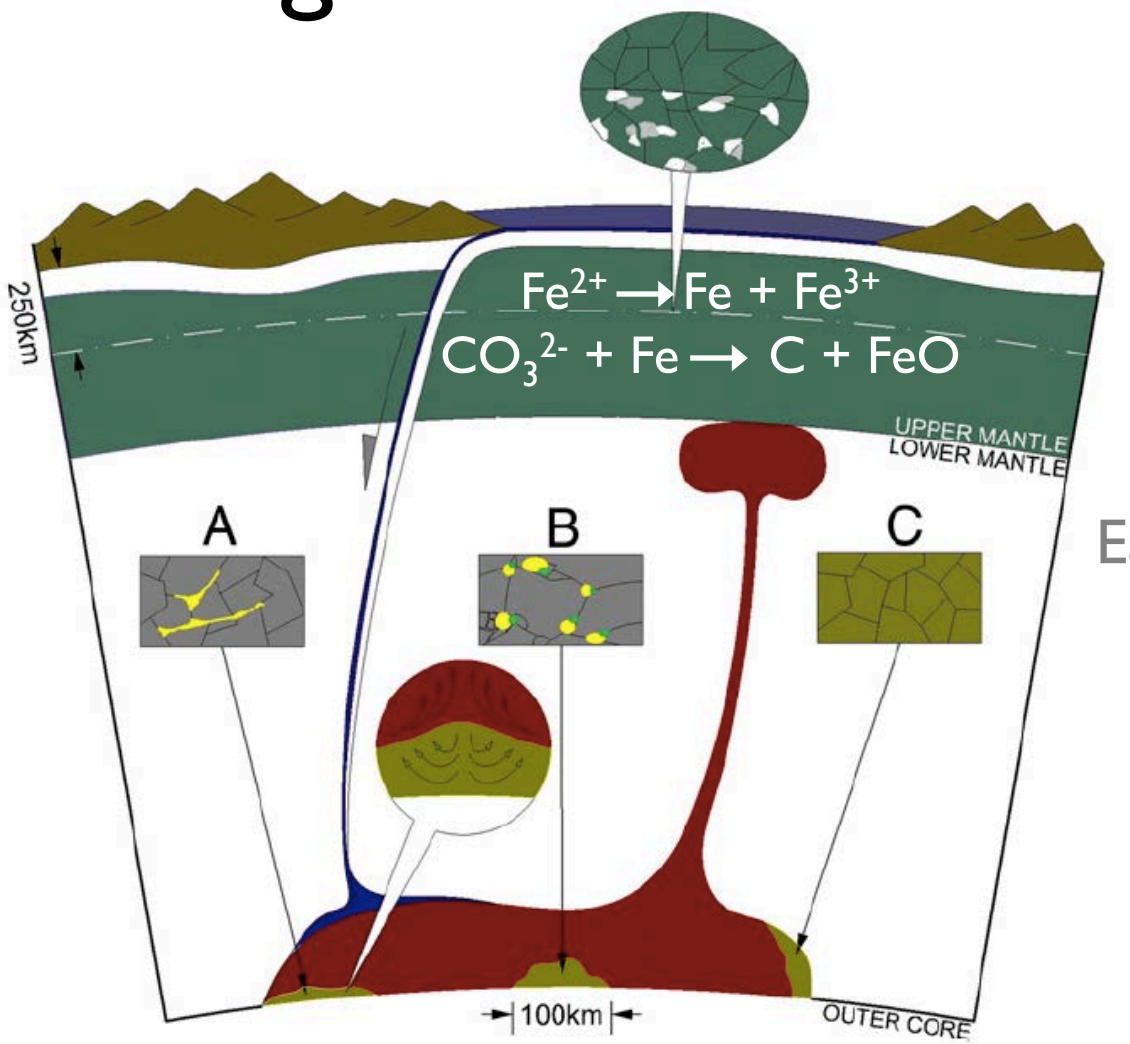
Origins of ultra-low velocity zones through mantle-derived metallic melt



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GEOPHYSICAL LABORATORY, Carnegie Institution of Washington

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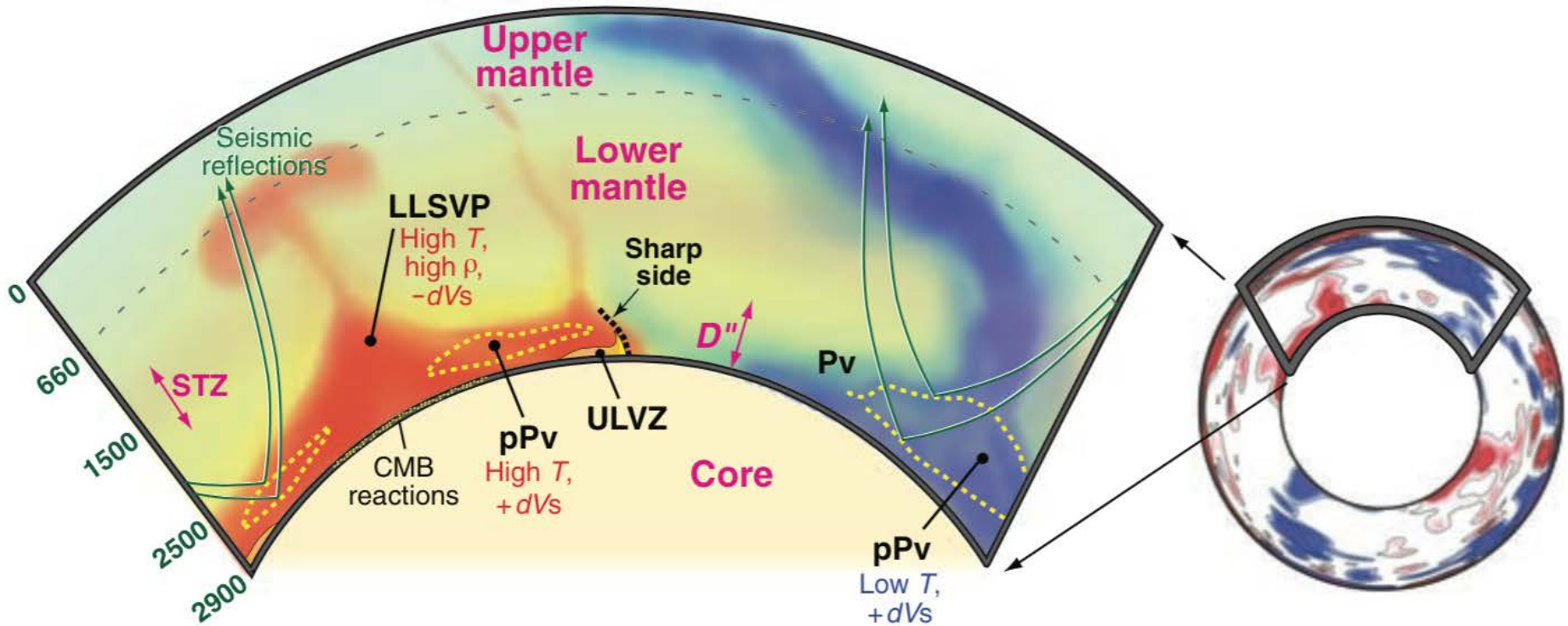
ULVZs at base of mantle



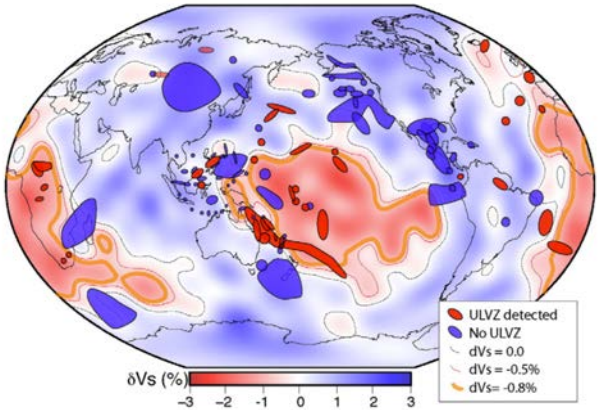
Height ~5 to 30 km, lateral extent ~100 km
Vs reduction ~30%
Vp reduction ~10%
Density excess 5 to 15%
Generally associated with LLSVP

