Geoneutrino Contributions from the Deep Lithosphere

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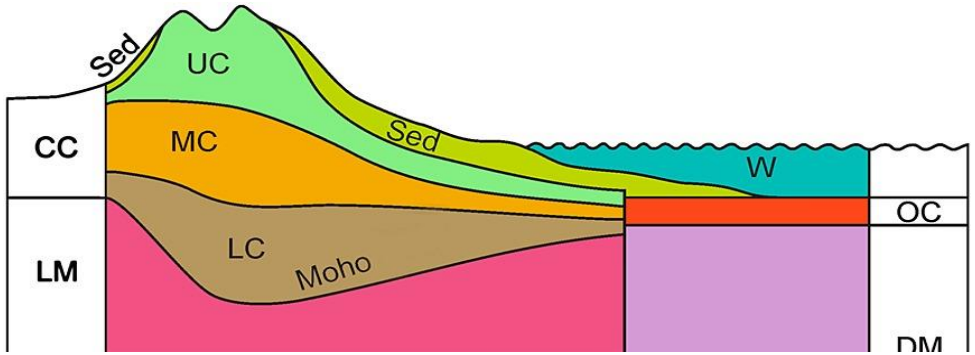
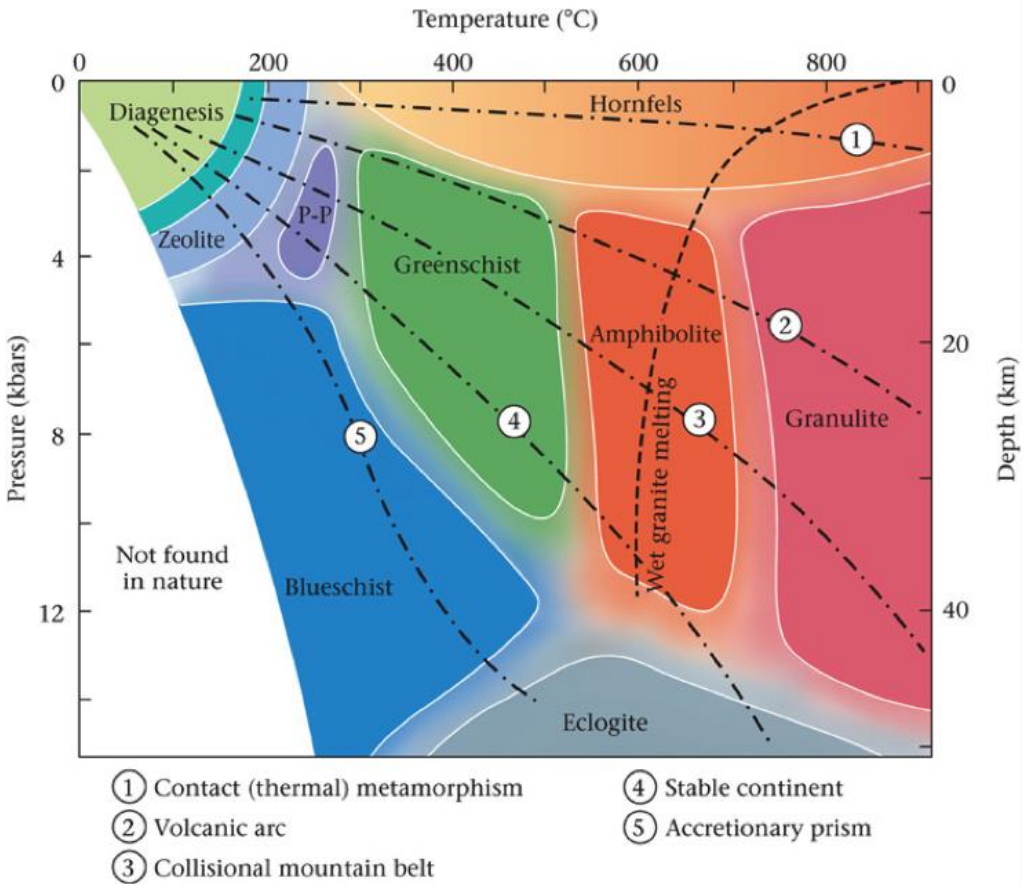
The Deep ~~Lithosphere~~ Continental Crust

- 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** → **SiO_2 + Density**

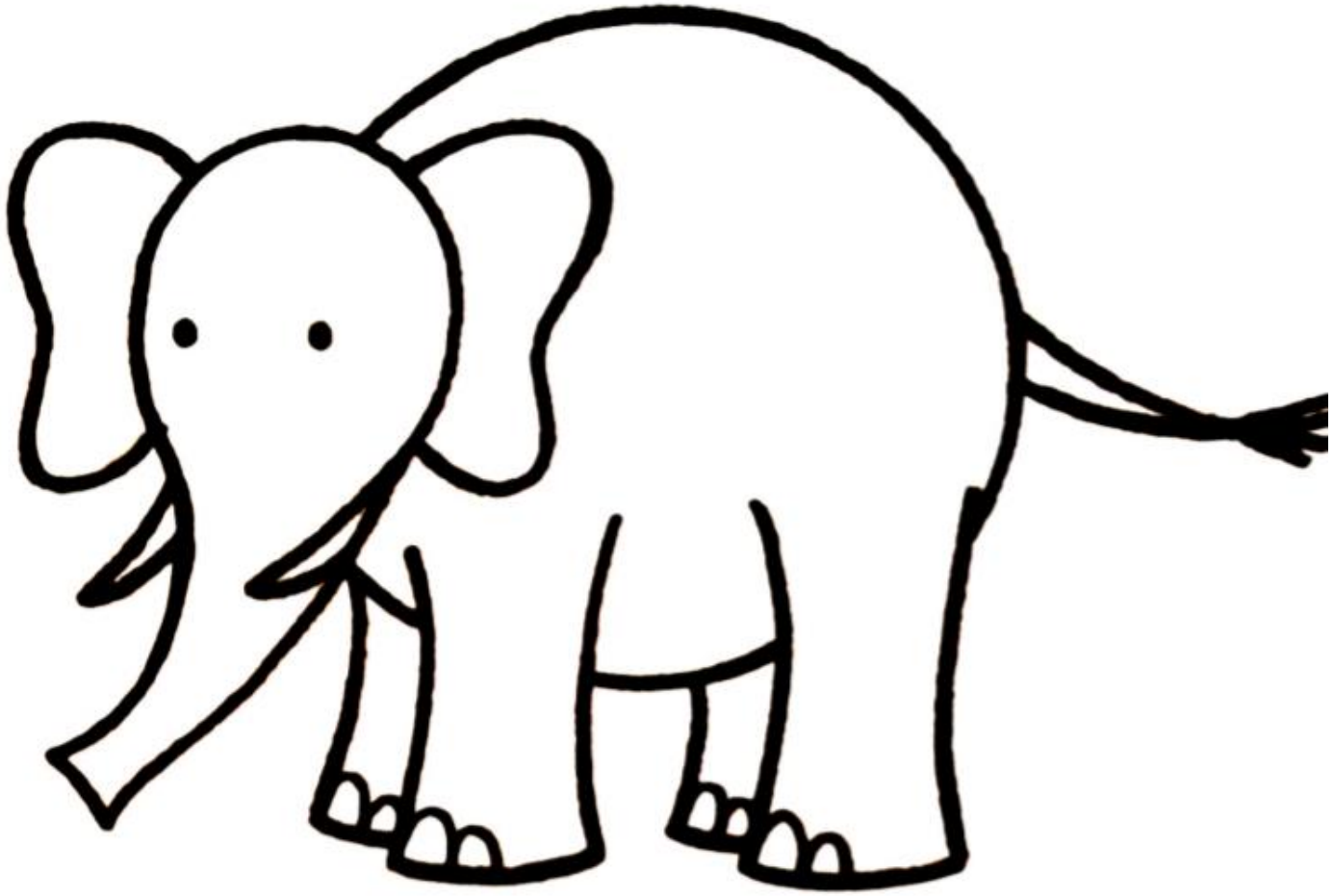
A straight forward process…

…but one with many steps

[U] → **[Th]** → **Geoneutrino Signal**

How do you describe a crust you can't see?

