Linking mantle petrology to the dynamics of the lithosphere/asthenosphere system

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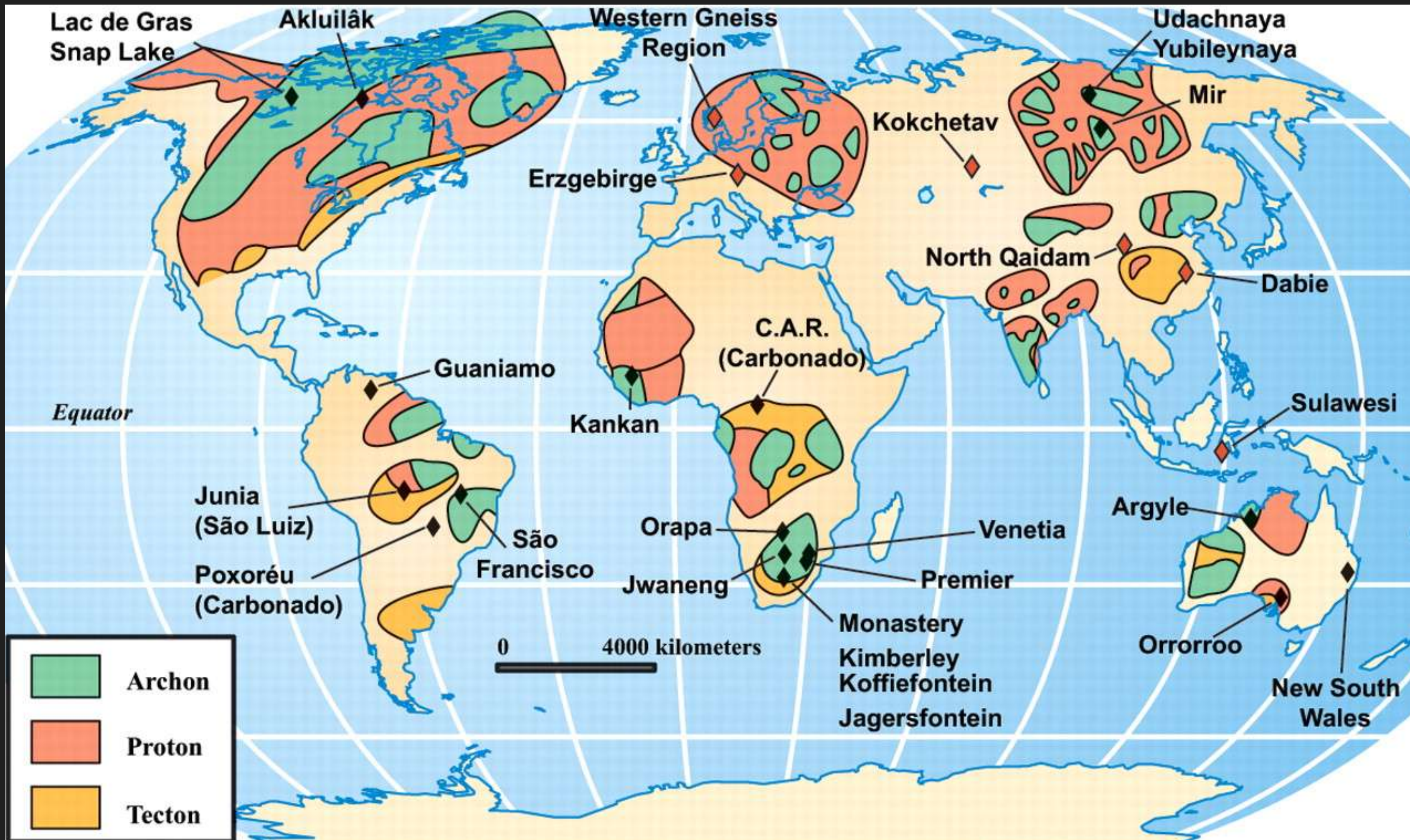
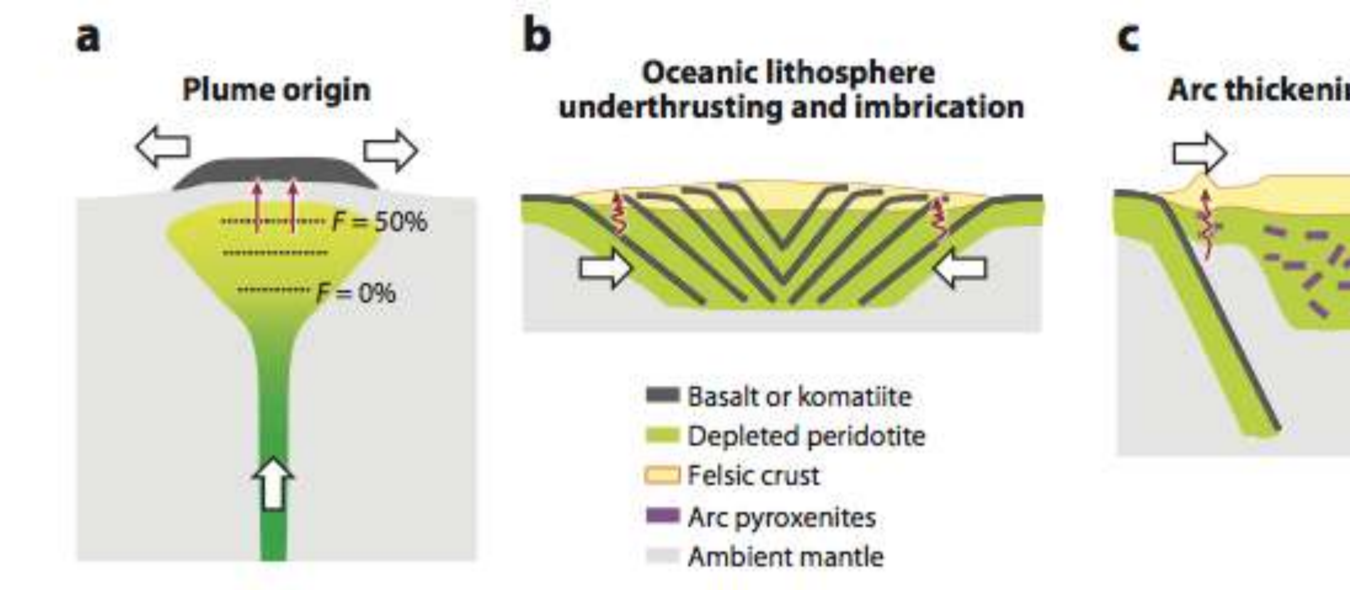


Harlow & Davies (2005)

Tectosphere Formation



Lee et al. (2011)

Basalt
(2.97 g/cc) → Eclogite (3.57 g/cc)

Fertile Garnet Lherzolite (3.4 g/cc)

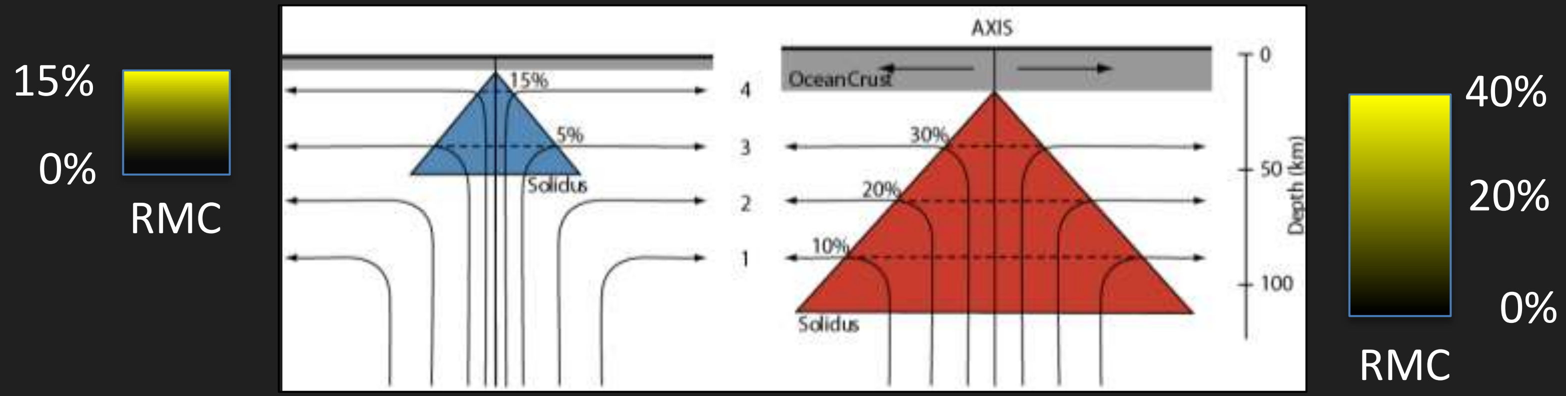
Melt → Basalt (2.97 g/cc)

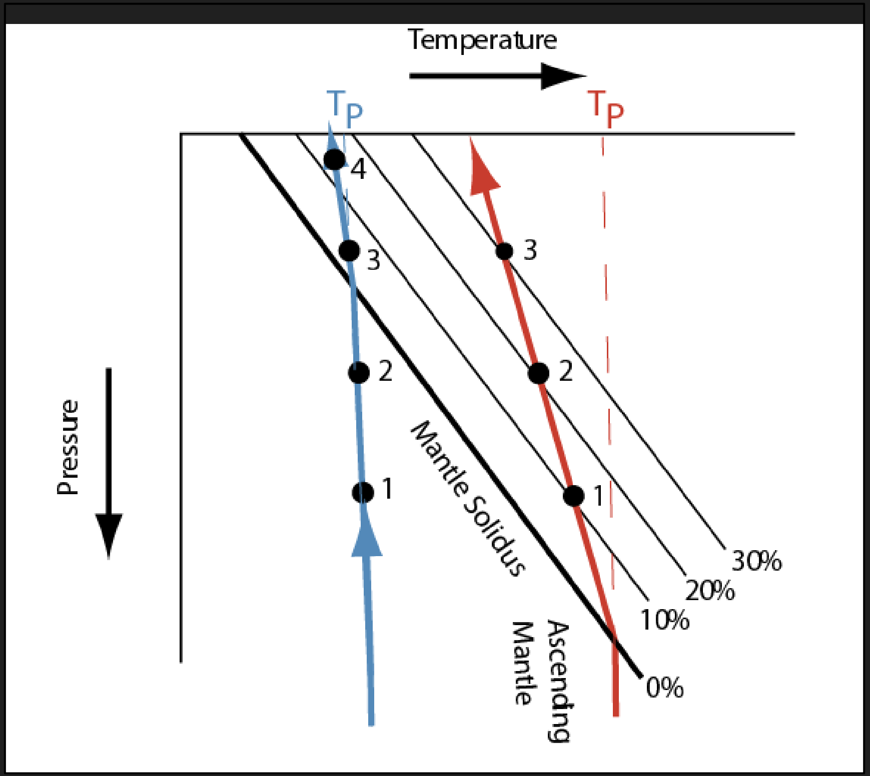
Residue → Melt-depleted Harzburgite (3.32 g/cc)

Density is NOT conserved!

