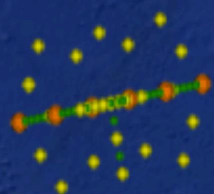
Imaging the Lithosphere-Asthenosphere System in the central Pacific: the NoMelt experiment



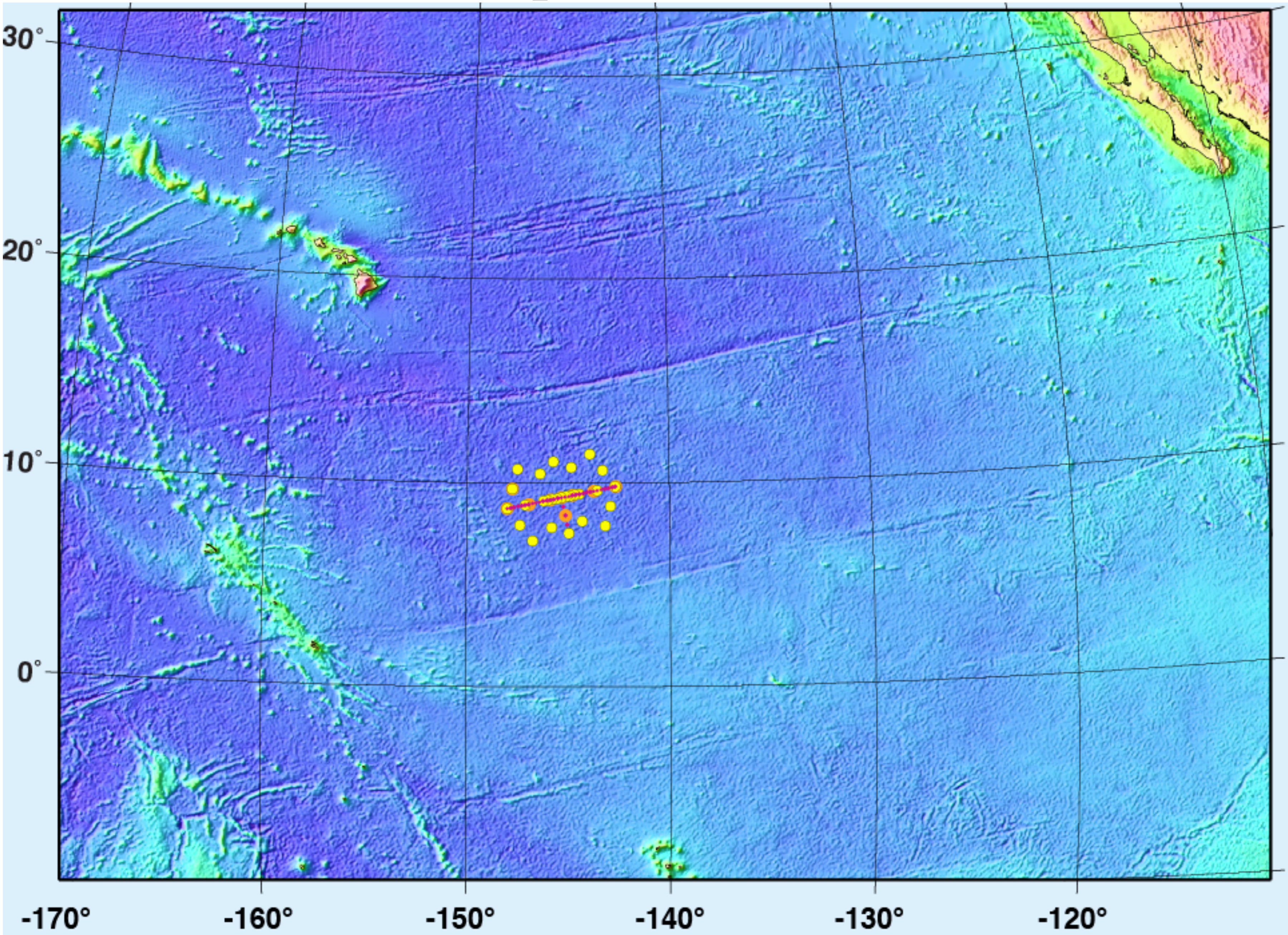
J. Gaherty, P. Lin, G. Jin, *LDEO*
D. Lizarralde, J. Collins, R. Evans, H. Mark, E. Sarafian *WHOI*
G. Hirth, *Brown Univ*

Langseth Community Meeting, San Francisco, Dec 2015

Motivation

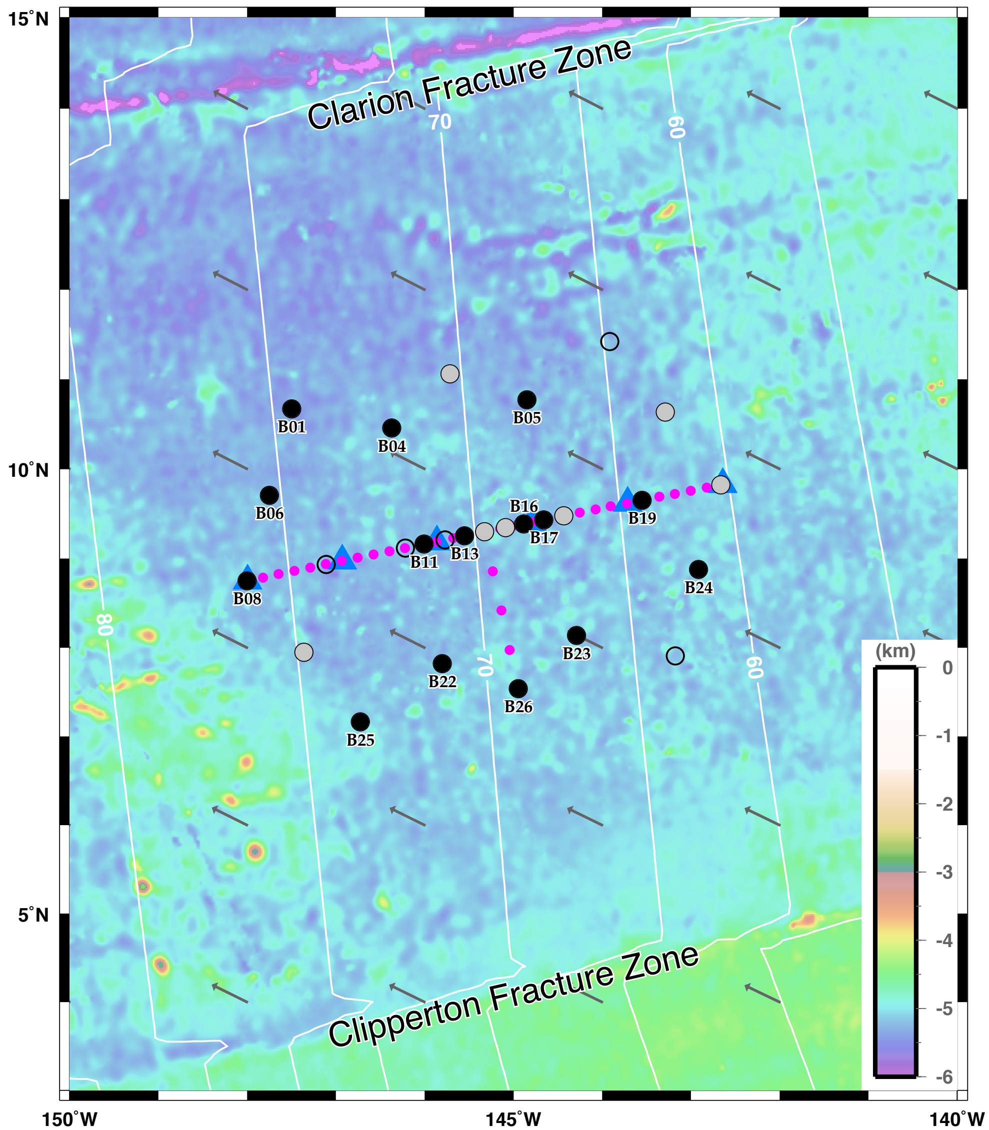
- Seismic observations from the ocean basins are inconsistent with our best theoretical models of oceanic upper mantle structure in two ways:
  - The Lithosphere-Asthenosphere boundary (LAB) is too shallow, and too sharp, to be thermally triggered
  - The velocity gradients in the shallow mantle are the wrong sign
- Explain with combination of temperature, composition (bulk and volatile), fabric, and physical state.
- Comprehensive, focused observations required to unravel these processes.

NoMelt Experiment 2011-2013



NoMelt

Characterize the stable oceanic lithosphere-asthenosphere system



- 70 Ma average seafloor age
- Minimal evidence of post-ridge volcanism
- 600x400 km Study Region

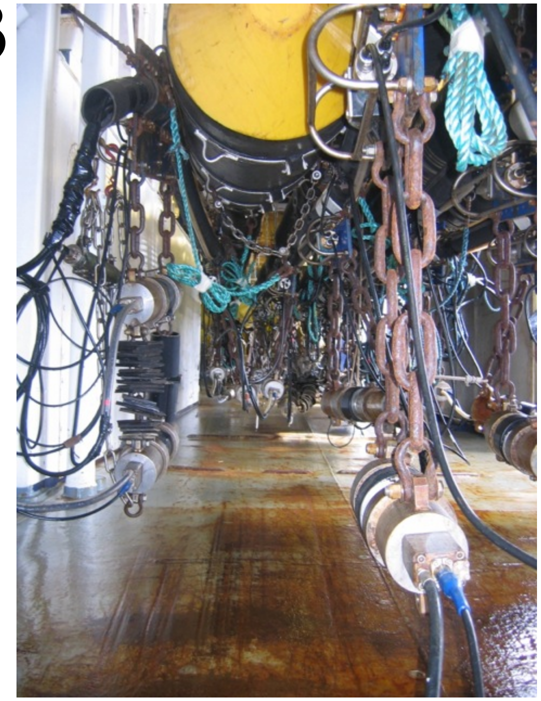
Short-period OBS array
Mark et al., DI33A-4286

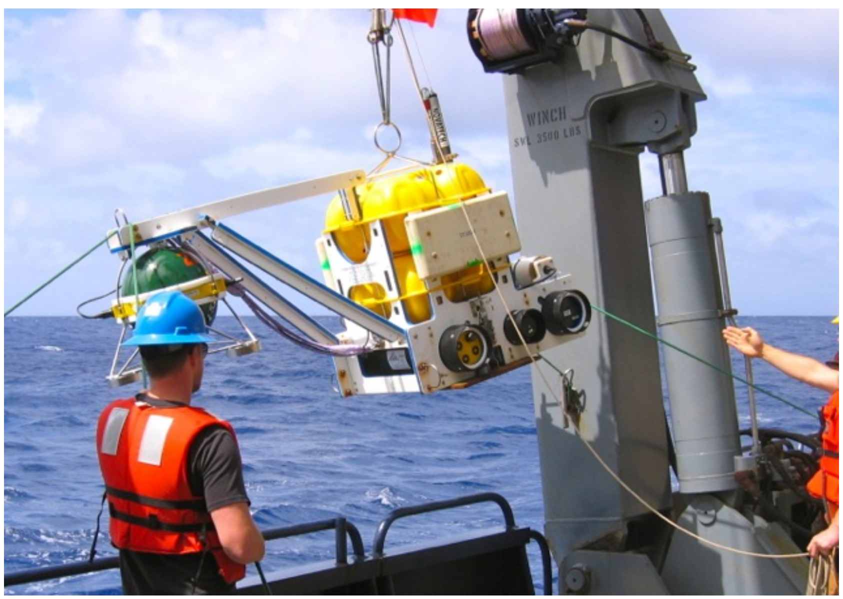
Magnetotelluric MT array
Evans et al., DI24A-02

