STABILITY OF QUATERNARY MORAINIC COMPLEXES CUT BY THE BOCONÓ FAULT, MÉRIDA ANDES, WESTERN VENEZUELA.

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KEY WORDS: Paleoseismic limnology; Liquefaction; Deep-seated sliding; Boconó fault, Venezuelan Andes.

INTRODUCTION

The Mérida Andes (MA) is a prominent geomorphic feature in the landscape of western Venezuela. It extends in SW-NE direction for some 350 km from the colombian-venezuelan border to the city of Barquisimeto (**Fig. 1a**). Its highest peaks reach 5000 m in elevation in the central portion, near Mérida. This chain appears to be in the northeastward topographic prolongation of the Eastern Cordillera (EC) of the Colombian Andes. The latter belongs to the main Andes chain that runs all along the Pacific coast of South America (SA). However, the MA and EC do not keep any direct genetic relationship between them. They are split by the southern termination of the left-lateral strike-slip Santa Marta-Bucaramanga fault and the NW-SE trending Santander Massif. Besides, while the SA Andes uplift results from convergence across a conventional type-B subduction, The present MA chain build-up results from Pliocene-Quaternary transpression due to oblique convergence between two continental blocks: SA and Maracaibo Triangular Block. This present geodynamic setting is responsible for ongoing strain partitioning along the MA where the foothills and the mountain belt have been shortened transversely in a NW-SE direction whereas the Boconó fault (BF) –roughly located axially along the MA - accommodates dextral slip (Audemard and Audemard, 2002).

Audemard (under review) indicates that the MA exhibits four distinct types of active deformations, but all linked to strain (stress) partitioning: (1)- axial dextral strike-slip along the BF and related transtensional basins at releasing geometries (overlaps or bends) or deep erosional valleys sitting on heavily-fractured bedrock; (2)- vertical uplift supported by: either erosional or depositional staircased alluvial terraces, disruption of pull-apart basins and deep transverse-to-chain incision; (3)- shortening across the chain, mostly attested in both foothills and not in the chain core due to lack of young deposits and (4)- seismically-induced mass wasting (slides, avalanches/flows and so forth) and deep-seated slope instabilities (i.e.: gravitational spreading) and earthquake-triggered liquefaction/soft-sediment deformation. This contribution intends to bring supporting evidence to the last type of ongoing active deformation, triggered by the Quaternary activity of the sub-axial BF in the lake Mucubají region, some 60 km northeast of Mérida.

BOCONÓ FAULT

The BF is a spectacular NE-SW trending dextral fault that extends for about 500 km, partly along the backbone of the MA. It runs slightly oblique to the MA chain axis and bounds the Caribbean Coast range of northern Venezuela on the west, thus extending between the Tachira depression, at the border between Colombia and Venezuela, and Morón -on the Caribbean coast of Venezuela-. This fault has been identified, mapped and characterized rather easily since the pioneering work of Rod (1956) by the large number of along-strike geomorphic features, among which: continuous series of aligned 1-5 km wide valleys and linear depressions, passes, saddles, trenches, sag ponds, scarps and sharp ridges. Among those, the alignment of valleys associated to the fault is the most conspicuous feature as it makes the fault easily recognizable and mappable in radar (SLAR) images (**Fig. 1a**).

The study area partly lies in the northeastern end of the Apartaderos basin that corresponds to a releasing bend of the BF (Soulas, 1985; Audemard et al., 1999). In fact, this part of the BF has a slightly more easterly strike with respect to the overall NE-SW trend. Here, the BF is well preserved along a 3,500-m-high drainage divide that separates the southeasterly flowing streams (Orinoco basin) from the northwesterly flowing streams (Maracaibo basin). This divide is nestled in the area of lake Mucubají (LM), belonging to the Sierra Nevada National Park, one of Venezuela's most spectacular alpine glaciated landscapes. The BF here comprises two conspicuous sub-parallel active strands located at about 1-1.5 km apart, both exhibiting magnificent geomorphologic expression preserved in latest Pleistocene and Holocene deposits (**Fig. 1d and e**). Even though the vertical component of slip appears to be significant at some localities (*e.g.*: near El Cerrito, in the village of Apartaderos, Los Zerpa and near Las Tapias), most of the fault geomorphology is typical of a strike-slip fault (**Fig. 1**). At present time, this high-altitude basin is being deeply dissected by both the Chama and Santo Domingo (SD) river headwaters, whose drainage divide is exactly at the LM, even though this depression seems to have accumulated a rather thick sequence of Pleistocene glacial deposits as those preserved at Mesas del Caballo and Julián. This sedimentary evolution seems to be strongly dependent on marked hydric changes between glacial and interglacial periods, there is no doubt though that the deactivation of sedimentation in this perched basin is due to generalized chainwide uplift that induces parallel-to-chain axis deep incision along the heavily-fractured bedrock or brecciated material generated by the present activity of the axial BF (**Fig. 1e**; notice perfect match between bottom valley and fault trace under Pleistocene moraine fill). The BF exhibits is highest slip rate at this basin, where the southern and northern strands respectively carry about 75% and 25% of the 7-to-10 mm/a net slip rate measured in this sector (Audemard et al. ,1999). From the Mucubají area, the BF slip rate decreases towards both ends.

