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Morphology of Ameghino Glacier and landforms of Ameghino Valley, southern Patagonia

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Abstract

Ameghino Glacier is 21 km long with an area of about 77 km^2. The altitude of the drainage area ranges from 2260 m to 201 m, and the inferred equilibrium line altitude (ELA) is located around 1000 m with a small AAR (Accumulation — Area Ratio) of 0.43. From the number of ogive waves in the upper ablation area, the annual flow velocity is estimated at about 200 m. During the past 23 years (1970 – 93), the glacier receded at a rate of 152 m/a, while between 1944 and 1970, the snout was almost stationary although it had been gradually narrowing and disintegrating.

The dry valley part is characterized by the flat, extensive cover of the valley train consisting of round gravel. On the river terraces along Rio Ameghino and in the stream, there are many exhumed, large, standing, but dead with broken top, trees which had been killed by deposition of the valley train. Subsequent river erosion exhumed these once-buried stumps. A large kame terrace and four sets of terminal moraines representing probably Neoglacial advances are recognized. The kame terrace was probably formed during the closing period of the Pleistocene Glaciation. The first Neoglacial advance was most extensive, while the second and the third with short durations. The fourth Neoglacial advance was probably more extensive with larger shear moraines and an associated conspicuous trimline than the preceding second and third ; however, due to the extensive valley train, its advance was held back.

1. Introduction

The Patagonia Icefield consists of two major icefields, Northern Patagonia Icefield (NPI, 4200 km^2, Aniya, 1988) and Southern Patagonia Icefield (13000 km^2, Naruse and Aniya). Although there are many types of glacial landforms relating to Holocene glaciations in Patagonia, detailed studies on glacial landforms are still scarce (*e.g.*, Nichols and Miller, 1951 ; Mercer, 1965 ; Aniya, 1985 and 1987 ; Malagnino and Strelin, 1992). It is important to identify and investigate glacial landforms around each glacier, from which glacial chronology may be reconstructed. Only after the accumulation of these individual glaciations, it becomes possible to establish a scheme of glaciations in Patagonia.

The Ameghino Valley is located on Canal de los Têmpanos of Lago Argentino, just north of the well-known glacier, Glaciar Perito Moreno in the SPI (Fig. 1). The large part of the valley is still occupied with a glacier and only the lower 7 km is now free of ice (Fig. 2). The valley bottom is mostly bare with the extensive cover of the valley train consisting of round gravel, spotted with a few islands of vegetation stands. The valley sides are in contrast covered with large, extensive *Nothofagus* (southern beech). The conspicuous features of the valley include prominent terminal moraines damming up a proglacial lake and trimlines associated with these terminal moraines. The valley was first scientifically studied by Nichols and Miller (1951) and based on the tree ring analyses, they have estimated the age of the recent glacial maximum to be *ca.* 1870 – 1880.

We were only the second to visit this valley for studies on glacial landforms. We have collected samples for ^{14}C dating at the trimlines and from stumps