Broad-band OBS array
* 5 missing
* 6 low S/N
* 16 high S/N

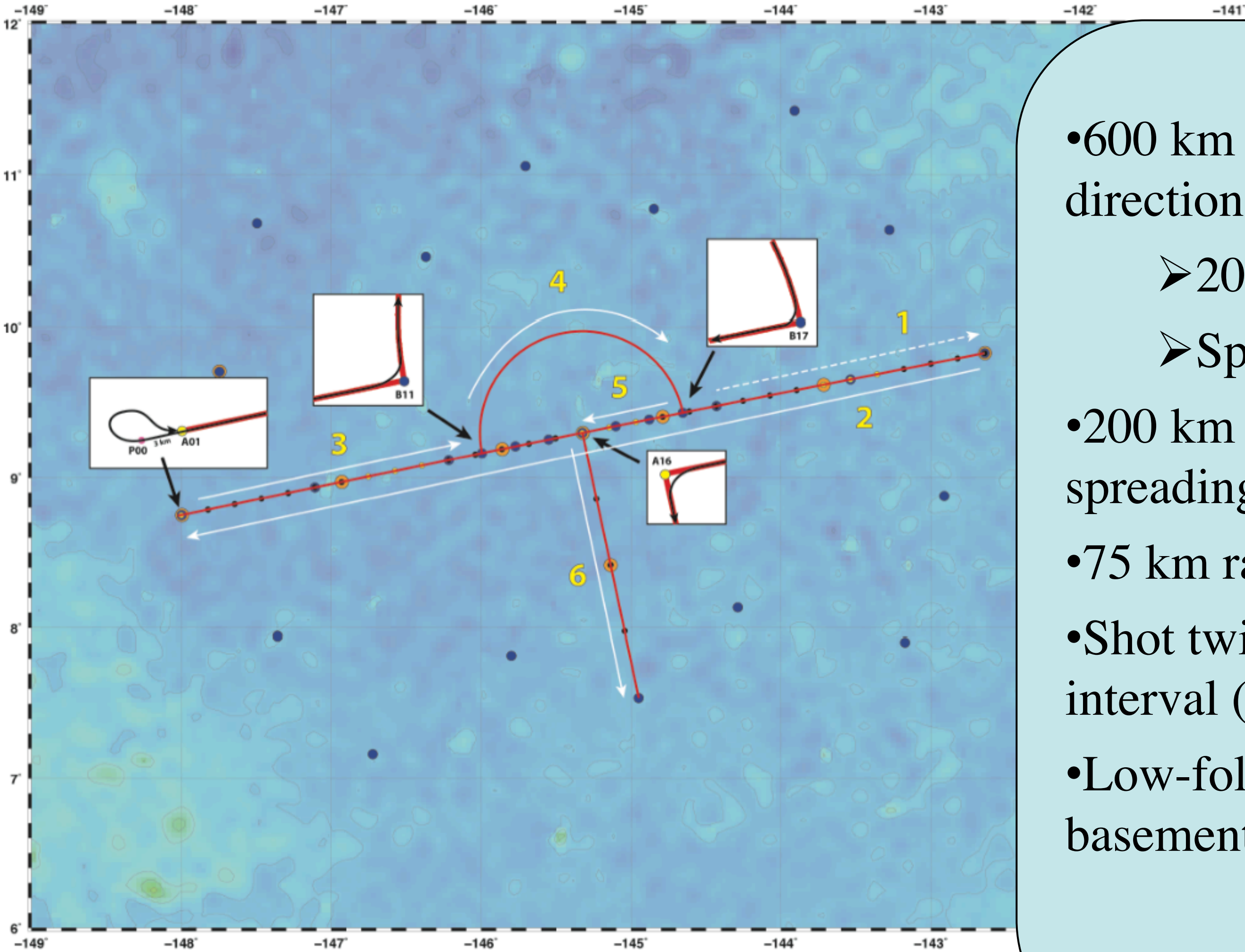
Lin et al., DI22A-01

NoMelt Experiment 2011-2013



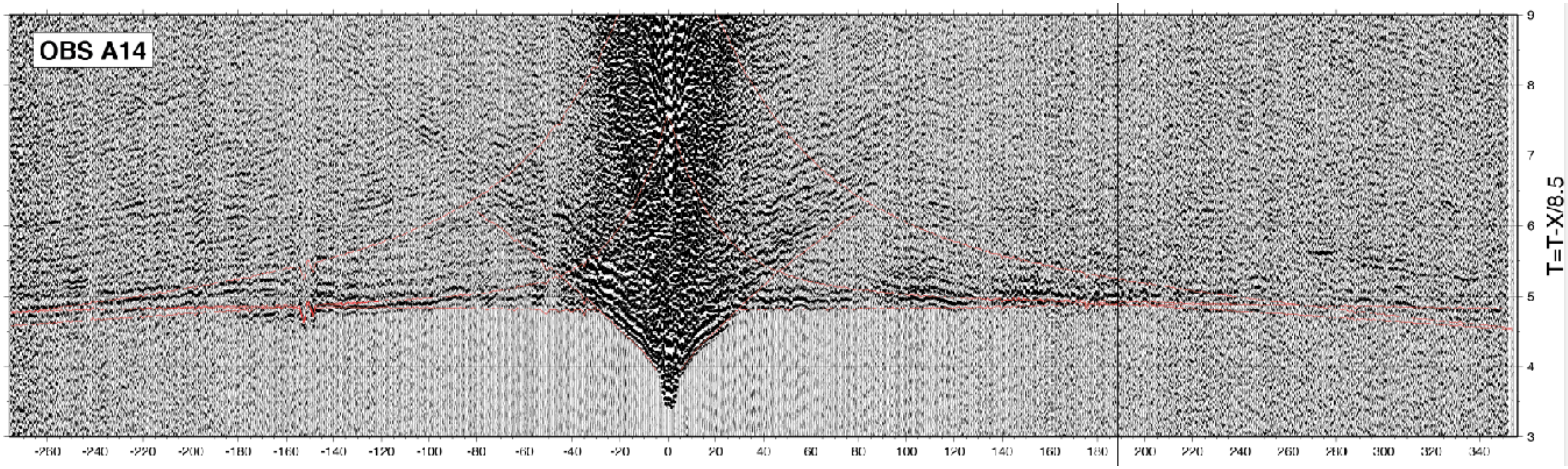


NoMelt Active Source 2011-2012



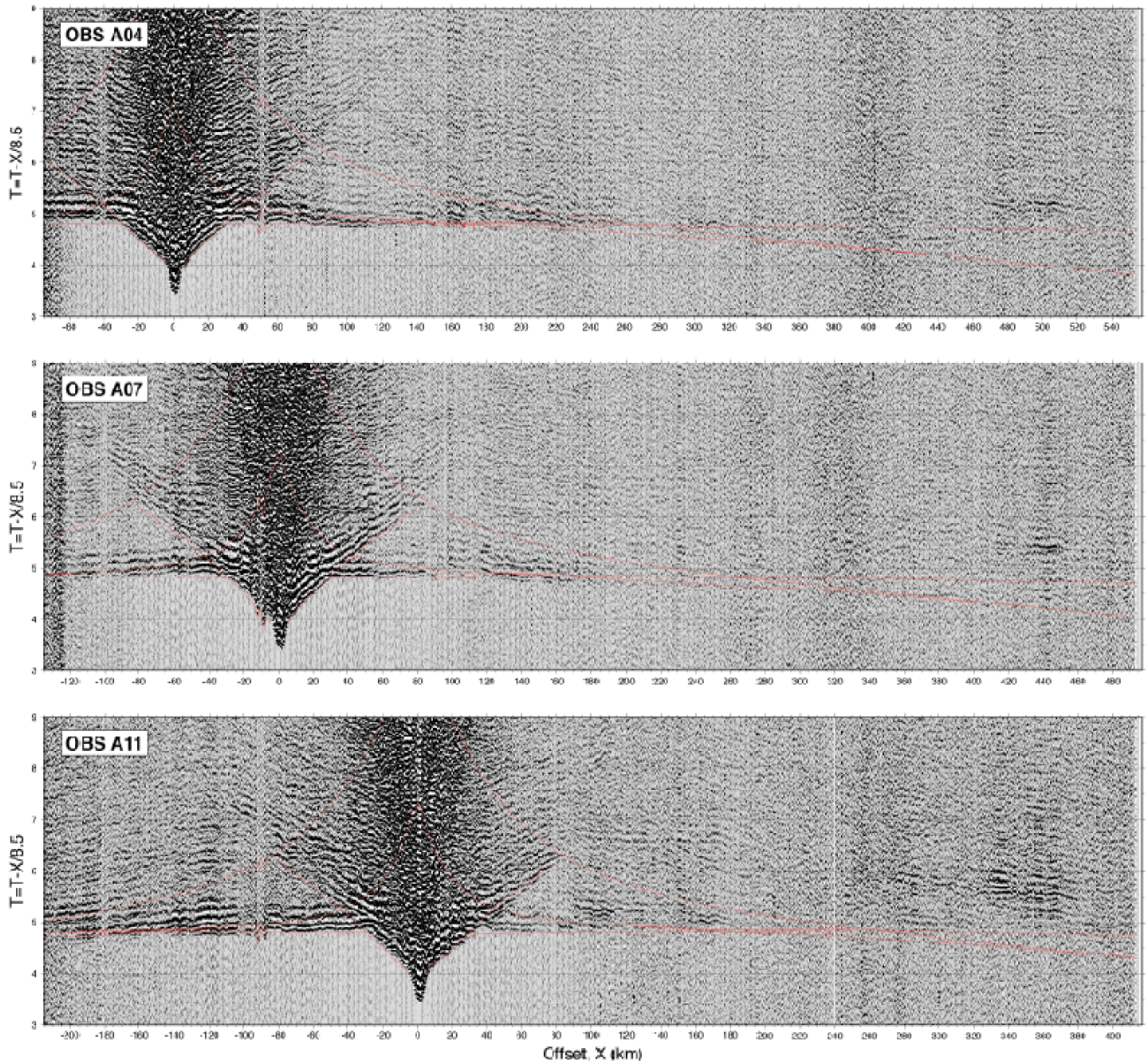
- •600 km line in fossil spreading direction
  - ➢20 km instrument spacing
  - ➢Spans dense BBOBS array
- •200 km line perpendicular to spreading
- •75 km radius semicircle
- •Shot twice on distance at 600 m interval (stack, cut PSN)
- •Low-fold MCS for sediment, basement, Moho contraints

