

# QUATERNARY TECTONIC ACTIVITY OF THE LLANOS FOOTHILLS THRUST SYSTEM, EASTERN CORDILLERA OF COLOMBIA: GEOMORPHOLOGICAL AND GEOLOGICAL EVIDENCES FROM LA FLORIDA ANTICLINE, BETWEEN THE UPÍA AND CUSIANA RIVERS.

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## INTRODUCTION

It is well known that oil exploration started at the end of the 19th century by drilling domes and anticlines as its main targets. However, large oil fields in fold-and-thrust belts are still uneasily discovered nowadays worldwide, such as the Cusiana anticline (name given in the oil industry literature; Cazier *et al.*, 1995 and Cooper *et al.*, 1995), located in the Llanos foothills of the Colombian Eastern Cordillera. However, for that particular case, that would seem astonishing since: (a) that fold had already been mapped, though it used to be known as the La Florida anticline (Ulloa and Rodriguez, 1981); (b) Robertson (1989) reported several geomorphic evidences of its Quaternary tectonic activity; and (c) that structure involves rocks as young as Pleistocene in age. Besides, several authors also indicate that the tectonic inversion and/or foreland overthrusting of the Eastern Cordillera is a recent process (Ulloa and Rodriguez, 1981; Hebrard, 1985; Page, 1986; Robertson, 1989; Cazier *et al.*, 1995; Cooper *et al.*, 1995). Therefore, all these facts put together clearly indicate the recent character of this deformation and also suggest indirectly its high oil prospectivity. In this paper, we present additional geomorphological and surface geological data that confirm the recent activity of a short segment of the Llanos fold-and-thrust belt of the Eastern Cordillera roughly east of Bogotá, and particularly of the La Florida (Cusiana) anticline.

## REGIONAL FRAMEWORK

Colombia is a country of sharp contrast: the Andes mountains in the west and the Llanos plains in the east. The studied area corresponds to a short segment of the frontier between these two huge geographical and geological units, known as the Eastern Cordillera Llanos foothills (Fig. 1). This topographical unit geologically corresponds to the east-vergent frontal fold-and-thrust belt of the Eastern Cordillera. La Florida (Cusiana) anticline belongs to this belt and is between the Upía and Cusiana rivers. This fold affects the entire Mesozoic-Cainozoic sedimentary sequence of the Llanos basin (Cazier *et al.*, 1995; Cooper *et al.*, 1995) and its eroded core exposes the Mio-Pliocene Caja Formation (Ulloa and Rodriguez, 1981). These authors report that this fold is symmetrical and no brittle deformation is associated to it. However, it can be observed that this anticline is in perfect prolongation to the south of the El Yopal fault -name given in the oil industry- (also Known as the San Miguel fault -name given in the geological maps of Colombia-) that dies out near the northern banks of the Cusiana river (Fig. 1), thus allowing to infer that the La Florida anticline south of this river is a Yopal fault-propagation fold with a southern periclinal closure. However, as we are going to demonstrate next, this fold is also genetically related to a more basinward reverse fault than the El Yopal (San Miguel) fault - non identified in Colombian surface

geology maps-, thus being a fault-bend fold located in the hangingwall block of the Cusiana fault which has been recently identified by seismic profiling by Cazier *et al.* (1995) and Cooper *et al.* (1995).

## GEOMORPHOLOGICAL AND GEOLOGICAL OBSERVATIONS

Besides the various geomorphic features of Quaternary tectonic activity of La Florida anticline already reported by Robertson (1989)\*, this author also indicates the existence of a  $\approx 50$  m high SE-looking fault scarp flanking the fold on the southeastern edge of la Mesa de Sisigua and northeast of it, between the Chita and Cusiana rivers, that he named the San Pedro-Sisigua fault. Nevertheless, this geomorphic feature should be regarded as a flexural scarp instead of a conventional fault scarp, between the Catuya and Chita rivers as observed in an abandoned cobble pit (Fig. 2a). At this locality (Fig. 2a), cobble beds correlable to La Corneta Formation (or younger Quaternary alluvial units), are warped around the clayey-silty beds of the Mio-Pliocene Caja Formation. The presence of this scarp on its own does not prove the existence of brittle deformation (major fault) at surface or in the near subsurface and neither do the other evidences mentioned by Robertson (1989), though it does definitely prove the occurrence of Quaternary folding in the Llanos foothills of the Eastern Cordillera. Nevertheless, we can provide further geological and geomorphological facts that prove that the La Florida anticline is partly an active fault-bend fold with respect to the Cusiana fault (the most basinward fault), besides being a fault-propagation fold: (a) a NW-SE landscape profile across the La Mesa de San Pedro, that corresponds to elevated Quaternary alluvial terrace deposits, shows an asymmetric, long-radius bend with a gently dipping rangeward backlimb and a shorter, steeper basinward forelimb; (b) the same configuration is also observed farther north, east of Monterrey and across La Loma de Buena Vista, but the core of the anticline is excavated and exposes the Caja Formation (Fig. 1), indicating a more evolved geomorphological stage due to the occurrence of topographic inversion. The previously mentioned flexural scarp (Fig. 2a) corresponds to the steeper forelimb of the fold. It is impossible in the field to differentiate the two coarse alluvial sequences that cap the Caja Formation on both flanks, though they are mapped as different units by Ulloa and Rodriguez (1981); (c) the presence of a tectonic "gutter" along the foot of the eastern scarp of La Mesa de San Pedro (Fig. 1), implying tectonic loading due to foreland-vergent thrusting; (d) recent road cuts of the main Llanos road under construction during early 1994, between the Catuya and Chita rivers, across the steeper southeastern anticline flank, have exposed brittle deformation (Pleistocene-or-younger, southeast-vergent, low-angle reverse faults; Fig. 2b and c). At depth, the presence of the reverse fault has been confirmed by recent seismic profiling (the Cusiana fault of Cazier *et al.*, 1995 and Cooper *et al.*, 1995). These authors also consider this fault as active.

