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Crack density and seismic velocities in Etna basalt

C. Trovato (1), S. Stanchits (2), S. Vinciguerra (3), G. Dresen (2)

(1) Dipartimento di Fisica e Astronomia, Universita' di Catania, 95129, Catania, Italy; 2) GeoForschungsZentrum Potsdam, Department 3.2, Telegrafenberg D423, 14473 Potsdam, Germany; 3) Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143, Rome, Italy (Tel ++39 06 51860478; Fax. ++39 06 51860507; e-mail: vinciguerra@ingv.it);

Acoustic emissions (AE), compressional (P), shear (S) wave velocities, and volumetric strain of Etna basalt were measured simultaneously during hydrostatic and triaxial compression tests. Tests were performed at confining pressures up to 400 MPa and at room temperature. Deformation-induced AE activity and velocity changes were monitored using twelve P-wave sensors and eight orthogonally polarized S-wave piezoelectric sensors; volumetric strain was measured using two pairs of orthogonal strain gages glued directly to the rock surface. Elastic wave velocities were used to model crack density of samples as a function of confining pressure and axial loading and compared to post-mortem microstructural analysis of crack density and orientation. P-wave velocity in basalt is about 3 km/s at atmospheric pressure, but increases by $>$ 50% when the hydrostatic pressure is increased to 120 MPa. The pressure-induced changes of elastic wave speed indicate dominantly compliant low-aspect ratio pores in Etna basalt that also contains high-aspect ratio voids. In triaxial loading, stress-induced anisotropy of P-wave velocities was high for basalt with vertical velocity components being faster than horizontal velocities. With increasing axial load, horizontal velocities only show a small increase. Using first motion polarity we determined AE source types generated during triaxial loading of the samples. With increasing differential stress AE activity in basalt increased with a significant contribution of tensile events. Close to failure the relative contribution of tensile events and horizontal wave velocities decreased significantly. A concomitant increase of double-couple events indicating shear, suggests shear cracks linking previously formed tensile cracks.

Crack density (CRD) of undeformed and deformed samples was measured from scanning electron micrographs for cracks with opening width $> 1\mu$m. We determined total

crack length per unit area up to 3.83 and 5 mm/mm^2 for undeformed and deformed samples respectively. In deformed specimens severe crushing of grains preferentially occurred at large and irregularly shaped pores. This observation is in good qualitative agreement with permanent crack damage estimated from seismic velocities, since hysteresis up to 15% after unloading is found. Crack orientation, defined as the average orientation over its entire length with respect to the long axis of the sample has been estimated. No preferred orientation of microcracks was observed in undeformed and deformed samples. However for cracks with opening width ≤ 1 μm we found a preferential alignment parallel to sample axis. This suggests that the observed strong anisotropy of velocities is largely due to opening of small cracks.