



Paleozoic to present-day kinematic evolution of the frontal part of the Andes between parallels 23° and 24° S (Jujuy province, Argentina)

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Abstract: A geological map and a transect across the thick-skinned Eastern Cordillera and the transition between the thin-skinned Subandean Ranges and the thick-skinned Santa Barbara System (all of them NNE-SSW striking) interfered by the NE-SW trending rift called Lomas the Olmedo Trough, at a latitude comprised between 23° S and 24° S, were constructed. The available data allowed us to illustrate the geometry and the kinematic evolution of the structures formed during three main tectonic events recorded in this region: a Cenozoic contractional event (Andean orogeny), an extensional Cretaceous event and a Paleozoic event (?).

Keywords: contraction, extension, Andes, Eastern Cordillera, Subandean Ranges, Santa Barbara System, Lomas de Olmedo Trough.

The Andean Cordillera resulted from convergence between the Nazca subducted plate and the South American plate, and displays important variations of structural style along-strike. An area located between parallels 23° S and 24° S in the NW corner of Argentina (Jujuy province) was investigated to understand the transition between four different geological provinces; from west to east they are: the thick-skinned Eastern Cordillera, the transition between thin-skinned Subandean Ranges (to the north) and the thick-skinned Santa Barbara Ranges (to the south), and the oblique rift known as Lomas de Olmedo

Trough (Fig. 1). Although six published sections close to the study area are available (Mingramm *et al.*, 1979; Cahill *et al.*, 1992; Mon and Salfity, 1995; Drozdowski and Mon, 1999; Rodríguez-Fernández *et al.*, 1999; Kley *et al.*, 2005), some aspects still need to be deciphered. This work aims to characterize the main geometric and kinematic features of the structures that resulted from the Andean contraction and previous tectonic events in this portion of the Andean orogen, through a geological map and a transect constructed using both geological interpretation of satellite images and field mapping.

