Report 12

Landforms in the proglacial area of Soler Glacier

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Abstract. There are four types of landforms in this area: 1) moraines, 2) glacial bench, 3) outwash plain, and 4) debris flow deposit area. The types of terminal moraines are: 1) moraines with linear, well-defined ridge, 2) hummocky moraines, and 3) washboard (De Geer) moraines. The moraine field was divided into five belts of different ages, mainly by vegetation condition. Near the crest of the second youngest moraine belt, a piece of wood was uncovered and dated ca. 850 B. P. There are several levels of old lateral moraines on the left bank, while ice-cored lateral moraines are distributed on the right bank of the glacier.

The glacial bench is located at elevations between 400 m and 500 m on the left bank of Cacho River. It was probably formed by the different erodibilities of the rock minerals (schist). The outwash plain occupies the lower part of the proglacial area.

The debris flow deposit area extends as far down as 2.7 km from Lake Soler. Large boulders are scattered around the area about 1.6 km long and 300–400 m wide. It was postulated that Lake Soler was dammed by an old lateral moraine left by the old Soler Glacier, and the subsequent outburst caused the debris flow.

Field work and stereoscopic analyses of vertical aerial photographs revealed the following four types of lanforms in the area: 1) moraines, 2) glacial bench, 3) outwash plain, and 4) debris flow deposit area (Figs. 1 and 2).

1. Moraines

1.1. Terminal moraines

The moraine field extends as far down as 1.4 km from the present glacier snout. The alignment, morphology, vegetation conditions and degree of weathering of tills vary widely, suggesting different ages of deposition. Taking into account these conditions, the moraine field appears to be divided into five belts (inset, Fig. 1) of different ages. The boundaries between belts I and II, and II and III are clear by the vegetation condition and the divisions are fairly certain. The boundaries between belts III and IV, and IV and V are not so clear, however. The division between belts III and IV is based on the abundance and size of trees, whereas that between belts IV and V is mainly based on physical separation by the outwash plain.

There are three types of terminal moraines here: 1) linear, well-defined single ridges whose trends are transverse to the valley direction, 2) hummocky moraines (HOPPE, 1952), and 3) washboard moraines (MAWDSLEY, 1936) or De Geer moraines (PREST, 1968). The first type constitutes belt V and the lower end of belt IV. The relief of the moraine ridge of belt V is about 18 m and its trends suggest that the snout was convex down-glacier. The isolated large moraine hill located on the right bank in belt IV has reliefs up to 44 m, indicating a major standstill phase of the glacier fluctuation. Located at the base of the moraine hills are cliffs, suggesting active glacio-fluvial erosion in the past. A somewhat spear-head shaped moraine

