ike, Mr. (Geologist), Undergraduate student
College of Natural Sciences, University of Tsukuba, Ibaraki, Japan

Acknowledgments:

Sr. Roberto León of Transportes Aereos "Don Carlos" LTDA in Coyhaique, Chile, provided information on winter condition of the HPN and Glaciar Exploradores, which prompted Aniya to go there in winter. As always, he made excellent flights for aerial survey of the HPN outlet glaciers in December 2003 and July 2004.

References

Aniya, M. (1987): Aerial surveys over the Patagonia Icefield. Bull. Glacier Res., **4**, 157-161.

Aniya, M. (1988): Glacier inventory for the Northern Patagonia Icefield, Chile, and variations 1944/45 to 1985/86. Arct. Alp. Res., **20**, 179-187.

Aniya, M. (1992): Glacier variation in the Northern Patagonia Icefield, Chile, between 1985/86 and 1990/91. Bull. Glacier Res., **10**, 83-90.

Aniya, M. and Skvarca, P. (1992): Characteristics and variations of Upsala and Moreno glaciers, southern Patagonia. Bull. Glacier Res., **10**, 39-53.

Aniya, M., Naruse, R., Shizukuishi, M., Skvarca, P. and Casassa, G. (1992): Monitoring recent glacier variations in the Southern Patagonia Icefield, utilizing remote sensing data. International Arch. Photogramm. Remote Sensing, **29** (B7), 87-94.

Aniya, M., Sato, H., Naruse, R,. Skvarca, P. and Casassa, G. (1996): Remote sensing application to inventorying glaciers in a large, remote area - Southern Patagonia Icefield. Photogramm. Eng. Remote Sensing., **62**, 1361-1369.

Aniya, M., Sato, H., Naruse, R,. Skvarca, P. and Casassa, G. (1997): *Recent glacier variations in the Southern Patagonia Icefield*, South America. Arct. Alp. Res., **29**, 1-12.

Aniya, M. and Wakao, Y. (1997): Glacier variations of Hielo Patagónico Norte, Chile, between 1944/45 and 1995/96. Bull. Glacier Res., **15**, 1-8.

Aniya, M. and Naruse, R. (1999): Late-Holocene glacial advances at Glaciar Soler, Hielo Patagónico Norte, South America. Trans, Japanese. Geomorph. Union, **20**, 69-83.

Aniya, M. (2001): Glacier variations of Hielo Patagónico Norte, Chilean Patagonia, since 1944/45, with special reference to variations between 1995/96 and 1999/2000. Bull. Glacier Res., **18**, 55-63.

Aniya, M. and Naruse, R. (2001): Overview of glaciological research project in Patagonia in1998 and 1999: Holocene glacier variations and their mechanism. Bull. Glacier Res., **18**, 71-78.

del Valle, R., Skvarca, P., Mancini, M. and Lusky, J. (1995): A preliminary study of sediment cores from Lago Argentino and fluctuations of Moreno Glacier, Patagonia. *Bull. Glacier. Res.*, **13**, *121-126.*

Iizuka, Y., Kobayashi, S. and Naruse, R. (2004): Water surface waves induced by calving events at Perito Moreno Glacier, southern Patagonia. Bull. Glaciol. Res., **21**, 91-96.

Glasser N., Hambrey, M.J. and Aniya, M. (2002): An advance of Soler Glacier , North Patagonia Icefield, at c. ad 1222-1342. The Holocene, **12** (1), 113-120.

Harrison, S., Glasser, N.F. and Aniya, M. (2004): Morphostra tigraphy of moraines in the Lago Tranquilo areas, Chilean Patagonia. Bull. Glaciol. Res., **21**; 37-43.

Halpern, M. (1973): Regional geochronology of Chile South of 50° latitude. Geol. Soc. Amer. Bull., **84**, 2407-2422.

Kay, S., Mahlburg, A., Ramos, V.A. and Marquez, M. (1993): Evidence in Cerro Pampa volcanic rocks for slab-melting prior to ridge-trench collision in southern South America. J. Geol., **101**, 703-714.

Mercer, J.H. (1962): Glacier variations in the Andes. Glaciological Note, **12**, 9-31.