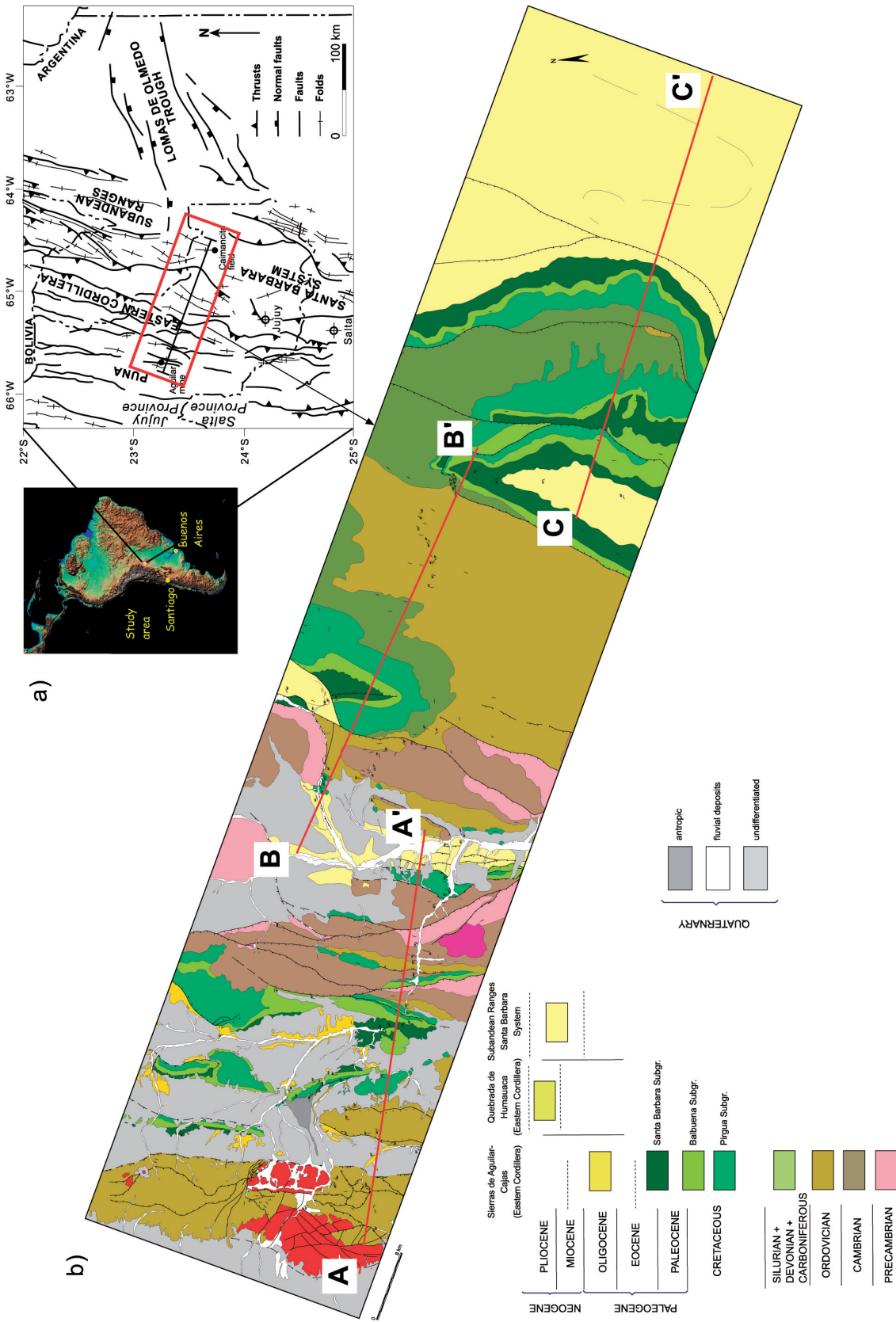


Figure 1. (a) Structural sketch of the north Argentina Andes with location of the geological transect. The fault including double triangles corresponds to the main Andean thrust which is the boundary between the Subandean Ranges-Santa Barbara System to the east and the Eastern Cordillera to the west. (b) geological map of the studied area.