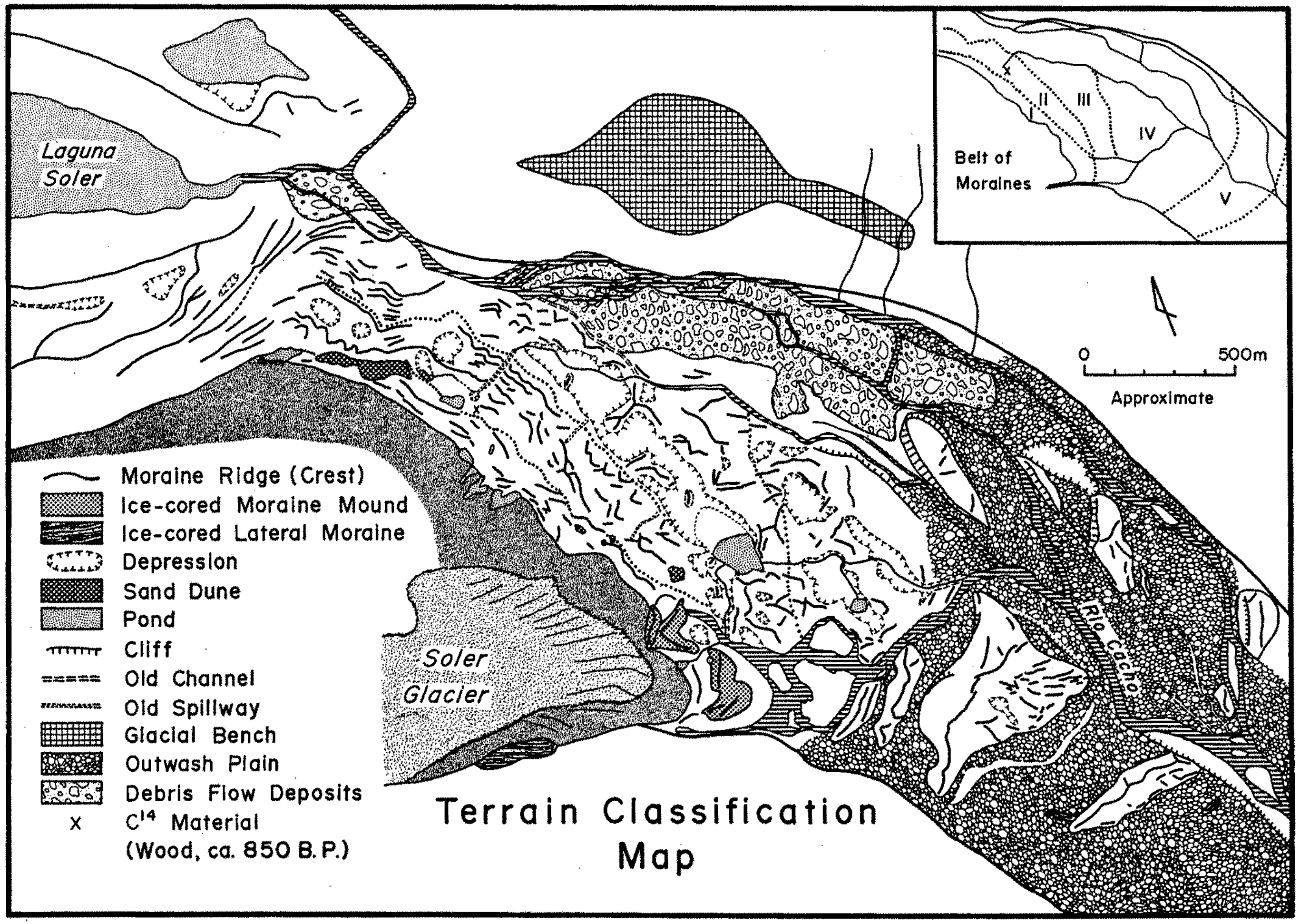

Fig. 1. Map showing landforms distributed in front of Soler Glacier. It was compiled from the ground survey and aerial photographic interpretation.

hill in belt IV has very interesting features. First of all, it is bounded by cliffs on all sides whose relief is up to 10 m, decreasing down-river. Topography of hill tops is typically hummocky, with reliefs up to a few meters. Linear cliffs of belt IV and V have probably been scoured by debris flow(s) to be discussed later. Moraines of belt IV, located between Cacho River and a branch coming from Soler Glacier, are hummocky. The orientation of the moraine ridges bears no relation to ice movement or valley direction. The depressions are flat-bottomed and filled with well-sorted, round pebbles, indicating their origin as proglacial lakes.

Those found in belt III are of two kinds, hummocky and washboard (De Geer). This belt also contains a long (1.1 km) linear depression whose south end is still occupied by a lake. Interestingly this lake is drained by two streams, one to the east and another to the south. North of this depression lies a series of very closely-spaced washboard moraines. The spacing is on the order of tens of meters. The field of these washboard moraines is very gently inclined toward the river. To the east and south of the depression lie hummocky moraines. Depression in this area are usually not flat-bottomed. South of the large depression are many small mounds whose relief is 1–2 m. These mounds consist of very well-rounded pebbles, often with reverse grading. Generally speaking, pebbles even on top of the ridges are relatively well rounded, suggesting a subglacial origin.

The moraines in belt II have the typical appearance of a washboard (Fig. 2). Especially the northern half consists of a series of ridges which are zig-zag shaped, yet parallel to each other. A large area of this belt, except for the northern one third, is rather steeply inclined (20–25°) toward the depression. There are three old spillways filled with large round boulders without vegetation. One of them, the northernmost one, has small stream flow, but other two are dry, at least during summer. Depressions in this belt are flat-bottomed with sand, not pebbles. They are conspicuously white. The relief of this belt from the neighboring depression reaches close to 50 m. Near the crest of this moraine belt, a wood piece was found and the buried part was excavated for C^{14} dating. It was dated ca. 850 B.P. by Tohoku University (sample number TH-1044). There are many other wood fragments scattered around this site.

