Mantle Anisotropy at Mid-Ocean Ridges

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James Wookey

(Nowacki et al., EPSL, 2011)

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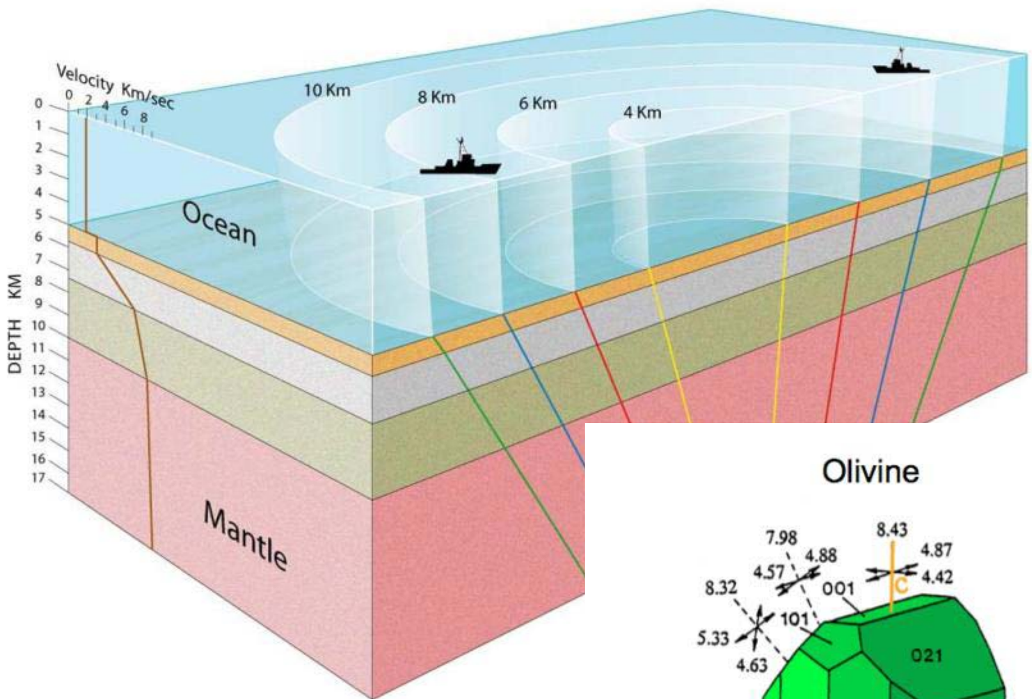
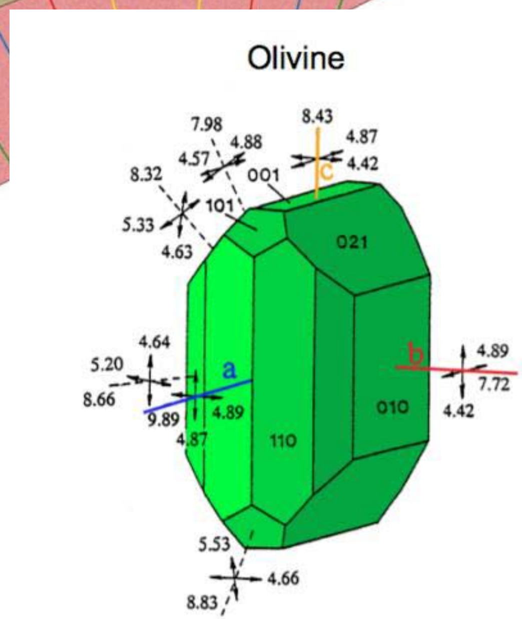
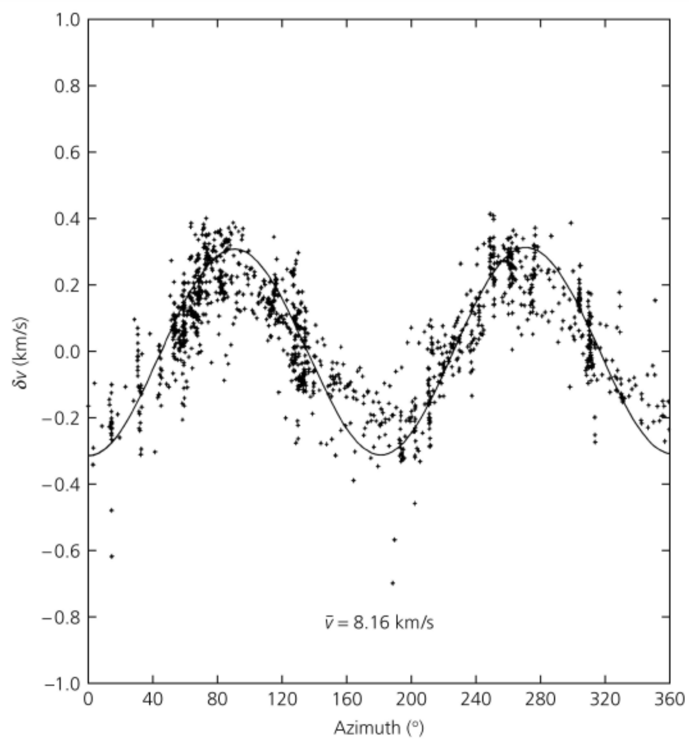
Plate spreading and seismic anisotropy

