Carbon-rich melts in the Earth’s deep mantle

Adrian P Jones*
University College London
United Kingdom

*acknowledgments Artem Oganov (Stonybrook)

Carbonate melts/magmas

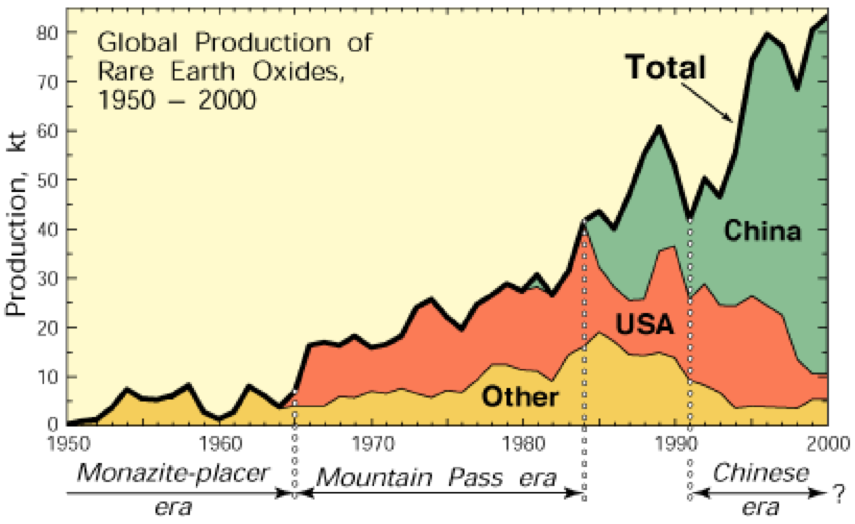
- Carbonatites, special properties
  - geophysical, geochemical properties, abundance, origin, distribution
- Are these unusual properties expected to be the same in the deep mantle?
- Review of carbonatite features
  - new dolomite, magnesite volcanism in Europe (see DK Bailey recent publications)
- New predictions for deep mantle carbonate melts

Carbonatites

- RARE , low volume
  - n = ~520, age 2.5 Ga to recent
- Active volcano Oldoinyo Lengai, Tanzania Africa
- Natroarbonatite, alkali-rich Ca-Na-K
- **Very low melt viscosity**
- low melting temperature
- Geochemical affinity for Ba, Sr, P, and **REE**
- Different carbonatites and origins
- Some carbonatites contain diamond (>5 GPa)
- Mg-rich carbonatites have Cr-spinel

Carbonatite chemistry example- REE

- Rare Earth Elements highest concentration in any terrestrial rocks = REE carbonatite



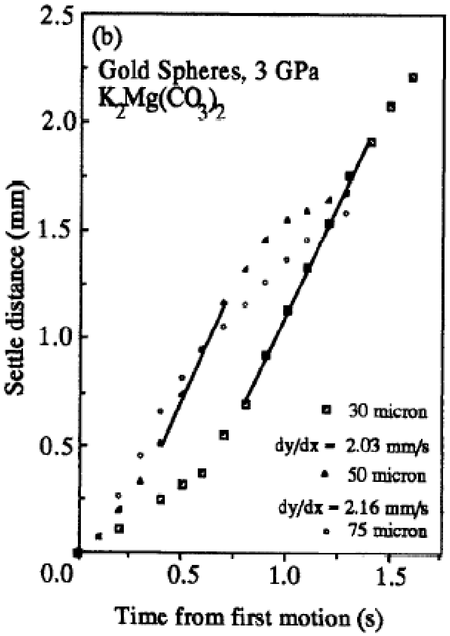
- Rare Earth Minerals: Chemistry, origin and ore deposits (1996) Edited by A.P. Jones, F. Wall and C.T. Williams *Mineralogical Society London*
- **Jones AP Wyllie (1983) Low-temperature glass quenched from a synthetic, rare earth carbonatite; implications for the origin of the Mountain Pass Deposit, California Economic Geology 78, 1721-3**
- **Valuable economic mining of mantle carbon, with up to 10wt% REE**
- **REE-rich = low temperature fractionated products, not primary liquids**