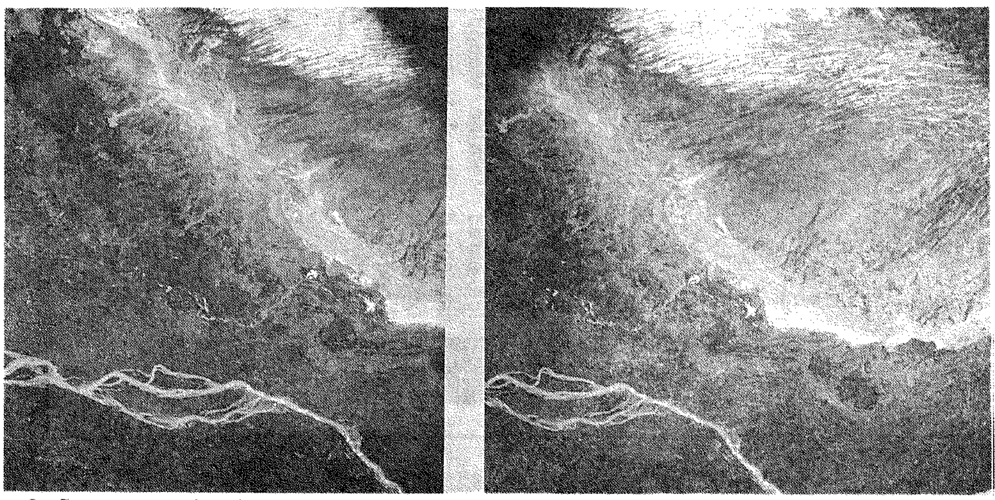

Fig. 2. Stereogram showing the glacier snout, left bank and proglacial area. Note tone difference in the terminal moraines and depressions. Compare with Figure 1.

Belt I represents moraines being formed at present. Here rocks are very loosely, precariously piled up with fine dust (clay) resting on top of the boulders. Rocks are more angular (subangular) as compared with those on other belts. There are a couple of very characteristic features in this belt. At the northern end lies a large sand dune field, about 300 m long and 50–70 m wide. Other interesting features are located at the southern end. Here are several ice-cored moraine mounds whose relief is 15–20 m. The thickness of debris mantle, sand and pebbles, is about 10 cm and up. The side slope is about 34–35 degrees, the angle of repose for these materials. On top of these mounds are nearly-horizontal, stratified sediments of silt, sand and pebbles, which often show reverse grading. The southernmost one consists of three peaks and is completely detached from the present snout. The other two lie adjacent to each other and right next to the present snout, although they are separated by deep supraglacial stream channels. Formation of these ice-cored moraine mounds is not known, although it appears similar to a "high relief disintegration moraine" described by PREST (1968).

1.2. Lateral moraines

Description and discussion of the lateral moraines are confined to those located on the left bank between Lake Soler and Soler Glacier. The right bank is generally very steep and no trace of old lateral moraines near the snout can be recognized, and presently a few ice-cored lateral moraines are found at the level slightly higher than the present glacier surface. At first sight, the hill between Lake Soler and Soler Glacier appears to consist solely of moraines. It is true that a large part is still covered with moraines; however, there is a hard, solid rock core, part of which is exposed at the southern flank. At the highest point of this hill, about 570 m, a survey station was established. Presently this point is more than 150 m higher than the glacier surface below, yet there is clear evidence that this hill was once completely buried under ice. There is a small depression filled with round pebbles and moraine ridges near the top.

Figures 3-A and 3-B show the distribution of lateral moraines sketched in the field and interpreted from aerial photographs, respectively. Figure 3-A is not drawn to scale because it

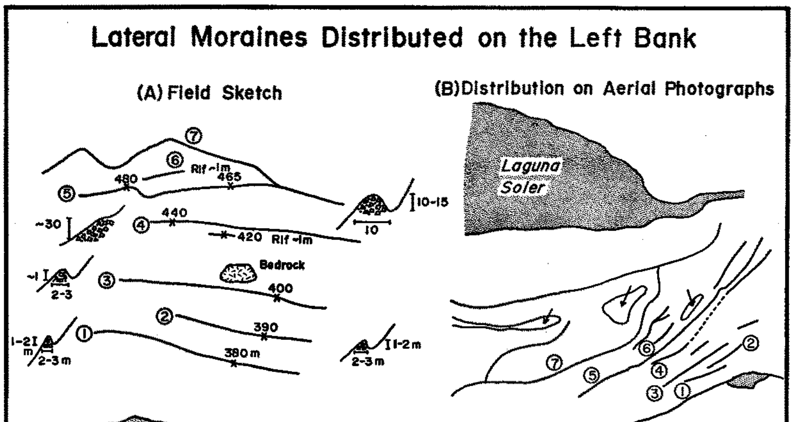

Fig. 3. Lateral moraines on the left bank, identified in the field and on vertical aerial photographs. Circled numbers indicate the same moraine in (A) and (B).

