

Carbon-rich melts in the Earth's deep mantle

Adrian P Jones*
University College London
United Kingdom

*acknowledgments [Artem Oganov](#) (Stonybrook)

Carbonate melts/magmas



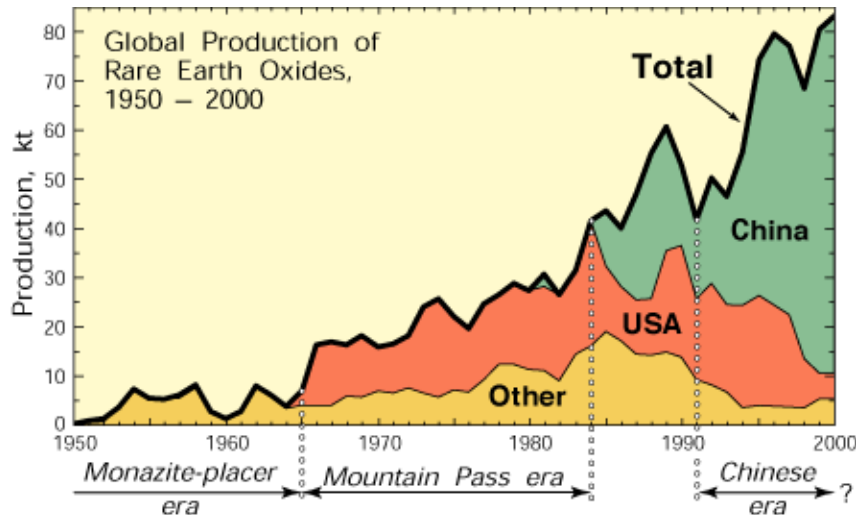
- Carbonatites, special properties
 - geophysical, geochemical properties, abundance, origin, distribution
- Are these unusual properties expected to be the same in the deep mantle?
- Review of carbonatite features
 - new dolomite, magnesite volcanism in Europe (see DK Bailey recent publications)
- New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

Carbonatites

- RARE , low volume
 - $n = \sim 520$, age 2.5 Ga to recent
- Active volcano Oldoinyo Lengai, Tanzania Africa
- Natrocarbonatite, 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