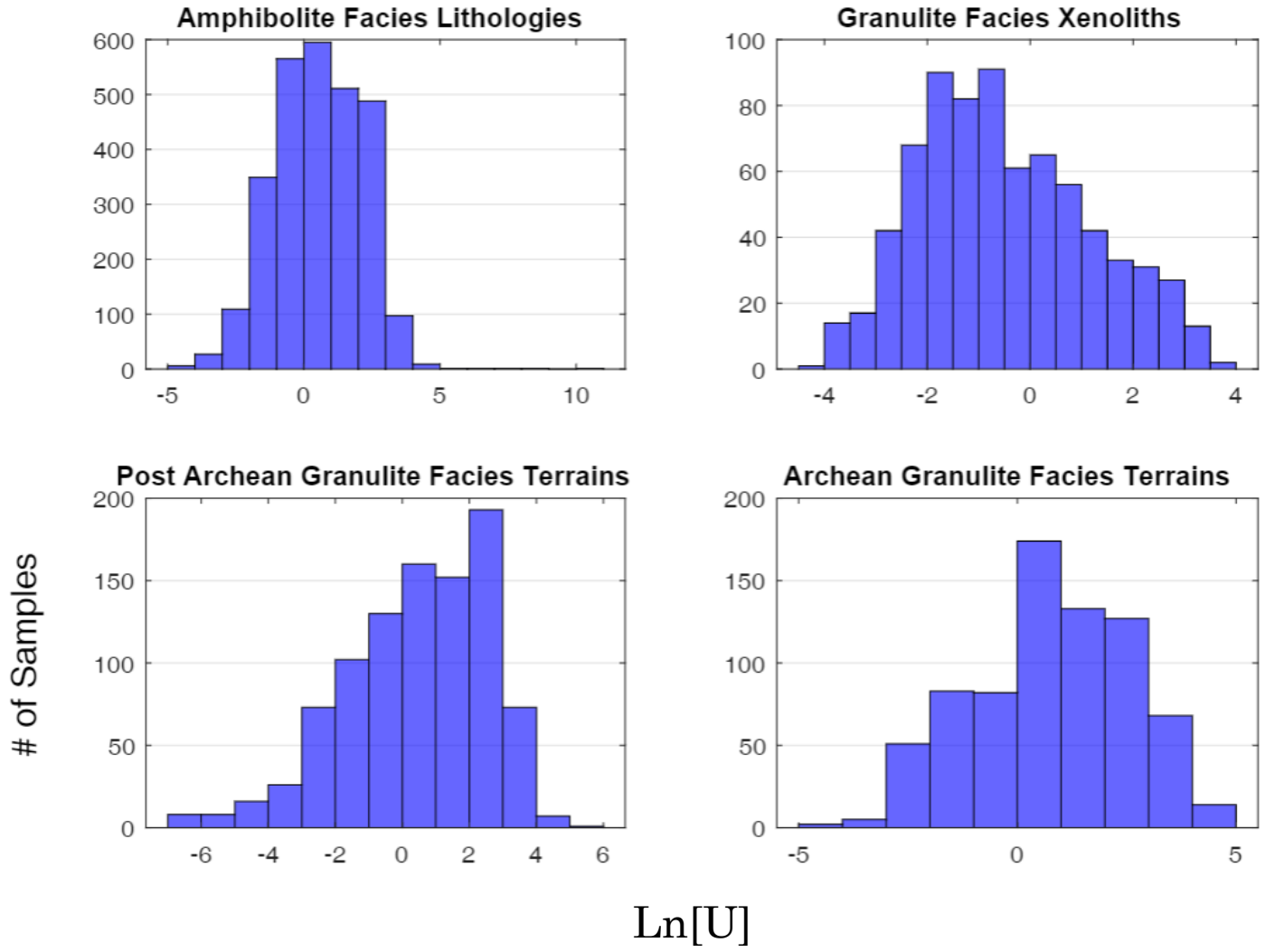
- Geochemically
- Seismologically
- Make a model



Geochemistry

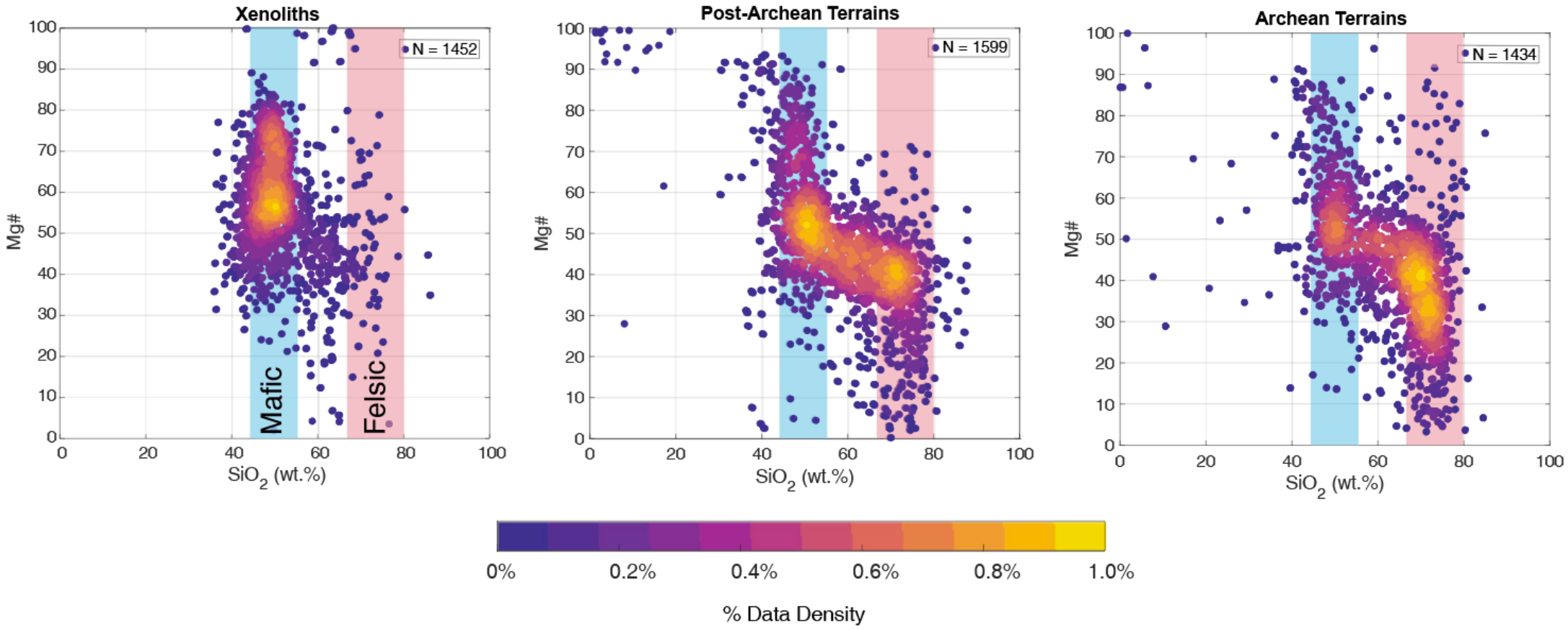
- Range of U and Th concentrations
  - 8 – 10 orders of magnitude
  - Log normal?

