ORIGIN OF TEXTURAL DIVERSITY IN APOLLO 11 HIGH-K BASALTS; T.L. Grove, Dept. of Earth and Planetary Sciences, Mass. Inst. of Tech., Cambridge, MA 02139 and D.W. Beaty, Div. of Geological Sciences, Calif. Inst. of Tech., Pasadena, CA 91125

Introduction

The origin of textural variability in the Apollo 11 high-K basalts has been the subject of discussion by several petrologists (1,2,3,4,5). The high-K samples vary from vitrophyric, porphyritic, intersertal, subophitic to poikilitic, and as an additional complexity display extreme textural heterogeneity within single thin sections (e.g. 10071,31 (6)). We have performed a combined study of quantitative petrography and experimental dynamic crystallization with the purpose of understanding the conditions that produce the textural diversity amongst members of the high-K suite.

Experimental

Equilibrium and cooling rate experiments were performed using synthetic glass starting material with the composition of 10085,832 (3) and both Fe capsule held in evacuated silica tubes and Fe-Pt alloy loop techniques. The loop experiments were performed in a $CO_2/CO$ gas atmosphere and $fO_2$ was maintained at 1/2 log unit below the iron-wüstite buffer and monitored by a $ZrO_2$-CaO electrolyte cell. The results of Fe capsule equilibrium and cooling rate experiments initiated at 3°C above the equilibrium liquidus (Fig. 1) are similar to those obtained by Gamble and Taylor (7) using Pt loops and a synthetic 10017 composition. The effect of cooling rate on phase appearance temperatures in 085,832 is similar to that found in crystallization experiments on other lunar basalts. The appearance temperatures of all phases are supercooled with increased cooling rate. This suppression of appearance temperature is slight for olivine, ilmenite and pyroxene, but significant for plagioclase and silica, which fail to nucleate at rates >50°C/hr. Armalcolite also fails to nucleate in the 150° and 600°C/hr experiments.

In agreement with (8), we find that the textures produced in Fe capsule and Pt loop experiments are generally comparable. Cooling experiments shown in Fig. 1 result in porphyritic textures. At rates <10°C/hr equant pyroxene and skeletal ilmenite form phenocrysts and fasciculate plagioclase, pyroxene, etc. constitute the groundmass. At rates >10°C/hr microphenocrysts of skeletal and dendritic olivine, ilmenite and pyroxene are produced. Cooling experiments initiated above pyroxene appearance ($T_{init}$ = 1148°C) crystallize with intersertal to subophitic textures.

Textural variability amongst the high-K samples

Several authors have emphasized the importance of the initial magma temperature and presence and distribution of crystal nucleii on the resultant textures produced during a basalt's cooling history (8,9,10,11). In fact, the textural diversity observed in the high-K basalts may result from variations in the presence of initial nucleii, initial temperature before final cooling and cooling rate at the site of solidification. We have quantified several textural characteristics in the lunar samples and in the experiments that reflect initial temperature, nucleii

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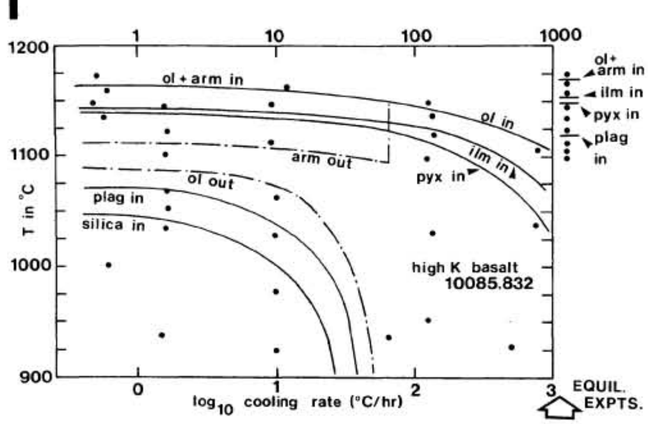

distribution, and cooling rate. The initial magma temperature and distribution of nucleii is recorded by ilmenite size (measured ⊥ to (0001), morphology, and nucleation density; pyroxene size, composition, and morphology; and the presence or absence of preserved armalcolite. Cooling rate is estimated from plagioclase size measured ⊥ to (010).

The crystal size data indicate that two diverging textural trends are present in the lunar samples: subophitic and granular. One trend is characterized by large numbers of small subhedral pyroxene and equant ilmenite nucleii and a variation in plagioclase size. When plagioclase is small, the texture is intersertal, but as plagioclase coarsens it poikilitically encloses pyroxene and ilmenite which do not appreciably change in size. Armalcolite is never preserved in these samples. This group is distinguished on the plot of ilmenite vs. plagioclase width (Fig. 2) as granular-poikilitic. The second trend is characterized by fewer euhedral pyroxenes, platy ilmenite nucleii, and more numerous plagioclase crystals. Of the 23 described high-K samples there are 6 that contain armalcolite and all lie in this second textural trend varying from vitrophyric to intersertal to subophitic. This trend is distinguished as subophitic on Fig. 2.

