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

$\text{Fe}^{2+} \rightarrow \text{Fe} + \text{Fe}^{3+}$
$\text{CO}_3^{2-} + \text{Fe} \rightarrow \text{C} + \text{FeO}$

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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

\[ v_s = \sqrt{\frac{G}{\rho}} \]
\[ v_p = \sqrt{\frac{K_s + 4/3G}{\rho}} \]

Increases density
Iron enrichment

\[ \rho = \frac{m}{V} \]
\[ \Delta \rho / \text{at\% Fe} \sim 1 \]

*Williams Garnero 96 Science
McNamara+ 10 EPSL*
Origin of ULVZs through partial silicate melt?

Non-ubiquitous
Melting $T$ can’t be too high or too low

Density excess/Fe enrichment

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

Nomura+ 14 Science
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

$d\ln V_s / d\ln V_p = 3$

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

\[ \text{Fe}^{2+} \rightarrow \text{Fe} + \text{Fe}^{3+} \]
\[ \text{CO}_3^{2-} + \text{Fe} \rightarrow \text{C} + \text{FeO} \]

_Frost+ 04 Nature_
_Rohrbach+ 07 Nature_

_Kaminski 11 CM_
Fate of Fe-C mixture in deep mantle?

Dr. Jiachao Liu

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 $\rho$. 

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”
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 $\rho$ excess

Test the models
Wetting
Melt concentration
Diffusion/reaction