Williams Garnero 96 Science
Garnero McNamara 08 Science

Thermal-chemical origin of ULVZs

Non-ubiquitous, isolated patches

Chemical heterogeneity



Lowers Vs and Vp

Melting

Iron enrichment

$$v_s = \sqrt{\frac{G}{\rho}} \qquad v_p = \sqrt{\frac{K_s + 4/3G}{\rho}}$$

Increases density

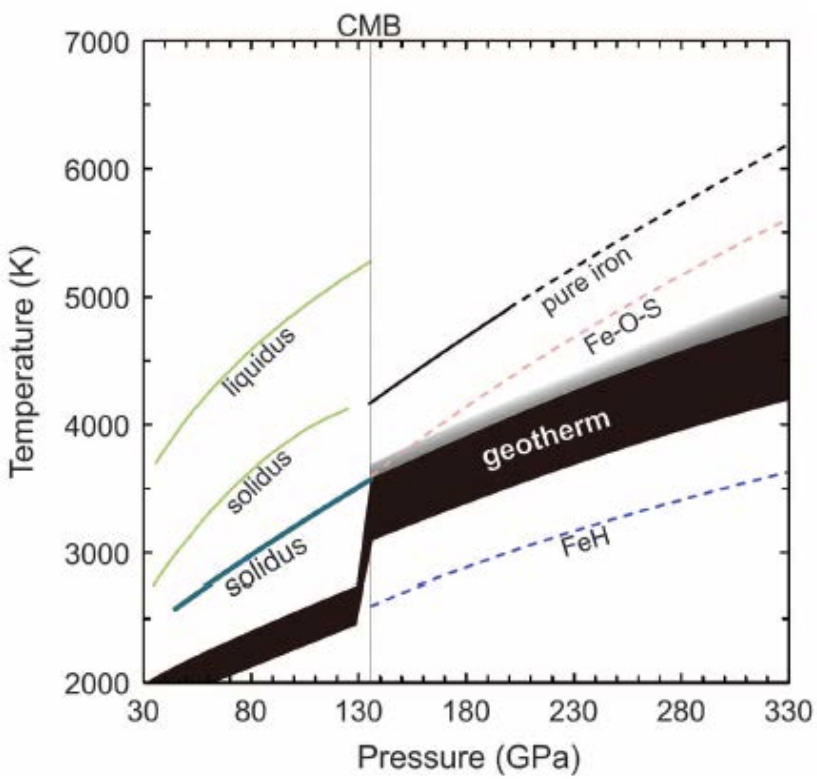
Iron enrichment

$$\rho = m / V \qquad \Delta\rho / \text{at\% Fe} \sim 1$$

Williams Garnero 96 Science

McNamara+ 10 EPSL

Origin of ULVZs through partial silicate melt?



William Garnero 96 Science
Dobson+ 05 Nature
Fiquet+ 10 Science
Nomura+ 11 Nature
Andrault+ 14 Nature

Non-ubiquitous

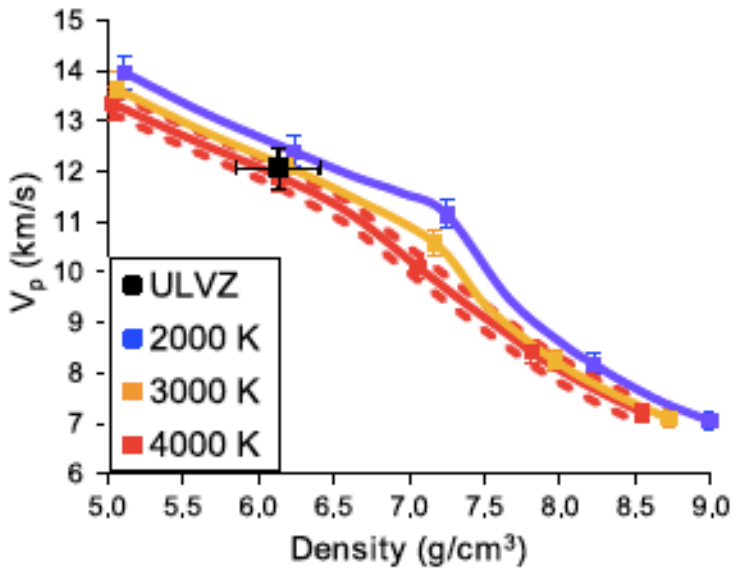
Melting T can't be too high or too low

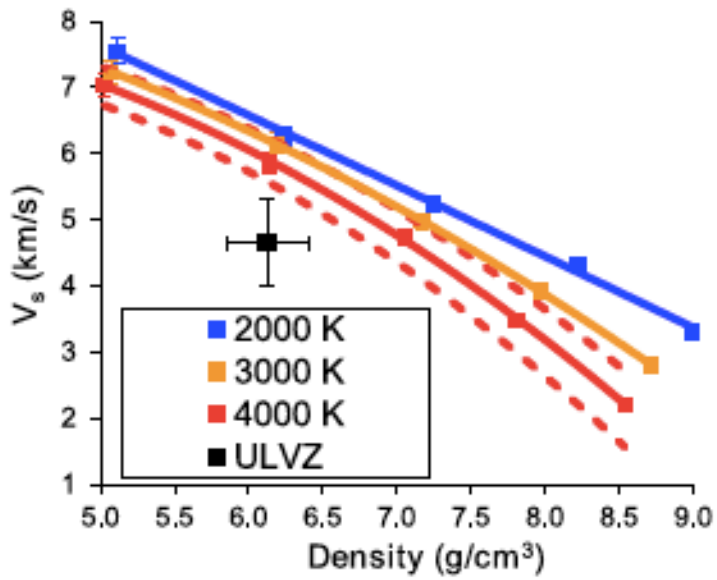
Nomura+ 14 Science

Density excess/Fe enrichment

Thomas+ 12 JGR
Thomas Asimow 13 JGR

Origin of ULVZs through Fe-rich solid?





Mao+ 06 Science
Wicks+ 10 GRL

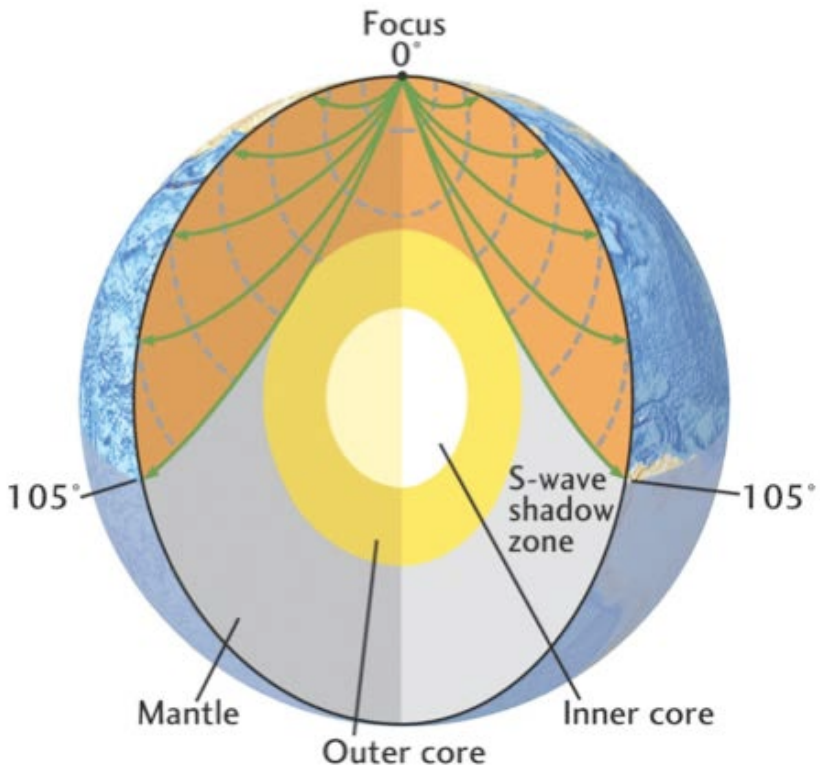
T effect on velocities
single phase does not work
Geometry of mixture critical

Muir Brodholt 15 EPSL
Muir Brodholt 15 GJI

$\mathrm{dln}V_s/\mathrm{dln}V_p = 3$

Non-ubiquitous/Fe enrichment

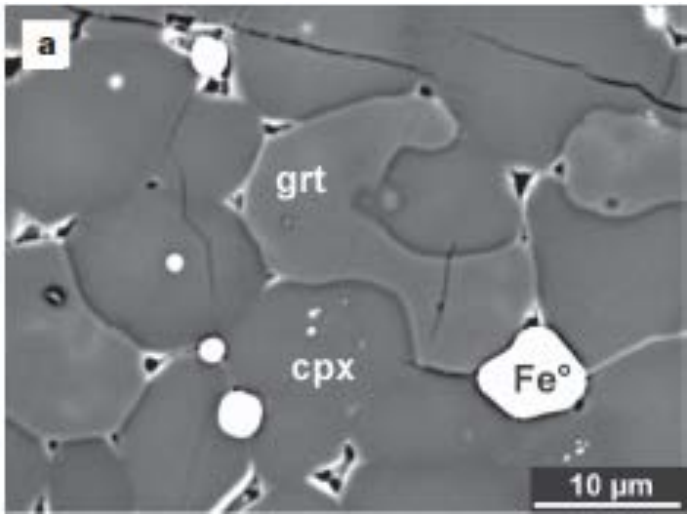
Origin of ULVZs through metallic melt?



