Deep mantle cycling of crustal components and formation of diamondiferous lithology in the sublithospheric mantle

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The indicators of subducted crustal sources for diamonds in sublithospheric mantle

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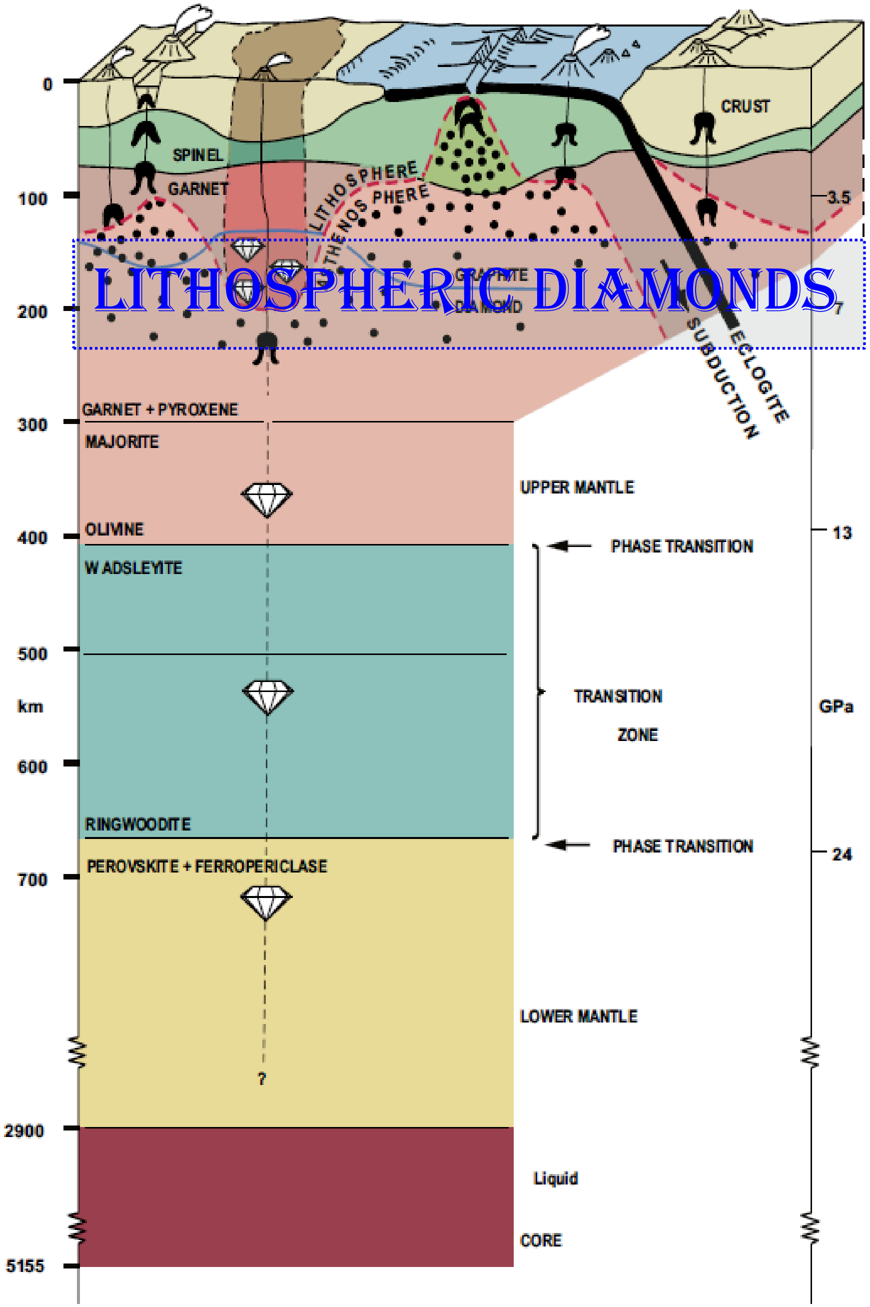
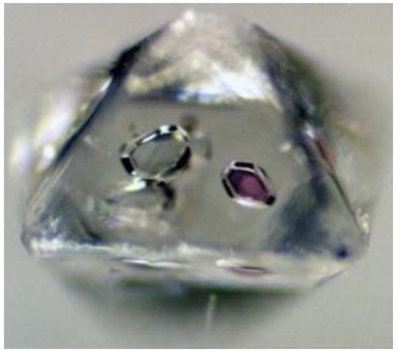
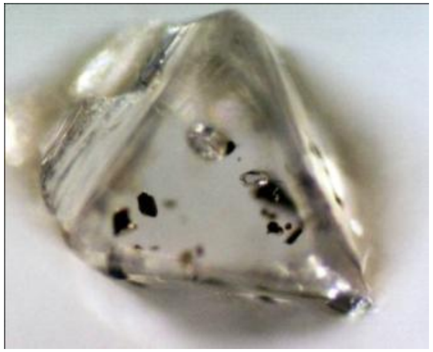


Diamond Inclusions





Crystalline inclusions in diamonds from the subcontinental lithospheric mantle (SCLM) testify that diamonds grow in a range of *peridotitic (P-type)* and *eclogitic (E-type)* host-rocks.

❖P-type

Ol, Grt, Opx,

CPx, Chr

Phl, Ilm, Sph

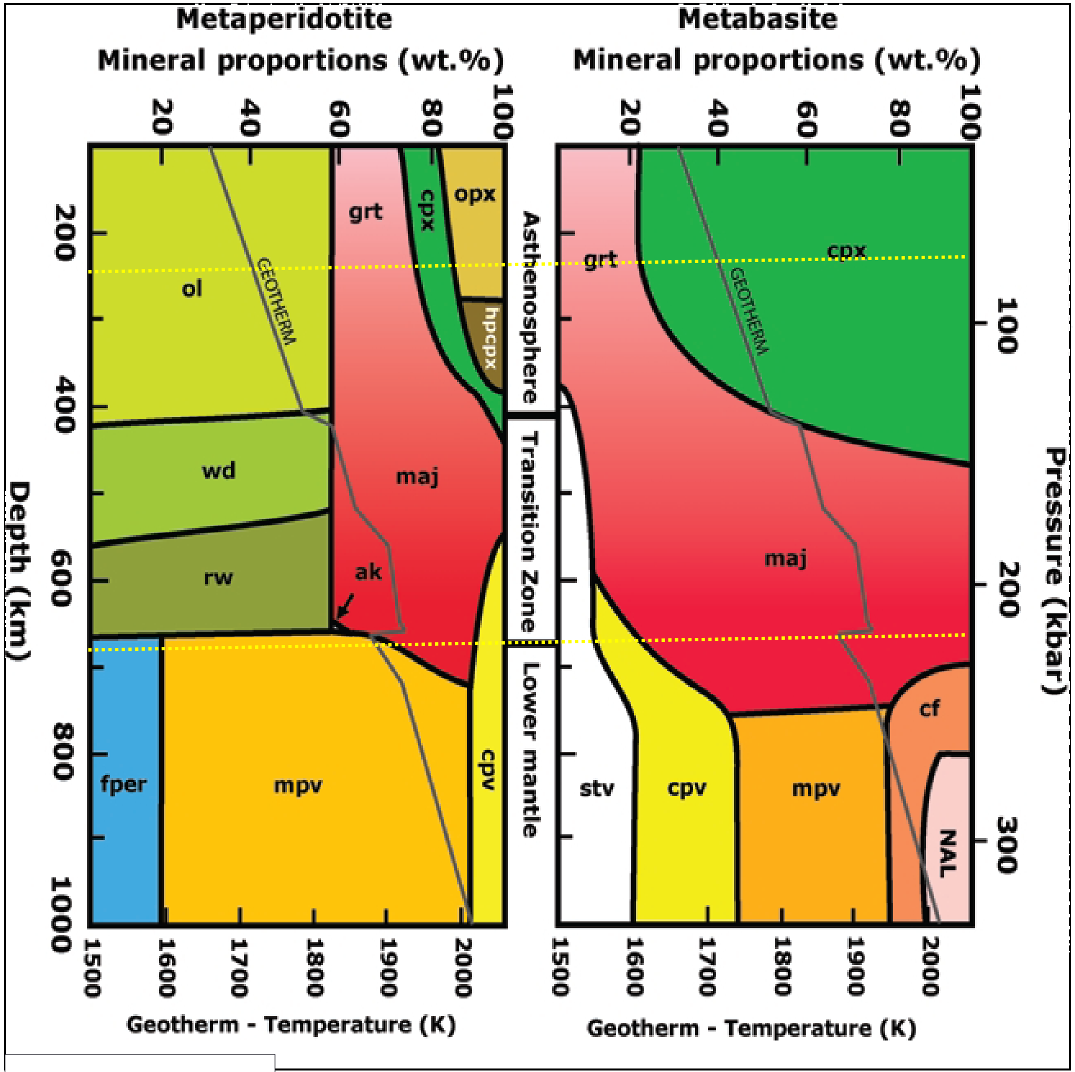
❖E-type

CPx, Grt,

Coe, Ky, Rt, KFsp,

Cor, Ilm, Sph

Both associations commonly testify to diamond growth at depths 150÷250 km and at temperatures of 900÷1300ºC.



Harte, 2010

Diamond Inclusions

Mantle Petrology: Field Observations and High Pressure Experimentation: A Tribute to Francis R. (Joe) Boyd
© The Geochemical Society, Special Publication No. 6, 1999
Editors: Yingwei Fei, Constance M. Bertka, and Bjorn O. Mysen

