Report 1

Outline of the Glaciological Research Project in Patagonia, 1983–1984

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1. Introduction

The study of global climatic change is very important for management of water resources and disaster prevention, and is one of the most serious topics of the World Meteorological Organization (W.M.O.). Between climatic changes and glacier variations there are intimate relations. The glaciers in Patagonia, South America, have the character of temperate glaciers, showing sensitive variations to short-range climatic changes. Thus, the study of glaciers in this region is very important in order to see the relationship between climatic change and glacier variations. However, very little research has been done in this area due to the its inaccessibility.

Patagonian glaciers are temperate glaciers because of the climatic conditions in this area. Normally, a belt of high pressures crosses South America at about 35°S in the annual mean surface weather chart. Further south, over Patagonia, a steep N-S pressure gradient corresponding to the upper westerly jet stream induces strong westerly humid winds over Patagonia. Thus, the western side of the Patagonian Andes has a large amount of precipitation, while the eastern side has little precipitation. This high pressure belt fluctuates in latitudes from season to season and from year to year.

Some of our members made the preliminary observations in Patagonia in 1967–69. Based on their experience, we planned research on hydrological, meteorological and glaciological characteristics of glaciers for the austral summers of 1983–84 and 1985–86. These factors control the mass balance of the glacier. In the first phase, we selected outlet glaciers located on the western and eastern side of the Patagonia Northern Icefield (Hielo Patagónico Norte) as the main research areas. These glaciers are the San Rafael Glacier (western) and Soler and Nef Glaciers (eastern). Comparison between conditions on the windward and leeward sides of the ice-covered mountain-range is one of the most important purposes of our project.

2. Objectives

The objectives of the Glaciological Research Project in Patagonia (GRPP), from November 1, 1983 through January 24, 1984, were divided into five broad topics as follows:

1) Meteorological Observations
   a) Local meteorological features on glaciers
   b) General meteorological conditions around glaciers
2) Hydrological Observations
   a) Ablation rate of glacier ice
   b) Behavior of melt water on/in glaciers
   c) Hydrological and chemical features in Lagoon San Rafael, Elefantes Fjord and Cacho River drained from Soler Glacier

3) Measurements on Glacier Dynamics
   a) Flow velocities of glaciers
   b) Morphological conditions of/around glaciers
   c) Behavior of calving at the terminus of San Rafael Glacier
4) Aerial Photographic Survey
   a) Distribution of glacial landforms
   b) Structure and morphology of glaciers
   c) Position of glacier terminus
   d) Cloud distribution around glaciers
5) Biological Survey
   a) Observations of insects in glaciers
   b) Ecological features of fish and zooplankton in Lagoon San Rafael and Elefantes Fjord

3. Areas for research activities

In the southern part of the Andes between 46°30′S and 51°30′S lie vast seas of ice called collectively the Patagonia Icefield (Hielo Patagónicos). The Canal Baker (or Estrecho Baker) at around 48°S separates the Northern and Southern Icefields. The Patagonia Northern Icefield is about 100 km long and 45 km wide with an area of 4400 km² (LLIBOUTRY, 1956, Map 1). The highest mountatin in Patagonia, Mt. San Valentin (3910 m), is in the northeastern corner of the Northern Icefield. Much of the icefield is at elevations ranging from around 1000 m on the western side to over 1500 m on the eastern side. Numerous glaciers flow out from this icefield. Reflecting the general precipitation pattern, outlet glaciers on the western side are longer and more active than those on the eastern side.

San Rafael Glacier, whose main ablation area is located around 46°41′S and 73°51′W, is one such glacier on the western side, flowing northwest into Lagoon San Rafael. It is 45 km long and 4 km wide (LLIBOUTRY, 1956); its elevation varies from sea level to well over 1000 m. The lower part is heavily crevassed and the surface is crisscrossed so much that it is impossible to walk about on the surface. The glacier surface gradually rises and merges into the icefield imperceptibly. During the past few decades, this glacier has been retreating.

Soler Glacier is located on the eastern side of the Northern Icefield, around 46°54′S and 73°10′W. It is separated from the icefield by an icefall about 700 m high. It is a valley glacier, flowing southeast, about 7 km long and 1.5 km wide with an area of 12 km². The elevation ranges from 350 m at the snout to 750 m at the base of the icefall. The glacier consists of two parts; 1) debris-covered and 2) clean bodies. There are two separate ogive systems, one on the body coming from the icefield, and another on the ice coming from the southeastern slope of Mt. Hyades. Although the clean part of the glacier is well crevassed, it is relatively easy to walk on the surface. This glacier has been stable or slowly retreating recently.

4. A brief history of glaciological research in Patagonia

From the beginning of this century, many explorers wanted to see Patagonia. Several books describing this area have been published by AGOSTINI (1945) and others. Systematic glaciological studies of Patagonian glaciers started after the Second World War, especially by LLIBOUTRY (1956), SHIPTON (1963), TANAKA (1958), BERTONE (1960), MERCER (1962, 1964), HEUSSER (1960, 1961), and others. Mainly by Bertone (Argentina) and Lliboutry (now in

France but then in Chile), an inventory of the glaciers in Patagonia was made and the glacier variations were described in their books. Similar work was also done as part of the UNESCO International Hydrological Decade (I.H.D.).