Borrowed from Rick Carlson (CIDER 2013)

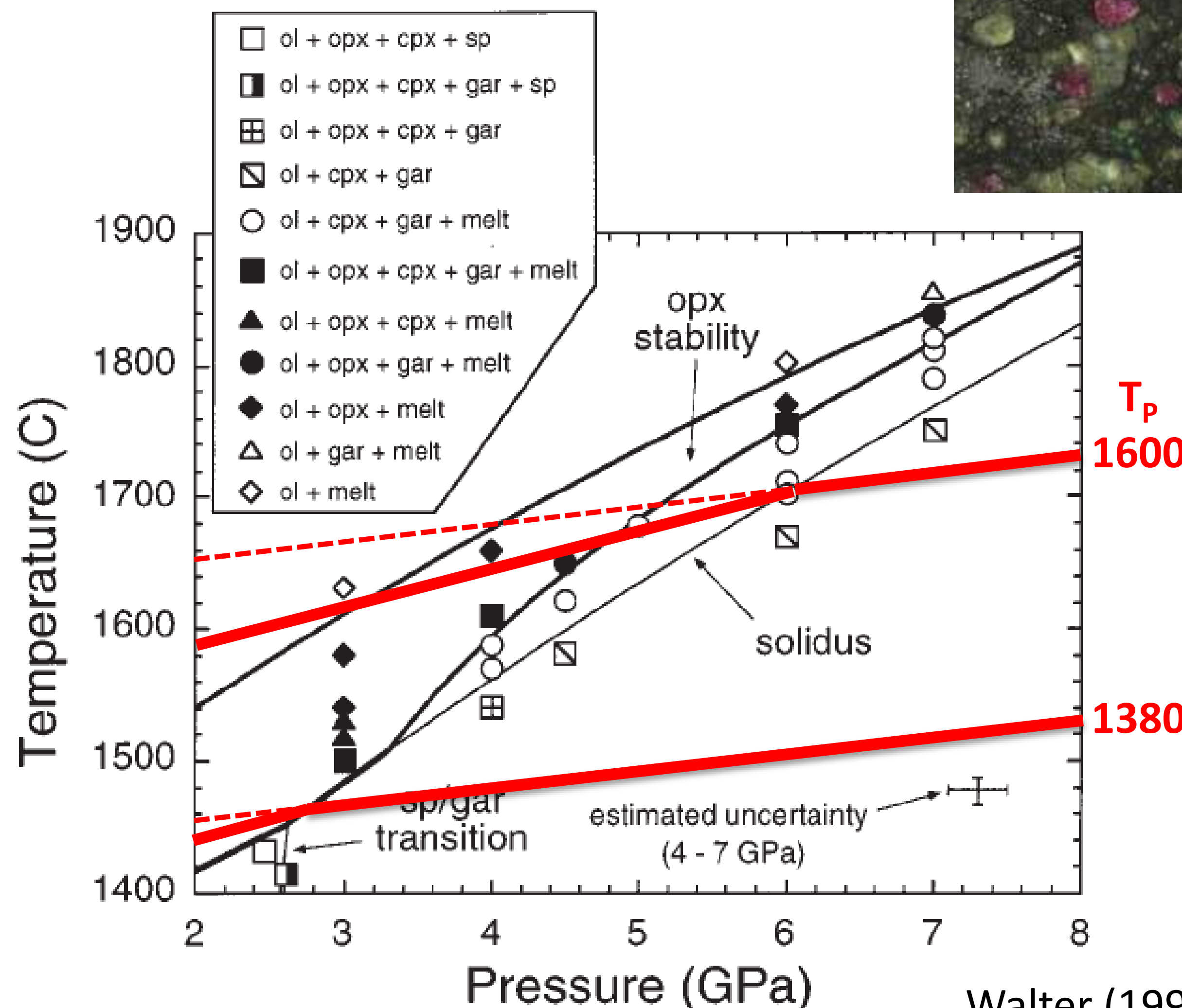
Adiabatic Decompression Melting





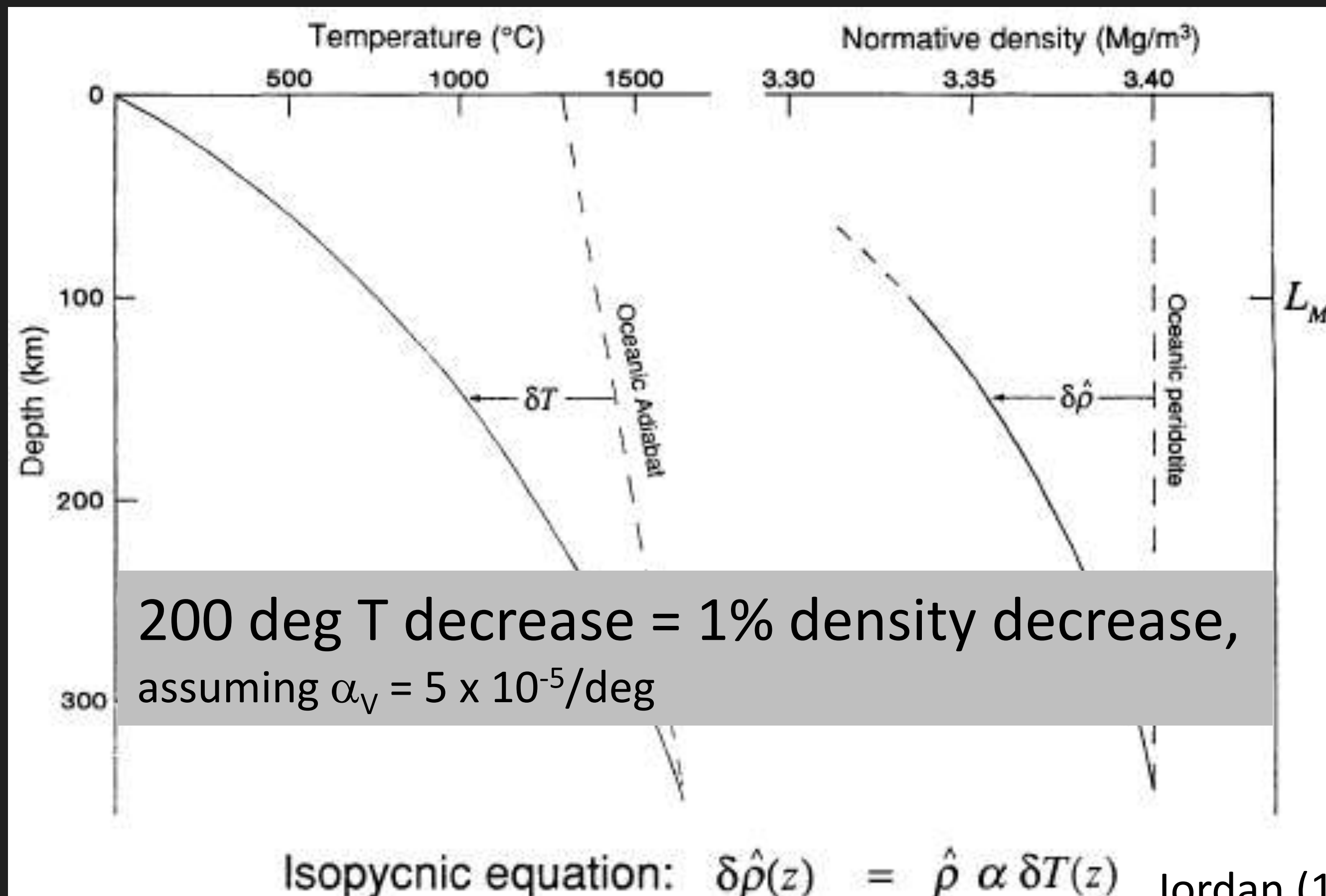
Langmuir & Forsythe, 2007

Phase Relations



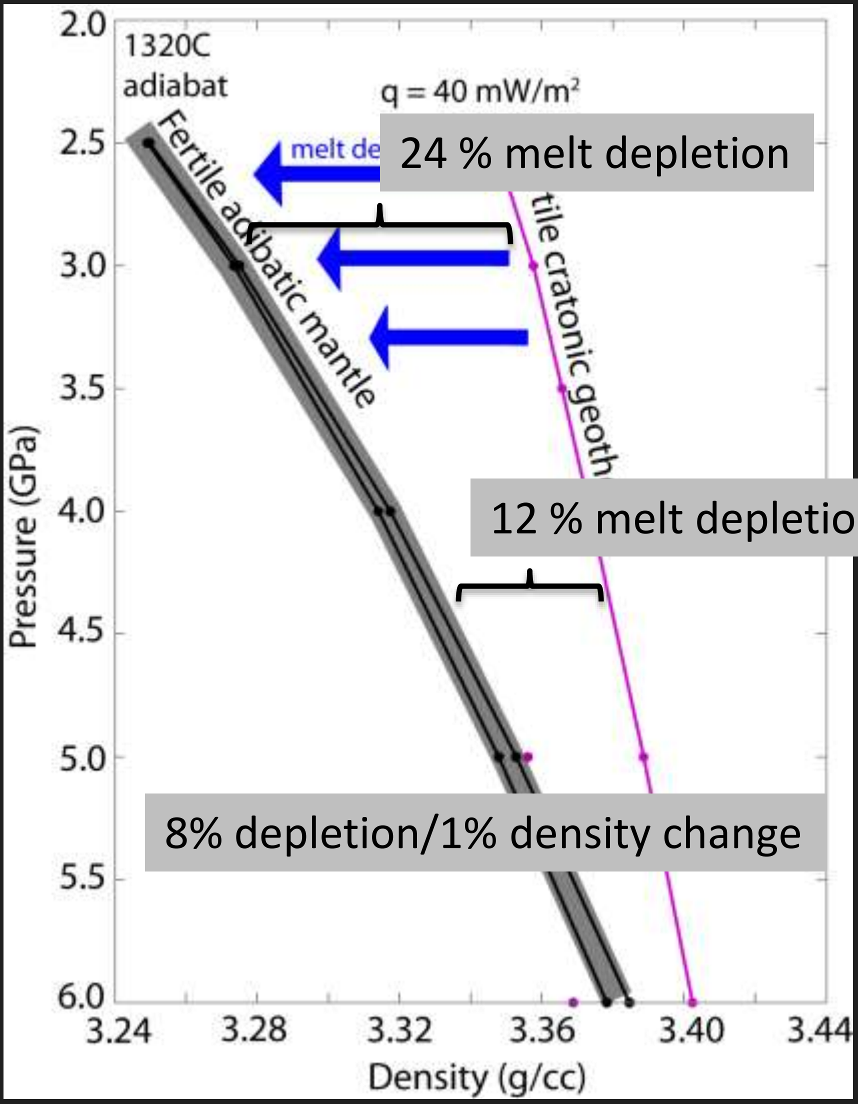
Walter (1998)