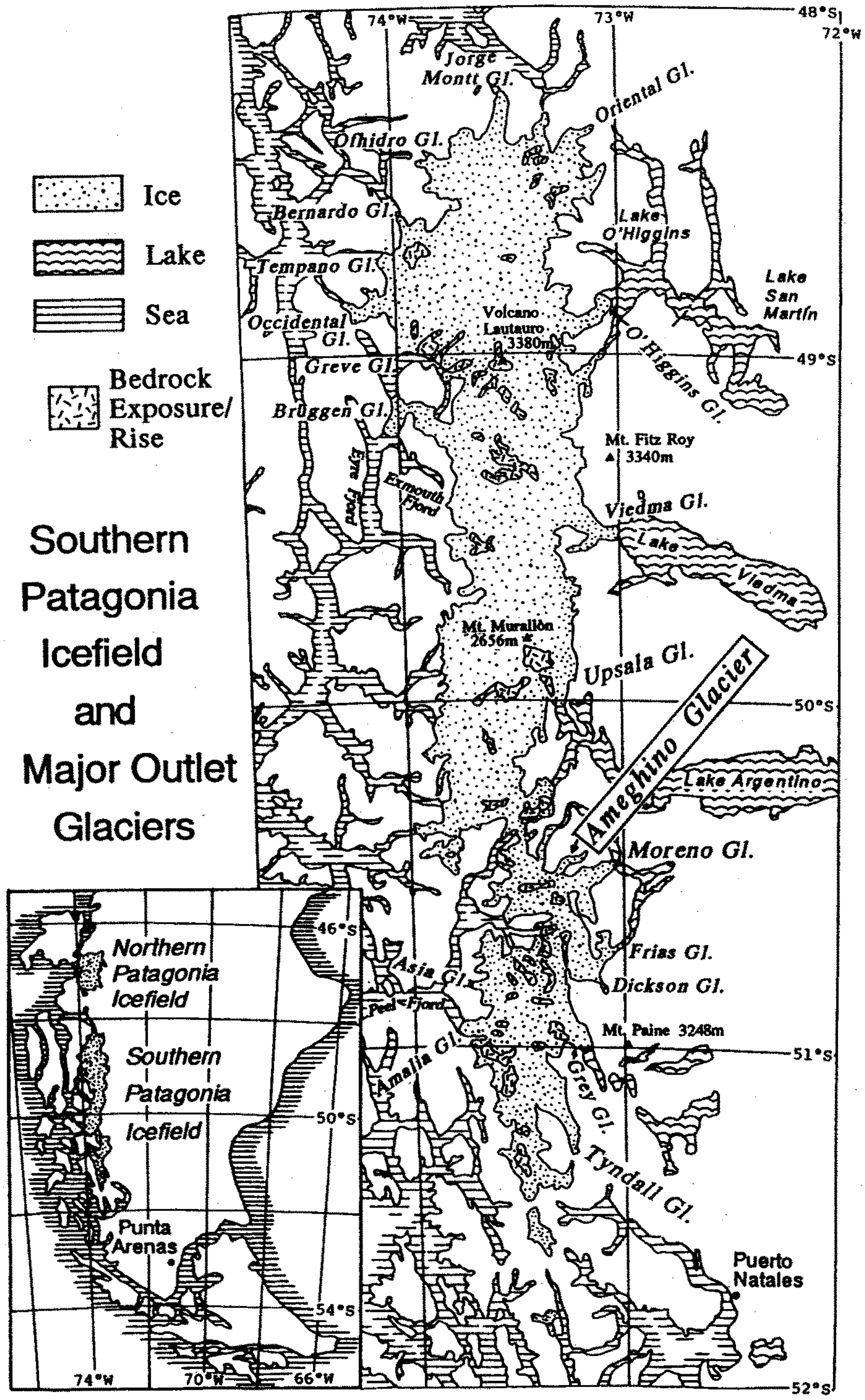

Fig. 1. Southern Patagonia Icefield (SPI) and location of Ameghino Glacier. Map modified after Lliboutry (1956). Elevations of Co. Murallón and Co. Paine Grande are taken from topographic maps published by the Argentinean and Chilean Governments, respectively.

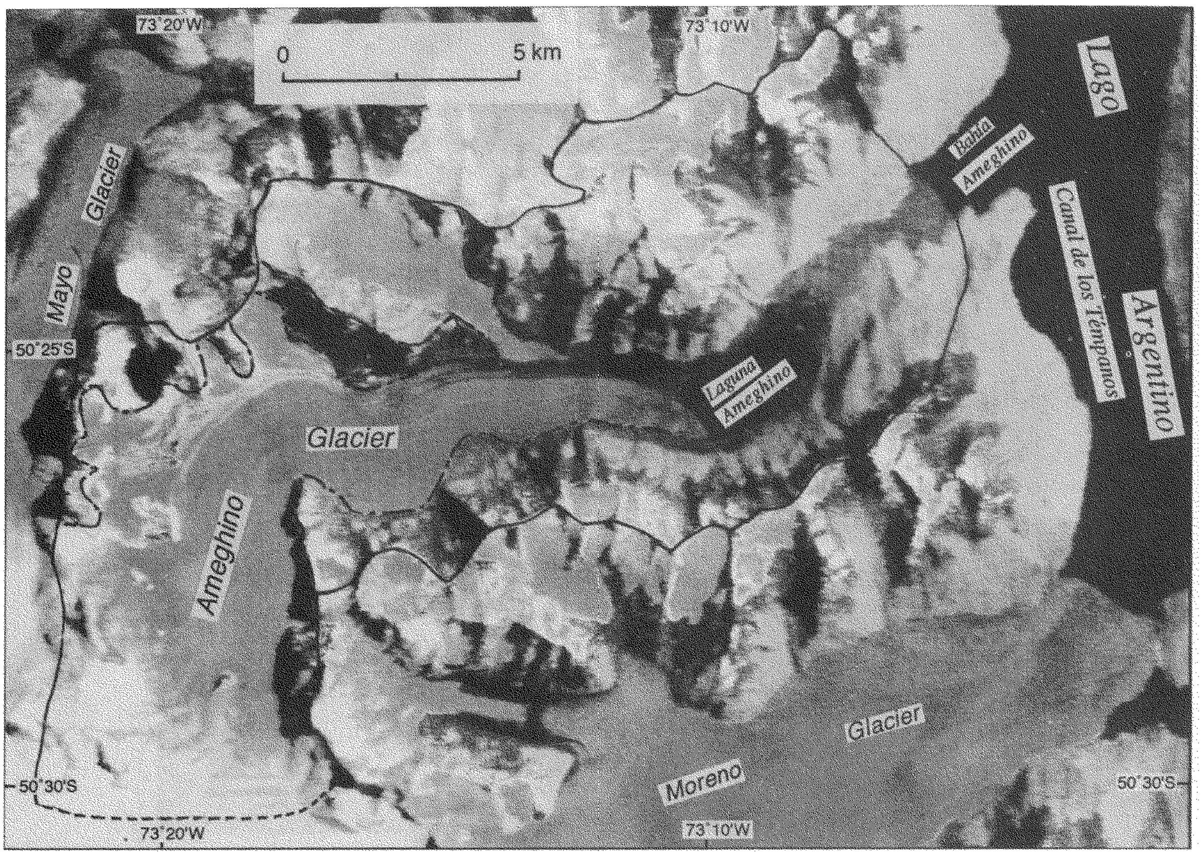

Fig. 2. Landsat TM image (January 14, 1986) showing Ameghino Glacier and Valley. Geometrcally corrected. The original image was produced using band 1 (0.45–0.52 5m), 4 (0.76–0.90 5m) and 5 (1.55–1.75 5m). Drainage divide of the valley is indicated with a solid line and the glacier drainage is shown with a chained line.

that were once buried under the valley train or killed in a submerging marsh to determine the ages of the major events in this valley. During this investigation, we have identified some glacial landforms that Nichols and Miller (1951) did not mention in their paper. It is the purpose of this paper to analyze morphological characteristics of Ameghino Glacier and discuss the detail of glacial landforms. However, since the results of ^{14}C dating have not been obtained yet, glacial sequences with concrete dates cannot be discussed in this paper.

2. Study area

The ice-free area of the Ameghino Valley stretches northeast-southwest for about 3 km between a proglacial lake (here, tentatively called Laguna Ameghino) and the shore of Lago Argentino, with the average width of about 1.2–1.5 km. The valley floor is completely covered by the extensive valley train consisting of round gravel of 10–15 cm in diameter, and is almost flat except for the area along Rio Ameghino where three levels of terraces have been formed. The elevation of the valley floor ranges from about 200 m at the foot of terminal moraines damming up Laguna Ameghino to 175 m (measured with a geodetic GPS, Trimble 4000SSE, Leiva, personal communication, 1993) at the shore of Lago Argentino. So the average valley gradient is very gentle, with only 0.87 % or 0.5 degrees. The valley floor is still mostly devoid of the vegetation cover except for several spots of tree islands. In contrast, the valley sides are covered with thick vegetation.

