SEDIMENTARY DISTURBANCES IN LATE QUATERNARY FLUVIO-LACUSTRINE DEPOSITS OF THE LOS ZERPA MORAINE INDUCED BY THE BOCONÓ FAULT, MÉRIDA ANDES, VENEZUELA

Eduardo CARRILLO *(1)*, *Franck* AUDEMARD *(2), Christian* BECK *(3) and Michel* COUSIN *(3)*

(1) Univ. Central de Venezuela, Fac. de Ciencias, Inst. Ciencias de la Tierra. (ecarrill@gea.ciens.ucv.ve)

(2) Fundación Venezolana de Investigaciones Sismológicas, Apartado Postal 76.880, Caracas 1070-A.

(3) Lab. de Geodynamique des Chaînes Alpines UMR, cnrs 5025, Univ. de Savoie, Bourget du Lac, France.

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INTRODUCTION

During the late Pleistocene glaciation in the Venezuelan Andes, known as the Mérida Glaciation, an important advance of moraines took place in the northern (shaded) slope of the Sierra de Santo Domingo (Schubert and Vivas, 1993). These moraines, among which are Mucubají, La Victoria, Los Zerpa and Las Tapias, were prominent landforms in that area at that time (**Fig. 1**). Not only climate has played a role in their sediment preservation and distribution, since they have also been subject to general Neogene-Quaternary chain uplift and to the tectonic activity of the right-lateral strike-slip Boconó fault. Therefore, climate and tectonic signatures are both simultaneously recorded in the late Quaternary high-altitude sediments of the Mérida Andes, in the lake Mucubají surrounds.

The sedimentary record in the fluvio-lacustrine deposits preserved inside Los Zerpa moraine is an outstanding example of sedimentation and active tectonics interplays (Audemard et al., 2001). The terminal part of this moraine is cut and right laterally offset by the main strand of the Boconó Fault, where a rather narrow and small pull-apart basin is being created, which in turn induces down-slope motion of the entire upstream section of the moraine (Audemard et al., in this volume). Therefore, these fluvio-lacustrines sediments deposited after the last glaciation (< 15 ka) are controlled by both climatic variability and local tectonics; the latter being chiefly due to the active Boconó Fault (BF).

SEDIMENT DISTRIBUTION AND TERRACING

A thick package of coarse conglomerates is the first fluvial sediments to fill the moraine bottom, after retreat of the Los Zerpa glacier. This aggradational terrace is about 25 m thick. Subsequently, this terrace was eroded due to runoff increase, leaving a slightly lower terrace with no pair on the right bank. Then, a second episode of valley fill is attested by an aggradational terrace. This terrace is presently hanging about 10 m high over the river bed, but it was subsequently cut by two other lower sets of terrace flights (**Fig. 2**). We presume that age of these terraces could give clues about the largest earthquakes on the BF. The second aggradational terrace used to end up into a small lake as an underwater delta. These alternating aggradation/erosion terraces, besides denoting a few-thousand-year-long climatic cyclity, have also recorded local tectonic instability because of exhibiting anomalous (sideward and back-) tilts, as well as quick river down-cutting. Tilting is attested by paleocurrent changes in some Los Zerpa lake-shore sediments (**Fig. 3**). The Mucubají, La Victoria and Las Tapias moraines and infills also show anomalous tilting.

LAKE SEDIMENTS AND SOFT-SEDIMENT DEFORMATION

Because lake deposits are specially prone to earthquake–induced deformation (Sims, 1973), they are excellent earthquake recorders. The pore-pressure build-up in unconsolidated well-saturated sands by a strong earthquake induces soil liquefaction which is typically recognized by structures such as: convoluted bedding, ball and pillows, sand dikes, sand boils and flame structures (Audemard and De Santis, 1991; Obermeier, 1996).

In the Los Zerpa paleolake sediments, locally cross-cut by the BF main strand, the most distal facies are almost totally clay-laminated. Occasionally, their are intercalated with some few-centimeter-thick sand beds that display flames and ball and pillow structures attesting earthquake-induced liquefaction (**Fig. 4**). Besides, small-scale slumps are also present in some clayey intervals. In the proximal lake facies, near the southeastern edge and closer to the submarine delta front, sand content and number of sand beds increase. Three clay beds intercalated within such sand units display slumping. Slumping is so intense that folds are almost isoclinal. Orientation of fold axial surfaces indicates that shortening is transverse to river flow and subparallel to the BF trend. Besides, many other few-centimeter-thick sand beds also underwent liquefaction. Chronology of the paleo-earthquakes recorded in these sediments is still under evaluation, but we believe that several (~5) earthquakes happened in the region in a shorter time span than the recorded by the flight of alluvial terraces.

