Mantle Anisotropy at Mid-Ocean Ridges

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(Nowacki et al., EPSL, 2011)
Plate spreading and seismic anisotropy

Hess, 1964
MOR Anisotropy

Anisotropy due to LPO versus Aligned Melt
Simple plate spreading

Buoyant Flow, Melt Production (1% CI)

Temp C

1200
1000
800
600
400
200
0

2.5D spreading center:
Flow rift perpendicular

Flow pattern controlled by:
- Spreading rate
- Mantle viscosity
- Melt production
LPO anisotropy controlled by:
- Spreading rate
- Mantle viscosity
- Mineralogy

Shear-wave splitting:
- Increases off-axis
- Fast SW polarisation parallel spreading

**Melt** adds additional component to anisotropy

Blackman and Kendall, G3, 2002
Simple plate spreading

SKS Splitting at the EPR (Wolfe and Silver, 1998; Harmon et al. 2004)

2.5D spreading center: Flow rift perpendicular

Model predicts rift-perpendicular orientation off-axis (large $\delta t$).

$\delta t$
• **EPR** anisotropy is very different from **MER** anisotropy
  – Continental rift versus oceanic spreading center?
  – Spreading rates?
• Difficult to measure SKS splitting at **MORs** – instead use source-side SWS.
Source side splitting
(Nowacki et al., Nature, 2010)

Splitting from UM anisotropy below source

Δ = 60–85°

Additional splitting from UM anisotropy beneath receiver

Earthquake

Seismometer

Upper mantle

Lower mantle

S

Outer core

SKS
Events and Stations
NWK methodology

Rigorous data selection and quality control:
- Receiver anisotropy must be simple and well characterised.
- Where possible use data from similar azimuths for both S and SKS.
- High-quality measurements, low error, clear signal and anisotropy.
- Inferred source polarisation must agree with CMT solution for the earthquake.

Nowacki, Wookey and Kendall, Nature 2010
Results
East Pacific Rise - source-side splitting

- Best sampled segment
- Results agree with Wolfe and Solomon (1998) and Harmon et al. (2004), but split magnitude is larger
- Ridge parallel (>50km) – $dt=1-3s$
- Transforms much more complicated
Mid Atlantic Ridge - source-side splitting

- Limited in latitude (-40 to 15)
- More complicated than EPR
- Ridge parallel (e.g., -30 degs); smaller than EPR
- Variations along transforms; magnitudes higher near ridge segments
Gakkel Ridge - source-side splitting

- Only 10 good results
- Plus 10 good nulls
- Smallest amounts of splitting
- Gakkel is mostly ridge parallel
- Some evidence of asymmetry
- South West Indian Ridge is similarly complicated (oblique spreading)
EPR S-wave vs SKS splitting - modelling

- Modelling B&K-02: S (red lines); SKS (blue lines); note raypath incl and Az are different
- B&K-02 predictions agree with SKS results (W&S - 98 and Harmon et al. - 04)
- S-splits are much larger – solution: TI anisotropy due to melt alignment?
Stress driven melt segregation
- most effective at flanks (marginal LAB)
Melt and the LAB

Slow spreading – steep sides
- GAKKEL- MER
- SKS very sensitive to melt anisotropy
- MER much more melt production
- Along strike flow?

Fast spreading – subhoriz LAB
- EPR
- SKS not sensitive to melt
- S and surface waves are sensitive to melt anisotropy
- Melt enhances LAB
Mechanisms for MER anisotropy:

- Large-scale flow beneath eastern Africa associated with super-swell.
- Melt focused at plate boundaries - leads to oriented vertical pockets of melt.
- Contribution from pan-African fabric in lithosphere away from rift.

Kendall et al., 2006
Conclusions

- Source-side shear-wave splitting provides global comparison of MOR anisotropy
- Off-axis splitting is generally ridge perpendicular (Gakkel is perhaps exception; Reykjanes Ridge? – along strike flow?)
- Delay times increase off axis; correlation with spreading rate
- More complicated near transform faults (patterns?)
- Melt needed to explain discrepancies between S and SKS splitting (EPR)
- Melt focused at marginal LAB
- Melt hypothesis compatible with surface-wave radial anisotropy (Nettles and Dziewonski 2008) and SRFs (Rychert and Shearer, 2009; Kawakatsu et al., 2009)