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Columnar Jointing Thermo-Mechanics

Fiona Iddon (1), Adrian Hornby (2), Jackie Kendrick (2), Fabian Wadsworth (3), Felix von Aulock (2), and Yan Lavallée (2)

(1) University of Leeds, Leeds, United Kingdom (ee11fi@leeds.ac.uk), (2) University of Liverpool, Liverpool, United Kingdom (Yan.Lavallee@liverpool.ac.uk), (3) Ludwig Maximilian University of Munich, Munich, Germany (fabian.wadsworth@min.uni-muenchen.de)

Thermo-mechanical effects, common to a wide range of geological phenomena, are integral to the formation of columnar joints during cooling and crystallisation of lava flows. The process, and resultant geometry, relies on a complex inter-play between heat distribution, contraction and tensile strength, yet the kinetics of their formation remains elusive. Results are presented from a combination of field survey, thermo-analytical characterisation and mechanical investigation to constrain conditions favourable for columnar jointing.

Columnar joints from Seljavallir, Iceland, produce quadratic to heptagonal cross sectional patterns with column widths ranging from 20 to 70 cm in size. The fracture surfaces are characterised by striae of which spacing (between 1 to 6 cm) appear to share a positive linear relationship to the joint spacing. The striae exhibit both a smooth and rough portion, interpreted to express a change in deformation regime from fully brittle, mode-I fracture propagation to an increasingly ductile response of the lava with tensile fracture dissipation as the fracture event wanes.

The contraction of the basalts has been investigated via the expansion coefficient determined in a dilatometer (at 3mN of normal stress and a rate of 2 °C/min). The expansion coefficient has been constrained to 10-5/°C and the onset of melting (and completion of natural crystallisation) at 1150°C. Experiments are currently being conducted to assess the effect of cooling rate and normal stress on the properties of the Seljavallir basalts.

The mechanical properties of the rock in tension have been tested at room temperature in a uniaxial press (high-temperature tests are also scheduled). During true-tension pull test at a strain rate of 10-4 s-1, elastic deformation agrees to a Young's modulus of 6.3 GPa. Tensile failure initiated after 0.35% strain with the generation of a large crack at a peak stress of 2.2 MPa. The fracture induced a stress drop and upon stress build-up to 0.6 MPa a series of small fractures ensued. We interpret this two-stage fracture dynamics as the cause for the change in fracture surface observed in nature.

A combined thermo-mechanical model is presented to constrain the onset temperature and dynamics of columnar jointing.