FLUVIO-DELTAIC SEDIMENTS AND DEFORMATION

The distal facies of the alluvial deposits essentially corresponds to an underwater front delta that used to pour into the previously-described lake. This delta exhibits a well-developed foreset, made of sands, micro-conglomerates and conglomerates. In the foreset sequence, seven stratigraphic packages bounded by unconformities ("tectono-sequence") were recognized (**Fig. 5**). These unconformities show progressive tilting to the NW although the two youngest unconformities lie almost subhorizontal. Both packages and unconformities are affected by SE-dipping normal listric faults, that seem to have also been progressively tilted. South of here, the delta sequence is crosscut by normal faulting conjugate to the previous one. We interpret that all these deformations correspond to a knee (?) fold propagating above a blind normal throw (slide-related) that simultaneously induces extension in the outer fold hinge (normal bending-moment faults). Each unconformity would correspond to a seismic event on the close BF and sedimentation would be definitely controlled by local tectonics/instabilities.

CONCLUSION

We presume that deformed clay beds, earthquake-induced liquefaction of sands and progressive fluvio-deltaic unconformities are all related to at least 4 to 7 large paleoearthquakes. This new paleoseismic record could complement the seismic history of the BF derived by Audemard et al. (1999) for the northern strand at the Apartaderos pull-apart basin. It is very likely that the number of recognized events shall increase with more detail and thorough sedimentological and paleoseismic analyses that are now in progress.

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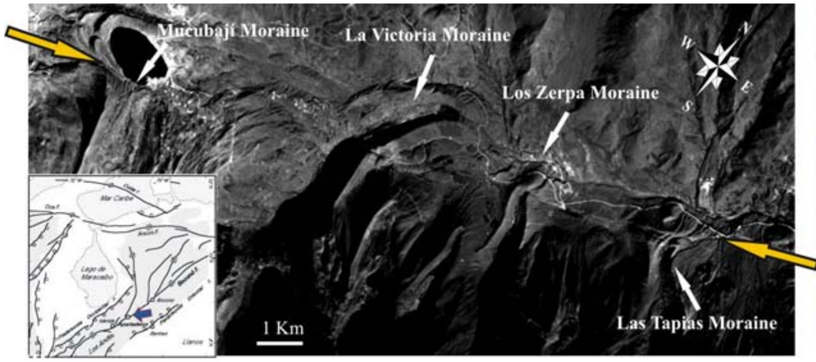

Figure 1. Los Zerpa, La Victoria, Mucubají and Las Tapias moraine locations at the Mérida Andes, Northern South America. The Yellow arrows point out the main Boconó fault trace. Notice how moraines are dextrally offset by fault.

Figure 2. Flight of terraces in Los Zerpa Creek. Terraces 1 and 3 are post glacial fill periods and terraces 2, 4 and 5 correspond to erosional episodes. Paleoclimatic variability and Boconó fault activity control these sedimentary/erosion cycles.

Figure 2. Earthquake-Induced liquefaction in Los Zerpa paleolake clayey sediments. The flame structure has been highlighted.

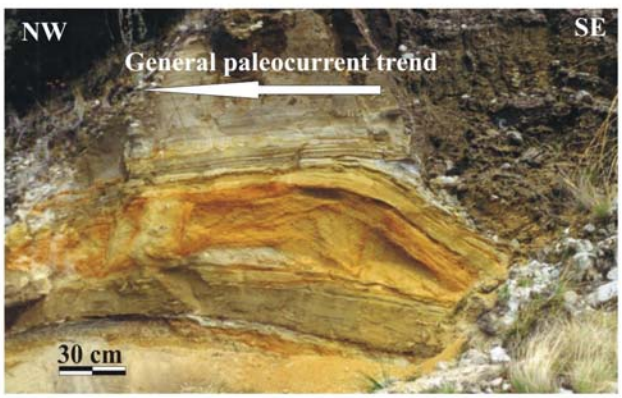

Figure 3. Small SE-prograding conglomeratic package against NW general fluvio-lacustrine paleocurrent direction in Los Zerpa Creek. Earthquake-induced back tilt in the paleolake basin momentarily changed the paleocurrents and facies distribution.

Figure 4. Los Zerpa paleolake underwater-delta sediments: these progressive unconformities bounded sequences show tectonics control in sediment distribution. The five oldest tilted sequences are truncated by subhorizontal sediments. It implies that sequences are folded during ongoing extension. The two youngest sequences represent a post-earthquake fill in the 10-m- high terrace. These unconfomity-bounded sequences are clear evidence of tectonic control on sedimentation.