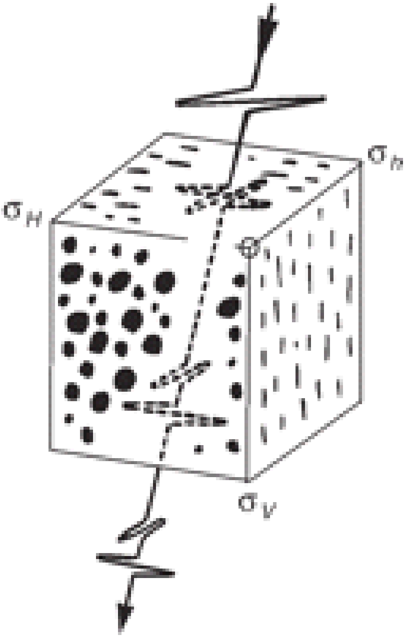


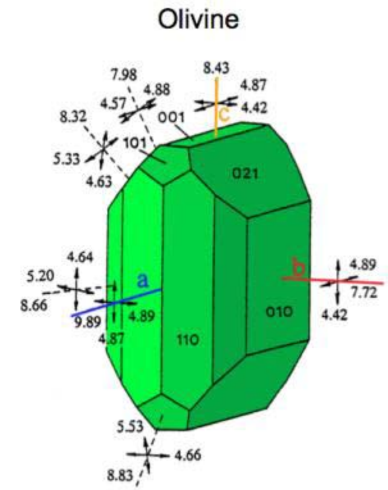


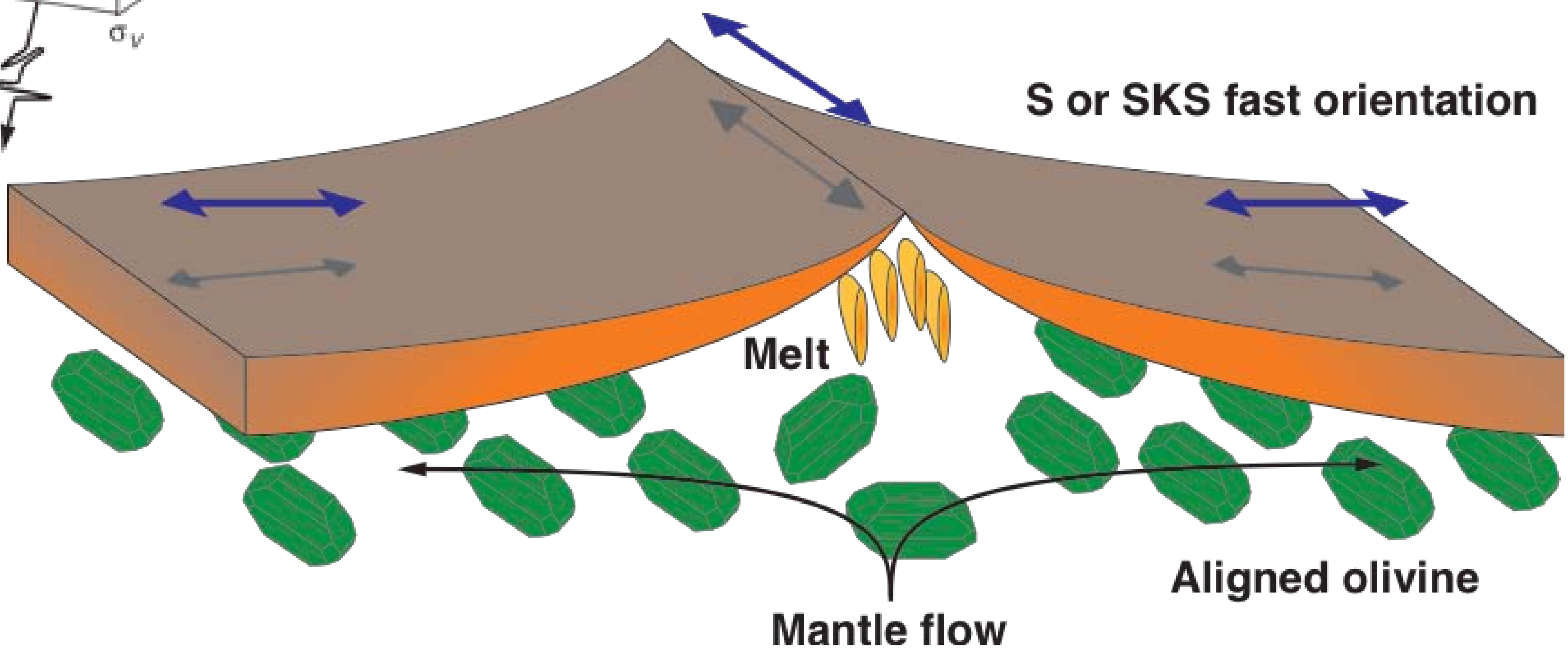
Hess, 1964



MOR Anisotropy







Anisotropy due to LPO versus Aligned Melt

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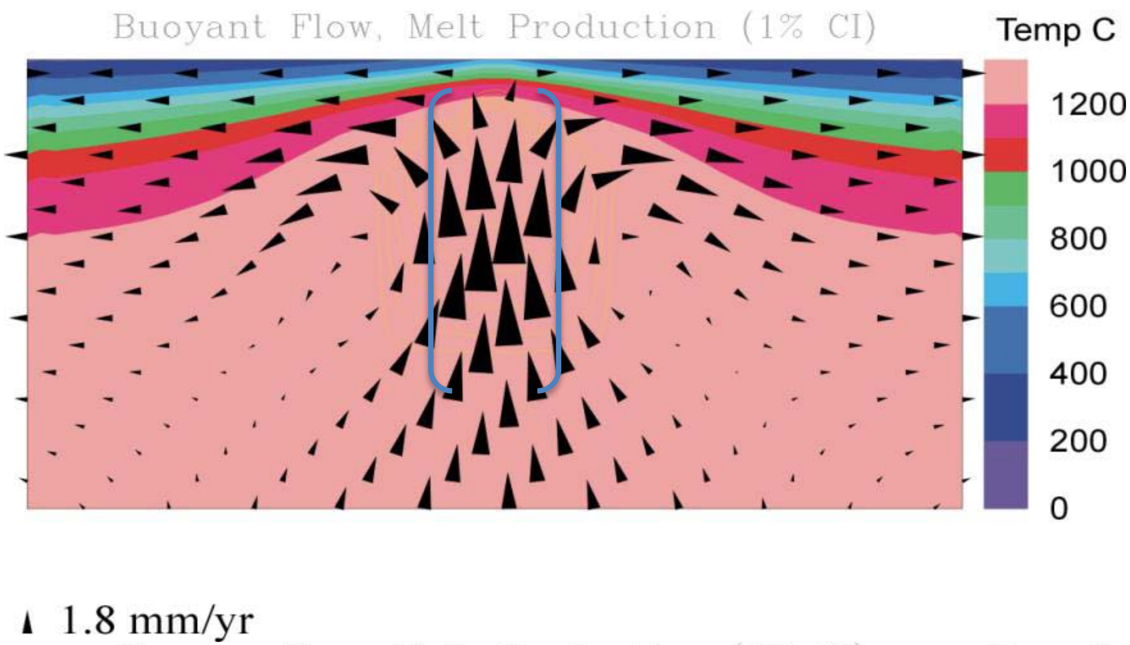
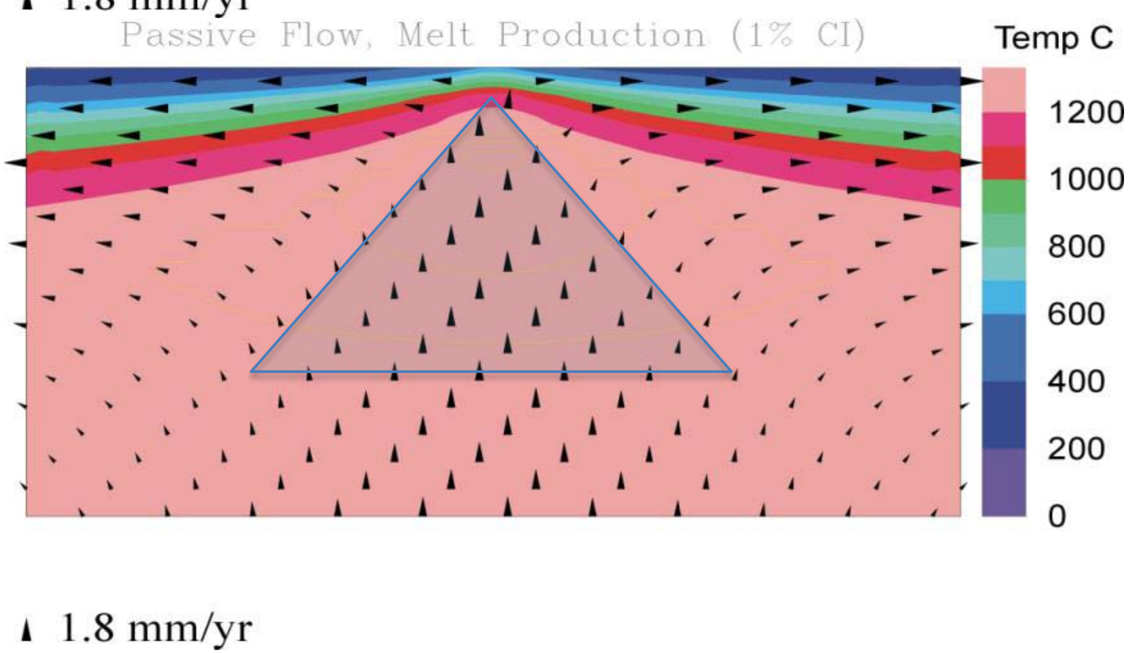
Simple plate spreading

Blackman and Kendall
1996; 1997; 2002a,b





2.5D spreading center:
Flow rift perpendicular

Flow pattern controlled by:

