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CRYSTAL FRACTIONATION IN THE SNC METEORITES: IMPLICATIONS FOR SAMPLE SELECTION

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Almost all rock types in the SNC meteorites are cumulates, products of magmatic differentiation by crystal fractionation (addition or removal of crystals). If the SNC meteorites are representative of rocks at or near Mars' surface, then the Mars Sample Return must include strategies for collecting from differentiated igneous bodies.

The SNC meteorites include ten lithologies (three in EETA79001), eight of which are crystal cumulates [1]. The other lithologies, EETA79001 A and B, are sub-ophitic basalts. The cumulate lithologies ALHA77005 and EETA79001C have not been fully described and are not discussed here.

Shergotty and Zagami

The Shergotty and Zagami meteorites, diabases or fine-grained gabbros, are enriched in clinopyroxene relative to their parental magmas [2]. It has been suggested that the pyroxene enrichments arose through crystal settling [3], but this is unlikely. The parent magmas were basaltic, and thus had significant yield strengths. If the parent magmas had yield strengths like those of terrestrial basalts [4], the stress generated by a pyroxene crystal would have been below the yield strength of the magma (e.g. [5]). The pyroxene would not move.

Another fractionation mechanism, crecumulation, is more likely for Shergotty and Zagami. Crescumulates form at moderate undercoolings when new crystals nucleate at the walls of a magma body and grow inwards as elongate blades. The blades continue to grow as the melt among them is replenished by exchange with the bulk magma. As the blades grow wider, melt among them is "squeezed out". Typical features of crescumulates are: mild to moderate enrichment in the blade minerals; grains with quench morphologies; grains longer (greater aspect ratios) than usual for the mineral species; and moderate lineations of the elongate minerals without strong foliation [6-8]. Examples of crescumulates include spinifex zones in komatiites [6], harrissite in ultrabasic intrusions [7], and "Willow Lake textured" rock in gabbros and basalts [8].

Shergotty and Zagami have most of the petrographic features of crescumulates. They are mildly enriched in pyroxenes relative to their parental magmas [2]; Shergotty is 28% and Zagami is 45% cumulus pyroxenes. Some whitlockite grains in Shergotty are very elongate and rich in inclusions [9], a typical quench morphology. Pyroxenes in Shergotty and Zagami are more elongate than typical basalt pyroxenes, which have aspect ratios < 3 ; in Shergotty, aspect ratios range up to 7 or possibly 20 ([10], Fig. 1). The pyroxenes also show a preferred elongation direction [2, 10], which could be either a lineation, a foliation, or both.

Nakhlites and Chassigny

The nakhlites and Chassigny are ultramafic igneous rocks, rich in augite and olivine respectively. They are cumulates, strongly enriched in crystals relative to their parental ultrabasic magmas [11-12]. The nakhlites and Chassigny are inferred to have formed through settling of crystals [11-13]; this inference is surest for the nakhlites because their cumulus augites form a grain-supported framework, and because the augites have preferred orientations typical of sediments [13]. Non-Newtonian

behavior of the magma is unimportant because ultrabasic magmas have low yield strengths (e.g. [14]).

Conclusions

Almost all of the SNC meteorite lithologies are products of crystal fractionation, and the likelihood of fractionation must be considered in choosing sample sites and individual samples. Based on the shergottites, a single sample taken from a basaltic igneous body may have experienced only moderate crystal fractionation and may be fairly representative of the whole body. Additional samples from the same body would be useful, but probably not essential. Based on the nakhlites and Chassigny, a single sample taken from an ultrabasic igneous body will have experienced extreme crystal fractionation and probably would not be representative of the whole body. Analogous bodies on Earth differentiated to yield peridotite, pyroxenite, and gabbros [15]. Multiple samples from ultrabasic igneous bodies would be essential in recovering the original magma compositions.

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