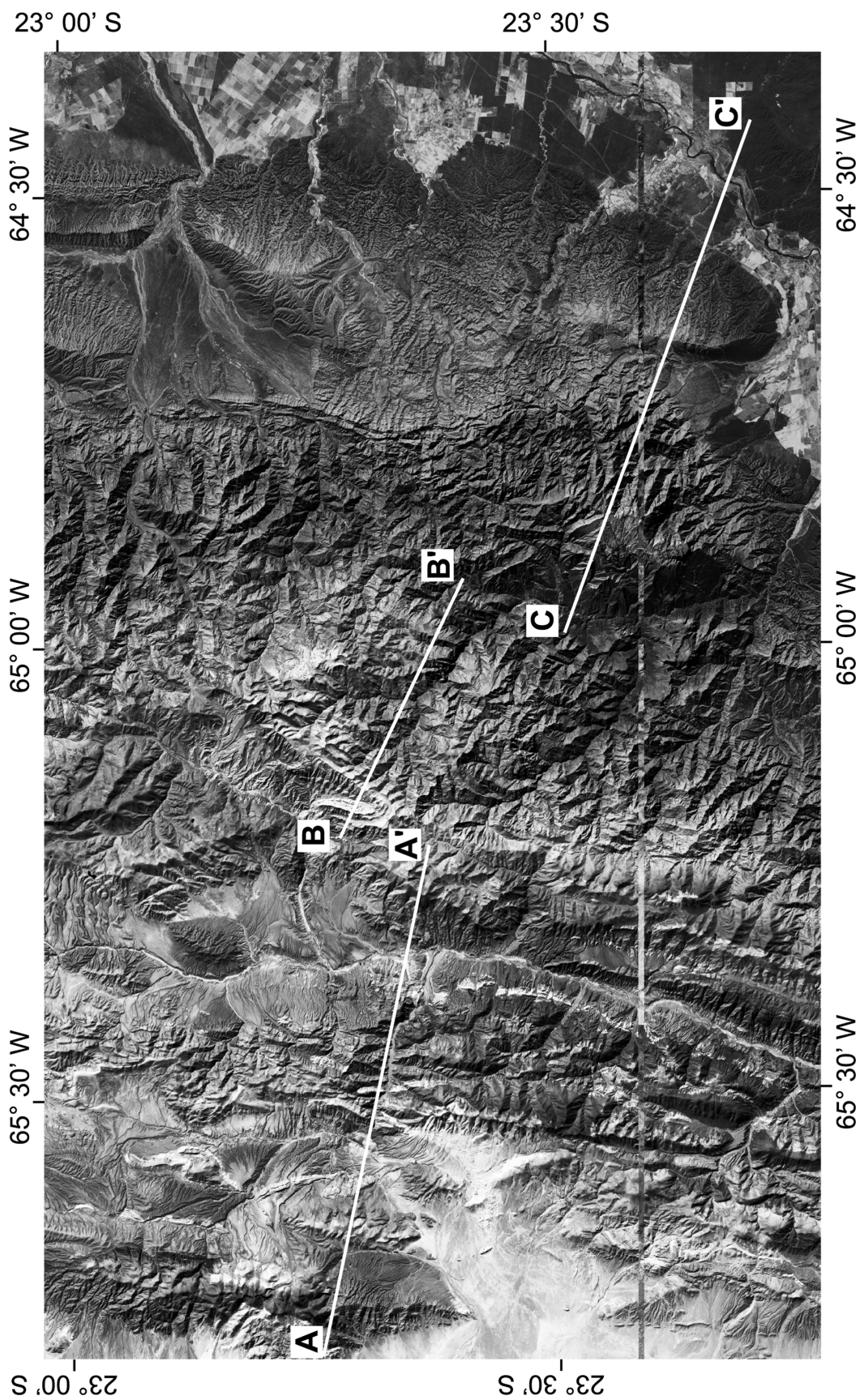


Figure 2. Satellite image of the surveyed area in the Eastern Cordillera, Subandean Ranges-Santa Barbara System and Lomas de Olmedo Trough. The large fold located in the SE corner of the image by the river corresponds to the Caimancito anticline. The fold located in the center of the image corresponds to the Cianzo syncline.

Cross-section construction

The outcrop conditions, accessibility and geological features (Fig. 2) led us to construct three geological sections subsequently merged into a single transect employing the along-strike prolongation of significant geological structures (Fig. 3). The transect relies on surface data, except for its east end in which an unpublished subsurface interpretation (YPF oil company) was used. Although some portions of the geological transect were constructed employing the dip domains method and projecting faults to depth using the available dips, the structures were modified by hand according to the field observations and honoring dip data.

Structural features

Subandean Ranges-Santa Barbara System-Lomas de Olmedo Trough

The main structures in this portion of the Subandean Ranges-Santa Barbara System are folds with vertical axial surfaces (in the western part and in the eastern boundary of the transect), and E-vergent folds (in the central part). In the eastern part there are also two major reverse faults dipping to the west and in the western part an east dipping normal fault. The main faults emanate from an E-directed sole thrust, located at 20-25 km depth (deduced from seismic data), that dips gently to the west. From west to east the sole thrust ramps up from Precambrian to Tertiary rocks.

The almost symmetrical anticline observed at surface (Caimancito anticline) in the east end of the geological transect (Fig. 3) shows a hinterland dipping duplex at depth. A flat-bottomed syncline separates the Caimancito anticline from the asymmetrical Callilegua anticline. The crest and steeply E-dipping east limb of this anticline are cut off by two reverse, E-directed faults that dip moderately to the west. The asymmetrical Valle Grande syncline crops out west of the Callilegua anticline. The Valle Grande syncline exhibits reverse faults sub-parallel to bedding in both limbs; in the eastern limb a detachment at the base of the Cretaceous-Eocene succession eventually ramps up, and three imbricate thrusts merge into a detachment within the upper Cambrian-Carboniferous sequence in the western limb. These structures are consistent with the occurrence of flexural slip. To the west of the Valle Grande syncline, an antiformal structure occurs, which includes a few smaller-scale, gentle anticlines and synclines in its "flat" crest. An

