3. Rift Initiation and Evolution (RIE) Initiative

3.1 Original Goals

Continental rifts and passive margins define the majority of the Earth's coastlines, encompass much of the world's population and hydrocarbon resources, and are vulnerable to irreversible changes induced by long-term climate change and sea-level rise. The overarching objective of the Rift Initiation and Evolution (RIE) initiative is to identify the key processes that drive continental rifting and margin evolution and to determine the parameters and physical properties that control these processes. Rifts are locations where the continental lithosphere is modified by tectonic, magmatic and sedimentary processes; where magmas and fluids are generated and transferred; where climatic and surface processes govern mass transfer and tectonic activity; and where volcanic activity and alteration of mantle rocks result in poorly understood volatile exchange. Continental margins reflect an active interplay of mantle, crustal, and surface processes requiring the system-level, amphibious research approach of the GeoPRISMS program.

The RIE initiative seeks to develop predictive models for the spatial and temporal evolution of rifts and rifted continental margins with a focus on four key questions identified by the GeoPRISMS Science and Implementation Plan:

- Where and why do continental rifts initiate?
- How do fundamental rifting processes, and the feedbacks between them, evolve in time and space?
- What controls the architecture of rifted continental margins during and after breakup?
- What are the mechanisms and consequences of fluid and volatile exchange between the Earth, oceans, and atmosphere at rifted continental margins?

Several of these questions can only be addressed in areas of active rifting, where rift initiation and the early and intermediate stages of rift evolution can be directly observed and measured. Such investigations are complemented by studies of passive margins, where rifting has gone to completion, and the cumulative history of tectonic, magmatic, isostatic, and surficial processes is preserved. RIE studies emphasize problems that span the temporal and spatial range of rifted margin evolution, including the influence of magmatism and volatile flux on rift evolution, documenting the feedback between surface processes, tectonics, and lithospheric and asthenospheric processes, predicting passive margin evolution from initial rifting processes and conditions, and understanding active processes and associated hazards throughout the entire evolution of rifts.

The community selected two primary sites that represent complementary end-member stages of the rifting process: the active East African Rift System (EARS) and the fully developed Eastern North American Margin (ENAM). The EARS exhibits the entire history of continental rupture, from the initiation of border faulting in the south to seafloor spreading in the Afar, whereas the ENAM captures an extensive post-rift evolution of the passive margin sedimentary prism, as well as the cooling and further evolution of the mantle lithosphere below. Both EARS and ENAM capture a diversity of magmatic and mantle influences on the rifting process. The ENAM system in particular encompasses archetypes of fully magmatic rifting adjacent to the southeastern US, as well as magma-limited continental break-up offshore Nova Scotia and Newfoundland. Both systems also span a north-south climatic gradient with resulting diversity in sediment flux and potential tectonic-climate interactions. There are further compelling logistical benefits to each site: ENAM leverages considerable US infrastructure, including EarthScope and the USGS Law of the Sea survey activities, while the intermingling of on-land and lacustrine rift settings in the EARS presents exciting opportunities to intimately connect across the onshore-offshore divide that motivates the scope of GeoPRISMS science.

Several thematic studies are also defined to enable studies of the full temporal evolution of continental rifts, as well as a wider range of rifting parameters. RIE thematic studies are intended to be subsidiary to research that can be carried out at the selected primary sites, but should also complement and complete such investigations. The five themes identified to guide such investigations include:

- Theme 1: Rift obliquity
- Theme 2: Rift processes as functions of strain rate
- Theme 3: Volatiles in rift zone processes
- Theme 4: Sediment production, routing and transport during and after rifting
- Theme 5: Discrete events at rifted margins

3.2 Major Accomplishments

3.2.1 The Eastern North American Margin (ENAM) Primary Site

As a mature passive continental margin, the east coast of North America represents a prime site to investigate rifting processes that have gone to completion, as well as post-rifting evolution. From a logistical point of view, GeoPRISMS-supported activities in ENAM have been enhanced by leveraging other data collection efforts, particularly through the USArray components of EarthScope providing extensive seismic and magnetotelluric data sets. The joint GeoPRISMS-EarthScope implementation workshop held at Lehigh University in October 2011 identified three major geographical focus areas within ENAM as priorities for focused research efforts in the northern, central, and southern portions of the margin. To date, there have been three GeoPRISMS-funded projects that have focused on the central and southern portion of the margin: a major community-led effort to collect a suite of onshore & offshore geophysical data within ENAM; a multidisciplinary project to study mantle dynamics, lithospheric structure, and topographic evolution of the southeastern US continental margin; and a geochemical and petrological investigation of Eocene basalts in Virginia and West Virginia. In addition to these GeoPRISMS-funded efforts, there have been a number of projects funded via other NSF programs and, in many cases, enabled by the collection of EarthScope data, that have yielded insights into the science questions posed in the GeoPRISMS science and implementation plans.