Data: Measured carbonate melt viscosity

- Field measurement of erupting lava (alkali carbonate)
- High PT experiments with synchrotron (X-ray) 2 to 5.5 GPa, 800-1500°C
  - Dobson, Jones et al 1996 EarthPlanetaryScienceLetters 143, 207-215

10^{-2} to 10^{-3} PaS

Lowest viscosity magma



Carbonate melt mobility

carbonate melt	silicate melt

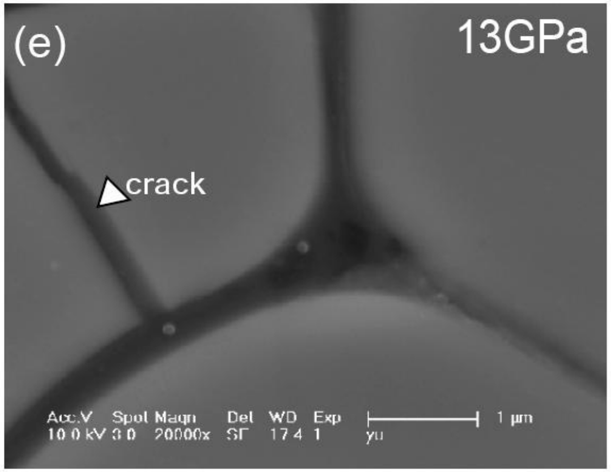
carbonate melt

- Low viscosity
- density/bouyancy
- wetting/surface tension

silicate melt

dynamic separation

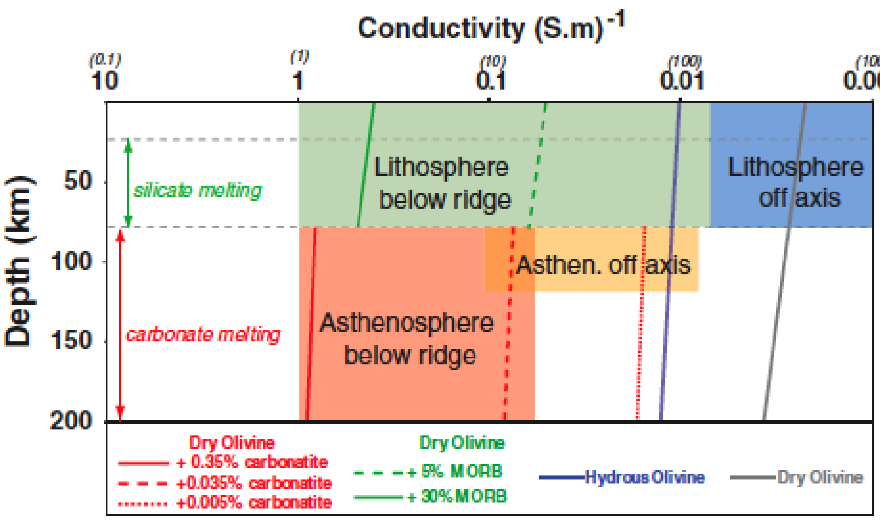
- immiscibility
- accumulation
- filter pressing
- dihderal angle



Electronic properties of carbonate melt

- Electrical high conductivity
- small melt fractions detected by deep geophysics?
- implications for distribution of carbon

- Highest electrical conductivity



- $MgCO_3 = MgO + CO_2$ or C wt% 12%

- Local concentration of C in mantle >10%?

- Gaillard et al Science 2008 322. Carbonatite melts ..in the asthenosphere.

