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Tectonics and Sedimentation: an example from the Mérida Andes (Venezuela)

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ABSTRACT

Two fluvio-glacial terrace levels (20-25 and 6-10 m) crop out in the Los Zerpa morainic valley (Sierra de Santo Domingo). The upper and older terrace contains alluvial sediments deposited within a morainic dam after post-Pleistocene glacier retreat from the valley. Right-lateral movement along the Boconó fault, underlying the terminal moraine, interrupted sedimentation and caused erosion. The lower and younger terrace contains three sedimentary facies (from the lower to the upper part of the valley): a lacustrine, a deltaic, and a fluvial facies, which represent the second sedimentation event. Later renewed movement along the fault interrupted this phase and caused incision and terrace formation, a process which continues today.

RESUMEN

En el valle morrénico de Los Zerpa, en el flanco noreste de la Sierra de Santo Domingo (Andes de Mérida), afloran dos niveles de terrazas (20-25 m y 6-10 m), conteniendo sedimentos fluvio-glaciales-lacustres, los cuales reflejan la evolución post-glacial de este valle. La terraza superior y más antigua, representa el primer relleno aluvial, después del comienzo del retiro post-pleistoceno del glaciar Los Zerpa. Esta sedimentación fue interrumpida por la apertura de una brecha en el arco morrénico que representa los sedimentos, probablemente debido a un desplazamiento hacia la derecha a lo largo de la falla de Boconó, la cual corta y separa la morrena terminal de las morrenas laterales. La deposición de los sedimentos de la terraza inferior, más joven, corresponde a un nuevo período de relleno del valle y consiste de tres facies: una facies lacustre en la parte inferior del valle, una facies deltaica en la parte media-superior y una facies fluvial en la parte alta. Estas tres facies muestran un panorama sedimentario fluvio-deltaico-lacustre durante este período. Una nueva apertura de la brecha a través del arco morrénico, debido probablemente a desplazamiento a lo largo de la falla, originó un nuevo período de erosión, con formación de una terraza, el cual continua actualmente.

RESUM

A la vall morrènica de Los Zerpa, en el flanc norest de la Sierra de Santo Domingo (Andes de Mérida), hi afloren dos nivells de terrassa (20-25 m i 6-10 m), que contenen sediments fluvio-glacio-lacustres, els quals reflecteixen l'evolució postglacial d'aquesta vall. La terrassa superior i més antiga representa el primer rebliment aluvial, després de començar la retirada post-pleistocènica de la glacera Los Zerpa. Aquesta sedimentació fou interrompuda per l'obertura d'una bretxa a l'arc morrènic que deturava els sediments, degut probablement a un desplaçament cap a la dreta al llarg de la fractura de Boconó, la qual talla i separa la morrena terminal de les laterals. La deposició dels sediments de la terrassa inferior, més jove, correspon a un nou període de rebliment de la vall i es compon de tres fàcies: una fàcies lacustre a la part inferior de la vall, una fàcies deltaica a la part mitjana-superior i una fàcies fluvial a la part alta. Aquestes tres fàcies mostren una panoràmica sedimentària fluvio-deltaica-lacustre durant aquest període. Una nova obertura de la bretxa a l'arc morrènic, degut probablement al desplaçament al llarg de la fractura, originà un nou període d'erosió amb la formació d'una terrassa que continua actualment.

INTRODUCTION

Almost all valleys located above 3000 m elevation in the Mérida Andes (Venezuela) were affected by the Mérida Glaciation, which represents the last important Pleistocene advance of the glaciers, which are restricted at present to the Bolívar, La Concha, Humboldt, and Bonpland massifs of the Sierra Nevada de Mérida (Schubert, 1972, 1974, 1975, 1980). At least two stades can be recognized within the Mérida Glaciation: an Early Stade, of which there are few remnants, such as possible tills between 2600 and 2800 m, and a Late Stade, dur-