Owing to the bad weather condition, it was very difficult to make maps from aerial photographs. However, this work began after trimetrogon photography was obtained in 1944 and 1945. Over the Northern Icefield, topographic maps at a scale of 1:50,000 with a 50 m contour-interval were completed by 1983 from the vertical aerial photographs taken in 1974 and 75 and subsequent aerotriangulation. Satellite imagery is also useful to make planimetric maps of larger areas, but good images are scarce due to cloud cover. By comparing these aerial photographs and several LANDSAT images, we can study variations of some glaciers between 1944 and recent times. In order to utilize these remote sensing data effectively, it is very important to obtain ground truth in this area.

Scientific explorations by Japanese parties were initiated by Kobe University in 1957 (Leader: Tanaka). From 1966 to 1971, glaciological research was done by several universities and organizations including Hokkaido University, Kyoto University, Tokyo Institute of Technology, Hiroshima University and Rokko Gakuin School. An outline of these activities was given by the "Research Committee on Patagonia Glaciers" (1983).

Recently, climatological studies in Patagonia have been done by FUENZALIDA (1982) and PITTOCK (1980a, 1980b). From 1974, images taken by the stationary satellites SMS/GOES are available, for synoptic weather analysis in this area.

5. Members

The members of the Glaciological Research Project in Patagonia, 1983–1984 were:

Leader:

Chotaro Nakajima, Dr. (Climatology), Professor, Disaster Prevention Research Institute, Kyoto University, Uji.

Field Leader:

Renji Naruse, Dr. (Glaciology), Research Fellow, Institute of Low Temperature Science, Hokkaido University, Sapporo.

Members:

Shun'ichi Kobayashi, Dr. (Meteorology), Associate Professor, Institute of Low Temperature Science, Hokkaido University, Sapporo.

Masamu Aniya, Dr. (Geomorphology), Assistant Professor, Institute of Geoscience, University of Tsukuba, Ibaraki.

Tetsuo Ohata, (Meteorology), Research Fellow, Water Research Institute, Nagoya University, Nagoya.

Takashi Saito, (Hydrology), Graduate Student, Disaster Prevention Research Institute, Kyoto University, Uji.

The following persons carried out cooperative research with the project in the field and in the data analyses.

Shiro Kohshima, (Biology), Graduate Student, Faculty of Science, Kyoto University, Kyoto.

Hiroyuki Enomoto, (Meteorology), Graduate Student, Graduate School of Environmental Science, University of Tsukuba, Ibaraki.

Hiroshi Kondo, (Meteorology), Graduate Student, Disaster Prevention Research Institute, Kyoto University, Uji.

Akira Zama, (Biology), Former Expert of the Japan International Cooperation Agency, Tokyo.
Kazumasa Hirakawa, Dr. (Biology), Marine Biological Research Institute of Japan, Co., Ltd., Tokyo.
Gino Casassa, Ing. (Glaciology), Instituto Antártico Chileno, Chile.

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We are also very much obliged to many Japanese in Chile, especially Ambassador Gen'ichi Akatani and secretaries.

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Reference

AGOSTINI, A. M. de (1945): Andes Patagónicos, 2nd Ed. Guillermo Kraft, Bs. As., 445 p.
BERTONE, M. (1960): Inventario de los glaciares existentes en la vertiente Argentina entre los paralelos 47°30' y 51°S. publ. No. 3, Inst. Nac. del Hielo Continental Patagonico, Buenos Aires, 103 p.
Committee on Patagonia Project of Hokkaido University (1974): Hyoga to iwa to mori no kuni (A country of glaciers, rocks and forests). Hokkaido University, Sapporo, 370 p. (in Japanese).
FUENZALIDA, H. (1982): Evidencias de Cambios Climaticos en el Centro y Sur de Chile. Tralka, **2**(2), 131–145.
HEUSSER, C. J. (1960): Late-pleistocene environments of the Laguna de San Rafael area, Chile. Geogr. Rev. **50**, 555–577.
HEUSSER, C. J. (1961): Some comparison between climatic changes in northwestern North America and Patagonia. New York Acad. Sci. Annals, **95**, 642–657.
IWATA, S. (1970): Kiko to Hyoga (Climate and Glaciers). Hielo Patagonico Sur. Rokko Gakuin Sangakukai Patagonia Tozantai, Kobe, 57–60 (in Japanese).
LLIBOUTRY, L. (1956): Nieves y Glaciares de Chile. Ediciones de la Universidad Chile, Santiago, 471 p.
MERCER, J. H. (1962): Glacier variations in the Andes. Glaciological Notes, No. 12, New York, 9–31.
MERCER, J. H. (1964): Advance of a Patagonian glacier. J. Glaciol., **5**, 267–268.
NAKAJIMA, C. and SATO, K. (1970): Climatic change in the southern part of South America. Kisho Kenkyu Notes, No. 105, 368–376 (in Japanese).
NARUSE, R. and ENDO, T. (1967): Glaciological investigations of northern Patagonian glaciers, Chile. Seppyo, **29**, (6), 167–176. (in Japanese with English abstract).