BOCONO FAULT AND QUATERNARY MORAINIC SYSTEMS INTERPLAYS

Besides the direct permanent ground deformation (surface fault rupturing) and its cumulative expression in landscape by repeat of earthquakes (geomorphic evidence of active faulting), moderate-to-large earthquakes induce other phenomena gathered under the name of indirect permanent ground deformations that includes soil liquefaction (soft-sediment deformation) and mass wasting of very diverse types (deep-seated and shallow slides, falls, flows and lateral and gravitational spreadings). Some of these permanent features are also been utilized to determine the seismic history of a fault or region, beyond the simple trenching of active surface faulting. This is the case for the Mucubají sector of the BF where both deep-seated slides and soft-sediment deformation (including soil liquefaction and lateral spreading) in late Pleistocene morainic systems are being induced by coseismic fault slip and direct disruption of the morainic systems by the BF (Audemard et al., 2001). Two particular cases will be dealt with in this contribution: LM

and Los Zerpa moraines. In both sites, both sesimically-induced effects are preserved in late Pleistocene lake and alluvial sediments.

Lake Mucubají morainic complex

This late Pleistocene morainic complex sits on the high-altitude water divide of the Chama and SD rivers. The Mucuñuque river –running along the moraine bottom- used to pour its waters into the Chama basin on the southwest before shifting to the SD basin on the northeast, as attested by the abandoned spillway of LM preserved on the southwestern side of the outermost frontal moraine (**Fig. 1c**). This glacial system is cut across by the southern and main strand of the Boconó fault composing the Apartaderos pull-apart basin, along the southeast edge of the present LM (**Fig. 1c**). This morainic complex shows the particularity of preserving an active lake (LM) leaning against the outermost frontal moraine (**Fig. 1c**) instead of being in a more rangeward position, as expected in a retreating moraine system, likewise in the La Victoria moraine. Besides, the present Mucuñuque river leans against the NE lateral moraine. We believe that these three issues are related to down-slope motion of the entire morainic complex that has also been slightly tilted to the north, inducing the spillway shift to the northeast as well as the present water ponding against the frontal moraine farthest to the northwest. This gravitational motion of the morainic complex is attested by a 5-6-m-high northwest-facing scarp that cuts across the Mucubají morainic complex near the moraine complex/underlying bedrock contact (**Fig. 1c**). We believe that destabilization of the Quaternary moraine complex is induced when the BF progressively disrupted and displaced coseismically the end section of the moraine complex to the northeast, thus reducing the confining horizontal forces that used to keep the moraine as one single resistant horse-shoe-shaped piece. The above-mentioned scarp exposes the penultimate lake sedimentary sequence, which exhibits soft-sediment deformation at the sequence top and slumping. Nowadays, it is being eroded by a set of rather small Holocene staircased alluvial terraces.

Los Zerpa morainic system and its paleo-lake

In the upstream section of the SD valley, several late Pleistocene morainic complexes are preserved, among which are La Victoria, Los Zerpa and Las Tapias, from SW to NE. All three are crosscut by the BF, and particularly by its main strand along the southern edge of the Apartaderos basin.

Los Zerpa moraines do not contain any lake at present but it used to be ponded behind the end moraine, next to the BF trace that just diconnects the frontal moraine from its lateral counterparts. The late Pleistocene paleolake sequence is also disturbed (rotational sliding, small-scale faulting, seismically-induced tight folding and liquefaction; Audemard et al., 2001), as in the penultimate paleo-lake at Mucubají, and the staircased late Pleistocene-Holocene(?) alluvial terraces are also down-faulted. But here, all these sedimentary disturbances are directly related to the formation of a narrow pull-apart basin along a very short segment of the main strand of the BF that strikes slightly more east than the fault trend, all exhibiting a releasing bend geometry. However, the upper section of the lateral moraines, as well as the post-glacial alluvial terraces, are also tractioned by the void effect introduced by the pull-apart sinking (**Fig. 1b**), that induces down-slope motion driven by gravitational forces. The creation of this small narrow pull-apart basin is responsible for desactivation of the original Los-Zerpa-paleolake spillway.