Lower mantle mineral associations in diamonds from São Luiz, Brazil

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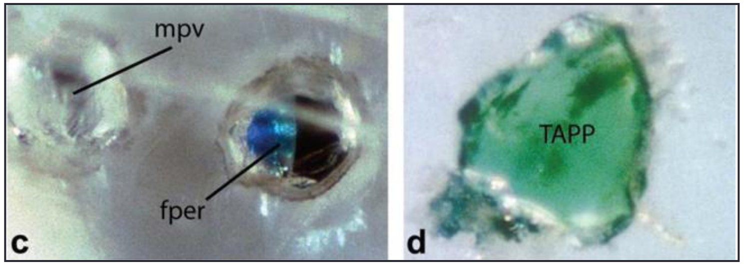
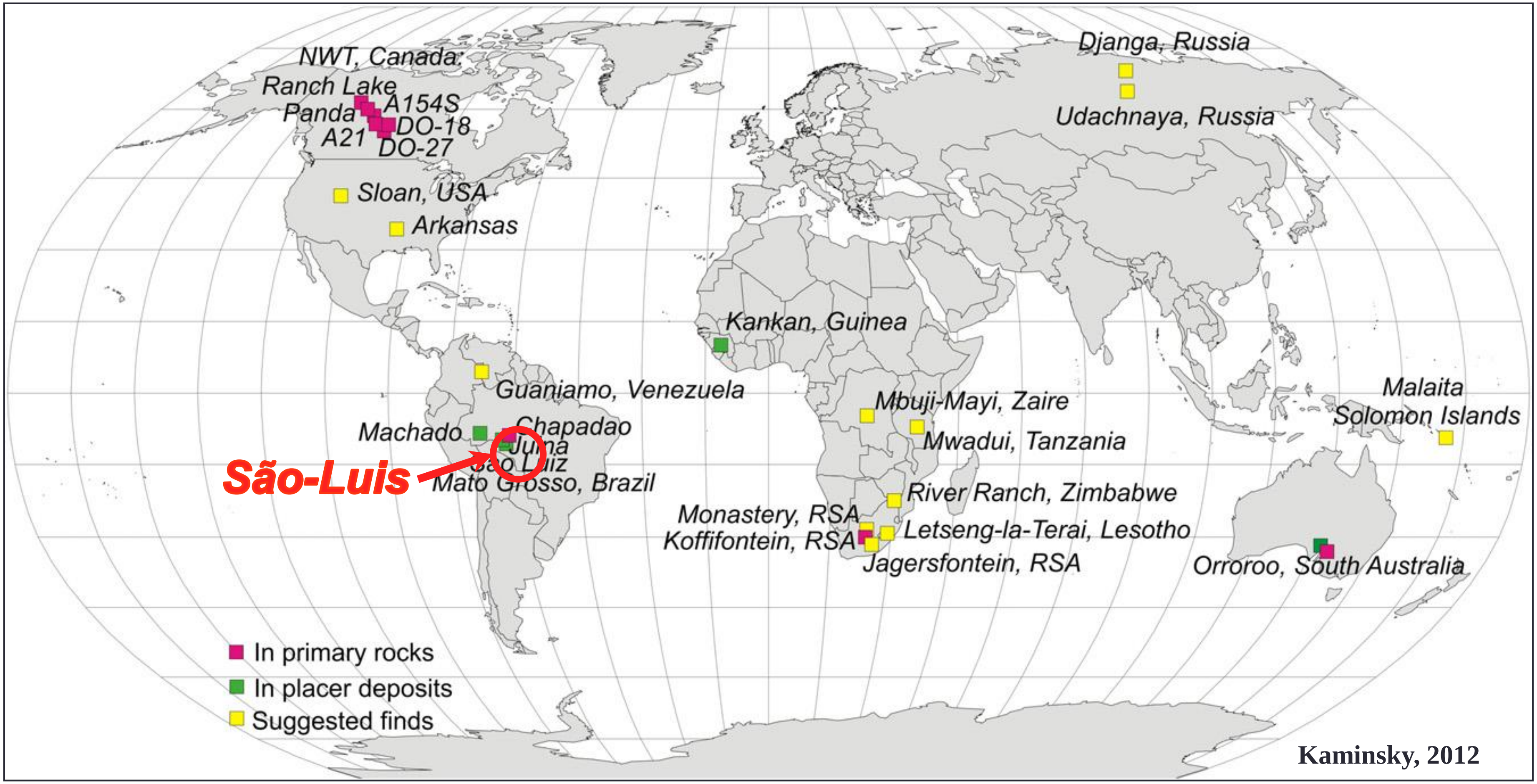
- MgSi-Pv, fPer, CaSi-Pv
- Maj-Grt, SiO_2 (Stv?)
- TAPP



Sublithospheric (Superdeep) Diamonds

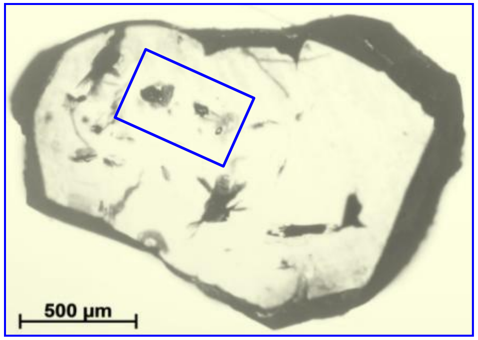
Superdeep Diamonds

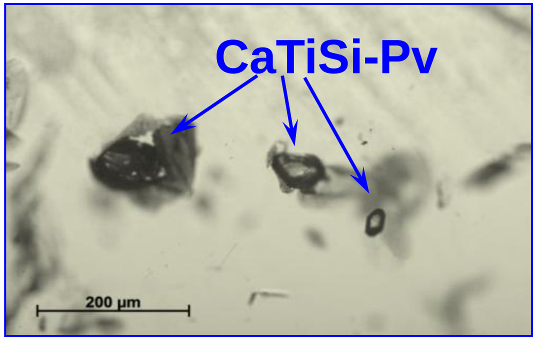


Diamonds from <u>São-Luis</u> river deposits (Juina, Brazil) are known to have originated from the depths of the *Transition Zone* (TZ) and *Lower Mantle* (LM).

Mineral inclusions

Mineral inclusions have been found in 61 diamonds





common

- Majoritic garnets (±clinopyroxene)
- CaSi-perovskite (±CaTi-perovskite)
- Ferropericlase
- MgSi-perovskite (bridgemanite)
- Olivine
- TAPP (tetragonal almandine-pyrope phase)
- SiO_2 (coesite±kyanite=stishovite?)
- Al-Si-phase

rare

- K-feldspar (K-hollandite?)
- Cr-pyrope
- Grossular (CAS?)
- Merwinite
- Nepheline+Spinel (NAL?, CF?)
- Native iron
- Fe-sulphides
- Carbonates ($MgCO_3$, $CaCO_3$)

Mineral inclusions

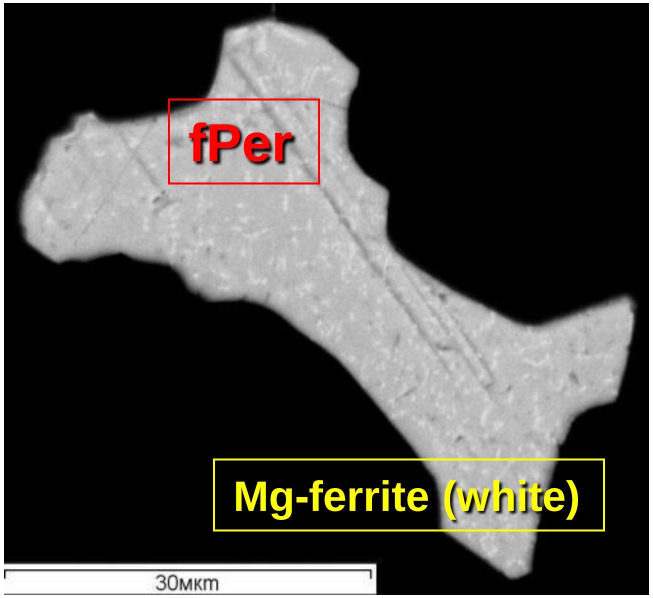
Ferropericlase (Mg,Fe)O

Associations

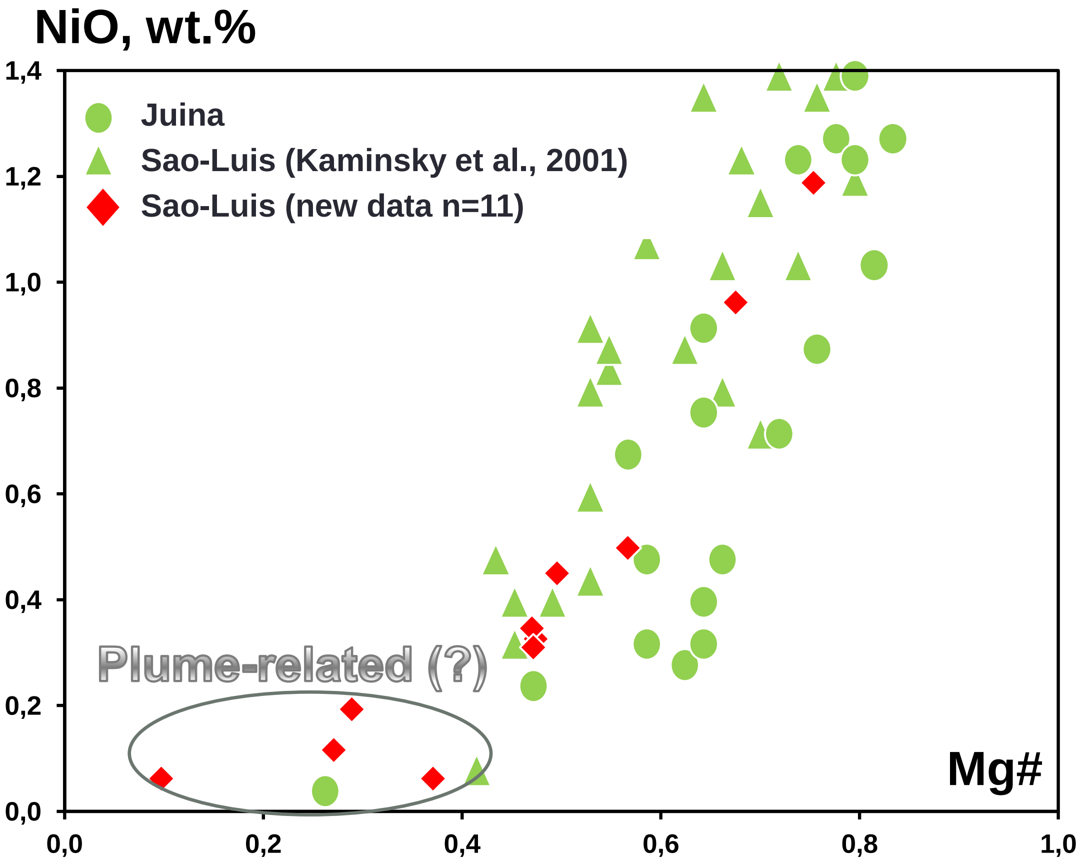
fPer+Ol

fPer+MgSi-Pv

Mg# 0.1÷0.8



Mg-ferrite ($MgFe_2O_4$)



