NUMERICAL SIMULATION OF CRYSTAL FRACTIONATION IN SHERGOTTITES

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Cumulus pigeonite and augite with preferred orientations in the shergottites suggest segregation of these pyroxenes from their parent magma. By numerically modeling this segregation for a variety of initial conditions, we infer some possibilities for the mechanics of accumulation in Shergotty and Zagami, the two best studied meteorites of this class (1,2).

The basic model of (3) has been used to simulate crystal settling in a non-convecting environment. Model input parameters, references, and derivations are given in Table I. The settling velocity depends on the size, shape, and concentration of phenocrysts, the melt/solid density contrast, the viscosity of the magma, and the strength of the gravitational field. For illustrative purposes, arbitrary initial phenocryst concentrations C_o of 2% and 20% are adopted (Figs. a-b). The surface or near-surface acceleration of gravity g and the crystal settling zone width L are varied as free parameters. Other parameters described above are specified by the physical and chemical properties of the shergottites and by the cooling geometry. Physically, L is some characteristic width of the magma where phenocryst settling occurs, e.g. the entire width of a body cooled mostly from below, or the width of a convectively stable layer at the bottom of a magma body cooled from both sides. Either greater L or g will increase concentrations of the cumulus phase. Also, limiting calculations consistent with the petrologic models of (1) and (2) are compared. The former postulates accumulation of unzoned phenocrysts with iron-rich overgrowths forming later from intercumulus liquid. The latter describes accumulation of greater amounts of larger, already zoned phenocrysts, which accumulate in a liquid of different composition and temperature from that of (1).

Note that in both Figs. a-b the fields between Shergotty and Zagami do not overlap, implying that the two meteorites had different crystal settling histories. However, a new shergottite, EETA79001, contains lithologies texturally similar to Shergotty and Zagami in direct contact (4). Because of this, and the consistency of chemical and isotopic data between Shergotty and Zagami (1,5), we assume that both are derived from the same parent body (hence the same g), and probably from the same intrusion. Under these constraints, there must be a combination of petrologic models, L, and C_o that permit overlap of the crystal settling calculations for the two meteorites. One simple model assumes a greater L for Zagami, and therefore a greater settling distance. However, this contradicts observed textural data: Zagami has a smaller average grain size than Shergotty, suggesting more rapid cooling and hence shorter settling distances. Another model would require a different C_o for the two meteorites. Reasonable agreement can be obtained if Zagami begins settling at about 3-10 times the phenocryst concentration of Shergotty, perhaps due to increased crystallization at depth prior to injection. A third alternative assumes model (2) was operative for Shergotty and model (1) for Zagami, i.e., accumulation of zoned phenocrysts in the former and unzoned phenocrysts in the latter. This model may be possible because of the close agreement between these two calculations (Figs. a-b). If the mean between Sh(2) and Za(1) is adopted as a guide, it seems virtually impossible to produce the observed crystal concentrations from C_O of only a few percent (Fig. a). In addition, the relatively small grain size in both meteorites suggests fairly rapid cooling, so we adopt L=1 km as a plausible upper limit. Hence even for larger initial concentrations (Fig. b), a planetary-sized parent body may be required for these models. This conclusion is in agreement with suggestions based on other arguments that the shergottite parent body may be Mars (5-8).

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On the other hand, if the magma chamber is fully convective, the model of (9) can be used to compare the average crystal settling flux downward with the upward convective flux to determine the average relative phenocryst distribution. The extremely small diameters of the phenocrysts (< 0.05 cm) and the small crystal/melt density contrast (about 0.1) facilitate entrainment of phenocrysts in convective flow, and a uniform distribution of phenocrysts is predicted. However, since crystal fractionation appears to have occurred, convective models must appeal to more complicated processes such as flow differentiation or double-diffusive convection.

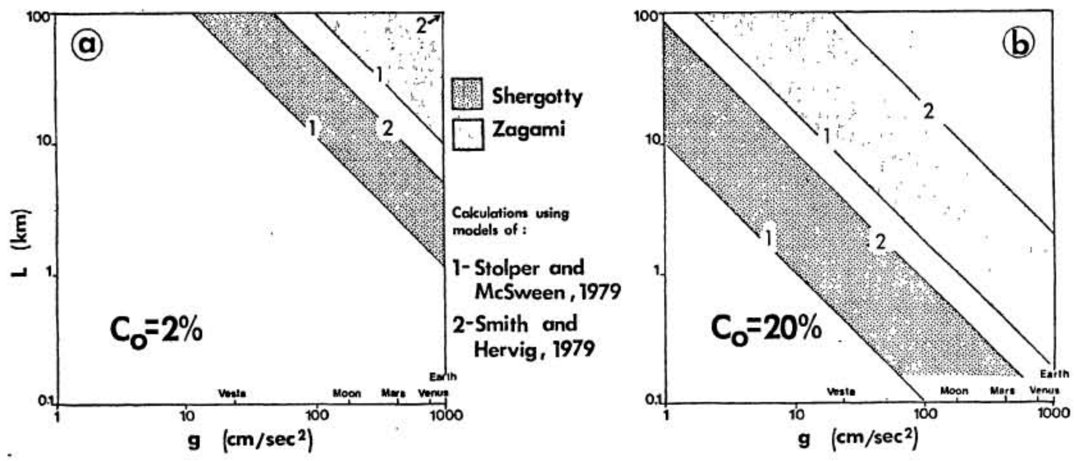

TABLE I. INPUT PARAMETERS IN CRYSTAL SETTLING MODEL

parameter	value	reference	derivation
gravity	10-1000 cm/s^2	-	magma is emplaced near surface and is small relative to planet size
crystal settling zone width	0.1-100 km	-	model dependent
initial phenocryst concentration	2%-20%	-	arbitrary
final phenocryst concentration	model (1): 28% Sh, 45% Za; model (2): 48% Sh, 63% Za	(1)	experimental determination
crystal radius	model (1): 0.19mm Sh, 0.11mm Za; model (2): 0.23mm Sh, 0.12mm Za	adapted from (1)	average of intergrain contacts of cumulus crystals and intercumulus liquid. Discrepancies between models are scaled as crystals of different radii
crystal shape factor	1.0	(10)	modeled spheres
crystal density	3.35 g/cm^3	(11)	approx. average for augite and pigeonite
liquidus temp	1200°C Sh, 1225°C Za	(1)	experimental determination
solidus temp	1050°C Sh, 1070°C Za	(1)	experimental determination
accumulation temp	model (1): 1140°C; model (2): 1105°C	(1)	experimental determination
heat flow parameter	0.48	(12)	depends on fixed melting ranges and choice of latent heat
thermal diffusivity	0.01 cm^2/s	adapted from (3)	inital thermal parameters of crystals, magma and country rocks similar
heat capacity	0.3 cal/g-deg	"	"
latent heat	80 cal/g	"	"
melt viscosity	500 P (average)	(13)	computation limited by composition of intercumulus liquid. of (1)
melt density	3.25 g/cm^3 (average)	(14)	"

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