PETROCHEMISTRY OF ULTRADEEP (>300 KM) AND TRANSITION ZONE XENOLITHS.

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Ultradeep xenoliths are defined on the basis of majoritic garnet (Mj-Gt) inclusions in diamond, and on Mj-Gt in kimberlite xenoliths (Haggerty and Sautter, 1990). The former have retained pyroxene (nominally $R_4Si_4O_{12}$) in garnet solid solution, whereas the latter have exsolved Px along {111} Gt planes. Modal and chemical reconstitution of Gt + Px yields majoritic solid solutions with ^{IV}Si and ^{VI}Si, which, based on natural and pure experimental systems requires stabilization at P>100 kb (300 km). The deepest xenoliths identified are from the TZ at 450 km, but equilibrated at holding stations, possibly in the asthenosphere, but certainly in the lithosphere at ~40 kb and 1200°C (Sautter et al., 1991).

A detailed petrographic and EMPA study, undertaken on 41 xenoliths shows an emerging pattern from the approximately 400 samples that have been processed to date from the Jagersfontein diamond diatreme in the Kaapvaal Craton. Discrete macrocrystic garnet (1-2 cm) with associated clinopyroxene, and {111} lamellar Cpx is the dominant ultradeep xenolith comprising ~10% of the ultramafic Gt suite (typically purple with 1-2 wt% Cr_2O_3). Gt-rich layers (~2 cm in width) in four phase lherzolites and mega-Gt (>5 cm in diameter) in harzburgite typify the larger (10-20 cm), but rare ultradeep xenoliths. In all cases, pyroxene (clino or otho or both) is crystallographically controlled, but Px may also be prismatic, lensoidal or annular to Gt implying multiple stages of exsolution and grain boundary diffusion. Jigsaw-type textures distinguish the majoritic assemblage from 120° dihedral annealing in lherzolitic and harzburgite substrate minerals (Fig. 1). Garnet ranges from Py_{68-74} and $CaO-Cr_2O_3$ relations are lherzolitic; $Cpx=Jd_{3-19}WO_{37-46}$ with 0.4-2.4 wt% Cr_2O_3; Opx=92-95 mole % En; and Ol averages 92.5 mole % Fo with max. wt% 0.1 CaO, 0.4 NiO, 0.1 Cr_2O_3. The Cr_2O_3(0.25-2.5 wt%) content in Cpx is related to Cr_2O_3(0.4-2.4 wt%) in Gt, and lamellar Cpx is typically more enriched in Cr_2O_3(by ~ 0.5 to 1.5 wt%) than grain boundary associated Cpx (Fig. 2). Five xenoliths in a new class contain oriented spinel (Cr/Cr+Al = 0.74; Mg/Mg+Fe = 0.58) in addition to Cpx in Gt.These Gts have >3 wt% Cr_2O_3 (cf 0.5-1.5 for Sp-free types) and provide a link to other non-alkremitic and enigmatic Gt (Py_{74} + Sp (Cr# 74; Mg# 57), and Sp (Cr# 69; Mg# 76) + lamellar Py_{72} + Jd_{14} assemblages. A possible reaction is $Mg_3(AlSi)_2(SiO_4)_3$(Mj) = $CaMgSi_2O_6$(Cpx) + $MgAl_2O_4$(Sp) + residual SiO_2 in Mj. Three ultradeep high pressure xenoliths have {111} rutile in Gt implying substitution by $Na_2CaTi_2Si_3O_{12}$. One xenolith contains optically anomalous, strained olivine inclusions in Gt possibly from the inversion of wadsleyite (β Mg_2SiO_4) or ringwoodite (δ Mg_2SiO_4). Collaborative studies on oxygen isotopes (with P. Deines), trace elements by ion probe (N. Shimazu), Sr, Nd, Sm (Macdougall), and HRTEM (S. Karato) have been initiated. Early results are in accord with the petrographic and EMPA study that the ultradeep TZ xenoliths are mineralogically and geochemically diverse and that the TZ is, therefore, heterogeneous.