Mineral inclusions

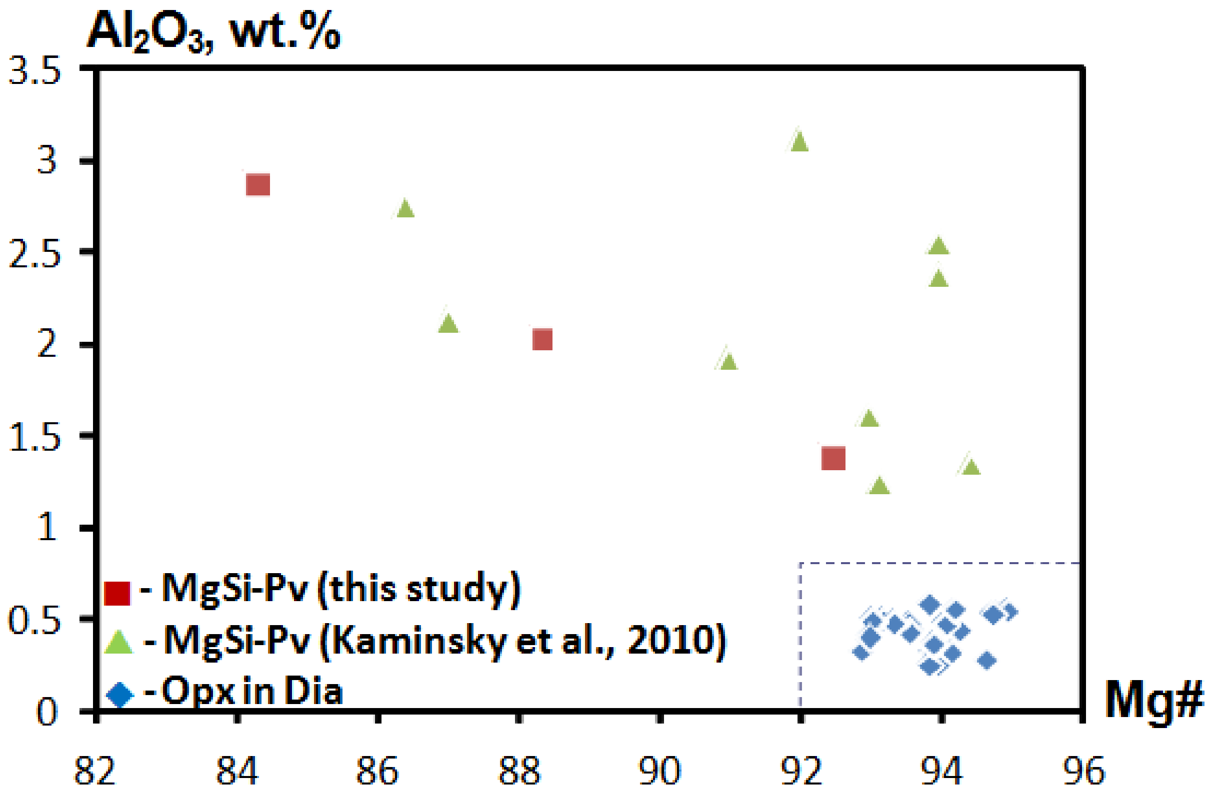
MgSi-perovskite $MgSiO_3$

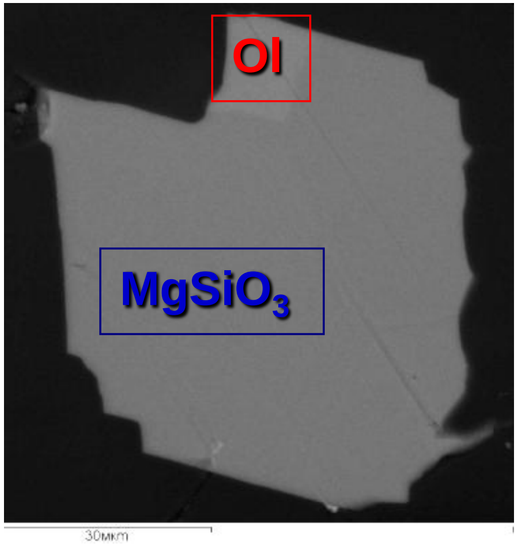
Associations

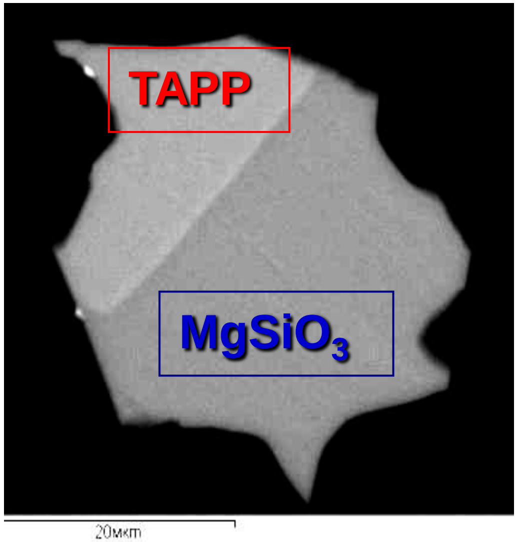
MgSi-Pv+fPer

MgSi-Pv+Ol+CaSi-Pv

MgSi-Pv+TAPP+CaSiTi-Pv







TAPP – tetragonal almandine-pyrope phase

Mineral inclusions

Majoritic Garnets $(Ca,Mg,Fe)_3(Fe,Al,Si)_2(SiO_4)_3$

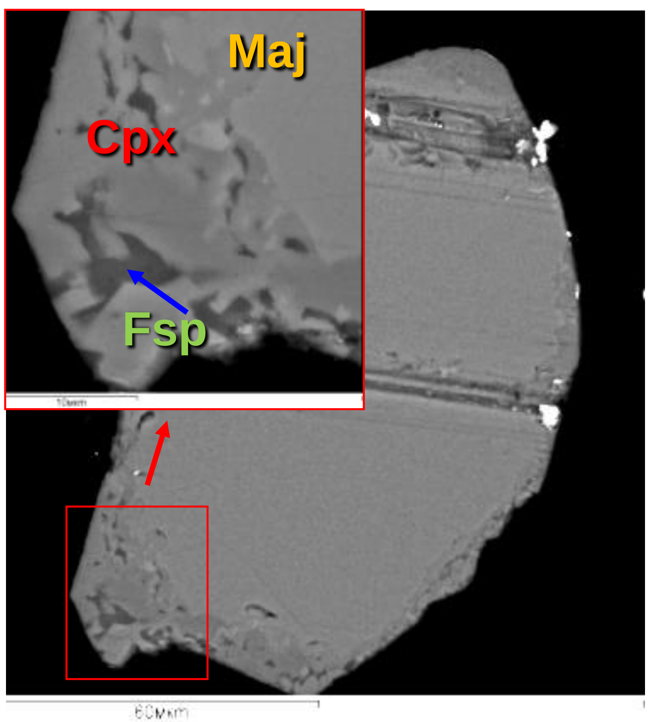
Associations

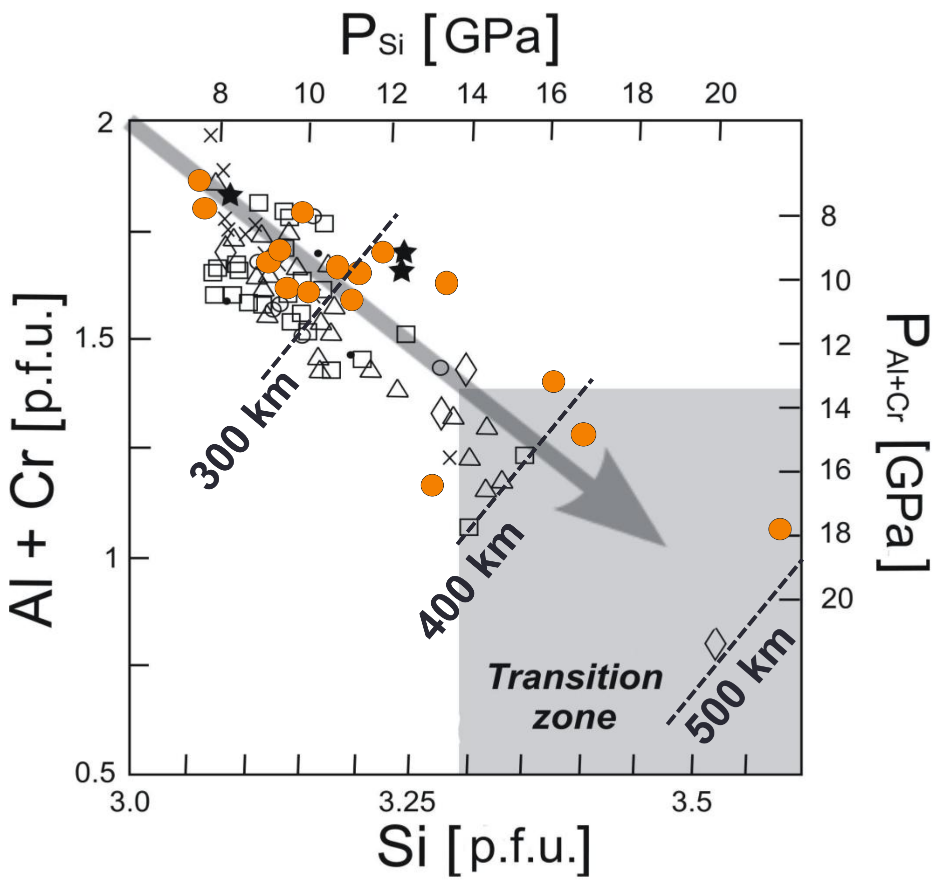
Maj-Gt+CaTiSi-Pv+SiO_2+Kya

Maj-Gt+SiO_2

Maj-Gt+CPx

Maj-Gt+Neph



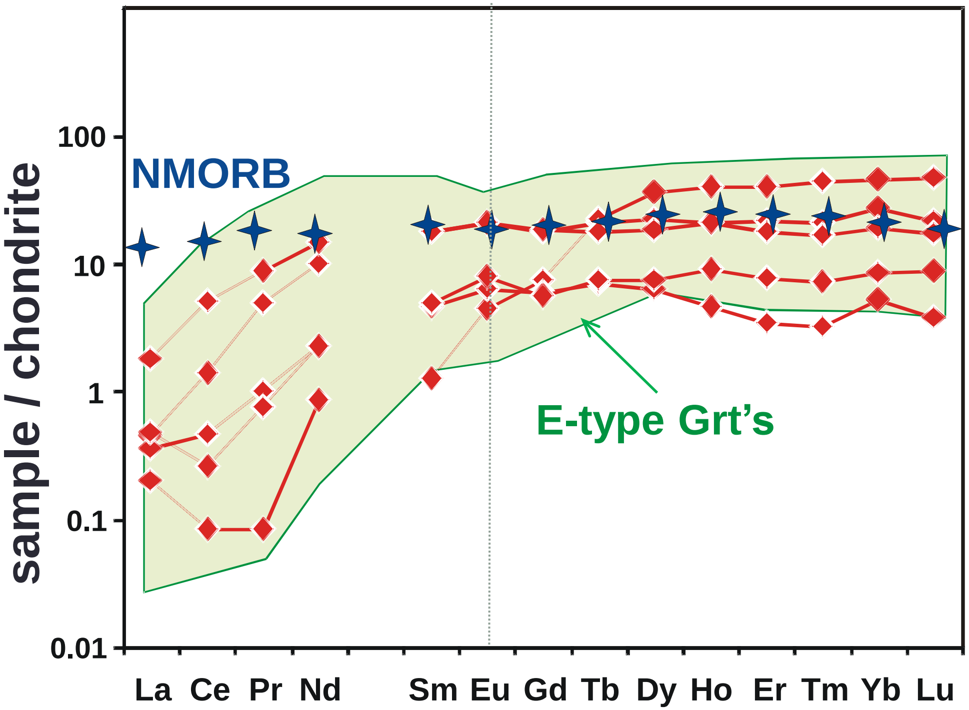


The formation of diamonds with majoritic garnets relates to the different levels of lowermost Upper Mantle and Transition Zone.