Williams Garnero 96 Science
Poirier+ 98
Lay+ 04 PEPI
Rost+ 05 Nature
Kanda Stevenson 06 GRL

capillary rise (20 m)
suction mechanism (1 km)

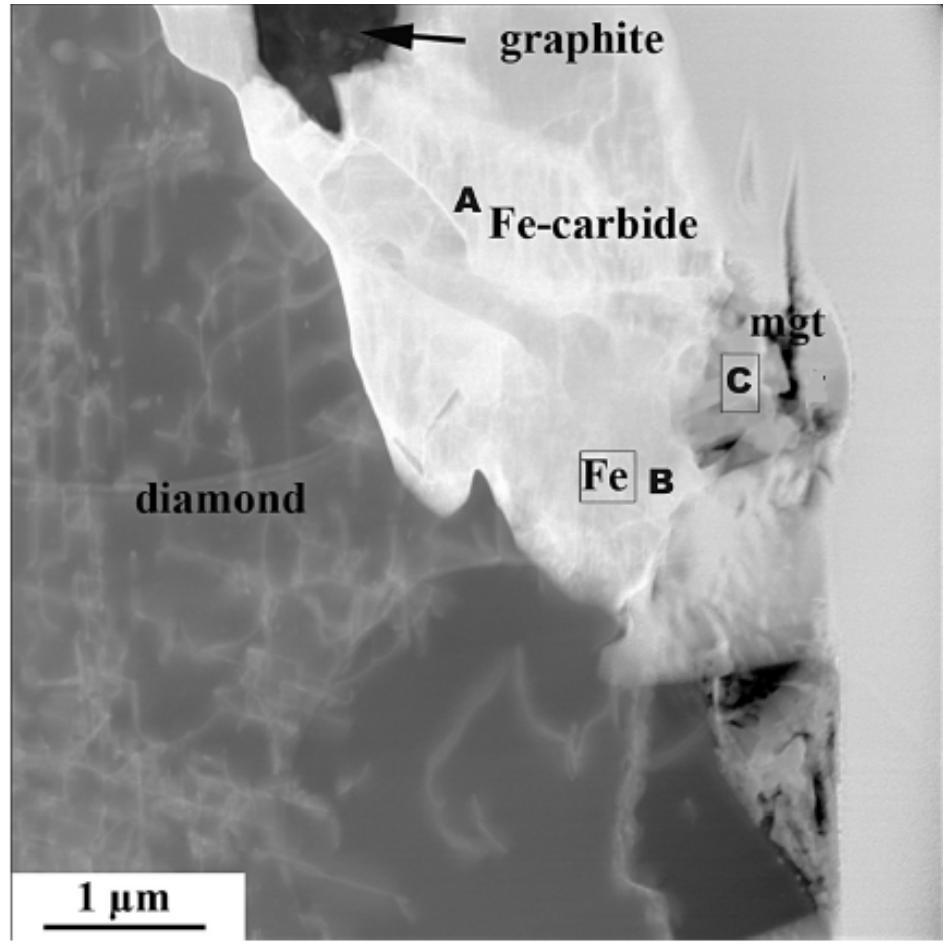
Slabs may carry Fe-C mixture to CMB



$$Fe^{2+} \rightarrow Fe + Fe^{3+}$$

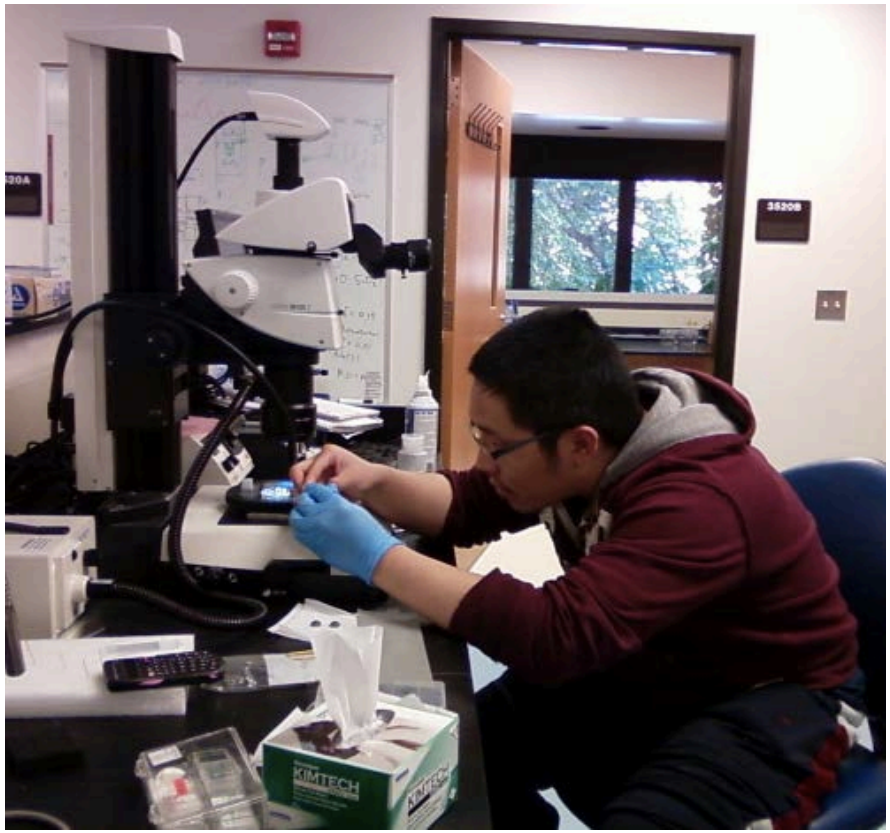
$$CO_3^{2-} + Fe \rightarrow C + FeO$$

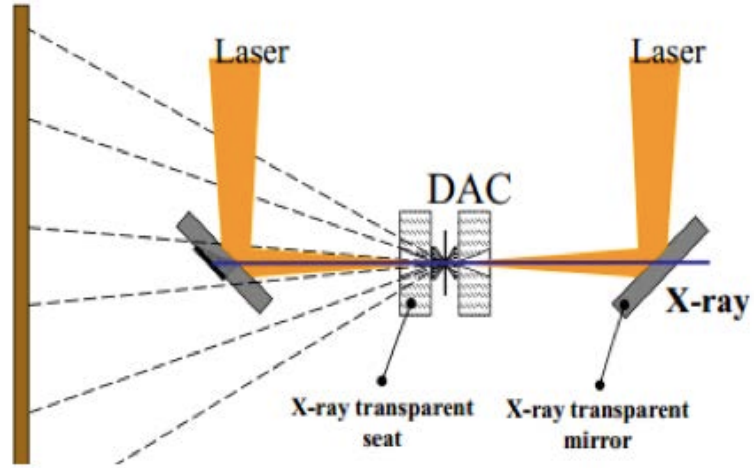
Frost+ 04 Nature
Rohrbach+ 07 Nature

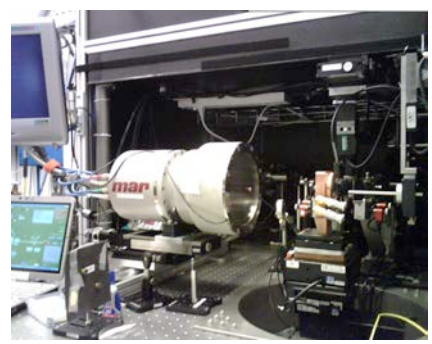


Kaminski 11 CM

Fate of Fe-C mixture in deep mantle?







