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Brittle ductile transition in experimentally deformed basalt under oceanic crust conditions

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The mid-ocean ridge system is the largest continuous volcanic feature on Earth, with significant interactions between tectonic activity, volcanism and sea-water circulation. Iceland is the biggest landmass straddling a mid-ocean ridge. The associated tectonic and volcanic settings resulting from the active rifting provide in this geodynamic context a major heat source for the geothermal exploitation.

High-pressure, high-temperature, conventional triaxial compression experiments have been conducted in a Paterson Press to explore the brittle–ductile transition of oceanic crustal rocks under in situ conditions at depth (3-10 Km). The study provides some insights into the prospect of producing geothermal fluids from deep wells drilled into a reservoir at temperatures and pressures of supercritical water (T>400°C).

We present a series of 20 axial compression deformation experiments performed on jacketed basalt cores of 10 mm diameter and 20 mm long. The experiments were performed at 100 and 300 MPa, with temperatures ranging from 400°C to 900°C, and pore pressures ranging from 0 to 100 MPa, a constant strain rate of 1×10^{-5} s^{-1} and up to strains of 15%. Two different types of basalts were selected for their simple compositions, low alteration degree and very low porosity (3%). The two samples differed in their percentage of glass, being zero in one case and 15% in the other.

For the vitreous sample at a confining pressure of 100 and 300 MPa, our experiments show that deformation takes place by three deformation modes; (1) brittle fracture at 400°C with a maximal strength of 900 MPa, corresponding to failure by localized rupture, (2) strain-hardening at small strains and followed by slipping on a localized fracture plane at a constant strength around 250 MPa at higher strains, for temperatures ranging from 500°C to 700°C, (3) distributed ductile flow at differential stresses from 50 to 100 MPa and temperature from 800 to 900°C.

For the non glassy sample, the experiments show (1) at a pressure of 100 MPa between 600°C to 900°C and at pressure of 300 MPa between 600°C and 700°C, the sample fails by localized rupture with a peak strength that depends on temperature and (2) at a pressure of 300 MPa between 800°C and 900°C homogeneous, distributed flow with strengths of 600 MPa and 300 MPa, respectively.

Mechanical observations at a constant strain rate of 1×10^{-5} s^{-1} and a confining pressure of 100 MPa and 300 MPa indicate that the rocks are brittle and dilatant up to 700 to 800°C. This indicates that, in the context of the Icelandic geotherm, hydrothermal fluids may circulate, at least briefly, through the oceanic basaltic crust down to 6 to 8 km depth. These results are coherent with the lower limit of the Icelandic seismogenic zone which seems to be associated with a 750 ± 100 °C isothermal surface.