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Characterization of Quaternary faults by electric resistivity tomography in the Andean Precordillera of Western Argentina

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ABSTRACT

Structural and geomorphic surface observations are frequently insufficient for a proper geometric and kinematic characterization of Quaternary faults. In order to improve the geological knowledge of three Quaternary faults in the Precordillera of western Argentina (30°46′ S–32°24′ S, 69°07′ W–69°15′ W), a shallow 2D Electrical Resistivity Tomography (ERT) survey was performed along seven short cross-sections, perpendicular to the fault traces. The survey was carried out across the San Bartolo fault, the Los Avestruces high and the El Tigre fault in the Precordillera of western Argentina in the San Juan and Mendoza provinces. During the survey, different electrical arrangements were assessed, including different arrays (dipole–dipole and Wenner–Schlumberger), diverse electrode separations and different depth of investigation. Tomographic models showed low resistivity zones lying below the fault scarps, as well as significant resistivity contrasts across the inferred fault-zones in the subsurface. This information permitted better characterization of the geometry and kinematics of these fault zones. ERT results showed that the San Bartolo fault is extensional. In the Los Avestruces high a positive inversion of an extensional fault was recorded by the electrical images. In the resistivity sections of the El Tigre strike-slip fault, a near vertical fault plane associated with blind splays could be identified. Our results confirm that the resistivity method is a valuable tool to image fault planes and to characterize the general geometry of extensional, reverse and strike slip faults at depth.

1. Introduction

Stratigraphic, structural and geomorphic studies are the usual methods that have been employed in the recognition and characterization of Quaternary faults in Argentina. Investigation of Quaternary tectonic activity has generally relied on superficial evidence of Quaternary deformation and the subsequent determination of the geometry and kinematics of the involved structures. Geomorphic features, like piedmont or bedrock scarps, pressure ridges and sag ponds are the main evidence of Quaternary faulting in the Precordillera of western Argentina (Bastías et al., 1990, 1993; Cortés et al., 1999b; Costa et al., 2000b). Although the trace of the fault plane is sometimes easily recognized in the field, the subsurface structural configuration is inferred only from the surficial features and trench data. These, however, are often poorly preserved or have an incomplete expression. Due to the limited depth of exposure, trench logging information does not necessarily represent the geometry of major faults at depth. Fortunately, in many cases, different geophysical techniques, such as shallow to standard reflection seismology, ground penetrating radar or potential methods as gravity or magnetics, have proved to be successful in determining the geometry and some structural features of the fault zone in the first tens to several hundred meters below surface (e.g. Wang, 2002; Donne et al., 2007). A relatively recent geophysical method applied to this objective is the electric resistivity tomography (ERT, e.g.: Fleta et al., 2000; Giano et al., 2000; Storz et al., 2000; Suzuki et al., 2000; Verbeeck et al., 2000; Demanet et al., 2001a, 2001b; Caputo et al., 2003, 2007; Wise et al., 2003; Colella et al., 2004; Rizzo et al., 2004; Nguyen et al., 2005, 2007). By imaging the fault zone to depths up to around 100 m, this geophysical technique, together with geological studies and ages of deformation, can help in achieving a better definition of the neotectonic activity of an area. Among the main specific targets of the geoelectrical investigation of fault zones, are the geometry of the fault plane, the presence, number and distribution of associated splays and blind faults, and the throw estimation. In spite of several successful cases, the geoelectrical investigation of fault zones has not yet been globally adopted as a customary technique in studies of Quaternary tectonics or seismic hazard assessments.

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In this contribution we present the results of 2D ERT across three Quaternary fault systems in the Precordillera of the Central Andes of western Argentina. Our aims have been to further investigate the capabilities and limitations of this technique when applied to fault zones and to better constrain the geometry and tectonic regime of these three areas. Quaternary tectonic evolution of the Precordillera of Mendoza and San Juan, in western Argentina, has been reviewed by Cortés and Costa (1996), Cortés et al. (1999b, 2006), Costa et al. (1999, 2000a,b, 2006) and Siame et al. (2006), providing contributions towards a better understanding of the seismic hazard of the region. However, and in spite of their well known advantages, shallow geophysical methods have not been used yet in this region to investigate tectonically active areas. The results of 10 ERT along seven profiles performed across three Quaternary fault zones in the Precordillera of western Argentina are analyzed and interpreted within the geological context. The studied faults are the regional San Bartolo fault, with poor kinematic evidence at surface, the regional strike-slip El Tigre fault and a minor reverse fault at the Los Avestruces high. These partially different tectonic settings provided further possibilities to get insights into the capabilities and limitations of the ERT technique.

2. Neotectonics of the Precordillera

The Precordillera of western Argentina is a first order morphotectonic unit uplifted during the Late Cenozoic on the southern flat-slab segment (28° S–33° S) of the Central Andes. Its Neogene tectonic evolution results from the migration towards the east of the magmatic arc and the contractional and transpressive deformation of the foreland basin as a consequence of gradual flattening of the Nazca plate in the last 20 Myr (Isacks and Barazangi, 1977; Jordan et al., 1983).