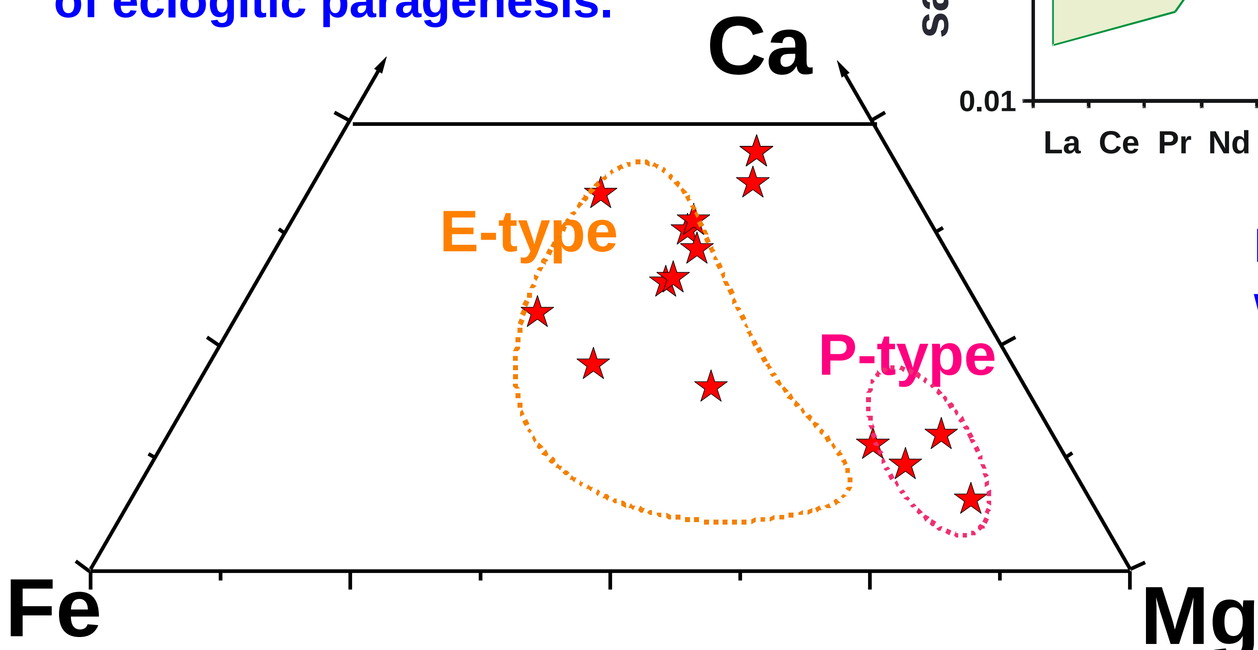
Mineral inclusions

Majoritic Garnets

$(Ca,Mg,Fe)_3(Fe,Al,Si)_2(SiO_4)_3$



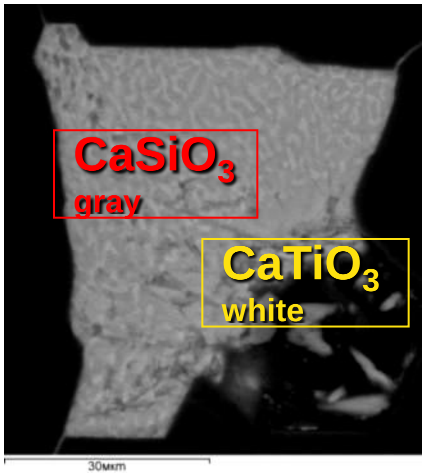
Most majoritic garnets in diamonds from Sao-Luis are of eclogitic paragenesis.

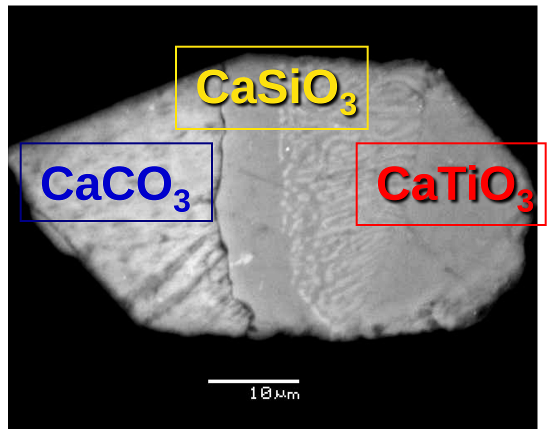


Majoritic garnets show wide range of REE.

Mineral inclusions

CaSi-perovskite (±CaTi-perovskite)



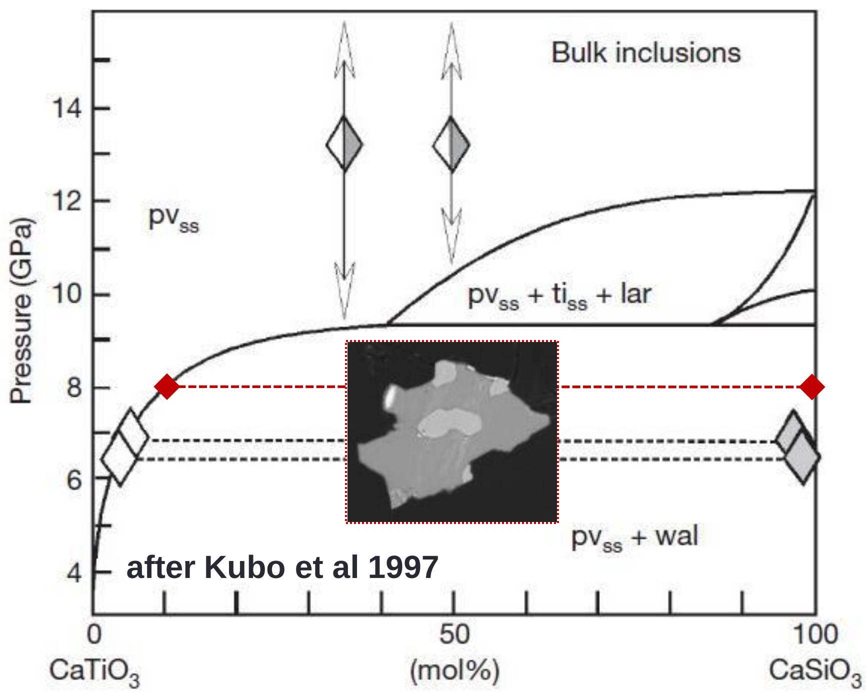


Associations

CaSi-Pv+Mrw+Ol
CaSi-Pv+MgSi-Pv+Ol
CaSiTi-Pv+TAPP+MgSi-Pv

CaSi-Pv+Maj-Gt
CaTiSi-Pv+Maj-Gt+SiO_2+FeS
CaTiSi-Pv+Maj-Gt+SiO_2+Kya
CaSi-Pv+SiO_2+AlSi-phase
CaSi-Pv+AlSi-phase