- What causes variation?

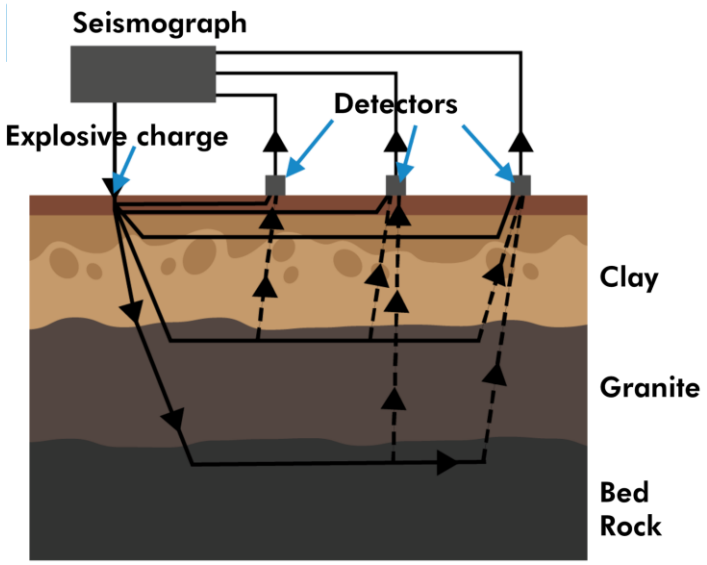


Geochemistry

Granulite Facies Lithologies



Seismology



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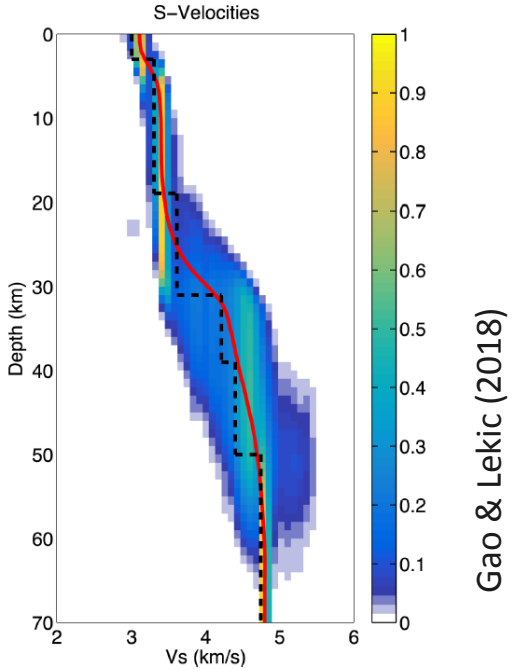
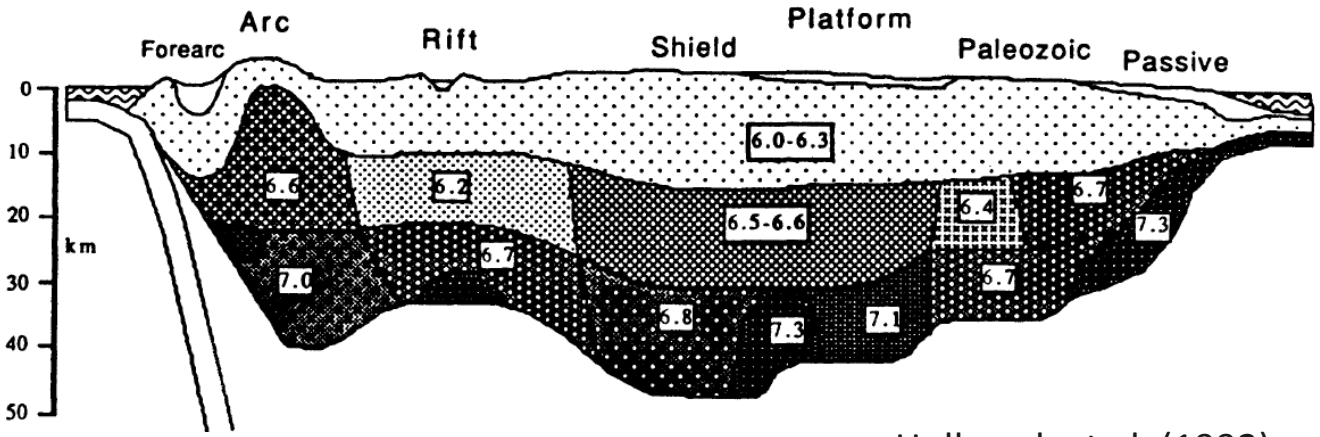


Gao & Lekic (2018)

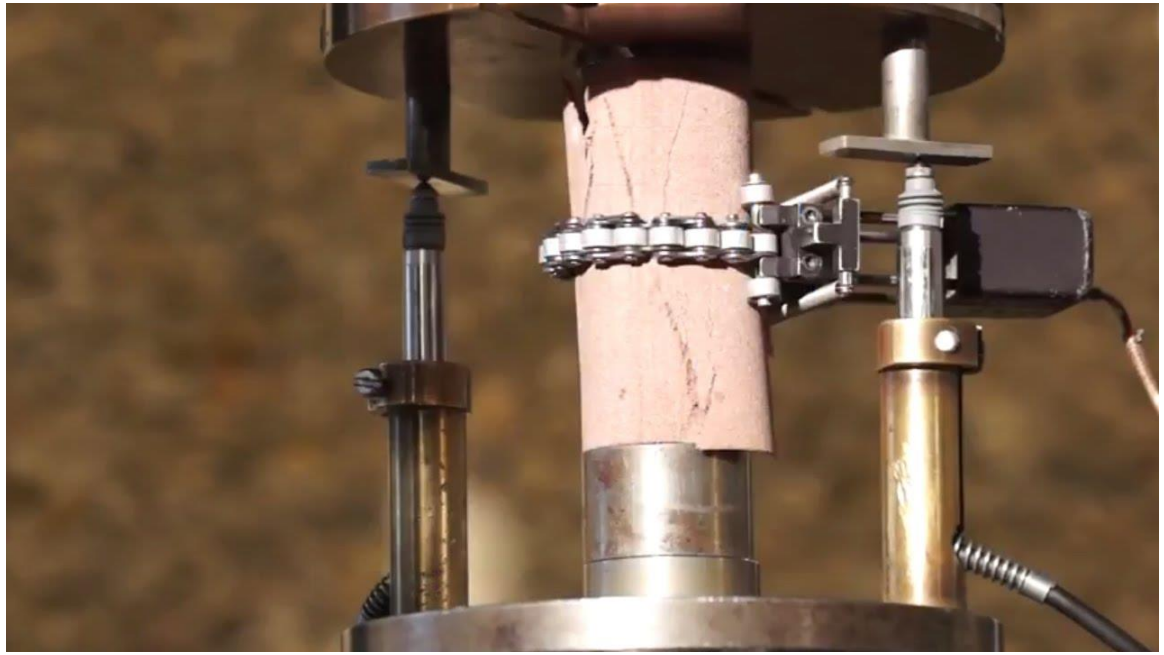


Holbrook et al. (1992)

