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Recent retreat of Soler Glacier, Patagonia as seen from vegetation recovery

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Abstract

Downstream from the snout area of Soler Glacier, three glaciofluvial zones, namely moraine field, outwash plain and inwash plain were recognized along the valley bottom of the Cacho River. As the name implies the morain field retained moraines and many other geomorphological features left behind by the retreating Soler Glacier. To reveal this deglaciation process a detailed topographic map of the moraine field was reproduced from a set of vertical air photos taken by the U. S. Air Force in 1974. An analysis of this map along with the preceding field observations disclosed six different terminal moraines of different ages in the moraine field. Of these six moraines, the four most recent ones were dated in the decades of the 1940s, 1910s, 1890s and 1850s respectively by using trees growing in the area. This estimation was obtained by allowing 50 years for the time neccessary before trees could invade a newly-deglaciated area, and adding it to the numbers of annual rings counted in the oldest trees on each moraine.

1. Glaciofluvial zoning of the Cacho River Velley

The Cacho River originates from the terminus of Soler Glacier at an altitude of 300 m a. s. l. and runs for eleven kilometers before it joins the Soler River at 210 m a. s. l. (Map 3 and Fig. 1). Along the valley bottom of the Cacho River, a distinctive glaciofluvial zoning was recognized which marked off the valley bottom into three zones, namely moraine field, outwash plain and inwash plain from the headwater area downstream to the junction.

This glaciofluvial zoning was also reflected on vegetation cover as a marked change across the zoning. Silty deposits in the inwash plain at the downstream end of the glaciofluvial spectrum had given rise to lush and dense forests of *Nothofagus* species intermingled with marshy vegetation, both of them disturbed by cattle grazing and man-caused fire to some extent. On the other hand the coarse deposits on the outwash plain, consisting of coarse sand and gravel, were so permeable and dry that they could hardly support any other vegetation than shabby grass species and dwarf woody perennials. So far as permeability or conversely moisture-holding capacity was concerned, the moraine field came between these two extremes. It seemed that the moraines had a higher load of silty deposits than did the outwash plain but lower than did the inwash plain so that trees were found in this zone to an extent as to be called an open woodland but not a forest. The major species found in this woodland was *Nothofagus betuloides* (Coigue), with sporadic mixture of *N. pumilio* (Nirre) and *Embothrium coccineum* (Notro).

In spite of their steepness, the slopes flanking the valley were covered by thick and tall forest even beyond the terminus of Soler Glacier upstream, and to an altitude of about 1,200 m a. s. l. uphill except on rocky cliffs and spotty shield-shaped outcrops of schistous bedrock. Having been free from the latest glaciation, soils covering the flanking slopes were far better developed and much more fertile than those covering the valley bottom. These forested belts on both sides of the valley consisted of *Nothofagus pumilio* exclusively on the upper half of the slopes, and mixed with increasing individuals of *N. betuloides* toward the valley bottom. A considerable part of this forested area had been destroyed by the fire which also affected parts of the inwash plain and the woodland of the moraine field. According to local pioneer settlers the area was set aflame sometime in the 1940s

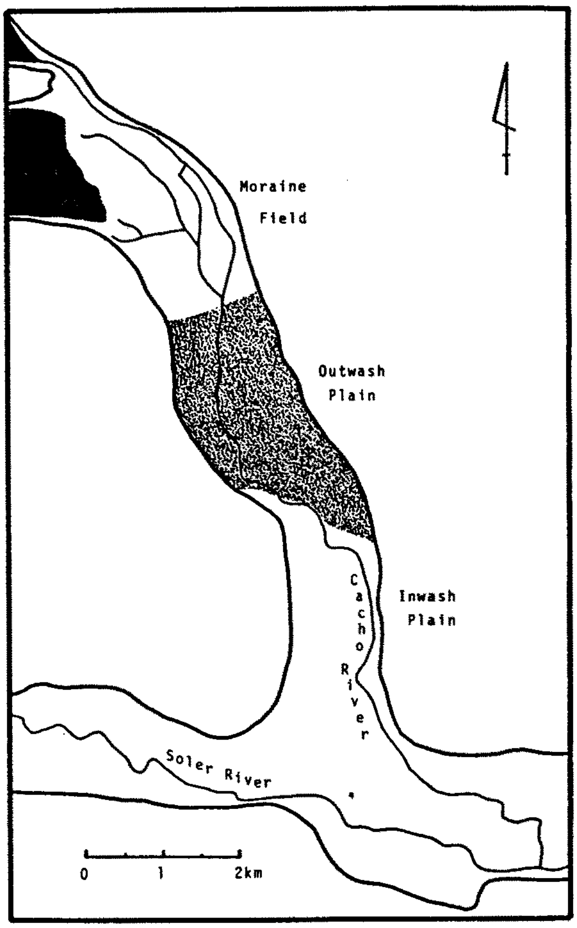

Fig. 1. Glaciofuluvial zoning along the Cacho River Valley.