Isopycnic Hypothesis

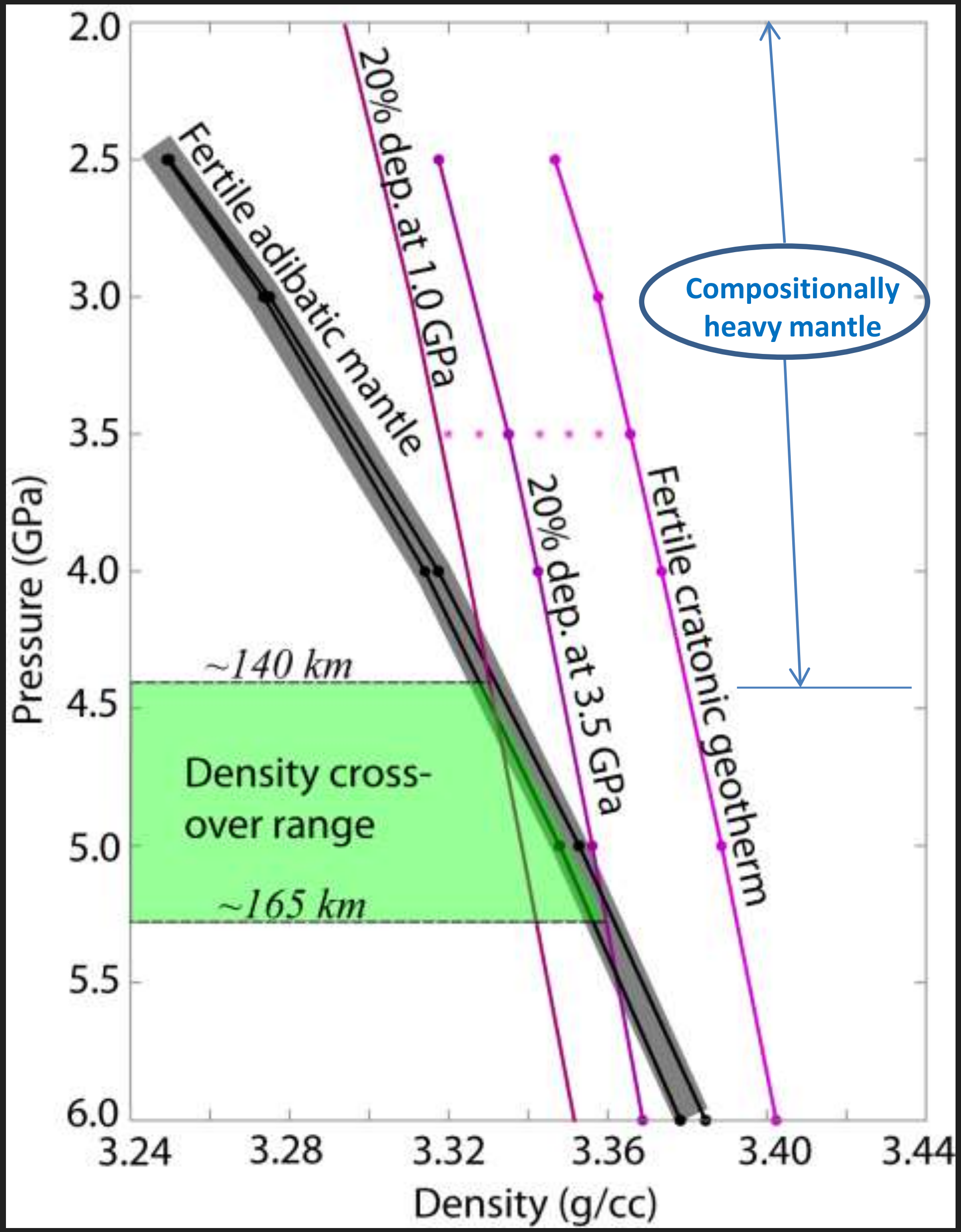


Jordan (1988)

Relative to asthenospheric mantle, the negative thermal buoyancy of cold SCLM is balanced at every depth by compositional buoyancy caused by compositional changes = SCLM is neutrally buoyant

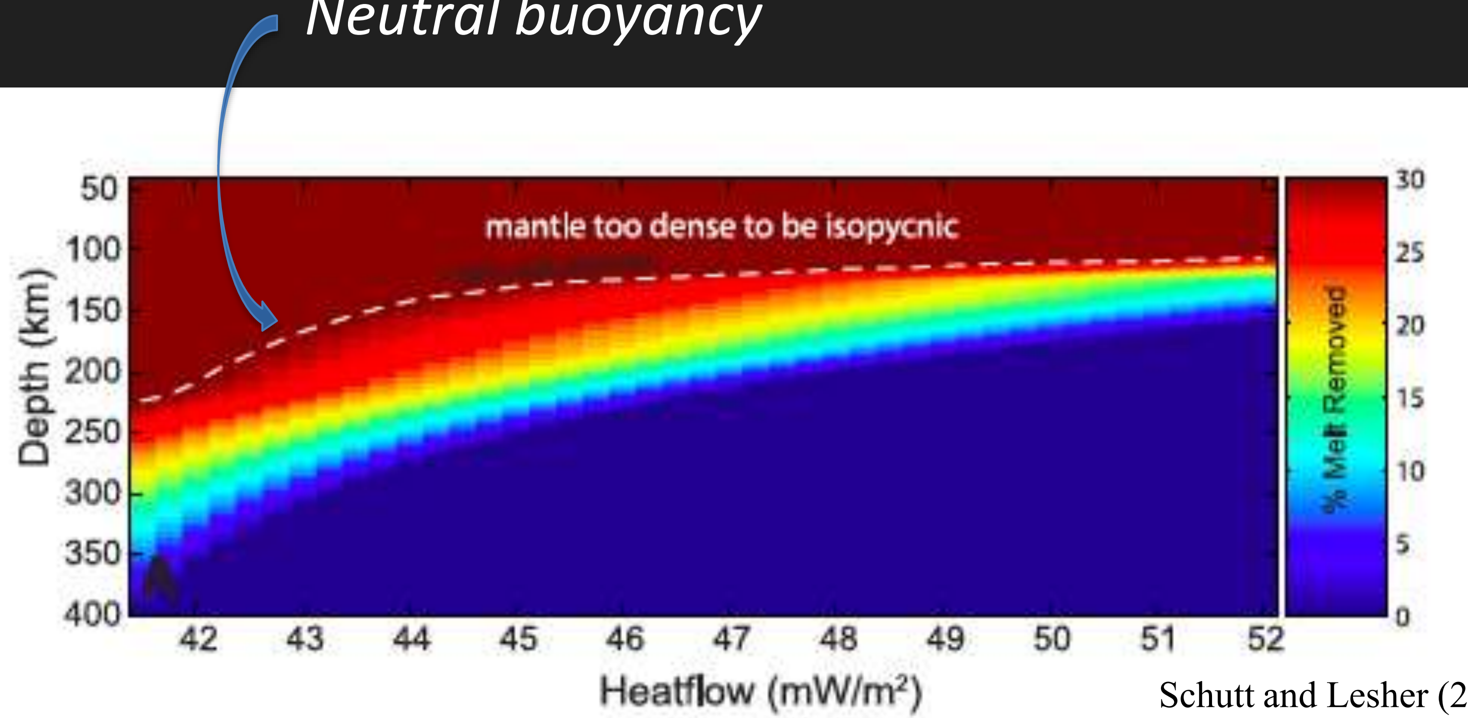


Can cold cratonic mantle be compositionally altered in such a way that it has the same density as hot asthenosphere at all depths?



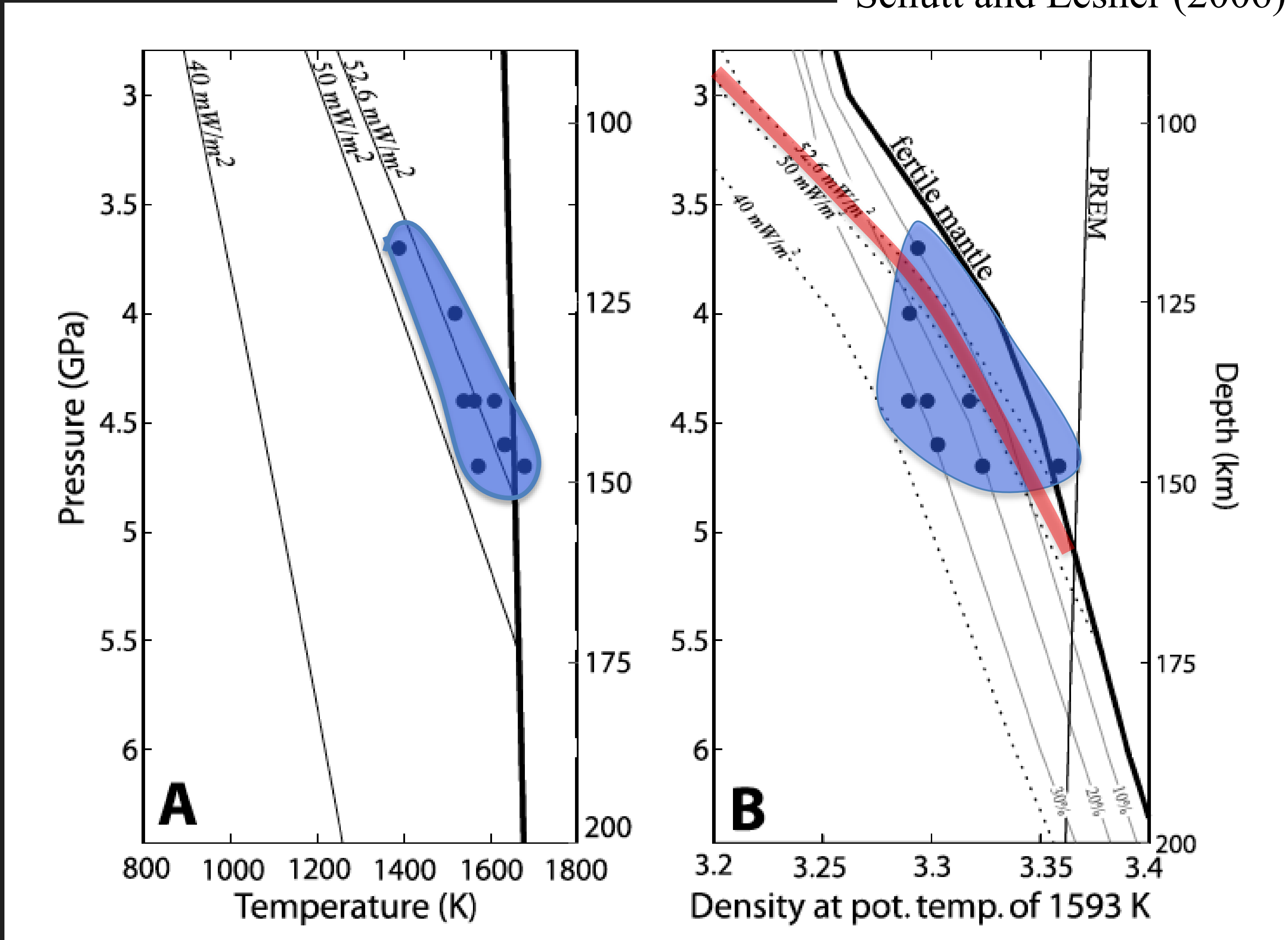
Schutt and Lesher (2006)