One of the most spectacular sights in this valley is a large number of stumps of dead *Nothofagus* standing in and around Rio Ameghino (Fig. 3). They are generally 50−60 cm in diameter at breast height (DBH) and have trunks broken at a similar height within the area of the same level. Rio Ameghino has incised the valley train up to five meters near the terminal moraines forming Laguna Ameghino.

3. Ameghino Glacier

Ameghino Glacier is currently terminating in Laguna Ameghino at around 73°10′30″W and 50°25′40″S (Fig. 4), about 7 km from the shore of Lago Argentino, and is about 21 km long with a total area of about 77 km², of which 11 km² belong to a small

Fig. 3. Exhumed *Nothofagus* (southern beech) stumps standing in the stream of Rio Ameghino.

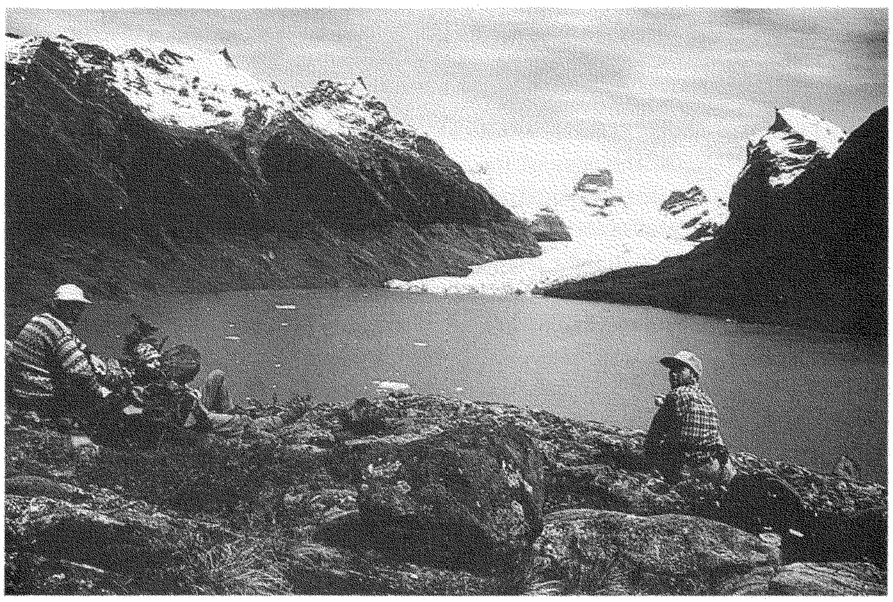

Fig. 4. The current snout of Ameghino Glacier and Laguna Ameghino (November 14, 1993).

branch on the north (left). The topmost accumulation area flows east for about 2–4 km. Then near and at icefalls the flow direction turns north, and after flowing 7 km, around the midway it sharply turns again to the east and flows 9.5 km to the current snout (Fig. 5). The elevation ranges from about 2260 m at the divide to 201 m (GPS measurement) at Laguna Ameghino. The small branch joins at about 4 km upstream from the snout and below the confluence, the left one-third of the glacier becomes heavily debris-covered (see Fig. 2). It is bordered to the west by Glaciar de Mayo (hereafter, Mayo Glacier) and to the south by Glacier Perito Moreno (hereafter, Moreno Glacier). It has two major accumulation areas from