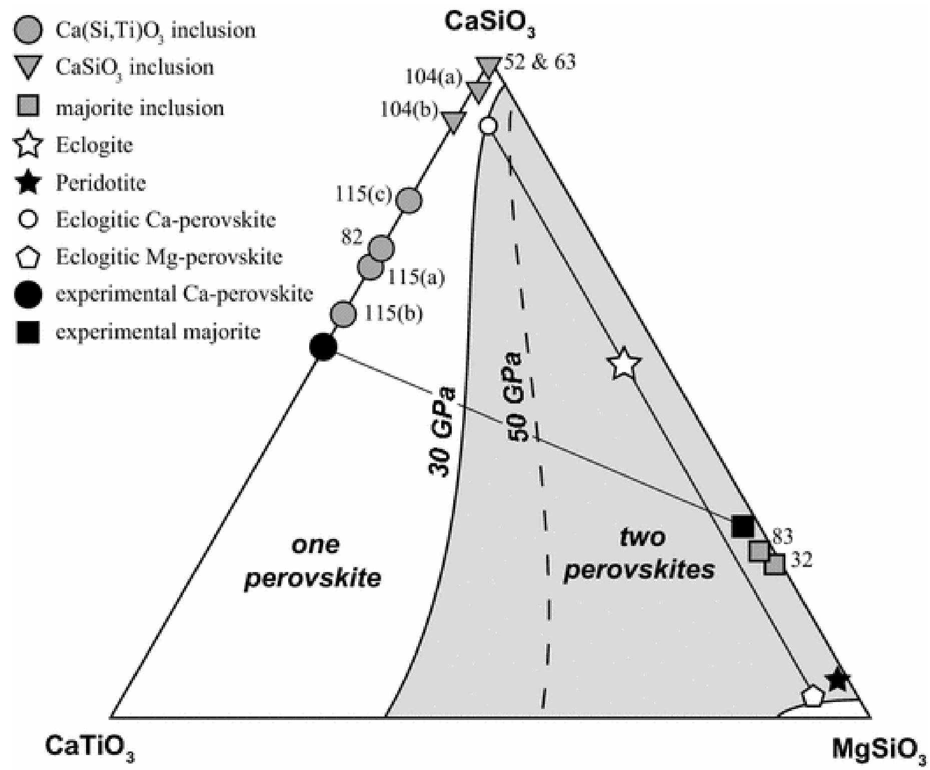
CaSi-Pv+$CaSi_2O_5$

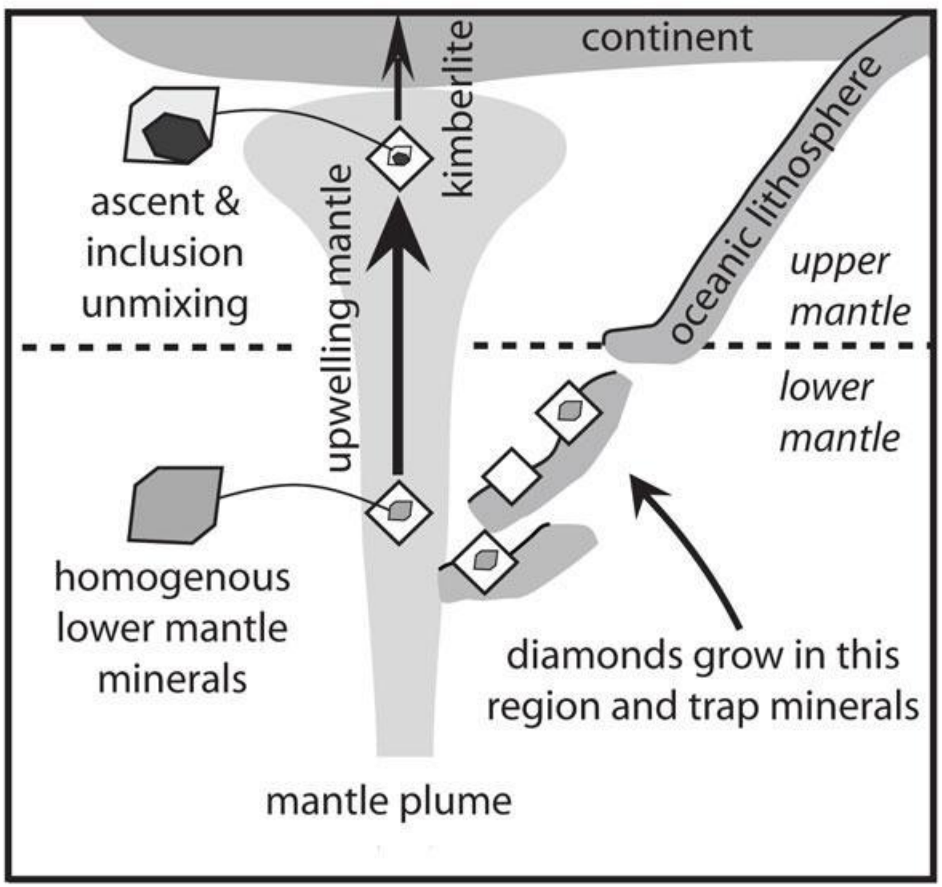


Estimated unmixing pressure ~ 9 GPa

Mineral inclusions

Ternary diagram showing the perovskite-phase relations in the system CMST (Thompson et al., 2014).

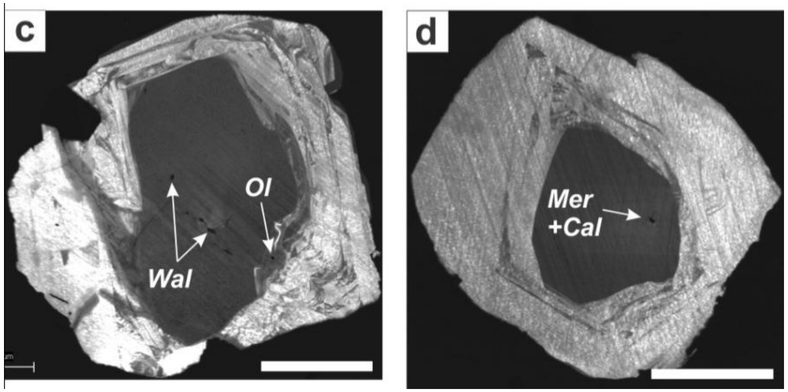


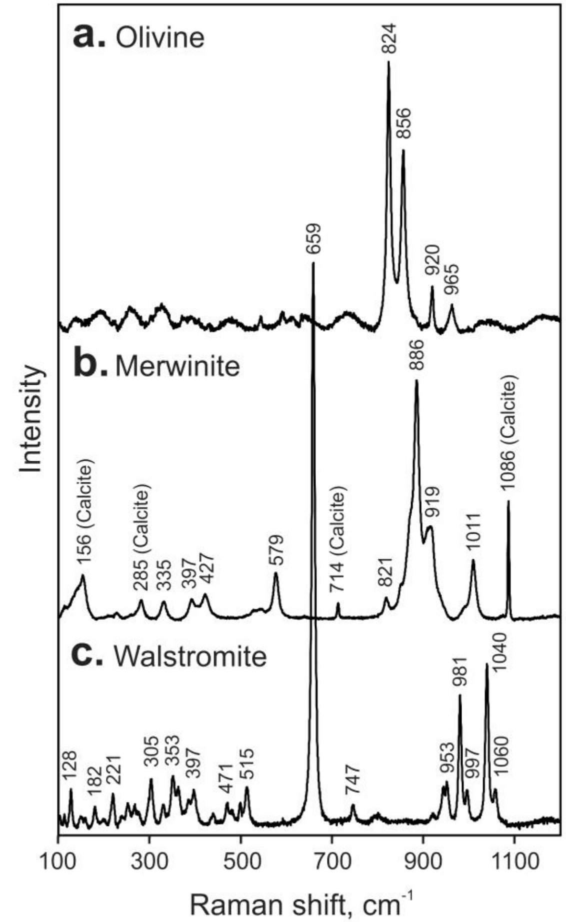


A conceptual model showing that the diamonds and inclusions form in the lower mantle in subducted oceanic crust, are then transported by mantle flow to the upper mantle, and finally to the surface in a kimberlite magma.

Mineral inclusions

Merwinite could be an apparent evidence of Ca-carbonatite metasomatism in the deep mantle.

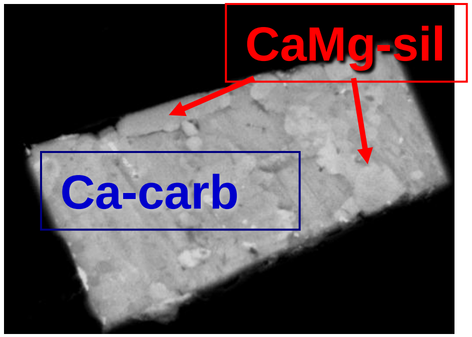




(i) $4Mg_2Si_2O_6$ **(OPx) +** $8CaCO_3$ **(Liq) =** Mg_2SiO_4 **(Ol) +** $CaMgSi_2O_6$ **(CPx) +** $Ca_3MgSi_2O_8$ **(Mw) +** $3SiO_2$ **(Liq) +** $4CaMg(CO_3)_2$ **(Liq)**

(ii) $2Mg_2SiO_4$ **(Ol) +** $6CaCO_3$ **(Liq) =** $Ca_3MgSi_2O_8$ **(Mw) +** $3CaMg(CO_3)_2$ **(Liq)**

Sharygin et al. 2014

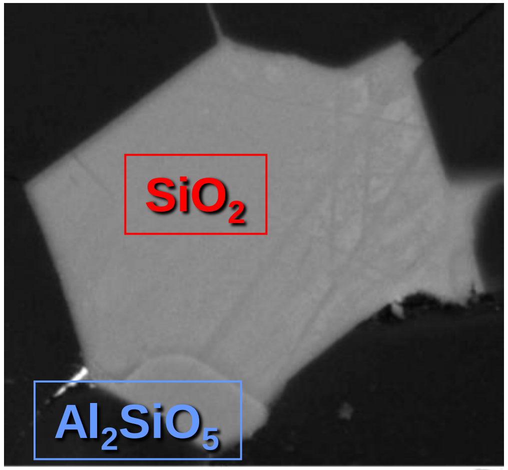


$3Mg_2Si_2O_6$ **(OPx) +** $2CaCO_3$ **(Liq) =**
$2Mg_2SiO_4$ **(Ol) +** $2CaMgSi_2O_6$ **(CPx) + 2C +** $2O_2$