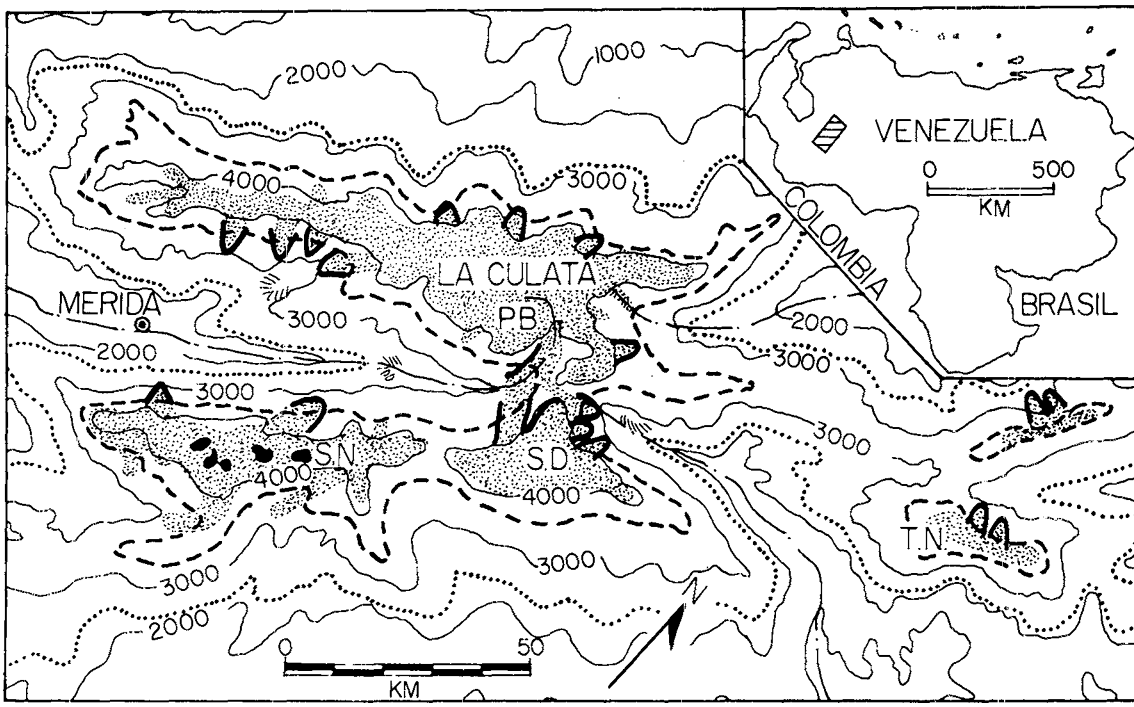


Figure 1. Approximate extent of the glacial and periglacial zones during the Mérida Glaciation and today in the Mérida Andes. Symbols: SN: Sierra Nevada de Mérida; PB: Páramo de Piedras Blancas; SD: Sierra de Santo Domingo; TN: Teta de Niquitao. Present-day glaciers are shown as small black areas in the Sierra Nevada. The maximum Pleistocene glacier extent is shown as stippled areas. The main morainic complexes (3000-3500 m) are shown as thick black lines. The broken lines and the dotted lines represent the Late Pleistocene and present-day periglacial limits, respectively. The hatched lines represent the probable lower morainic level (2600-2800 m).

ing which the prominent till complexes were deposited, located between 3000 and 3500 m. During the Late Stade, the area covered by glaciers in the Mérida Andes was about 600 km^2 and the periglacial zone covered approximately 2200 km^2 (Fig. 1); at present, the glacier covered area is less than 3 km^2 and the periglacial zone *(Páramo)* covers a surface of approximately 1200 km^2.

The main evidences left by the Mérida Glaciation are: lateral and terminal moraines, frequently forming long and closed valleys, recessional moraines, glacial lakes, striated, grooved, and polished rock surfaces, cirques, and arêtes. In most Andean valleys, the postglacial sedimentary record is fragmentary due to the erosive force of the rivers. In this report, I deal with the sedimentary and tectonic relationships in the Los Zerpa river valley, where these are well preserved.

The Los Zerpa valley is located in the northern flank of the Sierra de Santo Domingo (Fig. 2), approximately half-way between the towns of Santo Domingo and Apartaderos (State of Mérida). The Los Zerpa river is a tributary of the Santo Domingo river and drains an area of approximately 3.7 km^2 in its upper part (Fig. 3). The morainic valley proper (Fig. 4A) is approximately 0.75 km long and 0.1 km wide, and is bounded to the north by a terminal moraine, and to the east and west by lateral moraines, up to 100 m or more in height above the valley floor. To the south, the morainic valley passes into the Los Zerpa glacial valley (Schubert, 1970), cut in Precambrian gneiss, schist, amphibolite, and granite, characterized by a typical glacial morphology (three cirque levels, rock steps, and polished and striated rock).

In its lower part, the Los Zerpa morainic valley is traversed by the Boconó fault, which represents the active trace of the Boconó fault zone, an important strike-slip fault in the central Andes (Schubert, 1982). This fault trace cuts the lateral moraines and separates them from the terminal moraine (Figs. 3, 4A, 5), which has been offset by about 70 m in a right-lateral sense since the deposition of the moraines.