- 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



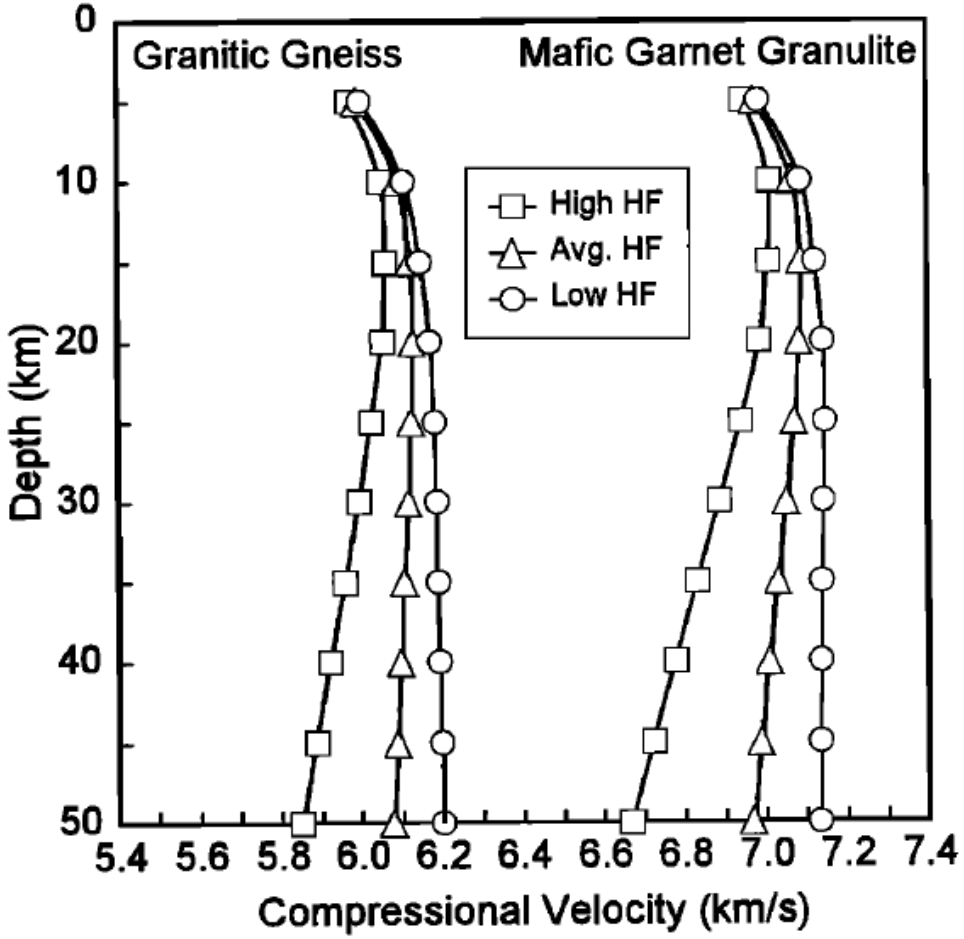
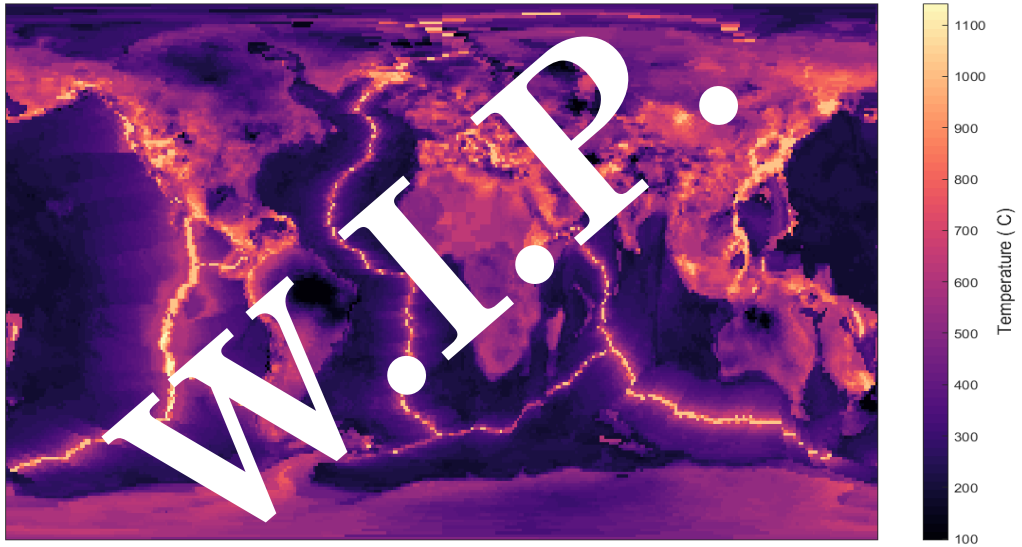


Figure 13. Velocity versus depth and heat flow province for average granite/granodiorite and mafic garnet granulite . For temperatures, see Table 4.

Temperature

- Why is temperature important?

- Vp, Vs are temperature dependent!
  - More sensitive to T than P



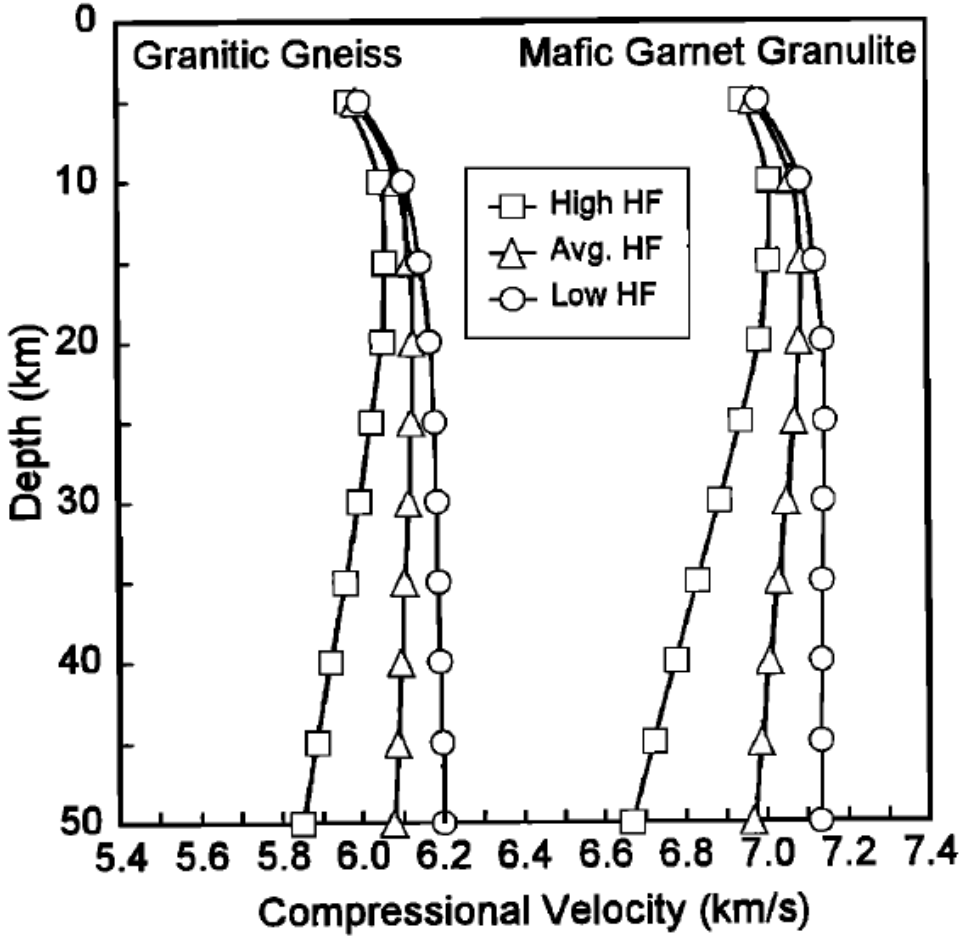


Figure 13. Velocity versus depth and heat flow province for average granite/granodiorite and mafic garnet granulite . For temperatures, see Table 4.