Lithosphere Stability



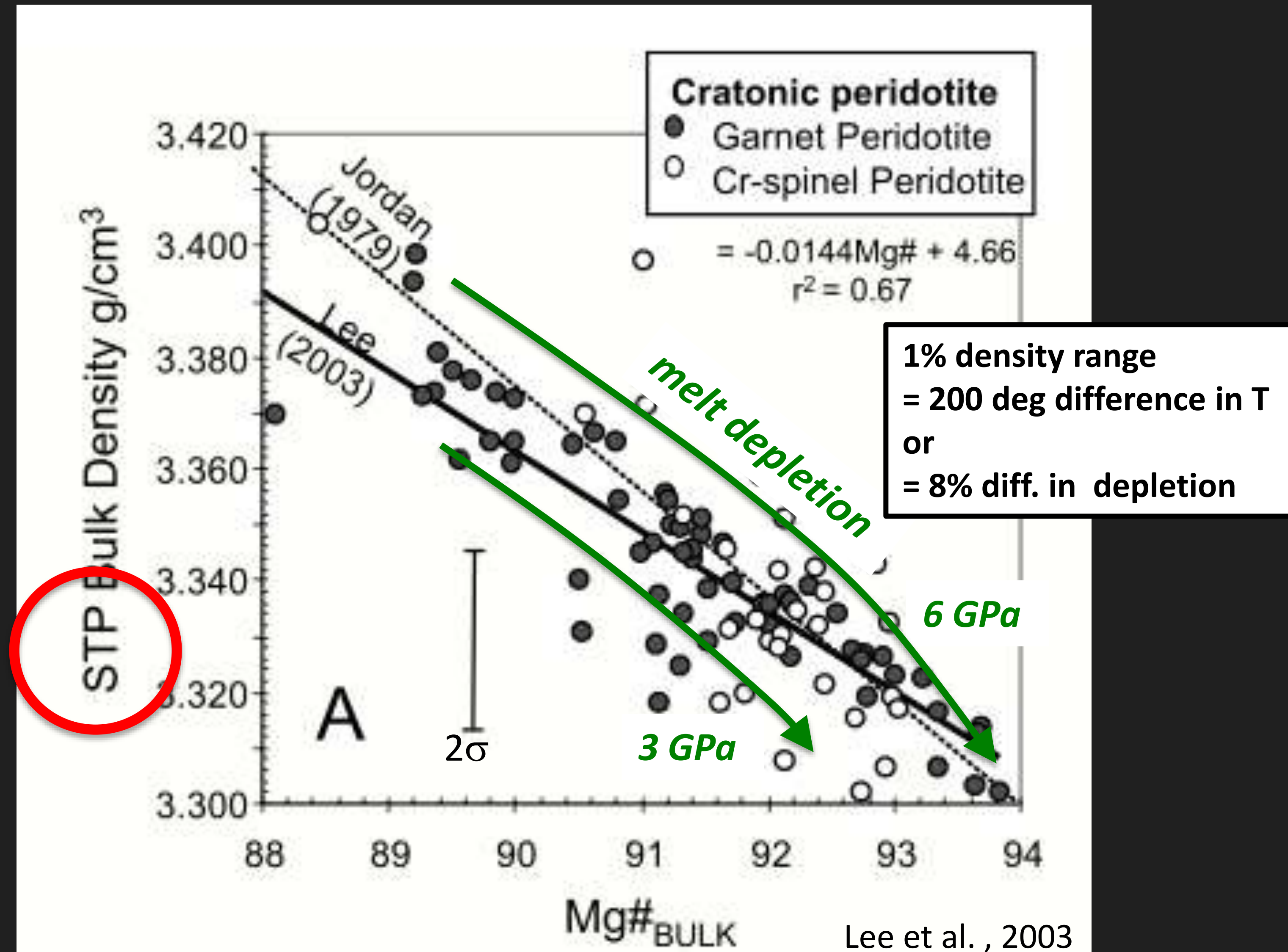
Schutt and Lesher (2006)

Schutt and Lesher (2006)

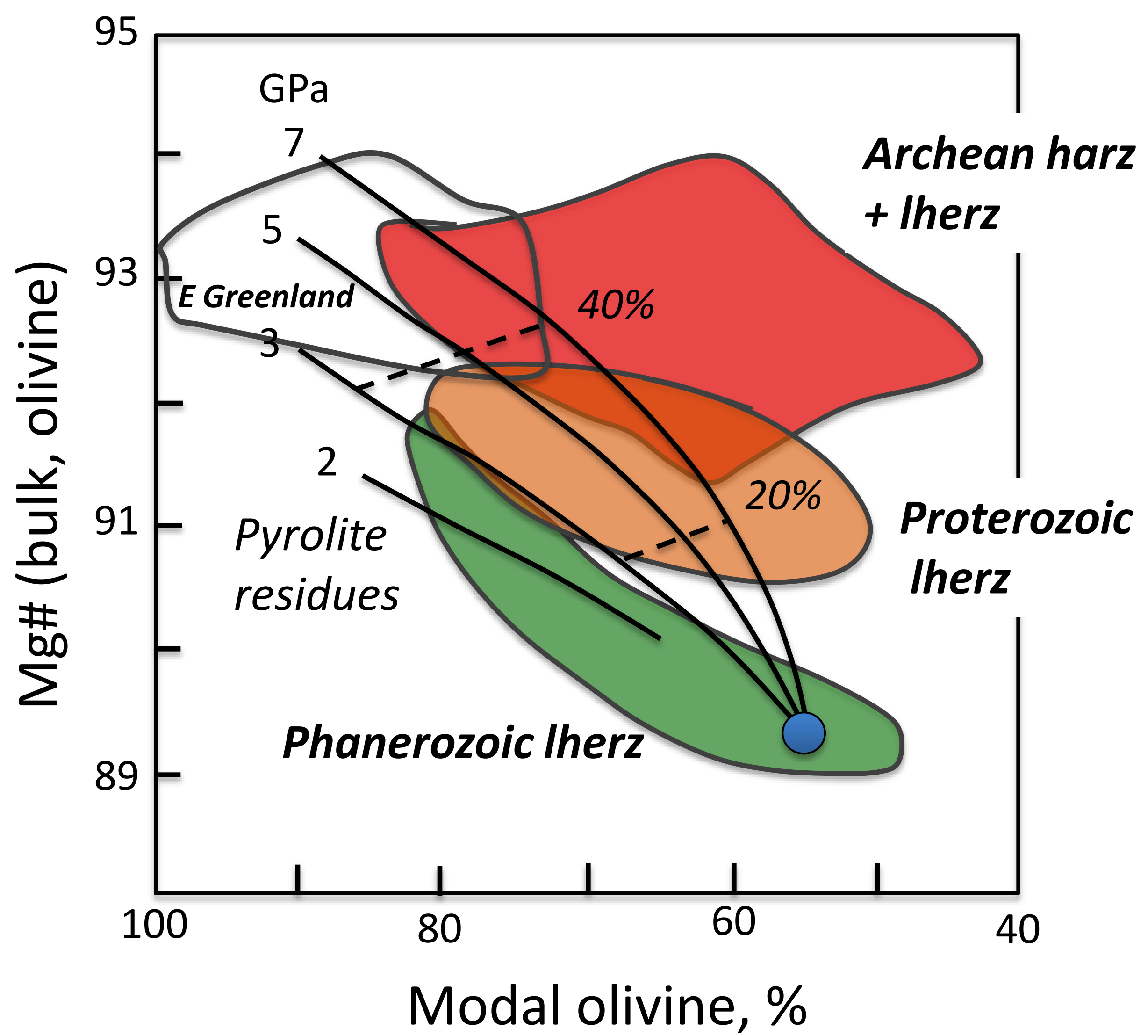


Tanzanian xenoliths (Lee & Rudnick, 1999)

Rm T
1 atm



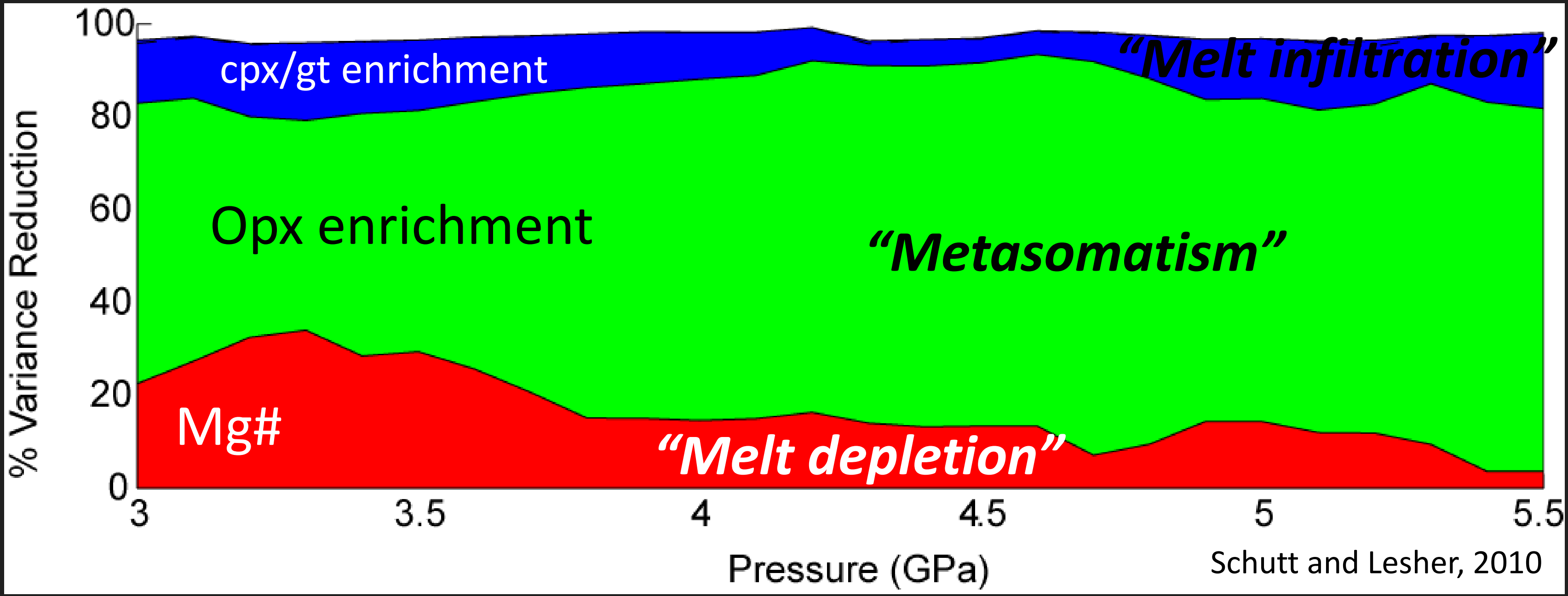
Lee (2003)…"the pressure and temperatures derivatives of the compositional end-members of peridotitic minerals are very similar, and therefore the compositional derivatives of the elastic moduli with respect to Mg# at STP conditions are applicable to elevated pressures and temperatures."



After Walter, 1989 & Griffin et al., 2002

Kaapvaal Xenoliths

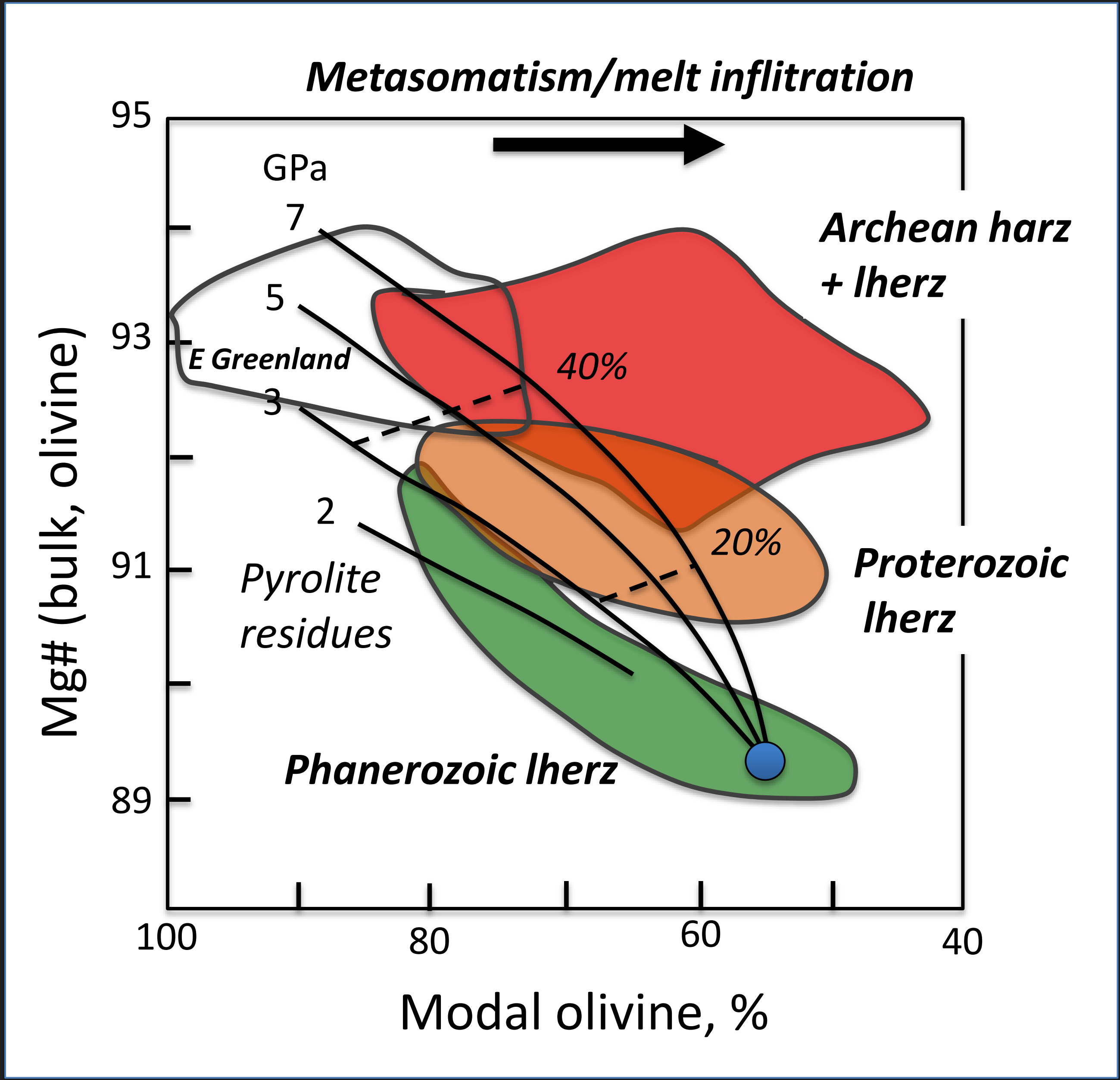
Principle component analysis



5 Components

- olivine Mg#
- olivine mode
- orthopyroxene mode
- clinopyroxene mode
- garnet mode

To get at pressure variations, we bin xenoliths in 1 GPa bins between 3-5.5 GPa.