in their attempt to open up a grazing ground for their sheep flock. When we visited the valley in 1985 the devastating effect of the fire was still visible 40 years after the fire. Owing largely to slow decomposition under the dry and cool climate, many charred snags of height up to 20 m and breast-height diameter 50 cm or more were still standing upright. Underneath the snags, however, young *Nothofagus* seedlings were regenerating.

2. Topographic map of the moraine zone

On the spot the topography of the moraine field was very complicated with an intricate system of moraine ridges, hummocks, grooves and depressions intermingled with each other, and split up by a complex system of braided water channels. To show the topographic features of the moraine field, a detailed topographic map was produced from a set of vertical air photos taken in 1974 by the United States Air Force.

The original photographs used for the present mapping were 230 by 230 mm taken with a 151.446 -mm focal length lens at an average scale of 1 : 58,400 as calculated at the vallley bottom. Ordinary paper positive prints were purchased from the Military Geografic Institute (Instituto Geogrãfico Militar) in Santiago and diapositives were made from them in Japan. Using these diapositives, a contour map was plotted stereoscopically with a Wild A7 Autograph installed at Tamano Consulting Co. Ltd., Nagoya. The resulting topographic map of the moraine field is shown in Fig. 2. Contours are given for every 5 m (thin line) on the valley bottom including the glacier surface and for every 25 m (thick line) on the slopes flanking the valley. Since there was no definite control point against which the absolute height could be checked, the contours are only relative. It suffices to indicate that the base camp was approximately at 277 m a. s. l. The same is true with the horizontal scaling ; thus, the scaling given in Fig. 2 is approximate, reduced from a comparision with the 1 : 50,000 topographic map published by the Military Geographgic Institute.

The boundary between the glacial body and the ice-free area in front of it is also approximate since the major part of the glacier snout was blanketed with ablation drift which was rather difficult to distinguish from glacial till sprayed over a seemingly ice-free area. It should be remembered that the terminus shown in Fig. 2 represents the state as of 1974, and the present (1986) terminus was 50 to 150 m further upstream (Aniya and Naruse, 1987).

3. Characteristics of the moraine field

Although the self-braiding of the waterways makes them appear complicated in Fig. 2, there are only three major channels running through this moraine field. The most important in relation to Soler Glacier is the one that originates as subglacial streams and emerges from the ice at the southeast end of the glacier terminus. Hindered by a series of terminal moraines, the channel first weaves its way eastward and then follows the axial line of the valley to the south. So far as the flow rate is concerned this channel makes the greatest contribution of the three