- Spreading rate
- Mantle viscosity
- Melt production

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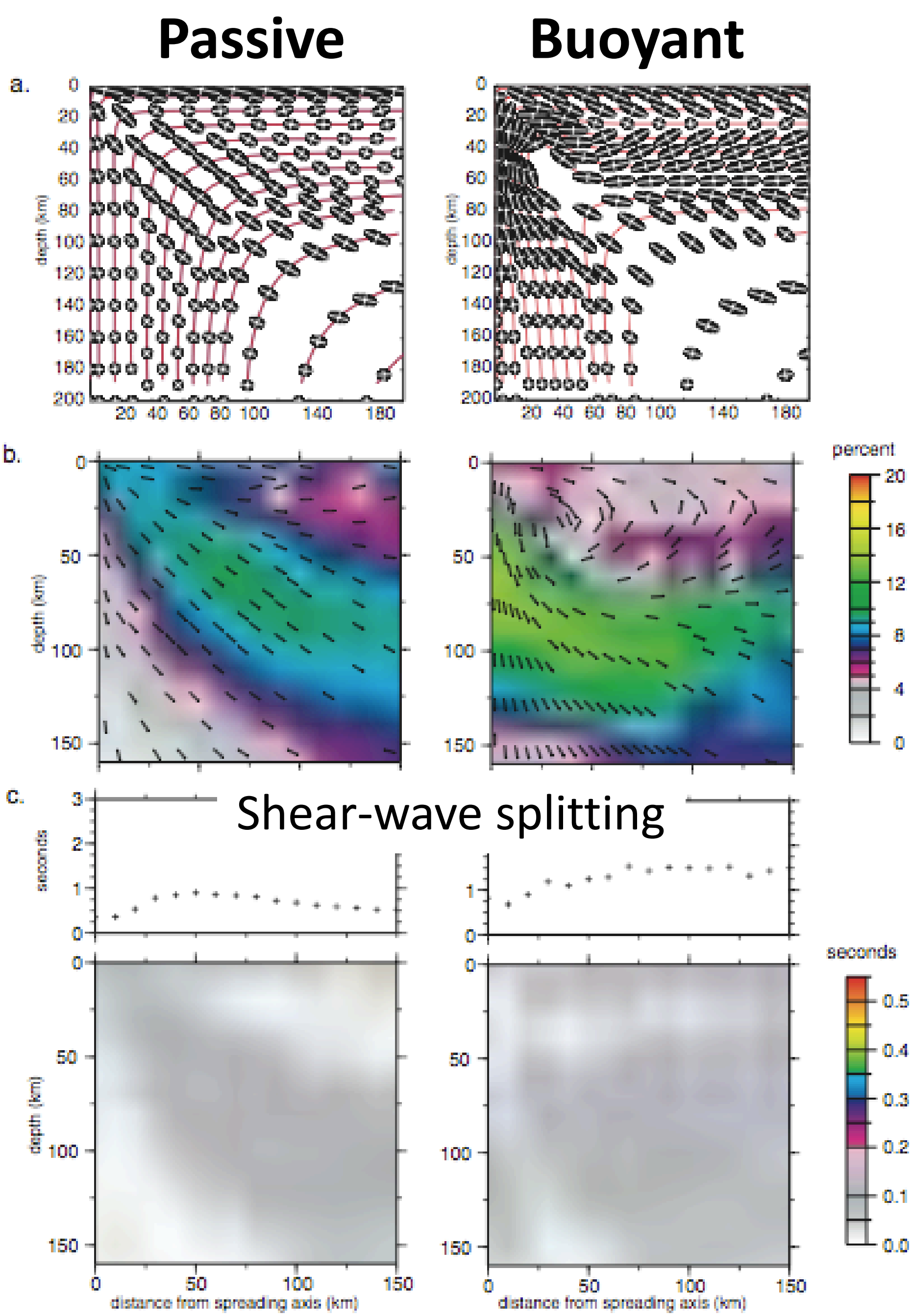

LPO anisotropy controlled by:

- 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

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Simple plate spreading

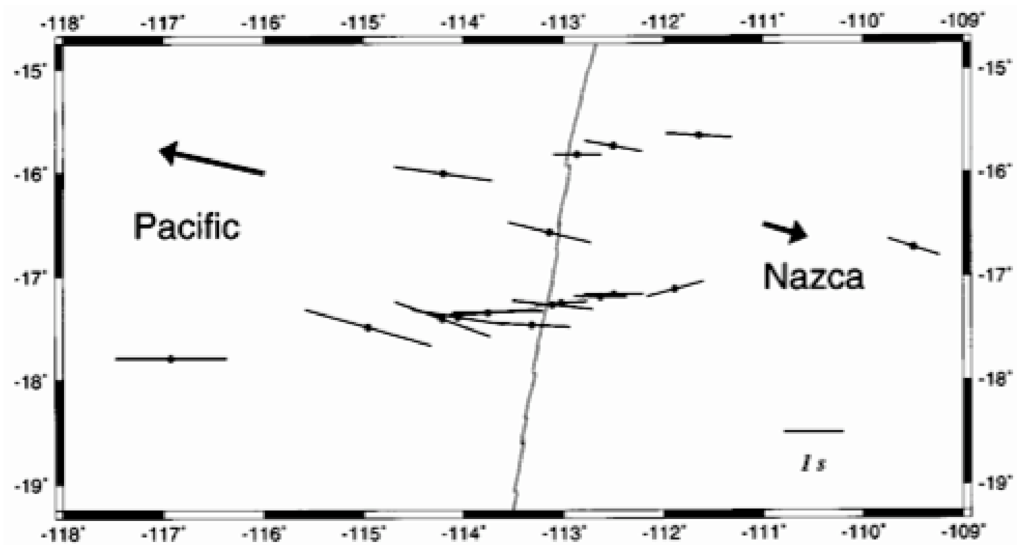
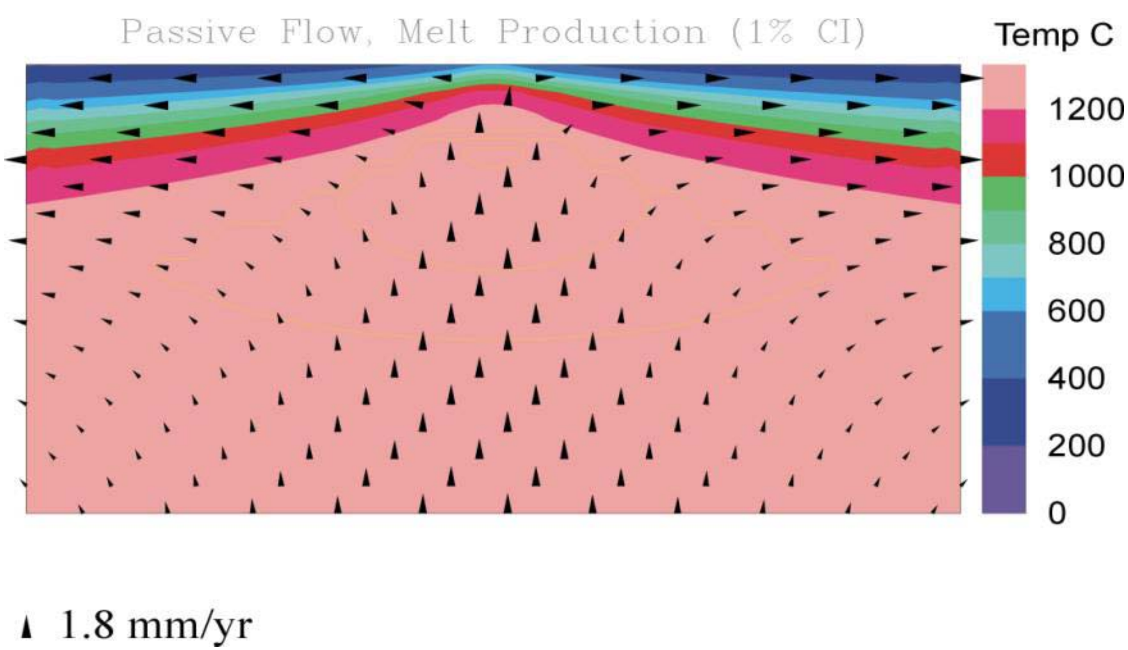


Fig. 3. Shear-wave splitting across the MELT array. Dots denote the position of the OBSs, and solid lines indicate the orientation of the fast direction ϕ, with the line length proportional to the delay time δt between fast and slow shear waves (Table 1). The rise axis is plotted as a solid line. Arrows indicate the magnitude and direction of absolute plate motion (*20*); the directions of absolute plate motion (*20*) and relative plate motion (*12*) are identical to within a few degrees in this region.



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 δt).

