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The Eastern Cordillera of the Central Andes: Inherited mechanical weakness as a first-order control on the Cenozoic orogeny

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INTRODUCTION

The Eastern Cordillera (EC) forms the structurally elevated continentward border of almost the entire Central Andean plateau. It is a Cenozoic, often doubly vergent, basement-involved thrust belt. The EC is marked by stronger structural relief and deeper exhumation than the westerly adjacent Puna and Altiplano, and it hosts only a few Cenozoic syntectonic sedimentary basins. Radiometric ages and thermochronologic data indicate that the Cenozoic deformation and uplift of the EC began at c. 40 Ma and largely terminated by 10 Ma (Ege et al., 2001; Kennan et al., 1995; Müller et al., 2002). However, there is also some very recent thrust and strike-slip deformation. From the middle Miocene onward the EC acted as a deformable backstop to the Subandean foreland thrust belts. Here we review the evidence that the location of the EC and its role as a first-order element of the Cenozoic Andean orogen were predetermined by older, Paleozoic and Mesozoic events, as was its response to Cenozoic contraction on a regional to local scale.

GEOLOGIC INHERITANCE AND THE CENOZOIC OROGENY

In much of NW Argentina and south-central Bolivia the stratigraphy of the EC is relatively simple: a strongly deformed basement of Late Proterozoic to Early Cambrian low-grade metasediments is unconformably overlain by a thick series of Late Cambrian and Ordovician sandstone and shale. The Lower Paleozoic strata are covered by a Cretaceous to Paleogene rift and post-rift succession, generally in disconformity or low-angle unconformity. This sequence of sandstones and shales with a few carbonate intervals is overlain by Eocene to late Miocene and locally also younger syntectonic continental clastics. In the southernmost parts of the EC the Cretaceous through Tertiary succession directly overlies the metamorphic basement. Towards the north, in central Bolivia, the stratigraphic column becomes more complete, including Silurian, Devonian, Carboniferous, Permian and pre-Cretaceous Mesozoic strata. However, many of these only occur in larger and smaller patches (SERGEOMIN and YPFB, 2000). Multiple unconformities suggest a complicated spatial and temporal pattern of deformation, differential uplift and subsidence throughout Paleozoic and Mesozoic time. The complex geology has demonstrably influenced Cenozoic deformation. In northern Argentina, the fabrics of W-verging Paleozoic deformation belts (Mon and Hongn, 1991) were proposed to have controlled the vergence of Cenozoic thrust faults. However, both the exact ages and the magnitude of pre-Cretaceous deformation are under debate, and there appear to be several diachronous events. Stratigraphic and isotopic ages place the peak deformation of the EC's basement in middle Cambrian time, coeval with the Pampean orogeny in the eastern Sierras Pampeanas (Mon and Salfity, 1995). Most isotopic ages from the metamorphic basement farther west and south (North

Chile, western Sierras Pampeanas) are younger. They range from c. 500 to 400 Ma (Lucassen et al., 2000), overlapping in time with deposition in the EC. There, regional stratigraphic correlation, facies trends and some remnants of sedimentary successions suggest that the widespread Upper Cambrian to Middle Ordovician