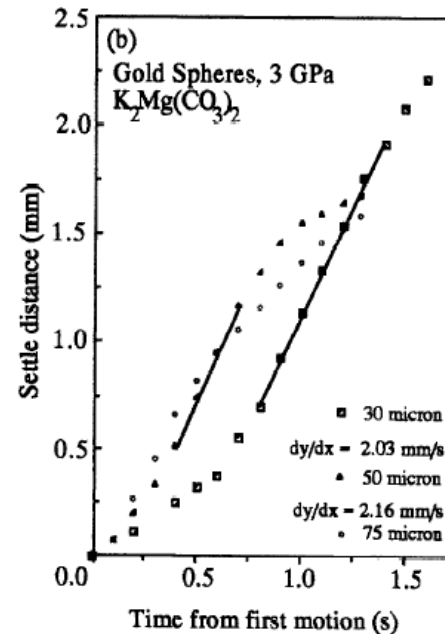
Data: Measured carbonate melt viscosity

- 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

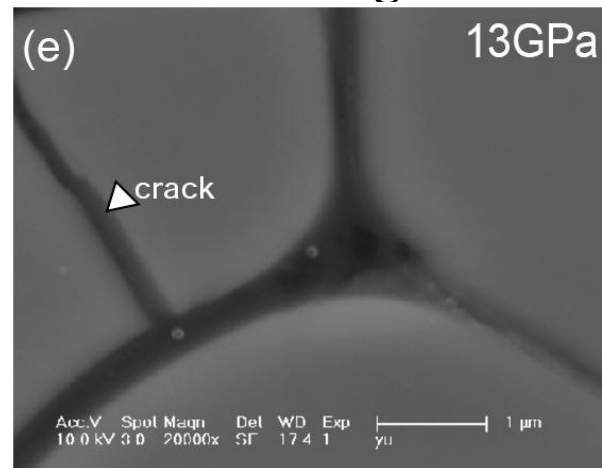
carbonate melt

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



silicate melt

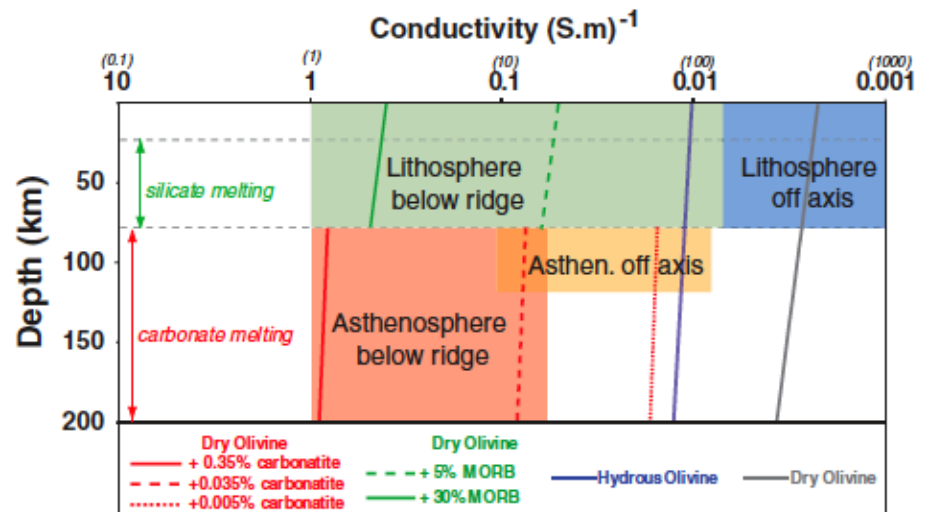
- dynamic separation
- immiscibility
- accumulation
- filter pressing
- dihderal angle



Electronic properties of carbonate melt

- Electrical high conductivity
- small melt fractions detected by deep geophysics?
- implications for distribution of carbon
- $\text{MgCO}_3 = \text{MgO} + \text{CO}_2$ or C wt% 12%
- Local concentration of C in mantle >10%?
- Gaillard et al Science 2008 322.
Carbonatite melts ..in the asthenosphere.

- Highest electrical conductivity



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

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

carbonate range

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

Summary of high pressure carbonate phases*

| | Pressure increases + | | | (C ₃ O ₉) ⁶⁻ rings of tetrahedra | | Chains of CO ₄ -tetrahedra | |
|-------------------|--|----------------------|----------------------------|--|-------------------------------|---------------------------------------|-------------------------------|
| | (CO ₃) ²⁻ triangles | | | | | | |
| | 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.

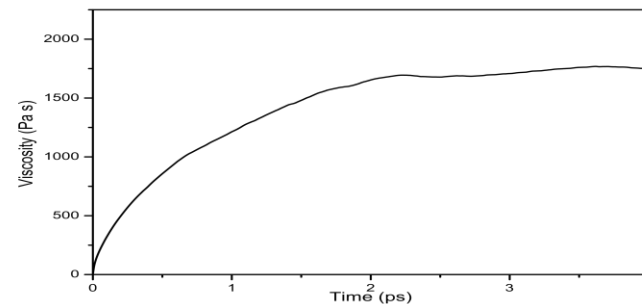
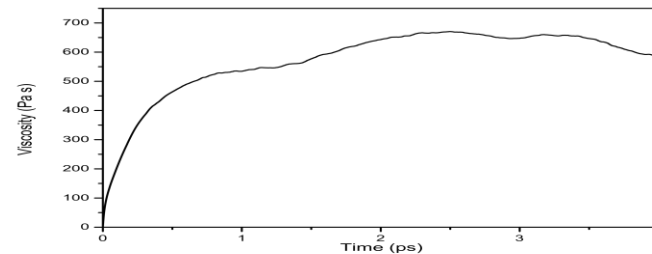
At pressures > 82 GPa structure of dominant MgCO₃ is predicted to change from (CO₃)²⁻ **triangles** to (C₃O₉)⁶⁻ **tetrahedra**.