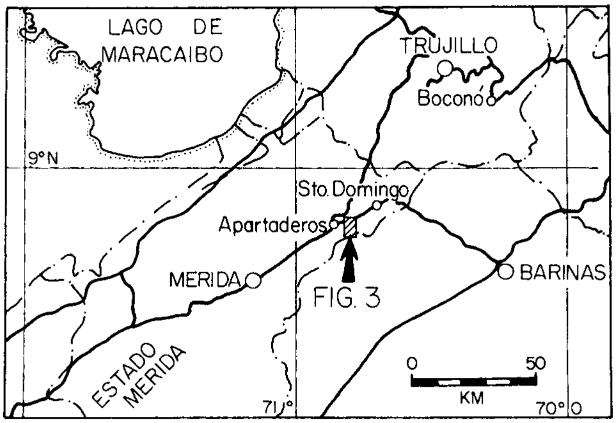


Figure 2. Index map.

Based on stratigraphic considerations and correlation with adjacent regions, it has been suggested that the Late State of the Mérida Glaciation approximately corresponds to the last stade of the Wisconsin Glaciation of the temperate regions (Schubert, 1974). Radiocarbon age determinations of post-glacial sediments indicates a minimum age of 13,000 ^{14}C years B.P. for the moraines of the Late State (Salgado-Labouriau et al., 1979). By that date, the glaciers had for the most part abandoned the morainic valleys, in which fluvioglacial sediments and peat were being deposited.

SEDIMENTARY GEOLOGY OF THE LOS ZERPA VALLEY

Fig. 5 shows the sedimentary geology of the Los Zerpa morainic valley. It consists mainly of two sedimentary groups: the till of the Los Zerpa moraines and the fluvio-glacial-lacustrine sequence contained in two terraces within the valley.

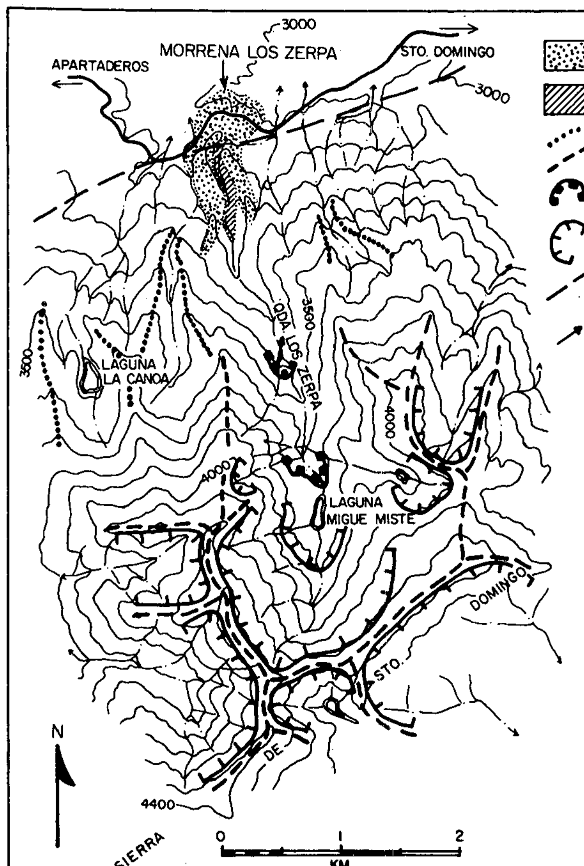
Glacial sediments

The glacial sediments were described in detail previously (Schubert, 1970, 1979), and consist of light gray till which can reach thicknesses of 100 m or more. The clasts contained in the till are mainly prismoidal and tabular; 6.3% of all clasts have well-developed facets and approximately 2.5% are striated or grooved. The majority of the clasts are subangular, due to the short distance of transport (4 km maximum). The most common lithologic types are banded and granitic gneiss; less common types are quartz-mica schist, amphibolite, granite, and quartz. These lithologies are typical of the La Mitisús Banded Gneiss, an informal unit of the Precambrian Iglesias Group in the Santo Domingo region (Schubert, 1969). The till fabric shows a down-valley preferential orientation.