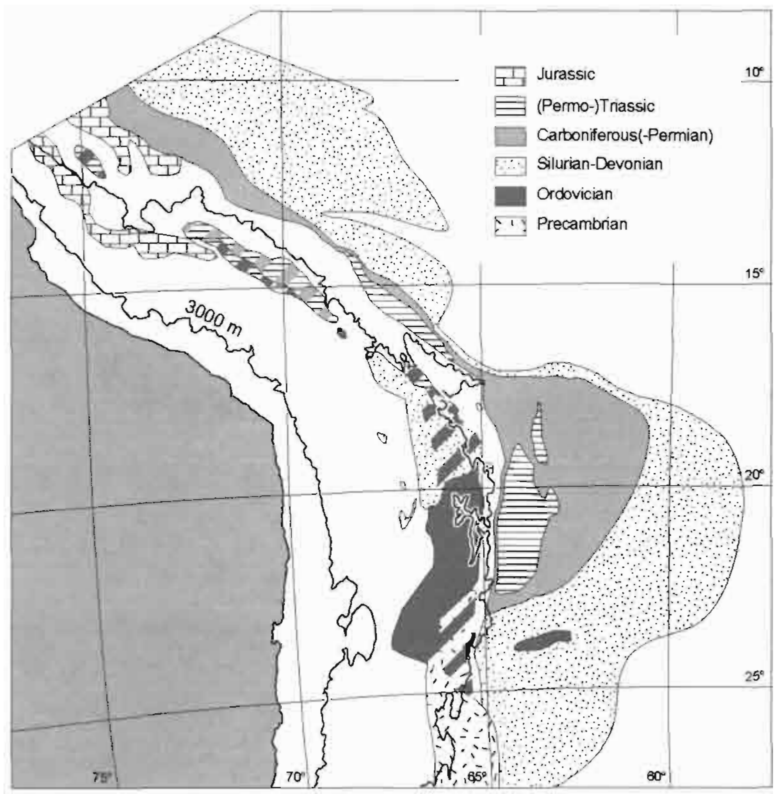

Fig.1: Pre-Cretaceous (including Tacurú group and equivalents) subcrop map of the eastern Central Andes. Note the axis of deepest exhumation (Early Paleozoic, dark grey) closely following the 3000m contour line which marks the plateau edge. Hachured areas mark those regions where Cretaceous strata overlie different older units. Data from many sources.

sequence was previously overlain by a probably discontinuous Upper Ordovician through Carboniferous cover from central Bolivia (18°S) to at least 23°S. K/Ar-dating of newly grown sericite gave Late Carboniferous to Early Permian ages for the cleavage formation in Ordovician slates from southern Bolivia (Jacobshagen et al., 2002), an event thought to be related to early uplift of a proto-Cordillera. In NW Argentina the few occurrences of Carboniferous strata show strong erosional relief at the base of the succession (Starck, 1995) but also evidence for synsedimentary normal faulting. Inverted thickness trends near the top of the Carboniferous sequence may hint at a switch from an extensional to a contractional regime and incipient tectonic inversion related to the shortening event dated in southern Bolivia.

Although still poorly constrained and uncompletely understood, the pre-Mesozoic history of the EC has shaped an element that was dominant during the Cenozoic Andean orogeny. On a pre-Cretaceous subcrop map (Fig. 1) the EC stands out as a positive area where strata down to the Ordovician are exhumed. This elevated axis nearly coincides with the present-day outline of the EC, demonstrating that the ancient structural high has been reactivated during the Cenozoic Andean orogeny and has controlled the location of the high plateau´s cratonward edge, a first-order feature of the Central Andes.

In terms of structural style it is clearly the Cretaceous rifting event that has most profoundly influenced the response of the EC to Cenozoic thrusting and folding. Many faults that were active during rifting have been recognized from their association with abrupt thickness jumps of the synrift succession, both in outcrops and on