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

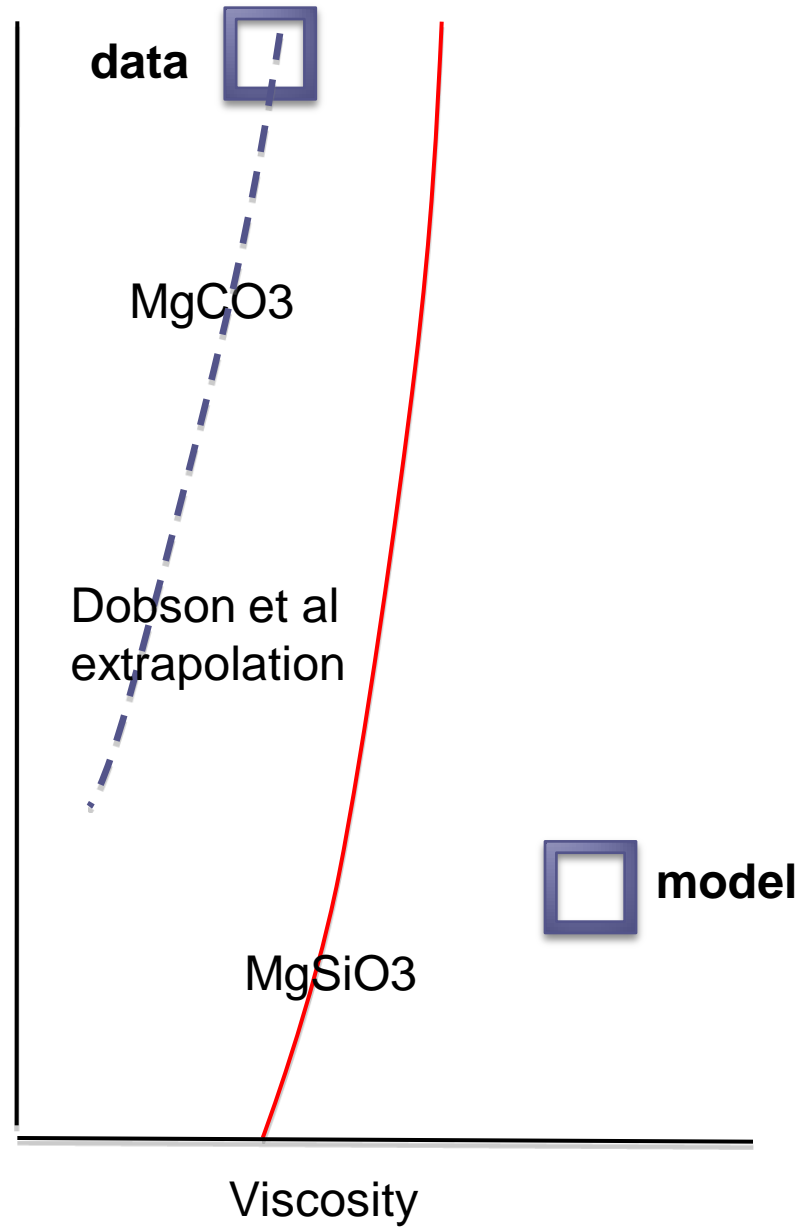
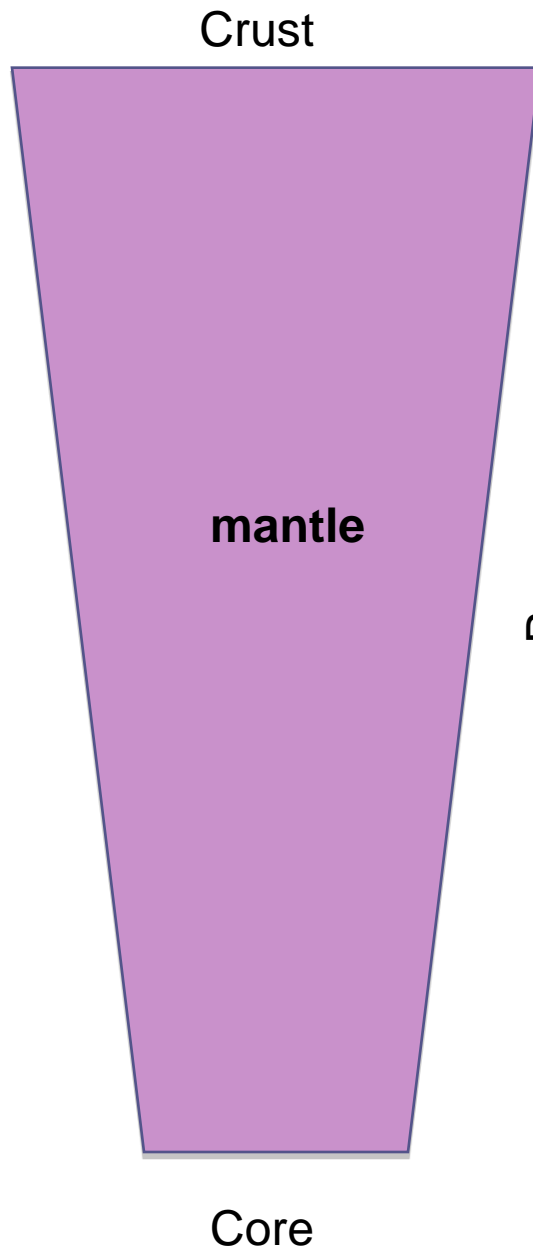