NoMelt Active Source 2011-2012

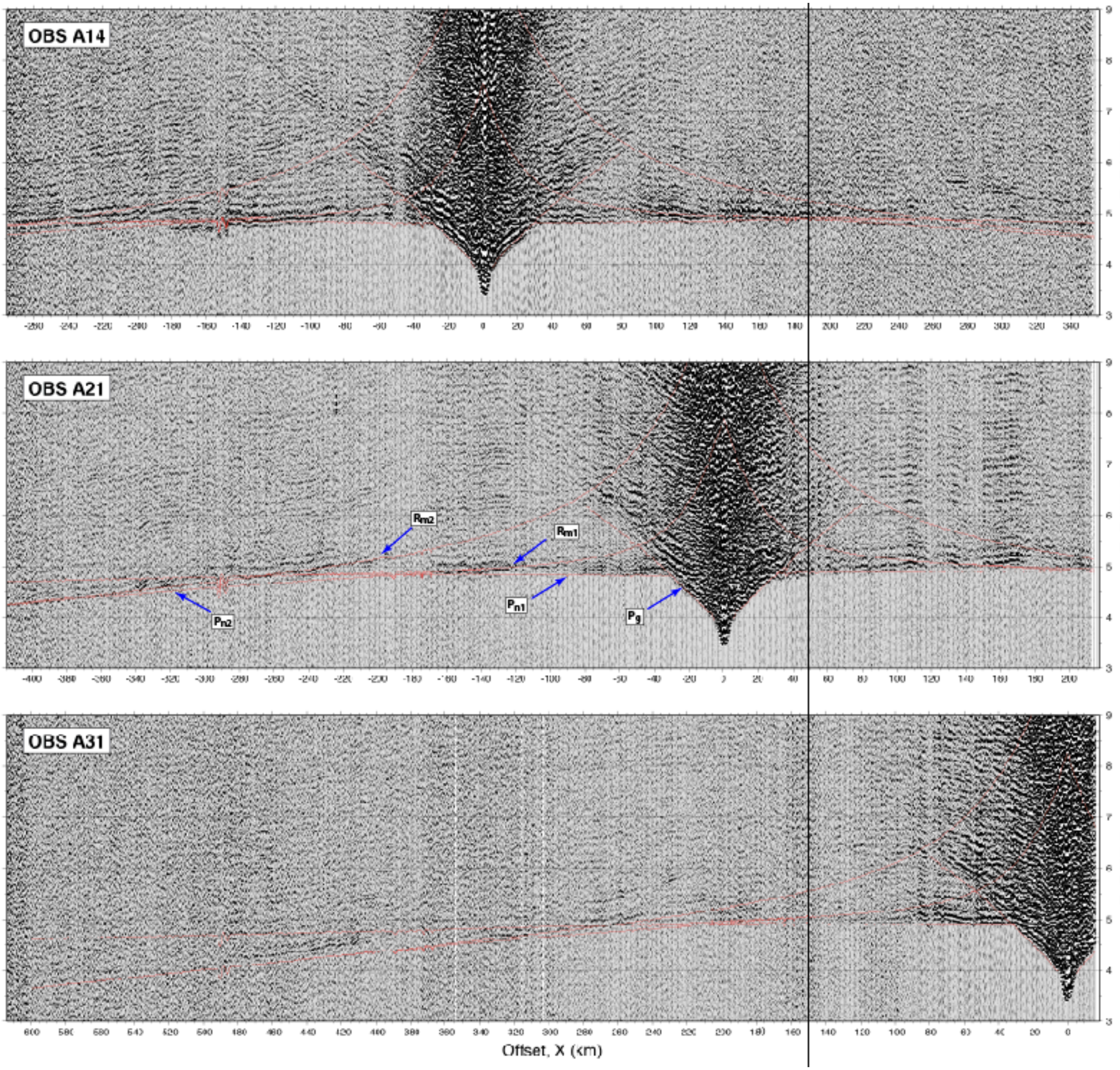


Receiver gather for one OBS
Range -280km to 320 km
Reduction velocity 8.5 km/s
Stack of two shots

NoMelt Active Source 2011-2012



NoMelt Active Source 2011-2012



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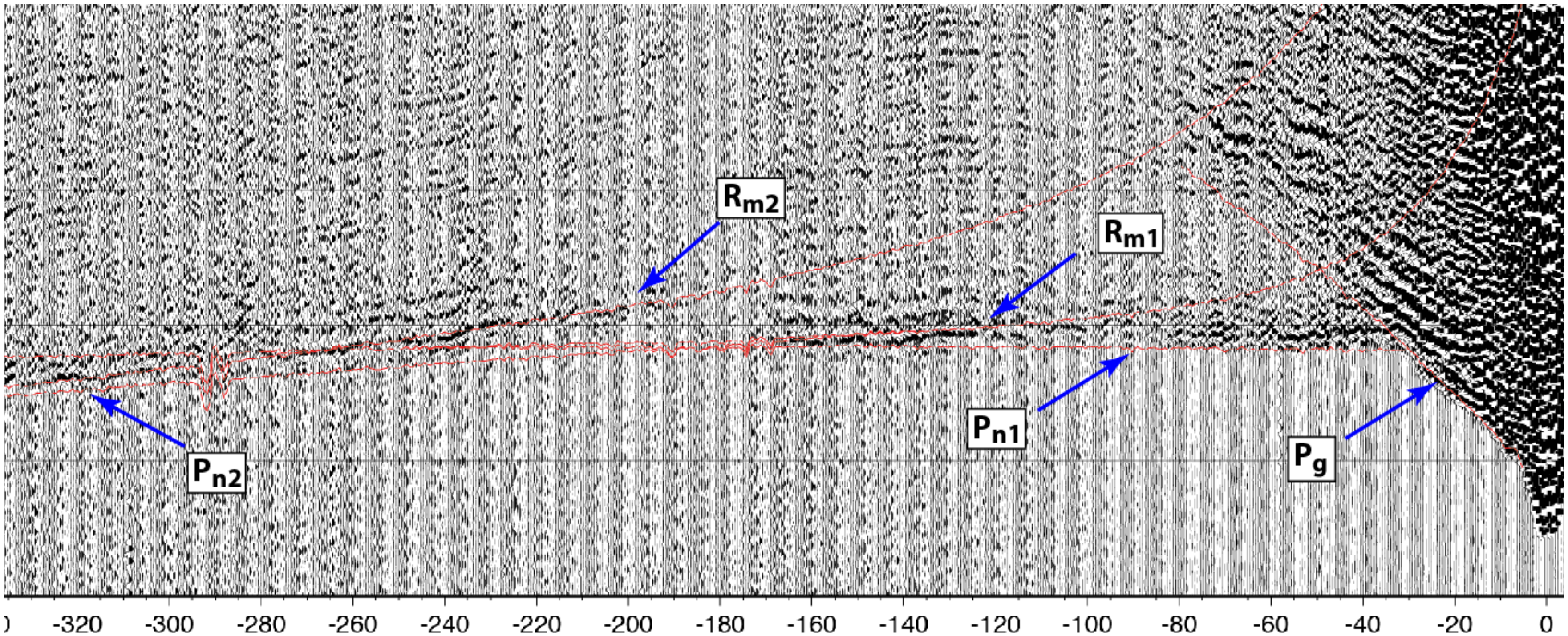
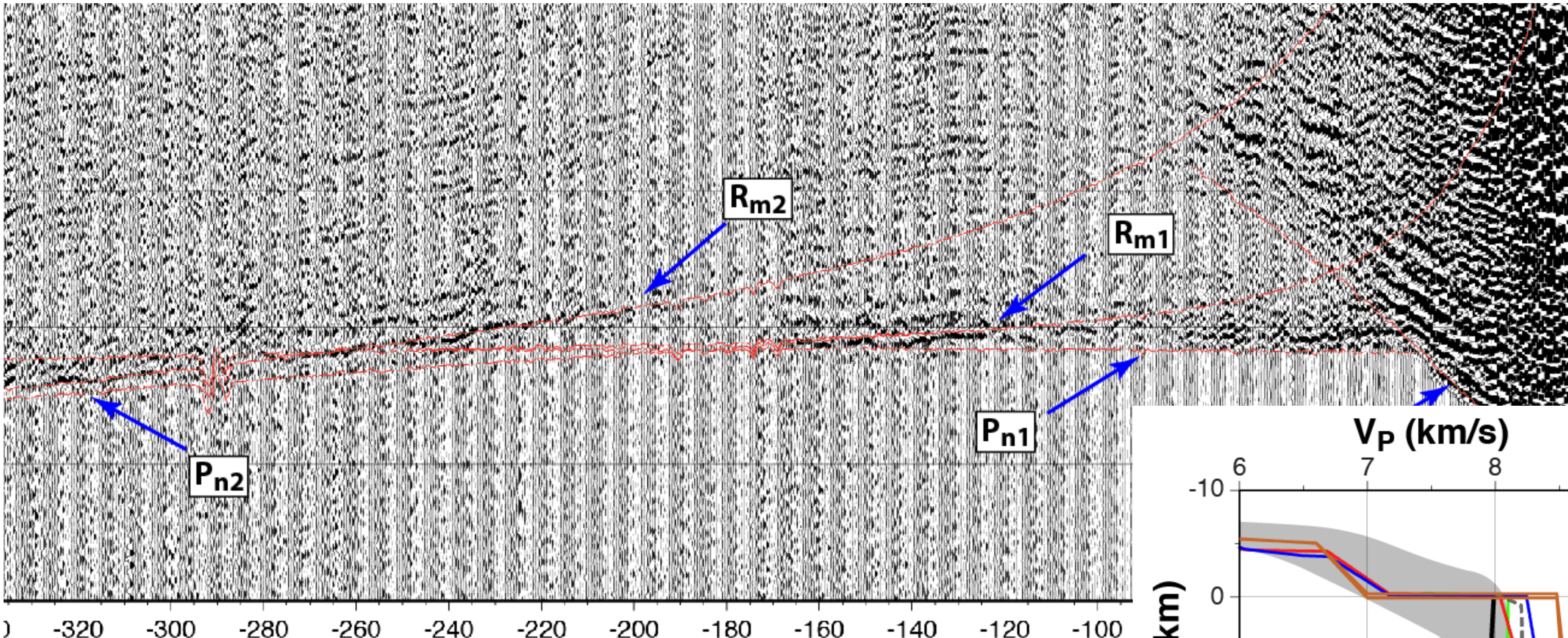


Basic character of 6 Line 1 instruments
- Fast (8.5 km/s) sub-moho velocities
- Positive velocity gradient
- Significant variations in refraction amplitude
- Significant reflectivity in mantle
- Extremely high velocities at large offsets suggest dipping structure