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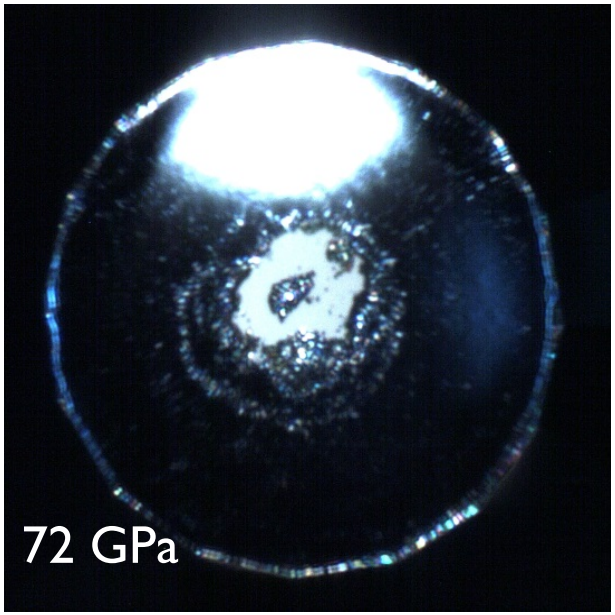
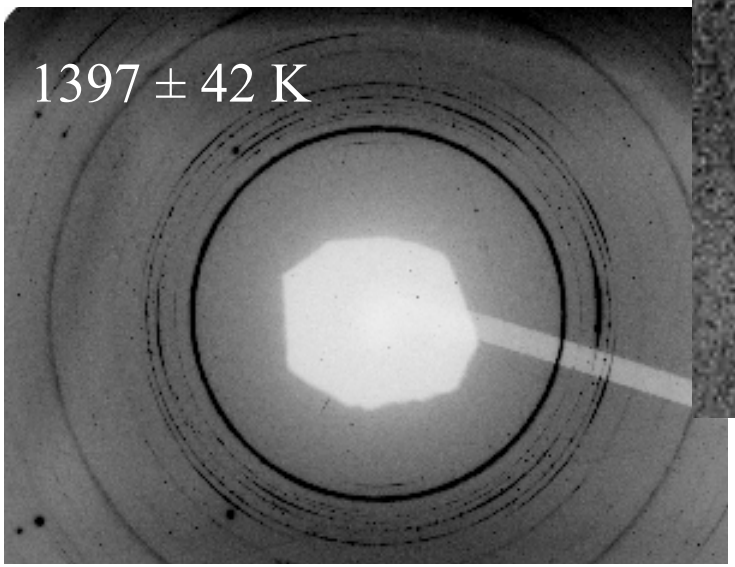
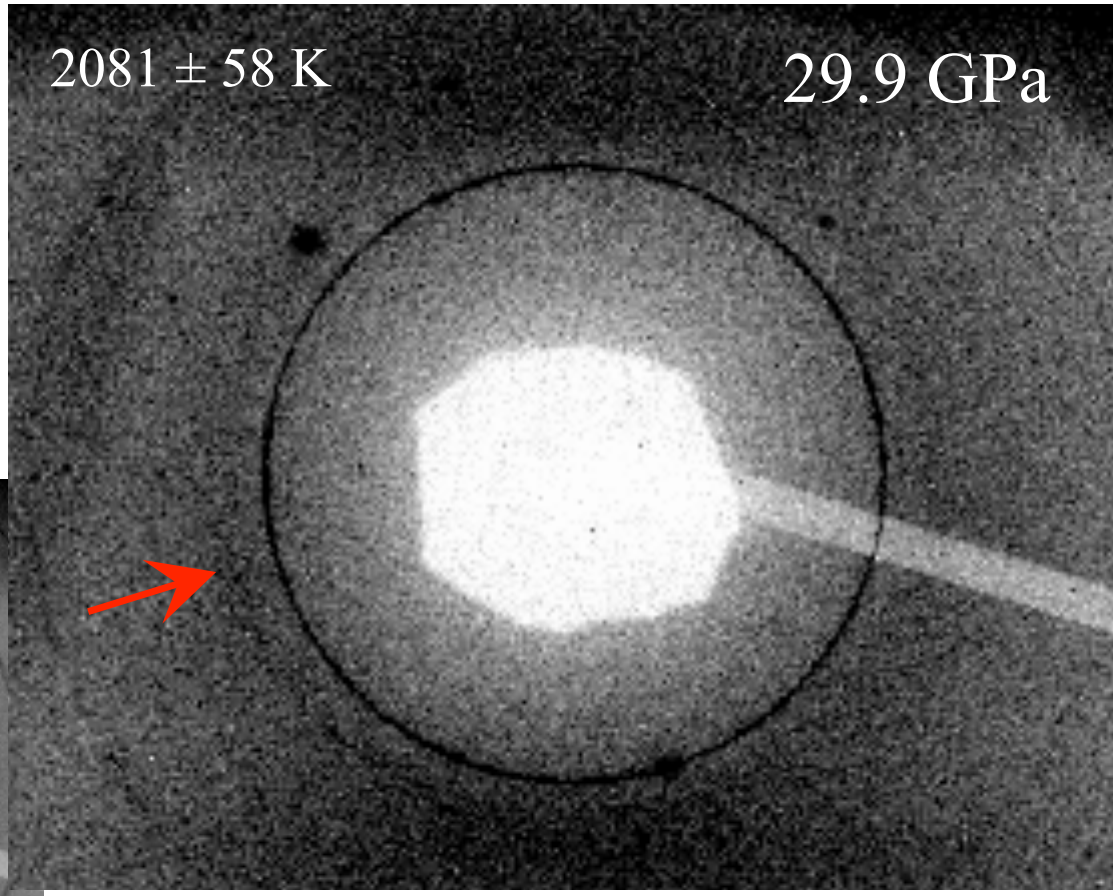
Advanced Photon Source,
Argonne National Laboratory