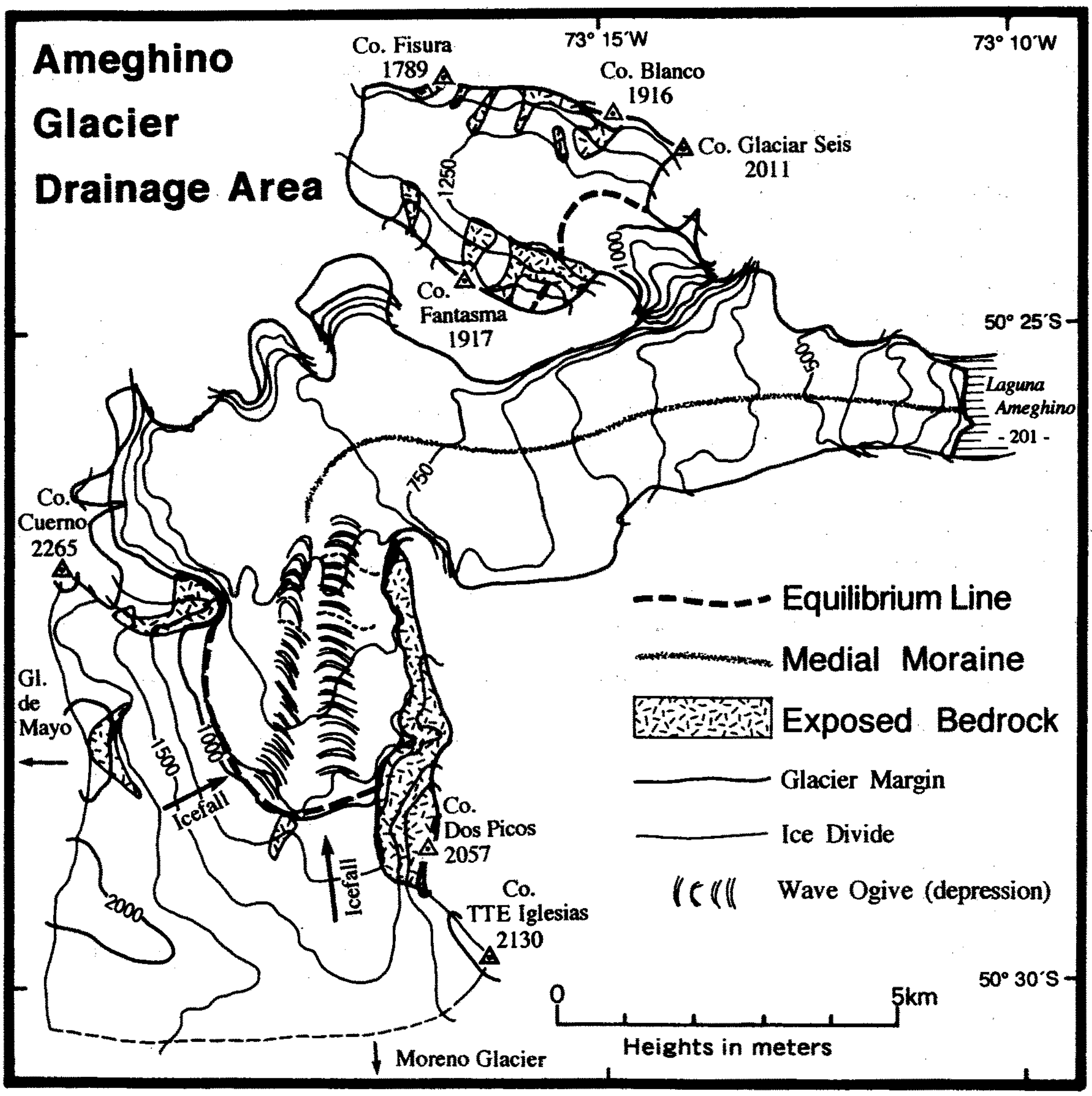

Fig. 5. Drainage area of Ameghino Glacier. Map based on 1 : 100,000 topographic map "Glaciar Perito Moreno" published by Instituto Geográfico Militar of Argentina. Location of the equilibrium line was inferred from aerial photographs (taken on March 11, 1970). Snout position is as of fall 1993 and the snout shape is drawn after an oblique aerial photograph taken by Pedro Skvarca in January 1993.

which nearly equal amounts of ice are supplied ; the one sharing the area with Moreno Glacier and the other on the east of the divide between Mayo Glacier. While the divide between Mayo and Ameghino glaciers is a distinctive ridge of about 1500−2000 m in altitude, the divide between Moreno and Ameghino glaciers is very vague as it is located in the middle of a longitudinal valley. Even on the vertical aerial photographs with stereoscopic inspection, it is impossible to precisely locate the divide. Consequently the divide was located along the median (about lowest) line of the valley, at the bottom of which the glacier flow diverges into Moreno and Ameghino.

Interpreting aerial photographs taken on March 11, 1970, and comparing with a topographic map at 1 : 100,000 scale (Quadrangle Glaciar Perito Moreno), the equilibrium line altitude (ELA) is located around 1000 m on the main body and around 1100 m on the northern branch. At the neighboring Moreno Glacier, the ELA was judged to be located at 1150 m (Aniya and Skvarca 1992). Since much of the Ameghino Glacier area above 1000 m is located on the lee side of the very steep, high divide between Mayo Glacier, snow accumulation by drift and avalanche may significantly contribute to the nourishment of the glacier. Then the total area of 77 km^2 can be divided into the accumulation area of 33 km^2 and the ablation area of 44 km^2, with an AAR (Accumulation — Area Ratio) of 0.43. However, the AAR of the main body is only 0.36, a very small figure, while that of the branch is 0.82. Rocky cliffs above the ELA (1.7 km^2) are included in the statistics of the accumulation area because they contribute to the accumulation through snow/ice avalanches, whereas those below the ELA are not included in the area statistics. An AAR of 0.43 is considerably small compared to many other Patagonian glaciers (Aniya, 1988 ; Aniya and Skvarca, 1992).

Figure 6 indicates a hypsometric curve of the Ameghino Glacier drainage area. The ELA lies at the bottom of the steep portion of the profile from which the profile becomes relatively flat, suggesting that a slight increase in the ELA would not result in a large change in the accumulation/ablation areas. Thus, at present Ameghino Glacier seems to be relatively insensitive to climatic changes.

Directly below the vague divide between Ameghino and Moreno glaciers there is an icefall, about 500 m high between elevations of 1000 m and 1500 m, and starting from the bottom of this icefall, wave ogives can be recognized with the crest appearing dark and the depression appearing light (probably due to fresh snow filling). Twenty ogives can be counted on the 1970 aerial photograph between the icefall and the point where the glacier sharply turns to the east below which ogives become obscure due to heavy crevassing. A distance covering this stretch is about 3.8 km. Since the width of a pair of ogive waves/bands repre-

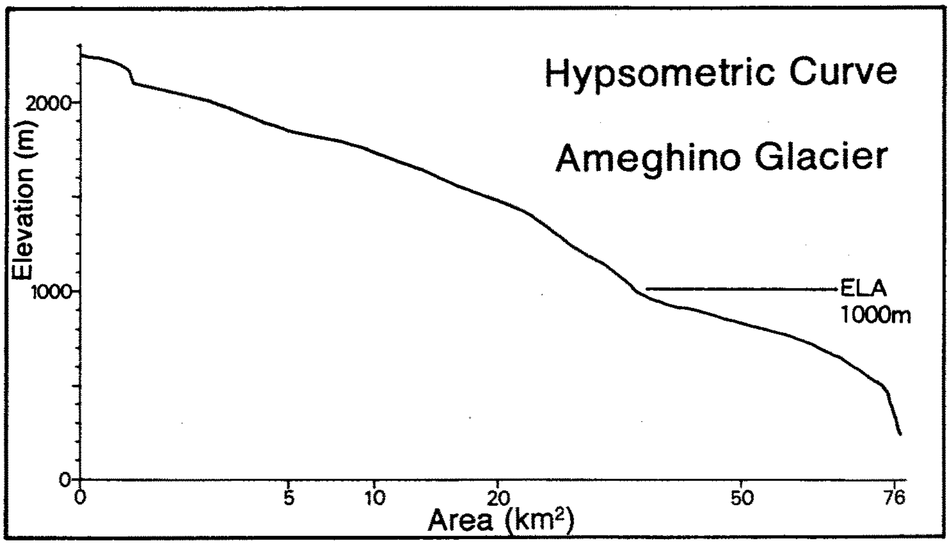

Fig. 6. Hypsometric curve of Ameghino Glacier. The scale of the X axis is taken as square root of the area so that the curve indicates a hypothetical profile resulting from concentric circles of contours.

sents a distance the glacier flowed in one year (King and Lewis, 1961), the average annual velocity in this stretch is calculated to be about 190 m. Another icefall, about 750 m high between elevations of 1000 m and 1750 m, is located on the icebody coming from the divide between Mayo Glacier and below this icefall, 18 wave ogives can be recognized in a distance of about 3.7 km. The average annual velocity of this icebody is therefore about 200 m. These two sets of wave ogives flow side by side below the icefalls. It can be concluded that the velocity of the ice flow at the upper ablation area is around 200 m/a. This flow rate is comparable to the rates at the ablation area of Soler Glacier of the NPI (300−100 m/a, Aniya and Naruse, 1987) ; but much smaller compared to some other glaciers of the SPI, for example, Upsala Glacier at 700 m/a (Aniya and Skvarca, 1992), and Moreno Glacier at 950m/a (Raffo *et al.*, 1953) or 730 m/a (Naruse *et al.*, 1992). A distinctive medial moraine emerges where ogives become obscure, which originates at the bedrock cliff separating the two icefalls.