Predicted carbonate melt properties

- Extrapolation from upper mantle 5 GPa data
- Results do not match new predictions

- Carbonate crystalline structures at high P T
- Carbonate melt viscosity at high P T

- Lower mantle carbonate melt structures

carbonate mineral stability

Method	carbonate range

Method

- natural mineralogy
  - mantle xenoliths
  - carbonatites
  - diamond inclusions
- experimental petrology
  - large volume press
  - synchrotron and HP
  - diamond anvile cell
- theoretical crystallography
  - modelling

carbonate range

- **CaCO3**
- **MgCO3**
- BaCO3
- SrCO3
- (FeCO3)
- (RECO3)

Summary of high pressure carbonate phases*

	Pressure increases →						
	$(CO3)^{2-}$ triangles			$(C_3O_9)^{6-}$ rings of tetrahedra		Chains of CO_4-tetrahedra	
	Calcite CN(M)=6	Aragonite CN(M)=9	Post-aragonite CN(M)=12	Phase II CN(M)= 8 and 10	Phase III CN(M) = 8 and 10	$Pna2_1$-20 CN(M)=9	$C222_1$ CN(M)=10
$MgCO_3$	0–82 GPa	–	–	82–138 GPa	138–160 GPa	>160 GPa	?
$CaCO_3$	0–2 GPa	2–42 GPa	42–137 GPa	–	–	–	>137 GPa
$SrCO_3$	–	0–10 GPa	>10 GPa	–	–	–	?
$BaCO_3$	–	0–8 GPa	>8 GPa	–	–	–	–

n's coordination number.

At pressures > 82 GPa structure of dominant MgCO3 is predicted to change from $(CO3)^{2-}$ **triangles** to $(C3O9)^{6-}$ **tetrahedra**.
Superdeep carbonates (post magnesite phases II and III) share some structural similarity with perovskite silicates.

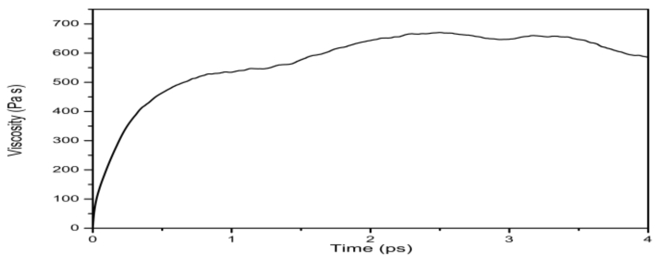
*__Oganov__ *AR, Ono S, Yanning M, Glass CW and Garcia A(2008) Novel high-pressure structures of MgCO3, CaCO3 and CO2 and their role in the lower mantle. Earth and Planetary Science Letters volume 273, p 38-47*

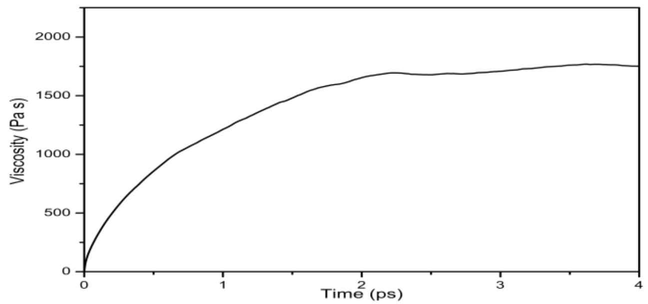
Oganov viscosity calculations

- Jones and Oganov mantle carbonate melt viscosity - *manuscript in preparation.*

- First calculated viscosities for lower mantle carbonate **liquids** ($MgCO_3$ and $CaCO_3$); calculations approach assymptotic limit.

- Graphs for viscosity calculated at 120 Gpa (post magnesite) carbonate liquids.