Diffuse scattering in XRD images



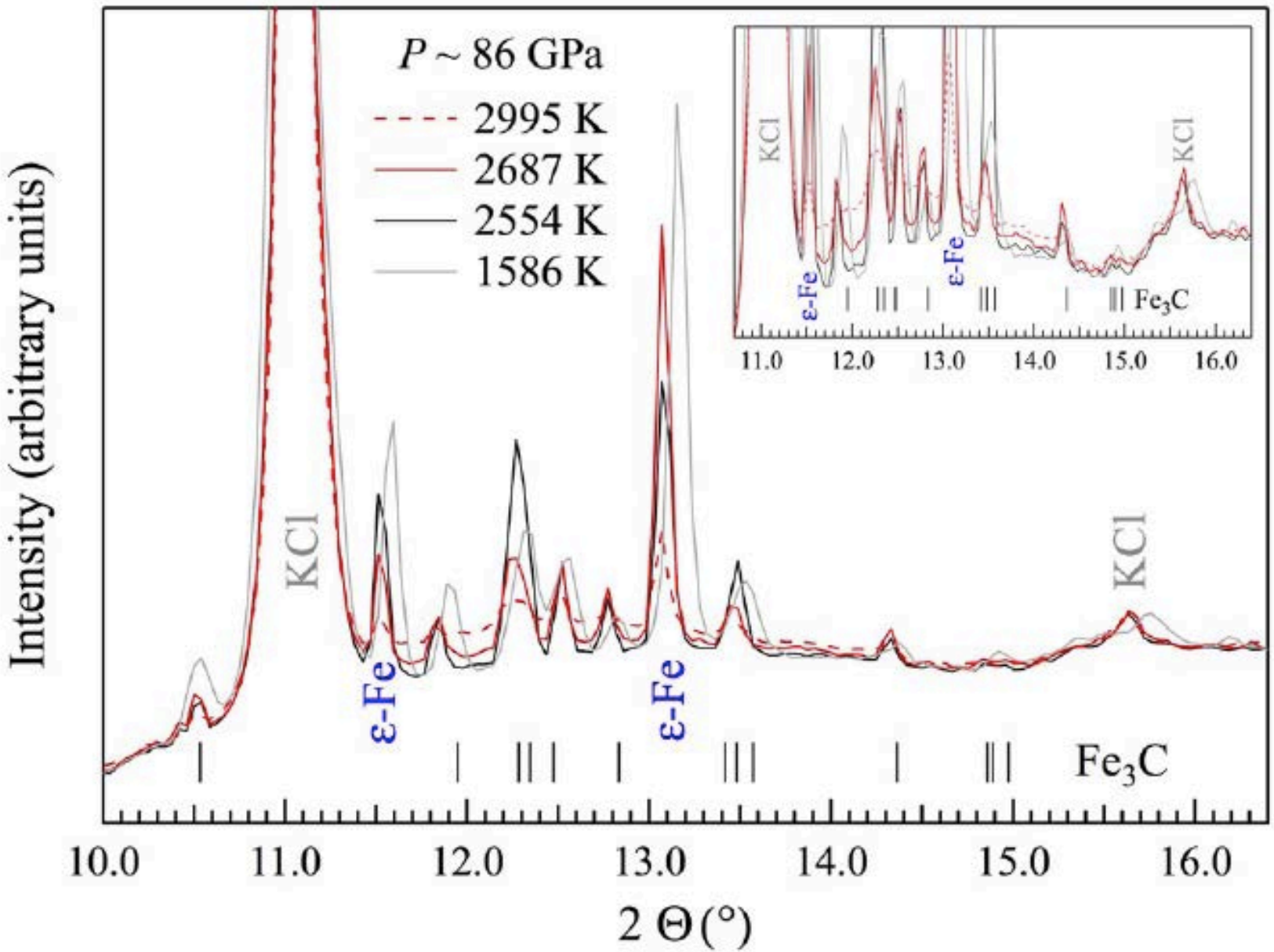




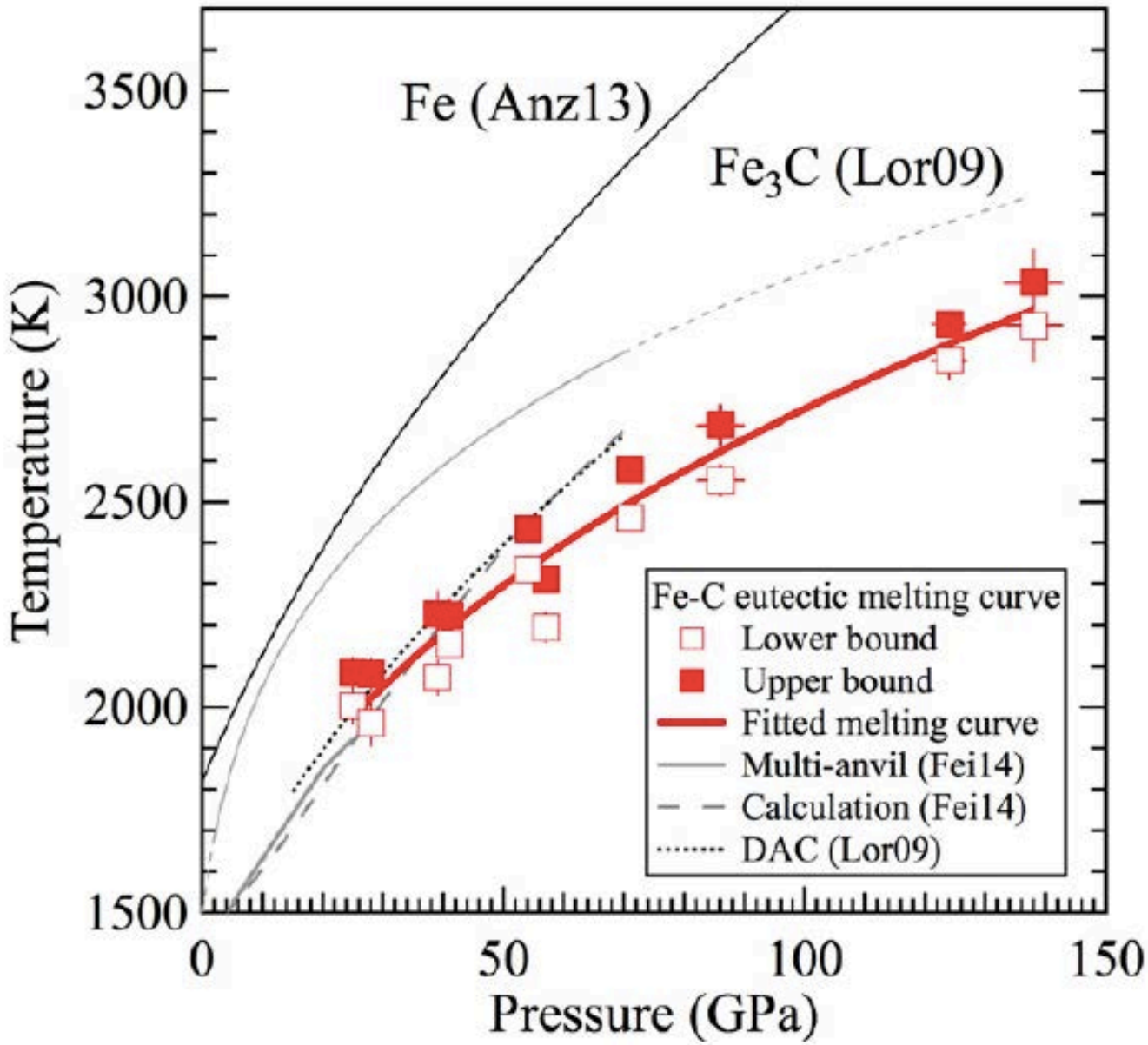
Liu+ 16 PNAS

Anzellini+ 13 Nature

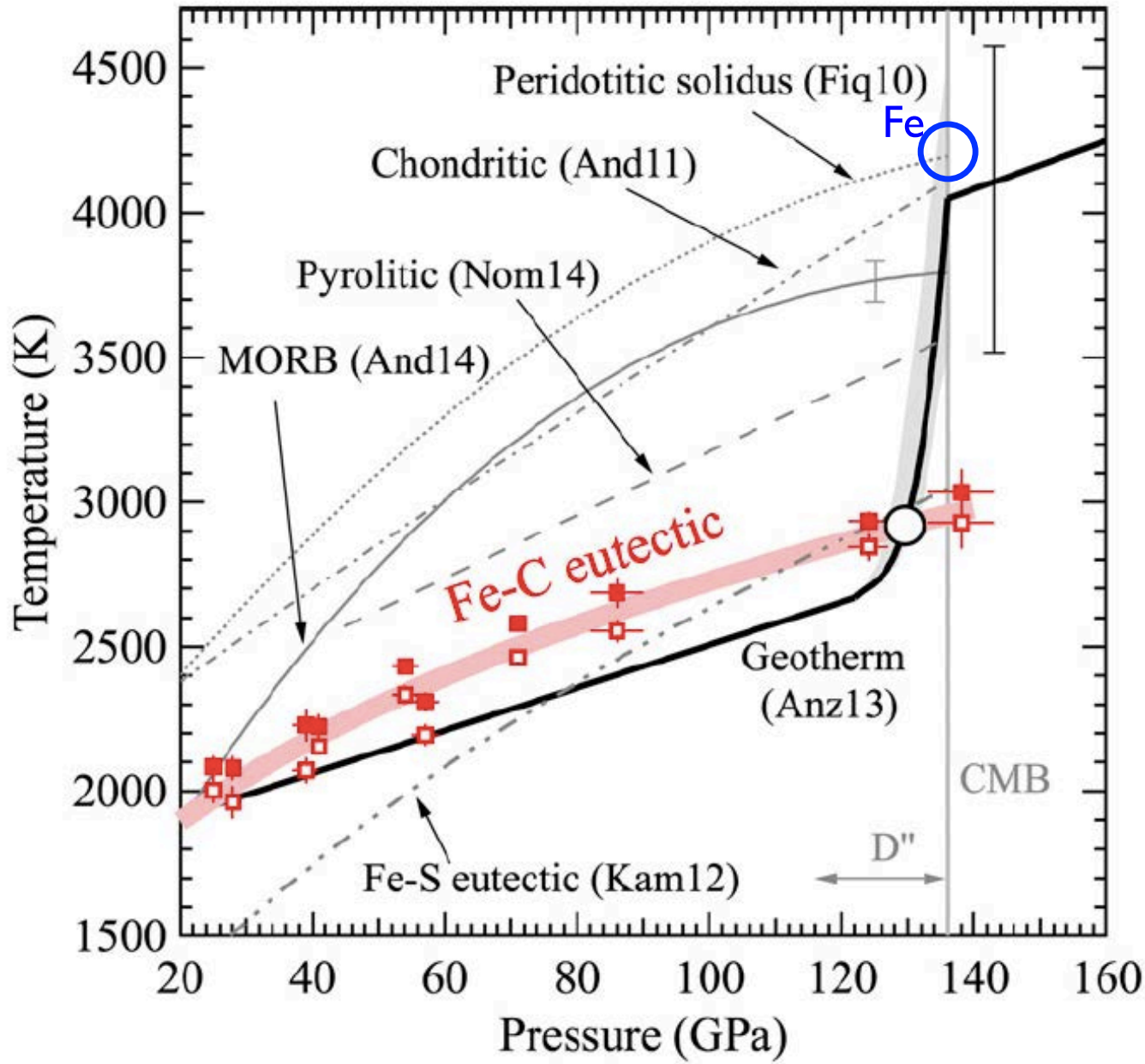
Diffuse scattering in integrated XRD



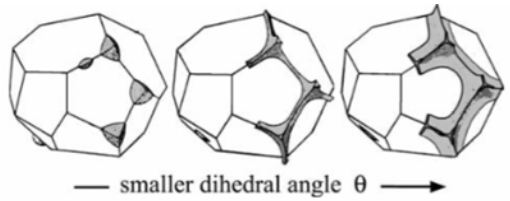
Fe-C eutectic melting curve

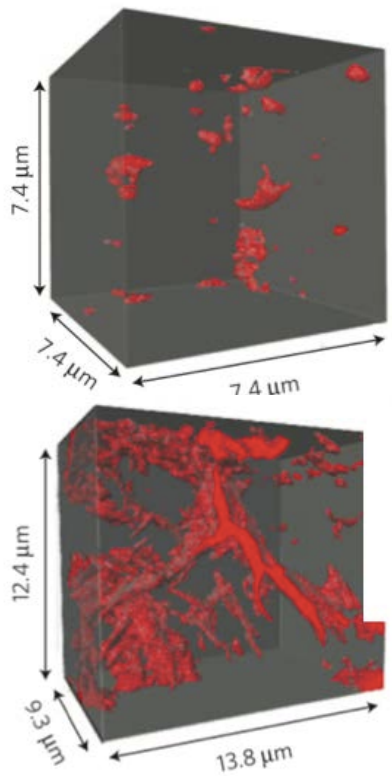


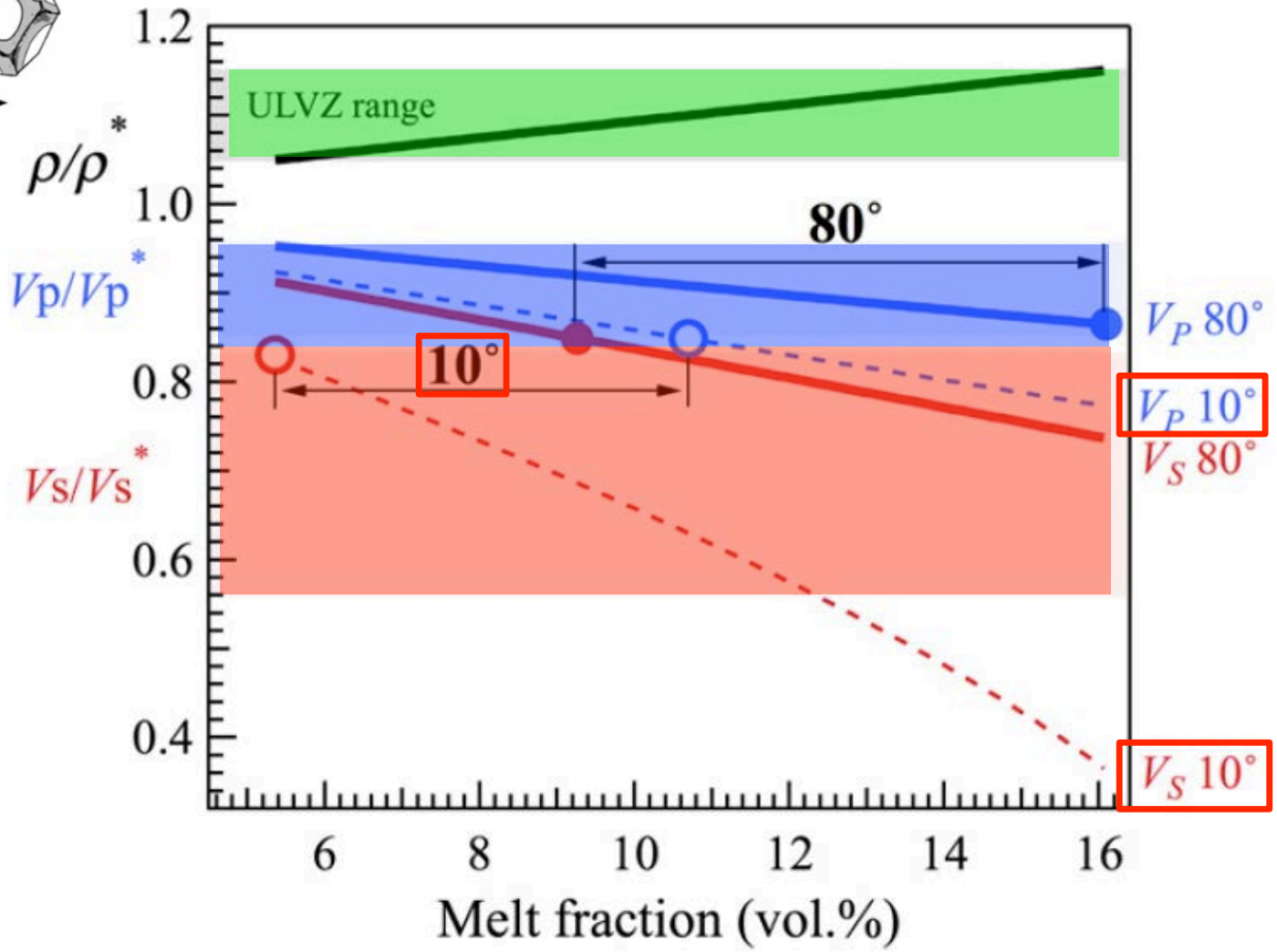
Fe-C melt at base of mantle



Metallic melt reduces *V*p, *V*s and increases ρ