After Walter, 1989 & Griffin et al., 2002

I. Subsolidus Mineral Modes and Compositions

- Inputs: T, P, bulk composition
- Outputs
  - Phases: oliv + opx + cpx + sp or gt
  - Phase compositions
- Constraints: 4 phases x 9 to 11 oxides each + 4 phase proportions
- Solve using mass balance and stoichiometric constraints, and exchange and distribution coefficients that are functions of T, P, and X.

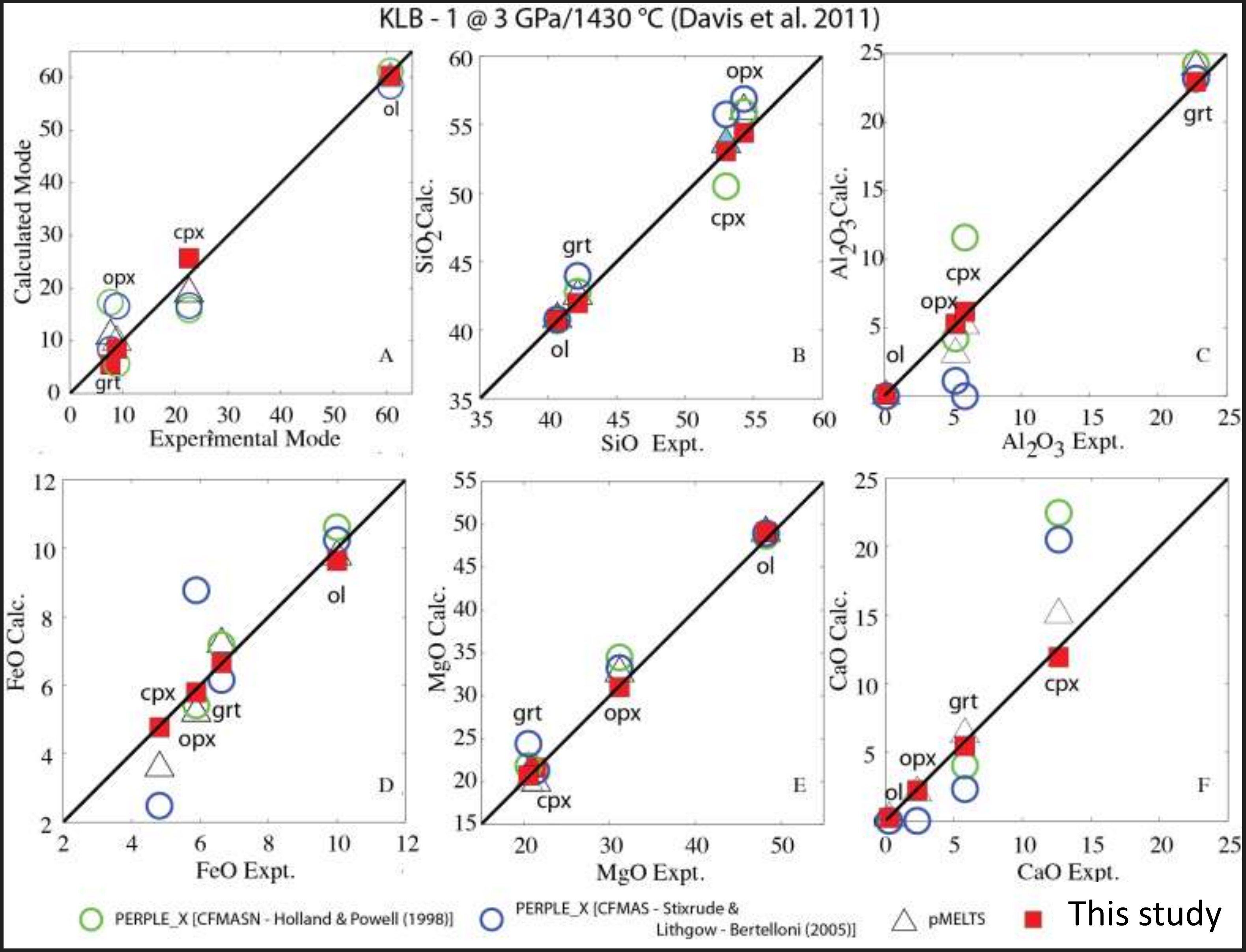
Based on 5700 experiments; T: 600 to 2453°C; P: 1-atm to 10 GPa

II. Density (@ T & P)

Schutt and Lesher (2006)

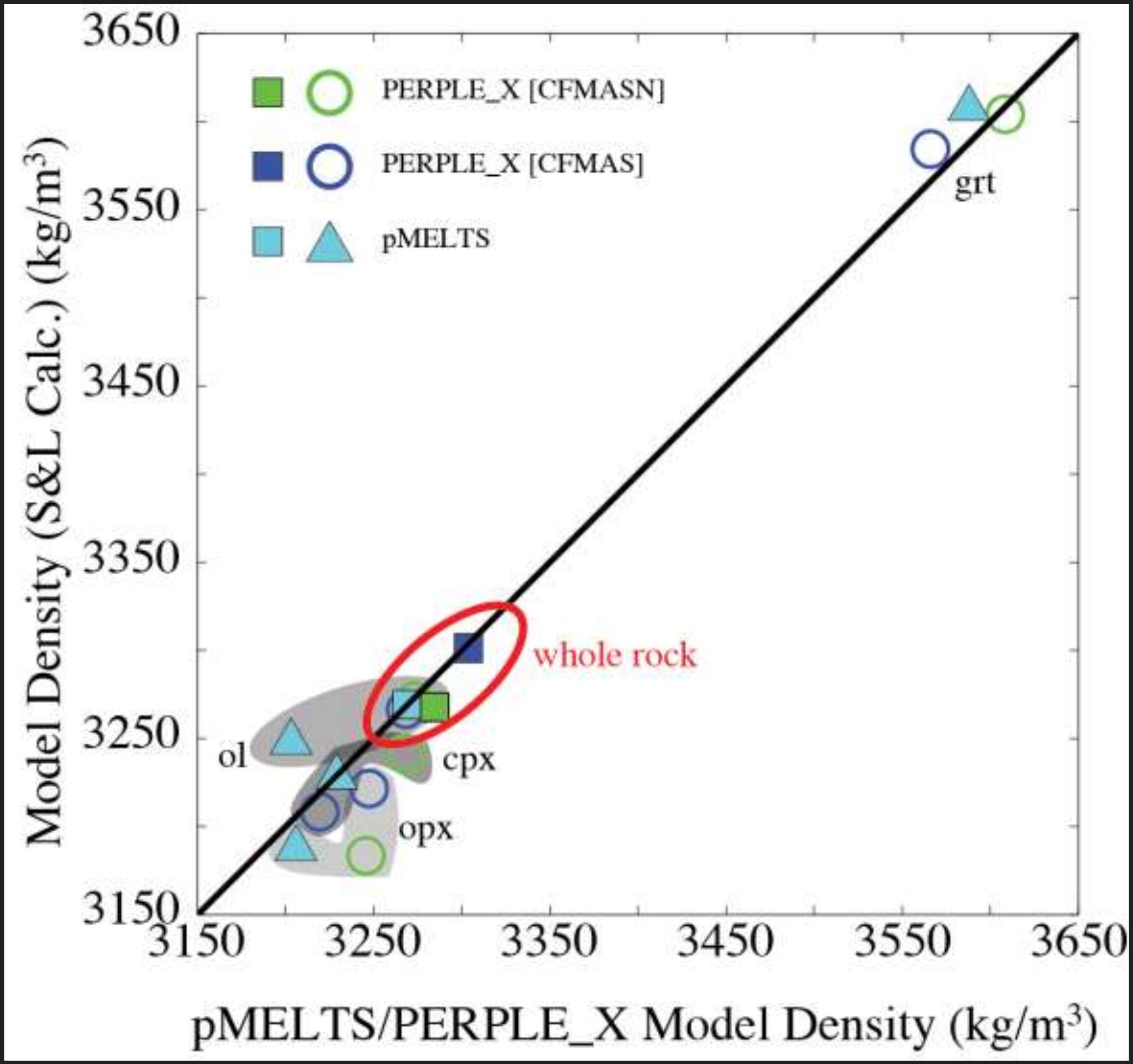
- Mineral physics data for 41 mineral end-members
  - 2 olivine; 15 orthopyroxene; 15 clinopyroxene; 6 garnet; and 3 spinel end-members
- Linear mixing between end-members
- P and T: 2^{nd}-order polynomial fits to mineral physics data