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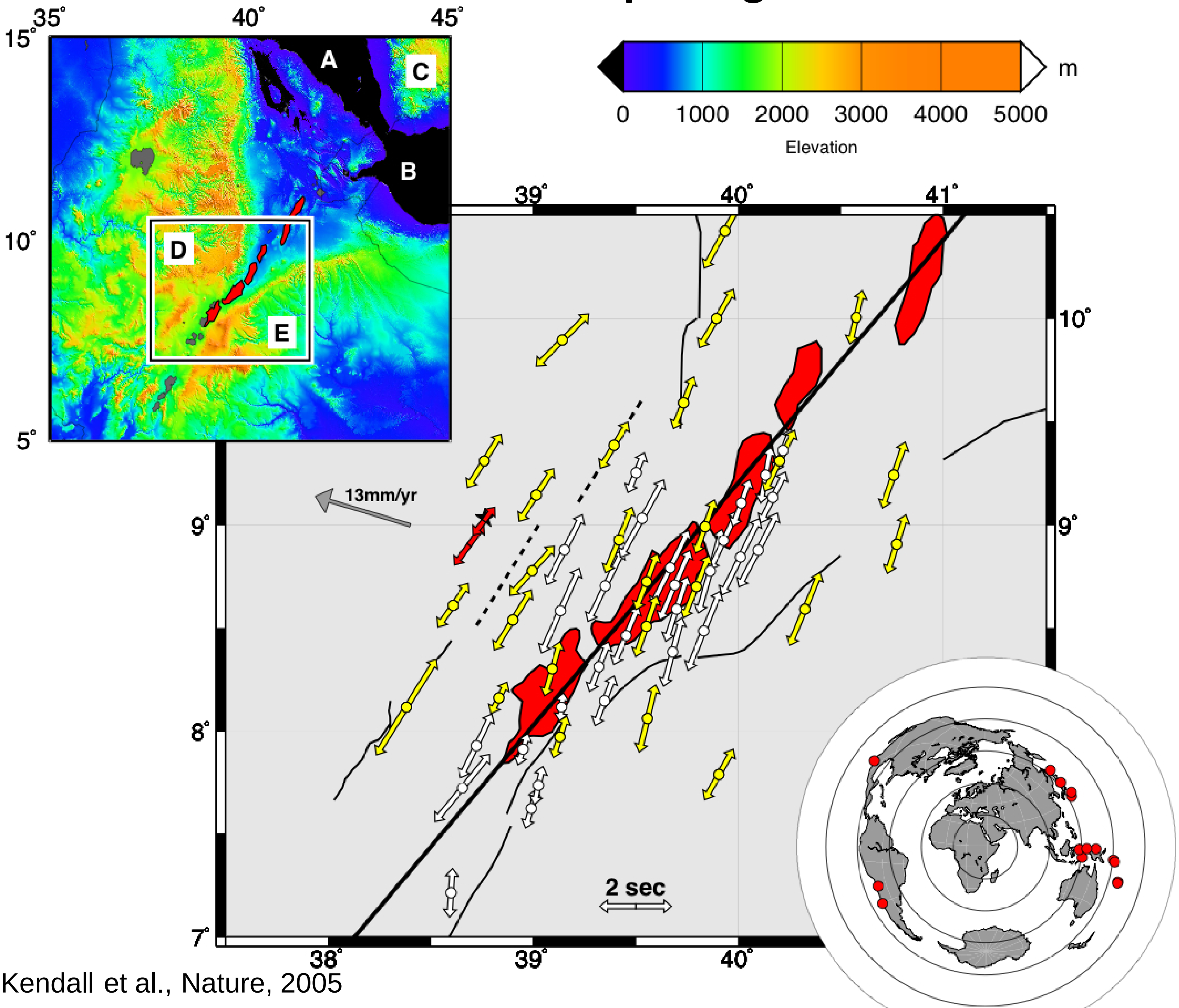
SKS splitting in the MER

