Plagioclase-chain networks in slowly cooled basaltic magma

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ABSTRACT

Plagioclase crystals in the slowly cooled interior of the thick Holyoke flood-basalt flow of Connecticut linked to form monomineralic chains at an early crystallization stage. Partial melting experiments reveal that when the quartz tholeiite was only 25% crystallized the chains had already linked to form a continuous 3-D network. At such an early stage of crystallization, the network was weak, highly permeable, and easily deformed. Consequently, the mush of plagioclase-chains and interstitial pyroxene crystals underwent compaction in the lower third of the flow with the expelled liquid rising to the center of the flow where it crystallized to form coarse-grained sheets of fractionated basalt.

Plagioclase chains are most easily seen in the basalt after it has been partly melted and the late crystallizing minerals converted to glass. The chains are several crystals wide. The crystals, which are ~0.5 mm long, are attached together randomly. Normal zoning patterns indicate crystals had a brief period of growth before linking together. The chains branch every few millimeters to form the 3-D network, which was mapped using serial polished sections and X-ray CT scans. The chain frequency measured along vertical and horizontal traverses decreases toward the center of the flow. In the compaction zone, the frequency in the vertical direction is greater than in the horizontal. Making the reasonable assumption that these frequencies were initially the same, the difference is used to calculate the degree of compaction. The resulting pattern through the flow matches almost exactly the pattern indicated by variations in the incompatible elements. Plagioclase chains are also found in some coarser-grained plutonic rocks. If they are common, their fabric may provide a new, direct means of measuring the degree of compaction in crystal mushes.

INTRODUCTION

Many thick flood-basalt flows contain horizontal sheets of rock whose composition indicates that the sheets form from residual liquid that segregates from the host basalt following as little as 30% crystallization of the basalt (Cornwall 1951; Lindsley et al. 1971; Dostal and Greenough 1992; Puffer and Horter 1993; Philpotts et al. 1996). Hawaiian lava lakes contain similar sheets, but their compositions indicate slightly higher degrees of crystallization (Richer and Moore 1966; Moore and Evans 1967; Wright and Okamura 1977; Helz 1980). Although the sheets are generally concordant and horizontal, they can branch or have small transgressive dikes that connect them to overlying and underlying sheets. The host basalt exhibits clear evidence of having been fractured during the emplacement of the segregation sheets. This raises the interesting question of how basalt that is only 30% crystallized can fracture.

Partial-melting experiments on samples from the thick Holyoke flood basalt of Connecticut (Philpotts and Carroll 1996) indicated that this basalt, on cooling slowly, develops a crystal mush when it is no more than 25% crystallized. The experiments further revealed that the mush is held together by a remarkable network of chains of plagioclase crystals (Philpotts et al. 1998). These chains change the physical properties of the magma, making it behave like a semi-brittle material that fails by rupturing during the emplacement of the segregation sheets, despite the large fraction of melt present. Of greater importance, however, is the fact that because the plagioclase chains form at such an early stage of crystallization, the resulting network is sufficiently weak and permeable that it can undergo compaction when the bulk density of the crystals exceeds only slightly the density of the residual liquid. In the Holyoke basalt this led to significant compaction of the crystal mush in the lower third of the flow, with the expelled liquid rising to form the segregation sheets in the central part of the flow (Philpotts and Carroll 1996).

In this paper we describe the nature of the network of plagioclase chains in the Holyoke basalt, and show how the deformation of this network can be analyzed to obtain a direct measure of the degree of compaction within a pile of crystal mush.

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