Comparison to PERPLE_X and pMELTS

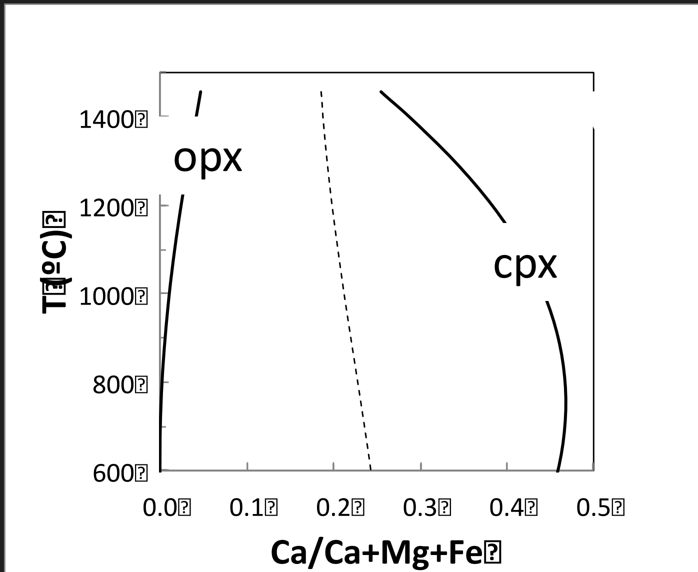


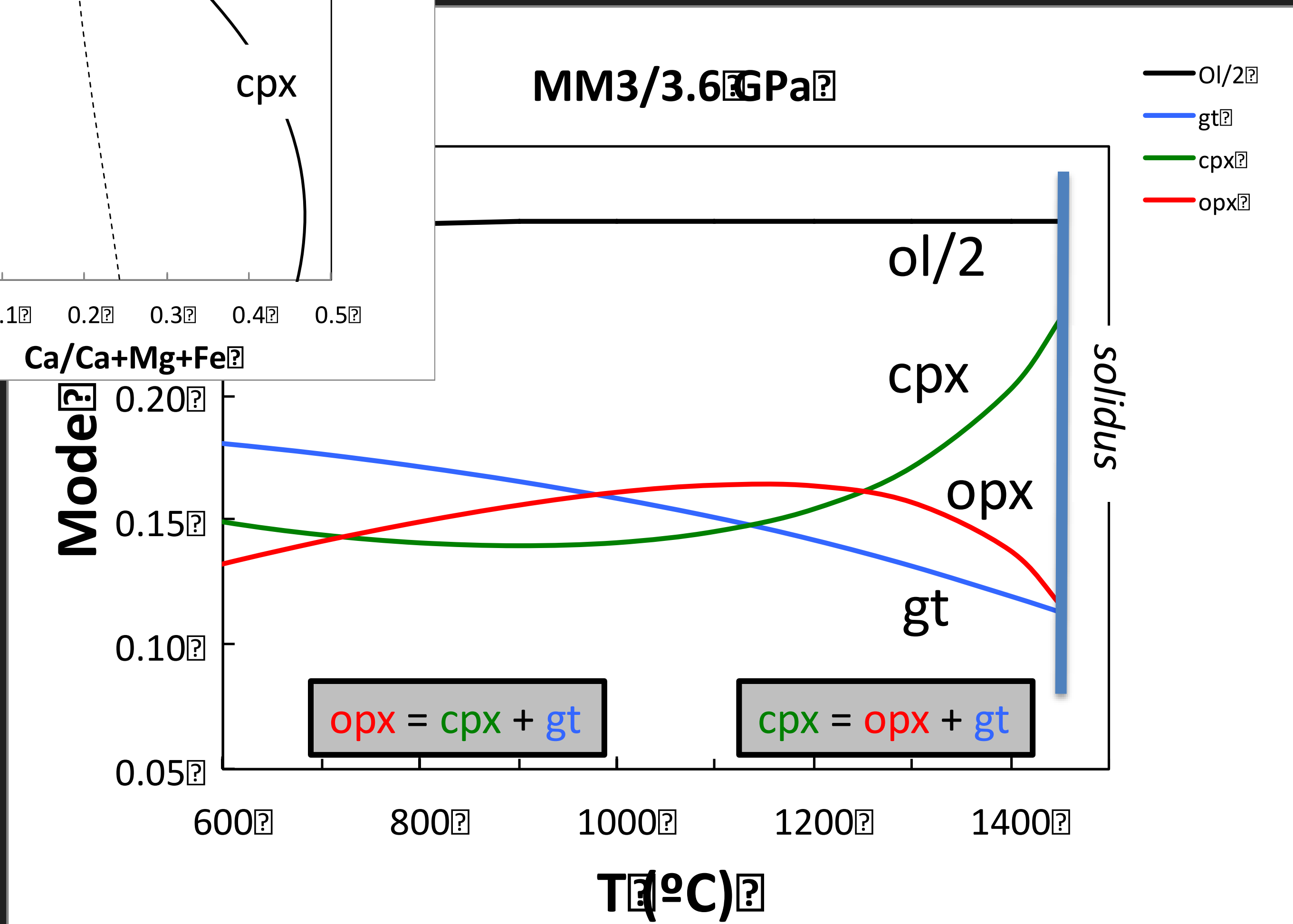
Comparison to PERPLE_X and pMELTS

KLB-1 3 GPa melting experiments by Davis et al. (2011)

