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Three-dimensional electrical resistivity image of the South-Central Chilean subduction zone

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ABSTRACT

Based on isotropic 3-D inversion, we re-interpret long-period magnetotelluric data collected across the geotectonic structures of the South-Central Chilean continental margin at latitudes 38°–41°S and summarize results of long-period magnetotelluric (MT) investigations performed between 2000 and 2005. The new 3-D conductivity image of the South-Central Chilean subduction zone basically confirms former 2-D inversion models along three profiles and complete the previous results. The models show good electrical conductors in the tip of the continental crustal beneath the Pacific Ocean, the frequently observed forearc conductor at mid-crustal levels, a highly-conductive zone at similar levels slightly offset from the volcanic arc and a – not well-resolved – conductor in the Argentinian backarc. The subducted Nazca Plate generally appears as a resistive but discontinuous feature. Unlike before, we are now able to resolve upper crustal conductors (interpreted as magma reservoirs) beneath active Lonquimay, Villarrica, and Llaima volcanoes which were obscured in 2-D inversion. Data fit is rather satisfactory but not perfect; we attribute this to large-scale crustal anisotropy particularly beneath the Coastal Cordillera, which we cannot include into our solution for the time being.

1. Introduction

Magnetotellurics is a passive method that uses the natural fluctuations of the Earth's external magnetic field and the phenomenon of electromagnetic induction to derive the conductivity distribution in the Earth and assess its physical conditions. In a subduction zone, where the rock matrix is exposed to plate-collision-related stress field and suffer brittle failure and deformation, an increase of conductivity is usually associated with electrolytic fluids. They fill an interconnected network of cracks and ruptures of the fractured rock, which provide pathways for carriers of electrical charges in the electrolyte. On the other hand, fluids play in a subduction zone a key role, as a trigger and a controlling factor of rupture evolution, and earthquake nucleation, as well as partial melting reactions and volcanic activity. Thus, there exists a close relationship between the electrical parameters of the magnetotelluric target and the rheological (mechanical) conditions in the underground. The presence of water enhances electrical conductivity, and thus there exists a direct connection between a magnetotelluric target and the processes which control or are related to the subduction mechanisms. By estimating the electrical conductivity, magnetotellurics enables to assess qualitatively and quantitatively fluid volumes in the Earth's interior and thus applies as an appropriate approach for investigating subduction zones.

Subduction zones have been regularly a focus of magnetotelluric investigations to image the electrical conductivity in the crust and mantle and to study subduction related fluid release and melt production in the earth's interior (e.g., Booker and Chave, 1989; Gough et al., 1989; Jiracek et al., 1989; Wannamaker et al., 1989; Brasse et al., 2002; Jödicke et al., 2006; Soyer and Unsworth, 2006; Brasse and Eydam, 2008; Worzewski et al., 2010; Evans et al., 2013; Kühn et al., 2014).

The first MT study at the South Chilean continental margin, conducted in 2000 with surveys along 2 profiles, revealed conductive anomalies in the crust and prominent indicators for anisotropic features (Brasse and Soyer, 2001; Brasse et al., 2009; Brasse, 2011). For an overview on the effects of electrical anisotropy, we refer to the review papers by Wannamaker (2005) and Martí (2014). To corroborate the partially unexpected findings, the area became subject of an amphibious study in 2004/2005 along a new profile, which extends the study area to the north.

In this paper, we summarize the results of magnetotelluric studies performed between 2000 and 2005 during two field campaigns and present conductivity models of the South Chilean subduction zone derived from 2-D and 3-D inversions. The long periodic data were collected at sites between latitudes 38°–41°S, predominantly aligned along

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three profiles running across the main geological and morphotectonic units of the South-Central Chilean continental margin and at two small networks of sites around active Villarrica and Llaima volcanoes. The northern profile was additionally extended into the ocean, beyond the Peru-Chile trench with several offshore instruments from Woods Hole Oceanographic Institution (WHOI) employed during RV Sonne cruise SO181. However, because of poor quality of most offshore data, we consider only the site closest to the coast.

2. Geological setting—the evolution and tectono-magmatic history of the South-Central Andes

Since the late Paleozoic, the tectonic and magmatic activity at the Chilean margin has formed several geological features, which reflect the changing geodynamic conditions during subduction of the Nazca Plate. However, the present prime morphotectonic units in our study area have mainly developed during the so-called "Andean tectonic cycle" which was initiated by N–S magmatism along the entire Pacific margin in the early Jurassic and imprints the Andean evolution until today (Glodny et al., 2006). After periods of intense volcanic eruptions/events like in the Jurassic and Cretaceous – where magmatism concentrated in the Main Cordillera and backarc and the granitoid north–south trending North Patagonian Batholith was formed – followed magmatic and tectonically quiescent intervals like in the Paleocene and Eocene in which erosion and sedimentary processes prevailed forming several main morphotectonic units being the focus or relevant to the study (e.g., Folguera et al., 2006; Melnick et al., 2006) (Fig. 1).