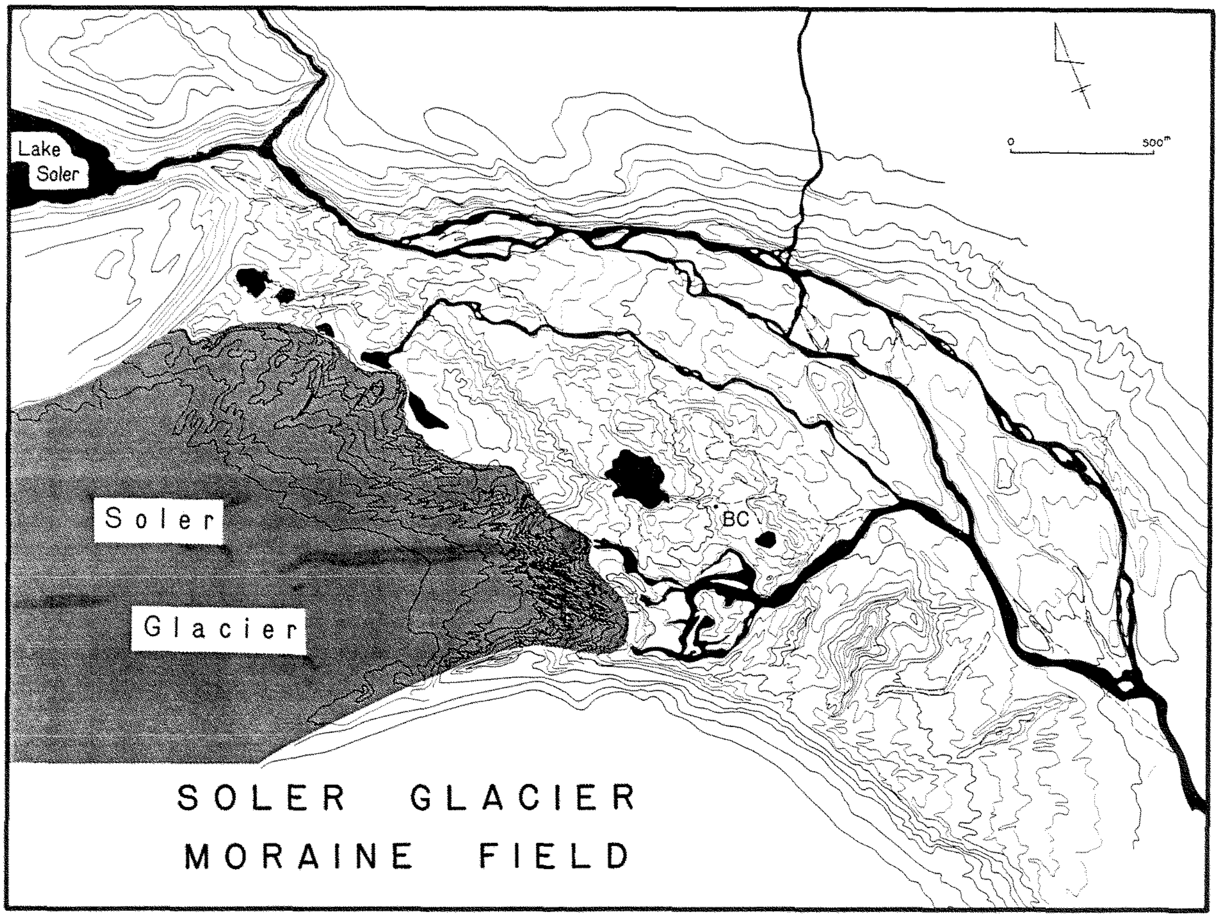

Fig. 2. Moraine field in front of Soler Glacier. Contours are given for every 5 m (thin lines) and for every 25 m (thick lines). The minor contours are omitted on the slopes flanking the valley. Base camp at approximately 277 m above sea level.

to the Cacho River. The second greatest contribution is made by the channel fed by Lake Soler and running along the northern margin of the valley. The smallest contributor seeps out from the northern half of the glacier terminus and runs between the other two. Seepage through the debris being the only source, the flow is almost negligible in comparison with the others. However, this channel is important because it marks the boundary between the debris-flow-flooded area to its north and the unscathed area to the south. These three channels are tentatively referred to by the prefixes Glacier, Lake and Seepage henceforth.

The topographic relief shows a marked contrast across the Seepage Channel. Moraines are tall and well preserved on the right bank of the channel, whereas they are modulated into a low profile on the left bank. This is most probably due to the glaciofluvial debris-flow caused by damming of Lake Soler by lateral moraines and its subsequent outburst as postulated by Aniya (1985). As can be clearly seen in Fig. 2, there are three conspicuous moraine sections on the right bank of the Glacier Channel and another three in the triangular piece of land delineated by the Glacier and Seepage Channels. Though not as well-defined as those above, there are three more elongated mounds on the left bank of the Seepage Channel, which seems to be the remnants of moraines eroded by the debris-flow.

Though they are thus cut into pieces by the channels, an observation from vantage points high up on the valley wall and subsequent analysis of air photos made it possible to put these separate sections of moraines together as in Fig. 3, in which what seemed to be the original lines of moraine ridges are shown. There are altogether six different moraine ridges of