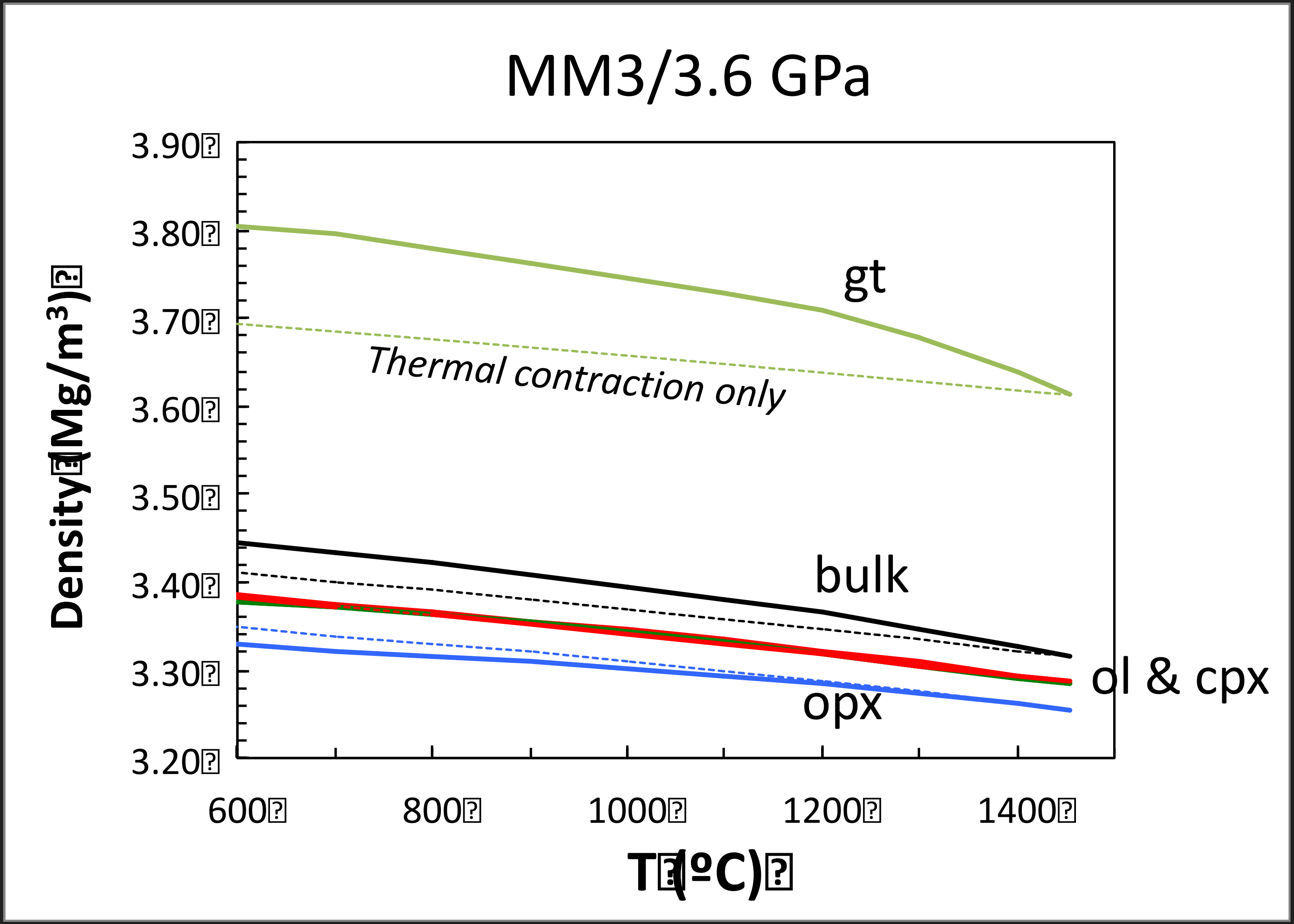


solidus evolution

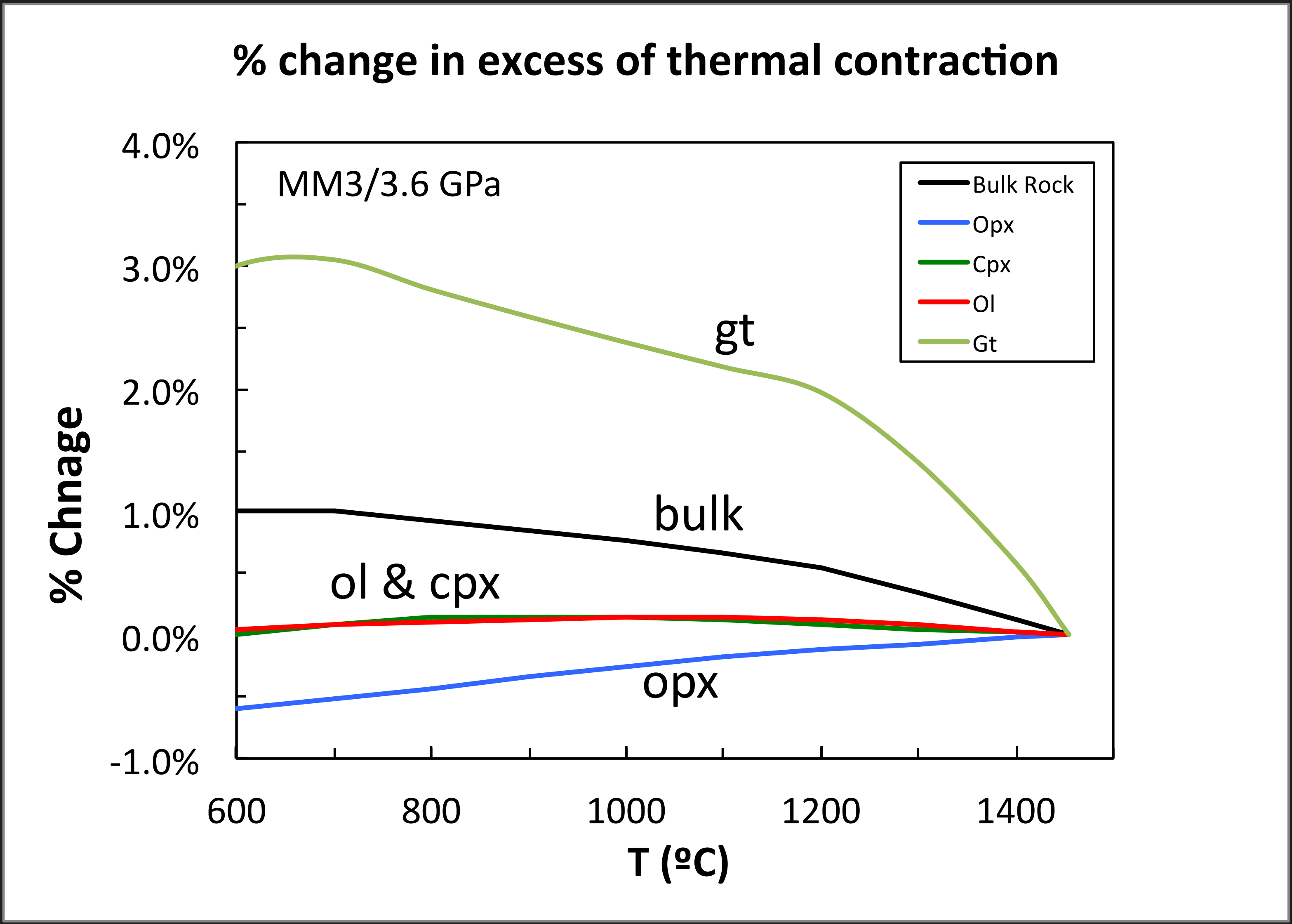




Subsolidus evolution



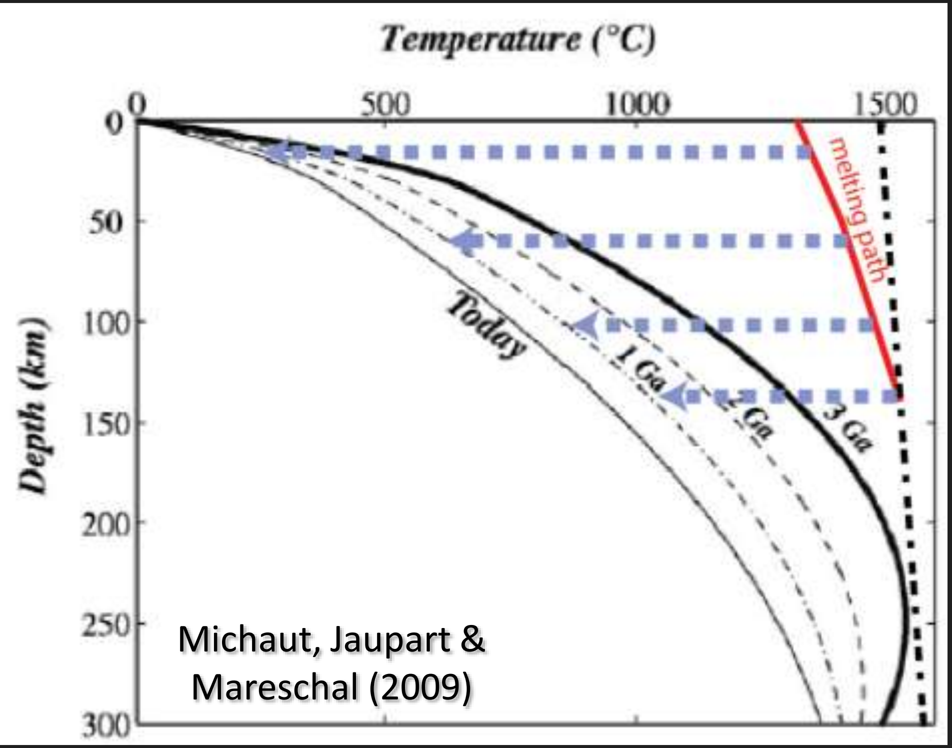
Subsolidus evolution



Forward Model - Subsolidus Evolution

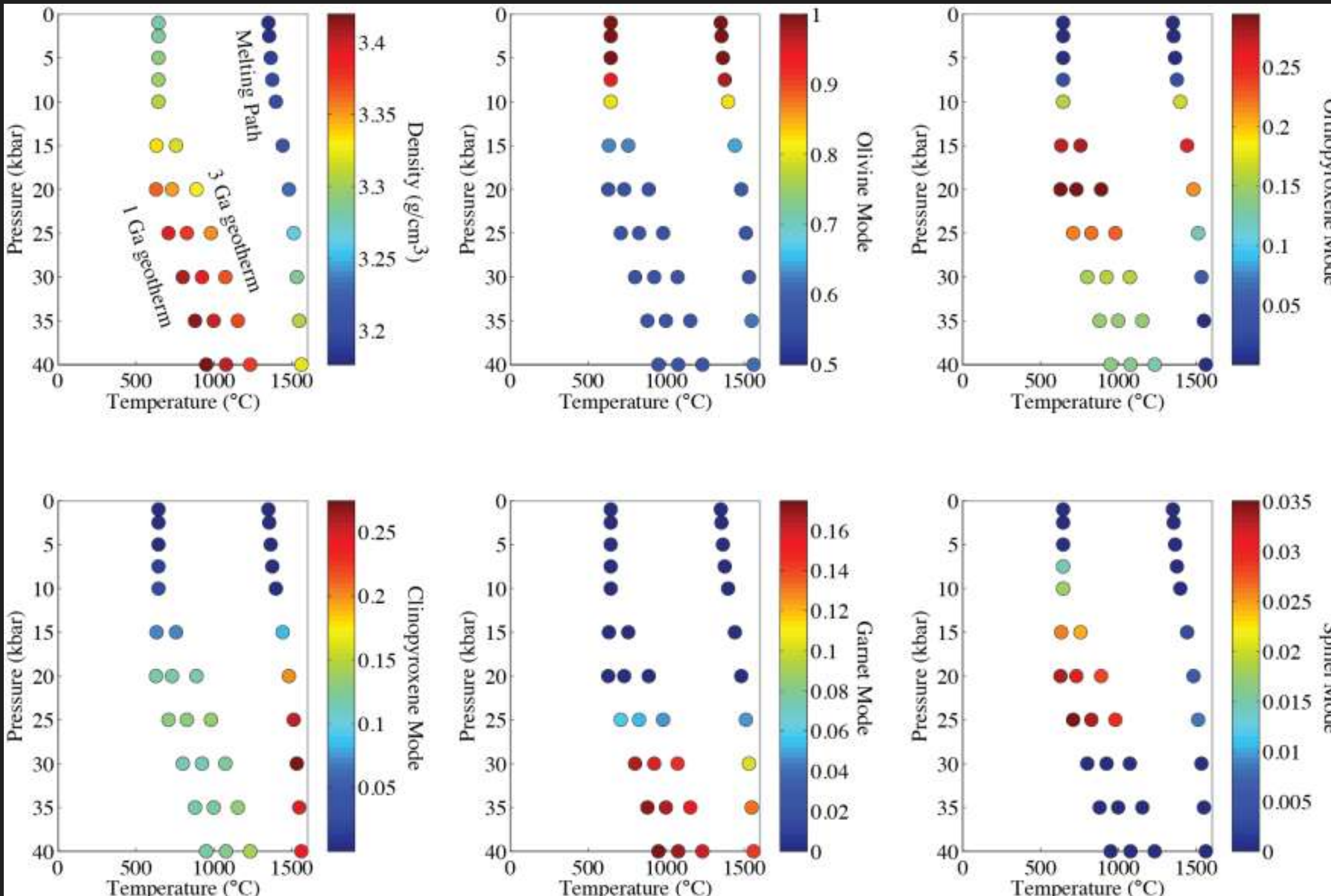
I. pMELTS: polybaric melting pyrolite to determine residues f(P,T); P_T = 1455ºC

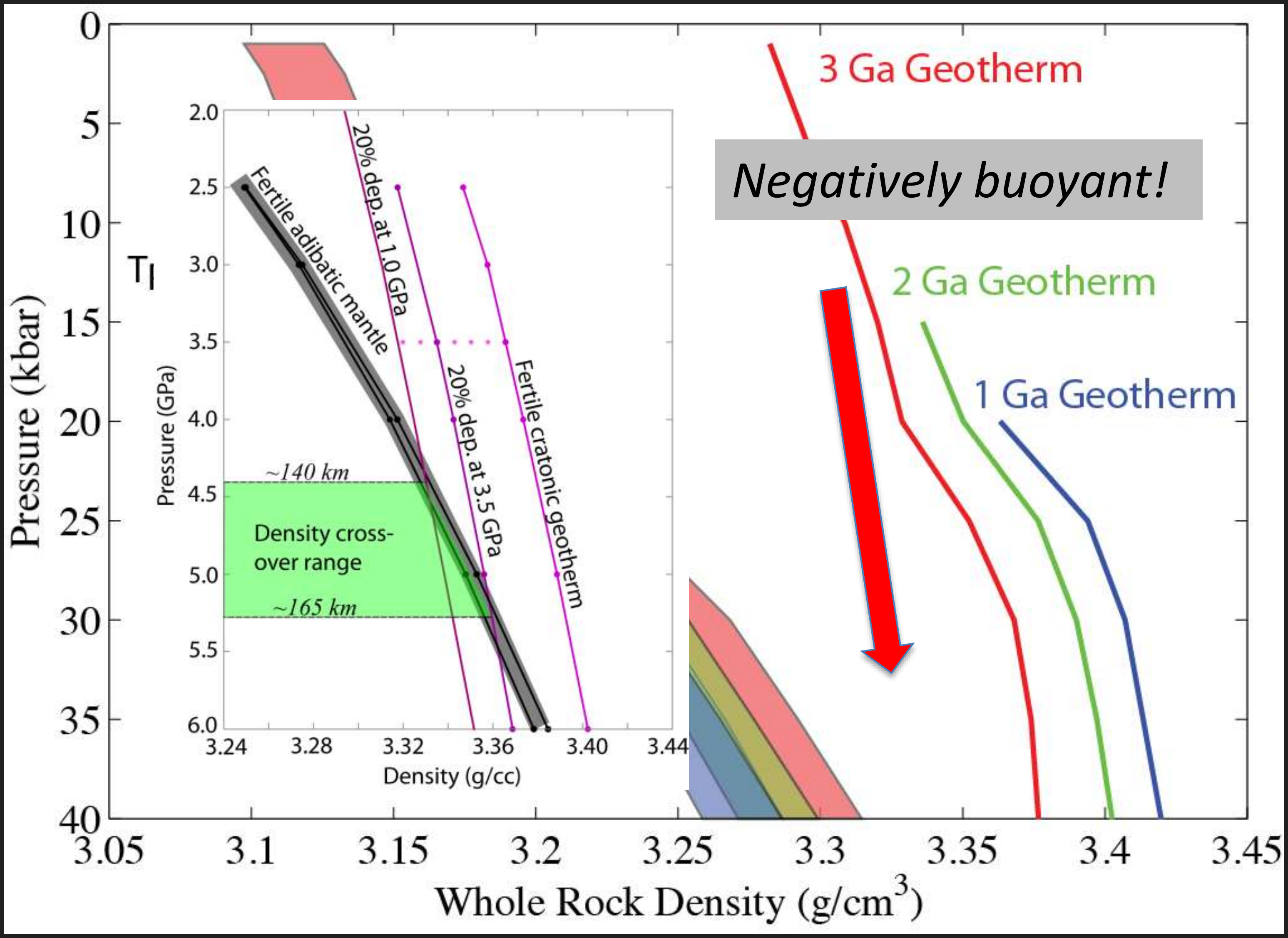
II. Evolve peridotite residues isobarically to new (continental) geotherms



