An analogue experiment of magma mixing: a case study of volcanic conduit with a magma pocket

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Magma mixing is a crucial process in igneous petrogenesis, and mixing both in magma chambers and within conduits have been investigated (e.g., Oldenberg et al., 1989; Koyaguchi, 1985, 1987; Blake and Campbell, 1986; Koyaguchi and Blake, 1989). In this study, we carried out an analogue experiment to examine magma mixing process in a conduit with a magma pocket. The aim of the experiment is to elucidate the conditions of flow instability in the pocket at low Reynolds numbers.

We used aqueous sodium-silicate solutions with density (d) ranging from 1400-1620 kg/m^3 and viscosity (v) ranging from 0.48-107 Pa sec. The apparatus was made of acrylic plate (5 mm thick) and pipe, consisting of an upper vessel (a cubic chamber, 4.5 cm on a side) connected downward to a pipe (7 mm inner diameter, 140 mm long) and a pocket (25 mm inner diameter and 35 mm high) and subsequently a pipe (7 mm inner diameter, 110 mm long). At first, we placed less dense, low-viscosity fluid 1 (red colored, d1=1400-1610 kg/m^3, v1=0.48-33.7 Pa s) over dense, high-viscosity fluid 2 (d2 =1470-1620 kg/m^3, v2 = 6.58-107.30 Pa s) in the upper vessel. The lower pipes and the pocket were initially filled with fluid 2. The two fluids fell down by gravity. The velocity of the fluid 1 ranges from 0.08-1.70 cm/s and Reynolds number is in the order of 10^-1-10^-4 in the pipe. When the fluid 1 enters into the magma pocket, the speed of fluid 1 decreases and shows shapes of a flat disc or a reversed umbrella. The head of the reversed umbrella may apparently float and entrain the fluid 2 in the magma pocket. The fluid 1 is continually injected into the magma pocket and the disc or umbrella may expand to spindle-shaped body. At this time mixing may occur between entrained fluid 2 and host fluid 1. It was considered that the two fluids collapse and the mixing occur when viscosity can not hold the density difference of the two fluids for larger diameter of the magma pocket. Koyaguchi and Blake (1989) proposed a dimensionless parameter I (=v2*U1/(g*(d2-d1)*R^2)), which is the ratio of viscous force to gravity force. In this experiment, the range of the I parameter was from 2.0 to infinity (d1=d2). In this range, distinct gravitational collapse was not observed. In the present experiment, another interesting feature of the behavior of the two fluids is that the diameter of the fluid 1 may vary and show the appearance of a string of beads traveling down the pipe. This may be due to the variation of viscosity/density of the prepared aqueous sodium-silicate solutions. It was observed that fluid 1 shows streak in the fluid 2, and subsequent mixing of two fluids proceeds. In the natural mixing of magmas, the temperatures of mafic and silicic magmas are generally different. If two magmas flow into a conduit, inner high-temperature mafic magma is locally cooled near the boundary and increase in viscosity, whereas the outer silicic magma would locally be heated near the boundary and become less viscous. Such transient conditions may bring about heterogeneity of the two fluids, which would cause flow instability of the annular flow resulting in the mixing of the two magmas.