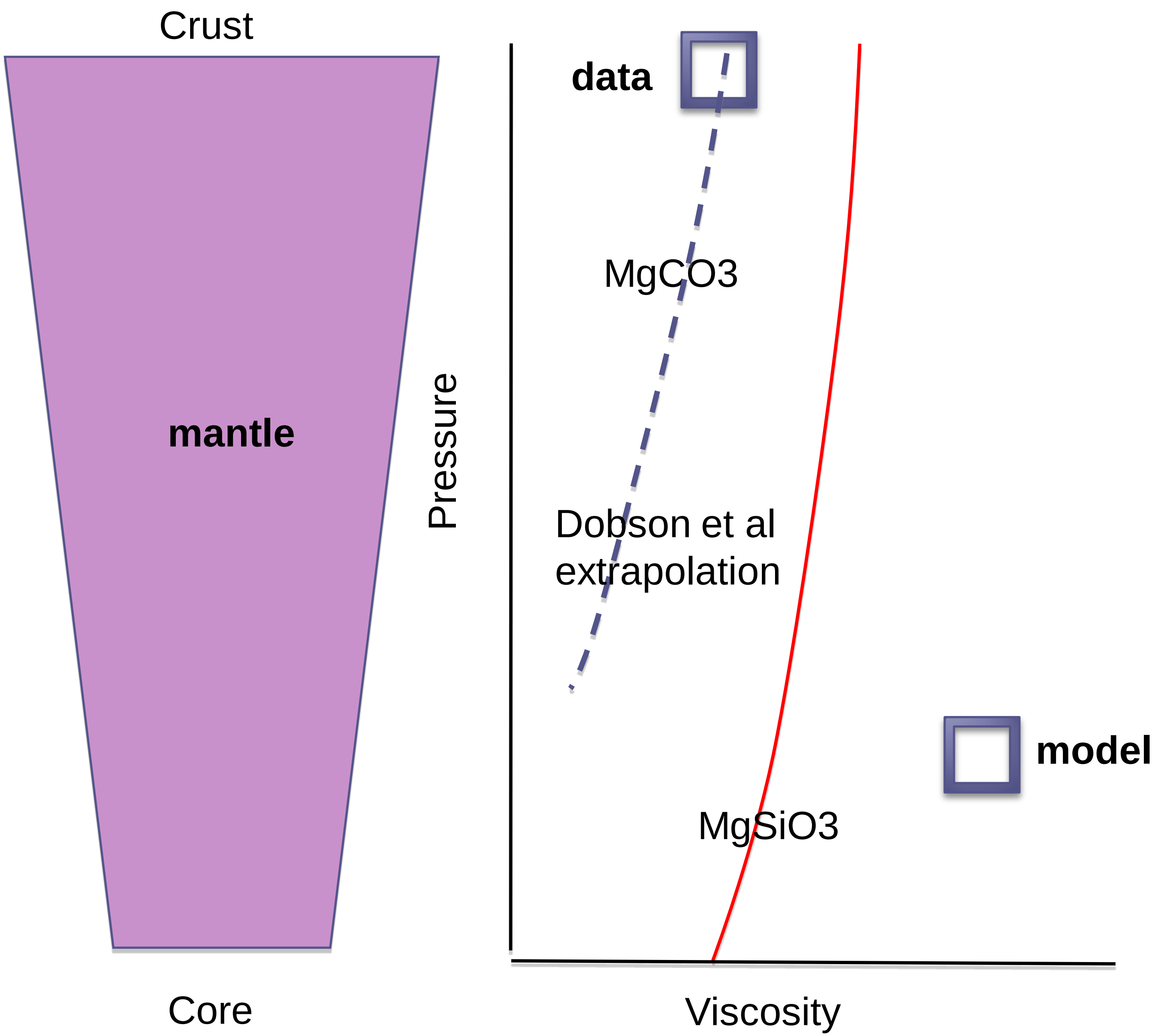


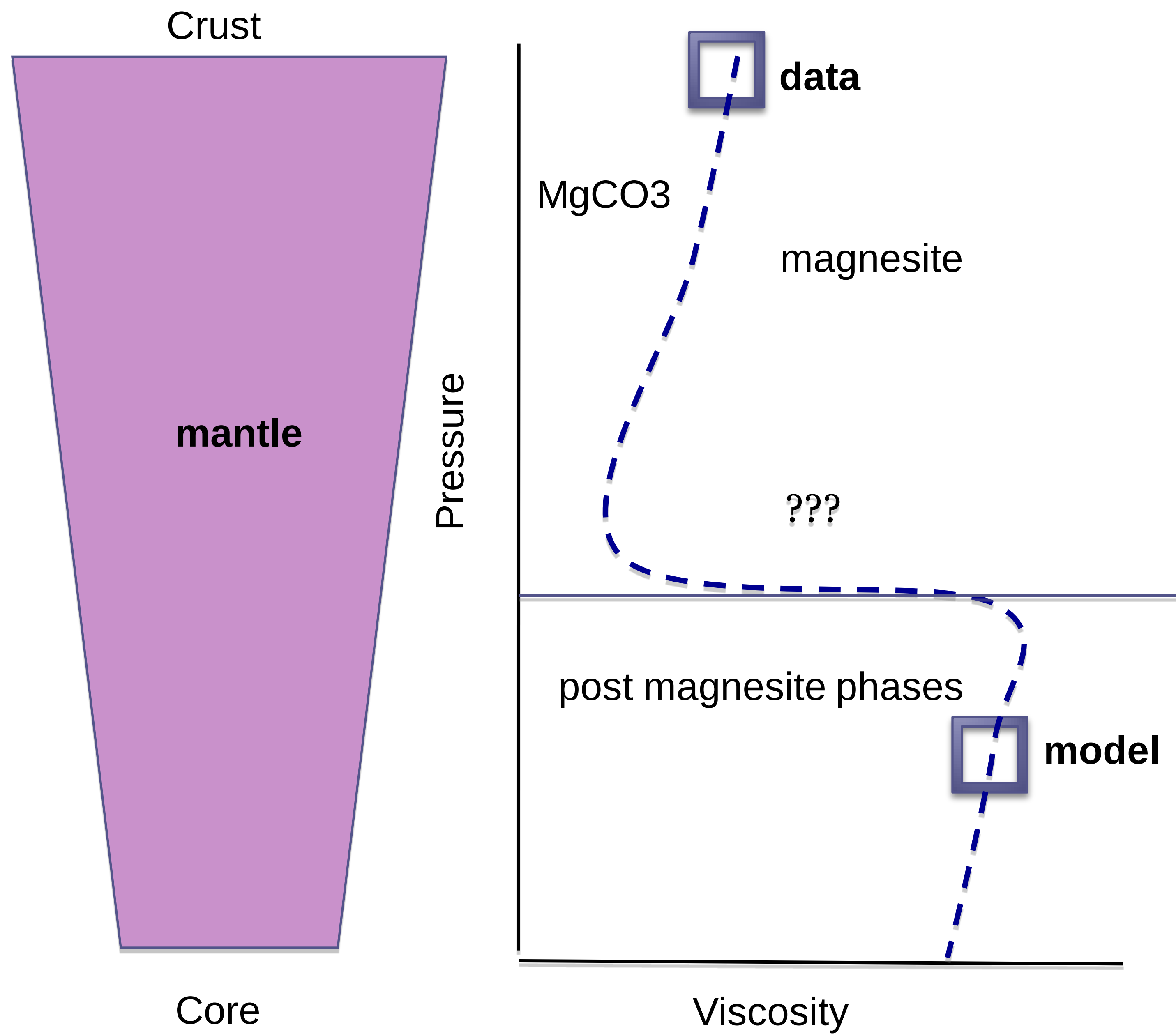


High P carbonates (Mg, Ca)

0-2 GPa	2-42 GPa	42-80 GPa	80-120 GPa	120-140 GPa
Calcite	Aragonite	PostAragonite	PostAragonite	
(Dolomite)				
Magnesite	Magnesite	Magnesite	PostMagnesite	PostMagnesite

→ "superdeep carbonates"


Crust
mantle
Core
Pressure
data
MgCO3
Dobson et al
extrapolation
model
MgSiO3
Viscosity