The ENAM Community Seismic Experiment (ENAM CSE; see nugget by van Avendonk et al.) is an ambitious effort to collect a suite of seismic data, designed for imaging structures over a range of spatial scales, with completely open data access that can be used by the community to address a wide spectrum of GeoPRISMS (and EarthScope) science questions. The ENAM CSE was executed by a diverse team of twelve PIs at eight different institutions, acting on behalf of the community. Plans for data collection were shaped by community input beginning at the 2011 ENAM implementation workshop and continuing through a series of straw polls, AGU workshops, and other opportunities for community feedback. It is important to note that funding for the ENAM CSE included support for data collection, but not for scientific investigations using the data; the intention is that individual PIs will write follow-up proposals to use the CSE data for GeoPRISMS-related investigations. An important aspect of the CSE is the effort to involve young scientists (students, postdocs, and early-career investigators) in the acquisition of a diverse onshore/offshore, active/passive dataset and to provide training in data collection, analysis, and interpretation through a series of workshops (see nugget by Shillington et al.). This project already has had significant impact on student and postdoc training (as will be discussed in Chapter 5).

The ENAM CSE data collection effort (Figure 3.1) included a number of components, designed to allow for multiscale imaging of crustal and lithospheric structure and stacked geomorphological features over a shoreline-crossing footprint. The passive source data acquisition included the deployment of 30 broadband ocean bottom seismometers (OBS) in spring 2014 and their recovery in 2015 aboard the R/V Endeavor (Figure 3.2), along with the deployment of three onshore broadband seismometers

