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

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Key Points

- We use constraints from xenoliths, heat-flow, and mineral physics to estimate the seismic velocity structure of the Slave Craton and the Colorado Plateau.
- The predictions generally yield Rayleigh phase velocities that *disagree* with those observed, demonstrating a problem with our understanding of cratonic mantle temperature and composition.
  - *Colorado Plateau.* The presence of a low velocity layer in the uppermost mantle is supported by Rayleigh phase velocities and past receiver function studies, but SS precursors place the low velocity layer somewhat deeper.
  - *Slave Craton.* The observed phase velocities are slightly faster than the predictions, but SS precursors place a velocity drop at a depth of 125 ± 10km. These constraints may be reconciled if the uppermost mantle is anomalously fast or if the true geotherm is cooler than suggested by xenoliths.
- Joint inversions hold promise in reconciling constraints, and will allow us to explore the compositions required to satisfy the observations.

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.
- 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 combine perspectives on cratonic temperature and composition by jointly analyzing surface wave observations and underside reflected waves (SS precursors) at the Slave Craton and the Colorado Plateau. Ultimately, we will wish to use constraints from surface-wave attenuation and receiver functions as well. In the future, we plan to extend this analysis to other cratons with available constraints from both xenoliths and seismology, including the Kalahari and Siberian Cratons.

Geotherm Constraints from Xenoliths

- Pressure–temperature constraints from xenoliths [1] and heat-flow modeling [2] to constrain a mantle geotherm, assuming a mantle potential temperature of 1350° C.

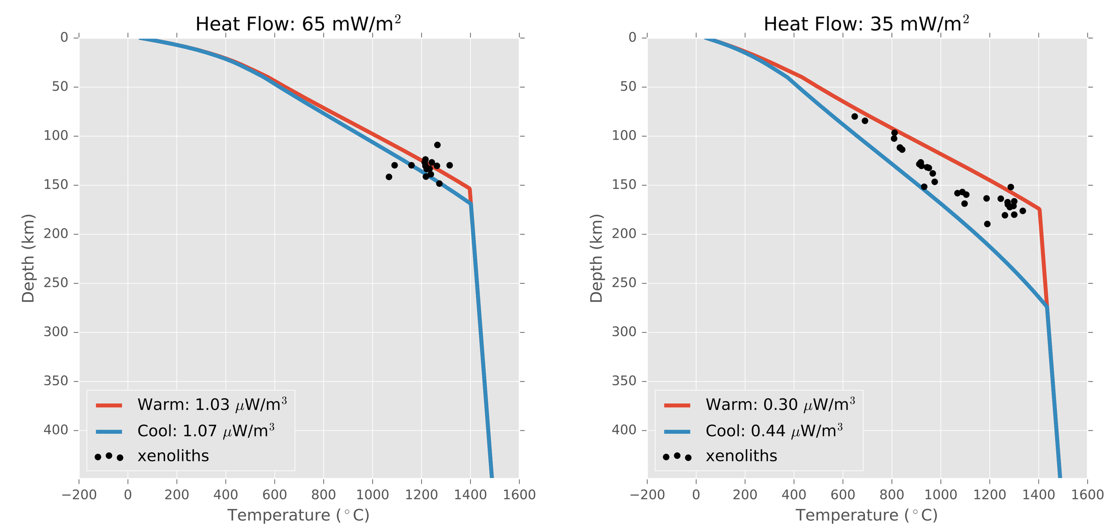

Figure 1: Constraints on geotherms from xenolith thermobarometry at the Colorado Plateau (left) and the Slave Craton (right). The warm–cool range represents 95% of the variability in the optimal solution from bootstrap resampling the xenolith population.

- Tradeoff between crustal heat production and surface heat-flow addressed by pegging heat-flow to defensible value, allowing heat production to vary to match variability in the xenoliths.