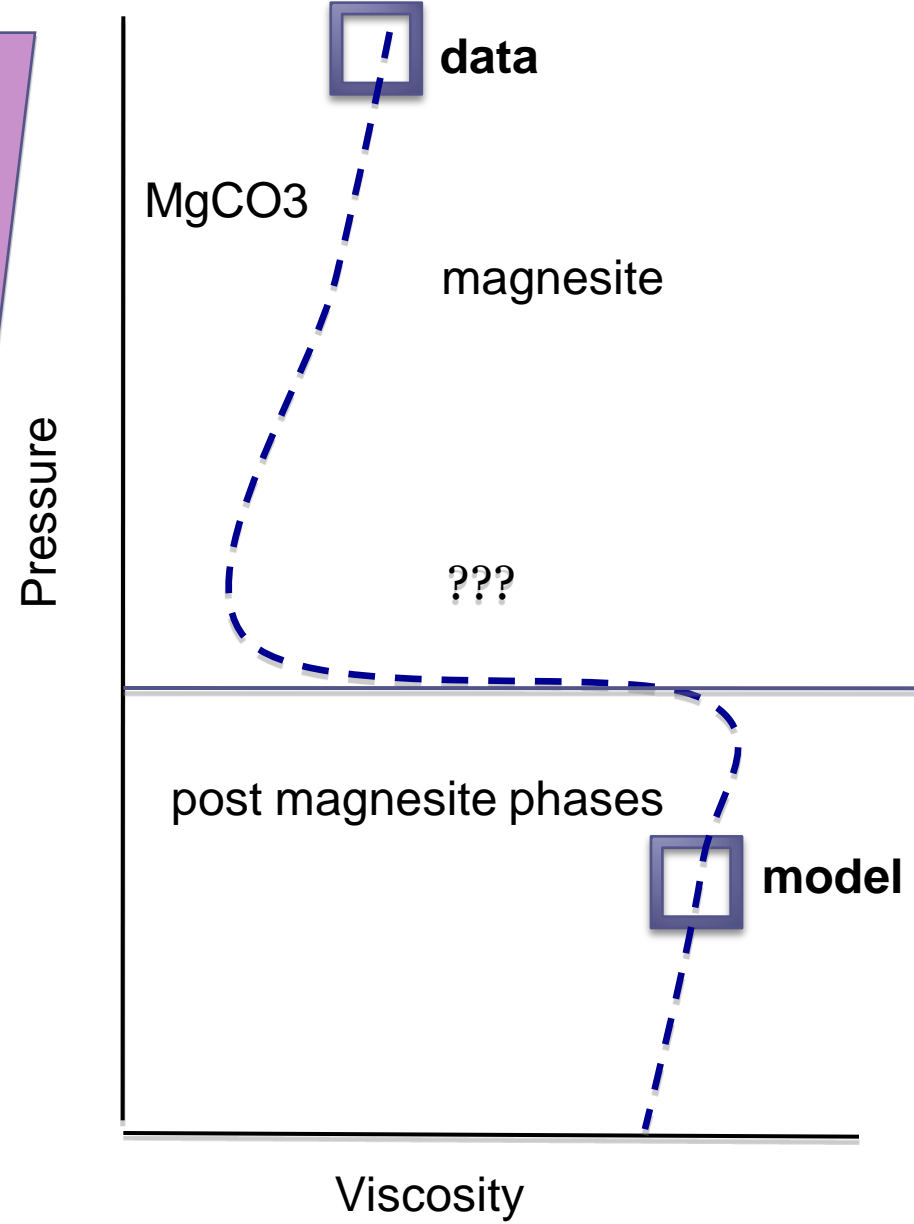
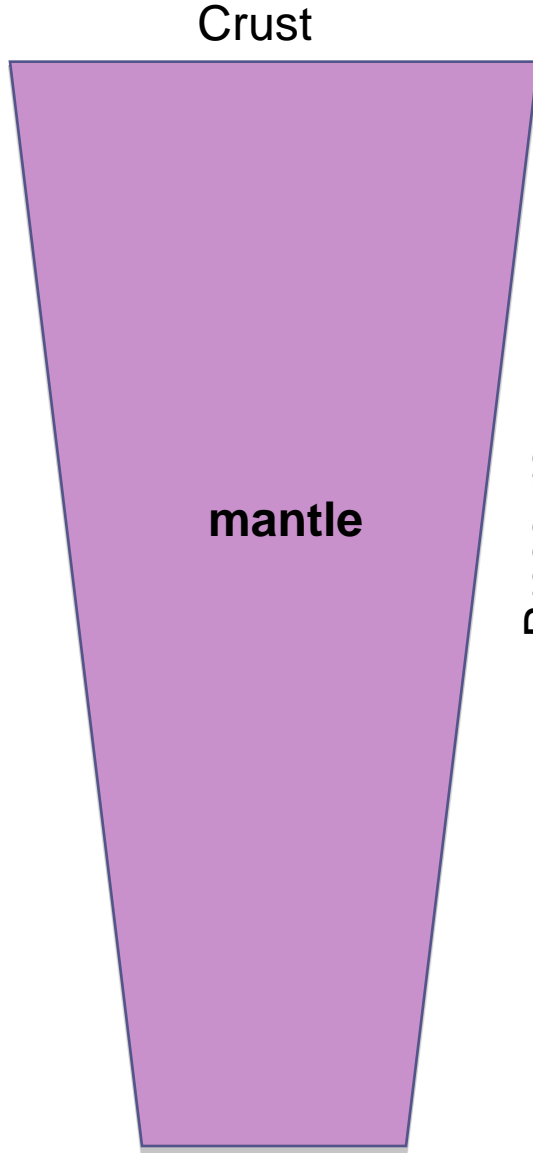
High P carbonates (Mg, Ca)

