The role of magmatism in rifting: insight from the lithospheric mantle

James B. Gaherty[1], Donna J. Shillington[1], Daniel Lizarralde[2], Harm Van Avendonk[3]

[1]Lamont-Doherty Earth Observatory of Columbia University, [2]Woods Hole Oceanographic Institution, [3]Institute for Geophysics, University of Texas

Passive margins store the cumulative record of syn- and post-rift deformation, magmatism and sedimentation, and examination of these margins thus provides unique information on several key aspects of the rifting process highlighted in the GeoPRISMS science plan. Mature, evolved margins provide critical constraints on the distribution of deformation and magmatism throughout the lithosphere and the emergence during rifting of primary characteristics of mid-ocean ridges – for example, segment-centered magmatism focused at the ridge axis and the formation of tectonic segmentation. The locus of melting and associated deformation during rifting is located within the mantle, and the lithospheric mantle preserves structure inherited from and diagnostic of these processes, such as the patterns of melt depletion and shear deformation. The east-coast margin of the North American continent displays a remarkable diversity of syn- and post-rift structures, including failed rift basins, strong variations in apparent magmatic production, and correlation between margin structures and present-day mid-Atlantic ridge segmentation. Seismic imaging of the lithospheric mantle across and along the margin of east coast North America can thus provide us with knowledge of the basic magmatic and deformation processes that control rifting and its subsequent evolution.

The majority of the constraints on the volume and bulk composition of magmatism during rifting are derived from seismic studies of the crust, and therefore omit the magmatic processes that occur in the mantle. The generation of melts during rifting leaves behind a depleted mantle that is stronger and more buoyant, influencing development of the rift and the stability of continental lithosphere long after rifting. The mantle lithosphere also provides unique information on magma generated during rifting. Studies of mid-ocean ridges suggest that the extraction of melts to form new crust can be incomplete in very slow-spreading systems (which have a thicker, colder lithosphere), and at very magmatic ridges, where the volume of magmas can overwhelm the melt extraction system. Detailed estimates of shear and compressional velocities in the lithospheric mantle across regions of magmatic production provide a means to constrain the balance of melt production and extraction. Furthermore, anisotropy of the mantle lithosphere holds the record of pre-existing fabrics imparted prior to rifting, mantle deformation during rifting, and relationship of the deformation to magmatism. Traditional marine refraction experiments provide important but limited constraints on shallow mantle structure; expanding these constraints using far-offset mantle refraction and passive-source imaging are critical for extending these constraints to greater depths and more broadly across the margin system.

The east-coast margin of North America provides an excellent opportunity to investigate these processes. The breakup of Pangea to form the Atlantic margins was associated with one of the largest magmatic events in Earth's history: the Central Atlantic Magmatic Province, and the along-strike variation in magmatism associated with this event are clear from potential field data and crustal-scale imaging, with length-scales of segmentation ranging from 100-300 km. Three dimensional imaging experiments that span the crust and upper mantle will constrain the balance of melt production and extraction and its impact on extensional deformation under different magmatic conditions. Coupled with onshore instrumentation, these data will provide new contraints on the underlying differences between the extensive network of failed rift basins (e.g., Newark Basin, South Georgia basin) and the adjacent successful rift. Extending far offshore, this imaging will illuminate the magmatic and deformation processes across the transition from rifting to seafloor spreading, and will allow us to probe whether segmentation during the rift stage seeds to the dominant segmentation structure of mid-ocean ridges.

Imaging mantle structure across the margin requires far-offset active source work coupled with passive-source arrays. It is clear that a full program to understanding magmatism and deformation during rifting requires embedded higher-resolution surveys to characterize the crustal structure that is complementary to the underlying mantle.