# VELOCITY STRUCTURE BENEATH THE SOUTHERN PUNA PLATEAU

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## SUMMARY

The southern Puna plateau (25S-28S) offers an excellent natural laboratory to study the formation of continental plateaus. Furthermore there are a number of features that set the Puna apart from the central Andean plateau to the north, the Altiplano. These features include a distinctive spatial and geochemical pattern of mafic lavas and giant ignimbrites, a high topography with a large deficit of crustal shortening, and an underlying slab with a gap in intermediate depth seismicity. The region is also believed to have experienced a delamination event that took place around 6-7 Ma.

An array consistent of 73 broad band and short period seismic station were deployed in the region for a period of two years starting in 2007. We obtained shear wave velocities from prior measurements of Rayleigh wave velocities. Our dispersion curve is compared with that of Northern Tibet and Eastern Turkey. We also observe an ultra low velocity zone beneath the slab. The shear wave structure shows a transition from abnormal low shear wave velocities at shallow depths to abnormal high shear wave velocities at greater depths beneath Cerro Galan. This is consistent with the hypothesis of delamination in which a piece of lithosphere detached and caused upwelling of hot asthenosphere which in turn causes widespread non-arc related volcanism.

## INTRODUCTION

The Andean Mountains (Figure 1) are the typical example of the subduction of an oceanic plate beneath a continent and uplift of a mountain range without continental collision. The Andes are characterized by the high active volcanoes (> 6800m), high peaks (> 7000 m), some of thickest crust (> 70 km), the second greatest plateau with the largest Tertiary ignimbrite calderas, among the most shortened continental crust. These features make the Andes a perfect place for investigating the effects of shallowly subduction oceanic plates (Isacks 1988, Cahill and Isacks 1992), continental lithosphere removal by forearc subduction erosion (Von Huene and Scholl, 1991; Kay et al 2005), and delamination of continental and mantle lithosphere (Kay and Kay 1993; Beck et al 2002; Sobolev and Babeyko 2005).

Kay and Kay (1993) and Kay et. Al. (1994) proposed a model with an episode of crustal and lithospheric delamination to explain a number of geodynamic features of the Central Andean Plateau and particularly in the Southern Puna Plateau such as the distinctive spatial and geochemical pattern of the mafic lavas and giant ignimbrites, the high topography with a large deficit in crustal shortening, the underlying slab with a gap in teleseismic intermediate depth seismicity and a transitional dip between a steeper segment to the north and a flat-slab to the south. Their model has a fundamental difference from previous models of delamination (Bird, 1979; Ducea et al. 2003) because they include the removal and sinking of dense eclogitic crust along with lithospheric mantle. However, the mechanism and extent of delamination remains controversial. Delaminating eclogitic crust along with mantle lithosphere would cause a large density contrast that accounts for the negative buoyancy needed for delamination to occur (Kay and Kay, 1993). However, the scale and mechanism of this type of delamination are still not well understood. The current models suggest that delamination occurs either as lithospheric pieces and drips falling in the asthenosphere (Jull and Kelemen 2002; Babeyko et. al. 2002; and Sobelev and Babeyko 2005), or as large crustal and lithospheric blocks being removed like those proposed for Sierra Nevadas (Ducea et al. 2003). An important reason to consider crustal delamination in the Andes is that it helps to explain the apparent paradox than mantle derived magmas enter the crust are basaltic in composition, yet the bulk composition of the crust is andesitic. The removal of mafic crust helps to resolve the andesitic crustal paradox. In this context, the southern Puna plateau is an excellent place to test models for crustal delamination and ultimately crustal destruction and recycling.

