8th International Symposium on Andean Geodynamics (ISAG)

Changes in anisotropy directions at volcanoes in the Ecuadorean Andes

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Several studies based on focal mechanisms have determined a predominant subhorizontal direction of the pressure axes between N106° (Segovia and Alvarado, 2009) and N121° (Corredor, 2003). At northern part of Ecuadorean Andes, slight changes were documented: Córdova (2013) found a N90° direction in the Chachimbiro area, Sierra (2015) reported N 97° in Chiles-Cerro Negro Volcanic Complex, and Ego et al. (1996) found a N76° direction. Polarization directions (Φ) and delay times (dt) of split shear-waves could also give the orientation of the principal stress directions. We will compute these parameters using a method based on the cross-correlation of displacement waveforms of shear-waves at all possible rotation angles near volcanic centers. Other studies have shown that a ~90° flip may take place either prior, during, or just after the main eruptive phase. Such a ~90° flip is probably related to micro cracks oriented parallel to the main axis, which are filled and pressuring during magmatic intrusions, creating a local reverse strain field.

A bimodal distribution of anisotropy angles was found beneath Tungurahua volcano using split shear-waves of tectonic events recorded by three broad-band temporal seismic stations between June and August 2004, a period that preceded the paroxysmal eruptions of 2006 (Ruiz, 2007). A non-linear inversion of Φ and dt of events recorded at stations MAS and RUN with signal-to-noise ratio >2.25 and cross-correlation coefficient >0.7, established two sets of anisotropy sources. The anisotropic source with the lowest inversion residuals had a NE orientation and was parallel to the elongated high velocity zones found by tomographic inversion. A second trend of anisotropy is found with an orientation nearly perpendicular to the first one. Both sets of cracks exhibit significant offset relative to the orientation of regional tectonic stresses. During this temporal deployment, Tungurahua volcano displayed three characteristic activity phases: vent-clearing, degassing, and vent-sealing phases (Ruiz, 2007). A decrease of dt was observed at the end of the vent-clearing phase, followed by an increase at the beginning of the sealing phase. Low dt values were found during degassing phases.

Chiles - Cerro Negro volcanic complex exhibited a significant increase in its seismic activity since June 2013, including a 5.6 Mw earthquake on October 20, 2014. For seismic activity between January and October 2014, 222 measures of anisotropy with a signal-to-noise ratio greater than 4.0 and a high correlation coefficient (greater than 0.95) in 13 different stations and two orientations of the maximum polarization of the S-wave anisotropy were found, one N83.5°, parallel to the direction of regional tectonic efforts and another N 179.8 ° perpendicular to it (Sierra, 2015). Considering that the seismicity is located mainly under the southern flank of the Chiles volcano, seismic rays recorded in the IMOR and ICAN with bimodal distribution are better suited for mapping the internal heterogeneities of the volcano.

Cotopaxi volcano experienced a major increase in seismic activity in 2001, and a VEI I eruption in April-December 2015. At Cotopaxi, 102 regional tectonic events recorded between 2006 and 2009 by the permanent broadband seismic network were used for anisotropy analysis (Douillet et al., 2010). These events were located at several sources inside a radius of 200 kilometers from the volcano and reached the Cotopaxi stations with different azimuths. Polarization directions and delay times of split shear waves were found using a method based on the cross correlation of displacement waveforms of shear-waves at all possible rotation angles. A bimodal anisotropic behavior was found with one of the fast-direction axes following the regional ESE Ecuadorian tectonic stress and the other one trend being perpendicular to the regional stress.

All these cases show a remarkable deviation of inferred directions of anisotropy from the general tectonic stress directions in the Ecuadorean Andes. These deviations are likely caused by magmatic intrusions underneath the volcanoes.

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