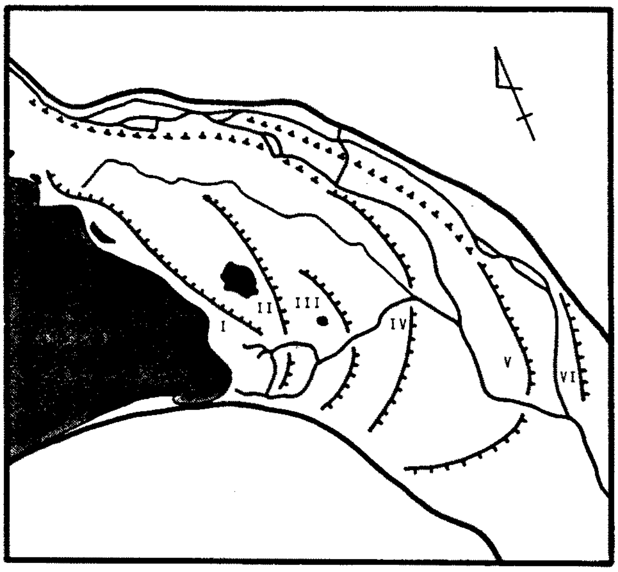

Fig. 3. Reconstructed moraine ridges, I through VI in the increasing order of distance away from Soler Glacier snout, *i.e.* in increasing order of age.

different ages, numbered I through VI in increasing order of age. Crescent groove areas between any two successive moraines can be identified also by the number of the moraine on their downstream side.

Although numerous factors such as lodgement sequence, curvature, tints, etc. were taken into consideration in connecting moraine sections across the channels, this matching was subjective and differed from the one proposed by Aniya (*op. cit.*). With our present knowledge, however, it is not possible to determine whose matching is better. A more detailed description of the landforms appearing in this area was also given by the same author, and thus is omitted here.

From the vegetation point of view, most of the moraine area is characterized as open woodland in which relatively young and small-sized trees are growing very sparsely, but there were several areas devoid of trees. The most conspicuous was the recently-deglaciated strip of land along the snout. The second most conspicuous was the burn in the central part of crescent IV resulting from the man-caused fire of the 1940s.

There was a tendency for trees to be more abundant on the moraines than on the level ground or depressions surrounding them. Field observations revealed that these low-lying localities were either too dry or too wet for trees. Dry sites were common in the flooded area to the north of the Seepage Channel where the flood had enhanced soil permeability. On the other hand, wet depressions and grooves were more common in the area to the south of the Seepage Channel where near-stagnant water had lodged silty sediments.

4. Dating moraines

The complete abscence of snags which had died of old age or their remnants in the moraine field indicated that the existing trees were the first generation invading the deglaciated area. This in turn suggests that the ages of the moraines can be determined by dating the existing trees, and assessing the lead time the trees had to wait before invading an area newly set free of ice. Accordingly the tree ages and the lead time were estimated as follows.

The sampling for determining the tree ages was carried out by the moraine-crescent complex, an areal sampling unit between two successive moraine ridges which included the hind slope of a given moraine, crescent area behind it and the frontal slope of the next moraine, and identified by the moraine/crescent number. This demarcation was besed on the preliminary observation that the degree of plant colonization changed drastically across the moraine ridge but not as much across the crescent between two successive moraines.

Ten individual trees were sampled from each of the moraine-crescent complexes II through V. As mentioned earlier no tree had been established yet in the crescent behind moraine I. Sampling from crescent VI was abandoned due to limitations on accessibility and time. In each crescent, apparently the oldest and/or largest individuals were sampled rather than choosing them randomly. A preliminary survey had indicated that within any given crescent there was a certain variation in tree age and size, indicating that trees were still in their invading stage even in the oldest crescent, and therefore the selective sampling of the oldest individuals is more representative of moraine age than random sampling.

For each tree sampled, total height and diameter at breast height (D. B. H.) were measured respectively with a Blumeleiss hypsometer and diameter tape. The ages of the trees were determined by counting annual rings on increment cores extracted with an increment borer from the lowest possible portion of the trunk. The absolute age at the base of the trunk was estimated by simply extrapolating the mean height growth rate obtained from the ring count on the core and the hight above the boring scar. Since the height growth is generally slower in the seedling stage than in later stages, the estimated absolute ages tend to be less than what they really are.

The results of the sampling are shown in Table 1, in which the maximum, mean and standard deviation of the observed height and diameter as well as the estimated absolute age are given for each moraine-crescent complex. Except for crescent V, both tree age and size decreased with increasing proximity to the glacier snout, indicating the relative seniority of the respective moraine-crescent complex.

This result suggests that the invasion by trees of a far less fertile deglaciated area would certainly require much more lead time. As a matter of fact, in spite of a thorough check throughout the similarly burned area in crescent III and IV on the right bank of the Seepage Channel, no trace of regenerating seedlings was found, meaning that the lead time here will certainly exceed 40 years.