PITTOCK, A. B. (1980a): Patterns of climatic variation in Argentina and Chile, I. Precipitation 1931–60. Mon. Wea. Rev., **108**, 1347–1361.
PITTOCK, A. B. (1980b): Patterns of climatic variation in Agrentina and Chile, II. Temperature, 1931–60. Mon Wea. Rev., **108**, 1362–1369.
Research Committee on Patagonian Glacier (1983): Glaciological and Meteorological Studies in Patagonia, Chile, by Japanese Research Expeditions in 1967–1982. Data Center for Glacier Research, Japanese Society of Snow and Ice, 18 p.
SHIPTON, E. (1963): Land of Tempest. Travels in Patagonia 1958–1962. Hodder and Stoughton, London, 224 p.
TANAKA, K. (1958): Dai Hyoga o yuku (Crossing the Great Glaciers). Mainichi Shimbun, 232 p. (in Japanese).

Resumen. Bosquejo del Proyecto de Investigaciones Glaciológicas en Patagonia, 1983–1984

El estudio del cambio climático global es muy importante para recursos de agua y prevención de desastres, y es uno de los problemas más serios en los trabajos de la Organización Mundial de Meteorología (W.M.O.). Hay una estrecha relación entre los cambios climáticos y las variaciones glaciares. Los glaciares de Patagonia, Sud América, tienen las características de un glaciar temperado, mostrando sensibles variaciones a los cambios climáticos. Así, el estudio de los glaciares en esta zona es muy importante para ver la relación entre el cambio en el clima y las variaciones glaciares, pero sin embargo hay pocas investigaciones en esta zona debido a su dificil acceso.

Los glaciares Patagónicos se denominan temperados debido a las condiciones climáticas de la zona. Normalmente, un cinturón de altas presiones cruza Sud América cerca de la latitud 35°S. Más al sur, sobre Patagonia, una fuerte gradiente de presión N-S correspondiente al jet stream ascendente del oeste induce fuertes vientos húmedos sobre Patagonia. Así Patagonia occidental tiene alta precipitación, mientras que la vertiente oriental tiene escasa precipitación. Este cinturón de altas presiones tiene fluctuaciones en latitud de acuerdo a la estación del año y de acuerdo al año.

Algunos de nuestros participantes habían hecho observaciones preliminares en Patagonia. Basados en estas experiencias hicimos un plan de estudios de las características hidrológicas, meteorológicas y glaciológicas que controlan el balance de masa de los glaciares en Patagonia desde 1983 a 1986. Este es un informe preliminar del trabajo hecho en el verano austral de 1983–84. En este primer período, se seleccionó glaciares de desagüe occidentales y orientales del Campo de Hielo Patagónico Norte como zona principal de observación. Estos glaciares son el Glaciar San Rafael (vertiente occidental) y los Glaciares Soler y Nef (vertiente oriental) La comparación entre las condiciones a barlovento y a sotavento de la cadena de montañas. cubiertas de hielo es uno de los objectivos más importantes de nuestro proyecto.

Las observaciones del Proyecto de Investigaciones Glaciológicas en Patagonia, Chile en Noviembre, Diciembre 1983 y Enero 1984 estaban divididas en cinco categorías como sigue:

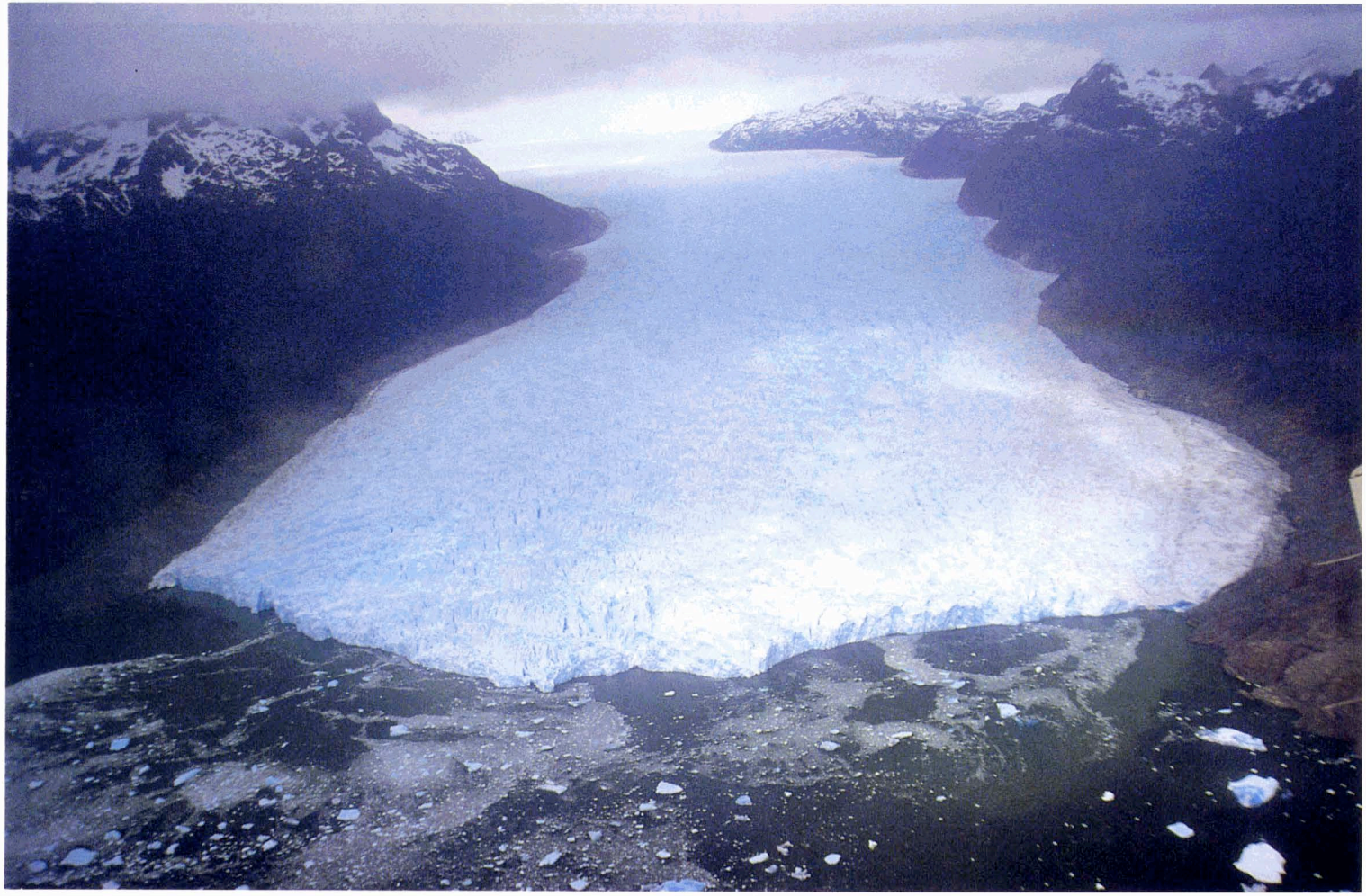
1) Observaciones Meteorológicas
   a) Características meteorológicas locales sobre los glaciares
   b) Condiciones meteorológicas generales alrededor de los glaciares
2) Observaciones Hidrológicas
   a) Tasa de ablación del hielo glaciar
   b) Comportamiento de agua de fusión sobre y en los glaciares
   c) Características hidrológicas y químicas en la Laguna San Rafael y en un río de descarga glaciar

