Geophysical Research Abstracts
Vol. 21, EGU2019-5757-1, 2019
EGU General Assembly 2019

Microstructural controls on thermal crack damage during temperature-cycling experiments on volcanic rocks

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The evolution of crack damage in volcanic and geothermal systems is largely controlled by the mechanical and thermal stresses acting on them. It is therefore important to understand the response of volcanic rocks to thermo-mechanical loading. Here, we present results from a series of thermal stressing experiments in which acoustic emission (AE) was recorded contemporaneously with changing temperature during both heating and cooling of three igneous rocks of different origin, mineral composition and grain size; Slaufrudalur Granophyre (SGP), Nea Kameni Andesite (NKA) and Seljadalur Basalt (SB). We use the onset of AE as a proxy for the onset of thermal cracking and the AE rate as a proxy for the rate of cracking. Samples of each rock type were subjected to both a single heating and cooling cycle to a maximum temperature of 900C, and multiple heating/cooling cycles to peak temperatures of 350C, 500C, 700C and 900C (all heated at a constant rate of 1C/min, and cooled partially at a constant rate of 1C/min and partially at the natural rate of <1C/min). As further evidence of thermally-induced cracking, comparative measurements of porosity, permeability and P-wave velocity were made on each sample before and after thermal treatment. We find that the vast majority of thermal crack damage (as evidenced by AE output) is generated during heating in the coarser grained SGP but, by contrast, the vast majority is generated during cooling in the finer grained NKA and SB. In addition to the maximum temperature to which the rock has been exposed, the total amount of crack damage generated due to heating or cooling appears to be dependent on the mineral composition and, most importantly, the microstructure (grain size and grain arrangement). We further note that the number of AE hits generated in SGP during a single heating-cooling cycle is about an order of magnitude higher than for either NKA or SB.

We have have also explored the possibility of a Kaiser temperature-memory effect (analogous to the well-known Kaiser stress-memory effect) during cyclic heating and cooling experiments. We find a clear temperature-memory effect in SGP, but no evidence of this effect in either NKA or SB. We similarly suggest that this difference is due to microstructural and mineralogical control on thermal cracking, which we attribute to a combination of thermal expansion mismatch between different mineral phases and large grains acting as mechanical inclusions within a fine-grained matrix.

Knowledge of thermal stress history and the presence of a Kaiser temperature-memory effect is potentially important in understanding magma chamber dynamics, where the cyclic nature of mechanical and thermal inflation and deflation can lead to sequential accumulation of damage, potentially leading to critical rupture.