Geophysical Research Abstracts
Vol. 12, EGU2010-12262, 2010
EGU General Assembly 2010

Effects of the curvature of a lava channel on velocity and stress fields

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Bends in lava flows due to local variations in topography are commonly observed in volcanic fields. The curvature of a channel affects the flow surface morphology, as described in literature by Greeley (1971) and Peterson (1994). Where channels make an especially sharp bend, crust plates break and are incorporated within the flow by remelting. In some places, they jam together welding to the sides of the channel and forming a stable roof.

We propose a model to explain the effects of the curvature of a channel on velocity, shear stress and formation of solid crust at the surface. Lava is described as a Newtonian, homogeneous, isotropic and incompressible fluid. The steady-state solution of the Navier-Stokes equation is found for a unidirectional flow, in cylindrical polar coordinates, neglecting the gradient of pressure and assuming a dependence of velocity on the radial coordinate only. The flow levees are described as arcs of concentric circumferences, with their centres in the origin of the reference frame. The equation is solved using non-slip boundary conditions at the levees. From the constitutive equation of a Newtonian incompressible fluid we obtain the nonvanishing component of the shear stress. As a consequence of the curvature of the channel, velocity and shear stress show an asymmetric behaviour in respect to the centre of the channel. The gradient of velocity and the shear stress reach larger values close to the levee with the higher curvature.

Heat radiation and convection into the atmosphere are considered as the main cooling processes. Solid platforms form at the flow surface during cooling. Crust plates are laterally confined by the shear regions with high stress values.

The model analyses the effects of the curvature of a channel on the development and shape of surface solid plates. The dimension and shape of plates are controlled by the competition between the shear stress and crust yield strength, and the degree of crust coverage of the channel width is studied as a result of the curvature.

Lava tube formation is often observed in bending flows. We propose an explanation of this mechanism of tube formation. When running across a channel bend, the downstream floating solid plates undergo fragmentation in the region close to the levee with the higher curvature. Solid fragments rotate under the effect of the torque due to the differential of the drag force exerted by the underlying fluid and drift toward one of the levee under the action of dragging. Solid fragments weld to the levee and jam together forming a stable roof.

The model reproduces field observations and experimental results (Cashman et al, 2006), thus supplying an explanation of the main thermal and dynamic features in bending lava flows.