NoMelt Active Source 2011-2012



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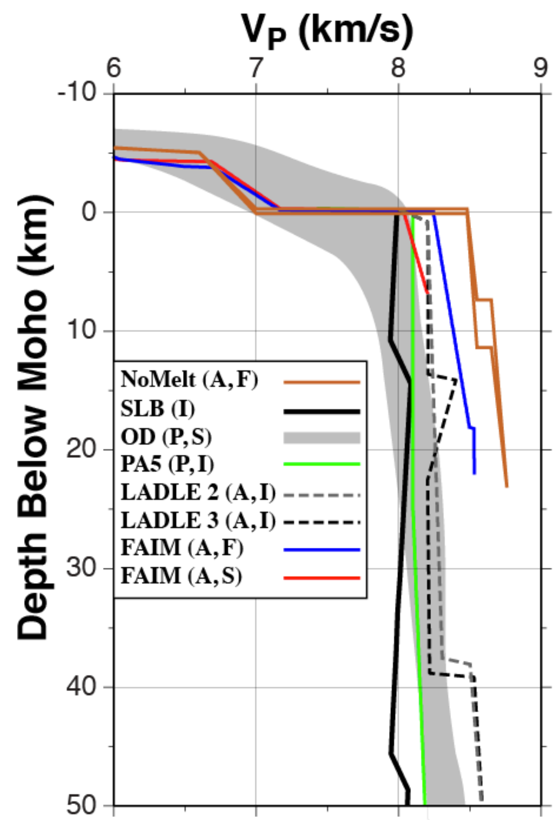
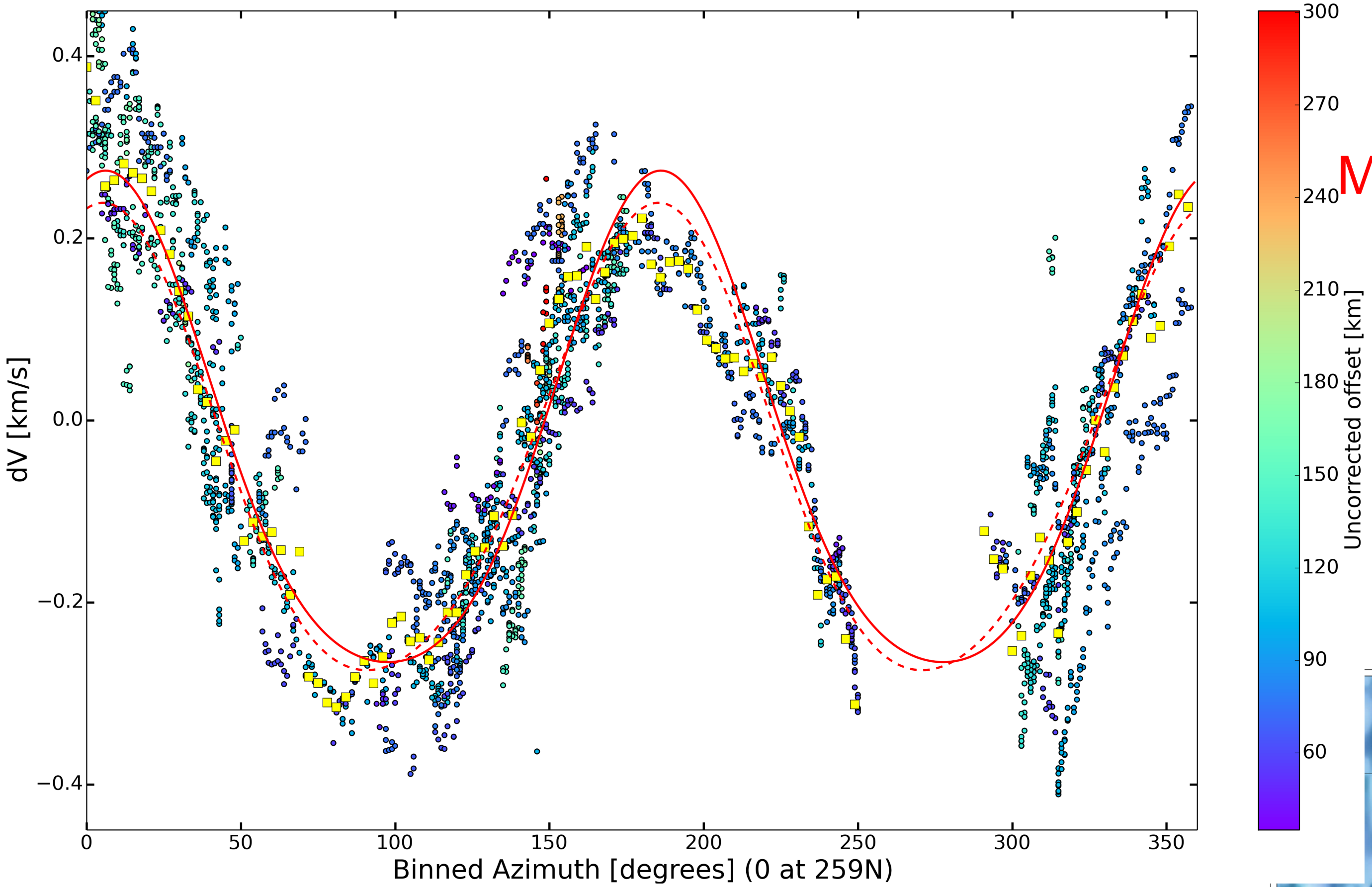
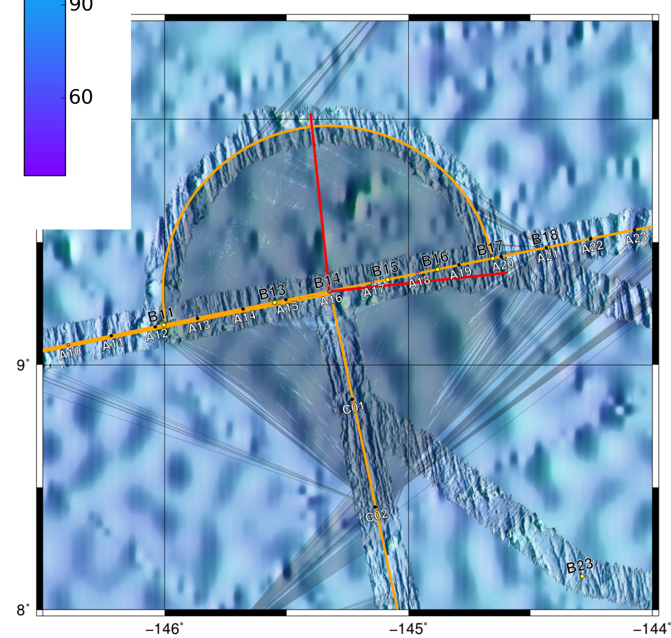


NoMelt Active Source 2011-2012



Mark et al., DI33A-4286



•Large (nearly 8%) Vp anisotropy (8.0-8.6)

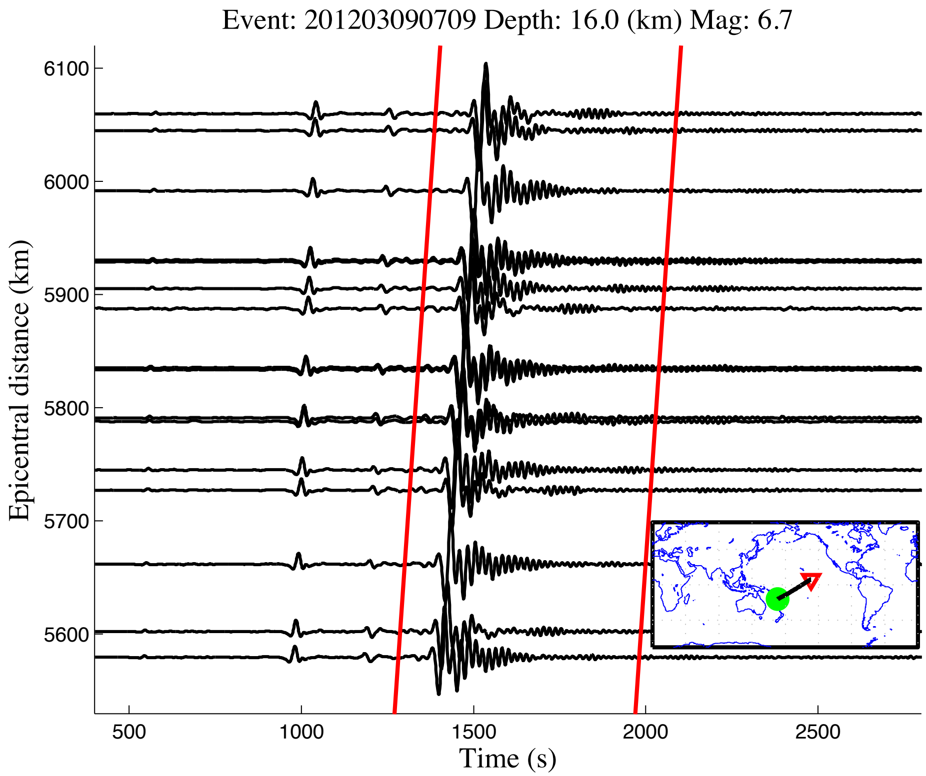
•Fast direction oriented in fossil spreading direction

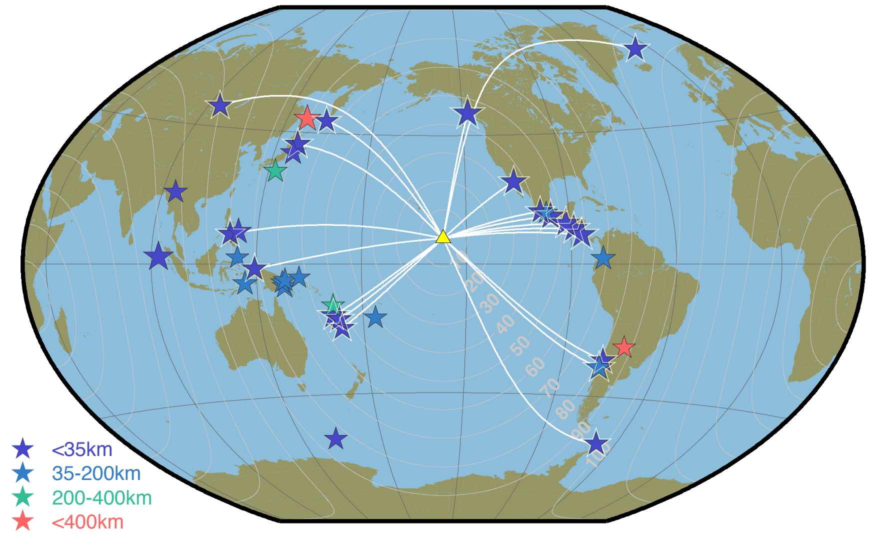
•Strong positive gradient in spreading direction

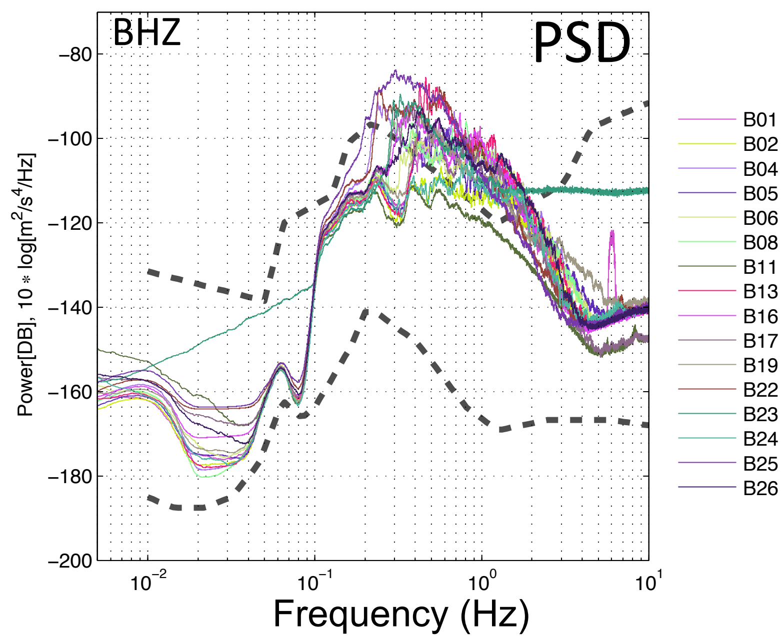
•Flatter gradient perpendicular to spreading