$$Vp = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}$$

Mineralogy

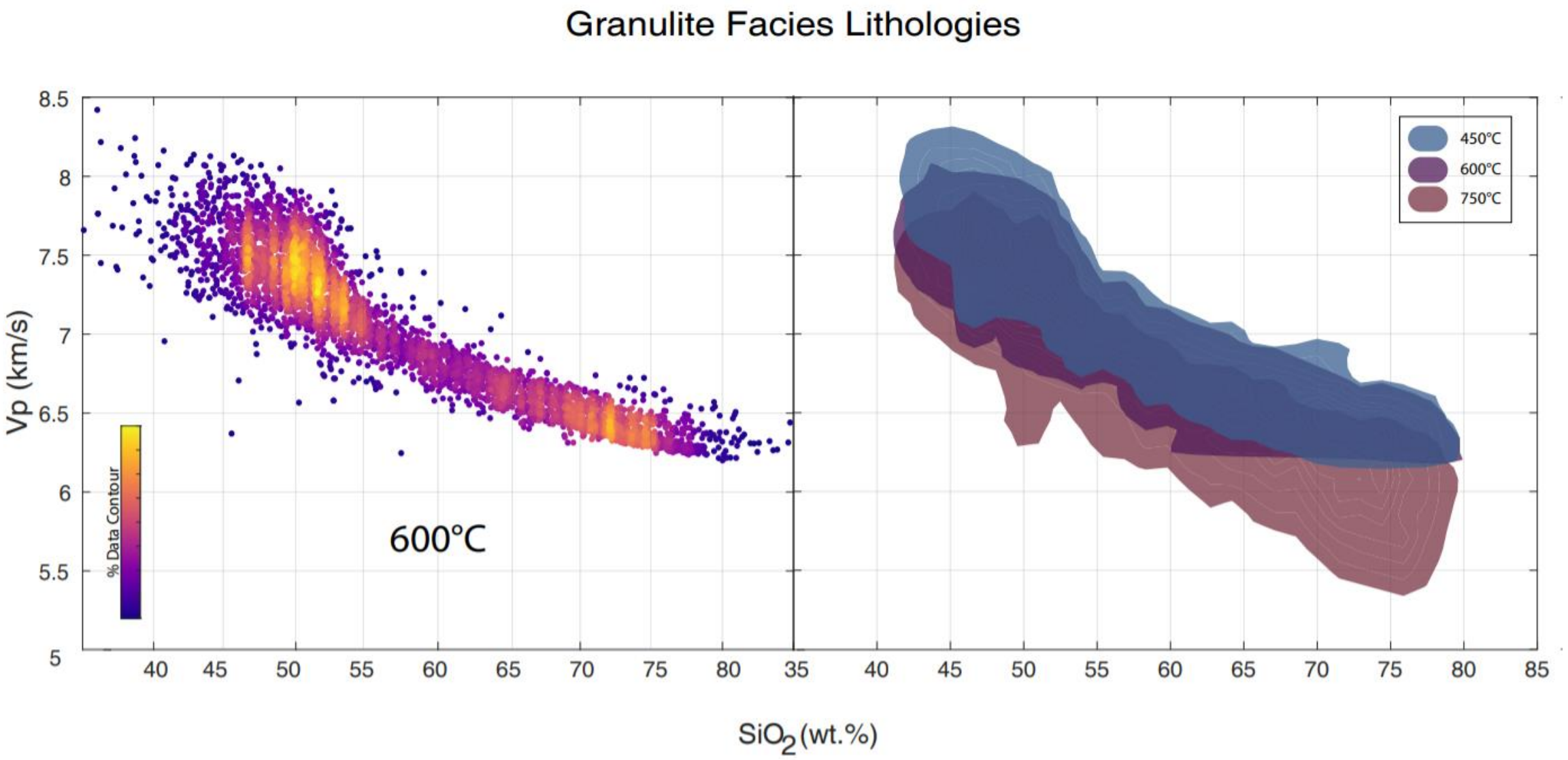
Pressure

Temperature

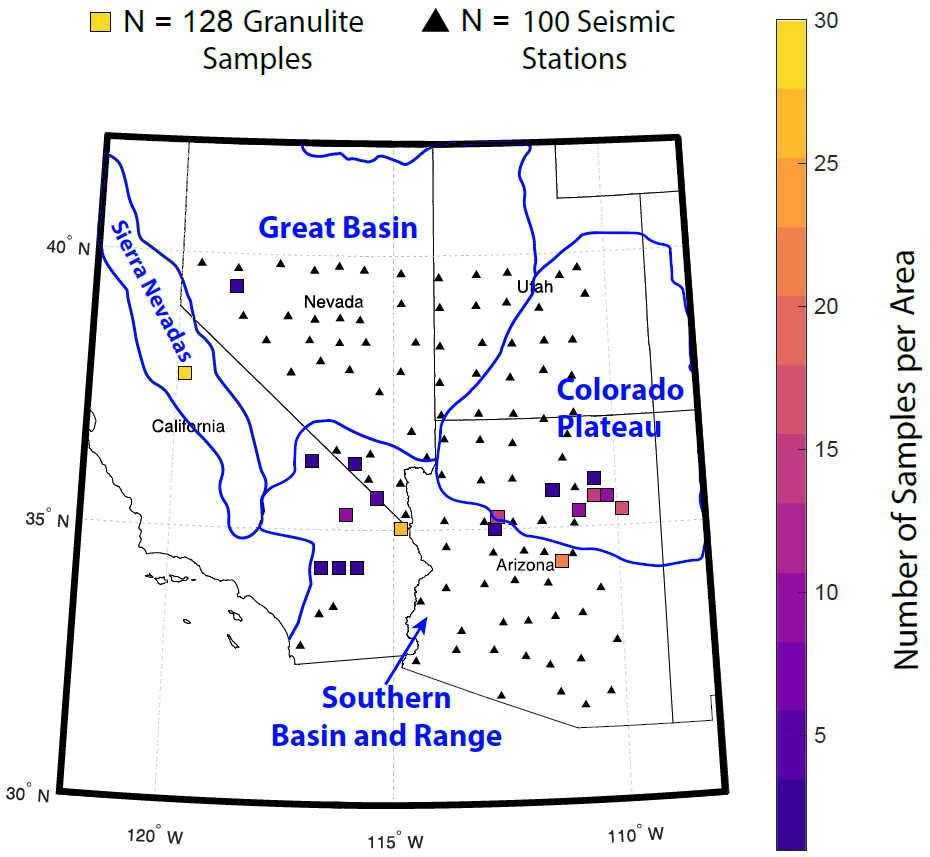
Composition

Perple_X

Seismic Velocities to Compositions



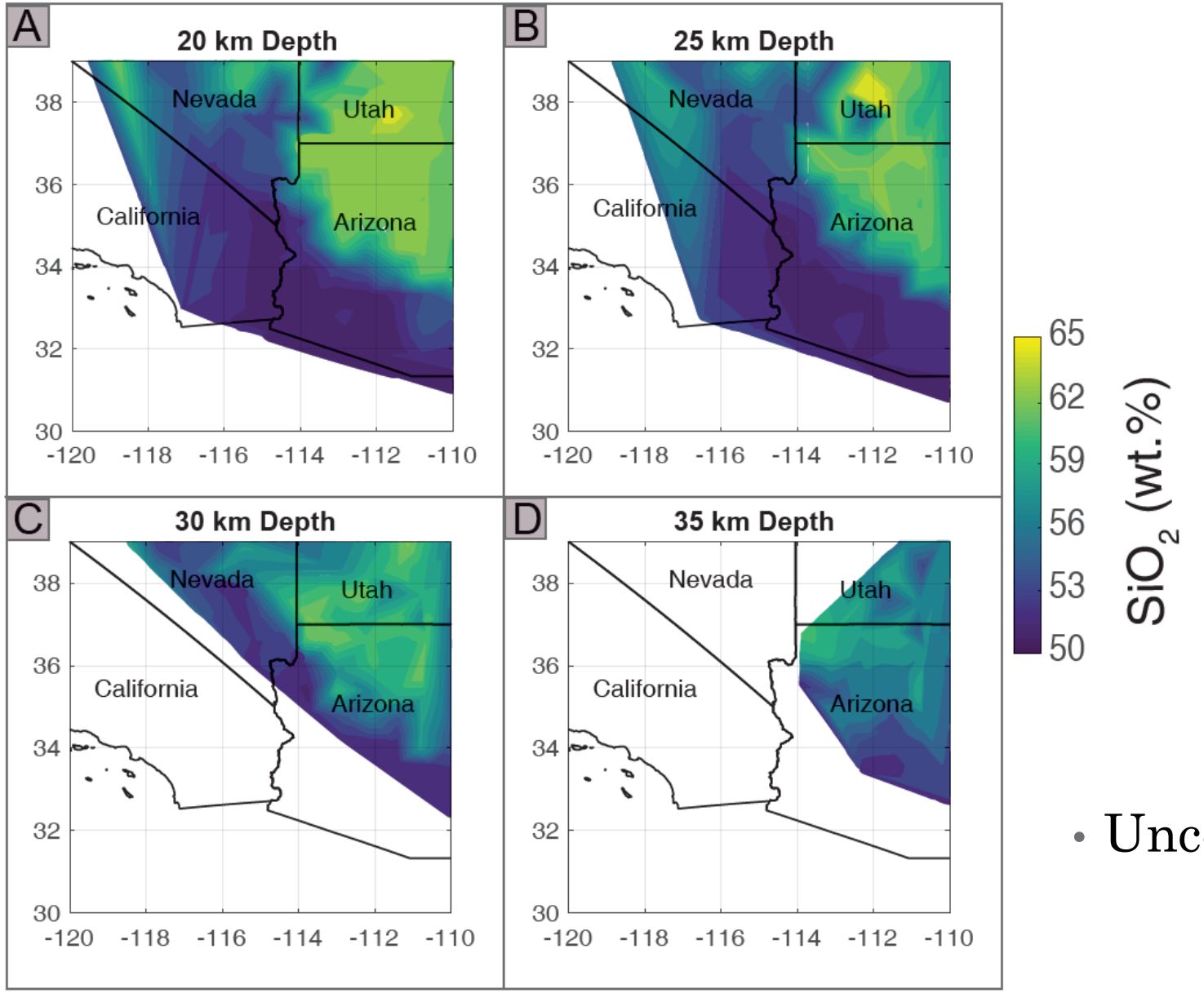