D" plumes are the most viable media for transporting the ultradeep xenoliths. The model is supported by the diamond inclusion assemblage of $CaSiO_3$ + (MgFe)O + SiO_2, which is most reasonably interpreted as a sampling of the lower mantle (Harte and Harris, 1994). Plume activity is correlated with kimberlite eruptions, and hot spot tracks, continental fragmentation and flood basalts, and atypical superchron events of the Earth's magnetic field (Haggerty, 1994). The overall theme is an adjunct to the superplume model but goes beyond that model by proposing that many, previously unaccounted for features in diamonds (e.g. ages, $\delta^{13}C$ anomalies, sulfides, metallic Fe, SiC), K-metasomatism, and the global synchroneity of kimberlite clan eruptions at 80-120, 250-320, and 440 Ma, as well as at ~ 1.1 Ga, are best explained by D" disruption and plume sampling along a conduit from the CMB to the crust (Fig. 3). There may, however, be other possibilities but alternate models will necessarily have to be constrained in space and time.

References

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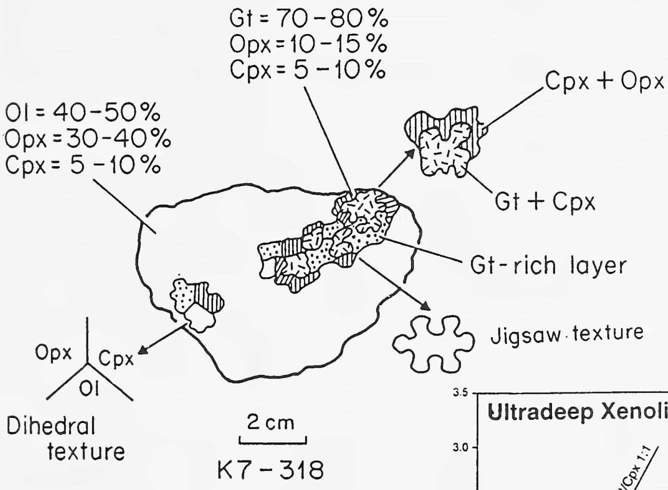

