Do Shear Velocities of Oceanic Lithosphere Reflect Temperature Variations at the Ridge?

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Basic Premise
Near-axis volcanic islands (hotspots) are produced by thermal and compositional anomalies in mantle source. Variations in extent of magmatism presumably represents source heterogeneity. Particularly strong source anomalies influence spreading processes ~100s km along ridge axis. As lithosphere moves off-axis, thermal, compositional, and anisotropic impact of axial heterogeneity is retained. Evolution of thermal anomaly will follow plate- or half-space cooling, and thermal effects can be evaluated using these well-tested models.

Here, we exploit on-island seismic stations and on-axis seismicity to evaluate upper-mantle shear velocities as a function of seafloor age near three potential mantle source anomalies ("hotspots") of varying strength:
- Iceland -- very high-flux hotspot
- Azores -- high-flux hotspot
- Ascension -- leaky transform? Low-flux hotspot?

These velocities can then be used to estimate the possible magnitude of the underlying mantle temperature anomalies, as well as test whether the hotspot effect is entirely thermal, or if the hotspot produces compositional or anisotropic signatures in the lithosphere.

Experiment Details
Four new regions along the MAR:
- Kolbeinsey, N. and S. Azores, N. and S. Ascension
- IRES PASSCAL and GSN stations (yellow triangles)
- HOTSPOT, IZEMELT
- MIDSEA, CMAL
- ASCON

Events from the Global CMT project (black circles)

Two age intervals: 5-10 Ma and 15-20 Ma

Propagation paths (red lines) roughly ridge parallel

9° ± 20°

Directly comparable to Reykjanes study of Gaherty (2001)

Upper-mantle Shear Velocity Models
Linearized least-squares inversion for age-dependent layered structures
- Radially Anisotropic -- VSH, VSV
- Left panels: Mean (Voight) Anisotropic Shear Velocity
- Right panels: Shear Anisotropy (2(VSV/VSH)) in (%)
- Two age ranges:
  - 5-10 Ma: 4.4-6.6 Ma for S, Ascension
  - 15-20 Ma: Bottom panels

Compare to Reykjanes models from Gaherty, 2000 (black dashed line)

A number of interesting features:
1) apparent cooling w/ age in all regions;
2) Kolbeinsey, Azores have similar isotropic velocities, while Ascension notably faster. Reykjanes notably slower;
3) Velocity variations correspond to hotspot flux?
4) Anisotropy very different than Reykj, even for Kolbeinsey;
5) Anisotropy weak at Ascension
6) Time-dependent anisotropy at Azores?

Mean Vs(Vkms)

S Anisotropy (%)

Lithospheric Velocity vs. Temperature

For each model, calculate:
1) mean upper-mantle shear velocity in top 40 km of mantle
2) mean temperature in top 40 km of mantle, assuming half-space cooling model with potential (half-space) temperature of 1350°C

Compare to:
1) estimates of Vp/Vs, Tp from Pacific (Nishimura and Forsyth, 1989; Gu et al., 2005) (black points)
2) theoretical predictions of Vs vs. T (grey band) based on:
   - Jackson et al. (2002) experimental estimates of dry peridotite anelasticity as a function of T
   - Karato (1993) relationship between dVp/dT and anelasticity

Critical free parameters in this calculation are:
- reference Vol(Ta) and grain size

(Top panel) The Atlantic models are systematically offset from the trend defined by the Pacific observations and the theoretical curve, with the Ascension models too fast, and the others too slow.

(Middle panel) If we perturb the Tp estimates by allowing for a regional temperature variation of 150°C (ranging from -50°C at Ascension to +100°C for Reykjanes), then the Ascension model is consistent with the theoretical prediction, but the northern Atlantic models remain too slow.

(Top panel) We can further assume a larger regional T variation (300°C), as well as anomalously low (4.0 km/s) velocities within a ~200 km radius beneath the receivers due to melt or other effects. This can bring the Azores and Kolbeinsey into marginal agreement with theoretical trend, but Reykjanes remains too slow.

Summary
Mean shear velocity at volcanic island stations correlate with apparent hotspot flux

Iceland is unique:
- much larger impact on Reykjanes than Kolbeinsey -- asymmetric hotspot ridge interaction
- Reykjanes anisotropy suggestive of buoyancy-driven flow or deformation in melt-rich shear bands
- Reykjanes lithosphere is too slow to be purely thermal, suggesting compositional effects

Ascension, Azores, Kolbeinsey possibly consistent with 1000°C temperature variation along axis

Anisotropy variations indicate weaker fabric development during "normal" slow spreading?

What is causing the anomalously slow velocities beneath the Reykjanes (and perhaps Azores and Kolbeinsey)?

- Anisotropic effects? We think not, but perhaps we’re missing something?
- Velocities in LVZ are much lower than modeled, trading off with lithosphere. Test suggest not. Also would require very low (~4.0 km/s) velocities in the asthenosphere.

- Compositional effects? Fe-rich mantle source beneath Iceland (Korenaga et al.). Gabbro retained in mantle due to high melt production and slow melt extraction along slow-spreading Reykjanes (Lizarralde et al.)

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