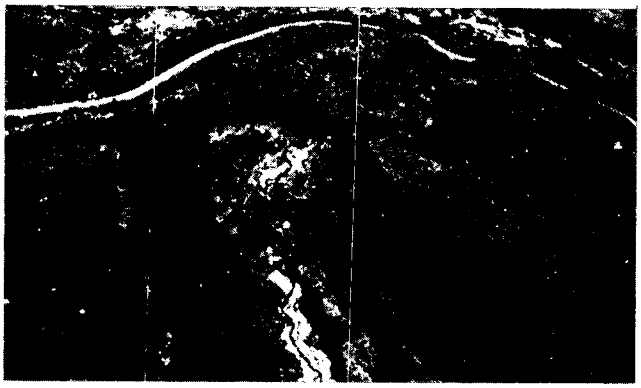
Fluvio-glacial-lacustrine sediments

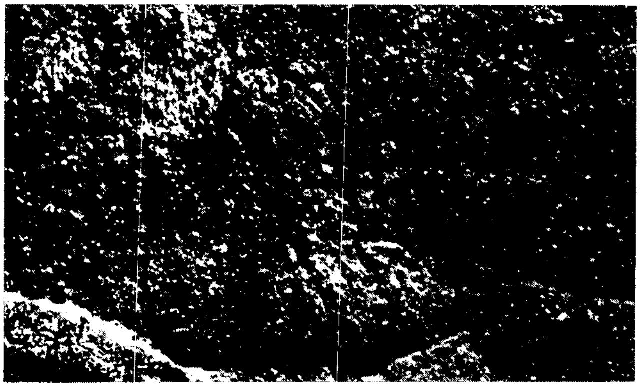
Within the Los Zerpa morainic valley, there are two trerraces whose surfaces are at 6-10 m and 20-25 m above present river level (Figs. 4A and B, 5).

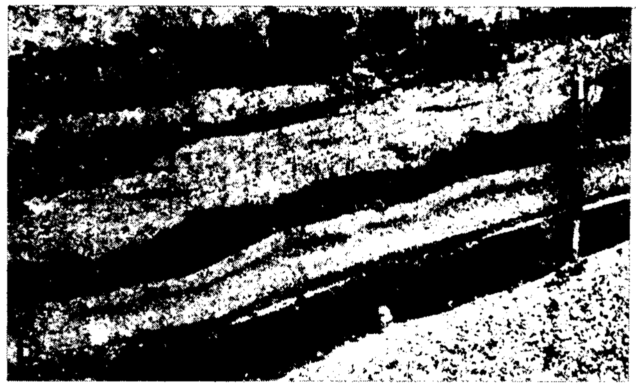
The 20-25 m terrace is best preserved in the higher part of the morainic valley. It consists of a sandy conglomerate interbedded with sand at the base, and sandy lenses with abundant cross-bedding; the upper 10-15 m consist of a bed of boulder and pebble conglomerate, in which the clasts (up to 1 m in diameter or more) are subrounded, frequently faceted and, less frequently, striated, suggesting their close glacial provenance.



Fige 3. Geologic map of the Los Zerpa river basin. Symbols: 1. Till; 2. Fluvio-glacial sediments; 3. Moraine crest; 4. Arete; 5. Rock step; 6. Cirque; 7. Boconó fault trace; 8. Glacial striae. The basement lithology south of the Boconó fault consists of banded gneiss, quartz-mica schist, and amphibolite of the Iglesias Group (Precambrian).







These sediments are within horizontal, poorly developed beds, with clast imbrication (Fig. 4C). The pebbles consist of banded and granitic gneiss, quartz-mica schist, amphibolite, and pegmatite. Minor normal faulting is observed in a few less competent beds within the sequence. These sedimentological characteristics are found throughout the 20-25 m terrace. It is lithologically homogeneous, probably represents the fluvio-glacial valley fill beginning whit the Los Zerpa glacier retreat, and resembles more spectacular alluvial sediments, mainly of climatic origin, in the lower parts of the major Andrean valleys (Schubert & Valastro, 1980).

The 6-10 m terrace is well exposed in the lower half of the morainic valley (Fig. 5), and outcrops are sufficiently abundant and extensive to allow reconstruction of the sedimentary environments. Figs. 4D to G show some of the characteristics of these outcrops. Three sedimentary facies can be distinguished within this terrace (from south to north): a fluvial, a deltaic (Fig. 4D to F), and a lacustrine facies (Fig. 4G).

The fluvial facies crops out in the extreme soulthern (and highest) end of the 6-10 m terrace, along the left margin of the river. It consists of a horizontal sequence of sandy conglomerate with frequent lenticular beds of sand and silt, and a few beds of clayey sand with a low organic content. Grain-size of the conglomerate is smaller than in the 20-25 m terrace, and it is much sandier. The lithology of the pebbles is identical to that in the conglomerate of the 20-25 m terrace and some reach boulder-size. The fluvial sequence is locally faulted due to settling of the unconsolidated sediment. Cross-bedding, ripple-bedding, and scour-and-fill structures are common.