A comparison of an oblique aerial photograph taken in 1944 (Skvarca, per. comm.) and vertical aerial photographs taken in 1970 indicates that Ameghino Glacier had slowly decayed in the proglacial lake between 1944 and 1970, with no apparent snout retreat but substantial narrowing and disintegration at the sides of the snout area. From the ground observation in November 1993, it was revealed that it has retreated very rapidly by 3500 m in 23 years (152 m/a), leaving a large proglacial lake, Laguna Ameghino, 3.7 km long and 1.5 km wide. A comparison of the photograph taken in 1949 (Nichols and Miller, 1951) and that taken in 1993 indicates that the surface lowering near the current snout is around 100 m (2.3 m/a). Currently the northern side of the glacier (left bank) terminates on the land, while the central and right parts are still calving. This behavior of the glacier is quite a contrast to the neighboring Moreno Glacier that has been fairly stable during the last 50 years with only minor oscillations (Nichols and Miller, 1952 ; Aniya and Skvarca, 1992 ; Naruse *et al.* 1995).

4. Landforms

Features associated with glacial advances include a kame terrace, moraines and trimlines (Fig. 7).

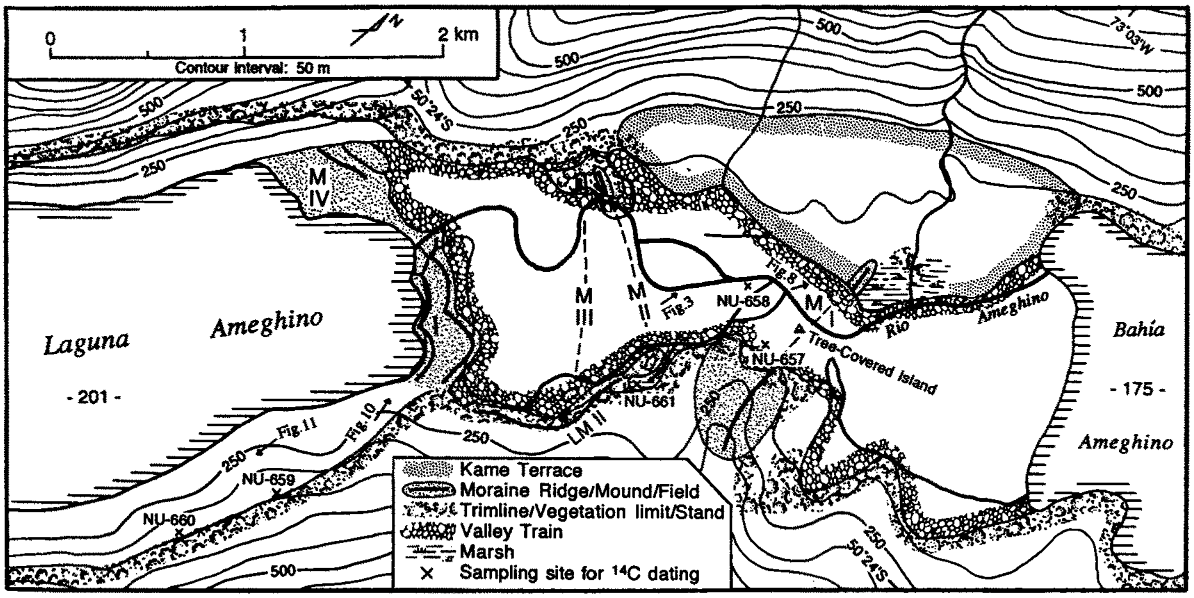

Fig. 7. Geomorphological Map of the Ameghino Valley, produced from field survey and aerial photographic interpretation. Base map : 1 : 100,000 topographic map "Glaciar Perito Moreno" published by Instituto Geográfico Militar of Argentina. Locations of Figs. 3, 8,10 and 11 indicated. In order to avoid crowded appearance of the map, only margins of the kame terrace and the valley train, and the lower edge of trimline/vegetation limt are patterned. Although not indicated by the pattern, the kame terrace is mostly wooded, while the M I at the southern side is tatally covered with vegetation. The large tree-covered island at the left side, on which M II and M III are located, is also a kame; but here shown as a vegetation stand.

4.1. Kame terrace

The terraced area (Fig. 8), that is located on the northern (left) side of the valley and 3−5 m higher than the adjacent valley floor, is judged to be a kame terrace on the basis of the following observations. The terrace is generally covered with thick vegetation, mostly *Nothofagus*. There are two marshy areas separated by a stream and a wood near the edge, that are studded with many large, seemingly dead trees (DBH about 30 cm) with greens only at the top of trees. They appear to have been almost killed by flooding. Cliff outcrops of these areas along Rio Ameghino tell that these marshy areas are underlain by an impermeable stratum of fine sand/clay that has been stained red from iron oxidation and water is oozing out from the top of the impermeable stratum. The southwestern part of the terrace is topped with eolian sand deposits, whereas on the northeastern part soil has well developed (thickness about 30−50 cm) and thick woods, mostly *Nothofagus* with DBH exceeding 1.5 m, have developed. Below this soil horizon is a layer consisting mainly of sand with a matrix of sparse angular clasts, below which is a layer of round gravel. These facts suggest that the terraced area was once impounded with water. There are two streams coming from the mountain side onto this terrace, which have incised 1.5−2 m on the terrace. Therefore, it can be interpreted that the terraced area used to be a glacier marginal lake into which two streams had emptied. Angular clasts were ice-berg rafted, along with finer materials (Nichols and Miller, 1951). There is a small terminal moraine on this terrace, with a relief of 3−5 m (see Fig. 8).