To the coast there is a narrow *Coastal Platform*, comprising uplifted Tertiary marine and coastal sequences and the *Coastal Cordillera*, with elevation ranging from 1500 m to only a few hundred meters, formed by a Permo-Triassic accretionary complex, the Western Series, and a late Paleozoic magmatic arc, the Eastern Series (Hervé, 1998; Glodny et al., 2006; Hackney et al., 2006). It follows the *Longitudinal Valley*, also called *Central Depression* or *Central Valley*, a basin filled with up to 2 km thick Oligocene–Miocene sedimentary and volcanic rocks, covered by Pliocene–Quaternary sediments. It is bounded in the east by the *Main Cordillera*, formed by the modern magmatic arc and also consisting of intra-arc volcano-sedimentary basins. East of the Main Cordillera continue the Bío-Bío *-Aluminé* and *Loncopué Troughs*, extensional basins associated with abundant mafic volcanism (e.g., Folguera et al., 2006). To the east, the troughs adjoin or are bounded by the southern extension of the *Agrio fold-and-thrust belt*, the Mesozoic *Neuquén Embayment,* and the Cretaceous–Tertiary foreland basin.

Changes in subduction geometry in the late Oligocene and early Miocene associated with increasing convergence rate and a steepening of subduction angle of the descending Nazca Plate initiated a migration of the volcanic front westward toward the Coastal Cordillera and formation of a coastal magmatic belt. An assemblage of volcanic rocks of this belt interbedded with marine sedimentary sequences indicates marine volcanism. Furthermore, the Longitudinal Valley developed, accumulating up to 2 km of deposits (Muñoz et al., 2000; Parada et al., 2007).

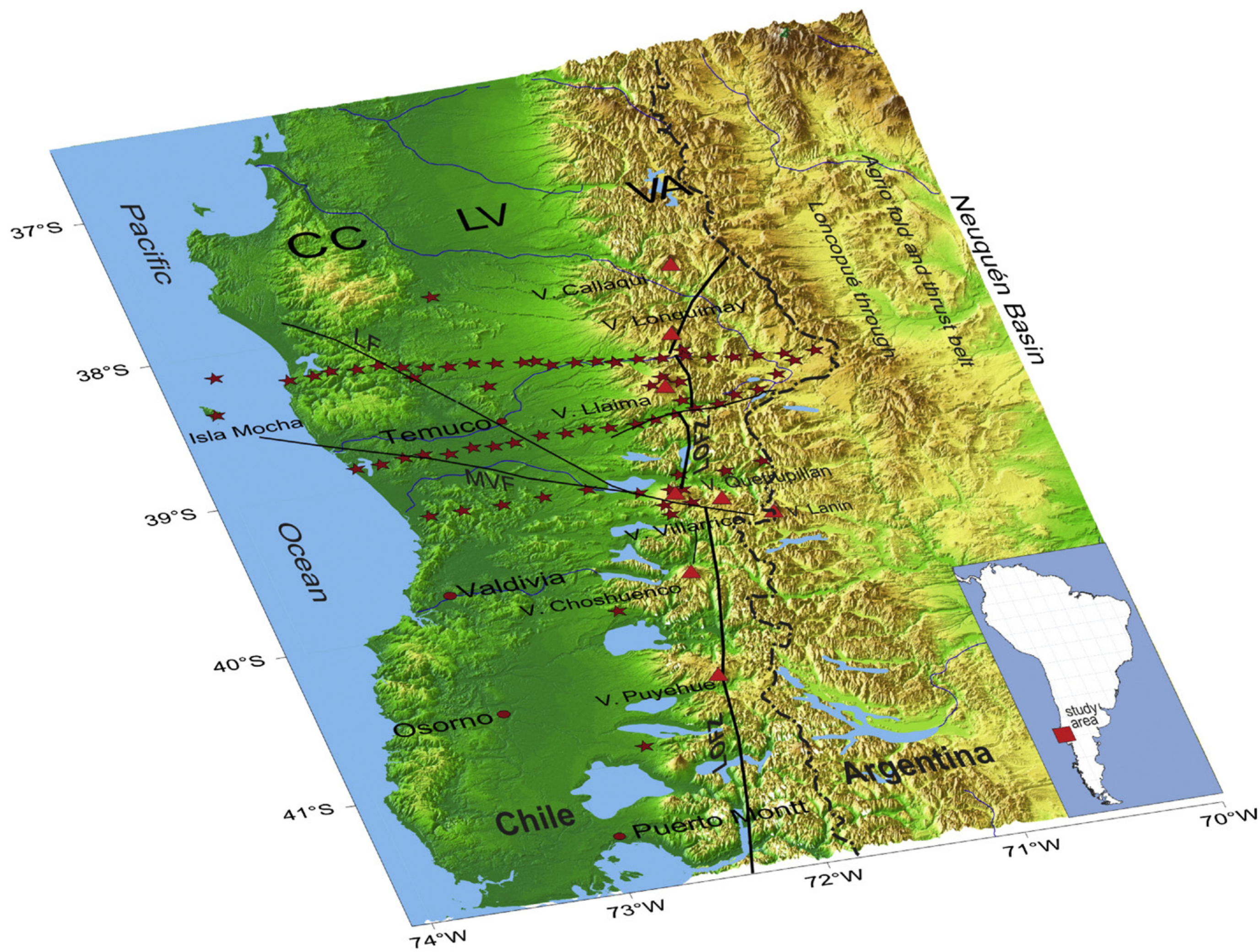

Fig. 1. Shaded relief map of the study area at the South Chilean margin. Topography is based on SRTM (NASA), and fault traces (black lines) are modified from Melnick et al. (2006). Faults mentioned in the text: LOFZ, Liquiñe-Ofqui; LF, Lanalhue; and MVF, Mocha-Villarrica Fault. CC denotes Coastal Cordillera; LV, Longitudinal Valley; VA, volcanic arc. Stars indicate MT sites.