As Usselman and Lofgren (4,5) found, it is necessary to initiate high-Ti basalt cooling experiments at subliquidus temperatures to observe textures typical of those found in high-K intersertal basalts. Since Beaty and Albee's (2) survey of Apollo 11 clasts located candidates that may have cooled from near liquidus temperatures, the natural samples are compared in Figs. 2 and 3 to textural variations in experiments cooled from 3°C above liquidus and experiments in which cooling was initiated at subliquidus temperatures (1148°C, below the stability field of armalcolite). The lower temperature was chosen because the granular samples contain no evidence that armalcolite was present during cooling. The porphyritic samples 10085,12-7 and 10085,832 have textures that approximate those of the superliquidus experiments. The armalcolite-bearing vitrophyres 060,δ and 031,7 contain wider ilmenite laths (Fig. 3) than the superliquidus experiments, suggesting that their cooling histories initiated at temperatures below the liquidus within the stability range of armalcolite. Members of the subophitic trend contain blockier ilmenites than the superliquidus experiments, and a plagioclase vs. ilmenite size variation similar to that of the superliquidus runs. These data suggest that the magma from which the subophitic samples solidified cooled from subliquidus temperatures and contained olivine, armalcolite and possibly ilmenite nucleii.

Textural variation in the

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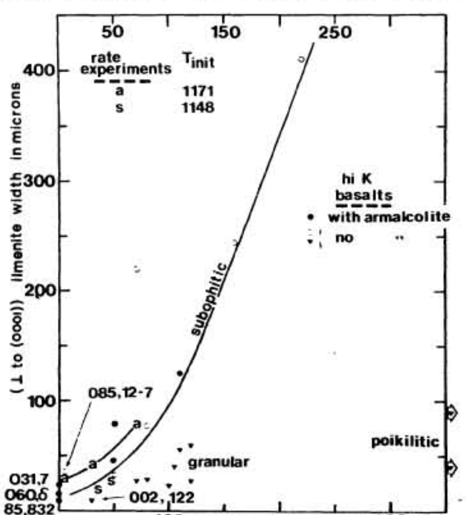


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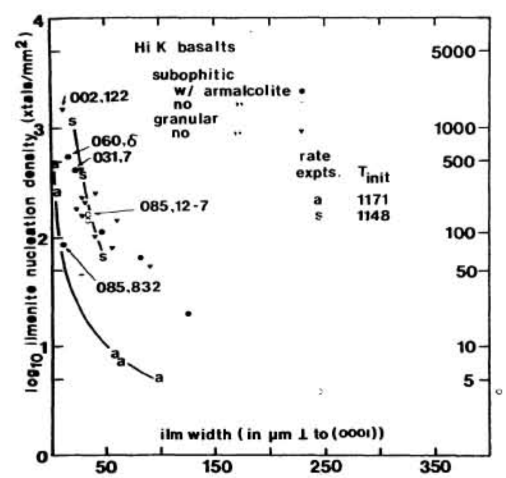

granular trend is most closely matched by the subliquidus experiments but a variation of initial temperatures to values lower than 1148°C is probably responsible for the resulting textures displayed by some members of this group. For example, the most magnesian pigeonites found in the antiophitic samples 10049, 10069 and 10017 indicate initial temperatures of 1125° to 1140°C, and suggest that these samples cooled from a mostly crystalline initial state and contained ilmenite, pyroxene, ± plagioclase nucleii. James and Jackson (1) proposed that the poikilitic samples were pieces of chilled crust that subsequently foundered and annealed in a flow. Our thermal histories are consistent with this hypothesis, but an equally probable alternative is complete crystallization from a supercooled magma containing pyroxene and ilmenite.

Textural heterogeneity is present in samples 024, 049, 069 and 071 and consists of coarse and fine-grained regions in intimate contact (6,2). The morphologies are equant in the coarse-grained portion while the fine-grained region contains elongate, accicular plagioclase, pyroxene and skeletal ilmenite. The textural diversity is similar to that observed by (10) and (11) in plagioclase-rich compositions, which they relate to the inhomogeneous distribution of crystal nucleii within the melt. When cooled, the initial distribution of nucleii controls the texture. The coarse-grained portion of the sample represents a region into which early formed nucleii segregated, leaving residual liquid depleted in nucleii. When crystals formed in the residue, they were far below their appearance temperature and a texture characteristic of extreme supercooling resulted. Thus, at similar cooling rates two very different textures evolved. This inhomogeneity has been reproduced experimentally by us, and suggests that the contact in 071,31 need not be a cross-cutting igneous contact as proposed by (2).

Cooling histories of Apollo 11 high-K basalts

Textures suggest a spectrum of complex crystallization histories for Apollo 11 high-K basalts. The subophitic samples cooled at their site of final emplacement from initial temperatures near but below the liquidus and the granular samples cooled from initial temperatures significantly below the liquidus at or near the nucleation temperature of plagioclase. For the subophitic basalts, the experimentally determined dependence of plagioclase size on cooling rate allows us to estimate (12) that a 10 m thick flow would be required to produce the coarsest sample. The field relations at the landing site suggest that the high-K basalts comprise the upper 9 meters of nearby West Crater (13). Thus, we may have a sample of an entire flow. The textural evidence can be interpreted in terms of one lava flow, but is also consistent with multiple igneous intrusions or extrusions. For example, one igneous event may be represented by the subophitic samples and another by the granular. There is some evidence that the high-K magma contained an inhomogeneous distribution of nucleii, as a positive correlation between $TiO_2$ content and ilmenite nucleation density exists in the vitrophyres. In the coarser samples there is no correlation of bulk chemistry and texture that would support differentiation by crystal settling during final cooling and solidification of the flow.

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