Shi+ 13 NG
Takei 02 JGR

Hypothesis I: Subduction-sustained ULVZs

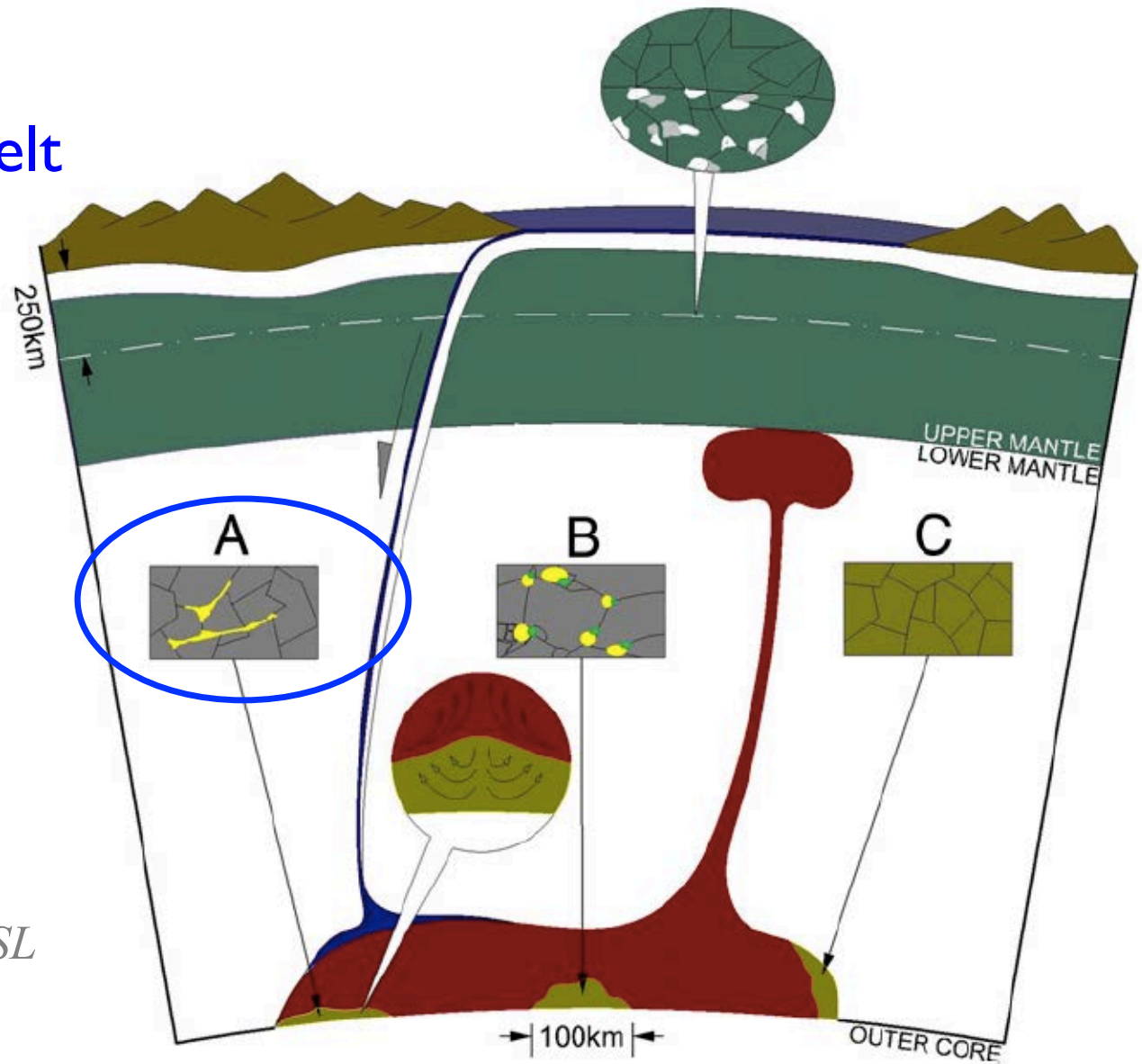
5-11 vol.% Fe-C melt

Concentrate through dynamic or chemical processes

Percolation threshold 5%
Viscous stirring
prevents settling

Likely short-lived

Yoshino+ 04 Nature
Hernlund Jellinek 10 EPSL
Kholstedt 09
Li+ 14



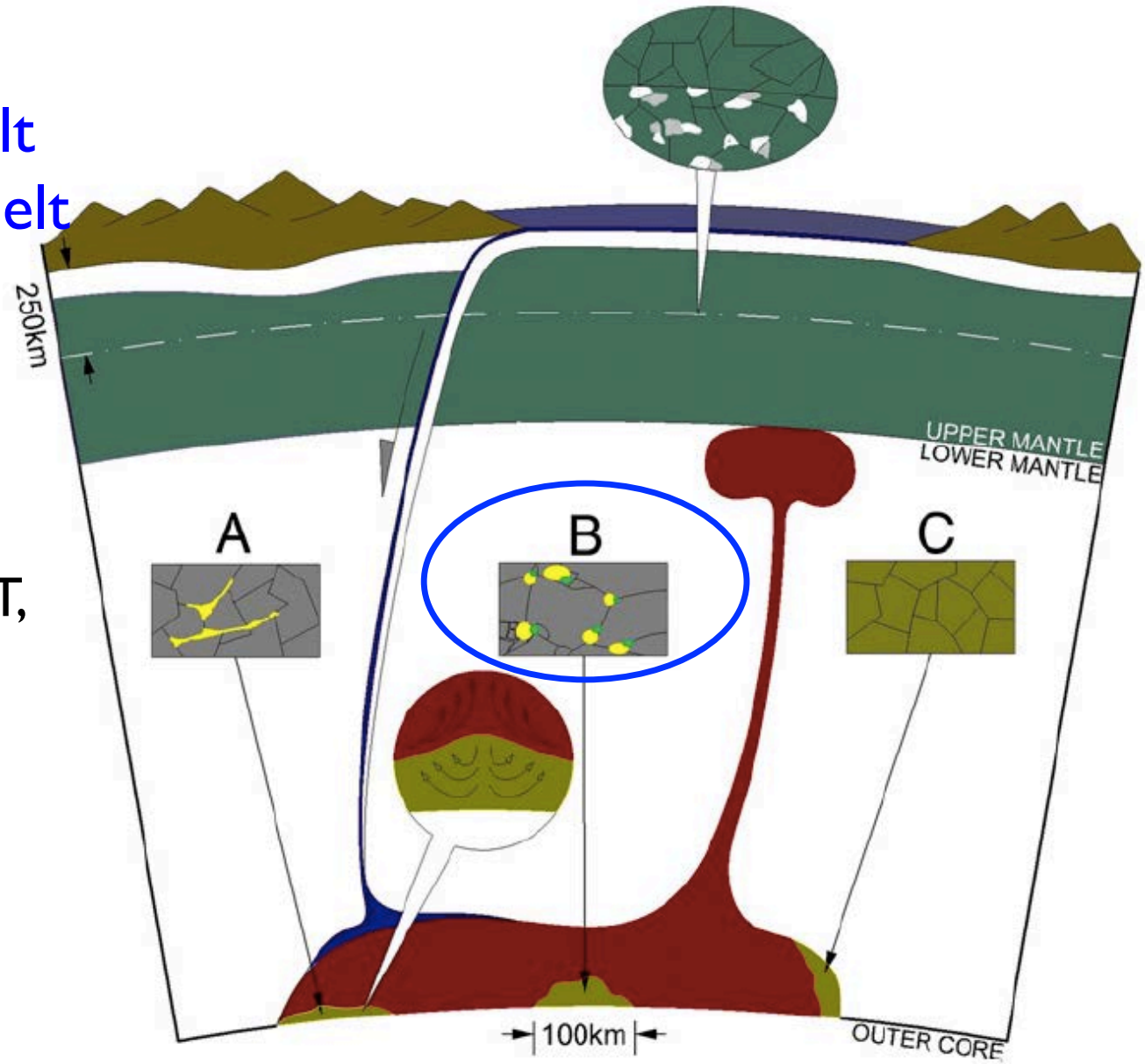
Hypothesis II: Two-melt ULVZs

>9 vol. % Fe-C melt
