

MELT CONNECTIVITY, DECOMPACTION AND POLYBARIC MELTING,

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It is generally assumed that porous flow of buoyant silicate melt through partially molten mantle is the initial transport mechanism leading to magma segregation. Such processes are inapplicable, however, if the partially molten mantle is impermeable. The permeability of the rock system is controlled, in part, by the connectivity of the melt within the crystalline matrix. The connectivity is a function of the porosity, here equated to the volume fraction of melt, and the ratio of the crystal-crystal interfacial energies to the crystal-liquid interfacial energies. Subject to the constraints of textural equilibrium, a condition surely obtained in planetary asthenospheres, the melt tends to distribute itself locally to minimize the surface energy of the system in a given volume. The driving force towards textural equilibrium is the pressure difference between the melt and the various crystalline solids caused by surface tension and the variations in mean curvature of the individual crystal grains (1,2). If the liquid phase becomes interconnected, then the buoyancy should enable the liquid to percolate upwards through the intergranular channels of the crystalline matrix.

Consider now the adiabatic rise and melting of a buoyant diapir of primitive, undifferentiated lunar mantle, perhaps from the zone below the cumulate pile of the magma ocean. A lherzolite mineralogy is assumed. Three types of relationships between progressive melting of the lherzolite diapir and the evolution of the connectivity can be envisioned.

1. The melt becomes connected at the onset of melting. This is favored if the interfacial energy of the crystal-crystal interface is greater than $\sqrt{3}$ times the crystal-liquid interfacial energy. In the ideal case where the solid-solid interfacial energy is independent of grain orientation, and the rock is monomineralic, this condition is met if the dihedral angle, θ , is less than 60° . (The dihedral angle is the angle subtended by the melt in contact with two adjacent crystalline grains). Waff and Bulau (2,3) found that the dihedral angles were in the range of 20° - 37° for olivine in chemical and textural equilibrium with melts ranging from tholeiite to nepheline basalt in composition. An olivine-rich diapir, therefore, would become interconnected at very small degrees of melting, perhaps with less than 1% liquid, and would become open to melt transport and segregation provided that gravity can overcome surface tension. For low dihedral angles (eg. $\theta < 50^\circ$; melt fractions < 0.05), the removal of melt from the partially molten rock increases the energy of the system because high energy solid-solid boundaries replace the lower energy liquid-solid boundaries. Van Barga and Waff (4), however showed that surface tension effects would not inhibit the segregation of partial melts provided that the melting zone is more than a few meters high (the critical height on the moon is six times greater).

2. The melt is initially confined to specific grain boundaries but is excluded from others. The melt zones are unconnected. Continued melting selectively consumes the dry grain boundaries until the percolation threshold is exceeded and the melt forms an interconnected network. Toramaru and Fuji (5), for example, found that basaltic melt wetted grain boundaries bounded only by olivine, whereas grain edges bounded on one or more sides by orthopyroxene and/or calcic clinopyroxene were dry. Nakano and Fuji (6) estimated that peridotite was permeable whenever olivine was more than 63% of the crystalline matrix. Since melting consumes mainly calcic clinopyroxene, it acts to destroy pyroxene bounded edges, thereby increasing the mode of olivine in the residue, and enhancing permeability.

3) Melts remain unconnected until a critical threshold of melting is exceeded. Below this critical threshold, melt accumulates only in isolated pools until such pools become interconnected. The grain boundaries are dry. The interconnection threshold depends on the value of the dihedral angle and the relative crystal-crystal and crystal-liquid surface energies. In a monomineralic rock of isotropic grains, the critical extent of melting varies from a few volume percent at a dihedral angle of $\theta=60^\circ$ to about 30% at $\theta=180^\circ$ (7). In an olivine-bearing-rock where some grain boundaries are wetted, the critical volume of melt needed to achieve interconnection would be a fraction of that estimated above.

The adiabatic rise of a peridotite or pyroxenite diapir eventually results in the onset of melting. Sparks and Parmentier (8) show that a fully interconnected matrix must ultimately be deformed for melt to be removed by porous flow. When compaction terms are included in the porous flow equations, a dilating boundary layer forms on top of the melting column, here taken as the upper cupola of the diapir. This "decompaction boundary layer" is on the order of 100's of m thick and has an average porosity at least equivalent to the maximum extent of melting. The upper portion of the diapir, therefore, is a molten region in which quasi-magma chambers are distributed. The magma in these high porosity zones might be substantially isolated from the surrounding mantle.

The composition of these magma pools depends on the extent and nature of the coupling of melting and melt segregation. An olivine-rich lherzolite rapidly becomes connected at even small percentages of melt. Melting and compaction produce a growing magma zone near the apical regions of diapir. Each melt parcel added to the melt pool bears the imprint of the local pressures of melting. The final composition of the melt pool is the sum of melt increments produced by the polybaric fractional melting of the lherzolite. The composition of the magma body is determined by the pressure at which the pool is drained or when fractional melting is essentially terminated. Phase equilibrium studies on such a melt could not be used to constrain its petrogenesis.

The composition of the magma pool for an olivine-poor diapir, say an ilmenite-rich calcic clinopyroxenite as might be produced as late stage cululates of the magma ocean, is quite different. The melt in this case is not interconnected but is trapped within grain junctions. The melt continues to grow in volume during the adiabatic ascent and continually reequilibrates with the surrounding crystalline matrix. Melting would more closely approximate equilibrium rather than fractional melting. Connection would occur after the critical threshold is exceeded. The melt could rapidly drain and collect into the apical regions of the decompacting melting column, or perhaps escape along fractures towards the lunar surface. In either case, the composition of the melt largely reflects the depths at which the critical threshold of melting was exceeded. The melt would be a primary magma and phase equilibria studies could establish its depth of origin and the nature of the mantle residuum.

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