Reconciling geophysical and geochemical constraints on the temperature and composition of cratonic lithosphere by considering mantle discontinuities

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Key Points

- Key point A
- Key point B
- Key point C

Geological Motivation

Much of Earth's cratonic lithosphere has resisted deformation throughout geologic time. Cooler-than-average temperatures make cratonic lithosphere strong and thick, and its depleted composition provides a buoyancy force which resists entrainment in deeper mantle flow.

- Surface-wave dispersion measurements place constraints on the absolute velocities of the cratonic mantle lithosphere, but it is difficult to reconcile these geophysical observations with the steady-state geotherms inferred from mantle xenoliths if a simple peridotite composition is assumed.
- Xenolith-derived geotherms predict shear velocities that are higher than observed in the shallow mantle lithosphere and slower than observed in the deeper cratonic lithosphere. One possible explanation is that a low-velocity layer pervades the shallow cratonic lithosphere, potentially a relict of metasomatic activity.
- Scattered body-waves have suggested the presence of a negative velocity discontinuity at depths ranging from 90 to 140 km; these have been interpreted as the top of such a low-velocity zone. At greater depths, converted waves occasionally reveal a velocity increase at a depth of 220 ± 20 km, the so-called Lehmann discontinuity, which is detected more often beneath continents than beneath oceans.

Here we plan to present an integrative perspective on cratonic temperature and composition by jointly analyzing surface wave observations (both shear velocity and attenuation), receiver functions (both Ps and Sp), and underside reflected waves (SS precursors) across the North American continent.

Geotherm Constraints from Xenoliths

- Pressure–temperature constraints from xenoliths (cite CT Lee) and heat-flow modeling (cite Rudnick) to constrain a mantle geotherm.
- Discuss assumptions

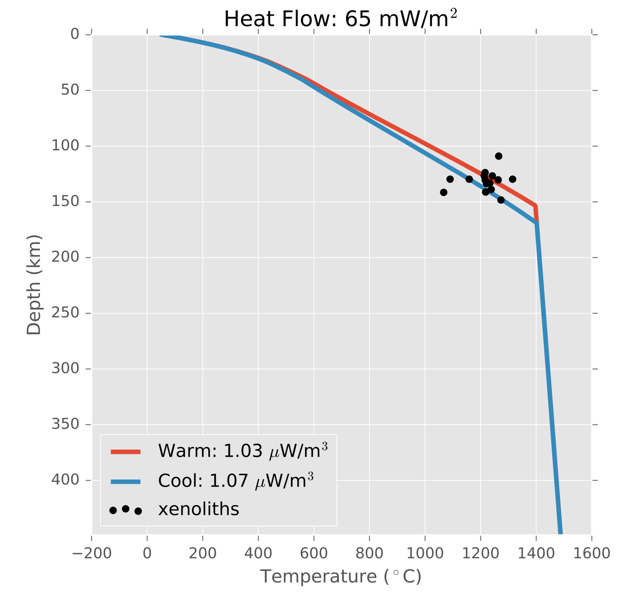


Figure 1: Colorado Plateau

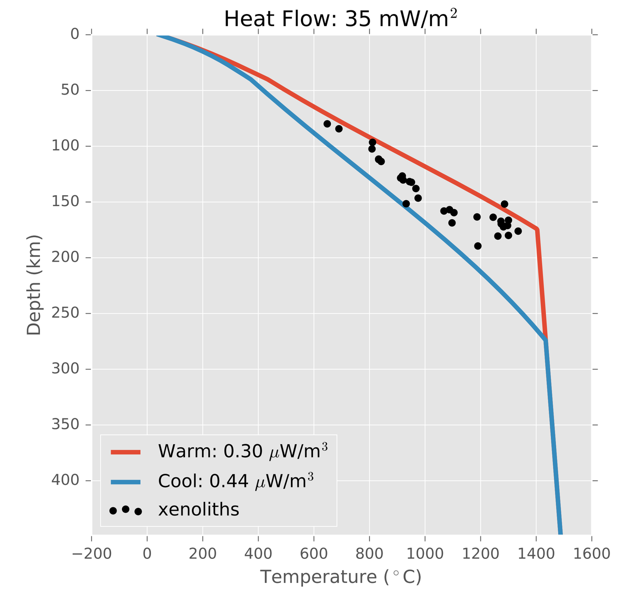
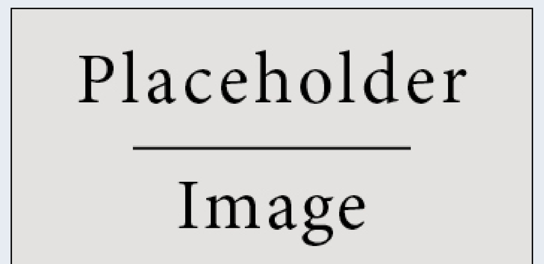


Figure 2: Slave Craton

- Strong tradeoff between crustal heat production and surface heat-flow. Solved by pegging heat-flow to defensible value, allow heat production to vary to match variability in the xenoliths.