| 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 |
| | | | | |

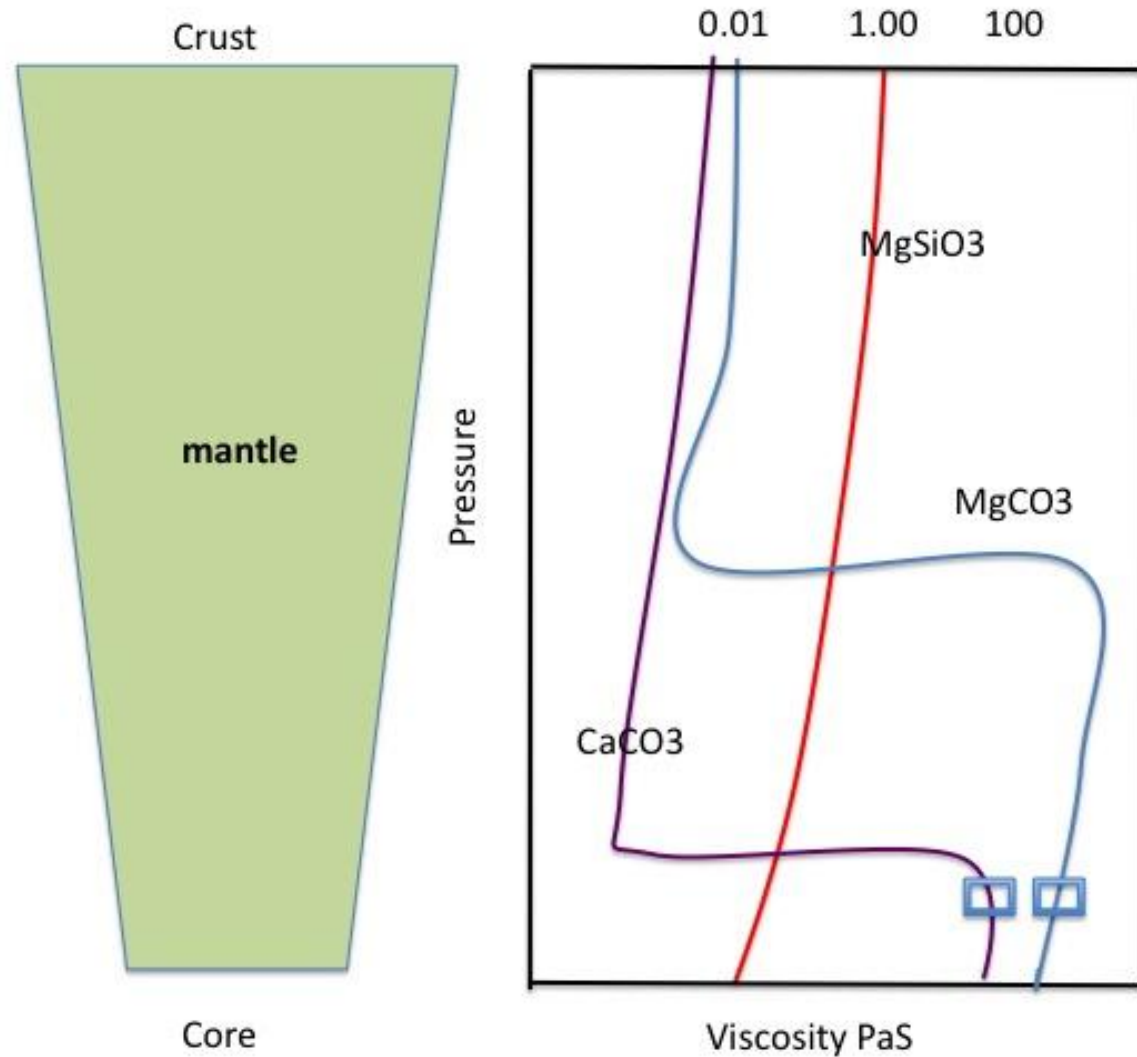


“superdeep carbonates”





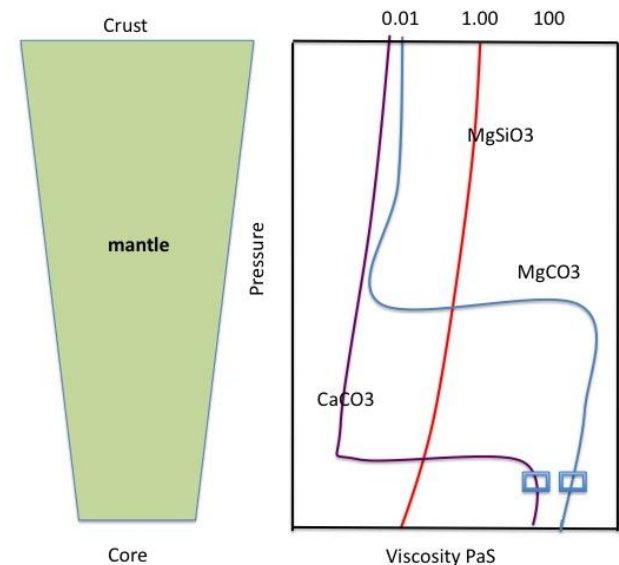