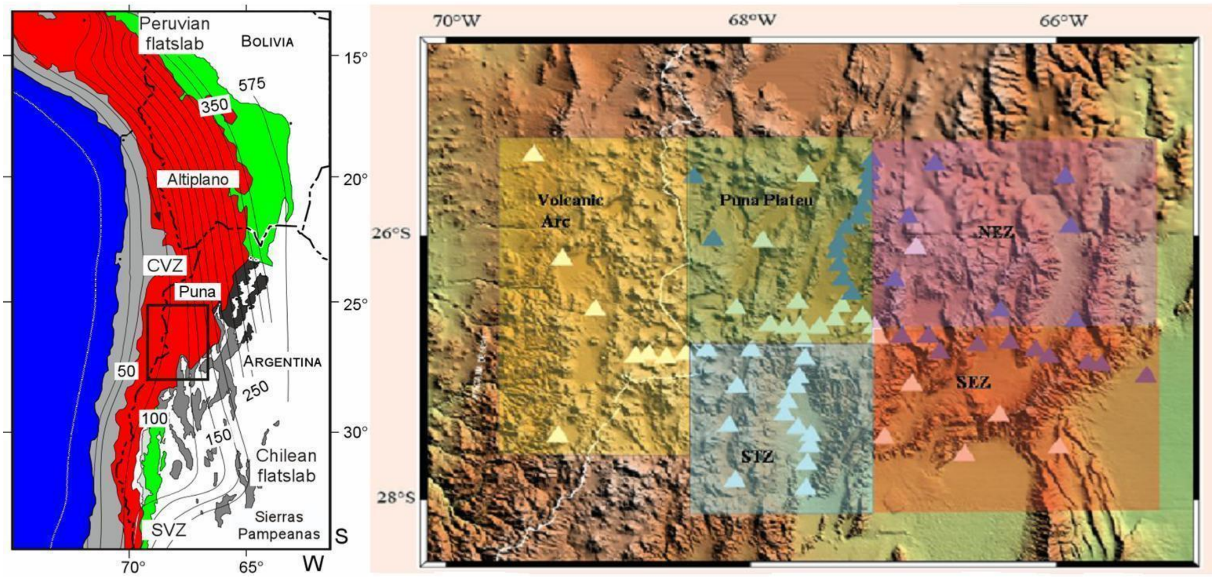

*Figure 1Left: Andean Orogeny and region of study (Southern Puna Plateau) shown in the black rectangle. Right: Array of stations used in this study.*

## METHODS

We use the two plane wave approach to obtained Rayleigh wave phase velocities. This method uses variation in amplitude and phases as the plane waves encounter variations of velocity in their path. The method has the advantage of solving for vertical distribution of anisotropy (Forsyth and Li, 2005). In the surface wave tomography method developed by Yang and Forsyth 2006, the variation of amplitude and phase of teleseismic surface waves are related to the phase velocity variations within the array. The method models the teleseismic wavefield using the sum of two plane waves at a given frequency for a given event. Each plane wave has initial unknown amplitude, phase and propagation direction.

We also used the method developed by Saito (1988) to invert our average Rayleigh wave measurements and obtain a 1-D shear wave velocity structure beneath the Southern Puna Plateau. We used an average Moho depth of 55 km. We also obtained a 3-D shear wave velocity model by using the same method for each grid point with regional average shear wave velocities as starting model.

## RESULTS

Figure 2 shows the dispersion curve shows that at short periods the phase velocities are slightly higher than those of Northern Tibet and lower than those of Eastern Turkey. At periods of around 150 s we observe an ultra low velocity zone that might be remnants of hot asthenosphere when the slab used to be flat (7-10 Ma). This ultra low velocity zone is also observed by a study of joint body wave tomography (Bianchi et al 2012) below 200 km depth. This method should have the ability to resolve the average lithospheric thickness for the region, which is estimated to be around 120 km. Figure 2 also shows a longitudinal cross-section of Vs at 25.5 S. The image clearly shows the slab as high shear wave velocity, which is also seen by the seismicity. However, at depths of 150 km and right below Cerro Galan (67 W) there seems to be an even higher velocity body, which we interpret to be the delaminated block, though it is not clear whether this high velocity block is sitting on top of the slab or part of it. Lack of seismicity precludes us from better constraining the slab geometry. At crustal depths we observe a regional of low shear wave velocities beneath Cerro Galan, which is possible due to heating caused by post-delamination asthenospheric upwelling.

