Seismic structure of the lithosphere in the ENAM area from wide-angle OBS data

Brandon Shuck and Harm van Avendonk
Introduction

• Eastern North American Margin (ENAM) contains the geologic record of the rifting event between North America and Africa that initiated approximately 200 Ma

• Sequence from continental rupture to seafloor spreading and formation of a passive margin

• NSF-GeoPRISMS community selected ENAM as a focus site

• Project Goals - understand fundamental rifting processes
  1. What was the state of the asthenospheric mantle during Mesozoic rifting?
  2. How did these mantle dynamics affect the earliest oceanic crust that formed following continental breakup?
Magnetic Anomalies

Legend
- Short-period OBS
- Broadband OBS
- Onshore BB seismometer
- Land seismometer
- Land explosion
- TA station

MCS and OBS

MCS only

Magnetic Anomaly (nT)
Tomography Methods

1. pick arrivals on OBS
2. build velocity model
3. trace rays and compute misfit
4. invert travel-time misfits
5. update velocity model

repeat until data misfit is small (RMS < 150 ms)

From Van Avendonk et al., 2004
Line 2 MCS Data

Modified from Bécel, 2017
Line 2 OBS Data

OBS 218
Line 2 OBS Data
Line 2 Vp model
Line 3 MCS Data

Modified from Bécel, 2017
Line 3 OBS Data

Distance (km)

Travel-time(s)-X/7

OBS 307
Line 3 OBS Data

- Picked travel-time (solid)
- Calculated travel-time (dashed)
- Refraction turning in crust ($P_g$)
- Reflection off top of mantle ($P_{mP}$)
- Refraction turning in upper mantle ($P_n$)

- OBS 307
- Top basement
Line 3 OBS Data

- Picked travel-time (solid)
- Calculated travel-time (dashed)
Line 3 Vp model

Magnetic Anomaly

Distance (km)

Depth (km)

P-wave velocity (km/s)
Line 3 OBS Data (S-wave arrivals)
Line 3 OBS Data (S-wave arrivals)
Line 3 OBS Data (S-wave arrivals)
Line 3 Vs model

Magnetic Anomaly

Distance (km)

Depth (km)

S-wave velocity (km/s)
Key Questions

1. How much mantle melt was generated?
2. What is the composition of the BSMA crust?

MELTS

• Software package to model phase (mineral, rock, and liquid) relations during melting and crystallization

Abers and Hacker (2016)

• MATLAB toolbox to calculate seismic wave speeds
MELTS - melting

From Plank and Langmuir, 1992
MELTS - melting

![Graph showing crustal thickness vs. mantle potential temperature]
1. **Styles of melt accretion**

   - *Gabbro Glacier*
   - *Hybrid*
   - *Sheeted Sills*

   From VanTongeren et al., 2015

2. **Is crystallization controlled by:**
   - Permeability barriers?
   - Temperature gradients?
Case 1: permeability barrier scenario

Melts migrate upwards with no heat loss, until they hit a permeability barrier and rapidly crystallize.

Result: pressure-driven crystallization produces a very weak vertical velocity gradient.
Case 2: temperature gradient scenario

Melts gradually cool as they migrate upwards, causing fractional crystallization to occur, creating layered cumulates.

Result: temperature-controlled crystallization produces a strong vertical compositional and seismic velocity gradient

(but still bad data fit!)
Combination of Case 1 and Case 2?

- **Middle crust formed by temperature-driven crystallization**
- **Lowermost crust formed by pressure-driven crystallization**

Graph showing depth below basement as a function of Vp (km/s).
Shear-wave results for gabbro

- Higher Vp/Vs ratio on south end of line 3
  - More plagioclase?
  - Lower temperature?
  - Less water in melt?
Conclusions

• Mantle was hot during the formation of BSMA crust
• Melts that formed BSMA crust were generated deep in the mantle
• The absence of a significant vertical velocity gradient in the lowermost crust can be explained by pressure-driven crystallization
• The presence of a strong vertical velocity gradient in the middle crust can be explained by temperature-driven fractional crystallization