Pacific upper-mantle shear attenuation and velocity from ocean-bottom observations and implications for asthenospheric temperature and melt

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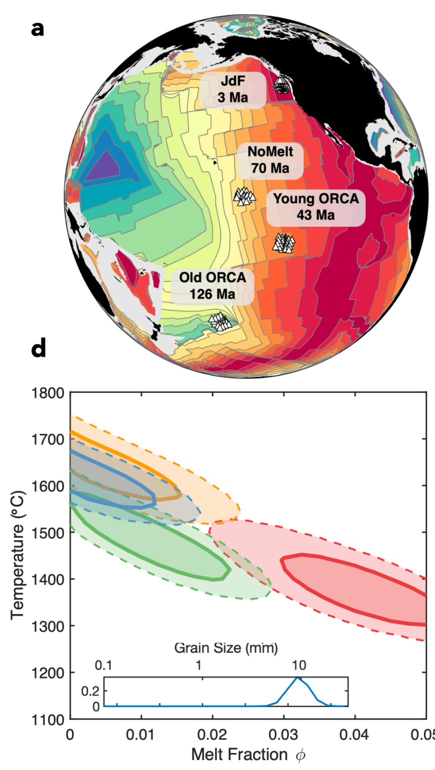
Shear attenuation (Q^{-1}_{μ}) and velocity (V_S) of the upper mantle are key parameters for understanding the state and evolution of the oceanic lithosphere-asthenosphere system. Recent deployments of dense arrays of ocean-bottom seismometers (OBS) in the Pacific provide an opportunity to measure both Q^{-1}_{μ} and V_S at high resolution at a range of seafloor ages, illuminating the age-dependence of anelasticity and corresponding temperature and melt variations in the upper mantle. Yet, measuring Rayleigh-wave attenuation (Q^{-1}) at local scales in the oceans remains a challenge due to complicating factors that impact wave amplitudes such as elastic focusing/defocusing and scattering, local site amplification, OBS tilt and compliance noise, and overtone interference.

We use Helmholtz tomography to measure Rayleigh-wave Q^{-1} and phase velocity (20–150 s) at four OBS arrays in the Pacific ranging in age from 3–125 Ma. The method utilizes phase and amplitude gradient fields from teleseismic earthquakes to extract local intrinsic Q^{-1} and site amplification while accounting for elastic focusing/defocusing. We validate the approach using realistic SPECFEM3D-GLOBE synthetics calculated for the Cascadia and NoMelt experiments, which represent coastal and open-ocean endmember structures, respectively. The true Rayleigh-wave Q^{-1} is recovered successfully at periods >20 s at both locations, even in the presence of extreme multipathing associated with coastline effects at Cascadia. We use this approach to measure Q^{-1} and phase velocity at four OBS arrays and invert for profiles of Q^{-1}_{μ} and V_S to 300 km depth at each location. Temperature and melt fraction are quantified in the low-velocity zone (LVZ) by jointly interpreting Q^{-1}_{μ} and V_S within a Bayesian framework utilizing laboratory constraints. The classic half-space cooling model is unable to explain our observations. At Juan de Fuca (~3 Ma), 2–5% partial melt is required within the LVZ, while at older ages temperatures are hotter than the half-space cooling geotherm. Asthenospheric temperatures inferred at Old ORCA (~126 Ma) resemble those of Young ORCA (~42 Ma) and both display a maximum in attenuation (Q_{μ} ~ 35–40) at ~130 km depth, suggesting a similar mantle state at these two locations of distinctly different age. We hypothesize that similar asthenospheric small-scale convective processes are active at both regions, modifying the sub-lithospheric mantle in comparable ways.



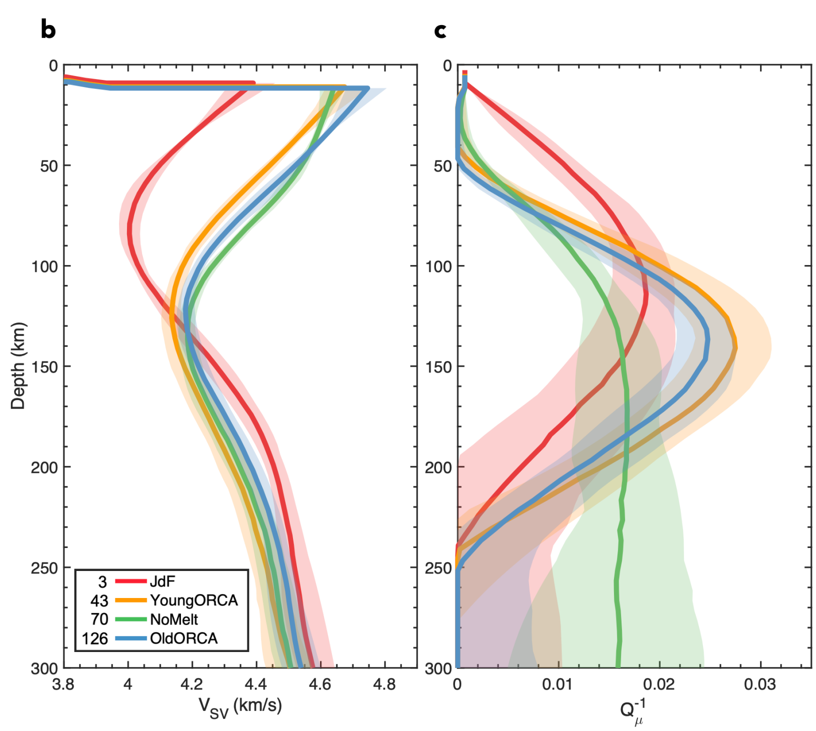


Figure (**a**) Map of the four OBS experiments used in this study. Vertical profiles of (**b**) shear velocity and (**c**) shear attenuation at each location. (**d**) Asthenospheric temperatures and melt fractions inferred from the observations in b) and c). The 68% (dashed) and 95% (solid) confidence intervals are shown.