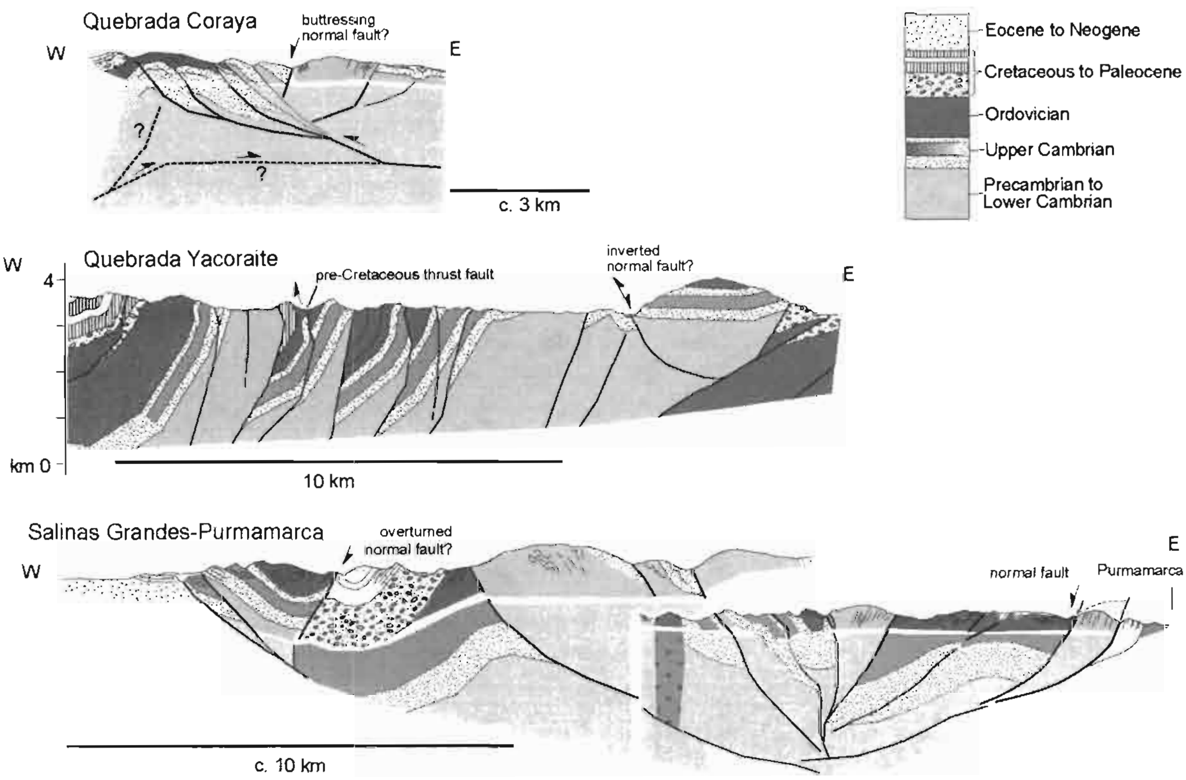

Fig. 2: Three cross-sections of the western part of the Eastern Cordillera in northern Argentina. The Coraya and Purmamarca section are only approximately to scale. Note the extreme variations in vergence and structural style over short distances.

seismic lines. The trends of these faults are highly variable, leading to different responses during Cenozoic inversion. Those trending N to NNE, approximately perpendicular to the Cenozoic contraction direction, were often reactivated as reverse faults. Besides these, oblique and transverse faults trending NW, W and SW are remarkably common. It is unclear if this reflects their true frequency in the rift system or if the thrust displacement on many approximately N-trending faults so much exceeded the previous normal offset that the associated synrift strata were eroded and the normal fault origins are no longer recognizable. Fig. 2 shows three transects across a part of the EC in NW Argentina, with known and suspected pre-Cenozoic faults marked. The complete switches in vergence over short distances along strike are remarkable and most likely controlled by inherited mechanical anisotropy. The NW- and SW-trending faults were reactivated as oblique reverse faults with sinistral and dextral strike-slip components, respectively. Prominent examples are the SW-trending Hornocal fault and the NW-trending faults of the El Toro lineament. Of the W- to WNW trending rift faults some remained inactive during the Andean orogeny, as expected from their trend nearly parallel to the main Cenozoic contraction direction. Surprisingly, however, other faults of the same direction do show fairly strong inversion, implying a component of approximately N-S shortening. These structures occur sporadically but over a relatively wide area (Mon et al., 2004; Strecker and Marrett, 1999) that may include part of the Subandean foreland (Kley and Monaldi, 2002). So far they have been reported from about 23° to 26° S. Many of them do not match well the "younger", Pliocene to Recent kinematic phase as defined by Marrett & Strecker (2000), and overprinting relationships show they are not always the most recent structures. They may reflect complex local kinematics caused by anisotropy within a constant regional regime of E to ESE directed thrusting. Intriguingly, these transverse contraction structures occur in an area of strong along-strike shortening gradient where orogen-parallel extension, not contraction, should be most prominent.

CONCLUSIONS

The EC, now the structural backbone of the Central Andes, had a complex Paleozoic and Mesozoic geologic history that conditioned its response to the Cenozoic Andean orogeny. Especially Cretaceous rifting created structures that were reactivated and exerted a strong influence on the development of particular structural styles and local kinematic patterns. Most significantly, however, there is an almost one-to-one correlation between the present-day EC and a pre-Cretaceous structural high that had apparently originated through several diachronous and spatially separated though partially overlapping deformation events. The early onset of deformation and the high elevation of the EC suggest that it was the mechanically weakest part of the South American plate when the Andean orogeny began. The renewed uplift of the ancient structural high along its former outline was probably controlled by two factors: (1) fault reactivation and (2) the transition from thick-skinned to thin-skinned thrusting prompted by the different stratigraphies of the EC and its forelands. There has recently been a tendency to ignore the tedious geologic complexities in favor of simple models of orogeny. Numerical models begin only now to incorporate stratigraphic variations. Such complex models will be required to fully understand the dynamic evolution of the Central Andes.

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