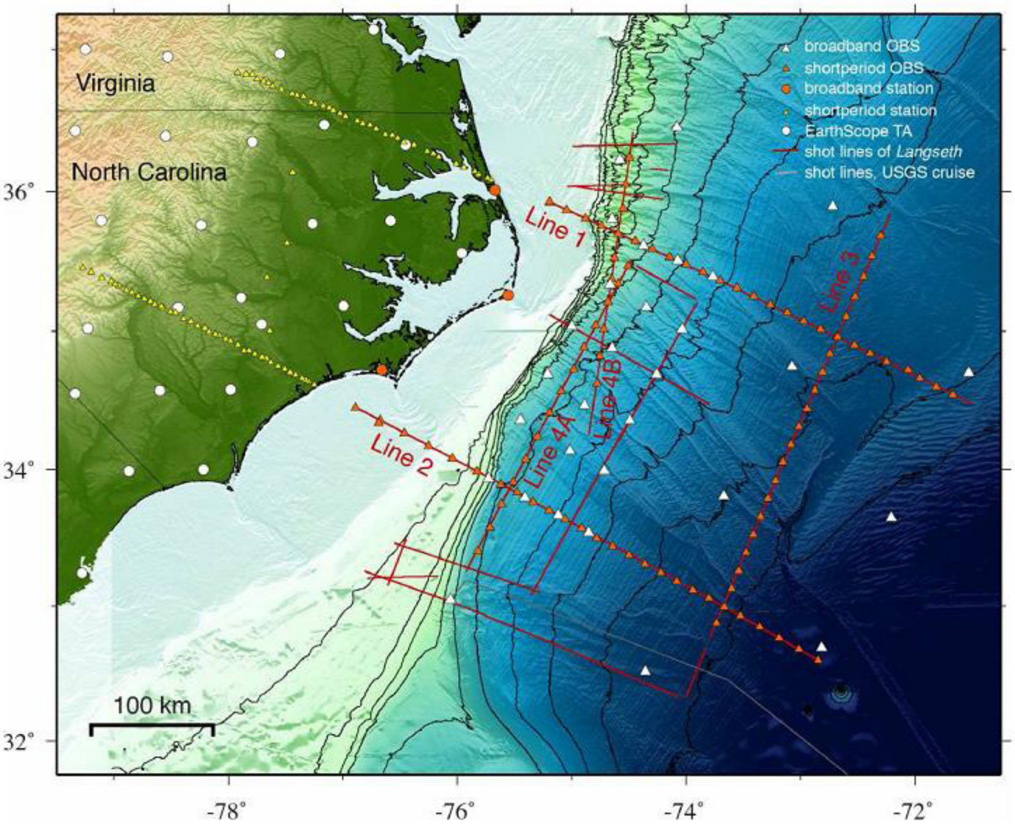


Figure 3.1. Map of ENAM CSE deployment. Broadband OBS instruments (white triangles) were deployed in April 2014 and recovered in April 2015 aboard the R/V Endeavor. Broadband onshore stations on the Outer Banks (orange circles) operated between May 2014 and May 2015. Orange triangles indicate short-period OBS stations deployed and recovered during September-October aboard the R/V Endeavor. Red lines indicate shot lines for the active source seismic program on the R/V Langseth in September-October 2014; those shots were also recorded on land (short period stations shown with yellow triangles). Active source refraction lines were shot on land during summer 2015.

Figure 3.2. OBS deployment by ENAM CSE crew working on the R/V Endeavor. Photo by Gary Linkevitch.

on the Outer Banks of North Carolina. Offshore active source data were collected in September-October 2014 with the R/V Langseth, which shot refraction profiles that were recorded on short-period OBS instruments deployed by the R/V Endeavor. The Langseth also acquired multi-channel seismic (MCS) data along both the primary transects and shorter ancillary lines, allowing for the detailed imaging of shallow (up to ~1 km) structure. The Fall 2014 offshore shots were also recorded with short-period instruments deployed onshore. Finally, an active source experiment was carried out on land in June 2015, with a series of 11 on-land shots recorded on ~1400 Texans. All data from the experiment have been (or soon will be) made publicly available via data portals such as the IRIS Data Management Center (DMC).

The Mid-Atlantic Geophysical Integrative Collaboration (MAGIC; see nugget by Long et al.) is a multidisciplinary project funded jointly by GeoPRISMS, EarthScope, and the Geomorphology and Land Use Dynamics programs of NSF. It is focused on understanding the structure and dynamics of the mid-Atlantic Appalachians and involves a collaboration among seismologists, geodynamicists, and geomorphologists. The scientific goals of MAGIC focus on the evolution of the margin through multiple episodes of orogenesis and rifting. Although ENAM has been a passive continental margin for nearly 200 Ma, the eruption of basalts during the Eocene (Mazza et al., 2014) and the likely rejuvenation of topography during the Neogene (Miller et al., 2013) provide evidence for its relatively recent modification, perhaps connected to processes in the deep mantle. MAGIC involves the deployment of 28 broadband seismometers in a dense linear transect from Charles City, VA to Paulding, OH, with data collection beginning in late 2013 and continuing until late 2016 (Figure 3.2). The geodynamical modeling effort focuses on quantitatively testing hypotheses for the pattern of mantle flow beneath eastern North America (e.g., Long et al., 2010) using 3-D, time-dependent, numerical models. Predictions from these models of seismic anisotropy and dynamic topography will be tested against observations from the seismology and geomorphology components of the project. The geomorphology component uses quantitative stream profile data and cosmogenic isotopes to understand past and present erosion rates, and to identify regional patterns in transient topographic change whose association with crustal and/or mantle features might illuminate the causes of topographic rejuvenation. The seismic deployment involves a substantial education and outreach component to primarily undergraduate colleges and universities in the MAGIC field area (see nugget by Long and Benoit).