3) Mediciones de Dinámica Glaciar
   a) Velocidad de flujo de los glaciares
   b) Condiciones morfológicas de los glaciares y sus alrededores
   c) Comportamiento del desprendimiento en el frente del Glaciar San Rafael
4) Levantamiento Aerofotogramétrico
   a) Distribución de formas del terreno glaciales y periglaciales
   b) Distribución de nubes alrededor de los glaciares
5) Reconocimiento Biológico
   a) Observación de insectos en los glaciares
   b) Características ecológicas de peces y zooplankton en la Laguna San Rafael

Los participantes del Proyecto eran:
Jefe: Chotaro Nakajima, Dr. (Climatología). Jefe de Terreno: Renji Naruse, Dr. (Glaciología). Participantes: Shun'ichi Kobayashi, Dr. (Meteorología), Masamu Aniya, Dr. (Geomorfología), Tetsuo Ohata (Meteorología), Takashi Saito (Hidrología).

Las siguientes personas desarrollaron investigaciones adjuntas dentro del trabajo de terreno del Proyecto y en el análisis de los datos. Shiro Kohshima (Biología), Hiroyuki Enomoto (Meteorología), Hiroshi Kondo (Meteorología), Akira Zama (Biología), Kazumasa Hirakawa, Dr. (Biología), Gino Casassa, Ing. (Glaciología).

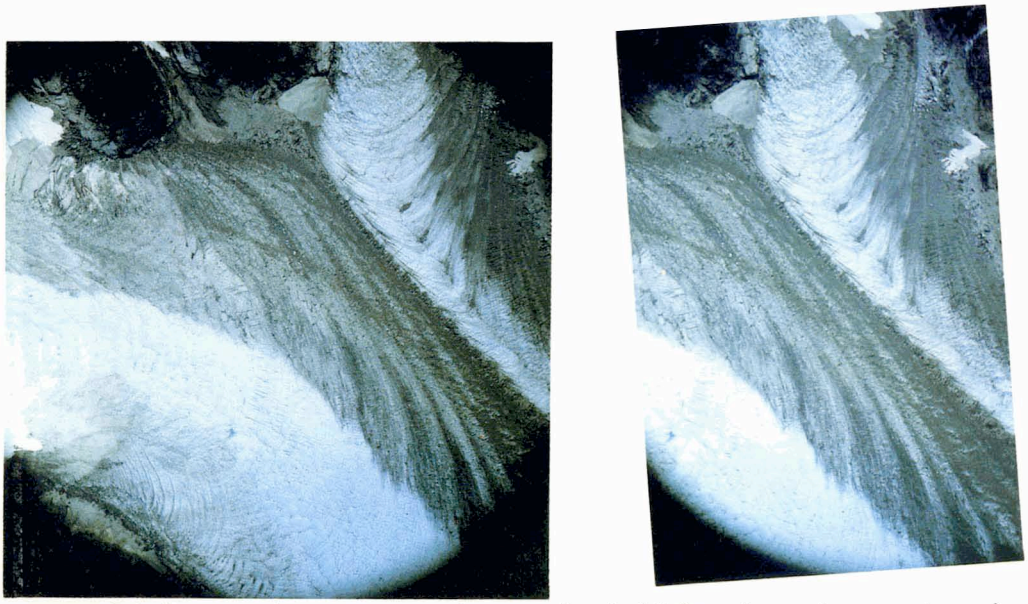
Queremos expresar nuestros sinceros agradecimientos al Gobierno de Chile por otorgar el permiso y consideraciones especiales a nuestro Proyecto. También deseamos expresar nuestros sinceros agradecimientos a un sinnúmero de personas en Chile por su gentil ayuda. El éxito en las difíciles observaciones en el Hielo Patagónico Norte dependio en gran medida del Sr. Juan Vargas, guía de esquí de Coihaique, el cual formá parte de nuestro grupo de observación. Nuestro Proyecto fue financiado por el Ministerio de Educación, Ciencia y Cultura del Gobierno Japonés.



