Geophysical Research Abstracts,
Vol. 11, EGU2009-7629-1, 2009
EGU General Assembly 2009

Time-dependent brittle deformation (creep) at Mt. Etna volcano

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Mt. Etna is the largest and most active volcano in Europe. Time-dependent weakening mechanisms, leading to slow fracturing, have been shown to act during pre-eruptive patterns of flank eruptions at Mt. Etna volcano.

Due to the high permeability of its volcanic rocks, the volcanic edifice hosts one of the biggest hydrogeologic reservoirs of Sicily (Ogniben, 1966). The presence of a fluid phase in cracks within rock has been shown to dramatically affect both mechanical and chemical interactions. Chemically, it promotes time-dependent brittle deformation through such mechanisms as stress corrosion cracking that allows rocks to deform at stresses far below their short-term failure strength. Such crack growth is highly non-linear and accelerates towards dynamic failure over extended periods of time, even under constant applied stress; a phenomenon known as 'brittle creep'.

Here we report results from a study of time-dependent brittle creep in water-saturated samples of Etna basalt (EB) under triaxial stress conditions (confining pressure of 50 MPa and pore fluid pressure of 20 MPa). Samples of EB were loaded at a constant strain rate of 10-5 s-1 to a pre-determined percentage of the short-term strength and left to deform under constant stress until failure. Crack damage evolution was monitored throughout each experiment by measuring the independent damage proxies of axial strain, pore volume change and output of acoustic emission (AE) energy, during brittle creep of creep strain rates ranging over four orders of magnitude. Our data not only demonstrates that basalt creeps in the brittle regime but also that the applied differential stress exerts a crucial influence on both time-to-failure and creep strain rate in EB. Furthermore, stress corrosion is considered to be responsible for the acceleratory cracking and seismicity prior to volcanic eruptions and is invoked as an important mechanism in forecasting models.

Stress-stepping creep experiments were then performed to allow the influence of the effective confining stress to be studied in detail. Experiments were performed under effective stress conditions of 10, 30 and 50 MPa (whilst maintaining a constant pore fluid pressure of 20 MPa). In addition to the purely mechanical influence of water, governed by the effective stress, which results in a shift of the creep strain rate curves to lower strain rates at higher effective stresses. Our results also demonstrate that the chemically-driven process of stress corrosion cracking appears to be inhibited at higher effective stress. This results in an increase in the gradient of the creep strain rate curves with increasing effective stress. We suggest that the most likely cause of this change is a decrease in water mobility due to a reduction in crack aperture and an increase in water viscosity at higher pressure. Finally, we show that a theoretical model based on mean-field damage mechanics creep laws is able to reproduce the experimental strain-time relations. Our results indicate that the local changes in the stress field and fluid circulation can have a profound impact in the time-to-failure properties of the basaltic volcanic pile.