The deltaic facies crops out in the upper third of the 6-10 m terrace (Fig. 4E), mainly along the right margin, because a recent landslide produced a fresh outcrop (Fig. 6), which is divided into two segments by gully erosion. There is no continuity in the outcrop along the whole 6-10 m terrace; therefore, the reconstruction of the sedimentary en-

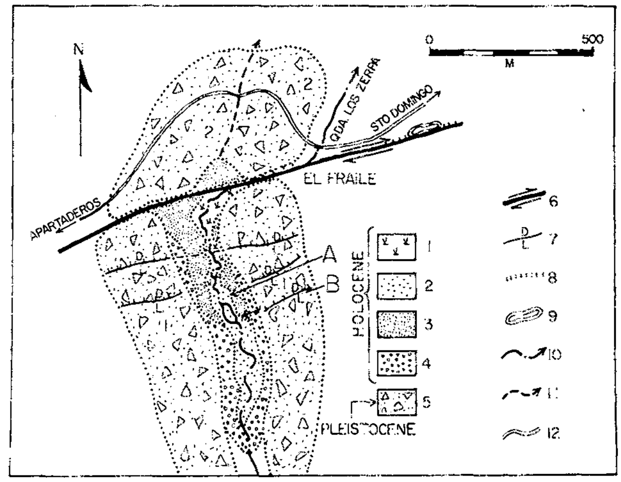


Figure 5. Geologic map of the Los Zerpa morainic valley. Symbols: 1. Bog on the present-day alluvial plain. 2. Fluvial sediments on the present-day alluvial plain. 3. 6-10 m terrace. 4. 20-25 m terrace. 5. Till. 6. Active trace of the Boconó fault. 7. Secondary normal faults. 8. Fault scarp. 9. Sag pond. 10. Present-day course of the Los Zerpa river. 11. Former course of the Los Zerpa river. 12. Road. Letters A and B show the location of the outcrops of Fig. 6.

vironments (Fig. 7) is based on the study of several individual outcrops along the morainic valley. The deltaic sequence consists of laminae and beds of sandy silt, sand, and pebble conglomerate, of variable thickness, frequently lenticular, with a N 35° E strike and approximate dip of 20 to 30° N. This is the initial dip of these sediments, which were deposited in a delta in the southern shore of a lake. The beds and lenses vary in thickness from several centimeters to several meters. The most common sedimentary and penecontemporaneous structures (some illustrated in Figs. 4D to F) are (Banerjee & McDonald, 1975; Gustavson et al., 1975; Saunderson, 1975): 1. Cross-bedding and cross-lamination, both of the planar and trough types (Reineck & Singh, 1975, p. 85); ripple-drift cross-lamination (Fig. 4D; Jopling & Walker, 1968) and scour-and-fill structures are also very common. In the outcrops of Fig. 6, there are good examples of foreset bedding, which dip approximately 30° N, and con-

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Figure 4. A. Helicopter view of the Los Zerpa morainic valley; the left lateral moraine is covered with pines; note the right-lateral ffset of the terminal moraine (Boconó fault marked by dotted line) and the two levels of fluvio-glacial terraces. B. View of the Los Zerpa morainic valley towards the south from the terminal moraine; note the two levels of terraces (20-25 m in the back, and 6-10 m in the center). C. Outcrop of sandy conglomerate of the 20-25 m terrace; note the poor bedding and the imbrication of the clasts; the outcrop has a height of about 15 m. D. Ripple-drift cross-lamination in a sand bed of the 6-10 m terrace; flow was from right to left. E. Part of an outcrop of deltain sediments of the 6-10 m terrace; note the penecontemporaneous sedimentary structures (foreset and topset beds, ripple-drift cross-lamination, and slump structures); the clip-board is approximately 30 cm long; flow was from right to left. F. Slump structure (*see* also Fig. 6); flow was from right to left. G. Laminar rhythmite of the lacustrine facies of the 6-10 m terrace.

sist of conglomeratic sand and silt (Fig. 4E); the topset beds crop out upriver in the transition zone to the fluvial facies. Draped lamination (Gustavson et al., 1975) is also very common. 2. Slump structures, which have been produced by the movement of sedimentary beds saturated with water, due to gravity (Fig. 4F and 6). All of these structures are associated with rapid sedimentation (Reineck & Singh, 1975, p. 79). 3. Convoluted bedding, particularly of silty sediments, which may have been produced by liquefaction of sediments during a disturbing event, such as a slump or an earthquake (Schlüchter & Knecht, 1979). 4. Minor normal faulting, which affects a few beds (Fig. 4F). Finally, some conglomeratic beds contain a brown to ochre oxidation layer, a few centimeters thick, which could be interpreted as the result of intermittent subaerial exposure of the top of the deltaic sequence.

The lacustrine facies is exposed in the lower part of the morainic valley, in contact with the lateral and terminal moraines. It consists of a monotonous horizontal sequence (Fig. 4G) of gray to purplish gray clay, finely laminated (rhythmite), with a few intercalated sandy layers and a few layers with a low organic content (however, not enough for radiocarbon dating; Teledyne Isotopes, personal communication, 1979). A few pebbles and boulders were found within the rhythmite which are interpreted as a probable result of ice-rafting; this implies that the Los Zerpa glacier still existed in the upper valley at the time of existence of the lake.

Fig. 7 shows a schematic reconstruction of the sedimentary environments during the deposition of the 6-10 m terrace.