Example 1



- Bain and Range, SW US
- Extended crust, 25 – 40 km
- Hot, 650 – 950 °C
- Compare USArray inversions to calculated velocities Gao & Lekic (2019)
- What compositions produce Vs that overlaps with seismic data?

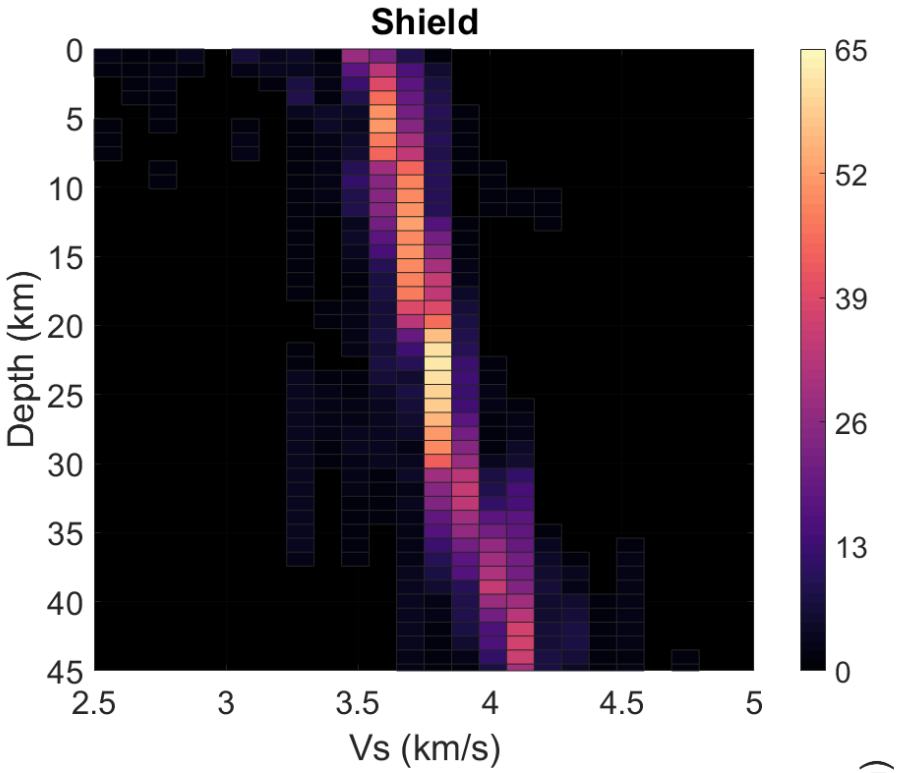
Example 1

- SiO_2 gradient!