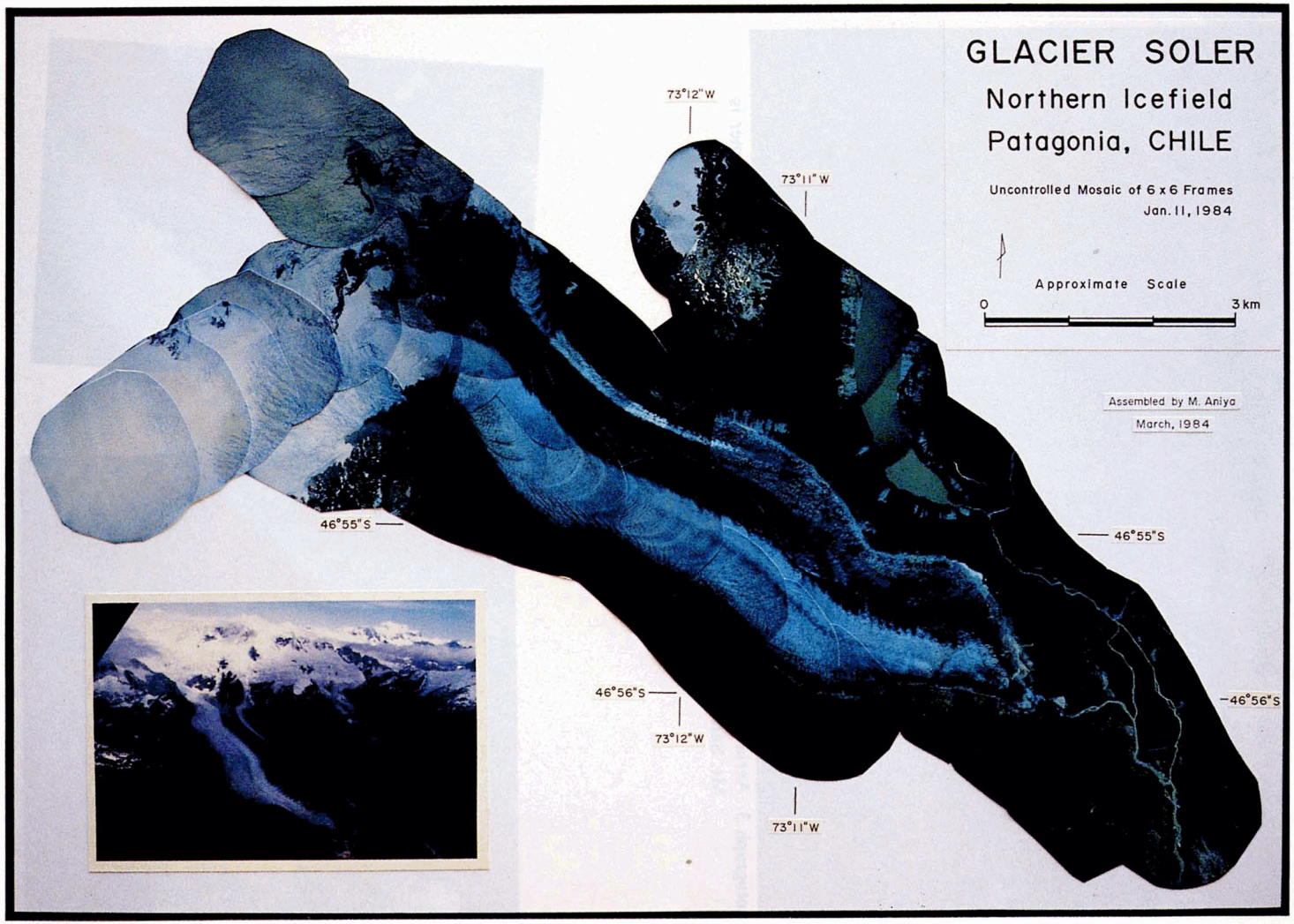
Photograph 1. San Rafael Glacier and Lagoon San Rafael

Photograph 2. The accumulation area of San Rafael Glacier taken from UC2.