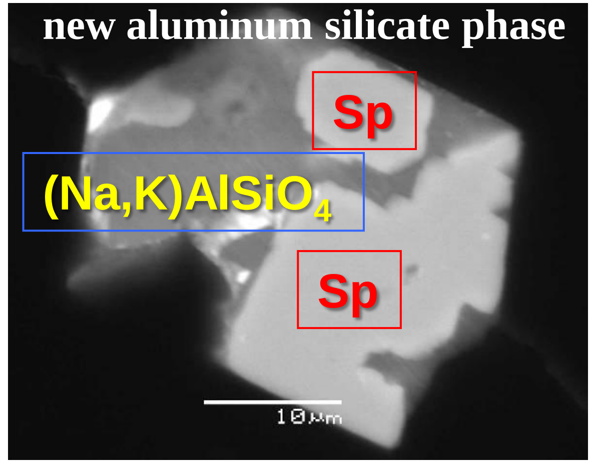
Sharygin et al. 2012

Mineral inclusions

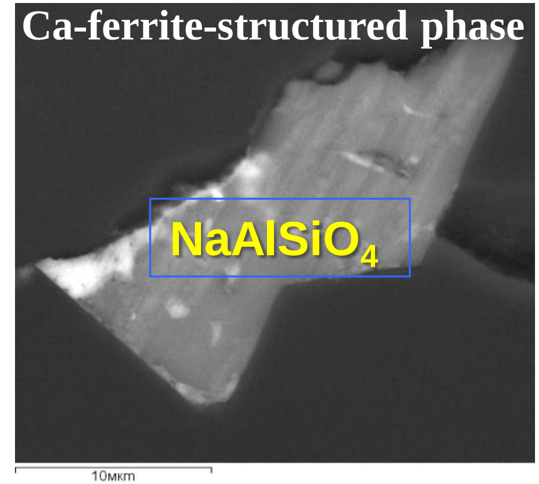
SiO_2 -phase

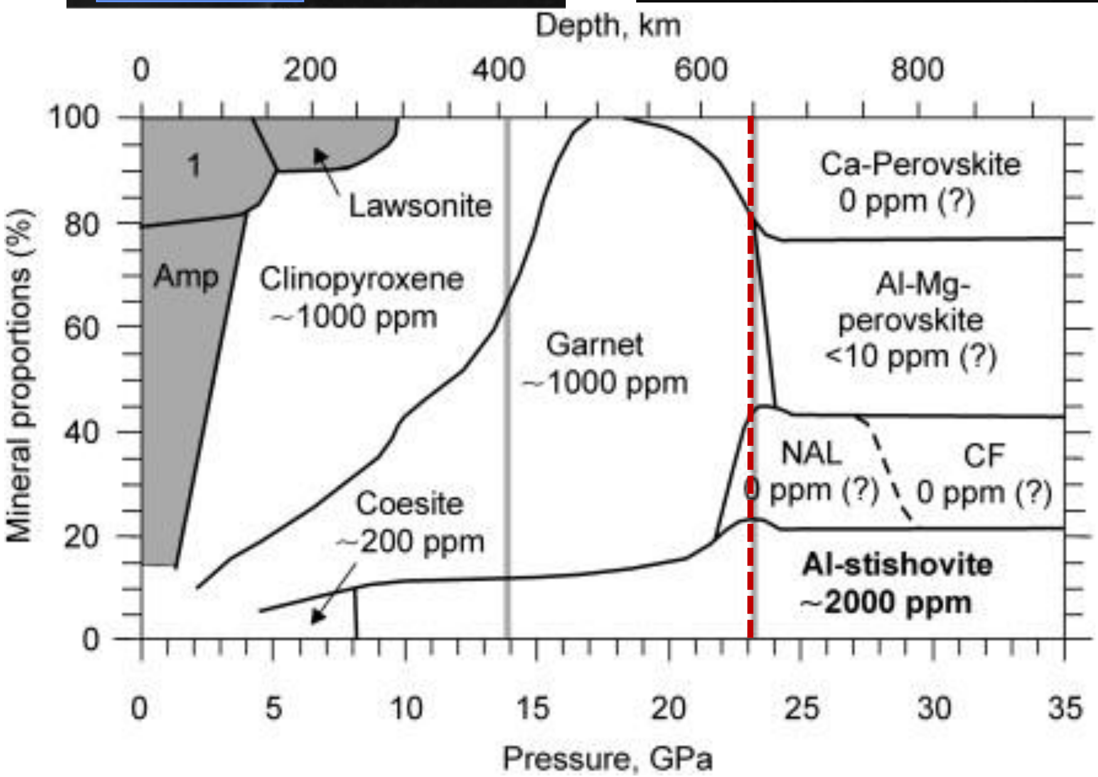


NAL



CF





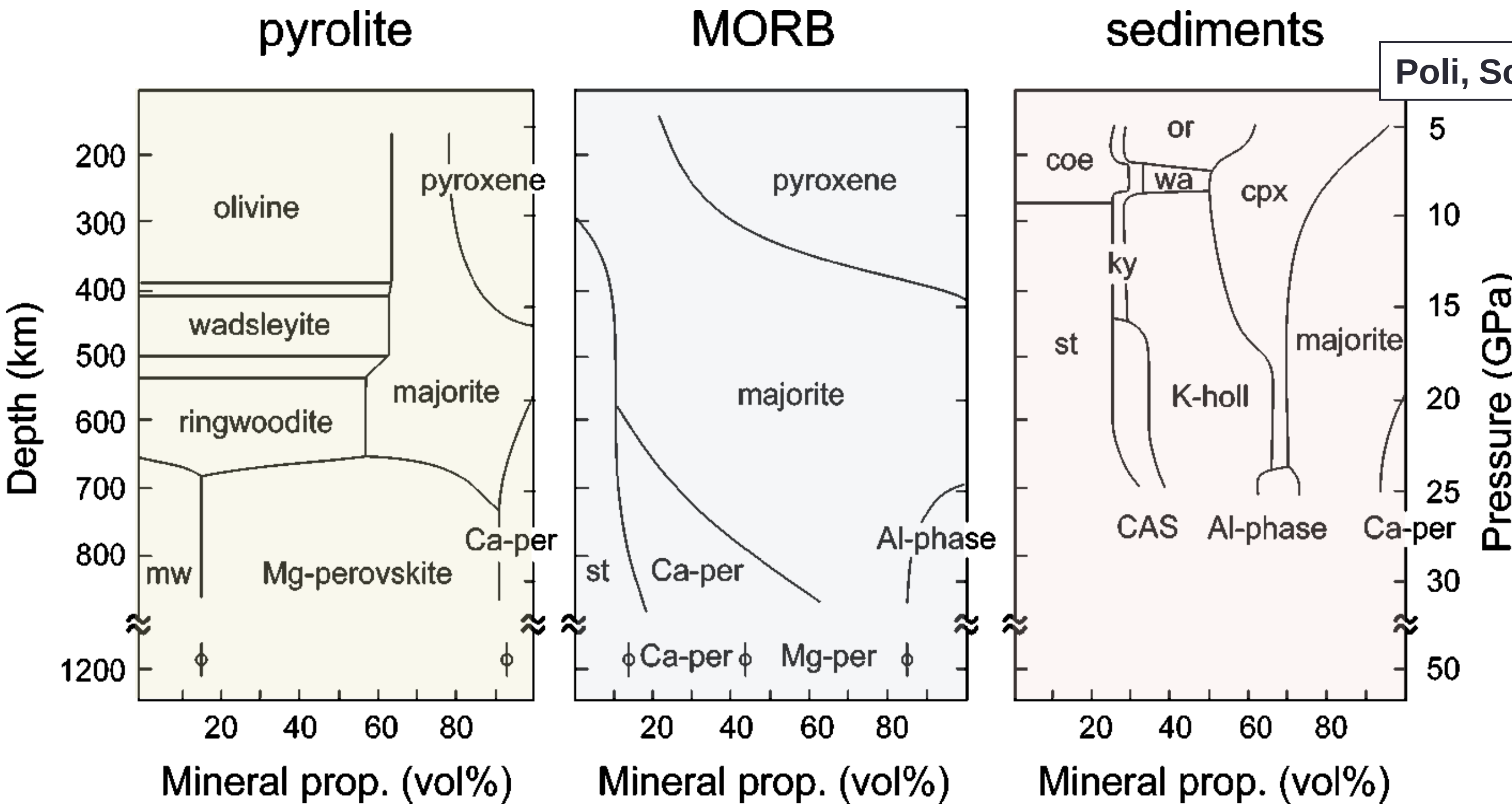
❖**Phases of CF and NAL may be formed only in oceanic crustal rocks subducted into the LM [Walter et al., 2010]**

❖**Al-stishovite is a potential "container (carrier)" of water in metabasite affinity into LM [Litasov et al., 2007]**

Mineral inclusions

Ol (Wd, Rw?), fPer, MgSi-Pv, CaSi-Pv, TAPP	Maj-Grt, Omph-CPx, CaSi-Pv, SiO_2 (St?), AlSi-phase	K-holl, CAS, CF, NAL, CaSi-Pv, SiO_2 (St?), AlSi-phase

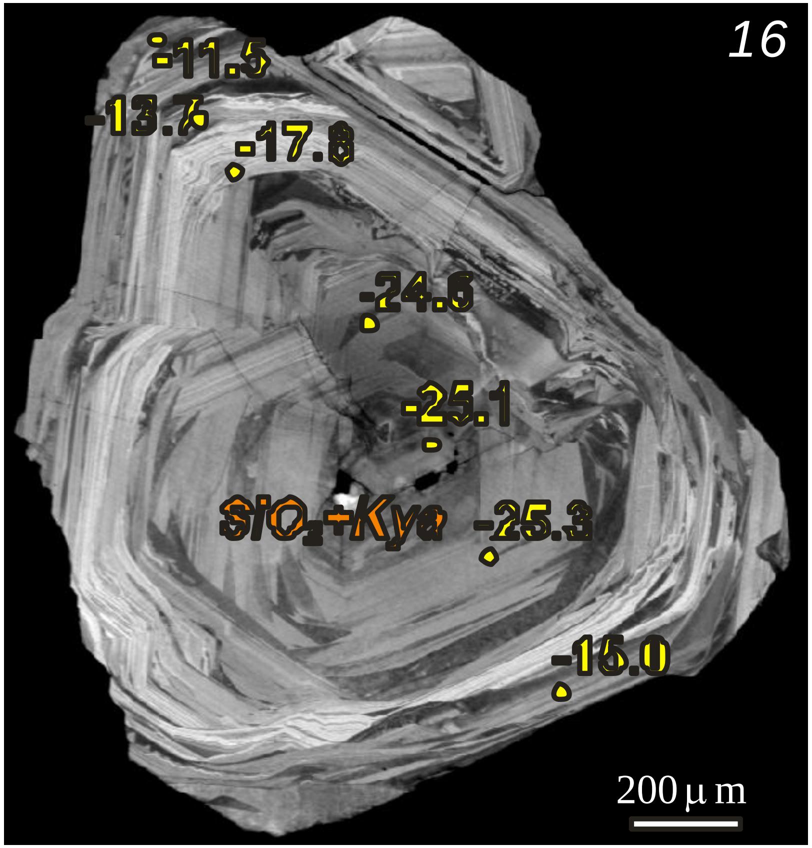
Poli, Schmidt, 2002

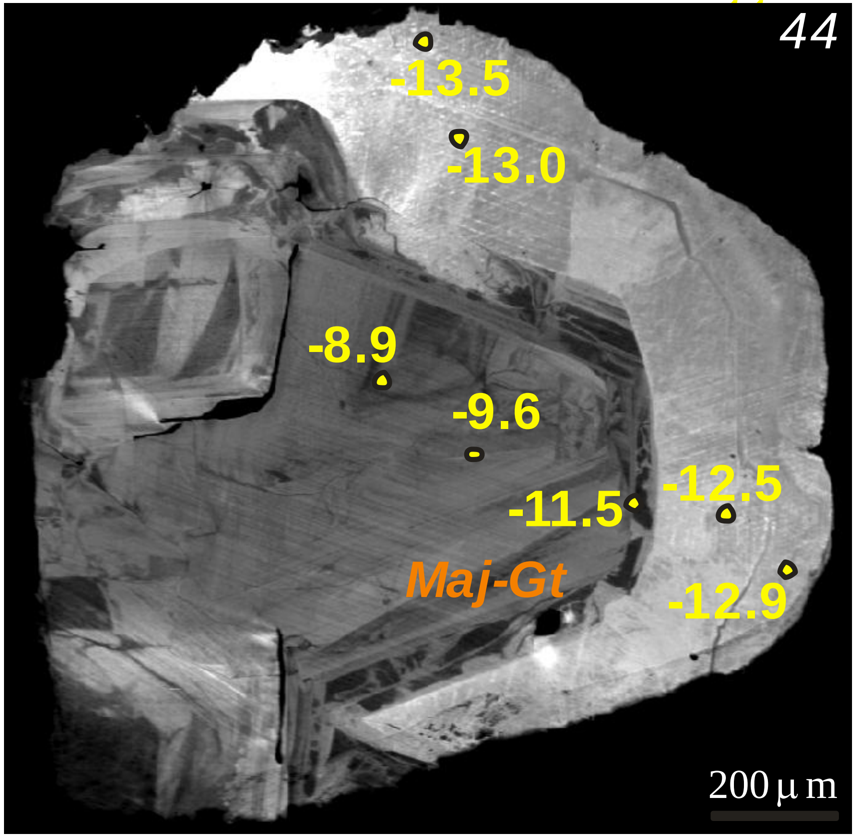


Association of CaAlSi- and SiAl-phases, K-hollandite, CF, NAL, Maj-garnets and SiO_2 correspond to experimentally founded association of deeply subducted *metasediments*.

Carbon isotope composition

CL imaging has revealed the complex growth history for most diamonds, reflecting their formation in several stages.