POST-GLACIAL EVOLUTION OF THE LOS ZERPA VALLEY

Giegengack & Grauch (1975, p. 262) briefly described the evolution of the Los Zerpa morainic valley, and attributed the formation of the two terrace levels to erosion induced by offset along the Boconó fault. Following is a more detailed description of this evolution.

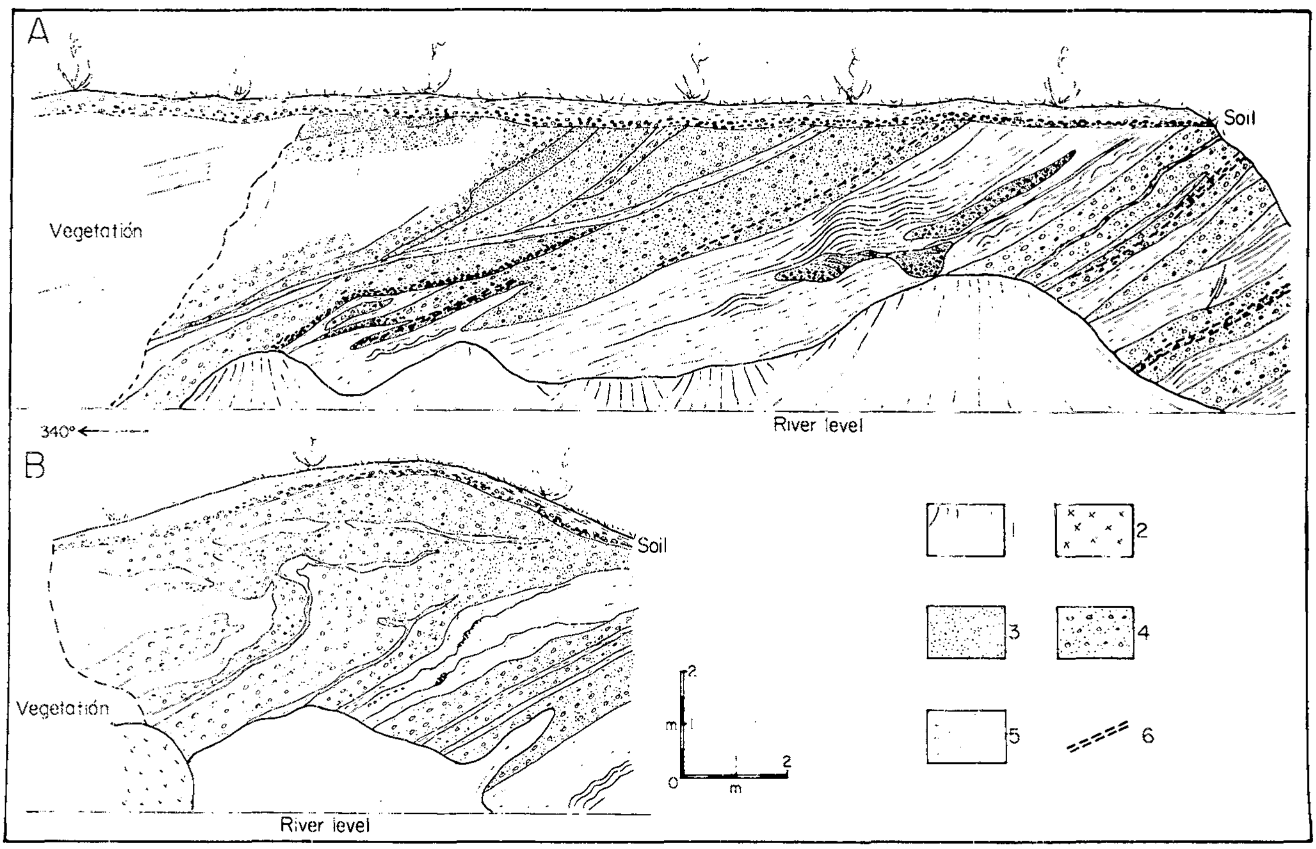

Figure 6. Outcrops of deltaic sediments of the 6-10 m terrace (*see* location in Fig. 5). Symbols: 1. Slump. 2. Gneiss boulder. 3. Light gray quartz-mica sand. 4. Lightgray sandy conglomerate. 5. Brown, laminated silty sand or silt, with wavy bedding (parallel, non-parallel, or discontinuous). 6. Oxidation zone.