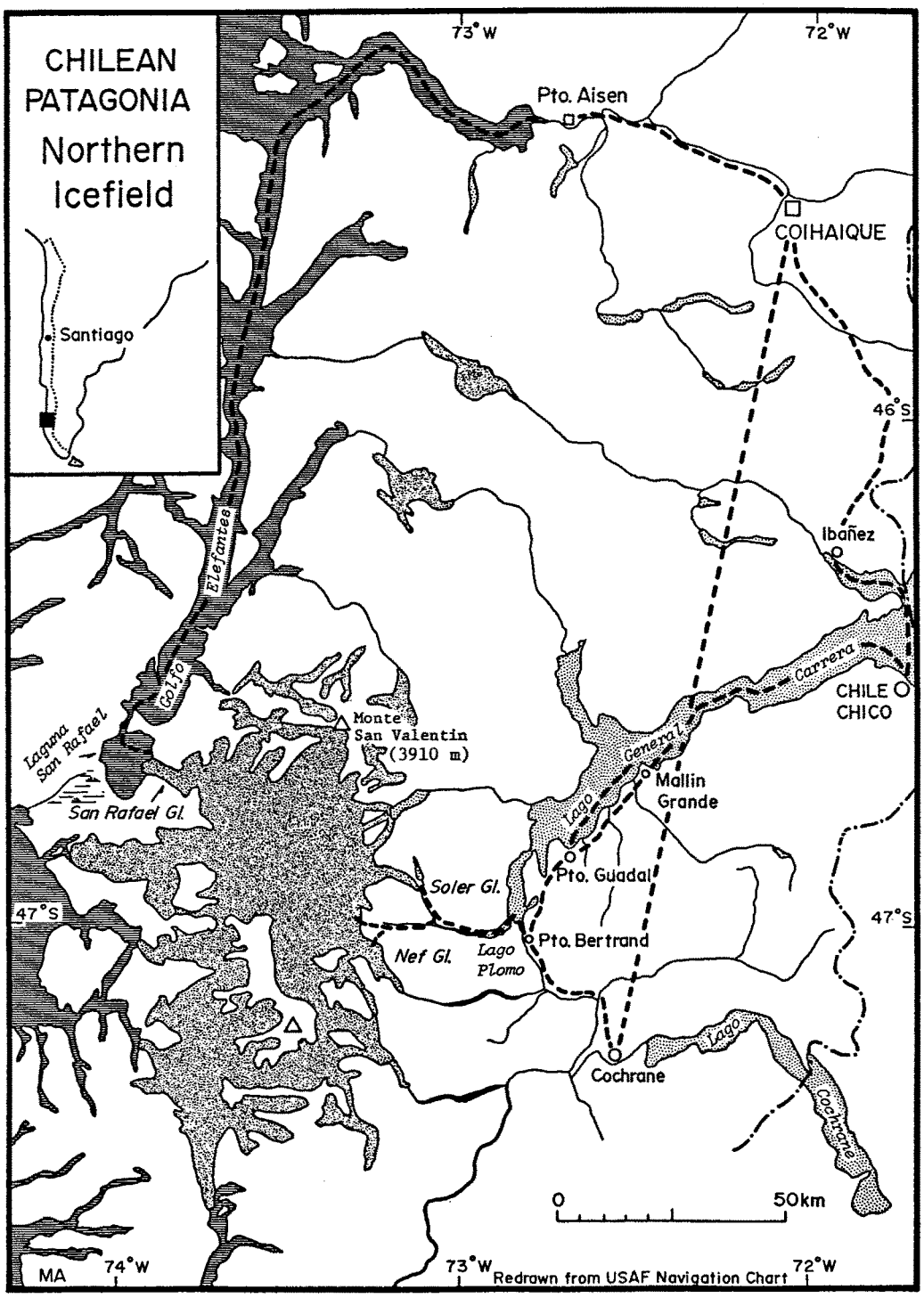
Photograph 3. Aerial view of Soler Glacier and Mt. Hyades. In the upper right corner is Mt. San Valentin.