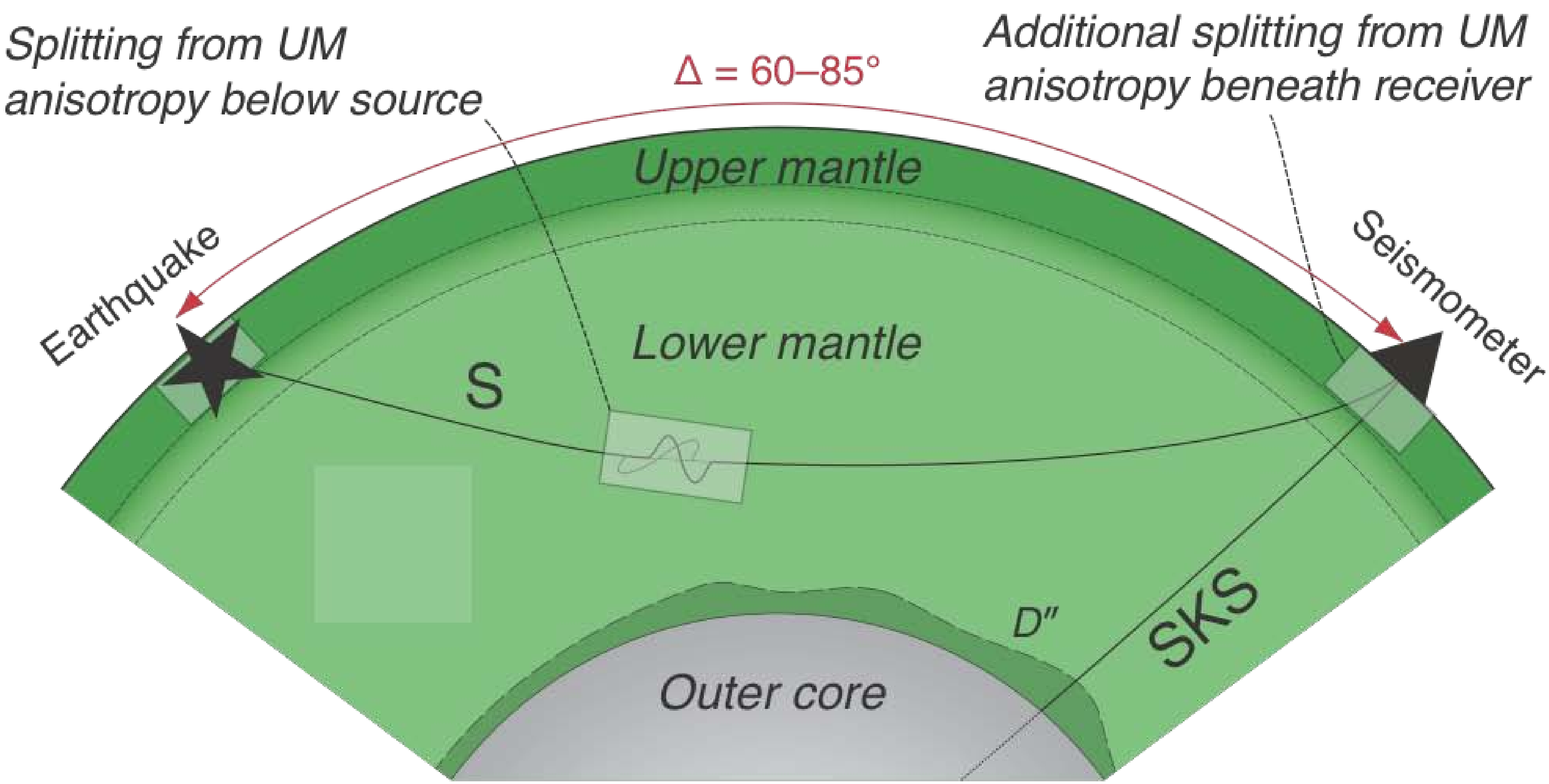


Kendall et al., Nature, 2005

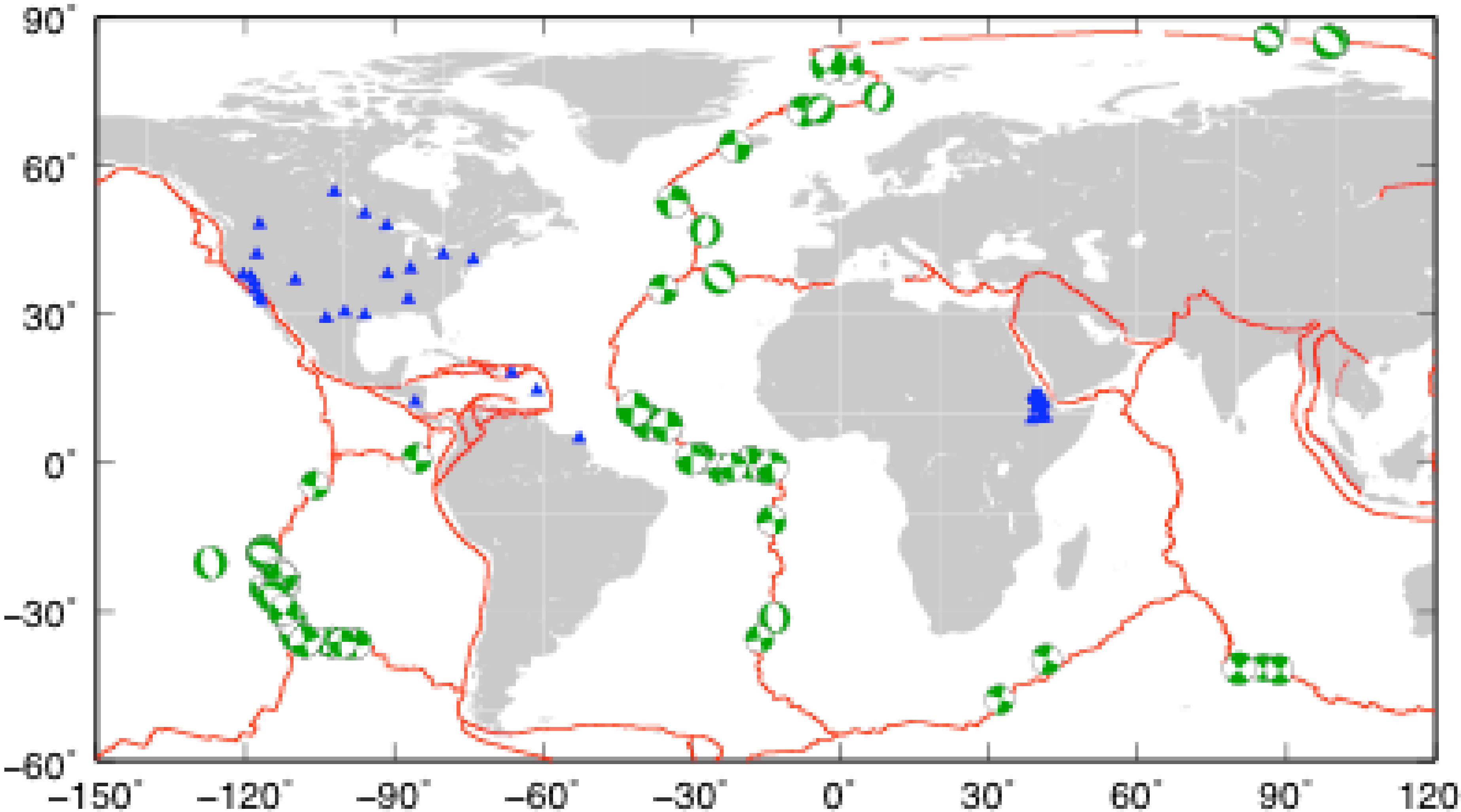
- **EPR** anisotropy is very different from **MER** anisotropy
  - Continental rift versus oceanic spreading center?
  - Spreading rates?
- Difficult to measure SKS splitting at **MORs** – instead use **source-side SWS**.

Source side splitting

(Nowacki et al., Nature, 2010)



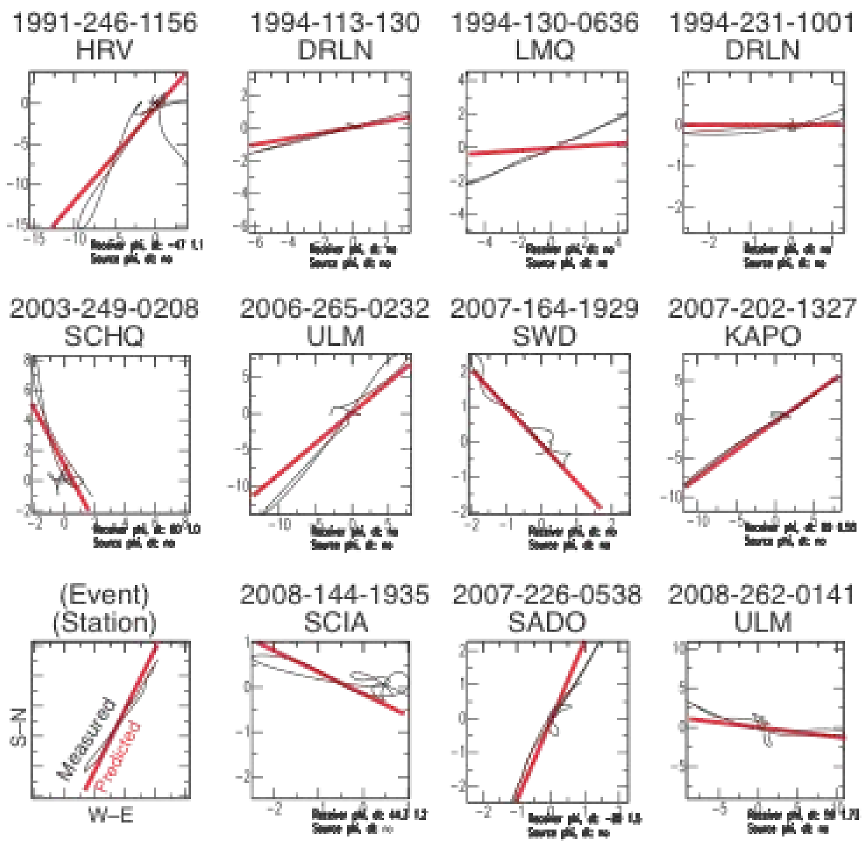
Events and Stations



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

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Results

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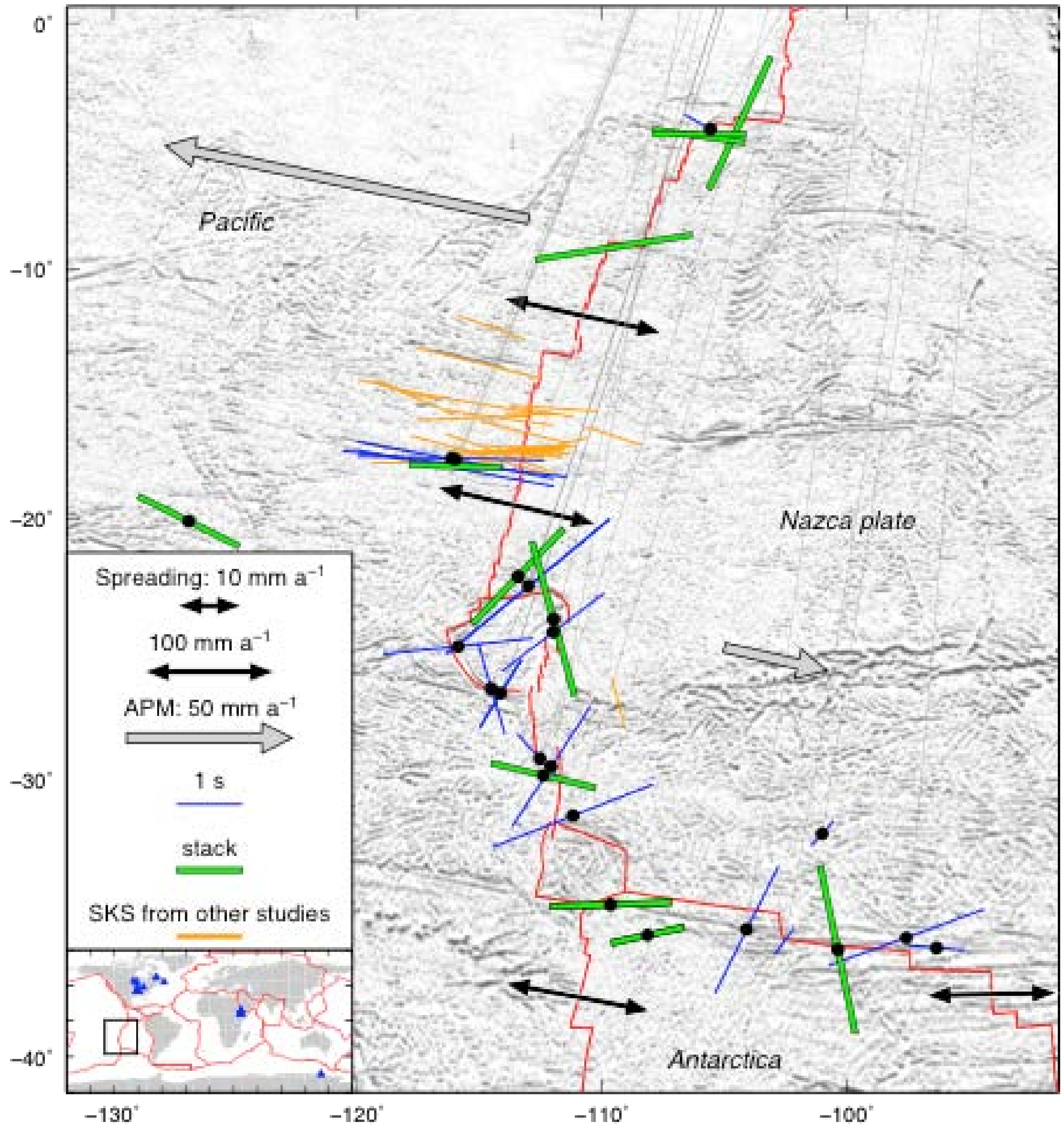
East Pacific Rise - source-side splitting