## CONCLUSIONS

The La Florida anticline and the Cusiana fault are tectonically active structures within the fold-and-thrust belt of the Eastern Cordillera Llanos foothills; confirming thus the activity of this belt. The Cusiana fault is a SE-vergent, low-angle reverse fault. The Florida anticline is an asymmetric fold with a northwest gently dipping backlimb and a steeply dipping forelimb. It can be genetically explained by two different but simultaneous mechanisms: a) fault-bend folding on the hangingwall block of the Cusiana fault and b) fault-propagation folding associated to the southern end of the El Yopal (San Miguel) fault.

Besides, it seems clear from this experience that comprehension of the Neotectonics framework is playing an important roll in identifying new oil prospects in areas as complexly deformed as fold-and-thrust belts -the new fashionable target of today's oil exploration-

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\* (1) radial drainage of La Mesa de San Pedro, indicating the southern periclinal closure of the anticline at surface and allowing to prolong the original Ulloa and Rodriguez's fold axis farther southwest for some extra 15 Km; (2) over-a-100-m high and densely dissected SE-looking scarp of La Mesa de San Pedro; (3) westward tilt of Quaternary alluvial units at La Loma de Buena Vista (east of Monterrey) on the northwestern flank of the fold and respective river pattern inversion (flow from the basin towards the range); (4) SW diversion of the Cusiana and Tua rivers, suggesting dyachronic and differential fold growth (older and stronger deformation to the north); and (5) several small fault scarps affecting Quaternary alluvial terraces on the Llanos flank of the fold, between the Chita and Cusiana rivers.

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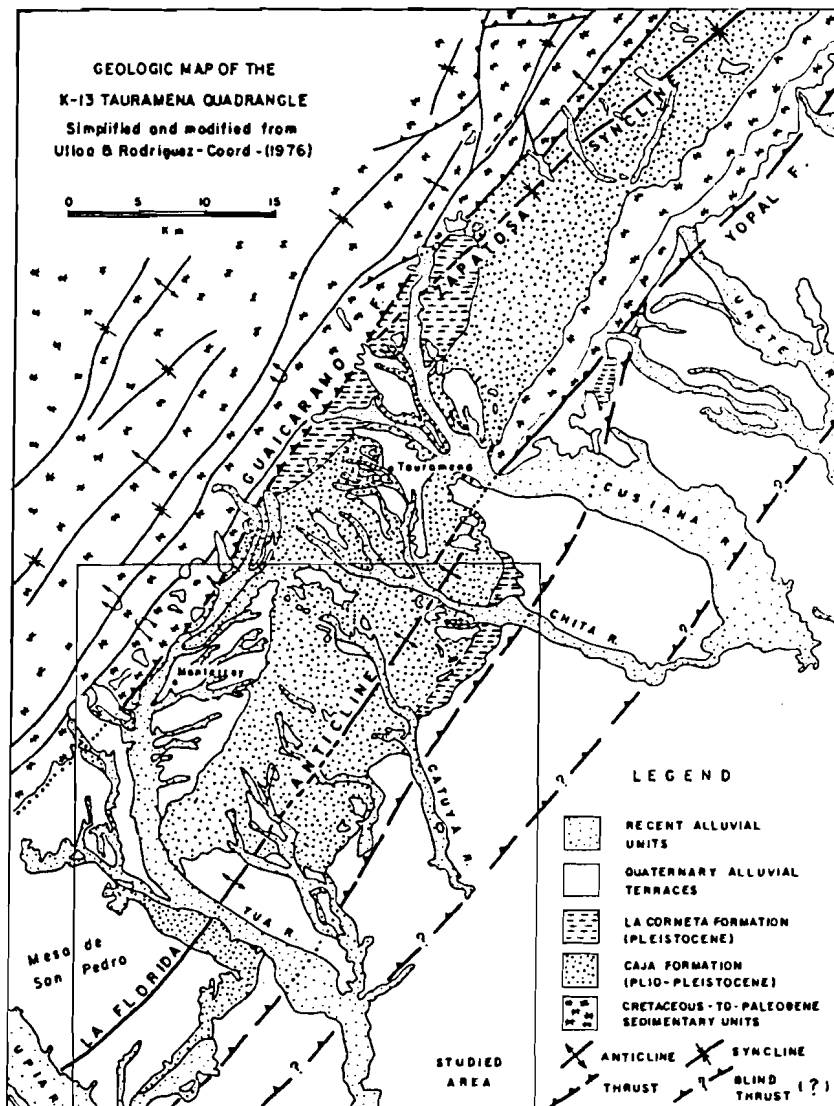


Figure 1.- Geologic map of a short segment of the Llanos fold-and-thrust-belt of the Colombian Eastern Cordillera, roughly east of Bogotá.

