

PHASE EQUILIBRIA PRINCIPLES OF PARTIAL MELTING OF GARNET-PERIDOTITE AND FRACTIONATION OF MAGMA PRODUCED

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When the garnet-pyroxene composition 'plane' is a thermal divide (fig 1) garnet-peridotite G begins to melt at a lower temperature than eclogite F with production of liquid B. No eclogite (F-F') can melt incongruently to yield olivine-bearing residua. Most popular prejudices about upper mantle composition fall close to G in a general composition field (four subsolidus phases). Eclogites are 'special' compositions with restricted number of phases best accounted for as residua of partial melting or crystal cumulates. Only initial olivine-bearing mantle compositions such as H could yield eclogite residua on partial melting. Eclogites F-F' can accumulate from liquids B-U. The residual liquids may become strongly undersaturated in silica and have at least some of the properties of kimberlite. The garnet-pyroxene plane is a thermal divide in synthetic and natural systems at high pressures (O'Hara and Yoder 1967; O'Hara 1968)

If the garnet-pyroxene composition plane were not a thermal divide (fig 2) garnet peridotite G and eclogite F-F' might begin to melt at the same temperature with appearance of liquid Q, and olivine, enstatite bearing residua (such as G) might be created from eclogite. The liquid Q would however be hypersthene- or quartz-normative and could only fractionate towards yet more silica saturated compositions, unlike kimberlite, by eclogite fractionation along Q-R. This possible form of the phase equilibria was considered, tested, and rejected by O'Hara and Yoder (1967). The crucial data which would support it (appearance of olivine during partial melting of a biminerally eclogite which retains that mineralogy to the solidus) have not been produced. Until they are produced, hypotheses which regard eclogite as the source mantle and garnet-peridotite as its residuum after partial melting lack a basis of known materials behaviour.

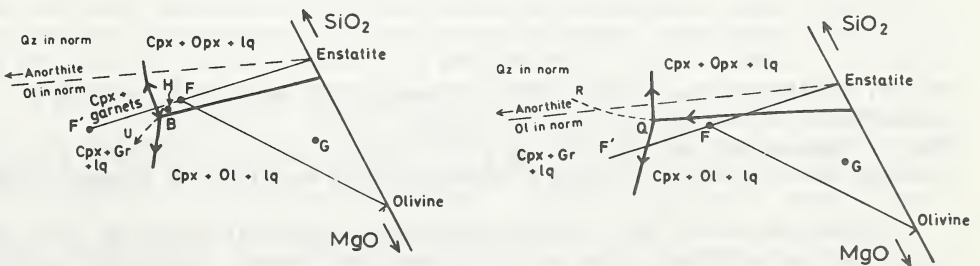


Fig 1. Diopside projection into the part of the system olivine-silica-anorthite showing the form of clinopyroxene-saturated equilibria at some high pressure when the eclogite 'plane' is a thermal divide (Projection method as described by Jamieson 1970).
Fig 2. As fig 1, but drawn for the hypothetical situation where the eclogite plane is not a thermal divide.

Fig 3 shows an isothermal section of the equilibria in fig 1, at the temperature of beginning of melting of the garnet lherzolite assemblage when liquid B appears, to illustrate why the orthopyroxene/olivine ratio will increase in the residua from initial partial melting of a garnet-lherzolite. (See construction lines through G from B, F to find enstatite/olivine ratios after and before melting). By construction it can be shown that the absolute weight per cent of enstatite in the whole liquid-crystal system increases at the beginning of melting (because of the reaction relationship orthopyroxene+liquid = olivine+garnet+clinopyroxene). Further partial melting producing a liquid P, however, causes the orthopyroxene/olivine ratio to decline, as shown in fig 4, an isothermal section drawn for a higher temperature.

The ratio clinopyroxene+garnet/orthopyroxene (fig 4) in the original garnet-lherzolite, G, determines how much partial melting can occur before orthopyroxene is eliminated from the residuum. While orthopyroxene remains, olivine does not increase much in the CIPW norm of the liquid while partial melting proceeds (see fig 1, liquid must lie along olivine-enstatite liquidus interface); once orthopyroxene has been consumed, normative olivine would increase quickly in the further partial melts, but so does the temperature required to produce that liquid.