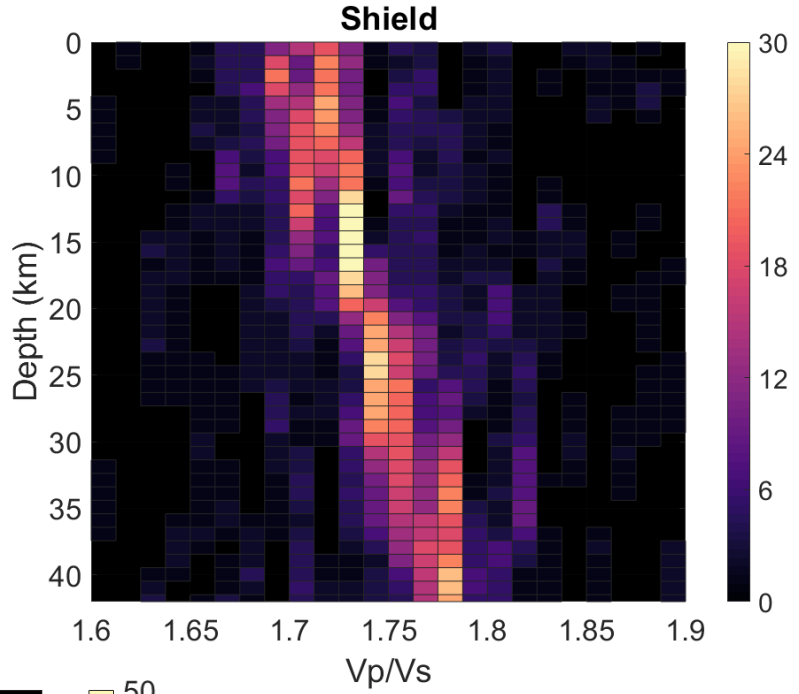


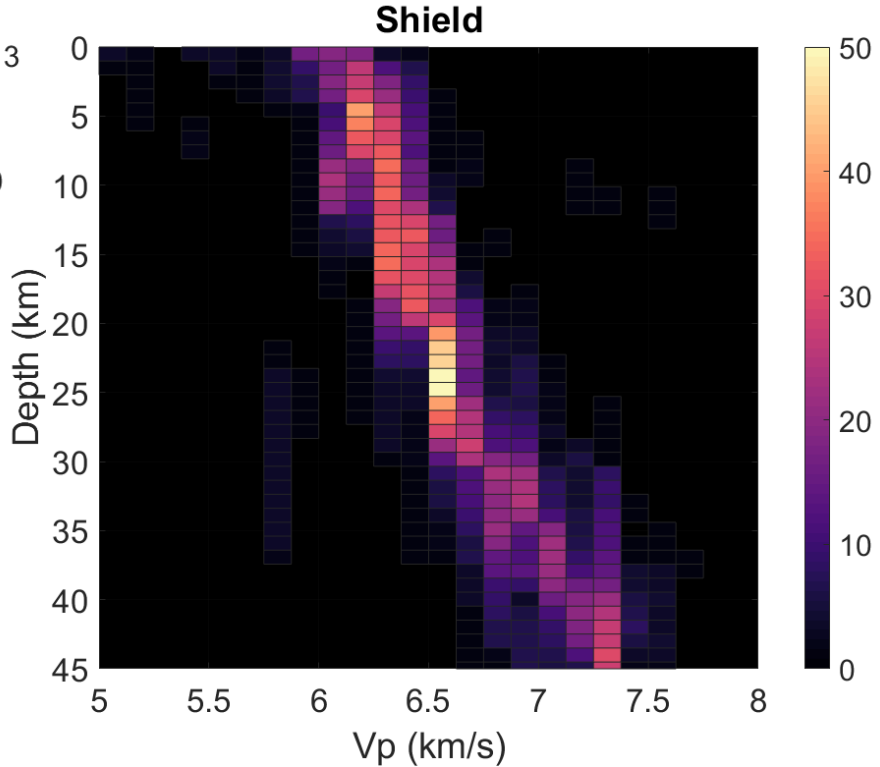
- Uncertainties!

Example 2



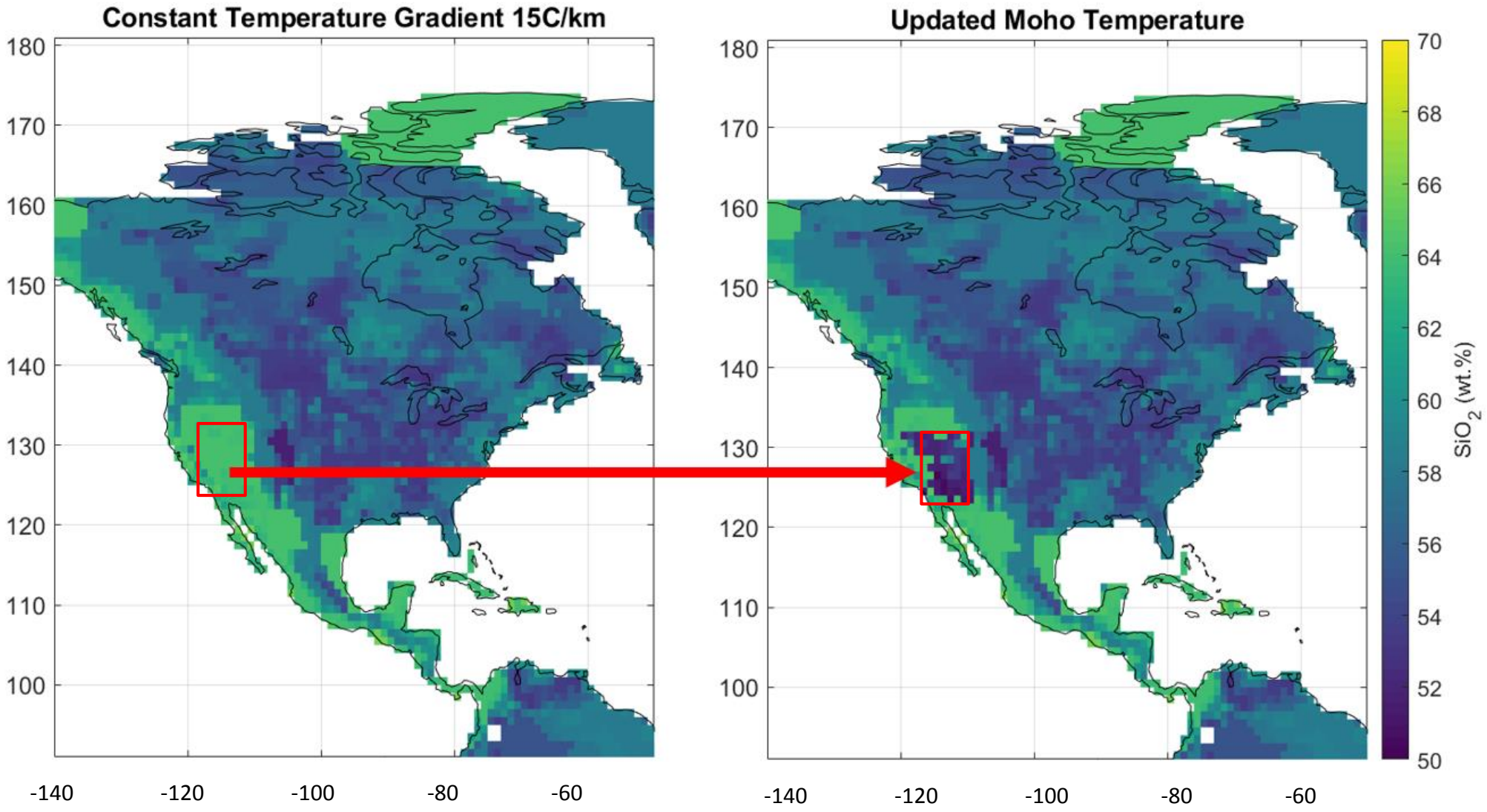
- Global data set
- Shields ≈ 130 controlled seismic profiles