Comparison with Observations

- We use mineos to estimate phase velocities assuming
  - V_p, $V_s \rightarrow V_{pv}$, V_{ph}, V_{sv}, and V_{sh} using the Voigt average and by taking scalings from the radially anisotropic reference model STW105.
  - crustal structure from Crust1.0 (Slave) or Shen and Ritzwoller (Colo. Plateau)
  - Q_μ from the geotherm predicted using Faul and Jackson (XXXX)



Velocity Profiles from Mineral Physics

- We used PerpleX (cite Connolly) to compute densities and seismic velocities for fertile and depleted compositions down to a depth of 350 km.

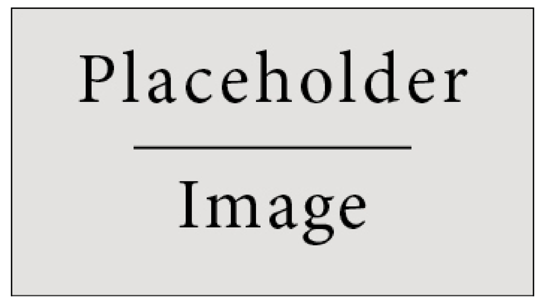


Figure 3: An example at Colorado Plateau.

- Different PerpleX database files give different answers. We have reason to believe Stixrude (2011) is the most reliable for anhydrous mantle calculations.

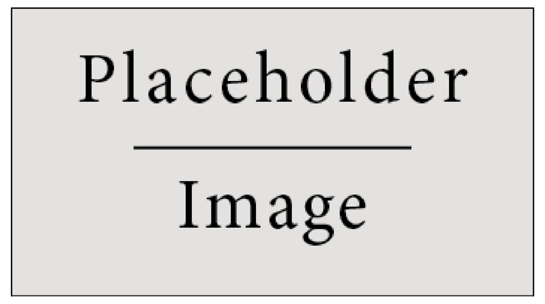


Figure 4: A comparison of databases.

SS Precursors

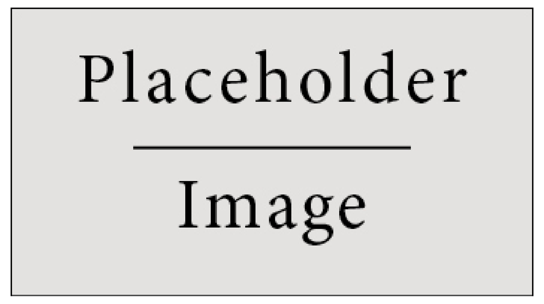


Figure 6: Slave Craton Stack.

Preliminary Joint Inversions

- We use an iterative, linearized inversion technique to estimate a layer-cake model of shear velocities using constraints from (1) the stacked SS waveform and (2) from Rayleigh phase velocity observations. Additional constraints:
  - $d \ln V_{sv} = d \ln V_{sh} = 0.55 \ln V_{pv} = 0.55 d \ln V_{ph}$
  - $d \ln \rho = 0$
- We have found it difficult to fit the large oscillations near SS, so these examples use synthetic SS precursor waveforms that approximate the phases observed in the stacks.

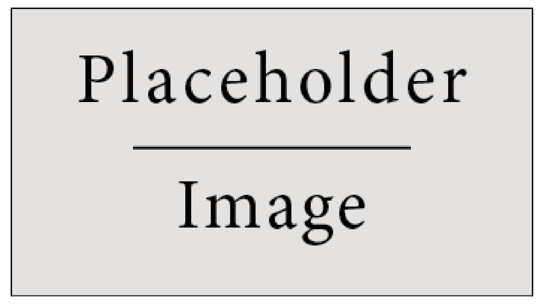


Figure 8: Colorado Plateau Stack.

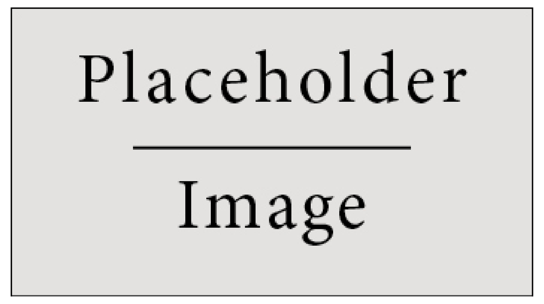


Figure 9: Colorado Plateau Stack.

References

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[3] D. Komatitsch, J.-P. Vilotte, P. Cristini, J. Labarta, N. Le Goff, P. Le Loher, Q. Liu, R. Martin, R. Matzen, C. Morency, D. Peter, C. Tape, J. Tromp, and Z. Xie. SPECFEM2D v7.0.0, 2012.

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