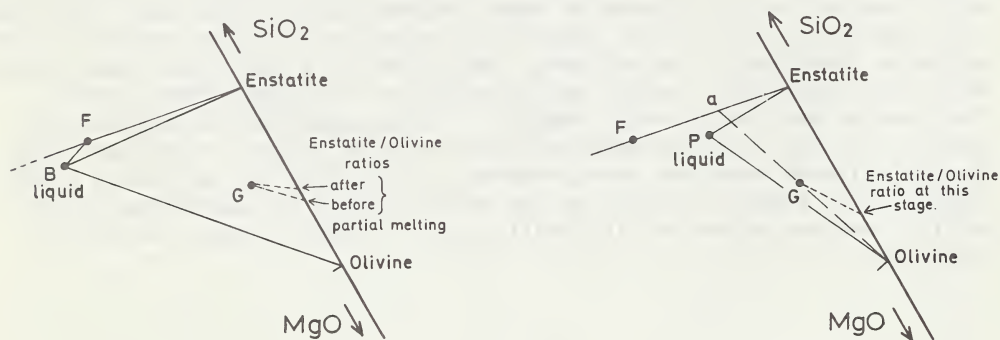


Fig 3. Isothermal section of fig 1, showing the cpx+opx+ol+liquid B assemblage in relation to peridotite G.

Fig 4. Isothermal section of fig 1 at a higher temperature than fig 3, showing the cpx+opx+ol+liquid P assemblage in relation to composition G.

A projection of the olivine-saturated equilibria involved in fig 1, from olivine into the plane of clinopyroxene, orthopyroxene and garnet is shown in fig 5. The critical plane olivine-enstatite-initial liquid B separates garnet-lherzolite compositions such as G, which would yield lherzolite residua in partial melting, from a superficially similar composition, O, which yields garnet-harzburgite residua in partial melting (note light dotted lines showing the isothermal section boundaries at the beginning of melting in fig 5). The position of this critical plane, is pressure dependent (see O'Hara 1970) but the relationship of a garnet lherzolite to this plane is determined essentially by the clinopyroxene/garnet ratio in the rock, or (equally crudely) by the CaO/Al₂O₃ ratio.

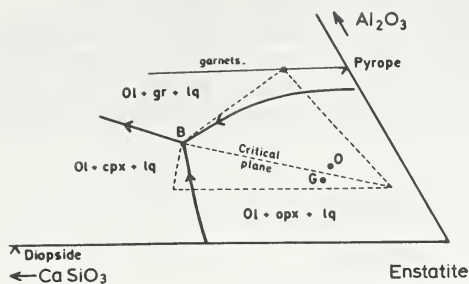


Fig 5

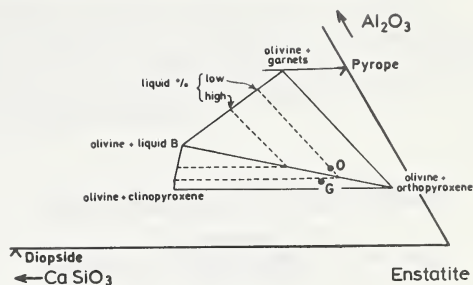


Fig 6

Fig 6 is a similar projection showing the isothermal section at the beginning of partial melting, contoured with isopleths of equal liquid/pyroxenes + garnet ratios produced at the beginning of melting (assuming adequate latent heat). The mineral ratio criteria in the subsolidus or geochemical criteria which govern how much liquid forms are not simple functions, the criteria differ on either side of the critical plane because the isopleths have different orientations. Moreover, the sensitivity of the situation to sampling errors, analytical errors or genuine variations in bulk composition, is different on opposite sides of the critical plane (this is an elementary consideration in quality control of industrial refractories (O'Hara and Biggar 1970) whose performance in service present an analogous situation to that discussed here).

Summarising, what constitutes a significant geochemical or modal measurement and acceptable limits of precision in sampling and analysis in the study of possible upper mantle compositions is itself dependent upon the bulk composition and the nature of the inquiry. When the behaviour of rocks during partial melting is considered, knowledge of the liquidus and solidus relationships is a prerequisite for the choice of meaningful criteria. Whereas the partial melting behaviour of garnet-peridotite is not very sensitive to variations in total SiO_2 or $\text{MgO} + \text{FeO}$ (which dominate the analysis) it is very sensitive to variations in the absolute and relative amounts of CaO , Al_2O_3 and of SiO_2 surplus to that required to form olivine, clinopyroxene and garnet. Simple addition of mineral compositions in a source rock in order to obtain an estimate of possible liquid composition is a defective method when one or more crystalline phases increases in amount as liquidus forms. Similarly it is important to pay due regard to these criteria when constructing hypothetical models of upper mantle composition.

References

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