- 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

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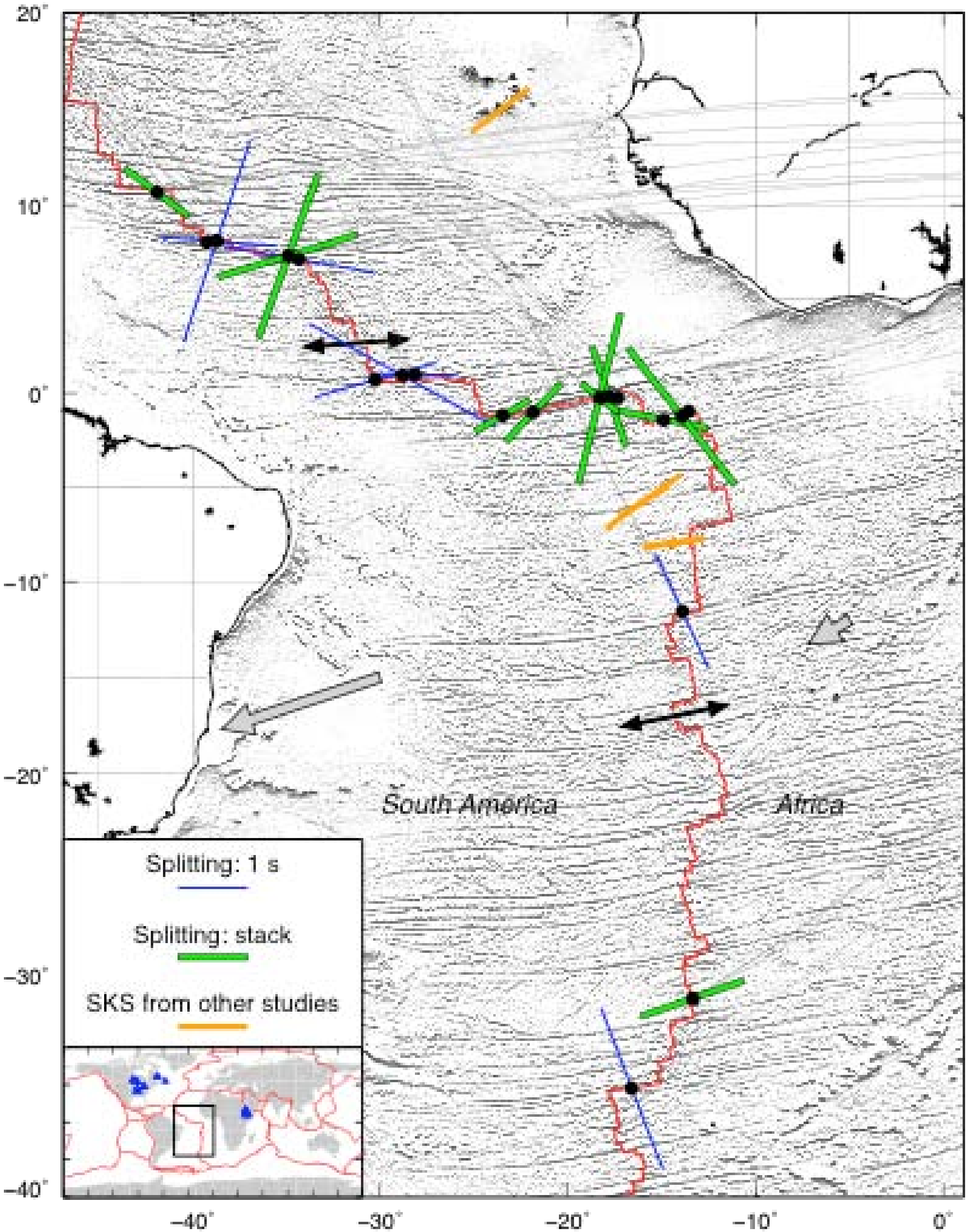
Mid Atlantic Ridge - source-side splitting



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

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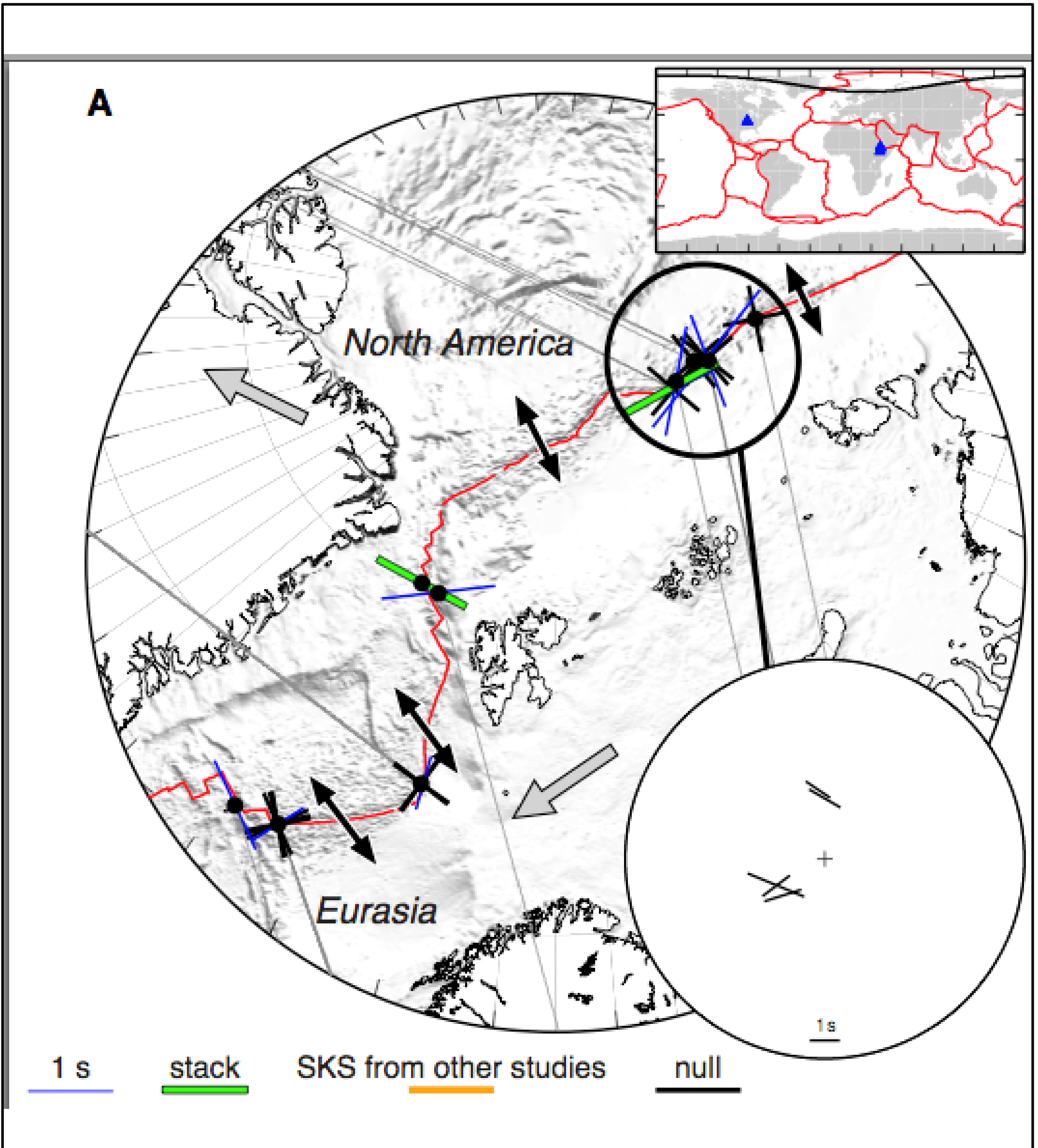
Gakkel Ridge - source-side splitting