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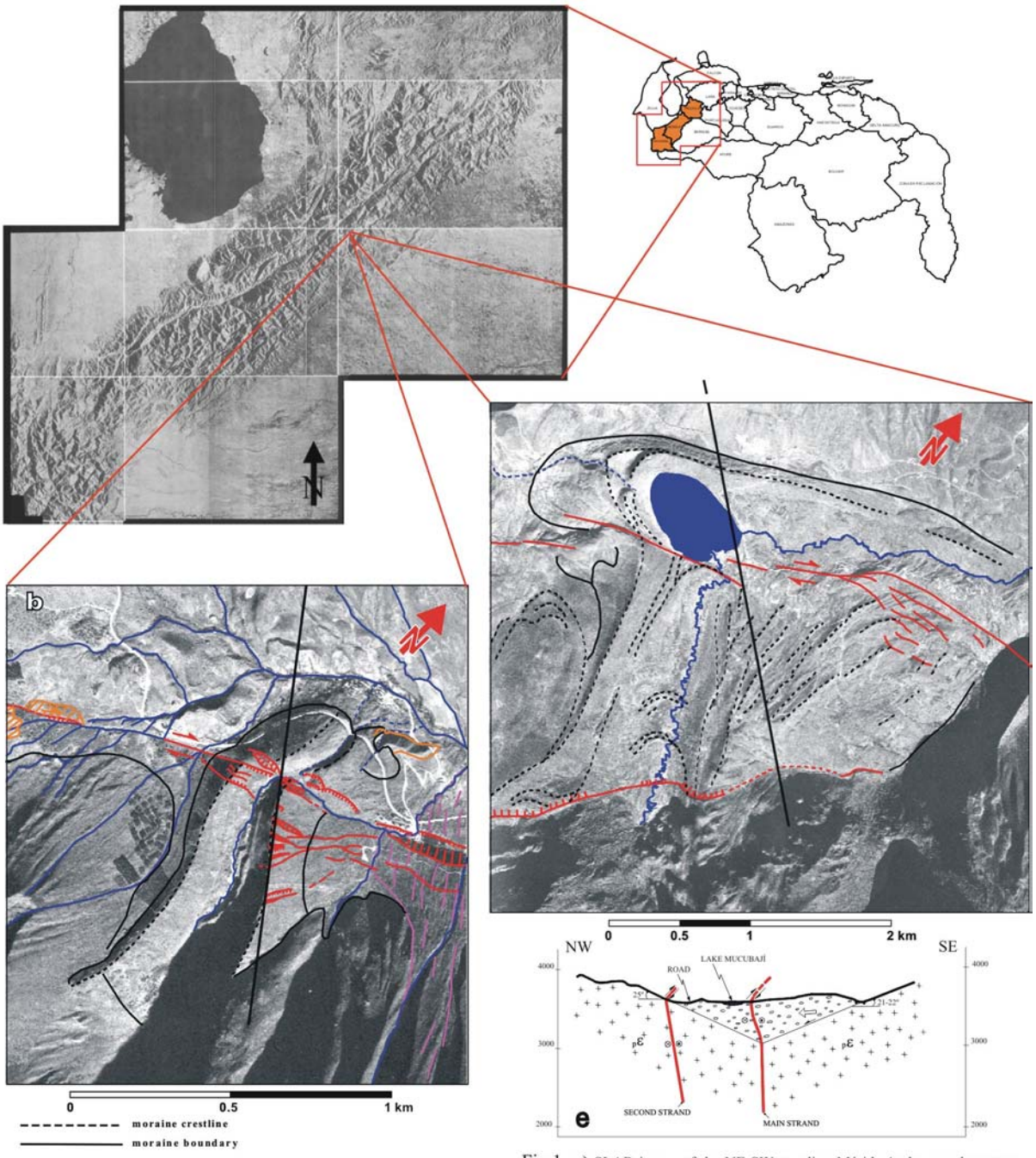

Fig.1 **a)** SLAR image of the NE-SW trending Mérida Andes, northwestern Venezuela. The Boconó fault images an outstanding alignment of deep axial valleys. **b)** Los Zerpa moraine system cut by main strand of the Boconó fault that offsets the end section of the moraine and generates a small pull-apart basin into the last glacial deposits where fault shows a slightly more east trend. **c)** Main Boconó fault strand across the Mucubají moraine complex exhibiting and en echelon R shear pattern that indicates that fault is cutting across a thick poorly-consolidated moraine deposit, as shown in **e**. In lower part of the image, scarp of deep-seated slide runs along bedrock-moraine contact, that pushes off fault trace to the northwest. **d)** Cross-section along Los Zerpa lateral moraine (along heavy line) imaging the sedimentary and tectonic environment. **e)** Cross-section across the Mucubají morainic complex, showing its significant thickness (≈ 500 m)