Comparison with Observations

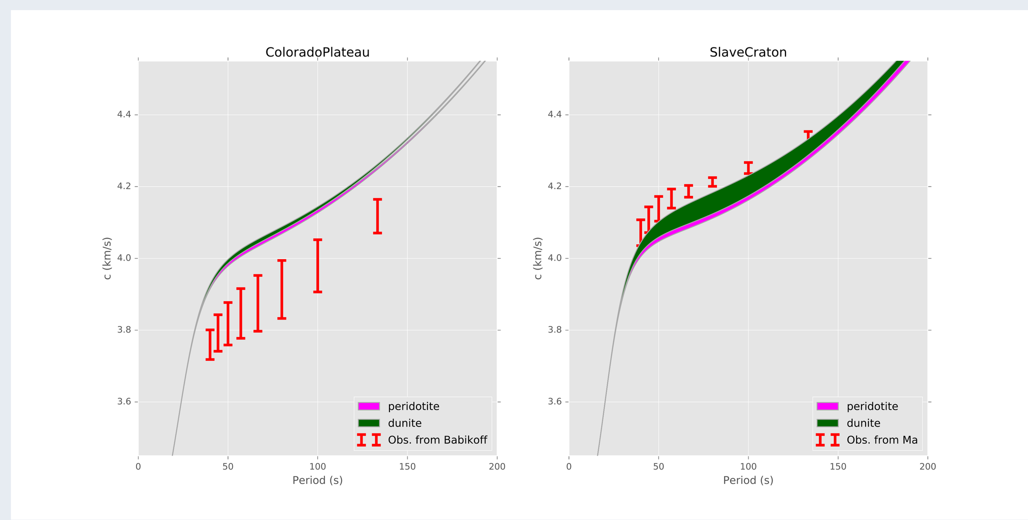

Figure 3: Rayleigh phase predictions (colored shading) versus observations (red errorbars) [5, 6].

- We used Mineos to estimate phase velocities from the following assumptions:
  - 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 taken from Crust1.0 (Slave) or Shen *et al.* (Colo. Plateau) [5, 7].
  - Q_μ from the geotherm predicted using experimental data [8].

Velocity Profiles from Mineral Physics

- We used PerpleX [3] to compute densities and seismic velocities for fertile and depleted compositions down to a depth of 350 km, with an anhydrous mantle minerals database [4].

