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Fracture propagation in the Central Andes forearc, Coastal Cordillera, Northern Chile: Insight from IKONOS data and surfaces topographic modelling

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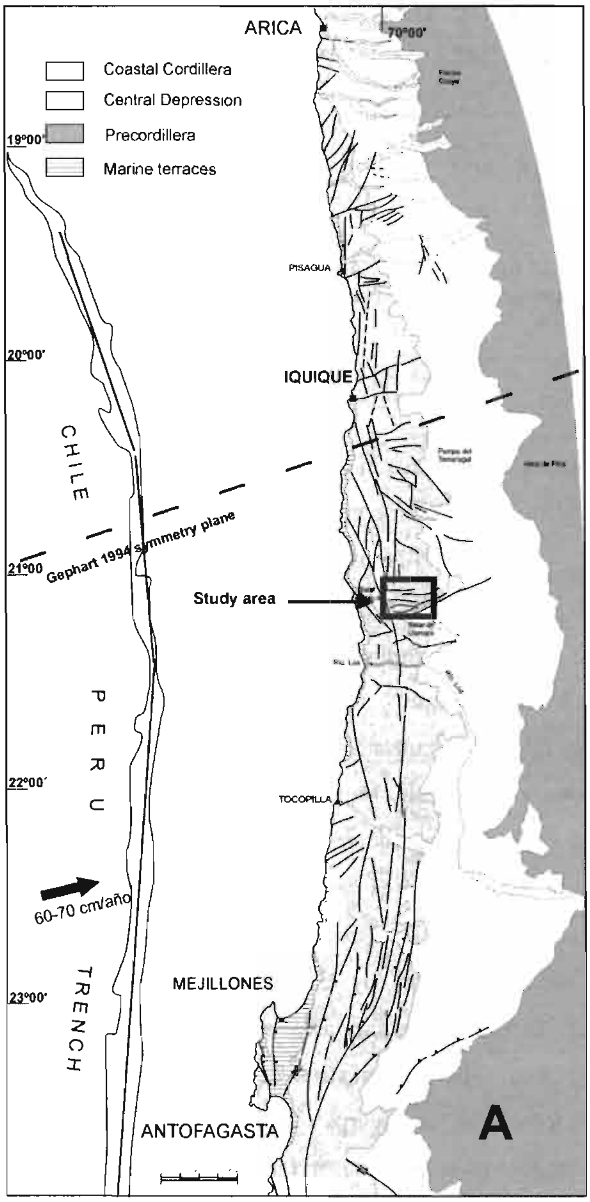
Introduction

Fractures are very common in active tectonic zones, but its significance in terms of upper crustal deformation is not trivial. At least two different processes can produce fractures in a forearc setting : 1) topographic collapse by seismic shaking during earthquakes (McCalpin et al., 1996) and 2) fault propagation processes. In the first case, fractures are a secondary effect of seismic wave propagation in the earth surface. In the second case, fractures are produced by stress release during fault slip. In active tectonic zones, such as the Central Andes, these two processes can occur simultaneously and/or alternate in time, forming complex fracture geometries whose understanding is relevant to formulate geodynamics interpretations and to evaluate seismic hazard.

In the Coastal Cordillera close to the Salar Grande a conspicuous mesh of open fractures (cracks) affecting the topographic surface is the prevailing structural feature of the area. The fractures are pervasive affecting a 1200 km^2 area of the Coastal Cordillera between 20-21°30'S. The fractured area can be divided into two portions, a western area, west of the Salar Grande and an eastern area localized east of this salt lagoon. The western area is dominated by NW-SE to N-S striking fractures and the eastern area by E-W trending fractures. In this contribution we report a detailed description of fractures of the eastern area and discuss their tectonic significance (Fig. 1). A particularity of the fractures in this area is the unusual strike direction which is normal to the trench orientation. These fractures are closely related to reverse fault scarps suggesting their origin is either connected with fault propagation or causally related to topographic collapse of fault scarps. Using IKONOS images (1 m spatial resolution) and 30 m resolution DEM, we describe the general geometry of fractures and their spatial relationship with fault scarp. Our goal is to find an explanation for the origin of fractures and its relation with active tectonic processes of this part of the Central Andes forearc.

Tectonic setting

The near surface structure of the study area is dominated by trench orthogonal reverse faults labelled Chuculay Fault System (Carrizo et al. in this issue). A description of the morphological character and the kinematic significance of these reverse faults have been recently made by Allmendinger et al. (2005). Incremental strain analysis shows that displacement along faults was controlled by N-S shortening. K-Ar and Ar-Ar geochronology (González at al. 2003 and Allmendinger et al. 2005) and Ne^{21} exposure ages in progress indicate that activity of these faults started in Miocene and was active at least until Pliocene-Pleistocene times. The Chuculay Fault System exerts a strong topography control forming E-W striking and 200-350 m in high fault scarps. The upper part of these scarps contains the fractures. Fractures are present on the upper part of these scarps.