+ silicate partial melt

metallic melt alone
not viable (drain)

silicate melt alone
not viable (melting T, density)

Yoshino+ 04 EPSL



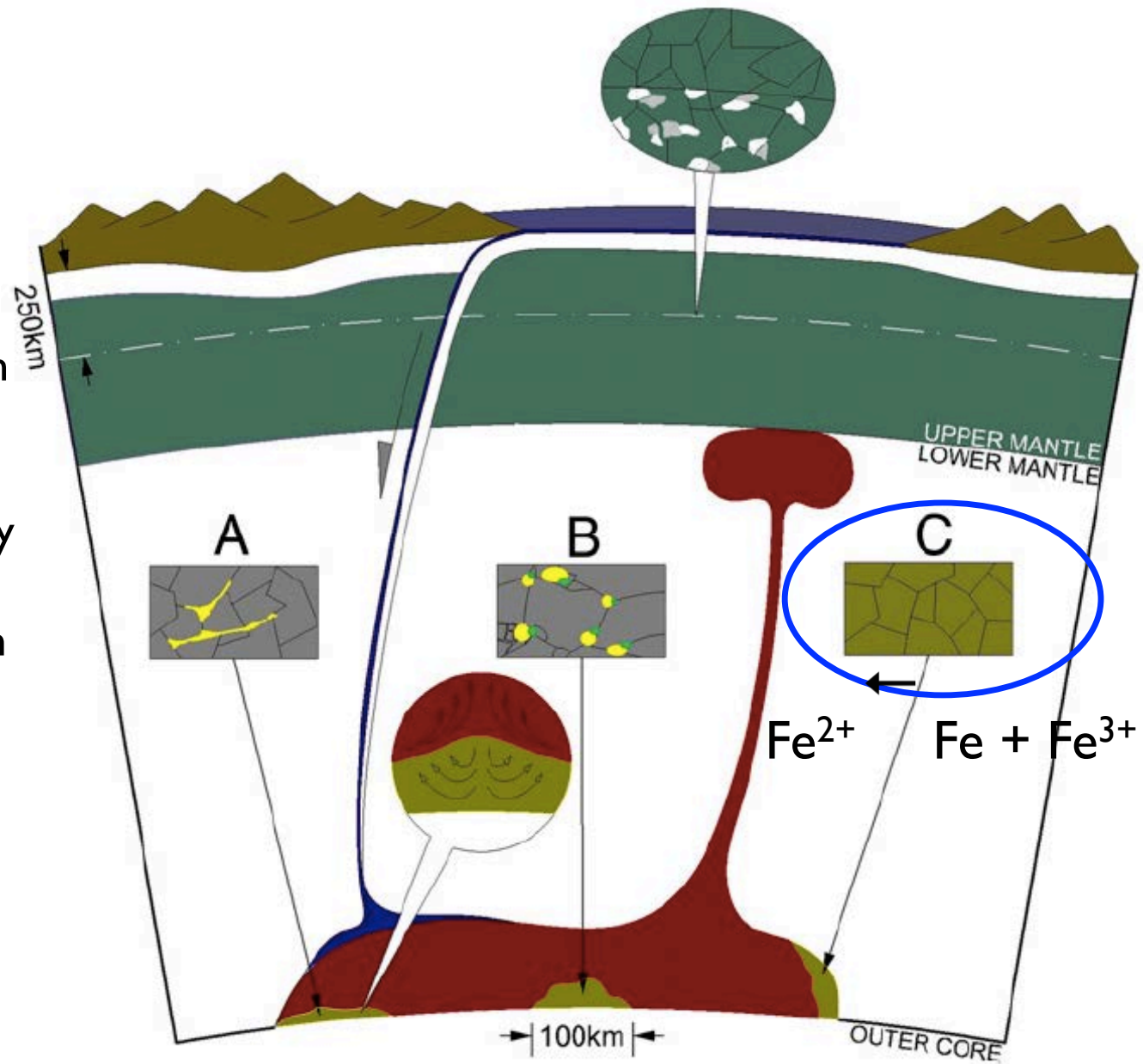
Hypothesis III: Solid ULVZs

Fe-rich pbm + fp

Isolated patches
- Melt delivers iron
- Size limited by reaction and diffusion rate

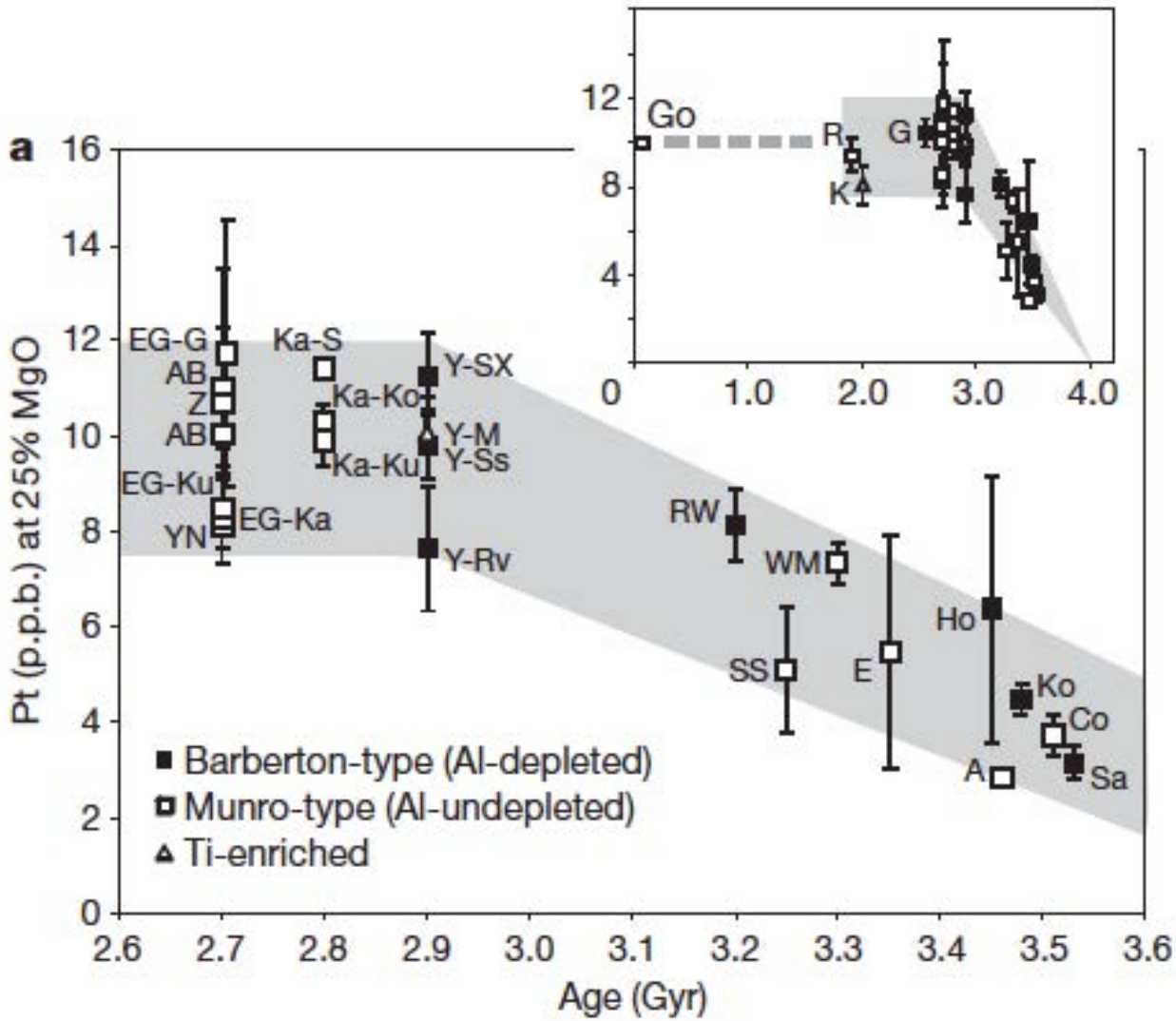
bm: m per Ga

Fp: through Earth history
lattice 1-10 km
grain boundary 100 km
- Likely tall and thin