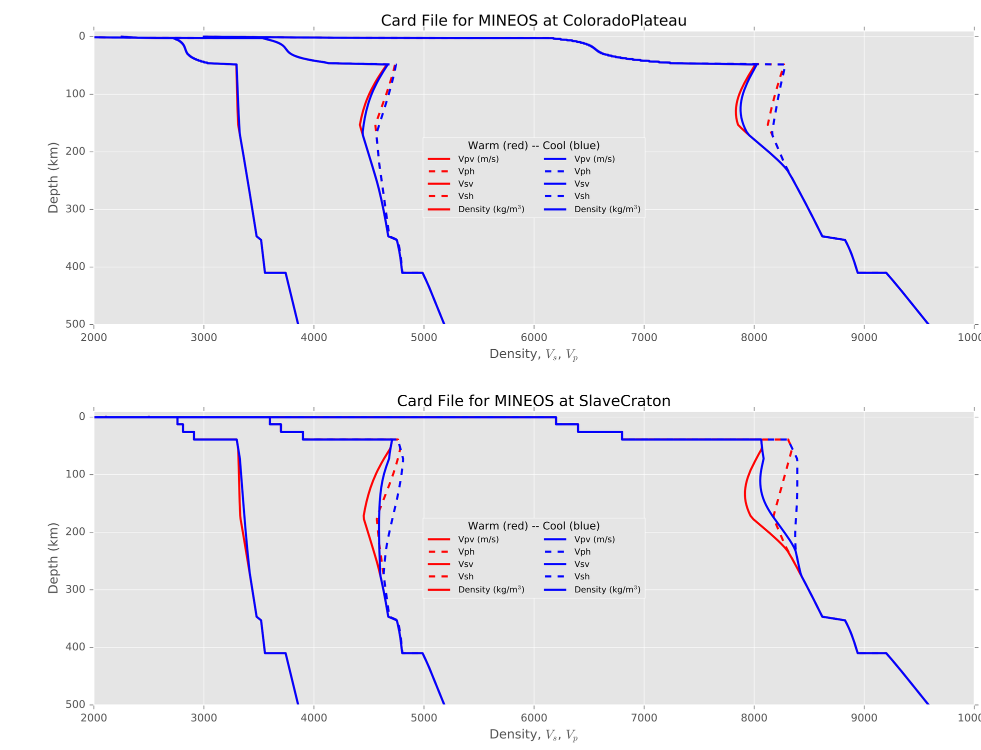

Figure 2: Example material properties for a dunitic composition at the Colorado Plateau (upper) and Slave Craton (lower).

SS Precursors

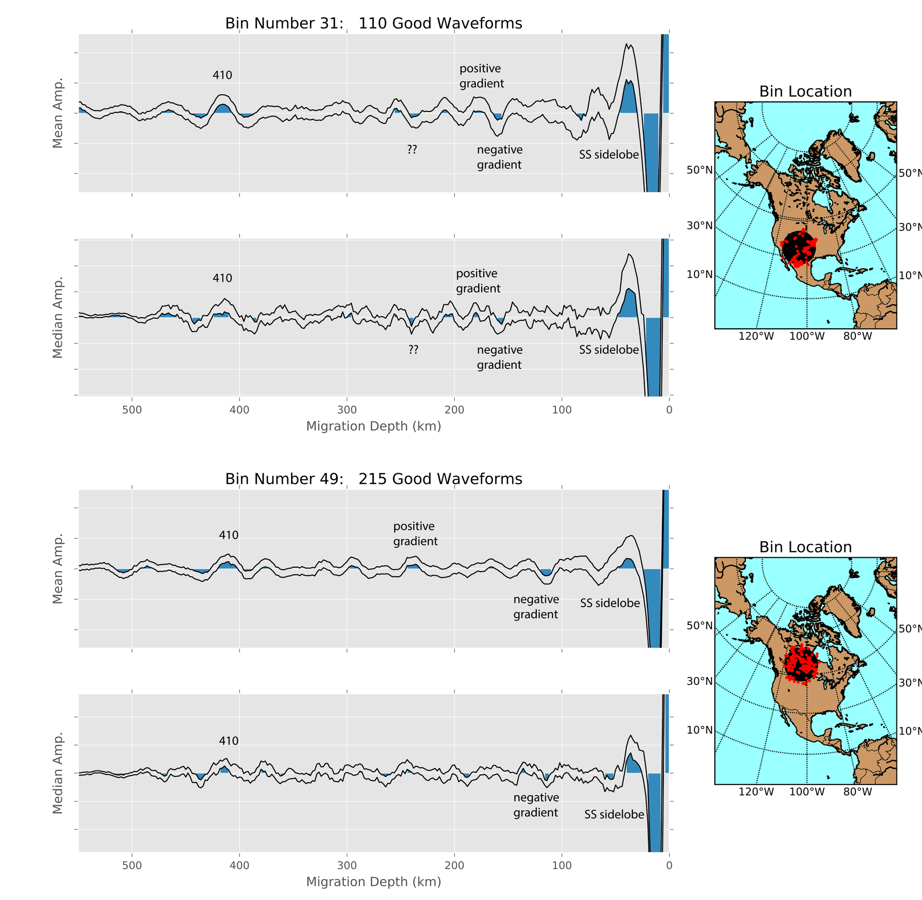

Figure 4: SS precursor stacks for Colorado Plateau (upper) and Slave Craton (lower), with 1σ uncertainties. The maps show individual bouncepoint locations (red dots). We follow a stacking approach following Schmerr [9]. Consistent phases among the mean and median stacks suggest the presence of sharp horizontal boundaries within the cratonic mantle lithosphere.