Mercer, J.H. (1968): Variations of some Patagonian glaciers since the Late-glacial. Amer. J. Sci., **266**, 91-109.

Michel, R. and Rignot, E. (1999): Flow of Glaciar Moreno, Argentina, from repeat-pass Shuttle Imaging Radar images: comparison of the phase correlation method with radar interferometry. J. Glaciol., **45** (149), 93-100.

Nakajima, C. (ed.) (1985): Glaciological Studies in Patagonia Northern Icefield, 1983-1984. Data Center for Glacier Research, Japanese Society of Snow and Ice, 133 p.

Nakajima, C. (ed.) (1987): Glaciological Studies in Patagonia 1985-1986. Data Center for Glacier Research, Japanese Society of Snow and Ice, 175 p.

Naruse, R. and Aniya, M. (1992): Outline of Glacier Research Project in Patagonia, 1990, Bull. Glacier Res., **10**, 31-38.

Naruse, R., Skvarca, P., Kadota, T. and Koizumi, K. (1992): Flow of Upsala and Moreno glaciers, southern Patagonia. Bull. Glacier Res., **10**, 55-62.

Naruse, R. and Aniya, M. (1995): Synopsis of glacier researches in Patagonia, 1993. Bull. Glacier Res., **13**, 1-10.

Naruse, R., Skvarca, P., Satow, K., Takeuchi, Y. and Nishida, K. (1995a): Thickness change and short-term flow variation of Moreno Glacier, Patagonia. Bull. Glacier Res., **13**, 21-28.

Naruse, R., Aniya, M., Skvarca, P. and Casassa, G. (1995b): Recent variations of calving glaciers in Patagonia, South America, revealed by ground surveys, satellite-data analyses and numerical experiments. Ann. Glaciol., **21**, 297-303.

Naruse, R., Skvarca, P. and Kobayashi, S. (2001): Measurements of surface height and flow velocity at the calving terminus of Perito Moreno Glacier, southern Patagonia, in December 1999. *In* M. Aniya and R. Naruse (eds.), *Glaciological and Geomorphological Studies in Patagonia 1998 and 1999*, 141-144.

Rott, H., Stuefer, M., Siegel, A., Skvarca, P. and Eckstaller, A. (1998): Mass fluxes and dynamics of Moreno Glacier, Southern Patagonia Icefield. Geophys. Res. Lett., **25** (9), 1407-1410.

Skvarca, P. and Naruse, R. (1997): Dynamic behavior of Glaciar Perito Moreno, southern Patagonia. Ann. Glaciol., **24**, 268-271.

Skvarca, P., Naruse, R. and Angelis, H. (2004): Recent thickening trend of Glaciar Perito Moreno, southern Patagonia. Bull. Glaciol. Res., **21**, 45-48.

Suarez, M. and De la Cruz, R. (2001): Jurassic to Miocene K-Ar dates from eastern central Patagonian Cordillera plutons, Chile (45°-48°S). Geol. Mag., **138**, 53-66.

Takeuchi, Y., Naruse, R. and Skvarca, P. (1996): Annual air-temperature measurement and ablation estimate at Moreno Glacier, Patagonia. Bull. Glacier Res., **14**, 23-28.

Wada, Y. and Aniya, M. (1995): Glacier variations in the Northern Patagonia Icefield between 1990/91 and 1993/94. Bull. Glacier Res., **13**, 111-119.

Warren, C.R. (1994): Freshwater calving and anomalous glacier oscillations: recent behaviour of Moreno and Ameghino glaciers, Patagonia. The Holocene, **4**, 422-429.

Welkner, D., Godoy, E. and Bernhardt, H-J. (2002): Peralkaline rocks in the Late Cretaceous Del Salto pluton, Eastern Patagonian Andes, Aisen, Chile (47°35′S). Revista Geológica de Chile, **29**, 3-15.

Wenzens, G. and Wenzens, E. (1997): Late glacial and Holocene glacier advances in the area of Lago Viedma (Patagonia, Argentina). Zbl. Geol. Palaont. Teil I, H. **3-6**, 593-608.

Zagier & Urruty Publications (2004): Patagonian South Icefield trekking-mountaineering map (1: 50,000). Zagier & Urruty Publications, Buenos Aires, Argentina.