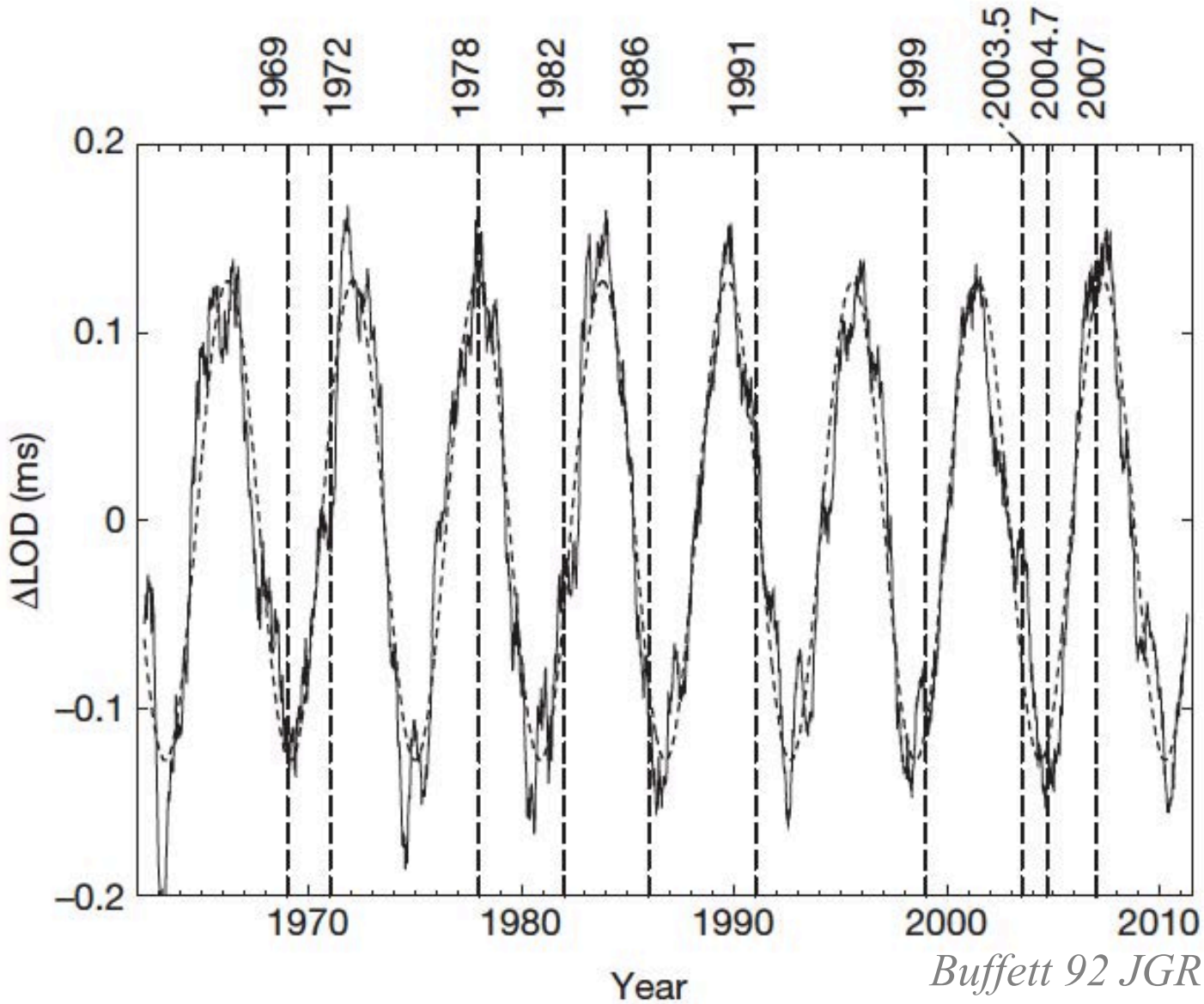
Yamazaki+ 00 PEPI
Van Orman+ 03 GRL
Muir Brodholt 15 EPSL

Implications: Mix "late veneer"



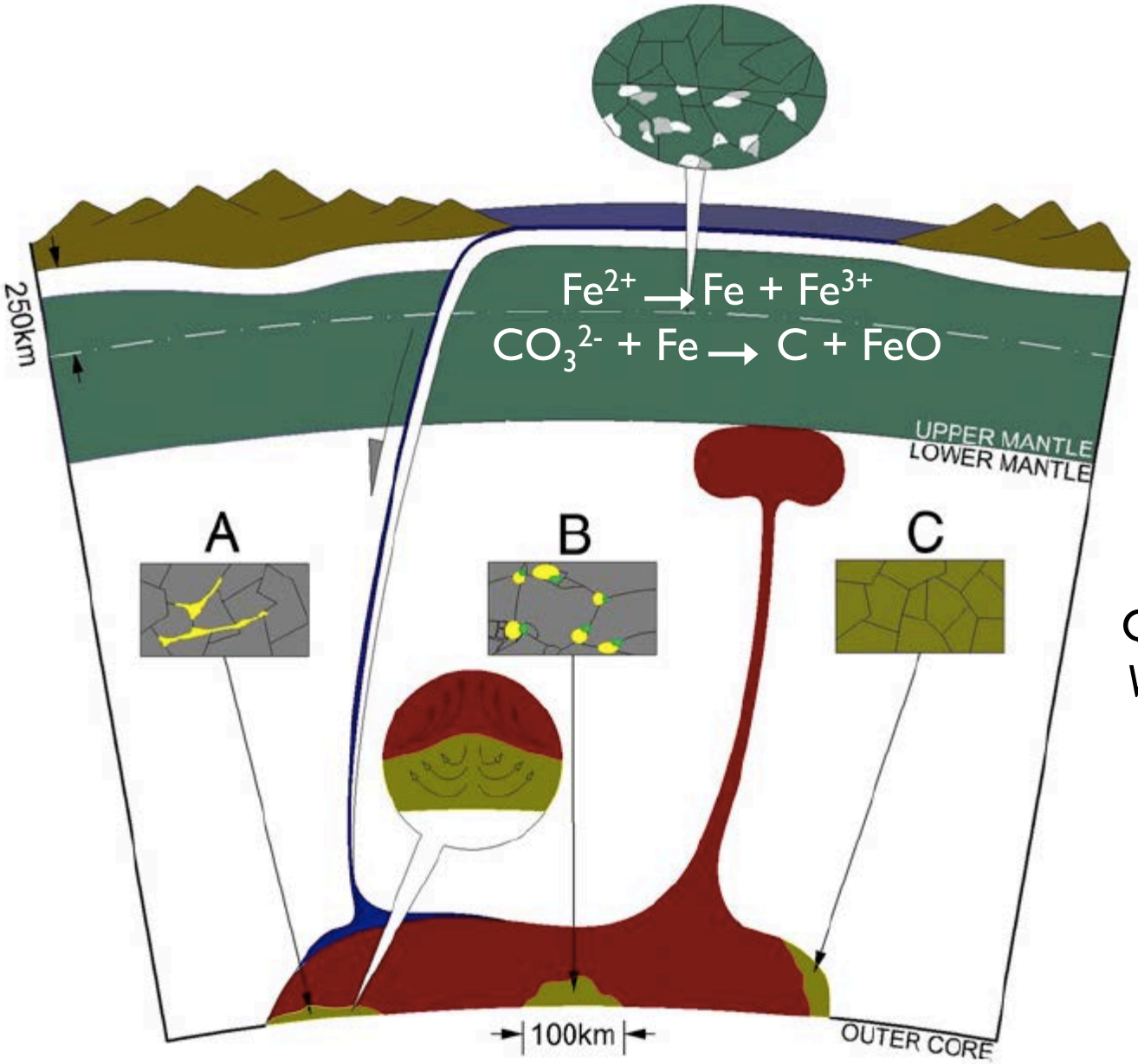
Maier+ 09 Nature

Implications: CMB conductivity



Buffett 92 JGR
Holme de Viron 13 Nature

Conclusions



Model features

Multiple origins
involving metallic melt
through subduction

Readily explains
isolated small patches

Quantitatively reproduces
*V*p, *V*s reductions ρ excess

Test the models

Wetting
Melt concentration
Diffusion/reaction