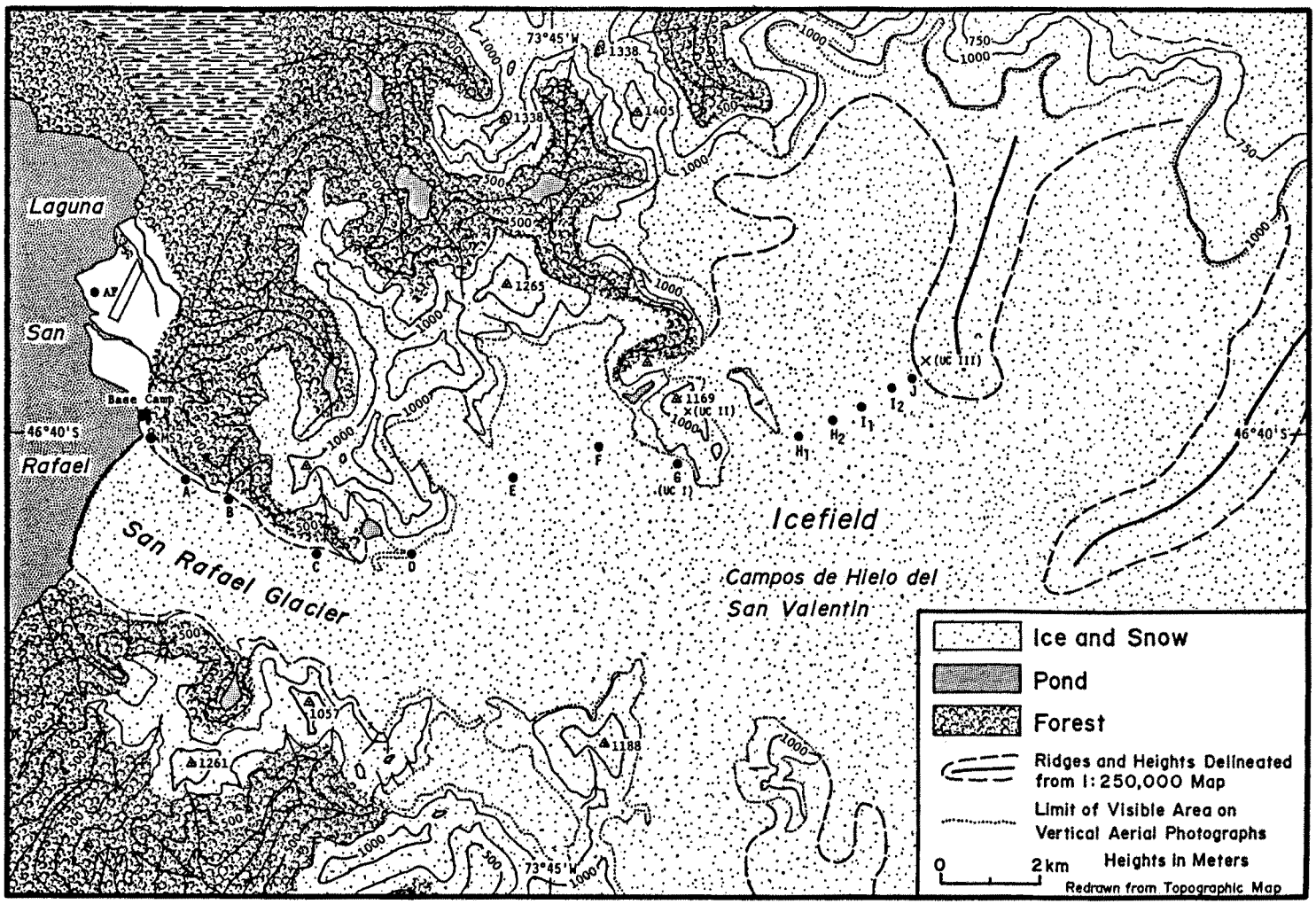
Photograph 4. Stereoscopic coverage over the base of an icefall from the southeastern slope of Mt. Hyades and vicinity.



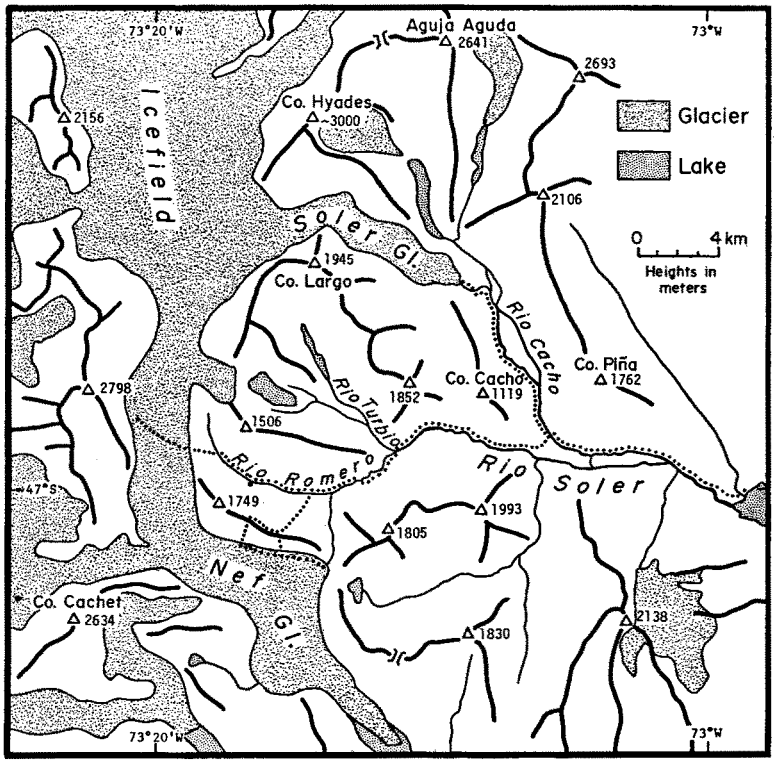
Photograph 5. Mosaic photograph of Soler Glacier.



Map 1. Northern Icefield and expedition routes.



Map 2. San Rafael Glacier and Icefield area showing meteorological observation stations. AF: Air Force Meteorological Station; MS: Meteorological Station; UC1–UC3: Upper stations; A–J: Ablation measurement sites.

