

SUBSOLIDUS MINERAL ASSEMBLAGES IN GARNET-PERIDOTITE AND ECLOGITE COMPOSITIONS

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The following direct or implicit identifications have been proposed (O'Hara and Yoder 1967, O'Hara 1968, 1970) linking ultramafic rock types found in kimberlite with source mantle, residual mantle, or high pressure cumulus formed during partial melting and recrystallization events at great depths:-

A. Residua from Partial Melting

I. Garnet-lherzolite (Gnt-cpx-opx-ol) represents (i) source mantle; (ii) source mantle depleted by the earlier stages of partial melting, in which garnet and clinopyroxene are reduced in amount but neither is eliminated; or residual mantle from which (iii) all clinopyroxene or (iv) all clinopyroxene and garnet had been eliminated at the solidus temperature but which have exsolved their present clinopyroxene and some or all of their garnet on subsequent cooling to the sub-continental geotherm. (Some of the garnet and clinopyroxene present in cases I(i) and I(ii) may have exsolved between solidus and geotherm.

II.(i) Garnet-harzburgite (Gnt-opx-ol) or (ii) lherzolite (Cpx-opx-ol) represents residual mantle from an intermediate stage of partial melting or still more residual material in which (iii) all garnet or (iv) all clinopyroxene present has exsolved from orthopyroxene during cooling from the solidus to the geotherm.

III. Harzburgite (Opx-ol) represents residual mantle from a still more advanced stage of partial melting.

IV. Dunite (Ol) represents the residuum after extreme partial melting.

Relative abundances of these materials appear to be $I > II > III > IV$. Experimental data (Ito and Kennedy 1967) imply that this situation will develop if partial melting temperature rarely exceeds the solidus by more than 50°C, and only exceptionally by more than 200°C, a result readily understood when the latent heat required to produce the liquid is taken into consideration. (The thermal energy which would raise subsolidus peridotite through 100°C will produce c.20% melt from it, without raising the temperature significantly, at the beginning of melting).

These petrographic groupings are correlated in table 1 with the stages of partial melting model proposed by O'Hara (1968, fig 8) and the ranges of residual peridotite composition shown in the partial melting model of O'Hara (1970).

B. Cumulates from the isobaric fractionation of magma at high pressures

If the liquids produced during the processes leading to the creation of the residual mantle compositions undergo crystallization at depth the products may be:-

V. Olivine-poor garnet-wehrlite or garnet-lherzolite representing (i) the total (equilibrium) or near total crystallization product of the liquid produced in partial melting (Cpx>opx) or the subsolidus exsolution products of (ii) olivine-orthopyroxenite or (iii) olivine-garnet-orthopyroxenite precipitated during fractional crystallization of more advanced partial melts.

VI. Olivine-garnet-orthopyroxenites representing either (i) the cumulates formed during fractional crystallization of olivine, garnet and orthopyroxene from the liquid, or (ii) a subsolidus exsolution product of an olivine-orthopyroxene cumulate formed from the liquid.

VII. Olivine (garnet)-websterites representing the cumulates from liquids

Table 1. Source and residual mantle

Category	Low T Petrography	Solidus Petrography	Stage of Partial Melting (O'Hara 1968)	Correspon- ding residua in model of O'Hara (1970)	Complemen- tary liquid in model O'Hara (1970)
I	(i) ol,opx,gr,cpx	ol,opx,gr,cpx	-	O	
	(ii)	"	stages 1,2	O - O	B
	(iii)	ol,opx,gr	stage 3	O' - O"	B - W
	(iv)	ol,opx	stage 4	O"-olivine	W - X
II	(i) ol,opx,gr	ol,opx,gr	stage 3	O' - O"	B - W
	(ii) ol,opx,cpx	ol,opx,cpx	"	-	B
	(iii) ol,opx,gr	ol,opx	stage 4	O"-olivine	W - X
	(iv) ol,opx,cpx	ol,opx	"	-	Y - Z
III	ol,opx	ol,opx	stage 4	O"-olivine	W - X, Y-Z
IV	ol	ol	stage 5	olivine	X - O, Z - N

fractionating (i) olivine, clinopyroxene and orthopyroxene, or (ii) olivine and orthopyroxene, from which clinopyroxene has later exsolved.