•Constraint is in upper 10 km of mantle

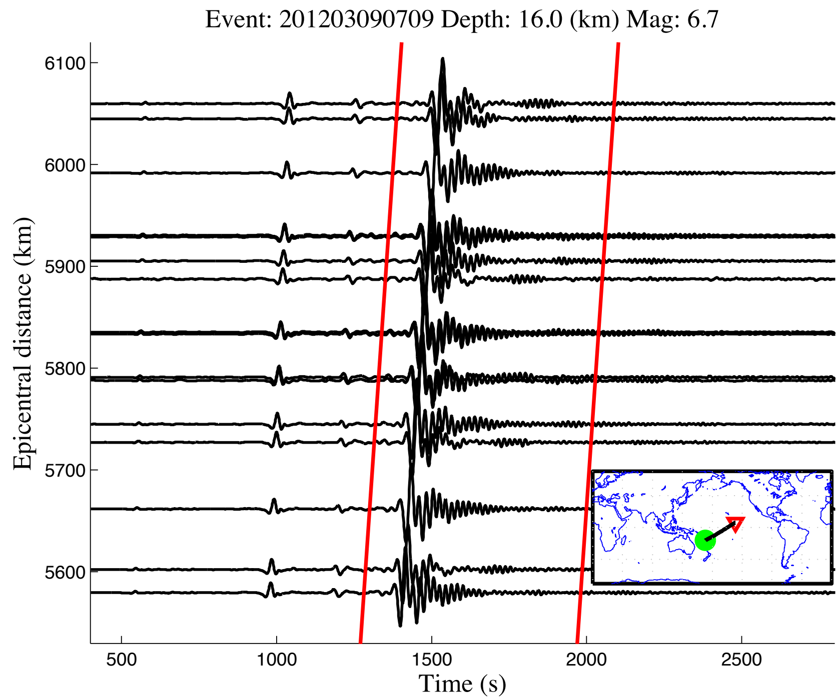
NoMelt Broadband 2011-2012



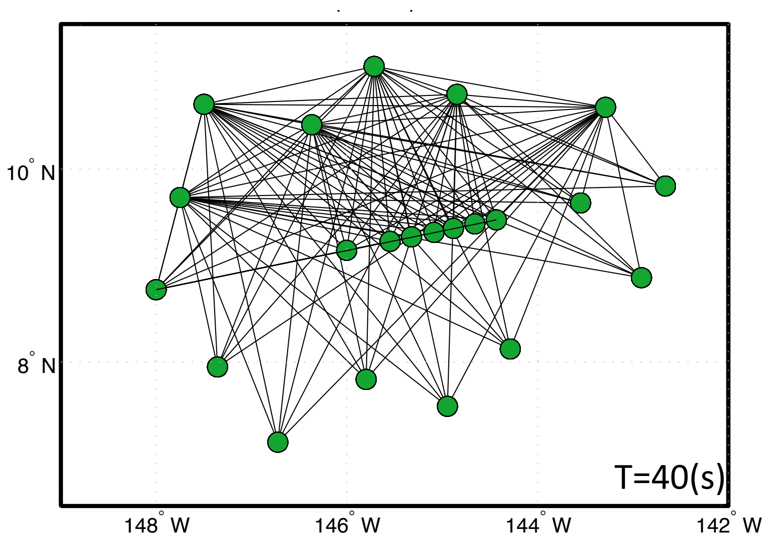




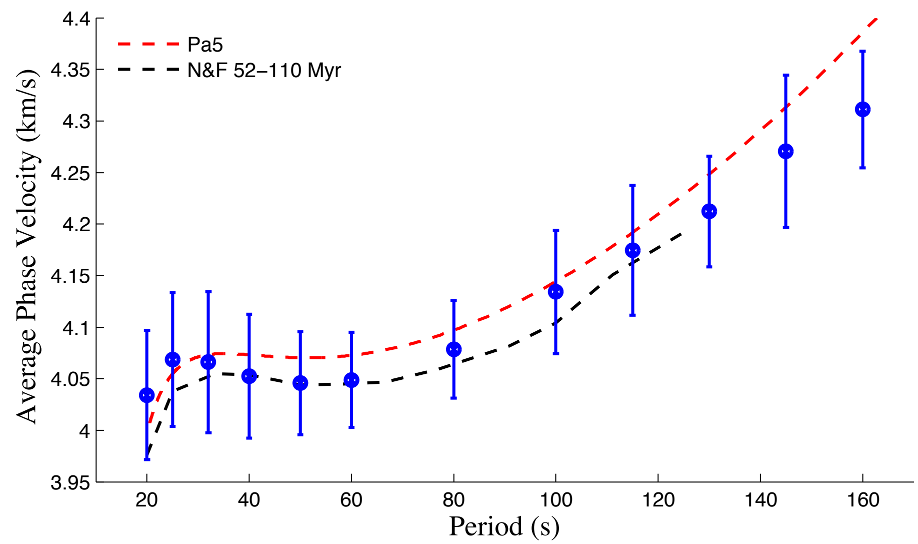
Phase Velocity from EQ Rayleigh Waves



- Using surface-wave dispersion to characterize Vs structure & its seismic anisotropy in upper 250 km beneath the array
- Accurate apparent phase velocity from cross-correlation between nearby stations. *[ASWMS, Jin and Gaherty, 2014]*

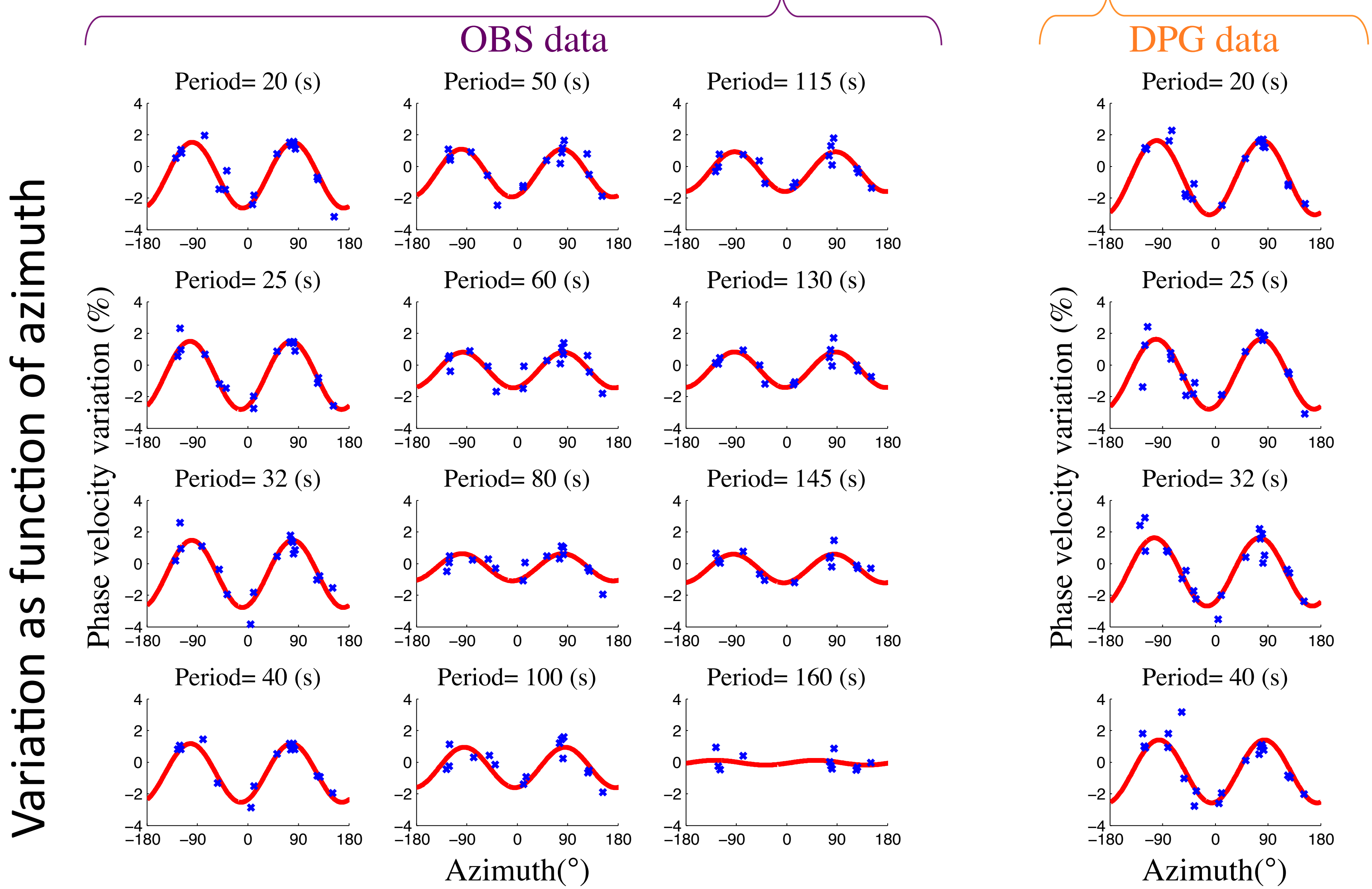


Phase Velocity Dispersion



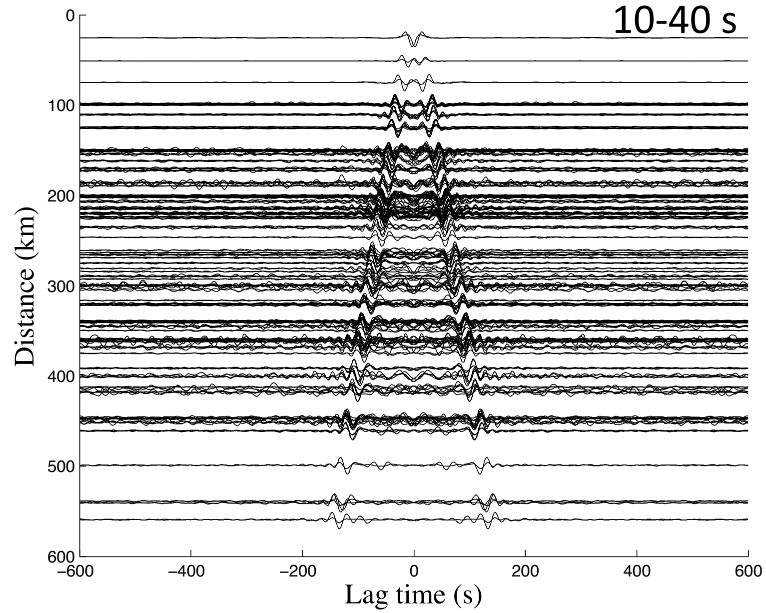
Azimuthal Phase Velocity Variations

$$C(\theta_{azi}) = C_{iso} + C_{iso} \times \frac{A_{peak-to-peak}}{2} \times \cos(2(\theta_{azi} - \psi_{fast-dir}))$$