Crust
mantle
Core
Pressure
data
MgCO3
magnesite
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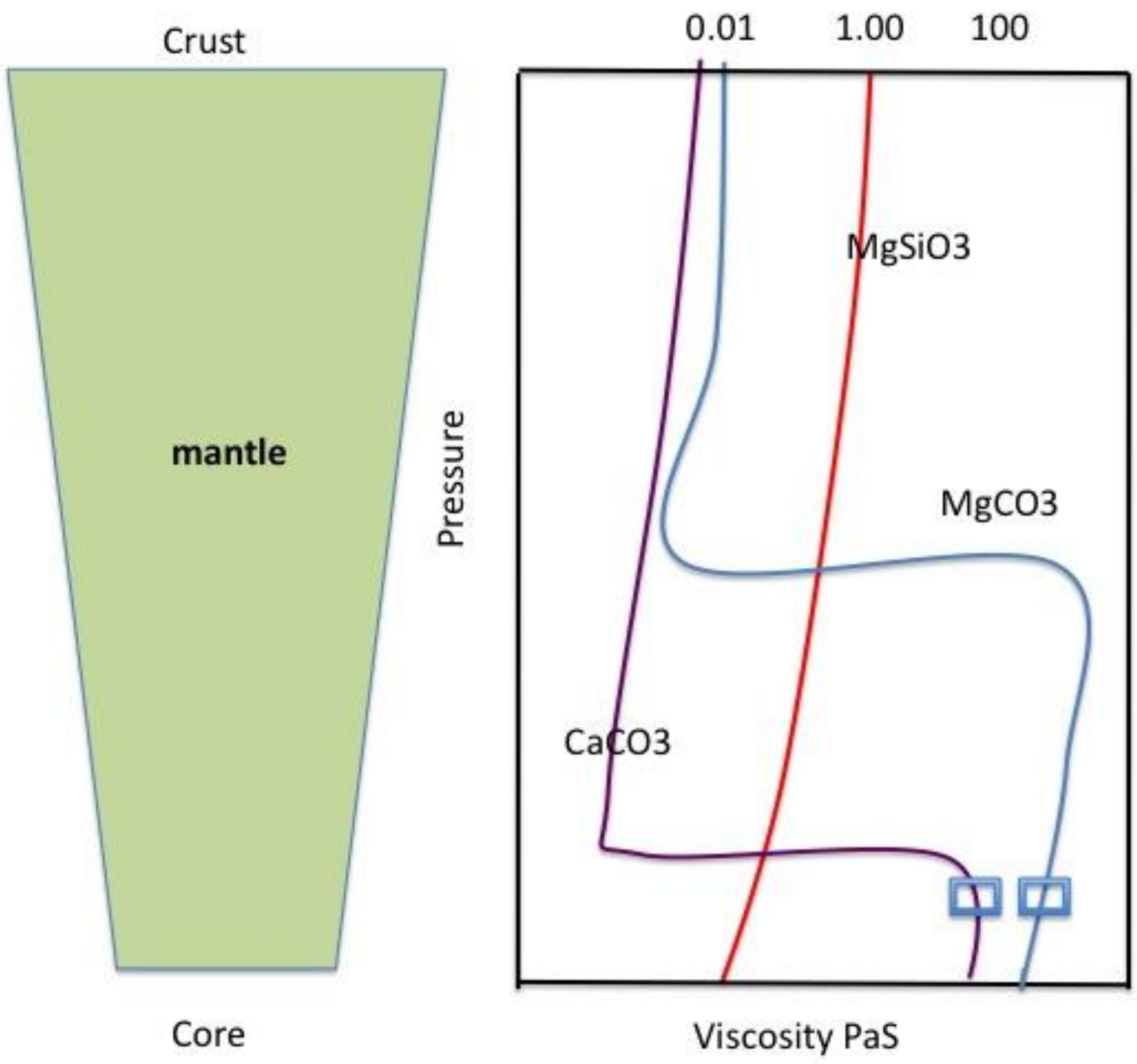
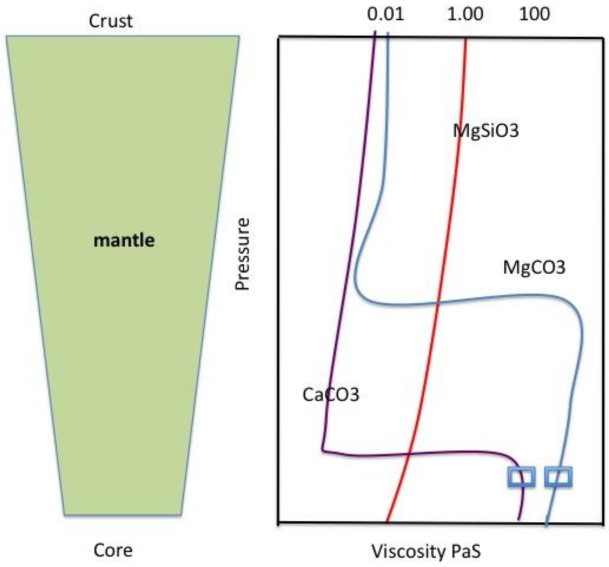
post magnesite phases
model
Viscosity