Continental lithosphere formed 3.5 Ga

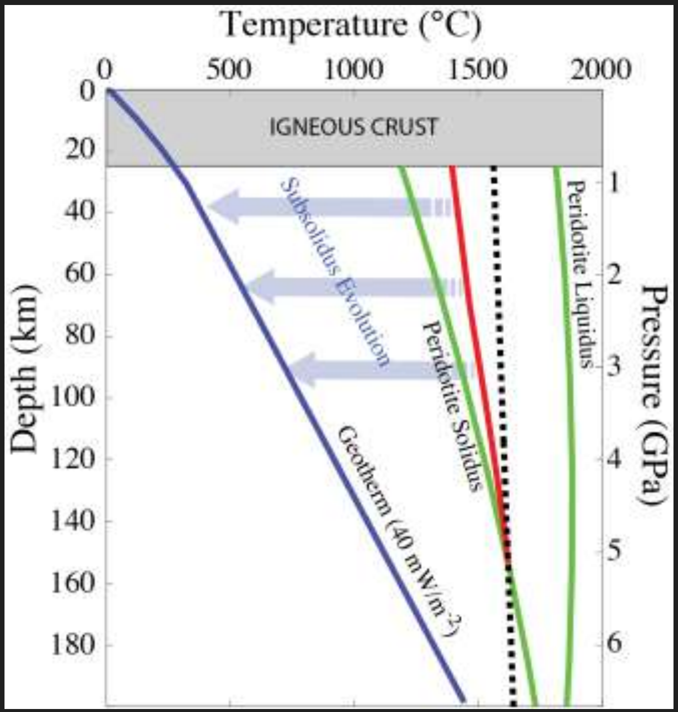
Density – Mineral modes



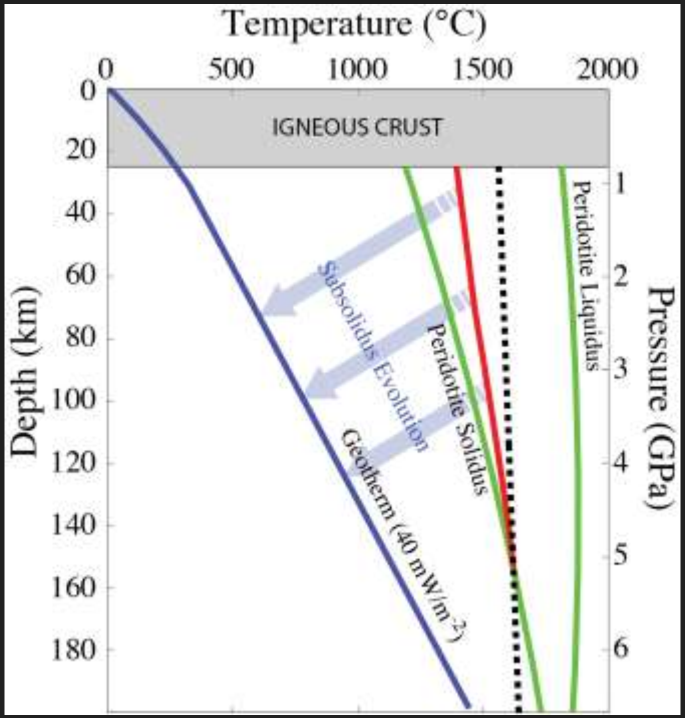


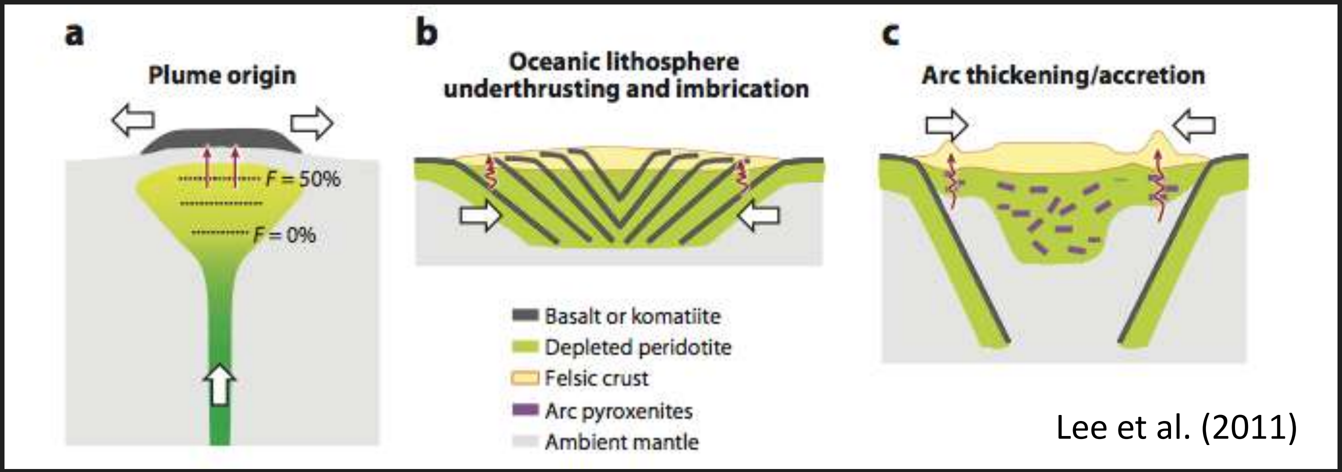
3 Ga Geotherm
Negatively buoyant!
2 Ga Geotherm
1 Ga Geotherm
Pressure (kbar)
Whole Rock Density (g/cm3)
0
5
10
15
20
25
30
35
40
3.05
3.1
3.15
3.2
3.25
3.3
3.35
3.4
3.45
T_l
Fertile adibatic mantle
20% dep. at 1.0 GPa
20% dep. at 3.5 GPa
Fertile cratonic geotherm
~140 km
Density cross-over range
~165 km
Pressure (GPa)
Density (g/cc)
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
3.24
3.28
3.32
3.36
3.40
3.44

Subsolidus evolution is important……



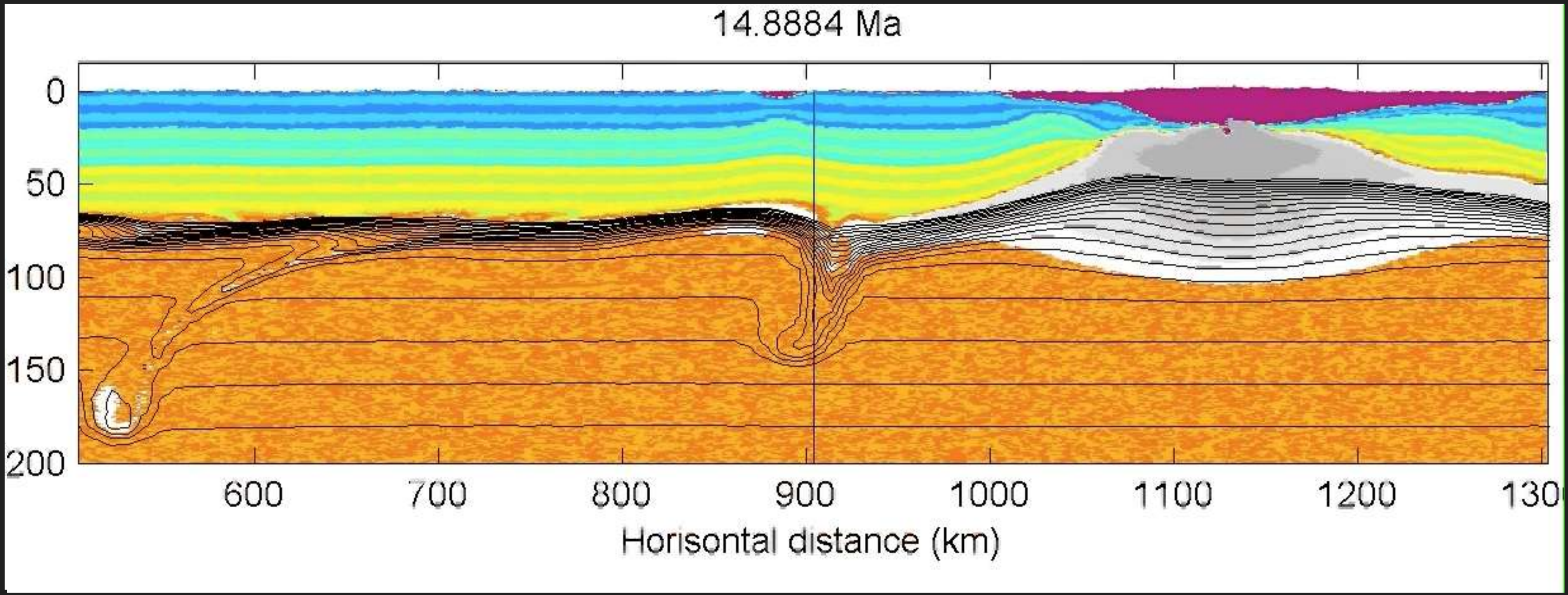
V.S.





Mini-Wilson Cycles

Very preliminary modeling by **Kenni Petersen (AU)**, based on the multi-grid – finite difference scheme including visco-elastic-plastic rheologies of Gerya and Yuen (2003, 2007).

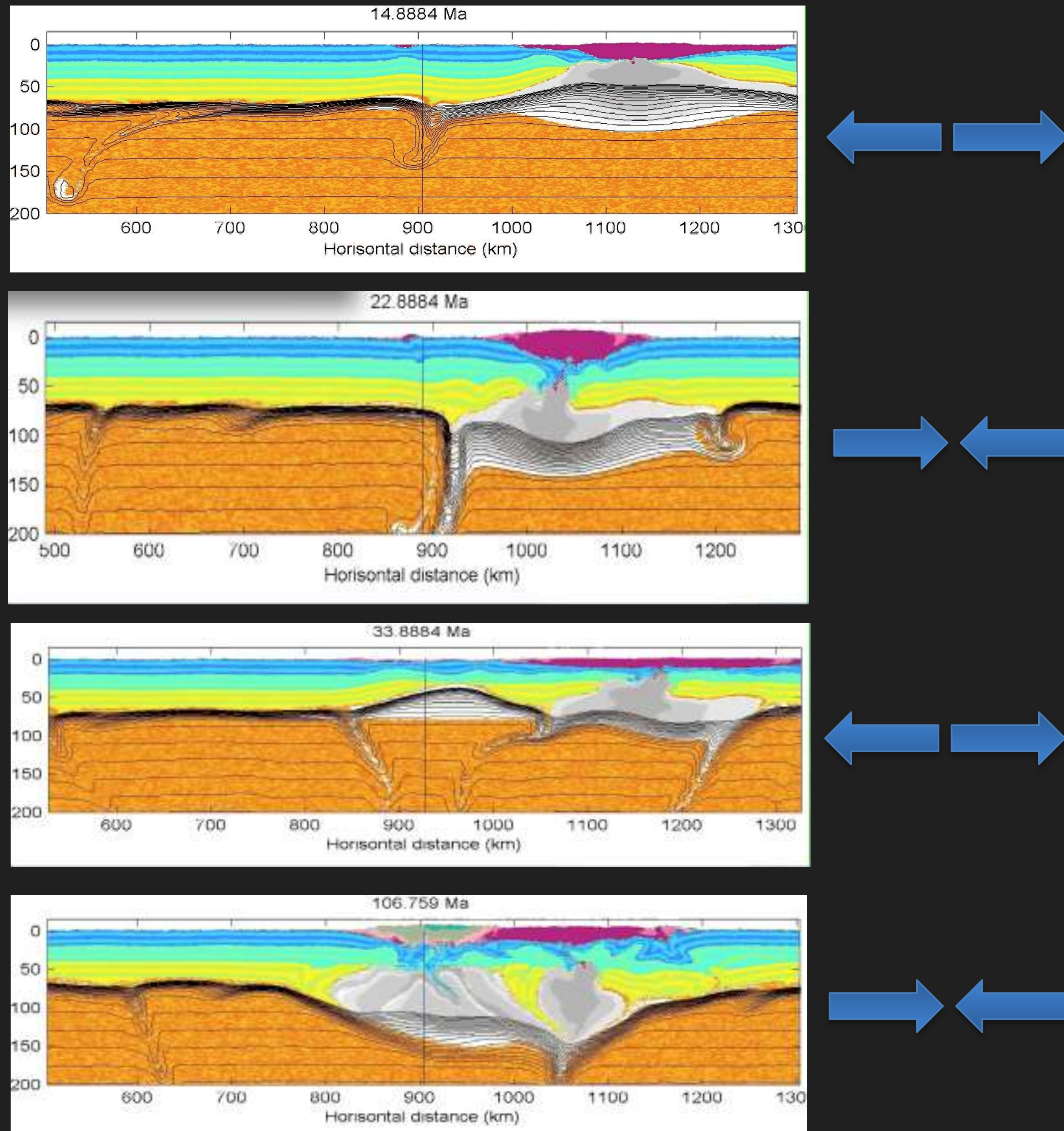


Tp = 1300 C

3500x1000 grid points

Blue = crust
Green/yellow = mantle lithosphere
Orange = unmelted asthenosphere
Greytones = melt depleted mantle; 2.5% intervals

Merci!



14.8884 Ma
0
50
100
150
200
600
700
800
900
1000
1100
1200
Horisontal distance (km)
22.8884 Ma
0
50
100
150
200
500
600
700
800
900
1000
1100
1200
Horisontal distance (km)
33.8884 Ma
0
50
100
150
200
600
700
800
900
1000
1100
1200
1300
Horisontal distance (km)
106.759 Ma
0
50
100
150
200
600
700
800
900
1000
1100
1200
Horisontal distance (km)