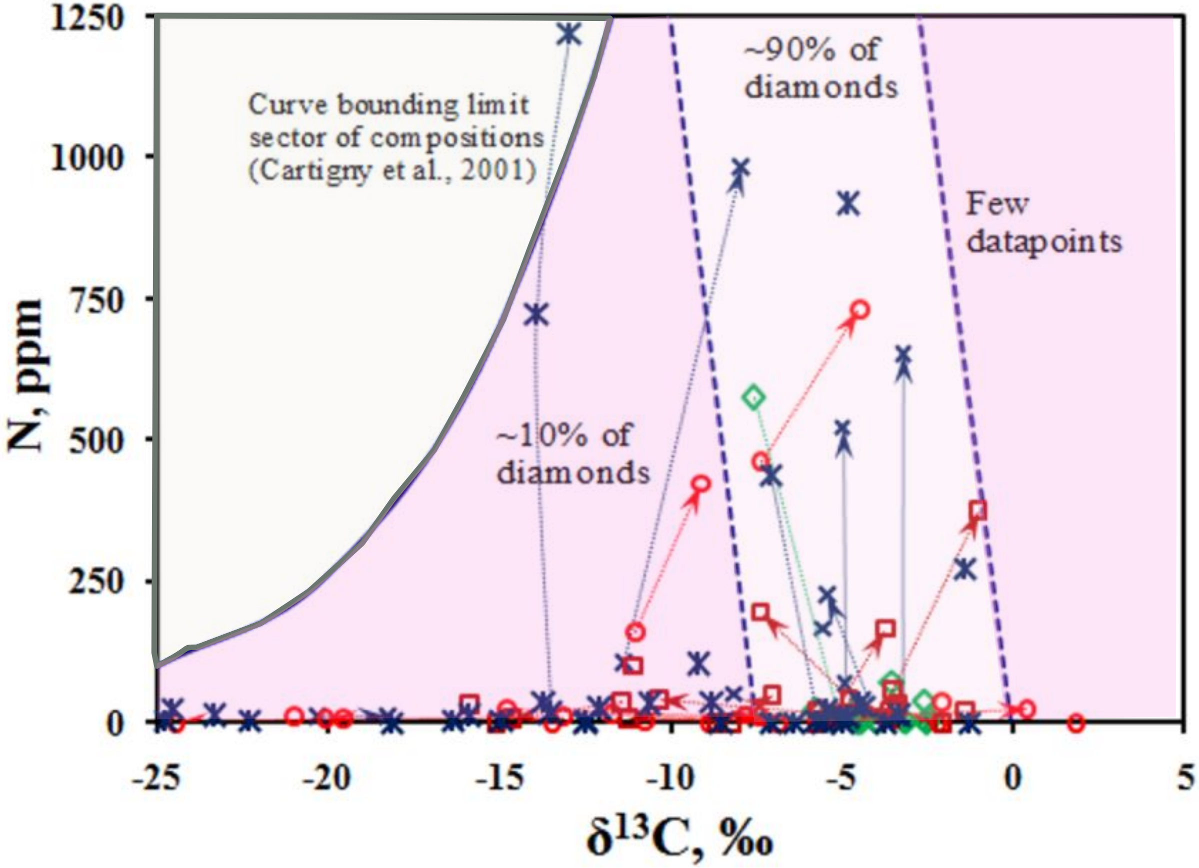




The δ[13]C measurements in core–rim traverses within some individual crystals varied substantially, indicating multi-stage growth histories.

Carbon isotope composition

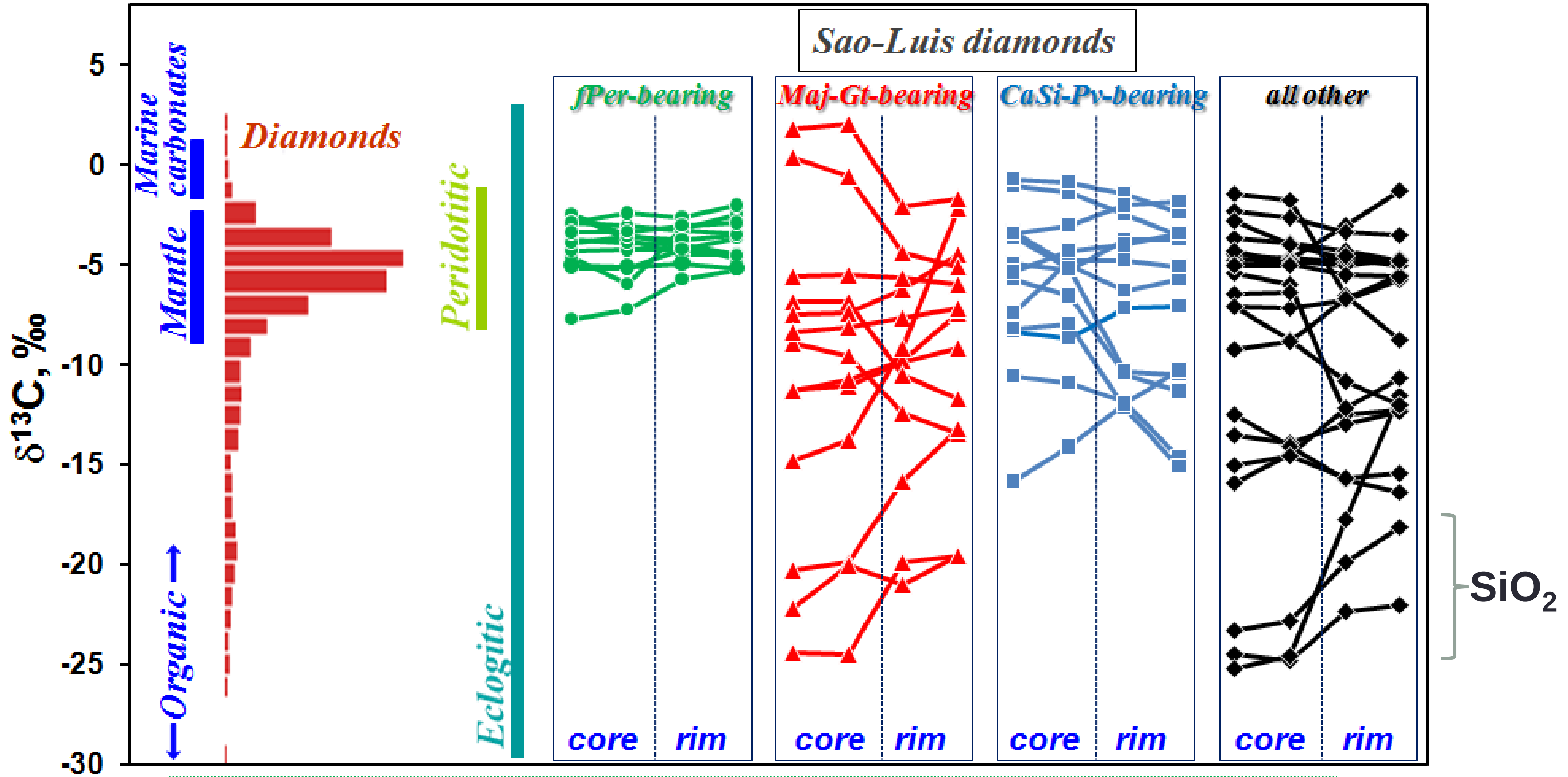
No correlation of carbon isotope composition and nitrogen content has been found in an individual diamonds.



The cores and rims of the São-Luis diamonds precipitated from *different fluids/melts* with variable N/C ratios and/or under *different growth conditions*.

Carbon isotope composition

The diamonds from Sao-Luis display wide variations of carbon isotope compositions ($\delta^{13}C$) from +2.7 to -25.3 ‰.



- Diamonds with inclusions of <u>fPer</u> ($\delta^{13}C$ -2÷-6‰)
- Diamonds with inclusions of <u>Maj-garnets</u> ($\delta^{13}C$ 2÷-25‰)
- Diamonds with inclusions of <u>CaSi-pv</u> ($\delta^{13}C$ -1÷-16‰)

Carbon isotope composition

Remarks

- ✓ The variations in $\delta^{13}C$ within individual diamonds may be attributed to either different source of carbon or fractionation effect during diamond growth.

- ✓ The highly negative $\delta^{13}C$ values in the core (-20÷-25 ‰) potentially represent *organic* matter in sediments or altered basalts, and the lower $\delta^{13}C$ values may represent mixing trends towards "normal" mantle compositions.

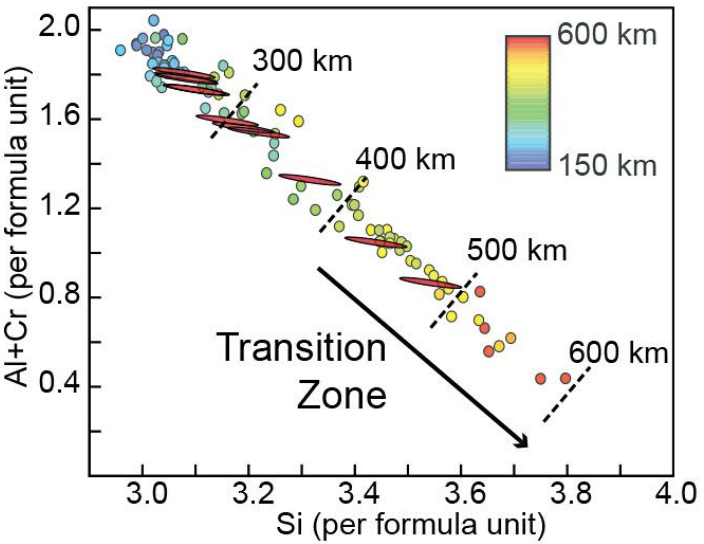
- ✓ In this study, we have also described a series of diamond which show opposite trend of change carbon source from primordial mantle to subducted/crustal (either biotic or abiotic carbon).

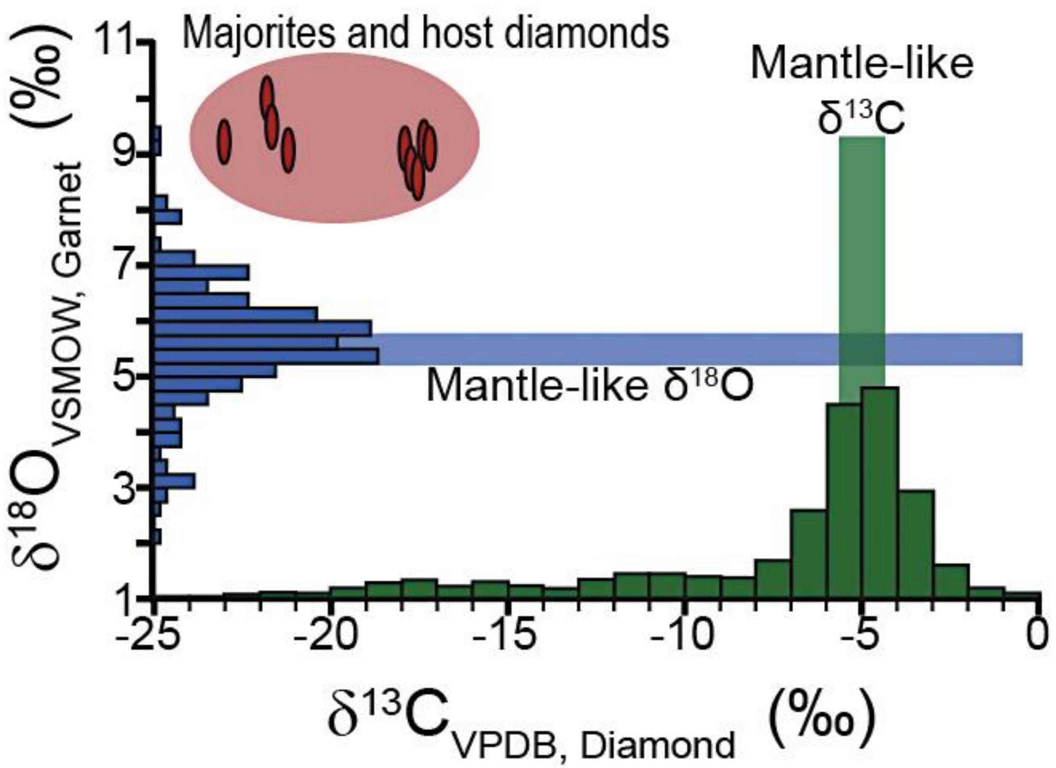
Mineral inclusions

Majoritic Garnets

$(Ca,Mg,Fe)_3(Fe,Al,$$Si$$)_2(SiO_4)_3$

Ickert et al., 2015





The majoritic garnets and their diamond hosts plot well away from the mantle field.