Carbonate melt viscosity schematic



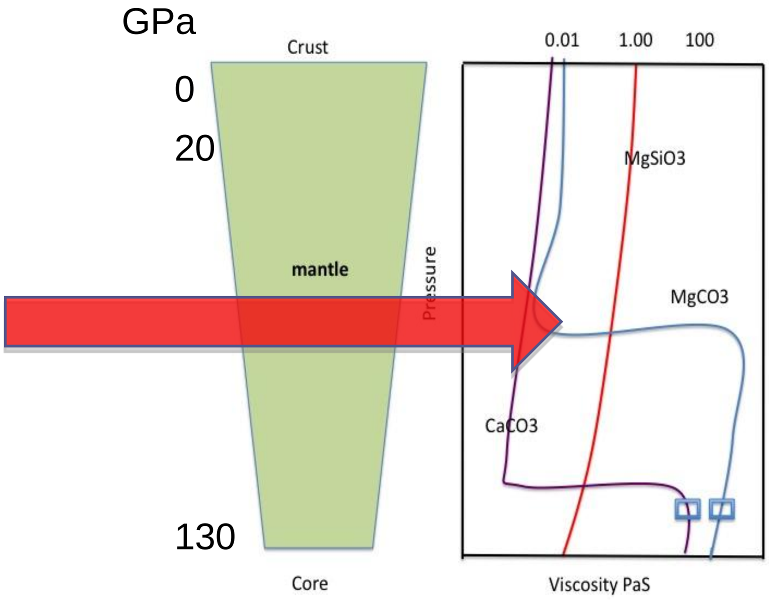
Lower mantle carbonate melt - predict very high viscosity?

- **Viscosity cross over** compared to mantle silicate melts
- Lower mantle carbonate melt much **more viscous** than silicate melts
- Very different to upper mantle carbonate melts and **NOT like** carbonatites?
- **Superdeep carbonate** solids and melts at >80 GPa possible carbon reservoirs



- Carbonates in the mantle maybe split into two zones, constrained by the predicted **crossover** in melt behaviour between carbonate melts and silicate melts.
- Upper carbonatites (very low viscosity) highly mobile
- Superdeep carbonate melts (high viscosity) immobile, possible reservoirs for deep carbon storage

Dynamic Earth model - carbonate



Conclusions

- Low pressure carbonate melts with **low viscosity** are expected to share geophysical and geochemical characteristics with carbonatites.
- Deep lower mantle (“superdeep”) carbonate melts are predicted to have very **high viscosity** and could be immobile compared with silicate melts.
- Mantle convection (or plumes) rising through the melt crossover at ~80 GPa could trigger phase separation of carbonate melts.
- New HPHT experiments and modelling are needed to validate these predictions.