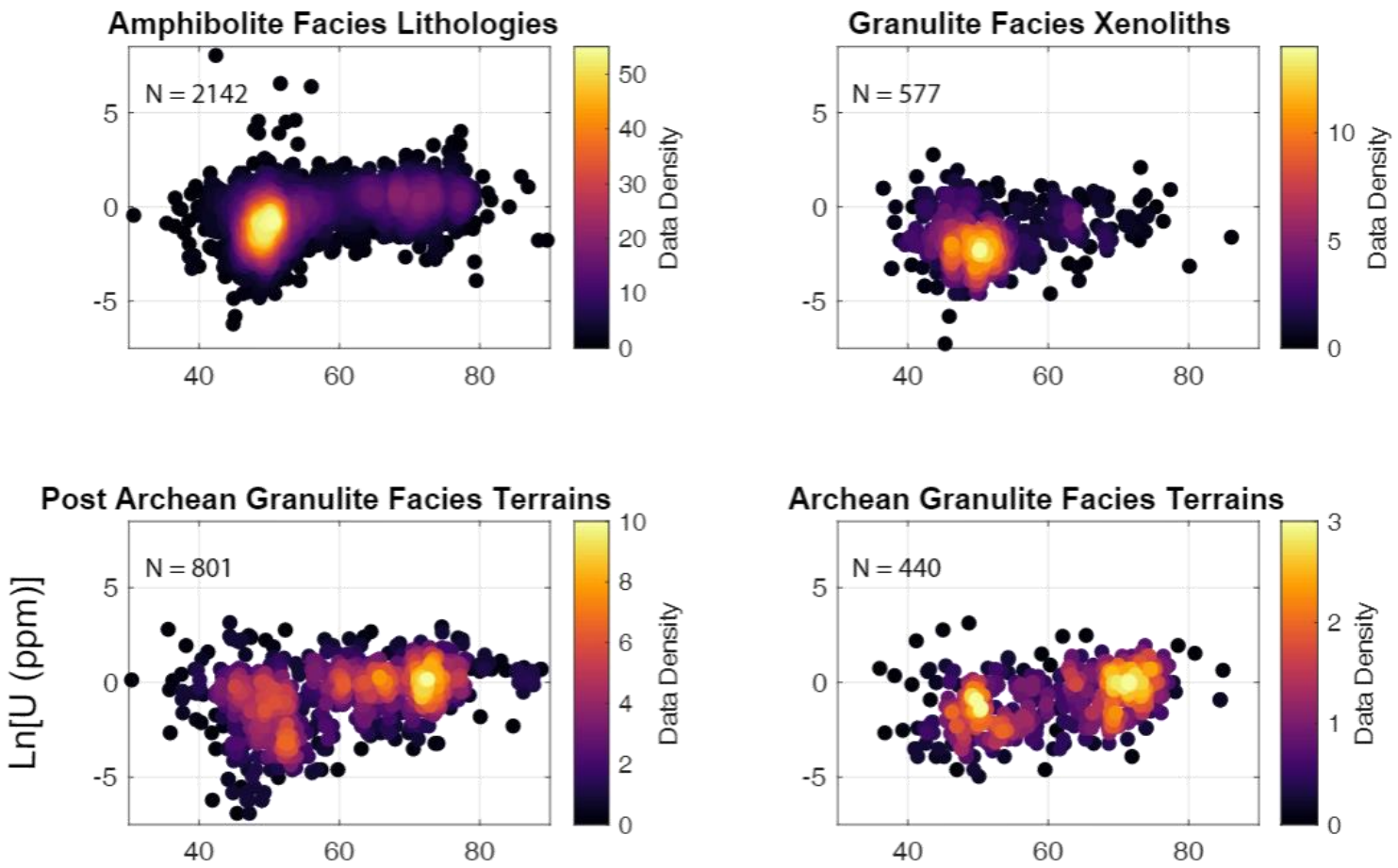
- Use Vs, Vp, & ratio when available
- Group similar crust types/tectonic regimes

Example 2


Constant Temperature Gradient 15C/km
Updated Moho Temperature
180
170
160
150
140
130
120
110
100
-140
-120
-100
-80
-60
70
68
66
64
62
60
58
56
54
52
50
SiO_2 (wt.%)

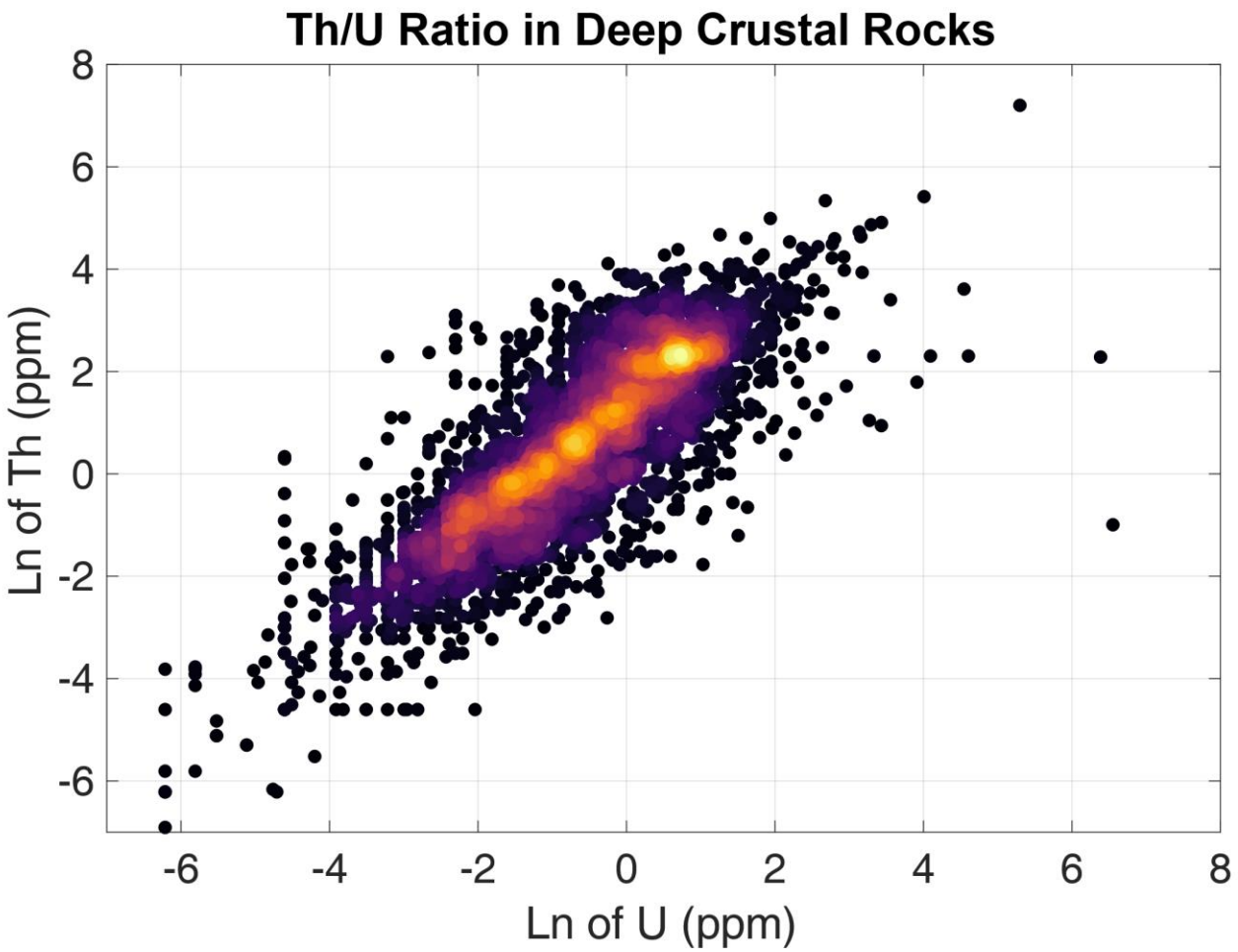
SiO_2 to U

- 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

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

- 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

Acknowledgements

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