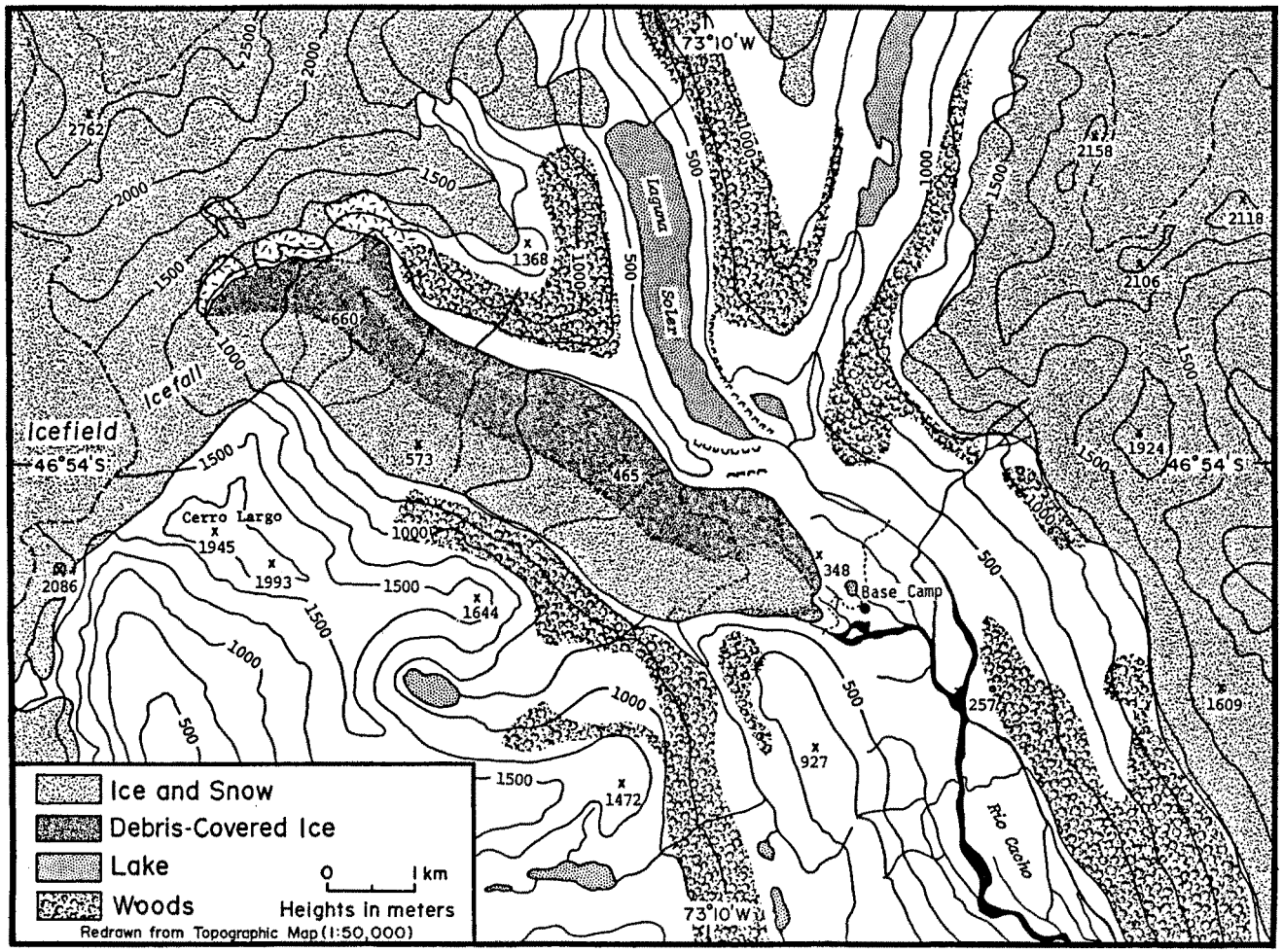


Map 3. Soler River valley and vicinities. Dotted lines indicate expedition routes. The map is based on the preliminary map at 1:250,000 scale and modified using topographic map (Cerro Hyades) at 1:50,000 scale.

Note

There are some mixed-ups in the names of mountains and rivers in the Rio Soler valley area. The mountain labelled "Cerro Hyades" on the 1: 50,000 topographic map (Cerro Hyades) is actually called "Aguja Aguda" by the local people. Lliboutry (1956) gave the name Cerro Hyades to a small peak of 2507 m located 1.5 km to the north of the highest, snow-and ice-clad peak looming over Soler Glacier. On the topographic map, no name and height are given to this beautiful peak owing to the measurement difficulty on aerial photographs. Since Lliboutry listed the height of Cerro Hyades as 3078 m, it seems probable that he meant this highest peak, but dislocated slightly on the map. New Zealand expeditions (1970, 1973) clearly indicated the highest peak as Cerro Hyades and gave a height of 10,100 feet (about 3,030 m). From the configuration of the ridges and peaks appeared on ground and aerial photographs, it seems probable that the height of this peak exceeds 3,000 m. This is why we put the height as about 3,000 m and called this majestic peak Cerro Hyades on our map. A chain of peaks limiting the right bank of Soler Glacier is labelled Cerro Largo on the topographic map as well as on the preliminary map at 1:250,000 scale, although the local people call this mountain Cerro Soler. According to Lliboutry and the natives, Cerro Largo (2798 m) is an elongated mountain with a few peaks over 2500 m located in the Icefield between Nef and Soler Glaciers. There is no name for this peak on the topographic map. For these features we followed the topographic map.

Another discrepancy is Rio Soler. According to the locals, Rio Romero is the southern branch fed by Nef Glacier, and Rio Turbio is the northern branch coming from the two morained-dammed lakes, and after confluencing, the river becomes Rio Soler. However, the topographic map indicates Rio Romero as Rio Soler, and there is no name for the northern branch. Here again we used the local names. On the other hand, Rio Cacho (Rio Soler on the 1:250,000 preliminary map) is called Rio Norte by the locals. We employed Rio Cacho in this case because we have learned this long after we have got used to use Rio Cacho.



Map 4. Soler Glacier and surroundings.