4.2. Moraines

Four sets of terminal moraines can be recognized in the valley. For the sake of description, they are designated as M I, M II, M III and M IV from the down valley (older). Because of the visibility and size of these moraines, the description is given in the order of M IV, M I, M II and M III.

Prominent terminal moraines (M IV) damming -up Laguna Ameghino are about 1.2 km long across the valley and are cut through near the middle by Rio Ameghino. This is the youngest moraine recognized in this valley. The moraine field on the left side of the river is very hummocky with only one distinctive moraine ridge, whereas the moraine field on the right side consists of two distinctive rows of moraines, each with two arcuate patterns, which are separated by broad depressions. This contrast of the moraine fields is due probably to the fact that the left side was laid out by the debris-covered part, whereas the right side was formed by the debris-free part of the glacier. The inner ones (closer to the glacier) are comprised mostly of sand coated with gravel of 1−2 cm in diameter, while the outer ones contain more boulders. The relief of the outer moraines from the adjacent

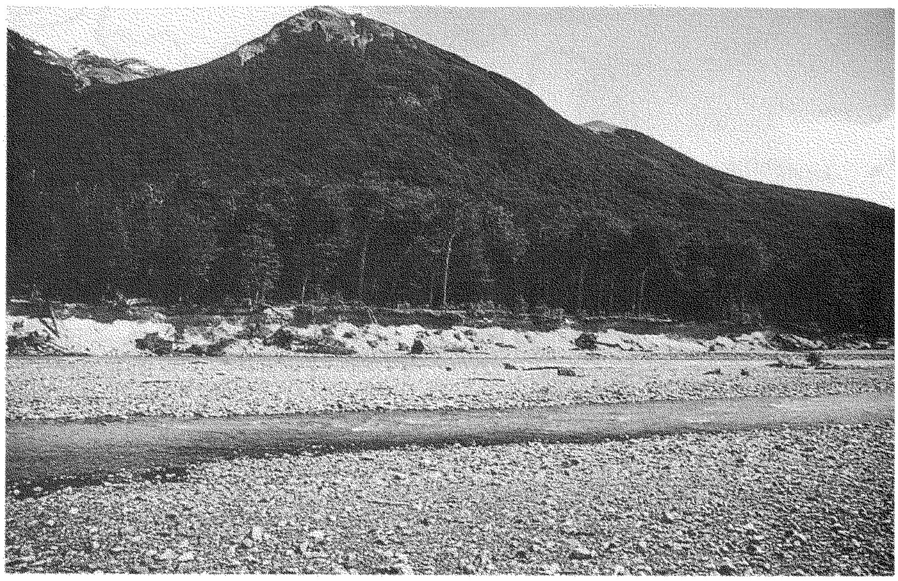

Fig. 8. Kame terrace and a small terminal moraine (M I, a small hump on the far right).

valley floor is up to 20 m, and their elevations are generally 10－15 m higher than the inner ones. Both are consisting of round gravel and sand, and were formed by the shear mechanism (Bishop, 1956) and once ice-cored. A comparison of the photographs taken in 1949 (Nichols and Miller, 1951) and in November 1993 (Fig. 9) indicates that the most inner moraines were still ice-cored as of 1949, as the shapes and sizes of the moraine mounds have conspicuously changed in 44 years. As for the outer moraines, it is difficult to recognize significant changes in the shapes, however, suggesting that they were probably mostly ice-free by 1949.

There is a large moraine hill (M I) on the southern (right) side of the valley, about midway between Laguna Ameghino and the shore of Lago Argentino. This is the oldest recognizable terminal moraine in the valley and its apparent size is by far largest. Its main ridge stretches transverse to the valley direction, for about 500 m long, and its elevation goes up gradually from 190 m at the valley floor to about 290 m near the hillslope, with a maximum relief of about 100 m. A valley formed between the hillslope and this moraine is only several meter deep, suggesting, together with

