Geoneutrino Contributions from the Deep Lithosphere

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The Deep Lithosphere

- Middle + lower continental crust
  - Lower 2/3 or lower 1/2 of the continental crust
  - Medium to high grade metamorphic materials
  - Facies ≠ composition
From Composition to Geoneutrinos

Geophysical + Geochemical Inversions → Seismic Velocities → \( \text{SiO}_2 + \text{Density} \)

A straight forward process...

...but one with many steps

Geoneutrino Signal ← [Th] ← [U]
How do you describe a crust you can’t see?

- Geochemically
- Seismologically
- Make a model
Geochemistry

- Range of U and Th concentrations
  - 8 – 10 orders of magnitude
  - Log normal?

- What causes variation?
Geochemistry

Granulite Facies Lithologies

[Graphs showing Mg# vs. SiO₂ (wt.%) for Xenoliths, Post-Archean Terrains, and Archean Terrains, with color-coded data density.]
Seismology

- P-waves, S-waves, dispersion waves
- Materials have characteristic wave velocities
- Variation with depth
- Different layers
- Nonunique
Seismic Velocities to Compositions

- Experiments relate composition to seismic velocity, physical properties
- Observed dependence on temperature

Figure 13. Velocity versus depth and heat flow province for average granite/granodiorite and mafic garnet granulite. For temperatures, see Table 4.
Temperature

- Why is temperature important?

- $V_p$, $V_s$ are temperature dependent!
  - More sensitive to $T$ than $P$

Figure 13. Velocity versus depth and heat flow province for average granite/granodiorite and mafic garnet granulite. For temperatures, see Table 4.
\[ V_p = \sqrt{\frac{K + \frac{4}{3} \mu}{\rho}} \]

- Mineralogy
- Pressure
- Temperature
- Composition

Perple_X
Seismic Velocities to Compositions

Granulite Facies Lithologies

$V_p$ (km/s)

$SiO_2$ (wt.%)

600°C
Example 1

- Bain and Range, SW US
- Extended crust, 25 – 40 km
- Hot, 650 – 950 °C
- Compare USArray inversions to calculated velocities
- What compositions produce Vs that overlaps with seismic data?

Gao & Lekic (2019)
Example 1

- $\text{SiO}_2$ gradient!

- Uncertainties!
Example 2

- Global data set
- Shields ≈ 130 controlled seismic profiles

- Use Vs, Vp, & ratio when available
- Group similar crust types/tectonic regimes
Example 2

Constant Temperature Gradient 15°C/km

Updated Moho Temperature

\text{SiO}_2 (w.t.%)
**SiO$_2$ to U**

- U correlated to SiO$_2$
- Increase in mean/median SiO$_2$ $\equiv$ increase in U
- Bivariate probability analysis
- Distribution of U for range of SiO$_2$
U to Th

- Fixed chondritic Th/U ratio
- Refractory lithophile elements
- Similar behavior except in cases of ore deposits, marine & water
- Th/U doesn’t fractionate between BSE reservoirs (Wipperfurth et al. 2018)
U, Th, Density to Geoneutrino Flux

- Mass of U and Th near detector calculated from
  - Concentration in specific rock types
  - Density

\[
\frac{dN(E_{\bar{\nu}_e}, \vec{r})}{dE_{\bar{\nu}_e}} = \epsilon \frac{N_A \lambda}{\mu} \sigma_P(E_{\bar{\nu}_e}) \frac{dn(E_{\bar{\nu}_e})}{dE_{\bar{\nu}_e}} \int_\oplus P_{ee}(E_{\bar{\nu}_e}, |\vec{r} - \vec{r}'|) d\vec{r}' \frac{a(\vec{r}') \rho(\vec{r}')}{4\pi |\vec{r} - \vec{r}'|^2}
\]

- U, Th have specific decay energies
Conclusions

1. Geoneutrino signal predictions/corrections require knowledge of crustal composition

2. Crust is a gradient of compositions

3. Felsic to mafic with increasing depth (?)

4. U & Th $\propto$ SiO$_2$

5. Combine geochemistry and geophysics to figure out composition

"Man, a mere inhabitant of the earth, cannot overstep its boundaries! But though he is confined to its crust, he may penetrate into all its secrets." - Jules Verne
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