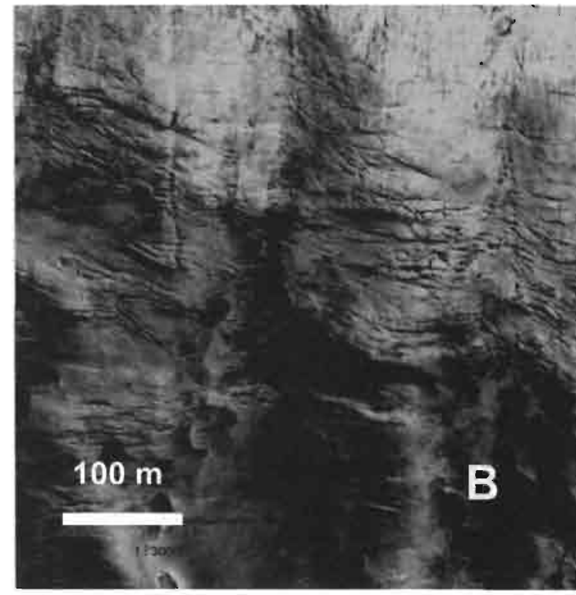


Figure 1. A. Structural map of the Central Andes forearc, B. IKONOS image showing the fractures. C. Structural map of the Chuculay Fault System showing the fractures occurring in the upper part of reverse fault scarps.

Nature of fractures

By using IKONOS data we have documented nearly 10,000 fractures (Fig. 1C). The width of the fractured area above the scarps varies between 300 to 1600 m. The fractured area is characterized by sand filled fractures and open cracks. Both types of fractures are orientated subparallel to the scarp trend. Filled fractures host strongly cemented sand and volcanic ash material. Episodic fracture propagation is suggested by internal banded infill consisting in layered detrital fabric of sand material alternating with volcanic ash. Open cracks are characterized by intense fracturing of the crystalline wallrocks or gypsum soil. Some cracks show a detrital infill in both walls of the fracture; whereas the inner part is void. Other cracks were formed directly by fracturing of previously undeformed rock. Filled fractures and open cracks penetrate in crystalline rocks at least 12 m below the topographic surface. Aperture of the open cracks varies between 0.2 to 1.5 m whereas the fracture infill reaches 1.5 m width.

Using topographic modelling of the relief affected by the Chuculay Fault System, we can demonstrate the fractures sets are localized in the highest parts of the scarps. However, field observation and GPS levelling of the scarps show that location of most open cracks does not match with the highest scarp. Furthermore, the best preserved open cracks are located in those areas where the scarps are comparatively lower in height.

Field characterization of fractures indicates that they were formed by a mode I fracturing and that only minor shear was involved. However, locally we observed up to 6 m of vertical displacement at the crest of the fault scarps evidencing later vertical shear along the fractures. Considering these field observations and using the fracture direction we can identify the bulk extension direction associated to fracture propagation, which is then closely normal to the scarp trend. Using cumulative fracture aperture along a trend drawn perpendicular the fracture strike we determined that extensional strain reaches magnitudes of ca. 1-1.5 %.

Origin and age of the fractures

Fracture reactivation in the Central Andes forearc associated with subduction earthquakes has been recently demonstrated by Keefer and Moseley (2004) in southern Peru. These authors documented fractures that were reactivated during the last subduction earthquake in the Arequipa area. The authors interpreted that fractures were produced by shaking of the topography. On the other hand, a most precise mechanism for margin parallel fracture formation has been formulated by DeLouis et al (1996) and González and Carrizo (2003). These authors propose that extension driving fracture formation is related to coseismic deformation of the overriding plate during subduction earthquakes, such as it was registered during the on July 30 Antofagasta earthquake (Ruegg et al. 1995; Klotz et al 1999). In this case, fractures are orientated parallel to the trench orientation. In our case study, fracture trend is normal to the trench orientation contrary to margin parallel extension. Shaking process would be the only alternative to relate subduction earthquakes with fracture propagation; in this case scarp collapse could be associated with rock fracturing. However, our field observations show that the cracks showing greater openings are preserved in an area where the reverse fault scarp is not comparatively higher than the other ones. Furthermore we do not observe large block collapse along the reverse fault scarps. Both lines of evidence strongly suggest that fracture origin is probably related to surface stretching resulting from reverse fault propagation.

Ne^{21} dating of hanging on scarps inactive valleys deformed by the reverse faults and the fractures indicates that the process leading to fracture formation is younger than 4 Ma. Moreover, the open character of the fractures indicates that they were formed probably in a recent time. However, because of the extreme arid climatic condition prevailing in the area we suspect that these fractures can remain open for a long time. The extent of this time cannot be exactly constrained with our current data.

Acknowledgement

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