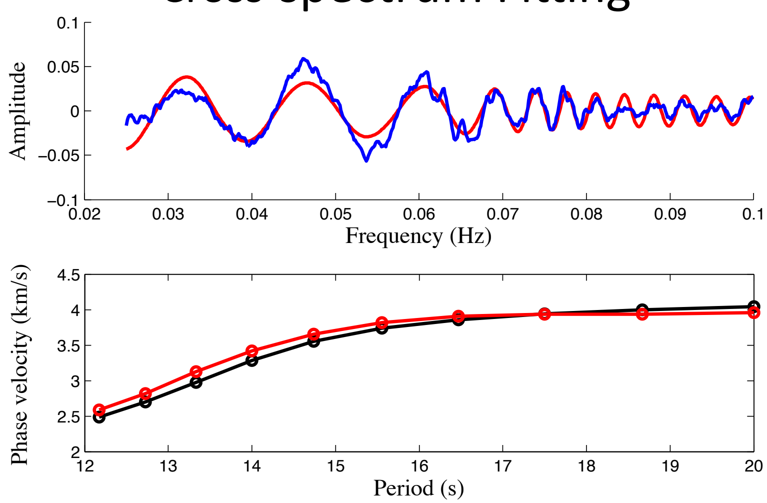


Phase Velocity & Azimuthal Variations from Ambient Noise

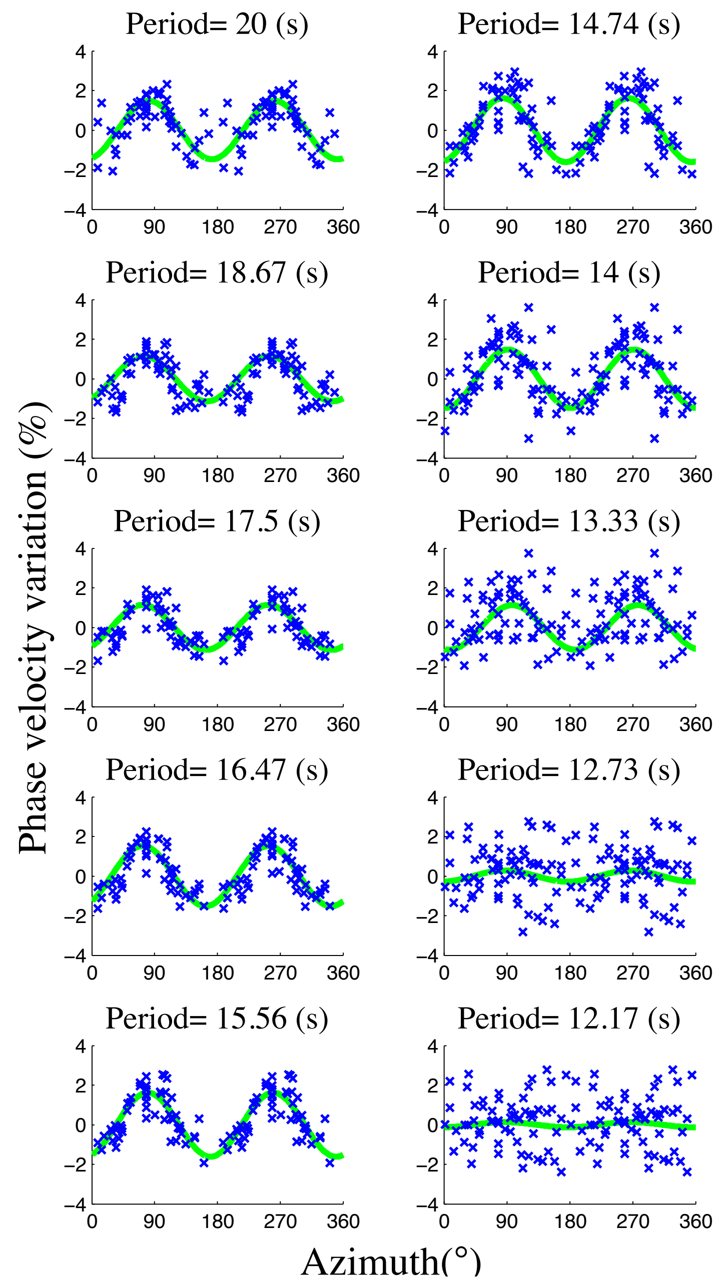
Cross-correlation Waveforms



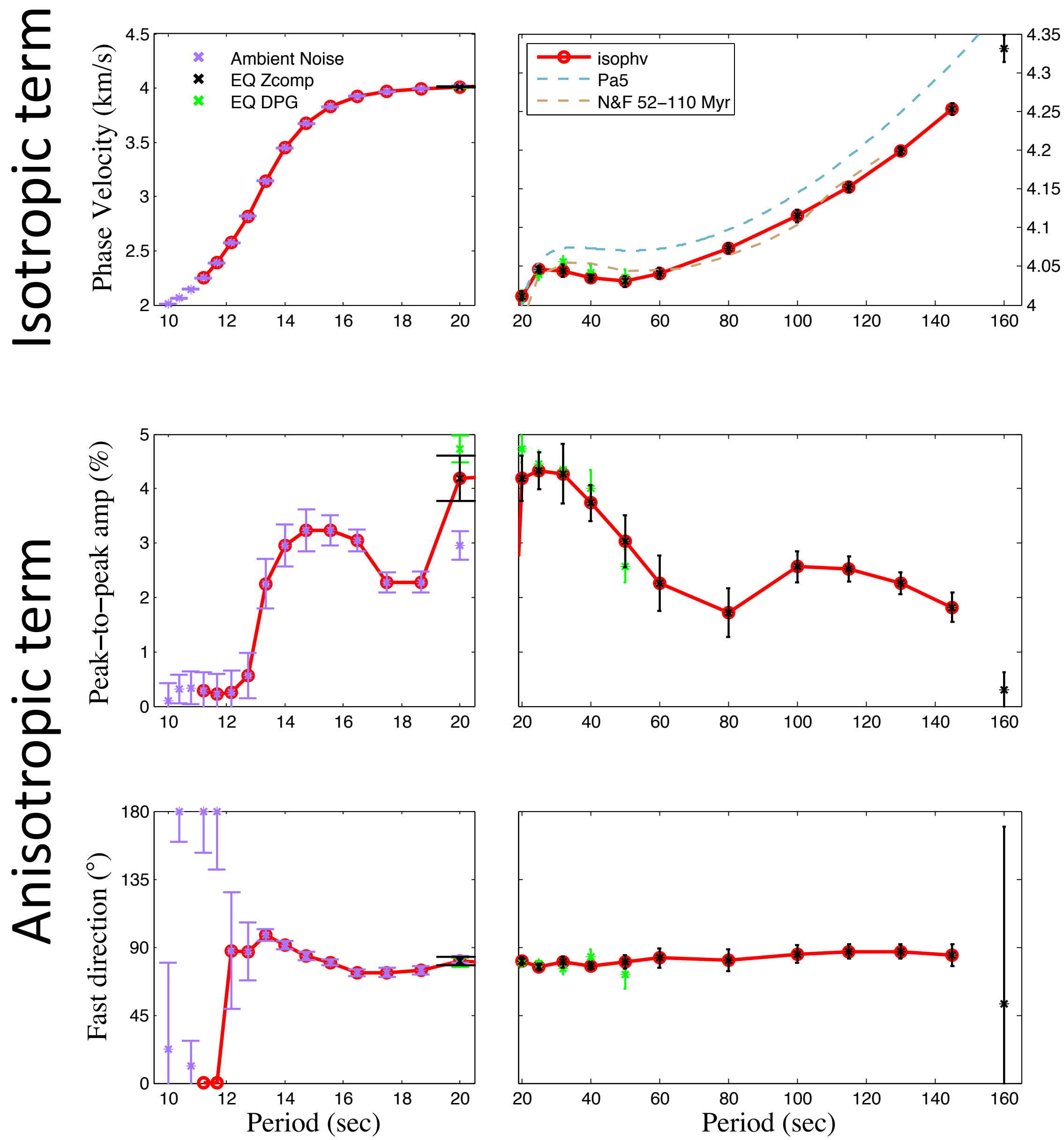
Cross-spectrum Fitting



Variation as function of azimuth



Phase Velocity & Azimuthal Anisotropy



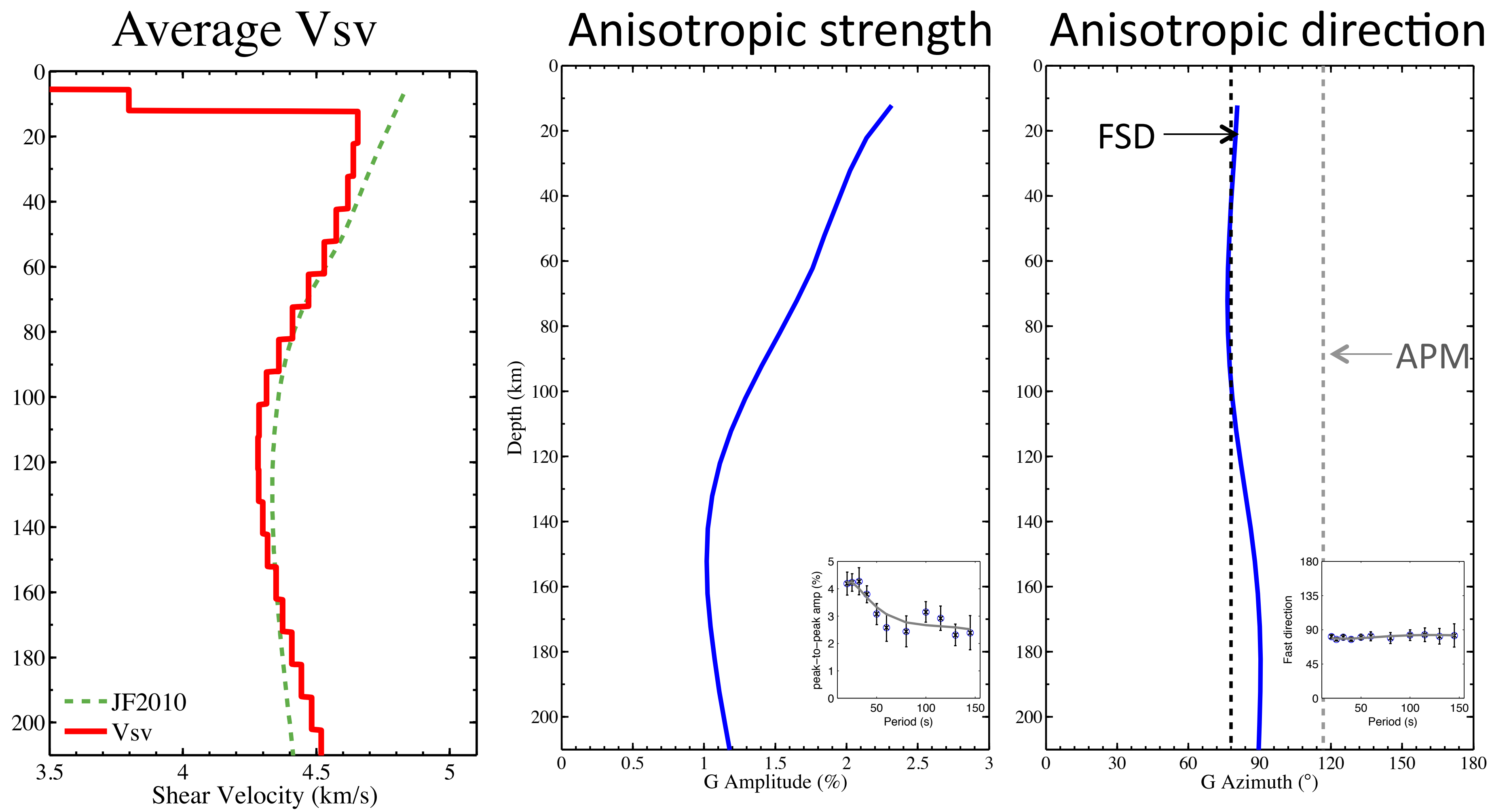
No strong lateral variation

Roll over in velocity

Strong anisotropy

Fast direction ~ 78°

Anisotropic Shear Wavespeed Model

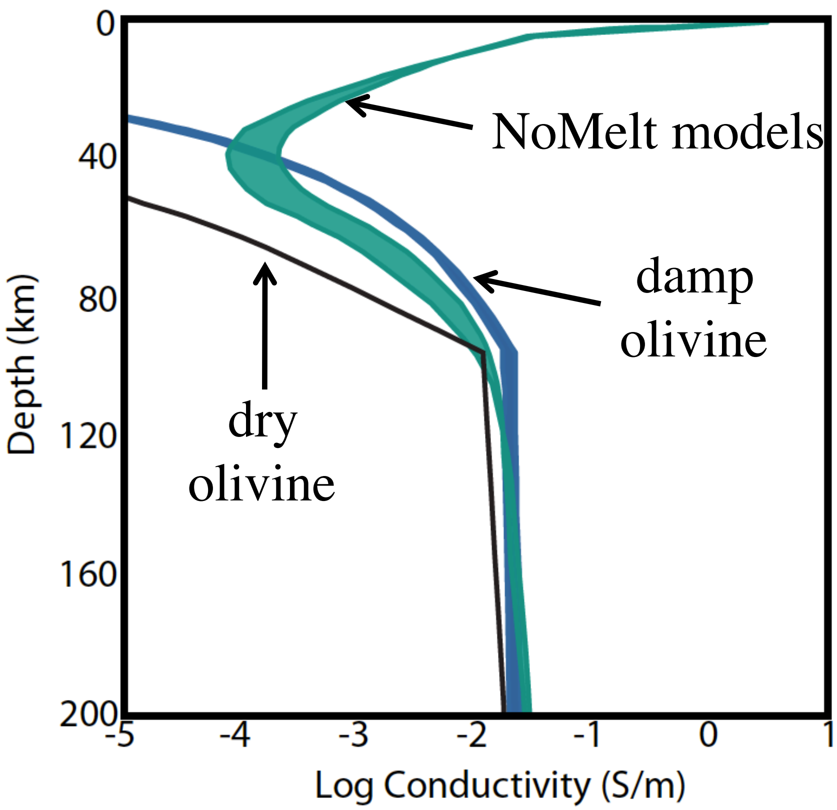


- High Vs lid
- No strong gradient
- No need for melt

- Parallel to fossil spreading direction
- Dominated by lithospheric signal

Lin et al., DI22A-01

Electrical Conductivity



Evans et al., DI24A-02

- Average model from four MT instruments
  - Very conductive shallow layer
  - 70-km-thick dry lithosphere
  - damp asthenosphere (5-800 ppm)
- Melt-rich layer at base of lid allowed but not preferred:
  - <0.5% silicate melt
  - <0.006% carbonitite melt
- Minimal need for anisotropy in the asthenosphere

Take Home Messages

Langseth and OBS are great tools for investigating the mantle

The mantle lithosphere is important!