- 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)

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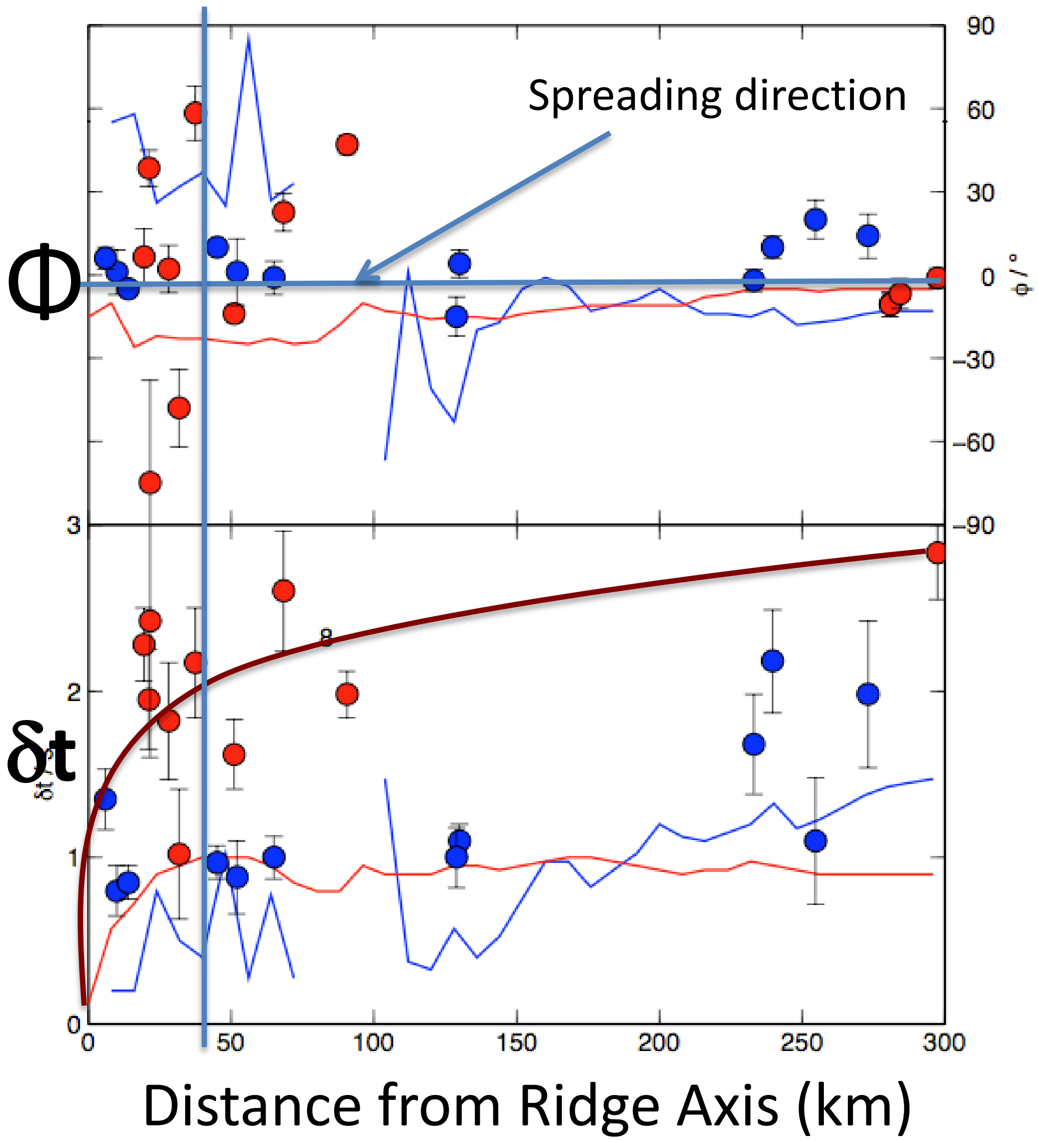
EPR S-wave vs SKS splitting - modelling



- 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?

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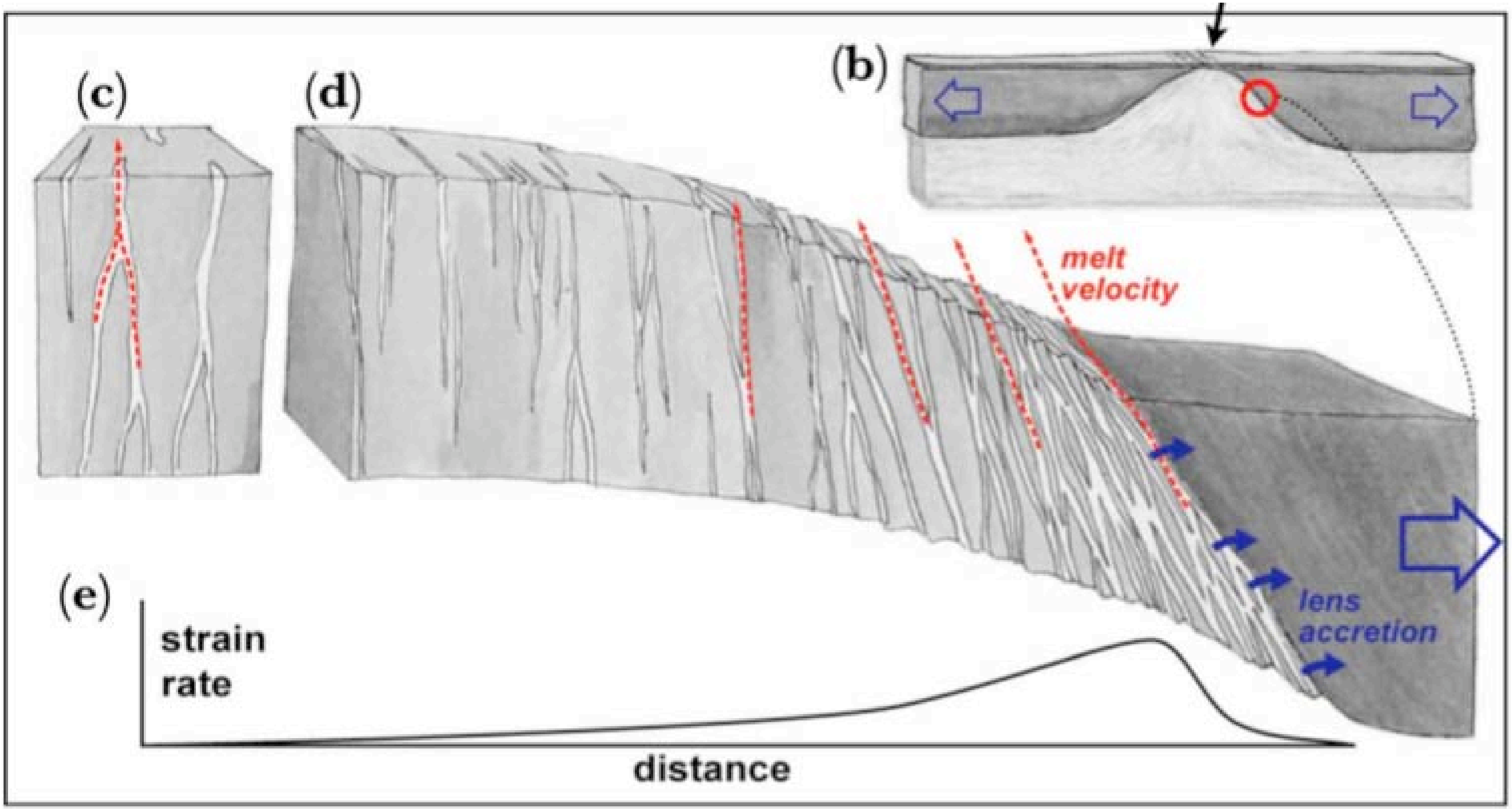
Stress driven melt segregation
- most effective at flanks (marginal LAB)