VIII. Dunites representing cumulates from liquids fractionating olivine only.

IX. Garnet-websterites representing early cumulates of garnet and clinopyroxene (in which at the solidus $cpx > gnt$) which have subsequently exsolved both orthopyroxene and garnet. N.B. The models discussed here do not provide for the direct accumulation of this mineral assemblage except as the result of a pressure increase in the liquids.

X. Eclogites representing the most abundant cumulate from the fractional crystallization of the liquids; formed at temperatures below the solidus temperature of the source mantle. At pressures of 25-40 kb solid solution of potential garnet in clinopyroxene at solidus temperatures means (i) that most of the present garnet has exsolved from the pyroxene (O'Hara and Yoder 1967; O'Hara 1969), but (ii) some eclogites may represent the exsolution product of homogeneous clinopyroxene which may precipitate from a magma originally fractionating eclogite, which is subject to a pressure drop.

These relationships are summarised in table 2.

Table 2. Cumulates

Category	Low T Petrography	Solidus or precipitation petrography	Complementary liquids in model (O'Hara 1970)*
V	(i) cpx,gr>opx,ol	cpx,gr,ol	B
	(ii) opx>ol,cpx,gr	(ol),opx	W - X
	(iii) gr opx ol,cpx	(ol),opx,gr	W - B
VI	(i) gr>opx>ol	gr,opx,ol	A - B
	(ii) opx>gr>ol	ol,opx	on surface EABD
VII	(i) cpx>opx,ol(gr)	cpx,opx,ol	D - B
	(ii) opx>cpx>ol(gr)	opx,ol	on surface EABD
VII	ol	ol	-
IX	cpx,opx,gr	cpx,gr	B - U near B
X	(i) cpx \approx gr	cpx,(gr)	B - U
	(ii) cpx>gr	cpx	inside clinopyroxene liquidus volume as result of pressure drop

*Refers to type of liquid only. Pressure may have changed between partial melting and fractional crystallization events.

Throughout it must be remembered that both low temperature and solidus petrography will be functions of the pressure as well as the bulk composition.

This classification is intended to summarise the implications of recent experimental work and thinking based on materials behaviour. Its application to the interpretation of rare earth element (REE) data will be discussed

REE are not strongly fractionated between liquid and either olivine or orthopyroxene. Light REE (REE_L) are enriched relative to heavy REE (REE_H) in clinopyroxene; for a given bulk composition the $REE_{(L/H)}$ ratio of coexisting liquid will be correspondingly reduced. REE_H are very strongly enriched in garnet, producing for a corresponding increase in $REE_{(L/H)}$ of a coexisting liquid (for a given bulk composition).

Assuming no relative fractionation of REE between chondrites and source mantle (category I(i)) then $REE^*_{(L/H)}=1$ where REE^* refers to chondrite normalised concentrations. Residual garnet-lherzolites (I(ii)) might display little change in $REE^*_{(L/H)}$ although reduced overall concentrations, and the same would be true to a greater extent of extreme residua (I(iv), II(iii), II(iv), III and IV); the corresponding primary magmas would similarly have $REE^*_{(L/H)}\sim 1$. Rocks developed as residual garnet harzburgites (I(iii), II(i)) would have $REE^*_{(L/H)}<1$ and the primary magma produced at the same time would have $REE^*_{(L/H)}>1$. A further partial melting event affecting such residua (after removal of the first liquid) would, however, produce primary magmas with $REE^*_{(L/H)}<1$, possibly $\ll 1$ if garnet was just eliminated from the residua. Conversely, rocks developed as residual lherzolites (II(ii)) will have $REE^*_{(L/H)}>1$, and the liquids will have $REE^*_{(L/H)}<1$ in a first cycle of melting, but in a second partial melting event in which clinopyroxene was eliminated the liquid would have $REE^*_{(L/H)}>1$.

Primary magmas which undergo fractional crystallization of garnet uncompensated by clinopyroxene removal will develop residual liquids of sharply increased $REE^*_{(L/H)}$ and produce accumulates with $REE^*_{(L/H)}<1$ (category VI). When both clinopyroxene and garnet are fractionating together the $REE^*_{(L/H)}$ of eclogite extract (categories IX,X) will depend primarily on the coprecipitation ratio of clinopyroxene/garnet, which is a function of pressure and temperature. $REE^*_{(L/H)}$ of eclogite need not differ greatly from 1, and it is not certain at this stage what effect eclogite fractionation might have on $REE^*_{(L/H)}$ of any derivative liquids.

References

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