The central segment of the Precordillera (Fig. 1), between 30° S and 31°30′ S in the San Juan province, is an east verging thin-skinned belt (Baldis et al., 1982; von Gosen, 1992). This thrusted and folded system exhibits in its eastern margin an opposite vergence with a deeper level of detachment in the basement, defining there a thick skinned triangle zone (Zapata and Allmendinger, 1996).

In contrast with the central segment, the Late Cenozoic tectonics of the southern section of the Precordillera, located mainly in the Mendoza province (31°30′–33° S, see Fig. 1), has evolved under the influence of structural anisotropies as oblique megashear zones and paleogeographic features of Paleozoic and Triassic age (Kozlowski et al., 1993; Cortés et al., 2005a; Cortés et al., 2006). Consequently, this morphotectonic unit, named the Precordillera Sur (Cortés et al., 2005b), shows a more complex structure, characterized by a combination of tectonic inversion of extensional Triassic half-grabens (Legarreta et al., 1993; Ramos and Kay 1991; Cortés et al., 1999a), the contractional and transpressive rejuvenation of Permian structures (von Gosen, 1995; Cortés et al., 1999a) and strike-slip displacements on NW trending faults (Cortés et al., 2005a).

The northern margin of the Precordillera Sur is defined by a Late Cenozoic deformation zone (the Barreal-Las Peñas belt), which is a left-lateral transpressive belt crossing the whole Precordillera from the Barreal region in the northwest to Sierra de Las Peñas in the southeast (Cortés et al., 2006). This tectonic feature consists of five left-stepping faulted blocks bounded by oblique strike-slip fault systems.

In the central section of the Precordillera (30°00′ S–31°30′ S), Quaternary ruptures generally result from the reverse and oblique rejuvenation along segments of range-front faults. Other evidence is commonly exposed at intermontane basins as fault scarps developed in alluvial fans of piedmont areas (Bastías et al., 1990; Cortés et al., 1999b; Costa et al., 2000b). The eastern flank of the Precordillera, between 31° and 34° S concentrates most of this Quaternary and active deformation (Costa et al., 2006). Nevertheless, as a consequence of strain partitioning, Pleistocene sediments at the western flank have been displaced along the 120-km-long right-lateral El Tigre fault (Bastías and Bastías, 1987; Siame et al., 1997; Siame et al., 2006; Cortés et al., 1999b).

South of 31°30′ S, in the Precordillera Sur, geomorphic and structural evidence of Quaternary deformation have been traditionally observed on the active front at the eastern border of the Precordillera (Bastías et al., 1993). Here again new neotectonic evidence were found to the west of the active front near the western border of the Precordillera Sur (Cortés and Cegarra, 2004; Terrizzano et al., 2007). At 32° S, the Barreal-Las Peñas belt seems to concentrate a large part of the Quaternary deformation of the Precordillera Sur (Cortés et al., 2005a; Cortés et al., 2006). There, the western piedmont of the Precordillera has been uplifted during the Quaternary by means of folds, blind faults, faults that shear the surface and faulted blocks that form discrete brittle–ductile shear zones (i.e. Loma de Los Avestruces high) at different scales. At the Barreal-Las Peñas belt, the association of contractional and strike-slip structures, their orientation and the kinematic indicators of faults are consistent with a left-lateral transpressive deformation (Cortés et al., 2005b).

The central region of the Precordillera Sur (32°20′ S) is characterized by NE trending faults scarps with evidence of local extensional deformation (Cortés et al., 1999b). There, the San Bartolo fault displays a complex association of geomorphic, stratigraphical and structural features of Quaternary deformation (Pasini, 1999).

Our studies were carried out in three areas of the Precordillera with significant Quaternary tectonic activity. They are: (i) the San Bartolo fault, in the southern region of the Precordillera Sur (Fig. 2); (ii) the Los Avestruces high, in the western piedmont of the Barreal-Las Peñas belt (northern region of the Precordillera Sur, Fig. 3) and (iii) the El Tigre fault, in the central segment of the Precordillera (Fig. 4).

3. ERT surveys: equipment and methodology

The location of the seven geoelectric profiles (SB1, SB2, A1, T1, T2, T3, T4) is presented in Figs. 2–4. Measurements were performed with a Syscal R1 Plus Switch 48 Georesistivimeter (Iris Company), which can be connected to a linear array of 48 electrode nodes, with a 10 m of maximum spacing. The electrodes are connected on the back of the resistivimeter by means of two strings of heavy-duty seismic-like cable with 24 output each. Acquisition and geometric parameters (maximum permitted standard deviation of the measurement, minimum and maximum numbers of stacks per measurement, input current time per cycle and desired signal voltage) have to be set. The resistivimeter is able to automatically perform the pre-defined sets of measurements according to the type of array selected and provides direct reading of input current, potential difference, electrode location and apparent resistivity. Geometric parameters n (level) and d (electrode spacing) were assigned according to the desired maximum depth of investigation and noise level.

The problem of finding an inverse 2D model of resistivity distribution in a profile was solved numerically in the form of a simple rectangular cell model by means of the RES2DINV program, of Geotomo software (Loke, 2001; Loke, 1996-2002). This program allows to estimate the resistivity of the cells (*model parameters*) that adjusts the quantities measured at surface, within certain discrepancy. At first, the quantities derived from the field measurements are presented in the form of a *pseudosection*, a contour diagram