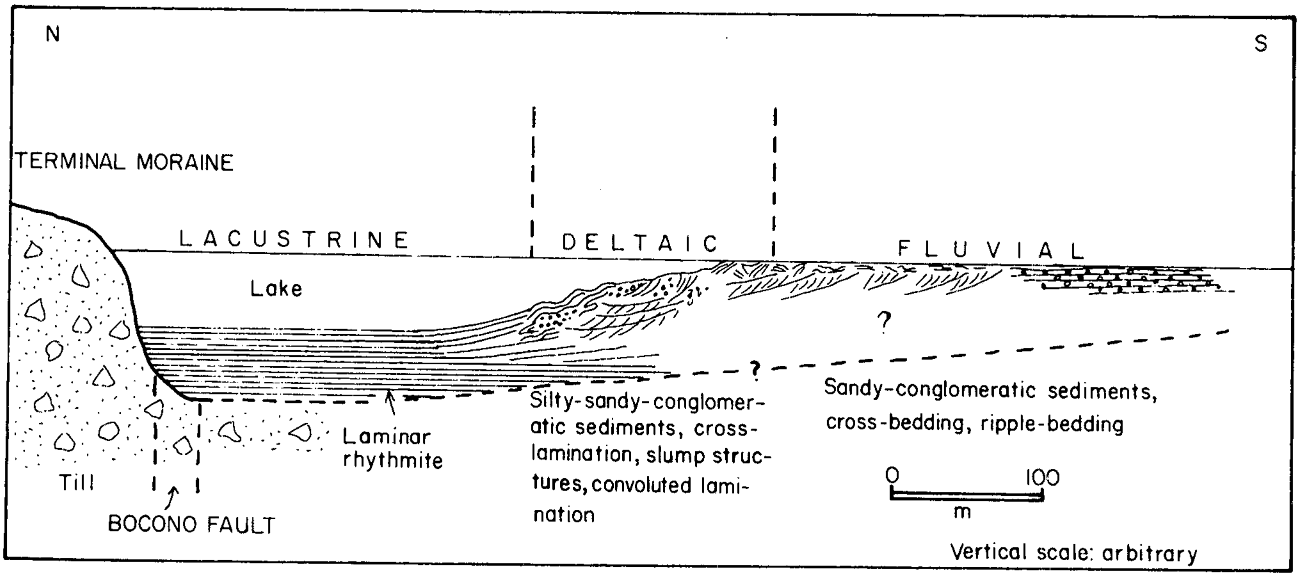

Figure 7. Schematic representation of the sedimentary environments of the 6-10 m terrace (adapted from Jopling & Walker, 1968, Fig. 2).

Approximately between 18,000 and 13,000 years B.P. (Salgado-Labouriau et al., 1979; Schubert, 1970), during the last important glacier advance in the Sierra Nevada de Mérida and the Sierra de Santo Domingo, the valley of the Los Zerpa river was occupied by the Los Zerpa glacier (Fig. 8A), which deposited the moraines that bound the valley today. This glacier had a length of 3 to 4 km and a maximum thickness of 100 to 150 m, and reached a lower elevation of about 3050 m. At this time, the glacier melt-water drained over and through the end moraine, towards the Santo Domingo river. When the Late Pleistocene or post-Pleistocene glacier retreat began (Fig. 8B), a lake probably was dammed in the lower part of the valley; outward drainage continued through the terminal moraine. Behind the lake, as the glacier retreated, small recessional moraines were deposited (as can be observed in adjacent valleys; Schubert, 1970), and which were later eroded, and also fluvio-glacial deposits as a product of glacier melting and erosion of the valley head. This stage of fluvio-glacial sedimentation continued until the valley was filled to an elevation of 20-25 m above the present-day river level. An alluvial plain of the Los Zerpa river formed at this elevation draining through the terminal moraine (Fig. 8C). This valley fill is represented by the remnants of the 20-25 m terrace.

Possibly due to a period of right-lateral offset along the Boconó fault, of an unknown magnitude, a breach was opened along the fault trace, through the right lateral moraine (Fig. 8D), which permitted drainage of the Los Zerpa river through it, abandoning the old drainage over and through the terminal moraine. The old drainage can be seen today at approximately 20 m above the river level. The opening of the breach produced an increase in the Los Zerpa river gradient and, therefore, and increase in erosive power. It has been postulated that uplift of a mountain range also produces an increase in river gradients; however, the terraces would by increasingly inclined the closer they are to the range (Leopold et al., 1964, p. 478; Schumm, 1977, p. 100-101), and this is not the case in the Los Zerpa valley. Therefore, evidence suggests that is was the opening of a breach in the lateral moraine which was responsible for the increase in gradient. In this manner, the river incised the fluvio-glacial fill of the previous stage and originated the 20-25 m terrace. The elevation of the terrace represents only the amount of incision since the opening of the first breach and includes the later incision of the lower 6-10 m terrace.