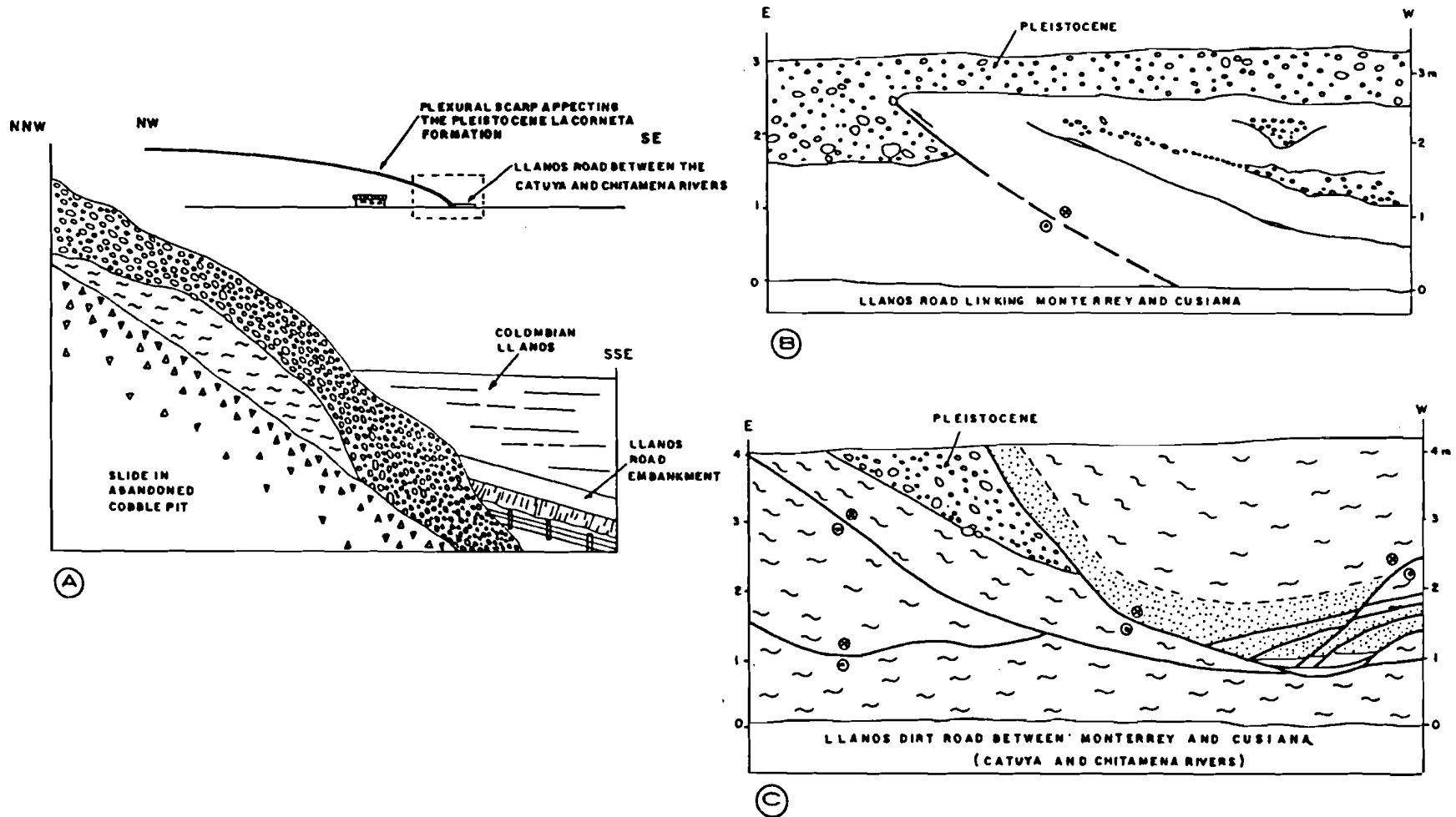


Figure 2.- (a) Flexural scarp on the southeast forelimb of the asymmetric La Florida (Cusiana) anticline, between the Catuya and Chita rivers, affecting the Pleistocene La Corneta Formation cobbles (or younger alluvial units?). (b) and (c) Pleistocene-to-Holocene, southeast-vergent, low-angle reverse faulting on the forelimb of the La Florida anticline, in recently-dug road cuts of the Monterrey-Cusiana road, slightly north of the Catuya river.