almost symmetrical structure called Cianzo syncline crops out west of the antiformal structure. The west limb of this syncline is cut off by a normal fault steeply dipping to the east and a reverse fault steeply dipping to the west. The reverse fault is an E-directed structure that ramps up from Precambrian to Tertiary rocks, cuts off the normal fault, merges at depth with a reverse fault whose tip is located within Cambrian-Carboniferous rocks beneath the Cianzo syncline hinge and is called the Main Andean Thrust (boundary between the Subandean Ranges-Santa Barbara System to the east and the Eastern Cordillera to the west). The Cianzo syncline, together with the anticline located to the west in the Eastern Cordillera, are interpreted as fault-propagation folds related to the Main Andean Thrust.

Eastern Cordillera

Apart from the anticline related to the Main Andean Thrust located to the east of this province, the main structure is interpreted as a pop-up structure formed by imbricate thrusts directed to the east (eastern part of the Sierra de Cajas and Quebrada de Humahuaca) and some backthrusts (central and western part of the Sierra de Cajas) that may merge at depth.

From the Quebrada de Humahuaca to the west, the dip of the E-directed thrusts increases progressively westwards from shallow to steep dips, and rocks within the thrust sheets are tilted but not strongly folded. In the west side of the pop-up, the W-directed backthrusts dip moderately to steeply to the east and rocks within these backthrusts are gently folded.

In the Aguilar Mine zone, a pop-up structure crops out bounded by two moderately to steeply reverse faults that dip and move in opposite senses, to the east and to the west. The fault located in the east part of the Sierra de Aguilar corresponds to the boundary between the Eastern Cordillera to the east and the Puna to the west.

Age of the structures

Structures developed from Paleozoic to almost present day occur in the surveyed area. Three main tectonic events are identified: a) a Cenozoic contractional event that corresponds to the Andean orogeny and is recorded by reverse faults and folds, b) an extensional Cretaceous event involving normal faults and folds, and c) a Paleozoic event that includes some faults. Evidences to support the tectonic scheme presented are discussed below.

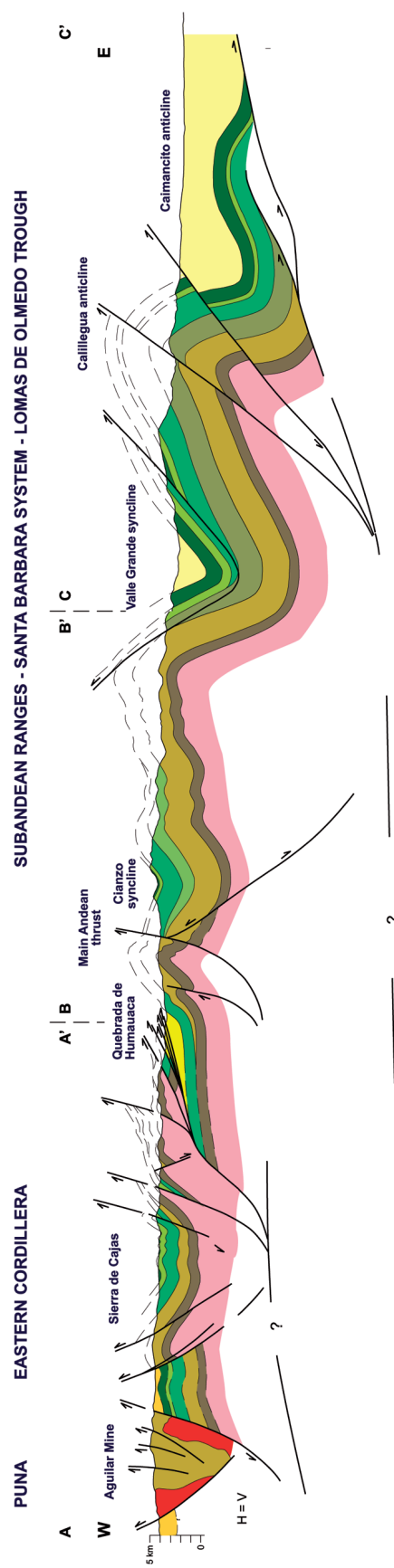


Figure 3. Geological transect across the Eastern Cordillera, Subandean Ranges-Santa Barbara System and Lomas de Olmedo Trough obtained from merging three cross sections. See figures 1 and 2 for location.