Holtzman and Kendall, G3, 2010

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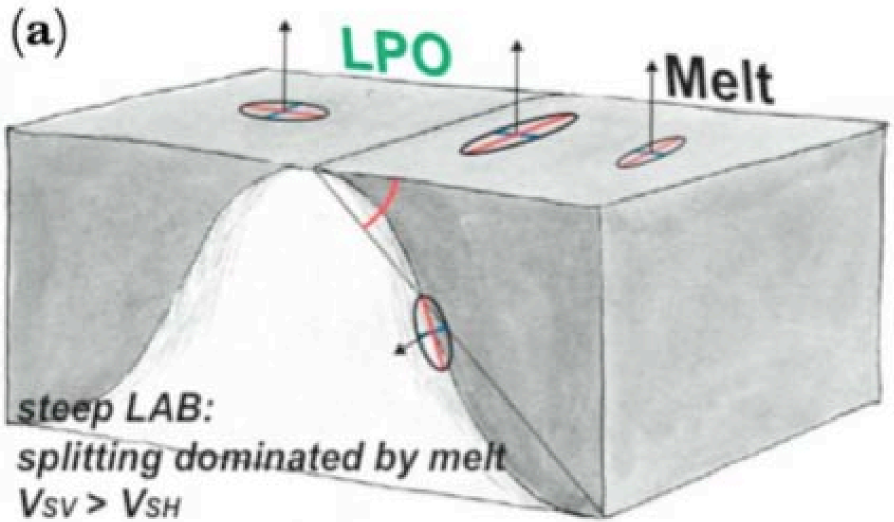
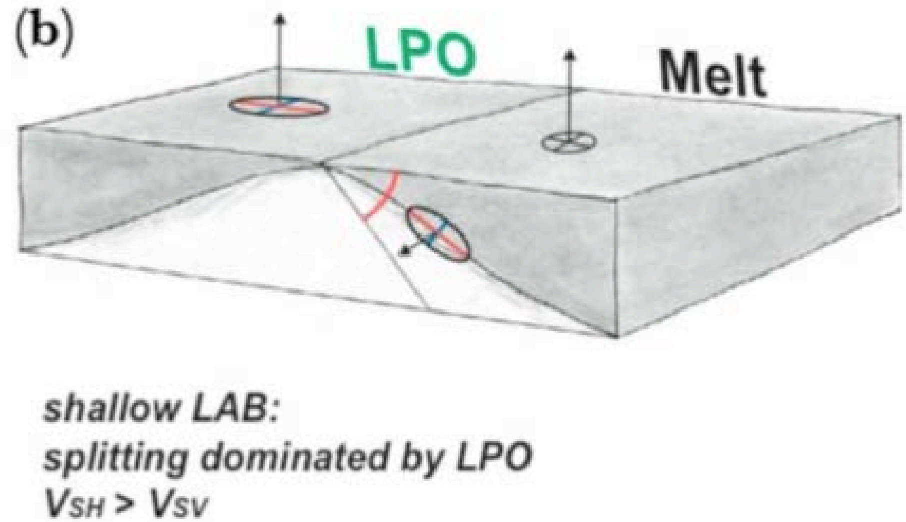
Melt and the LAB





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

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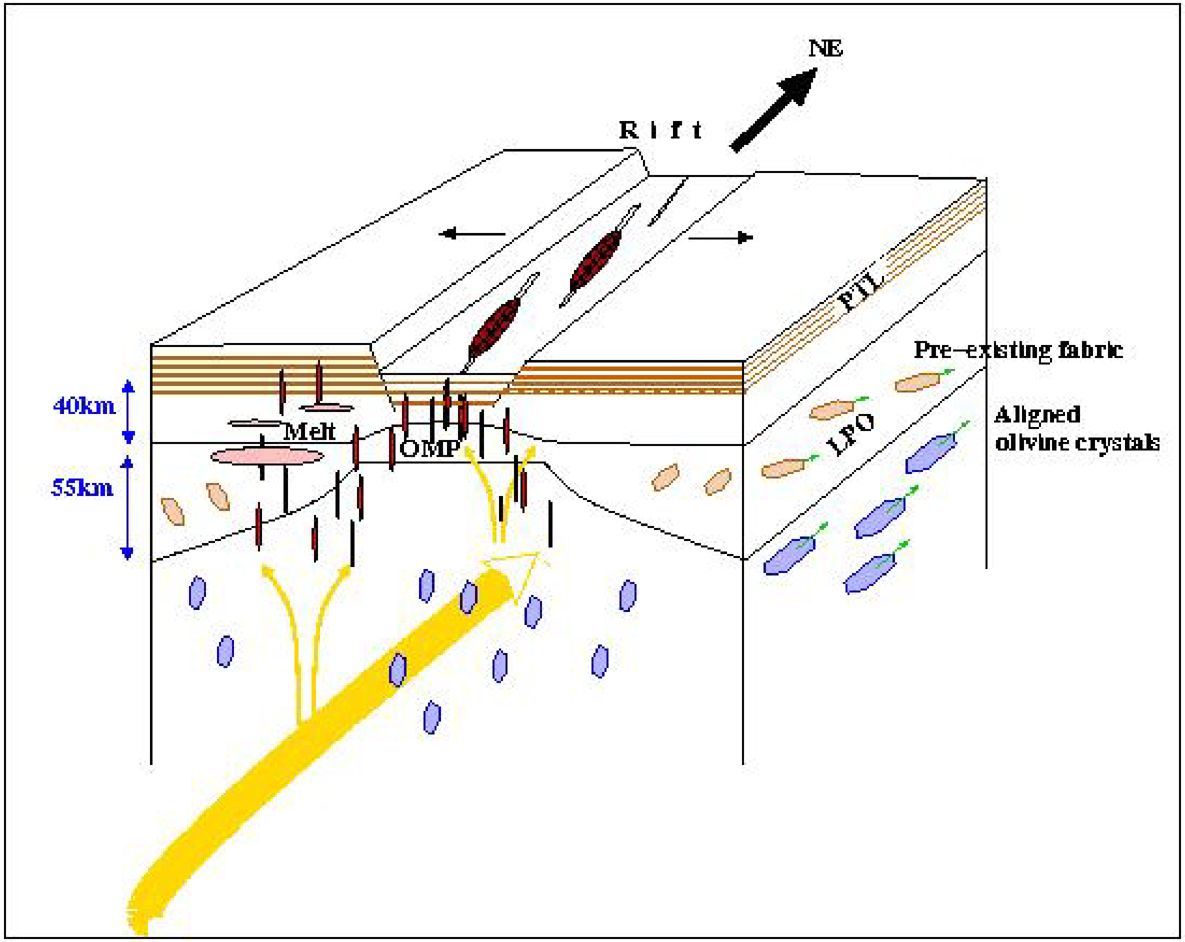
Mechanisms for MER anisotropy:



- 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

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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)

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