is a simple sketch. Elevation was read with an altimeter after setting the height of the base camp at 300 m, which was estimated from the 1:50,000 topographic map. These lateral moraine ridges generally consist of large boulders, whose diameters are up to 10 m. Except for lateral moraines Nos. 5 and 7, they are not so large, with reliefs of 1–2 m and widths of 2–3 m in general. From No. 1 through No. 4, there is no vegetation on the moraines. No. 5 is a very prominent ridge with relatively thick vegetation, on which trees as thick as 30 cm at DBH can be sporadically seen. This moraine is clearly much older than No. 4, which does not form a prominent ridge, but consists of large boulders spreading out on the slope. No. 5 has two distinctive levels of ridges, which are connected by a steep-sloping ridge. The sloping part is very sandy and is heavily vegetated so that it is completely hidden from view. Only walking along this ridge revealed its interesting nature. The relief is very high, 10–15 m, and the near the depression it is up to 20 m. This No. 5 lateral moraine probably represents the latest major advance of Soler Glacier. Lateral moraine No. 7 is very large with heavy vegetation. From the configuration of the ridge, this moraine used to be connected with the one located on the north shore of Lake Soler and was impounding a stream from Cacho Glacier.

2. Glacial bench

The glacial bench is located on the left bank of Cacho River, to the east of the debris flow deposit area. The elevation ranges from 400 m to 500 m, and it is about 100–200 m higher than the valley floor. Near the southeastern end, the bench consists of several small steps at an elevation of around 400 m. There are one major and three minor steps, each separated by a cliff 2–4 m high. Rocks on the left bank of Cacho River are schist on the lower part of the slope, and are quite different from those on the right bank where granitic rocks are dominant. COTTON (1958, p. 294) mentioned such glacial benches developed on mica schist in New Zealand. Ground photographs taken from the other side show several near-horizontal terraces or benches at higher elevations at a few levels on the slope. Clearly the bench is formed by glacial erosion because striation and fluting on the side of the cliffs are conspicuous. It is difficult to consider that these small steps were produced by different cycles of erosion. It appears plausible that these steps were molded simultaneously by the rock control of schist, whose apparent strike is almost parallel to the glacier flow direction.

3. Outwash plain

The outwash plain is distributed in the lower half of belt IV and down the river, at elevations ranging from 300 m to 250 m. At present Cacho River has incised the outwash plain up to several meters, leaving small terraces here and there. Old channels are particularly abundant in the lower half of belt IV on the right bank and belt V.

The thickness of the valley train was estimated using the model $Z = aX^b$ (see Report 11 for a detailed explanation). The results indicate that in front of the glacier it is on the order of 300 m, whereas about 4 km down from the snout, it is on the order of 200 m.

4. Debris flow deposit area

The debris flow deposit area is identified mainly on the basis of scattering large boulders and interstitial gravel and sand of fluvial origin. Depositional form is clearly different from

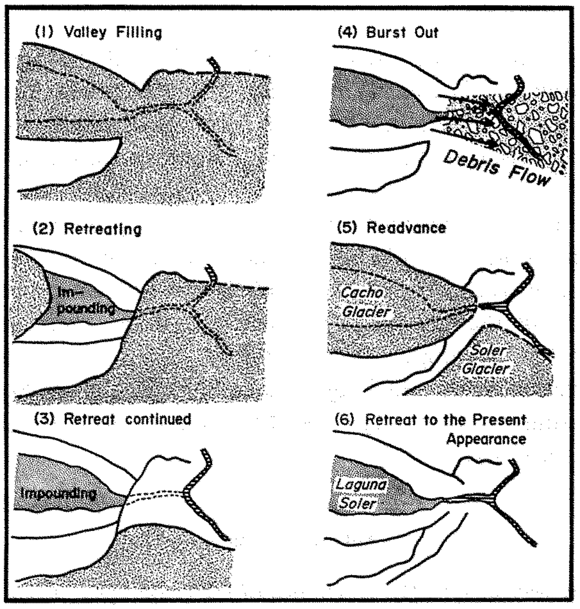

Fig. 4. Schematic sequence of glacial advance and retreat to account for the debris flow.

the moraines. The area spreads out as far down as 2.7 km from Lake Soler. However, the area is not continuous all the way. It is obliterated between 1.1 km and 0.6 km with moraines deposited during the subsequent glacial advance. The size of the main deposit area is about 1.6 km long and 300–400 m wide. Although the climate in the past may have been quite different from that of the present day, it is not conceivable that the debris flow was caused directly by heavy rains in this climatic environment.

