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Exploration of Magma Porosity Wave Dependence on Initial Melt Fraction and Viscosity

Peter Webb and G. Houseman
Institute of Geophysics and Tectonics, School of Earth and Environment, Leeds, LS2 9JT, UK

Partial melting beneath rifts is initiated at around 120km depth over a cross-sectional area of hundreds of kilometers centered on the rift axis. Somehow, vertical melt migration is focused towards the surface into narrow zones of volcanism and plutonism. The mechanism by which the melt is focused and transported to the surface is likely to be by upward motion of enhanced porosity regions that propagate in the form of solitary waves as melt slowly percolates along grain boundaries.

An understanding of two-phase fluid-solid dynamics is vital in modeling the magma transport system. At small melt fractions partial melt most likely travels along the grain boundaries as a few percent of the volume driven by buoyancy forces acting upon the density difference between the crystal matrix and melt. Exploration of this system has been dependent upon analytical or numerical models, constrained by data from lab experiments on hot-pressed materials. We have generated a one dimensional model of two phase flow following McKenzie (J. Petrol., 25, 13-765, 1984). We use this model to explore how a melt concentration develops and migrates upwards with time.

The natural 1D solutions to this system have a Gaussian dependence on depth with a preferred scale and propagation velocity. An arbitrary initial distribution results in one or a train of solitary waves that rise under buoyancy, superimposed on a constant porosity background. This exploration of solitary porosity waves seeks to constrain the factors that determine the amplitude, wavelength and velocity of the waves. We find that the width of the wave is proportional to the square root of the ratio of matrix to fluid viscosity, while its amplitude varies inversely with this ratio. The velocity of the solitary wave however varies linearly with the logarithm of the matrix viscosity and inversely with the fluid viscosity. We find that the initial perturbation amplitude, width or volume affect the resulting primary solitary wave. We also show that the width of the primary solitary wave has a complex dependance on the width of the initial melt fraction distribution, as well as the volume.

An upward increase in matrix viscosity with depth has an impact on the transport mechanism; as the porosity wave moves upward into higher viscosity matrix, the preferred wavelength of the solitary waves increases. The volume is conserved by a reduction in the amplitude of the wave and this in turn will change the time-scale over which the melt escapes the system. The dependence upon the width of the initial perturbation also means that solitary waves formed from thin bands of melting move more slowly than those from thicker bands. If melting varies laterally, thicker in the center than in the peripheral region, longer and faster solitary waves will be formed above the central region.