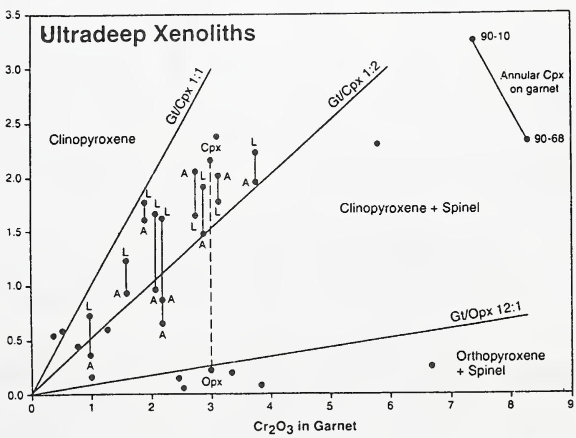

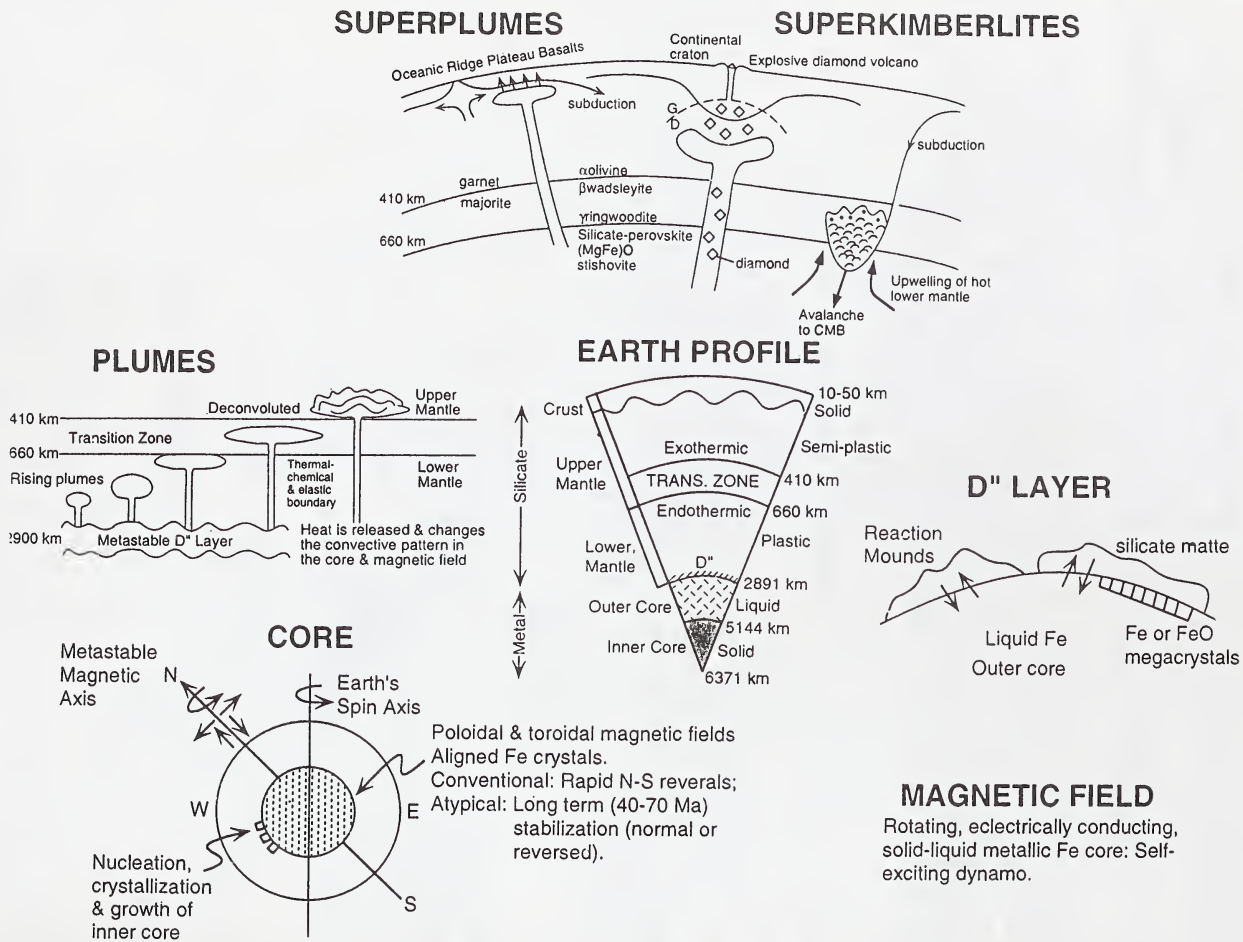
SUPERPLUMES
Oceanic Ridge Plateau Basalts
subduction
410 km
660 km
garnet
majorite
αolivine
βwadsleyite
γringwoodite
Silicate-perovskite
(MgFe)O
stishovite
SUPERKIMBERLITES
Continental craton
Explosive diamond volcano
G
D
subduction
diamond
Upwelling of hot lower mantle
Avalanche to CMB
PLUMES
410 km
660 km
Transition Zone
Rising plumes
2900 km
Metastable D" Layer
Deconvoluted
Upper Mantle
Lower Mantle
Thermal-chemical & elastic boundary
Heat is released & changes the convective pattern in the core & magnetic field
EARTH PROFILE
Crust
Upper Mantle
Lower, Mantle
Outer Core
Inner Core
Silicate
Metal
Exothermic
TRANS. ZONE
Endothermic
D"
10-50 km
Solid
Semi-plastic
410 km
660 km
Plastic
2891 km
Liquid
5144 km
Solid
6371 km
D" LAYER
Reaction Mounds
silicate matte
Liquid Fe
Outer core
Fe or FeO megacrystals
CORE
Metastable Magnetic Axis
N
W
E
S
Earth's Spin Axis
Nucleation, crystallization & growth of inner core
Poloidal & toroidal magnetic fields
Aligned Fe crystals.
Conventional: Rapid N-S reverals;
Atypical: Long term (40-70 Ma) stabilization (normal or reversed).
MAGNETIC FIELD
Rotating, eclectrically conducting, solid-liquid metallic Fe core: Self-exciting dynamo.