It was postulated in the field that the blocking of Lake Soler by the lateral moraines of Soler Glacier and the subsequent burst-out had caused this debris flow. Later, aerial photographs clearly supported this postulation by exposing a lateral moraine which once was blocking Lake Soler. Although the date of events cannot be ascertained yet, a sequence of events can be reconstructed as in Figure 4. At one time, Soler Glacier and Cacho Glacier joined and filled up the present Cacho River valley from bank to bank (Fig. 4-1). Then the glaciers started retreating. Since Cacho Glacier was small, its retreat was much faster than that of Soler Glacer. Consequently, at one time, Cacho Glacier had become too short to join Soler Glacier and between the snout and the side of Soler Glacier was an impounded lake (Fig. 4-2). While ice was blocking Cacho River, the impounded lake probably drained subglacially in a periodic fashion after enough pressure built up to float the ice.

Meanwhile the retreat continued and eventually the glacier retreated to the south of Cacho River, leaving only the lateral moraine to block the stream (Fig. 4-3). Then the lake water spilled over and eroded blocking material until the water burst out (Fig. 4-4), causing a debris flow which involved boulders weighing a few hundred tons. It is probable that this process of impounding and burst-out was repeated, but there evidence among the debris flow deposits to indicate this repetition has not yet been found. After this episode of the debris flow(s), the glaciers once more advanced (Fig. 4-5) and retreated to the present state (Fig. 4-6).

5. Summary and conclusions

Field survey and subsequent stereoscopic analyses of aerial photographs helped recognize the following landforms in this area: 1) moraines, 2) glacial bench, 3) outwash plain, and 4) debris flow deposit area. The terminal moraine field was divided into five belts of different ages. A wood piece was recovered from the second youngest moraine belt and dated ca. 850 B.P.

Seven levels of lateral moraines on the left bank are well preserved and could possibly be correlated with the position of the old Soler Glacier snouts. A glacial bench is regarded as a product of differential erosion. The thickness of the valley train on the Cacho River flood plain is estimated to be on the order of 200–300 m. The present river has incised the outwash plain up to several meters, leaving small terraces.

Debris flow was caused by the blocking of Lake Soler by the old Soler Glacier, and subsequent outburst during the retreating stage. More dating of materials is required to date events revealed in this study.

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Resumen. Formas del terreno en el área proglacial del Glaciar Soler

Las formas del terreno reconocidas en esta área son de cuatro tipos: 1) morrenas; 2) escarpe glacial; 3) planicie fluvioglacial; y 4) área de depósito de flujo de detritos. Hay tres tipos de morrena terminal; 1) con cordón lineal bien definido, 2) morrenas de colina, y 3) morrenas corrugadas. El campo de morrenas aparenta estar dividido en cinco cinturones, especialmente por la diferencia en la condición de la vegetación. El cinturón I representa el cordón morrénico actualmente en formación, mientras que el cinturón V es el más antiguo reconocible en el valle del Río Cacho. Cerca de la cúspide del cinturón II, contiguo al conturón I, un trozo de madera fue desenterrado de la morrena y datado en aproximadamente 850 años de antiguedad por el método de C^{14}.

En el margen derecho (mirando valle abajo) del Glaciar Soler hay morrenas laterales con núcleo de hielo, pero no existen antiguas morrenas laterales que podrían indicar niveles anteriores de la superficie del glaciar. Por otro lado, hay cerca de siete niveles de morrenas

laterales en el margen izquierdo (Fig. 2). Estos están compuestos por grandes bloques cuyos diámetros alcanzan hasta 10 m.

El escarpe glacial se ubica al noreste del Río Cacho en su margen izquierdo, a una cota entre 400 y 500 m. Se eleva cerca de 100 a 200 m por sobre el lecho del valle. Las rocas aquí son esquistos, lo cual es bastante distinto a aquellas encontradas en el margen derecho y la zona del Cerro Hyades, donde dominan las rocas graníticas.

La planicie fluvioglacial se distribuye en la mitad inferior del cinturón IV y a lo largo del río. Su superficie es casi plana con gravas redondeadas que están clasificadas en cierta medida. Hay pocos canales antiguos y pocos niveles de terrazas formadas por el Río Cacho.

El área de depositación del flujo de detritos se extiende hasta 2,7 km aguas abajo del extremo del Lago Soler. Está obliterada, sin embargo, entre los km 0,6 y 1,1, por las morrenas depositadas durante el subsiguiente avance glaciar. Grandes bloques están dispersos en el área, de approximadamente 1,6 km de largo y 300–400 m de ancho. Se postula el siguiente mecanismo de flujo de detritos (Fig. 3). Cuando los glaciares retrocedían luego de una etapa de relleno del valle, una morrena lateral del Glaciar Soler bloqueó un tiempo el Río Cacho, causando una inundación. Consecuentemente, el aumento del tamaño del lago causó una descarga violenta de agua, produciendo un flujo de detritos.