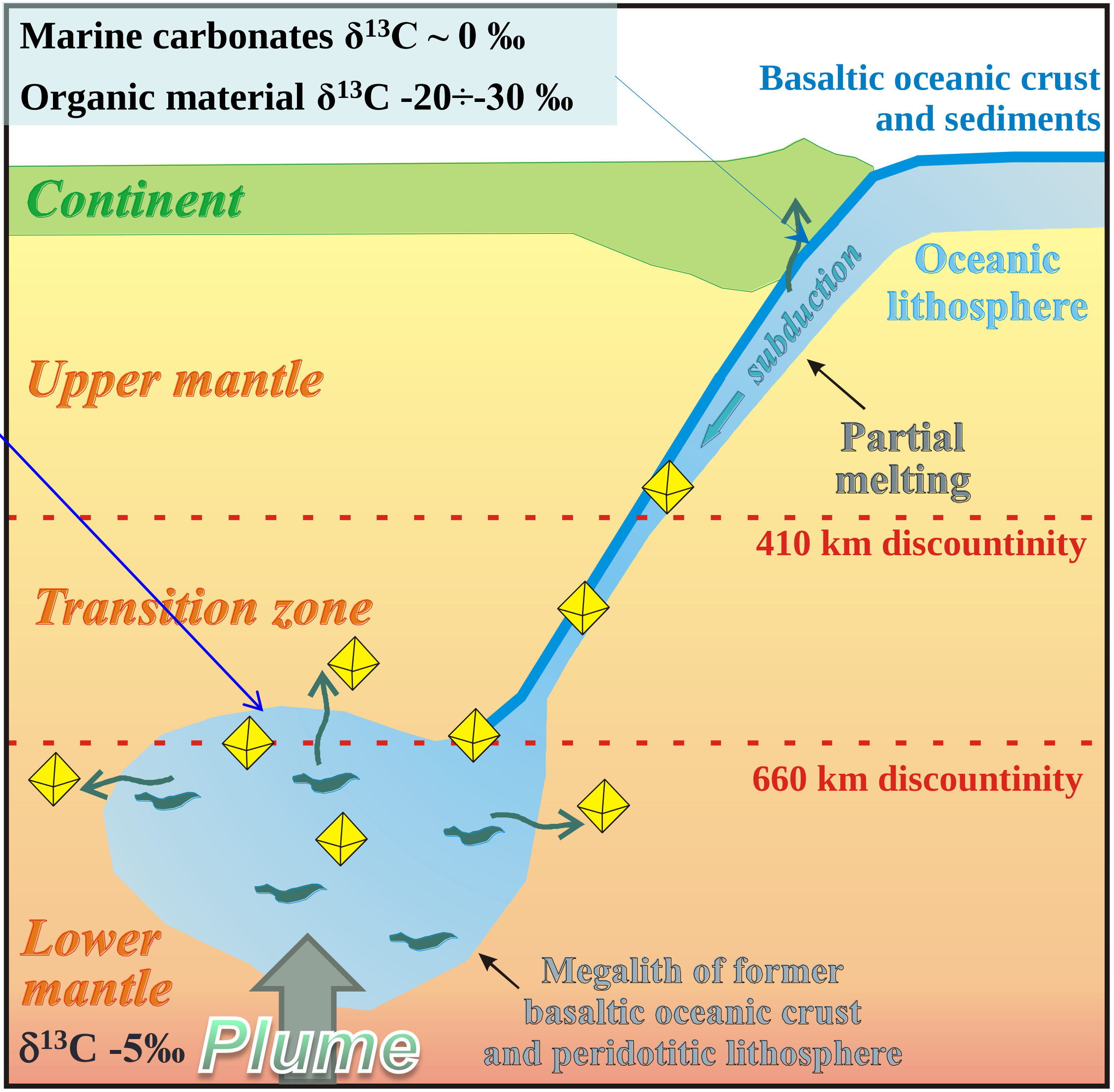
The histogram on the Y-axis is of garnets from eclogite xenoliths (compilation of Ickert et al., 2013), the histogram on the X-axis is of cratonic diamonds (Stachel et al., 2009).

Superdeep Diamonds

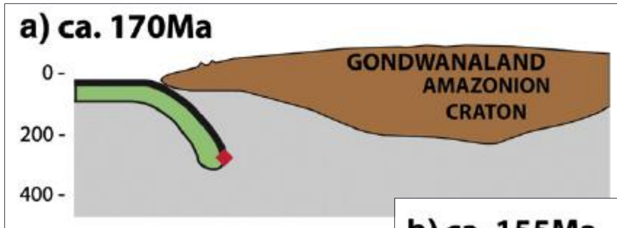
There are some evidences that *superdeep diamonds* were not derived from <u>primitive mantle</u> but from <u>former oceanic slabs</u> that accumulated at the top of the lower mantle (the "megalith model" of Ringwood, 1991).

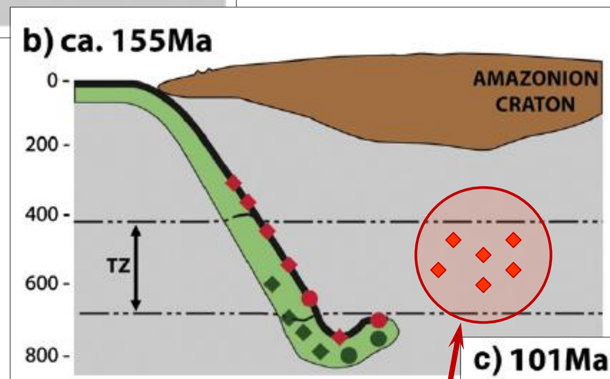
Growth media of *superdeep diamonds* are not well constrained (?)

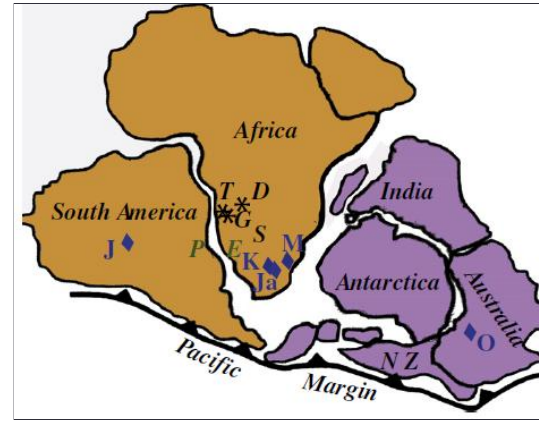
- <u>Carbonated melts</u>
  (Walter et al., 2008; Bulanova et al., 2010)
- <u>Reduced C-O-H fluids</u>
  (Davies et al., 1999; Kaminsky et al., 2001)
- <u>Both</u>
  (Harte et al., 1999; Stachel et al., 2002)



Model





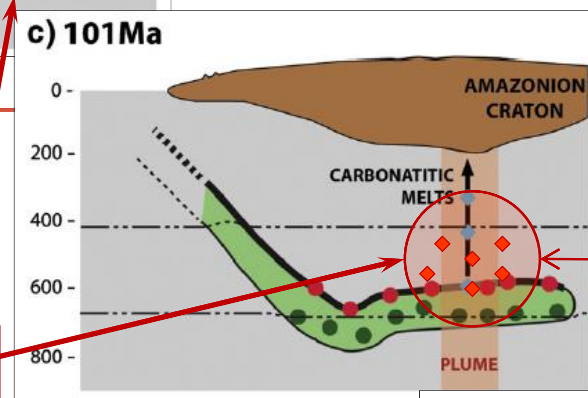


Harte&Richardson, 2011

Timing

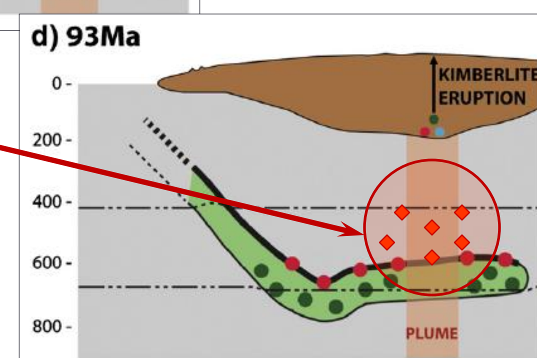
►CaTiSi-Pv Pb/U 101 Ma – Collier 4 pipe (Bulanova et al., 2009)

►Grt Nd/Sm 180-200 Ma – São-Luiz (Harte&Richardson, 2011)



Remnants of Cambrian slab

☺Zrn Pb/U 460-465 Ma;
Rt Pb/U 418-512 Ma (this study)



✓Most probable source for *Ca-silicate environments* might be carbonatitic melts/fluids from deeply subducted oceanic lithosphere.

✓*Fe-rich reduced environments* might be formed in the D″ layer at the CMB uplifted in plume.

Conclusions

❖Superdeep (sublithospheric) diamonds from São-Luis were formed at different mantle levels (lowermost UM, TZ and LM) over a long period of time.

❖The mineral assemblages described in this study reveal metabasic lithology as a major (but not only) source of superdeep (sublithospheric) diamonds from São-Luis.

❖Superdeep (sublithospheric) diamonds from São-Luis often have complex growth histories, reflecting several separate growth events. The range of carbon isotope composition is from 2.7 to -25.3 ‰ ($\delta^{13}C$):

(i) The lowest values potentially represent organic matter in sediments or altered basalts subducted to the TZ and LM, and the higher values may represent mixing trends towards normal mantle compositions.

(ii) Some superdeep diamonds have initiated their growth in the LM and following slow uplift in a convective mantle have equilibrated in the TZ, and in doing so show another evolution in carbon isotopic composition.