Preliminary Joint Inversions

- We used 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:
  - $d\ln V_{sv} = d\ln V_{sh} = 0.55 \ln V_{pv} = 0.55 d\ln V_{ph}$
  - $d\ln \rho = 0$
- At present, it is difficult to fit the large oscillations near SS, so these examples use synthetic SS precursor waveforms approximating certain phases observed in the stacks.

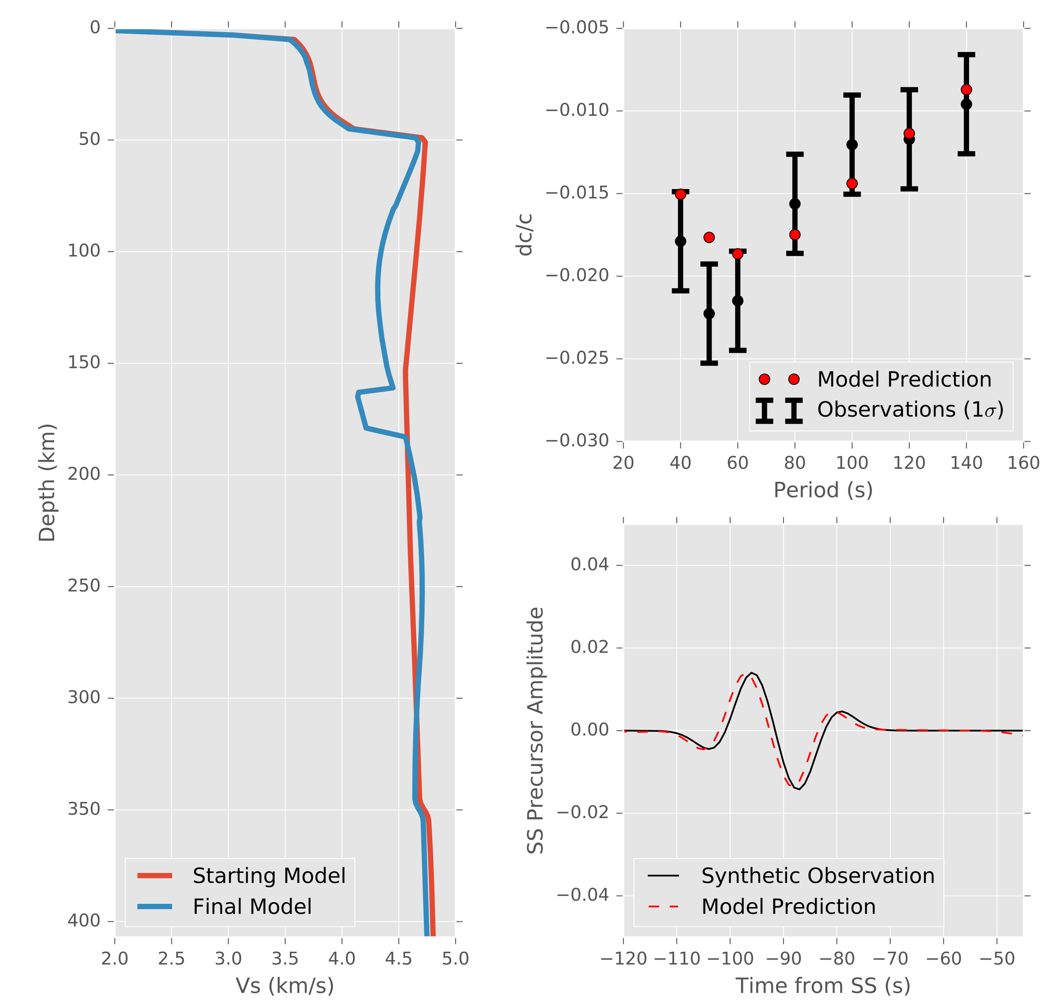

Figure 5: Joint inversion at the Colorado Plateau.

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