- extremely strong anisotropy
- anomalous positive velocity gradients are common, with steep positive increase in spreading direction

Anisotropy in asthenosphere is weak in seismic and MT data

Little need for melt in the normal oceanic asthenosphere

Acknowledgements:

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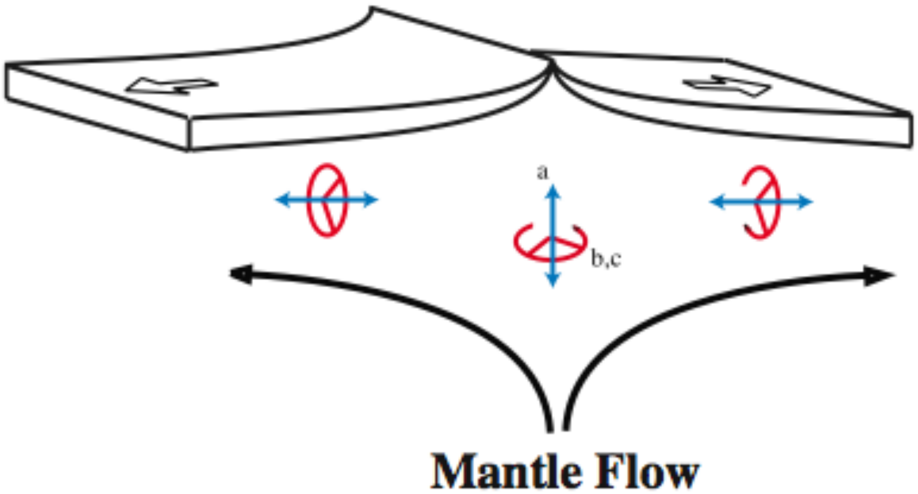
Crews of the *R/V Marcus G. Langseth R/V Roger Revelle*

Seismic Anisotropy in Oceanic Lithosphere



What we know

Scale	Anisotropy	Sample type
Hand	9-10% dV_p	Aggregates (olivine only)
	7-8% dV_p	Aggregates (whole rock)
Outcrop	3-8% dV_p	Ophiolites (olivine only)
	2-7% dV_p	Ophiolites (whole rock)
100 km	3-8% dV_p	*Pn* Velocities
1000 km	4-6% dV_s	Love-Rayl Discrepancy
	2% dR	Rayleigh wave velocities

Implications for MOR mantle flow:

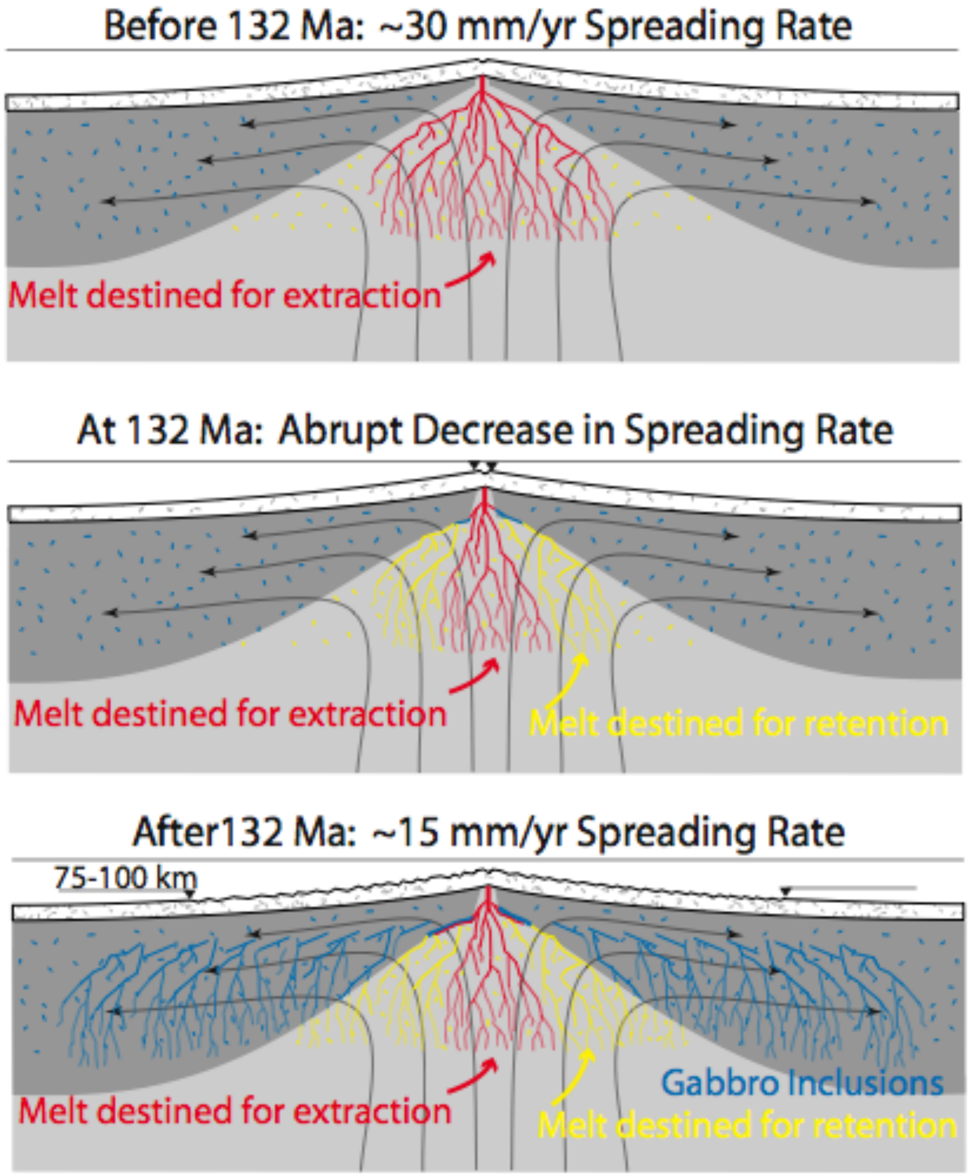
Corner-flow-induced simple shear
Sub-horizontal shear plane
Largely 2D, parallel to spreading
Strain in dislocation regime
Strain of order 1 or greater

But what about:

Spreading-rate dependence?
Three-dimensional flow due to
- along-axis transport
- diapiric upwelling
- plume-ridge interaction
- ridge segmentation

Figure from Hammond and Toomey, 2001.

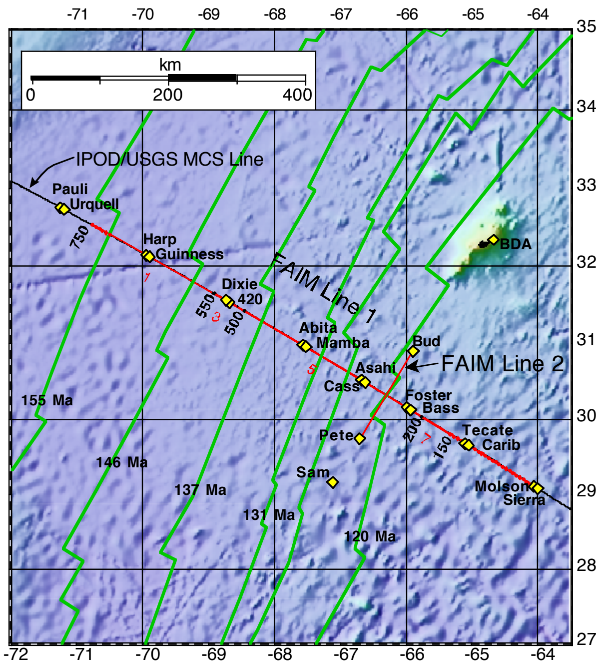
Seismic observations in ocean basins
2) lid gradients too strongly positive

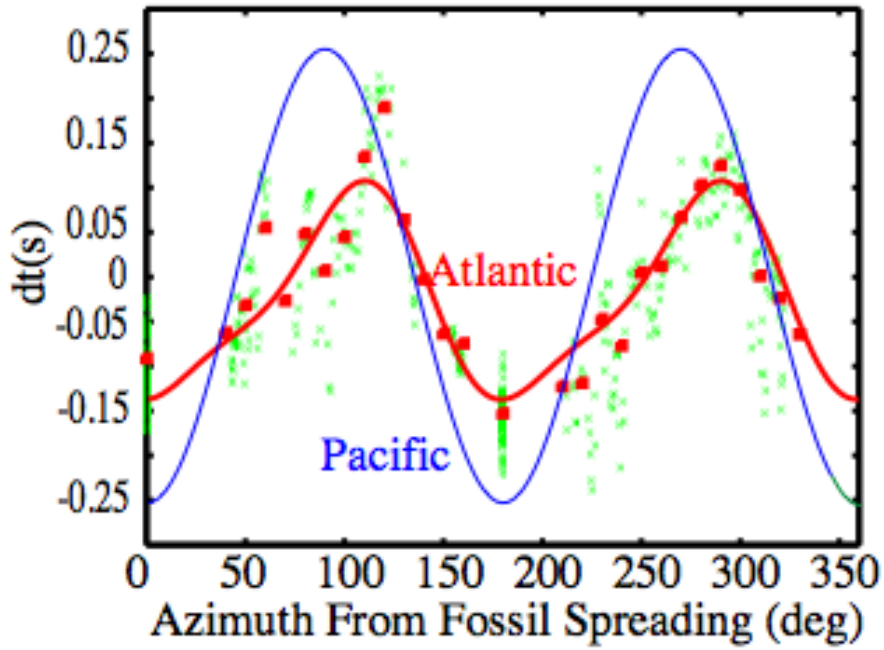


Efficiency of melt **extraction** controls gradient: retained gabbro

- Approximate balance between missing crust and sub-Moho gabbro suggests that production unchanged
- Consistent with geochemistry observed at slow spreading rates
- Consistent with observation of retained gabbros in oceanic peridotites (Cannat, Leg 209, Warren, etc).

