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Unravelling columnar joints temperatures: a thermo-mechanical experimental approach

Yan Lavallée (1), Anthony Lamur (1), Fiona E. Iddon (2), Jackie E. Kendrick (1), Adrian J. Hornby (1), Gudjon H. Eggertson (1), Felix W. Von Aulock (1), and Fabian B. Wadsworth (3)

(1) Department of Erath, Ocean and Ecological sciences, University of Liverpool, Liverpool, United Kingdom (anlamur@liv.ac.uk), (2) Department of Earth sciences, University of Cambridge, Cambridge, United Kingdom, (3) Department of Earth and Environmental sciences, Ludwig Maximilian University, Munich, Germany

Columnar joints are a widespread, spectacular volcanic phenomenon representing a complex cracking pattern induced by contraction of the lava upon cooling. The hexagonal geometry results from the complex interaction between heat dissipation, contraction and tensile fracturing of the material. While the formation mechanism is nowadays fairly well constrained, very little is known on the temperature at which these features form. Here, we present the results of a novel type of thermo-mechanical experiment, in which the ends of 16 mm rods of basalt were locked into position during cooling at different rates. We monitored the stress build-up and temperature within the samples in order to constrain the temperature of columnar jointing. Our experiments were applied to basaltic rocks sampled on a lava flow at the base of Eyjafjallajokül volcano in Iceland. Results demonstrate that thermal contraction upon cooling triggers microscopic fracturing (at ~820 ºC) that quickly evolves into localised macroscopic fracturing at 750-780 ºC. Striaes observed along fracture planes can hence be interpreted as the reflection of this two-stage fracture propagation dynamics. We emphasize that columnar jointing occurs well within the solid state of volcanic rocks, not in a molten regime. These results are supported by complementary analysis of the expansion coefficient of these lavas as well as strain-to-failure acquired during Brazilian tensile tests. The nonlinearity of the coefficient of expansion has important implications for the development of a permeable network. At higher temperatures, micro-fracturing is caused by a quasi-linear coefficient of expansion, leading to a small increase in permeability. As cooling occurs, the coefficient of expansion drops increasingly rapidly, leading to an increasingly faster developing permeable network, which is controlled in-part by the scale of the columns that influences crack aperture opening. Our findings hence have implications in volcanic, geothermal and hydrothermal environments.