Magnetotelluric images of magma distribution beneath Volcan Uturuncu, Bolivia

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**SUMMARY**

The Altiplano-Puna magma body (APMB) is recognized as one of the largest crustal magma bodies on Earth. Geophysical studies have detected a thin low velocity zone at a depth of about 20 km that is inferred to be a layer of > 20% partial melt. Volcan Uturuncu, near the centre of the APMB, has been inflating over the past two decades at rates of 1-2 cm/year. Broadband magnetotelluric data collected at Volcan Uturuncu detected a region of low resistivity at a depth of about 20 km, believed to be the APMB. The magnetotelluric data have also shown pathways of fluid extending from the APMB to the surface, and suggest that the uplift is associated with magma movement towards the surface.

**Keywords:** Magnetotellurics, Central Andes, Volcanoes

**INTRODUCTION**

The Central Andes is a volcanically active and well studied subduction zone, where the Nazca plate subducts beneath the South American plate. The Altiplano and the Puna are high plateaux with average elevations of more than 4000 metres, and have crustal thicknesses reaching 75 km (Cahill and Isacks 1992; Beck et al. 1996; Beck and Zandt 2002).

This region is characterized by the Altiplano-Puna Volcanic Complex (APVC), caused by an ignimbrite flare-up during the last 10 million years (de Silva 1989). Seismic studies revealed that the APVC is underlain by a major magma body, the Altiplano-Puna Magma Body (Chmielowski et al. 1999; Zandt et al. 2003). This combination of observations make this region an excellent natural laboratory to study the processes associated with silicic magmatism and super-volcano eruptions.

**ALTIPLANO-PUNA MAGMA BODY**

The Altiplano-Puna magma body (APMB) is recognized as one of the largest magma bodies on Earth. Geophysical studies reveal a thin (~1 km) ultra-low velocity zone (LVZ) at a depth of about 20 km (Zandt et al. 2003). Researchers have inferred 14-27% partial melt to account for the very low resistivities (Schilling et al. 1997).

Furthermore, the APMB is spatially associated with the major ignimbrite eruptions of the Altiplano-Puna Volcanic Complex (APVC). Volcan Uturuncu in Southern Bolivia is located near the centre of the APMB and has been inflating over the past two decades at rates of 1-2 cm/year. It has been suggested that this represents a location where pluton formation may be occurring in real time (Pritchard and Simons 2004; Sparks et al. 2008).

**Figure 1.** A relief map showing the locations of 180 MT stations (small circles) collected around Volcan Uturuncu. MT stations shaded black were used for the 2-D inversion. The location of volcanoes are shown as red triangles. Pink circle shows the limit of measured inflation and purple circle shows the limit of subsidence. Inset rose diagram shows a consistent geoelectric strike direction of N30°E.
The PLUTONS project is making a comprehensive set of geological and geophysical measurements to define the distribution of magma beneath Volcan Uturuncu, and also to understand the eruptive history. This has included geological studies, seismic monitoring, and detailed geodetic measurements.

Magnetotelluric (MT) data use passive electromagnetic signals to image subsurface resistivity from the surface to the upper mantle. Electrical resistivity is an important property because it is sensitive to the presence of partial melt and hydrothermal fluids in the crust (Budach et al. 2013).

Initial analysis of the data has revealed a number of interesting features as shown by the 2-D inversion, presented in Figure 2. An anomalous region of low resistivity at a depth of about 20 km is detected and can clearly be identified as the APMB (C1). This body begins below the volcanic arc at the Bolivia-Chile border and stretches eastward ending in North-Western Argentina, defining the extent of the body. The surface deformation and uplift observed at Uturuncu seems to be centered above the shallowest part of the APMB. The rising conductor below Uturuncu is assumed to be the reason for the volcano’s high rate of inflation.

A number of low resistivity pathways can also be seen (C2). These connect the APMB conductor to the surface above, possibly representing conduits with hydrothermal alteration, or shallow accumulations of magma beneath Volcan Uturuncu (C3), near sea level.

Analysis of MT data requires that the dimensionality of the data is understood. The geoelectric strike direction was determined using both the tensor decomposition method and the phase tensor analysis (Groom and Bailey 1989; McNeice and Jones 2001; Caldwell et al. 2004). These techniques showed that a strike direction N30°E was appropriate for this data set over the period band 10-300 s (see rose diagram inset in Figure 1). These periods correspond to depths of about 5-90 km (assuming a 10 ohm-m halfspace).

Figure 2. Magnetotelluric data shown as apparent resistivity and phase curves. Red curves are North-South electric fields (TE mode) and blue curves are East-West electric fields (TM mode).

Figure 3. A 2-D resistivity model from inversion of MT data in both TE and TM modes. Black triangles denote MT stations used in the inversion. All stations are projected onto a profile perpendicular to the geoelectric strike direction. A r.m.s misfit error of 1.4 was achieved. Label C1 represents the Altiplano-Puna Magma Body and C2 represents low resistivity pathways and shallow accumulations of magma beneath the volcano (C3). The symbol U represents the location of Volcan Uturuncu.
CONCLUSION

The magnetotelluric data collected at Volcan Uturuncu show a region of low resistivity at a depth of about 20 km, believed to be the APMB. Our new results also show a set of low resistivity pathways, which connect the APMB conductor to the surface. The geometry of these features is being defined with a fully 3-D inversion using a grid of MT stations collected around Volcan Uturuncu.

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