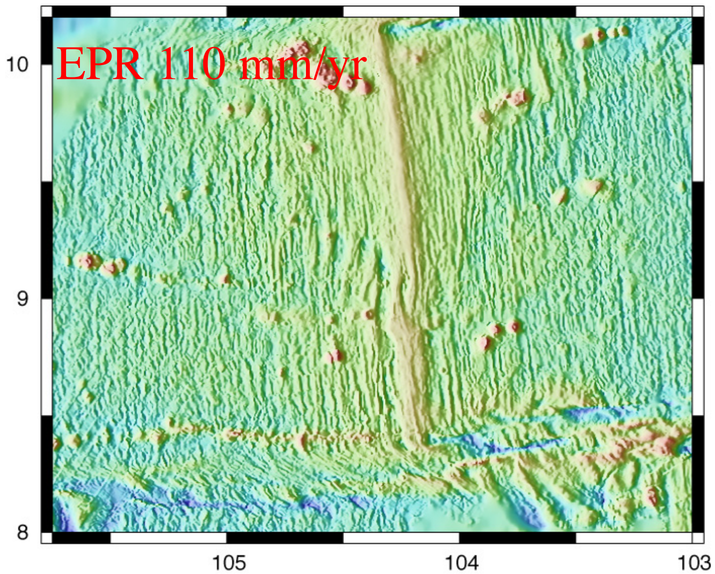
Lizarralde, Gaherty, Collins, Hirth, and Kim, ***Nature***, 2004.

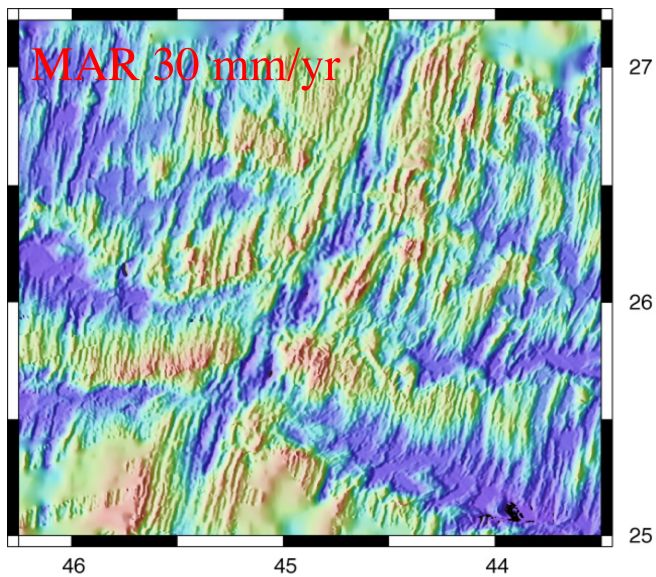


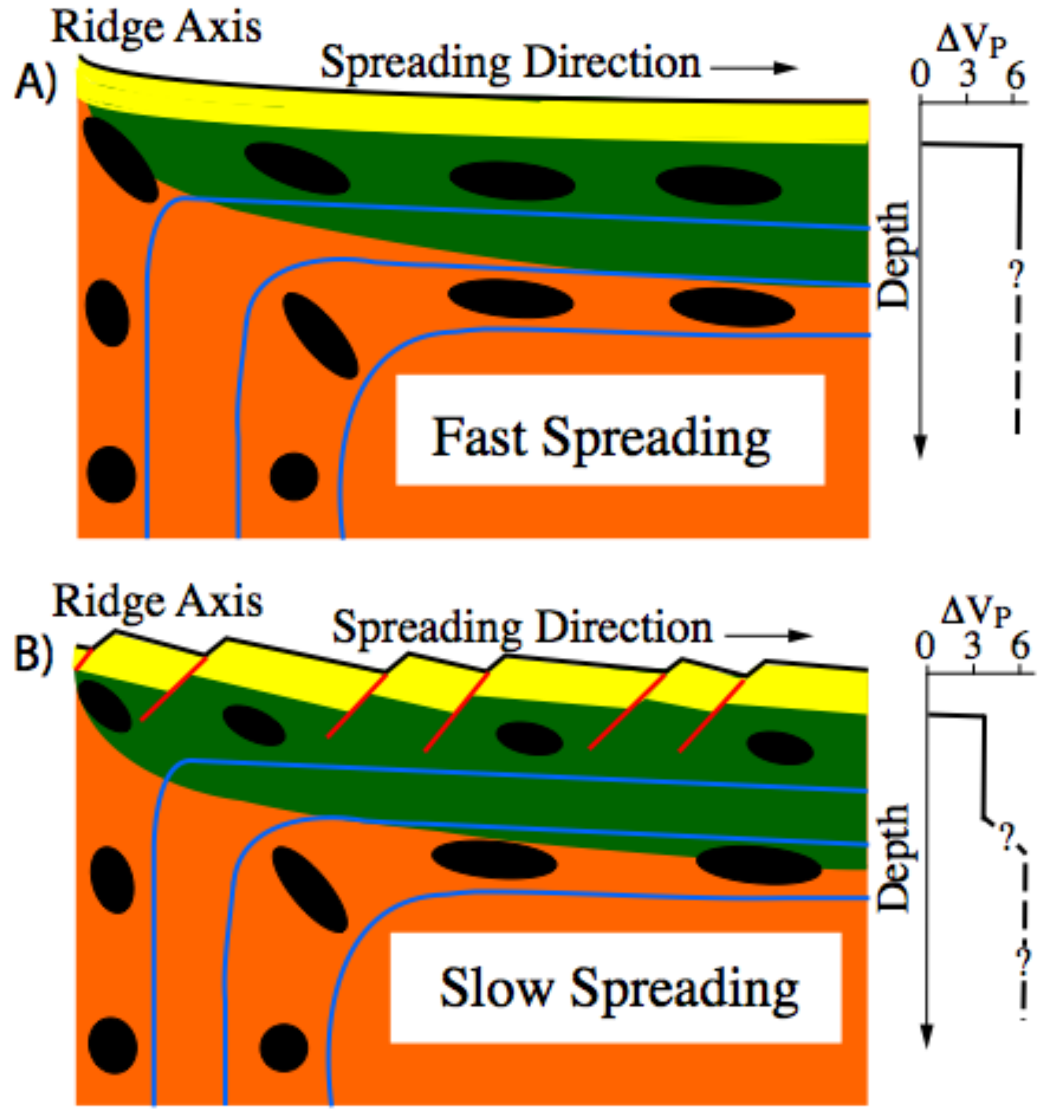


- *P*-wave anisotropy of 3.4±0.5%
- Fast direction ~ parallel to fossil spreading
- Slightly non-orthorhombic structure
- Suggests corner flow deformation in peridotite, but with half the magnitude of that observed at fast spreading
- Consistent with minimal deformation fabric in leg 209 peridotites (Kelemen et al., 2004).

Gaherty, Lizarralde, Collins, Hirth, and Kim, ***EPSL***, 2004.

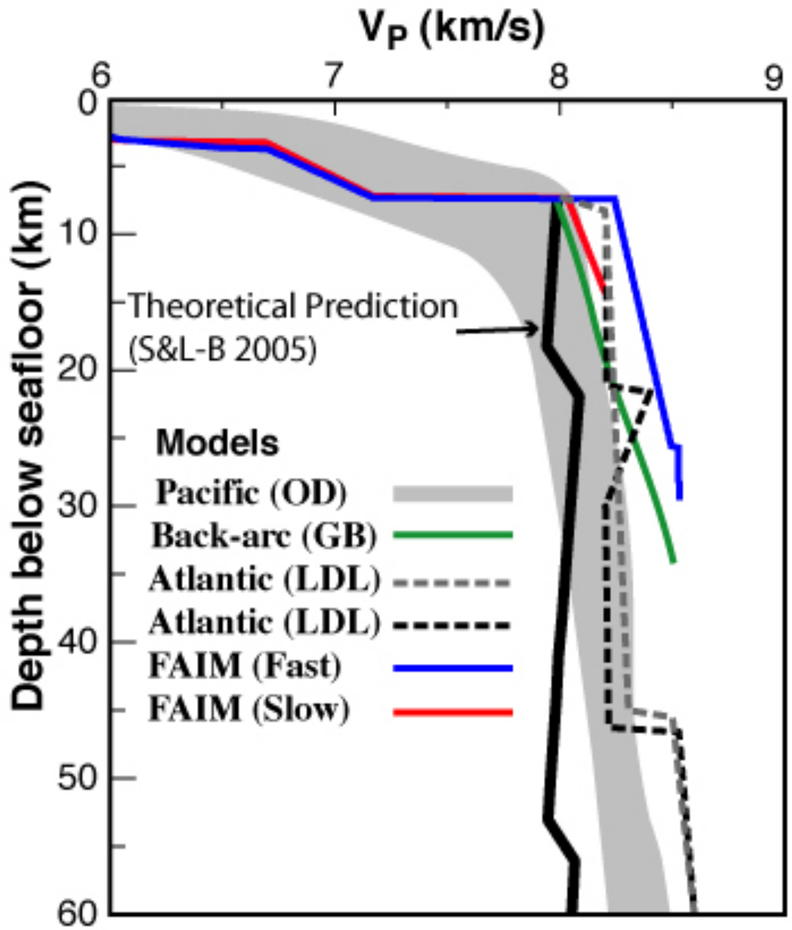


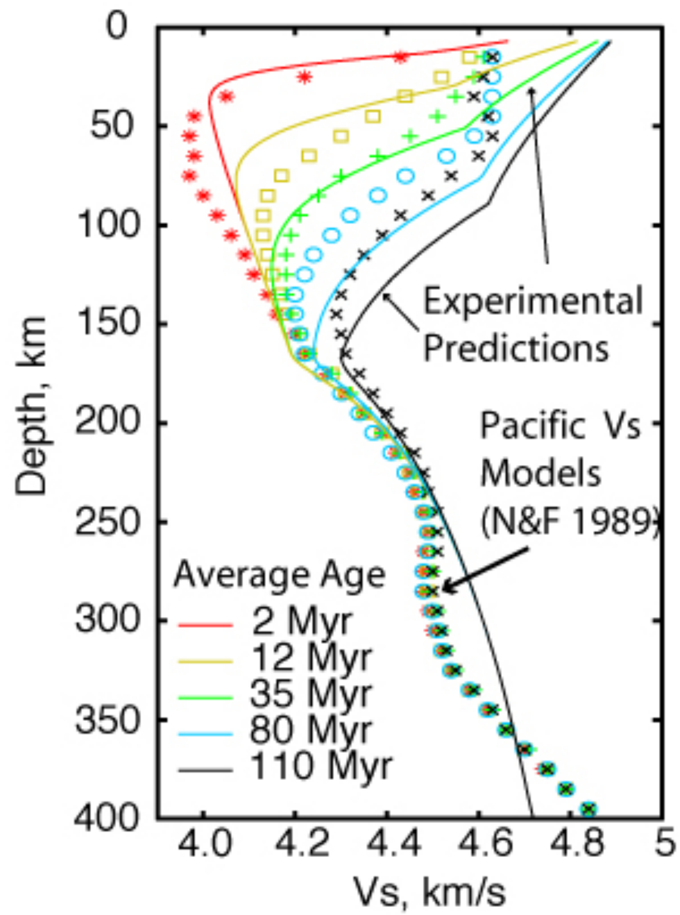




Gaherty, Lizarralde, Collins, Hirth, and Kim, ***EPSL***, 2004.

Seismic observations in ocean basins
2) lid gradients too strongly positive





Faul and Jackson, EPSL, 2005.

Velocity gradient in lid may be critical

•Mineral-physics based models – negative gradient

•Observed velocity models – positive gradient – **what controls this?**