Carbonate melt viscosity schematic



Lower mantle carbonate melt

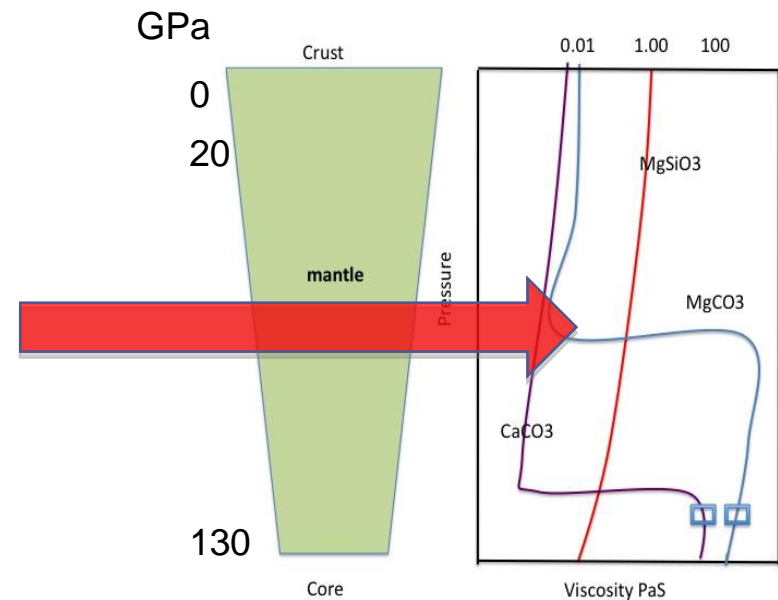
- predict very high viscosity?

- **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.