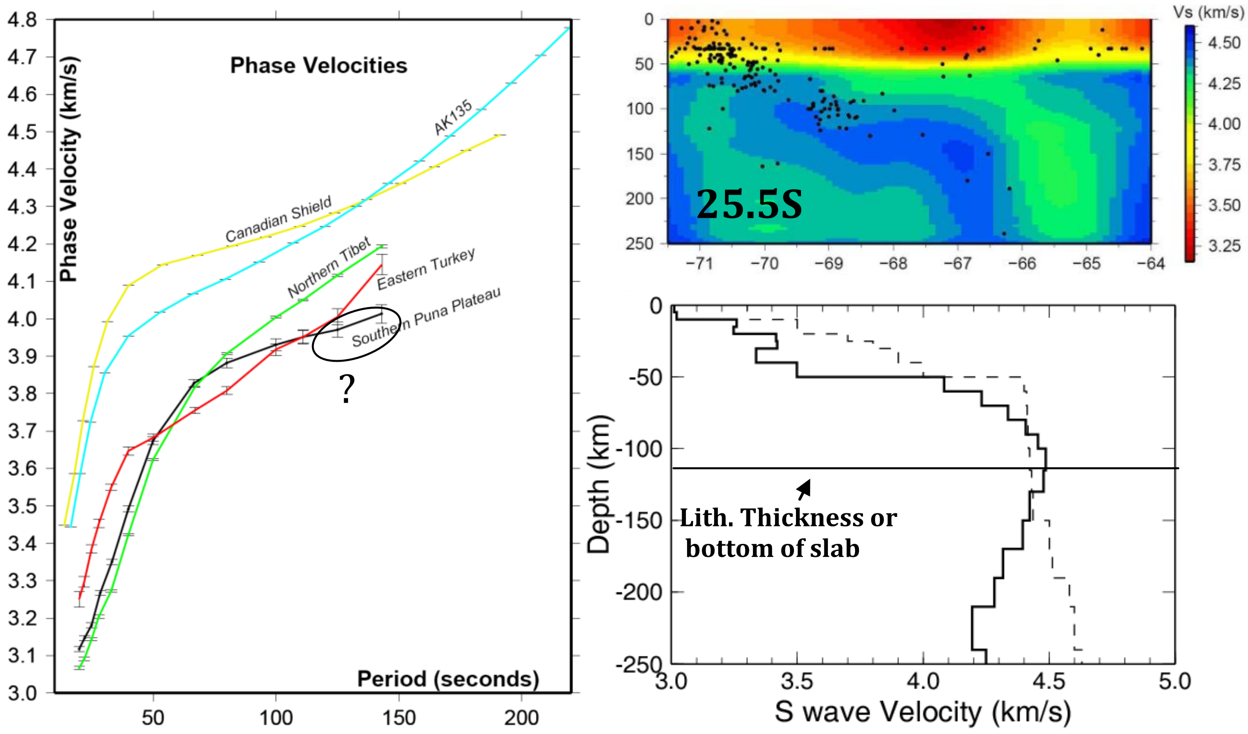

*Figure 2Left: Average Rayleigh wave phase velocities for the Southern Puna plateau (black). The dispersion curves for Canadian Shield, AK135, Northern Tibet and Eastern Turkey are shown for comparison. Upper right: Shear wave velocity East-West cross-section along 25.5 S. Lower right: 1D shear wave velocity with estimated average lithospheric thickness.*

## DISCUSSION

Delamination seems to be a plausible candidate that explains many of the geochemistry and geophysical observations throughout the Southern Puna Plateau. Although our images are not conclusive, there seems to be delaminated block sinking beneath Cerro Galan, which is causing asthenospheric upwelling and a number of other perturbations in the region, which includes regional changes in stress regime, eruption of young ignimbrites. Heating of the slab by the upwelling of hot asthenosphere could be responsible for the gap in intermediate seismicity right beneath Cerro Galan, which precludes us from better constraining the subducting slab.

Shear wave splitting (Calixto et al, 2012, in prep) gives further evidence for the current complex regional stress. A circular pattern of fast directions around Cerro Galan seems to be linked to asthenospheric upwelling around the delaminated block.

The delamination hypothesis is consistent with the model of Kay and Coira (2009) in which a moderately shallowly dipping slab causes a significant amount of backarc volcanism and delamination of dense lithosphere as the slab steepened, followed by the eruption of the Cerro Galan ignimbrite at 2 Ma. All this evidence indicates that the lower lithosphere, including the eclogitic root beneath Cerro Galan detached and sank, and led to post-delamination asthenosphere upwelling which probably underwent partial melting during its ascent.

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