Seismic Evidence that Oblique Mantle Divergence Causes Segmentation of Mid-Ocean Ridges

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The Question
What is the origin of mid-ocean ridge segmentation (at the scale of 2°-order segments)?

Driven from above—changes in plate motion (e.g., Lonsdale et al. 1989)
Driven from below—upwelling dynamics (e.g., Macdonald et al. 1988)

Main Conclusions
1) We find evidence, across spreading rates, that viscous stresses related to oblique mantle divergence contribute to the formation of tectonic offsets.
2) The tectonic offsets in turn perturb the axial thermal structure thus defining magmatic segmentation.

Mantle Seismic Structure at Fast- and Slow-spreading Rate Segments

Fast-spreading 9°N East Pacific Rise (EPR)
Mantle anisotropy is rotated 9° anticlockwise from the plate spreading direction

Mantle low-velocity zone strikes perpendicular to fast axis of mantle anisotropy

Similar to Endeavour, the broadest region of slow seismic velocities are beneath 2°-order offset

Slow-spreading 35°N Mid-Atlantic Ridge (MAR)
Mantle anisotropy is rotated 38° anticlockwise from the plate spreading direction

Seismic structure investigation...
1) Mantle flow does not parallel plate divergence
2) Tomographically imaged mantle velocity structure suggests distribution of mantle melt is increasingly influenced by thermal structure as spreading rates decrease

New Observations from the ETOMO Experiment

ETOMO Experiment
Endeavour Troughom (ETOMO) experiment was designed to seismically image the patterns of melt delivery between the crust and mantle beneath the intermediate-spreading (56 mm/yr) northern Juan de Fuca Ridge

We use over 5000 P, (seismic energy refracted beneath the Moho) arrival times to tomographically image the isotropic and anisotropic uppermost mantle (~1 km beneath the Moho) structure

Seismic anisotropy constrains geometry of mantle flow
Coaxial pattern in travel-time delays suggests 2D flow

Mantle flow contributes a driving force for the formation of tectonic offsets

Mantle flow and plate motions
Misalignment between plate and mantle divergence directions exhibits a spreading rate dependence

Orientation of mantle divergence is ahead of recent changes in plate motion

Infer plate spreading directions are lagging behind a more rapidly evolving mantle flow field

Hypothesis for tectonic segmentation
Skewed mantle flow field results in basal traction on lithosphere

If oblique mantle divergence is related to larger scale pattern in mantle flow, then viscous stresses may integrate to a tectonically significant force

This force may contribute to the formation of tectonic offsets that facilitate plate boundary reorganization

Magmatic Segmentation is a Consequence of Tectonic Segmentation

Rifting dynamics control melt distribution
Mantle melt production is uniform between 1st-order offsets

Away from offsets, mantle melts are thermally focused toward a discrete plate boundary

At OSCs, where rifting is distributed, melts are distributed between spreading limbs

- less efficient delivery of mantle melt to crustal reservoirs
- greater magma storage at mantle depths
- compositionally evolved and denser magmas
- thinner crust

Melt stored beneath OSCs provides an additional melt source for crustal production following propagation

At NTOs, age offset results in cooler and thicker axial lithosphere and focusing of melt away from segment ends (e.g., Magde & Sparks 1997; Cannat 1996)