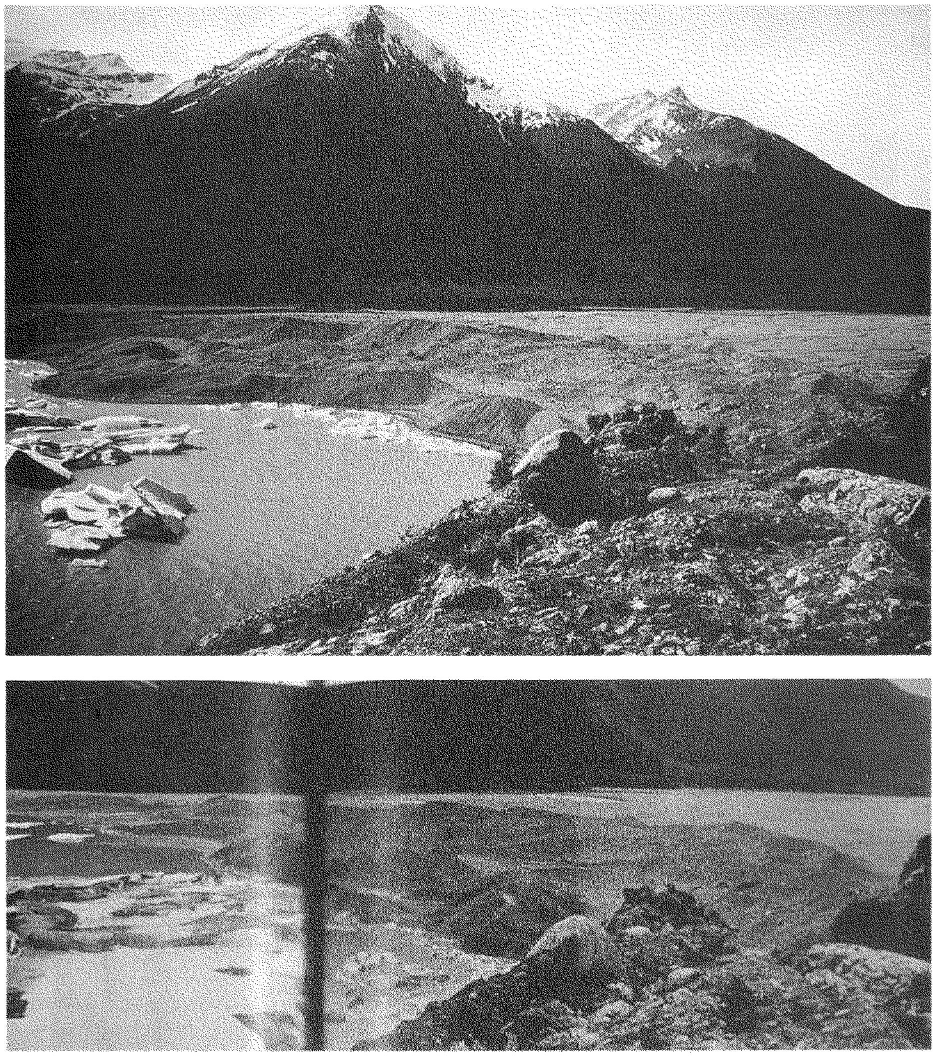

Fig. 9. The current appearance of the terminal moraine (Top, taken on November 11, 1993) as compared to the photo (Bottom, taken in 1949, copied from Journal by permission of the American Geographical Society) appeared in Nichols and Miller (1951). Note : changes in the shape of the inner morains in 44 years, suggesting that these moraines were still ice-cored in 1949.

the occasional outcrop of the bedrock in the moraine, that this moraine was probably formed on the sloping spur of the hillslope. The slope of this moraine is covered occasionally with pumice, and humus layers of about 12 cm thick have developed. Also we can see much sand as the top layer, which is probably eolian in origin. On this moraine, *Nothofagus* with DBH exceeding 1 m are abundant. To the west of this moraine ridge, several lateral moraines with a relief of a few meters are scattered on the hillslope and the valley floor at the foot of the hillslope, indicating a complex formation of the topographic lump protruding into the valley. From the location and the direction of this moraine ridge, it is certain that the small moraine on the kame terrace was once continuous to this large moraine. Between these two moraines located across the valley, there is a tree-covered island on the barren floor of the valley train (Fig. 10). According to Nichols and Miller, (1951), young living trees have grown on the eolian sand and silt covering the weathered profile beneath, whereas the dead large trees are rooted in the weathered

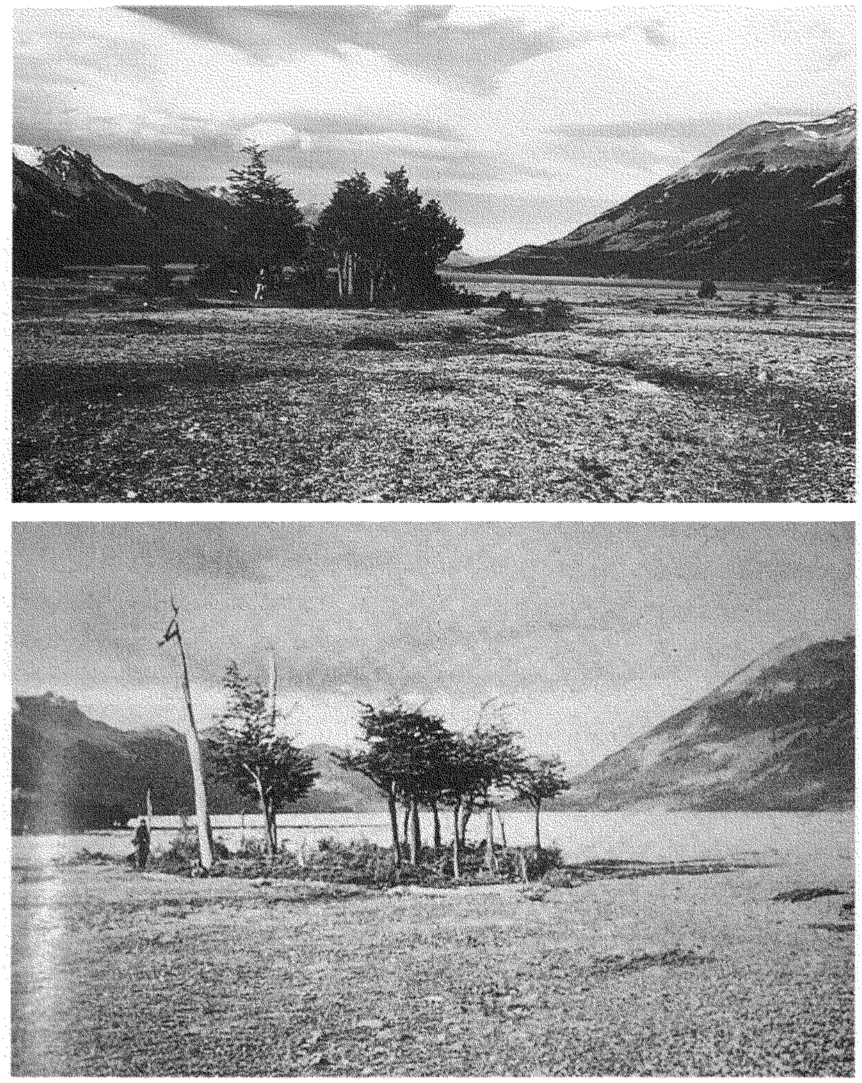

Fig. 10. Tree-covered island in the middle of the valley train (Top taken on November 10, 1993 ; bottom in 1949 by Miller, copied from Journal by permission of the American Geographical Society). In 44 years, large dead trees fell down and are laying on the ground in 1993. Living Nothofagus are about 120 years old now as they were estimated to be about 76 years old in 1949.

profile. Since they found round stones beneath the weathered profile, they tentatively suggested that this tree-covered island was a buried terminal moraine. At that time they did not identify the large moraine located on the south and the small moraine located on the north of this tree-covered island. Now it is certain that this tree-covered island is a moraine, a part of M I.