Andean contractional event

Many reverse faults and related folds involve Cenozoic rocks pointing out that their development occurred during the Andean orogeny (Fig. 3). Around the Quebrada de Humahuaca (Eastern Cordillera), Miocene-Pleistocene rocks, slightly folded, onlap unconformably over folded Cretaceous-Eocene deposits suggesting that Andean deformation initiated some time during the interval Eocene-Miocene. Shallow W-dipping thrusts, also located in the Quebrada de Humahuaca, place Mesozoic and Tertiary rocks over hardly consolidated Quaternary rocks (Drozdowski and Mon, 1999; Rodríguez-Fernández *et al.*, 1999); this evidence, together with earthquakes recorded around the surveyed area (Cahill *et al.*, 1992), indicate that tectonic activity is still taking place.

Cretaceous extensional event

A fault that crops out at surface at the eastern portion of the transect and offsets the east limb of the Callilegua anticline (Subandean Ranges-Santa Barbara System), exhibits a thick sequence of Cretaceous deposits in the hangingwall and a much thinner Cretaceous sequence in the footwall. This geometry indicates that this fault was an active normal fault during Cretaceous times and that the Cretaceous rocks consisted of syn-rift deposits. The Cretaceous deposits in the hangingwall of this fault thin progressively away from the fault until they disappear westwards. The features of the fault and the sedimentary record suggest a tilted fault block within a half-graben related to a listric normal fault. The crest of the rollover anticline, where the maximum uplift occurred, would approximately correspond to the crest of the present anticline in between the Valle Grande and Cianzo synclines, where the Cretaceous-Paleocene rocks lay on top of Paleozoic rocks and no Cretaceous deposits occur. In addition, this fault cuts and offsets the Miocene-Pleistocene sequence pointing out that it was reactivated during the Andean orogeny. Summarizing, this fault is a Cretaceous listric normal fault reactivated as a reverse fault during Andean times.

The normal, E-dipping fault in the west limb and beneath the Cianzo syncline cuts and offsets the whole Precambrian-Tertiary sequence. The

Cretaceous-Cenozoic rocks overly younger Paleozoic rocks to the west block of the fault than to the east one. The absence of part of the Ordovician, Silurian, Devonian and Carboniferous-Permian deposits in the footwall can be explained assuming no deposition and/or an intense pre-Cretaceous denudation in an uplifted fault block. The thickness of the Cretaceous deposits is greater in the hangingwall than in the footwall pointing out that this fault was an active normal fault during Cretaceous times and that the Cretaceous rocks consisted of syn-rift deposits. Since this fault cuts and offsets Tertiary deposits, the simplest hypothesis is that it was an active normal fault during Cretaceous which was reactivated as a reverse fault during the Andean contraction.

Paleozoic event

Within the imbricate thrust system that crops out between the Quebrada de Humahuaca and the Sierra de Cajas (Eastern Cordillera), small-scale faults, that dip to the east and offset Ordovician and older rocks, are sealed by Cretaceous deposits. This suggests that these faults were active some time from Ordovician to before the deposition of Cretaceous rocks.

Conclusions

The structural style of this portion of the Andean Cordillera does not exhibit the typical features of thick- or thin-skinned belts because multi-stage fault reactivation during different tectonic events and settings, separated by a large number of million years, play an essential role in the configuration of the present-day structural building. These events consisted of contraction during Cenozoic that gave rise to the present-day Andean Cordillera, extension during Cretaceous responsible for the Lomas de Olmedo Trough and Paleozoic tectonics.

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