The breach along the fault trace eventually was closed by sedimentation, landsliding, or later offset along the fault, giving rise to a new sedimentary cycle within the morainic valley (Fig. 8E). In the

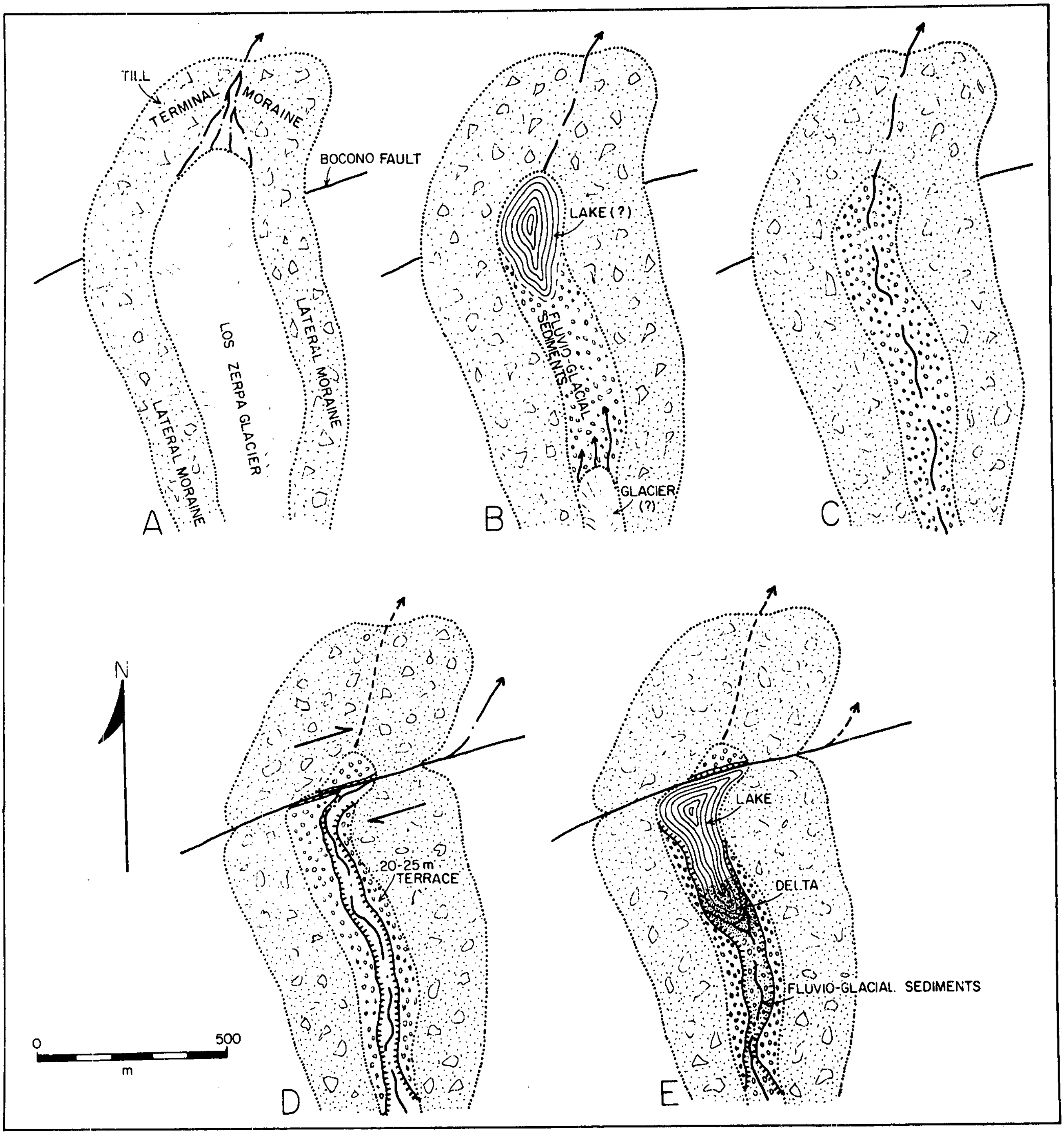

Figure 8. Schematic post-glacial evolution of the Los Zerpa morainic valley. See text for explanation.

lower part of the valley, a lake was formed which, in its maximum extent, occupied approximately half of the valley. On its southern shore, the sediments carried by the Los Zerpa river were deposited in a small delta. In the higher part of the morainic valley, fluvioglacial sediments were deposited on an alluvial plain. The lake probably drained through the same locality of the previous breach, but at a higher level. Later, due to renewed right-lateral offset along the Boconó fault, the breach was re-opened through the right lateral moraine, the lake was drained, and the same erosional cycle described before began again, incised the sediments, and formed the 6-10 m terrace, and also continued to erode the remnants of the 20-25 m terrace. Thus, we arrive at the present geological conditions, described above and shown in Fig. 5.

ACKNOWLEDGMENTS

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