There are two small terminal moraines (M II, M III), between M I and M IV. M II on the southern (right) side is a small mound only about 2–3 m higher than the surrounding valley floor. Between this moraine mound and the hillslope, a small marsh is located with many large, dead *Nothofagus* still standing. It seems certain that this marsh was formed due to the deposition of M II. A sample was collected for ^{14}C dating (NU-661) from one of these dead trees. M III, another tiny tree-covered island, is located about 400 m further inland from M II. On the hillslope south of the M III is located lines of lateral moraines, which appear to correlate with M II. On the northern (left) side of the valley, there is a large tree-covered island separated from the hillslope by an ablation valley and channel, west of the large kame terrace. This tree-covered island is also a kame terrace judged from the underlying sediments, and probably was once continuous to the large one. On this island, there are two small elongated mounds that are located less than 100 m apart. These two mounds correspond to M II and M III on the southern side.

One of the notable characteristics of the Ameghino Valley is roundness of gravel and boulders found all over the valley. Including those of terminal moraines that have formed Laguna Ameghino and lateral moraines on the right bank, we rarely see angular gravel and boulders in this valley. Although the valley walls are shear cliff of mudstone, from which numerous rocks fall onto the glacier, we seldom find angular rocks in the lateral moraines. They are mostly subangular/subround, with subround boulders up to 1.5 m in diameter (Fig. 11). Bedrocks exposed on the right bank have striations oblique upward, indicating that forward glacier movements were accompanied by upward movements. From the glacier movements, roundness of the materials and the subdued appearance of the moraine mounds, it seems certain that these lateral moraines were mostly formed by what Shaw (1980) termed "secondary flow (upward and lateral movements)". He called the feature "half-fluting." They were once ice-cored.

Fig. 11. A gigantic round-edged boulder at the lateral moraine. Note : roundness of other smaller boulders. Trimlines at the right bank of Laguna Ameghino, located 140–150 m above the lake surface are visible. Note : numerous horizontal lineations parallel to the trimline, suggesting the intermittent retreats since the recent glacial maximum.

4.3. Trimlines

Above Laguna Ameghino, distinctive trimlines are located on both sides of the valley, at about 140–150 m higher than the lake surface level (see Fig. 11). As seen in Fig. 11, the height of the trimline is not the same everywhere ; however, we can recognize one prominent horizontal line. Below this prominent line there are numerous horizontal, linear features rougly parallel to the prominent trimline, which are caused by the difference in vegetation and lines of lateral moraines. These features indicate that the glacier had retreated intermittently after the recent glacial maximum. From dendrochronological analyses of *Nothofagus* at the trimline, which appeared to have been shoved away by the advancing glacier, Nichols and Miller (1951) inferred the age of this trimline to be *ca.* 1870–1880. If this date is correct, it has passed only about 100 years since the recent maximum glaciation. The bedrock (mudstone) below the trimline has plastic forms with striations all over on it ; however, its surface is rather rough, not retaining polished appearance at all. This fact suggests that the bedrock has been weathered considerably and gives an impression that time may have passed much more than 100 years since their exposure. Two samples were collected for ^{14}C dating (NU-659 and 660) from trees at the trimline that were apparently killed by the advancing Ameghino Glacier (Fig. 12).

The most part of the dry Ameghino Valley is covered with the extensive valley train whose deposition, according to Nichols and Miller (1951), occurred after the recent glacial maximum. In order to estimate the age of the deposition, two samples for ^{14}C dating (NU-657 and 658) were collected from trees that were apparently killed by the deposition. One is an exhumed stump located at the bank of Rio Ameghino, and another is a dead, but still standing, tree near M I on the southern side.

5. Discussion and concluding remarks

Although we cannot discuss the glacial chronology with concrete dates because we have not yet had the results of ^{14}C dating, we can infer the glacial events in the relative manner.

The kame terrace was probably formed near the end of the Pleistocene Glaciation, when the glacier was slowly decaying. Two streams coming from the left side hillslope melted ice and formed a marginal lake. Since the left one-third of the glacier is debris

Fig. 12. *Nothofagus* (southern beech) pushed away and tilted by a lateral moraine formed by the advancing glacier at the trimline. A sample for ^{14}C dating was collected near this moraine.

-covered today, the similar condition was probably true in the past and the sedimentation of the marginal lake was fast.

Four Neoglaciations can be inferred in this valley from the four sets of terminal moraines. From the size of the moraine, the first Neoglaciation was probably most extensive, reaching up to 100 m above the present valley floor. The second and third ones were much smaller, leaving tiny moraine mounds only a few meters above the present valley floor. The moraines of the fourth Neoglaciation are much larger than those of the second and third Neoglaciations. The altitude of the moraine top is 10−15 m higher than the altitudes of the moraines of the second and the third, suggesting together with the associated trimline that the fourth glacier advance was probably more extensive than the second and the third. However, due to the extensive valley train on the valley floor, its advance was held back. Then the deposition of the valley train antedates the formation of M IV, which is contrary to the conclusion of Nichols and Miller (1951).

Recently, Aniya and Sato (1995a, b) identified four Neoglaciations at Tyndall Glacier located at the southern end of the SPI and Upsala Glacier located at mid-east of the SPI with new radiocarbon data. Their dates are *ca.* 3600 yr B.P., *ca.* 2300 yr B.P., *ca.* 1400 yr B.P. and the Little Ice Age (17−18th Century). At Tyndall Glacier, the magnitudes of the first two Neoglaciations were very similar, while at Upsala Glacier, the second one was more extensive than the first one. At Ameghino Glacier, the first one was by far extensive than the other threes.

When we receive the results of ^{14}C dating of the samples we collected, we can assign certain dates to the glacial events such as the occurrence of the Neoglaciation II and IV and the deposition of the valley train, and see whether the ages of these four Neoglaciations roughly correspond to those four recognized at other Patagonian glaciers.

Acknowledgments

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