

HIGH-PRESSURE CRYSTAL-LIQUID FRACTIONATION OF
 BASALTIC MAGMAS: A PHASE-EQUILIBRIA FRAMEWORK; D. Elthon,
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Experimentally-determined high-pressure phase equilibria are used to construct a series of pseudo-liquidus phase diagrams for evaluating the high-pressure (up to 40 kbar) crystal fractionation of basaltic liquids. Because of the changes in mineral assemblages with increasing pressure in basalt-mantle systems, it is necessary to formulate three different mineral tetrahedra. The olivine (OL) - plagioclase (PL) - clinopyroxene (CPX) - silica (SIL) tetrahedron (which contains orthopyroxene (OPX)) is suitable at pressures where a PLAG lherzolite assemblage is stable (<10 Kbars); the OL-spinel (SP)-CPX-SIL tetrahedron is suitable at pressures where a SP lherzolite assemblage is stable (10-25 kbars); the OL-garnet (GAR)-CPX-SIL tetrahedron is suitable at pressures where a GAR lherzolite assemblage is stable (>25 kbars).

The positions of multiply-saturated phase equilibria (including isobaric pseudo-invariant points) are constrained by the results of numerous high-pressure experimental studies. In a manner similar to that observed at 1 atm [e.g.,1], the positions of these multiply-saturated phase equilibria control the evolutionary paths of basaltic magmas during crystallization at high pressures.

The physical processes of high-pressure fractionation can be divided into the two end-member situations of polybaric fractionation and isobaric fractionation. A fractionating magma probably evolves through the interplay of both processes; they are separated below only two emphasize their fundamentally different nature.

As shown by O'Hara [2], polybaric fractionation is dominated by the expansion of the OL primary phase volume with decreasing pressure, which will produce cumulate dunites. A decrease in pressure (and resulting temperature) results in the crystallization of olivine until residual liquids reach a multiple saturation boundary and the following isobaric crystallization processes occur.

On the basis of shifts of phase-equilibria with changing pressure, the upper mantle can be divided into the following 5 different regimes of isobaric fractionation:

Regime 1 (<4 Kbars) Within this pressure interval the pseudo-invariant point lies outside of the OL-PL-CPX-OPX volume and is therefore a reaction point, with OL and OPX in reaction with the liquid. Typical cumulates within this pressure interval will be mixtures of OL, CPX, PLAG, OPX (+/- minor phases) that are not substantively different from those that form at 1 atm.

Regime 2 (4 to 10 kbars) Within this pressure interval, the pseudo-invariant point lies within the OL-PL-CPX-OPX volume and is a subtraction point. OPX, but not OL, is in reaction relationship with the liquid. Cumulates will be similar to those from Regime 1, but will not have the OL-out reaction relationship.

Regime 3 (10 to 25 kbars) Within this pressure interval, SP is the aluminous mantle phase. The pseudo-invariant point lies outside of the OL-SP-CPX-OPX volume, indicating that it is an invariant point with OL (but not OPX unless the CPX is subcalcic) in reaction with the liquid. An example of this reaction relationship has been demonstrated for a Hawaiian picrite [3]. The dominant phase of fractionation is a spinel clinopyroxenite until the pseudo-invariant point is reached; at this point, OL+SP+OPX are in reaction relationship with the liquid, with further crystallization resulting in eclogite cumulates.

Regime 4 (25 to 30 kbars) Within this pressure interval, GAR is the aluminous upper mantle phase. The pseudo-invariant point lies outside of the OL-GAR-CPX-OPX volume, indicating that it is a reaction point with OL and OPX in reaction with the liquid. Examples of these reaction relationships are evident in Green and Ringwood [4] and other experimental studies. Within this pressure interval, eclogite fractionation will occur during the crystallization of very primitive (near primary) magmas, compared to the relatively late crystallization of eclogite in Regime 3.

Regime 5. (30 to 40 kbars) Within this pressure interval, GAR is the aluminous upper mantle phase. The pseudo-invariant point lies within the OL-GAR-CPX-OPX volume, indicating that it is a subtraction point, with no minerals in reaction relationship with the liquid. Websterite and garnet websterite (with small amounts of olivine) cumulates will dominate.

Dunite, wehrlite, websterite, eclogite and clinopyroxenite xenoliths [e.g., 5-9] are reported from many localities and have been interpreted as re-equilibrated cumulates. The phase equilibria framework outlined above, when integrated with geochemical data, should enable these rocks to be linked with their appropriate petrogenetic history.

References: [1] Walker et al., (1979) Contrib. Mineral. Petrol. 70:111-126 [2] O'Hara (1968) Earth Sci. Rev. 4:69-133 [3] Tilley and Yoder (1964) Carnegie Instn. Wash. Yearbook 63:114-121. [4] Green and Ringwood (1967) Contrib. Mineral. Petrol. 15:103-190. [5] O'Hara and Yoder (1967) Scott. J. Geol. 3:67-117. [6] Wilshire and Shervais (1975) Phys. Chem. Earth 9:257-272. [7] Hatton and Gurney (1977) Abs. Vol. Sec. International Kimberlite Conf. [8] Irving (1977) Abs. Vol. Sec. International Kimberlite Conf. [9] Frey (1980) Am. J. Sci. 280-A: 427-449.