Taking these results and other detailed field observations into account, the lead time for tree invasion of a newly-deglaciated area was estimated here rather subjectively at 50 years. Adding this to the ages of the oldest trees, the ages of 70, 90 and 130 years were obtained for moraine-crescent complexes

Table 1. Age and size of trees on wooded moraines.

Moraine	Major	Height (m)			D.B.H. (cm)			Absolute Age (yr)		
(Crescent)	Species	Max.	Mean	S.D.	Max.	Mean	S.D.	Max.	Mean	S.D.
II	*Nb*	2.66	2.35	0.19	6.7	4.3	1.4	20.7	19.3	1.46
III	*Nb*	6.80	5.01	1.14	22.0	13.7	5.0	40.5	34.8	4.19
IV	*Nb*	9.50	7.62	0.93	43.6	22.6	8.8	80.9	60.5	10.36
V	*Nb*	6.90	4.72	1.54	23.1	14.4	5.4	59.2	42.5	10.64

Nb: *Nothofagus betuloides*

For the rather inconsistent result of crescent V, there are two possible causes, both arising from the fact that the samples were taken from the flooded area to the north of the Seepage Channel. One possibility is that they were not the original settlers but the secondary regeneration after the flooding. The other possibility is that they were original settlers but their invasion was retarded due to the drier and more permeable soil conditions of the flooded area. If the former is the case it is possible to date the debris-flow as well.

The lead time for the tree invasion was estimated from the regeneration process following the fire of the 1940's since there was no way of determining it directly in the deglaciated area. Two small sampling plots, each containing ten seedlings, were established in the burn on the northern flanking slope of the valley at altitudes of 600 and 800 m a. s. l., and then the size and the absolute age of the seedlings were measured. These 20 sample seedlings showed a variation of 90 to 209 cm in height, 1.3 to 4.9 cm in base stem diameter and 10 to 16 years in absolute age counted at the base of the stem. Assuming that the fire took place in 1945, the above age distribution means that the lead time was 24 to 30 years even on the flanking slope where soils were better developed and more fertile than the valley bottom.

II, III and IV respectively. Assessing from the state of colonization by lichens, mosses, grasses and dwarf woody bushes on moraine ridge I, it was estimated that it would take another decade or so before trees could invade here, which makes the age of moraine I some 40 years. Assuming a 5-year allowance on both side of these point estimates, it may be concluded that these four moraines were formed in the decades of the 1940s, 1910s, 1890s and 1850s. So far as moraine I is concerned, the validity of the above estimation can be confirmed through old air photos taken in 1944. Using these air photos, Aniya and Enomoto (1986) delineated the glacial front of the time, according to which the terminus was in direct contact with moraine I in 1944, in good agreement with the present estimation.

5. Concluding remarks

Though not very accurate, the approximate ages of the four recent moraines were determined from the ages of the oldest trees and the assessment of the tree invasion process. Similar methodology of dating moraines would certainly apply to the neighbouring glaciers in which a series of wooded moraines are found in their proglacial area. Accumulation of such dating results will not only improve the consistency of dates obtained but also clarify the process of recent deglaciation of the Patagonia Icefields.

Acknowledgments

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Resumen

Retroceso reciente del Glaciar Soler bajo el punto de vista de la recuperación de la vegetación en Patagonia

A lo largo del valle del Río Cacho se reconoció tres zonas fluvioglaciales aguas abajo del frente del Glaciar Soler : campo morrénico, planicie fluvioglacial con rocas y sedimentos gruesos y planicie fluvioglacial con sedimentos finos. Tal como el nombre lo indica, el campo morrénico ha retenido morrenas y muchos otros rasgos geomorfológicos que ha dejado el Glaciar Soler durante su retroceso. Para revelar este proceso de deglaciación se reprodujo una carta topográfica detallada del campo morrénico a partir de una serie de fotografías aéreas verticales tomadas por la USAF en 1974. A partir del análisis de esta carta y las observaciones de terreno se diferenciaron seis morrenas terminales distintas de diferentes edades. De estas seis, la formación de las cuatro más recientes se datő en las décadas de 1940, 1910, 1890 y 1850 respectivamente, basándose en el crecimiento arbóreo en cada zona. Para ello se consideró que desde el momento del retroceso del glaciar se necesitan 50 años para el comienzo del crecimiento arbóreo, agregando este lapso de tiempo al número de anillos registrados en el árbol más antiguo de cada morrena.