A third GeoPRISMS-funded project in the central corridor of ENAM is a geochemical and petrological study of Eocene magmatic rocks in the Valley and Ridge province of Virginia and West Virginia, near the city of Harrisonburg (Figure 3.3, Mazza et al., Geology 2014; see nugget by Gazel et al.). The Eocene magmatic event provides a direct window into the composition and structure of ENAM upper mantle and furnishes a complementary view to that of geophysical data. To date this project has yielded ^{40}Ar/^{39}Ar ages, geochemical data, and radiogenic isotope measurements that constrain the likely processes that produced a pulse of magmatism ~150 Myr after rifting. Application of a geothermobarometer to the measured chemical composition of basalt samples yielded temperature and pressure estimates of ~1410°C and ~2.3 GPa, respectively, which are conditions close to the dry peridotite solidus (Mazza et al., 2014). The inferred temperatures are slightly higher than would be expected for ambient mantle melting at a ridge, but not as high as would be expected for a mantle plume. Isotopically, Eocene ENAM samples resemble the signatures of Atlantic hotspots, suggesting that the Atlantic upper mantle may have been homogenized via large-scale dissemination of mantle material following the opening of the Atlantic. Mazza et al. (2014) suggest that a lithospheric delamination event may have triggered asthenospheric upwelling and melting to form the ENAM Eocene magmas; ongoing analyses of geophysical data from USArray (including the MAGIC experiment, which includes 5 stations deployed within ~25 km of the Eocene magmatic rocks) will provide additional observations to constrain this hypothesis.

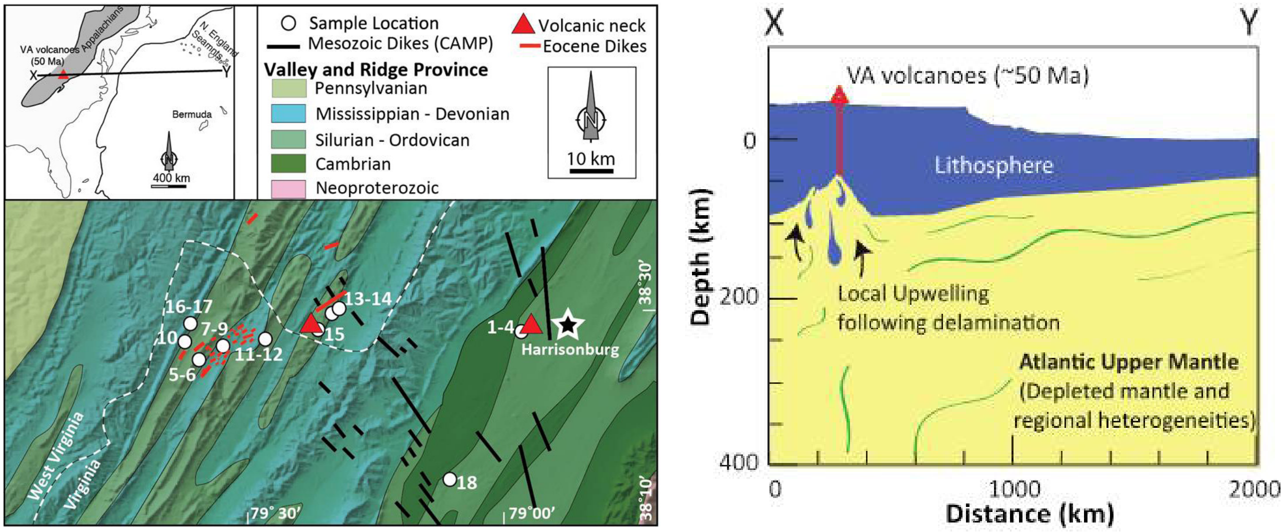


Figure 3.3. From Mazza et al. (2014). Left: Simplified geologic map showing sample locations of Eocene magmas, along with the (contrasting) orientations of Mesozoic Central Atlantic Magmatic Province (CAMP) dikes and Eocene dikes. Right: Schematic model of melting mechanism by lithospheric delamination and possible mantle sources of Virginia volcanoes. Line of cross-section X-Y is shown in map at left.

In addition to these three GeoPRISMS-funded projects, a number of ongoing research initiatives in the ENAM region are synergistic with GeoPRISMS projects. For example, tomographic models that include data from Transportable Array stations on the East Coast are revealing intriguing features in the upper mantle, including a pronounced low-velocity zone beneath the Eocene volcanics (Figure 3.4; Schmandt and Lin, 2014). A number of PI-driven Flexible Array deployments funded by the EarthScope program are exploring science questions encompassed by the ENAM science and implementation plans. This includes i) SESAME (PIs Fischer, Hawman, Wagner and Forsyth); ii) SUGAR (PI Shillington), which crosses the Suwanee Suture and the South Georgia Rift Basin; iii) the Quebec-Maine Transect (PIs Menke, Levin, Darbyshire, Forte and Hynes) in the northern ENAM corridor identified in the GeoPRISMS implementation plan, and iv) the planned collection of magnetotelluric data along the MAGIC line.

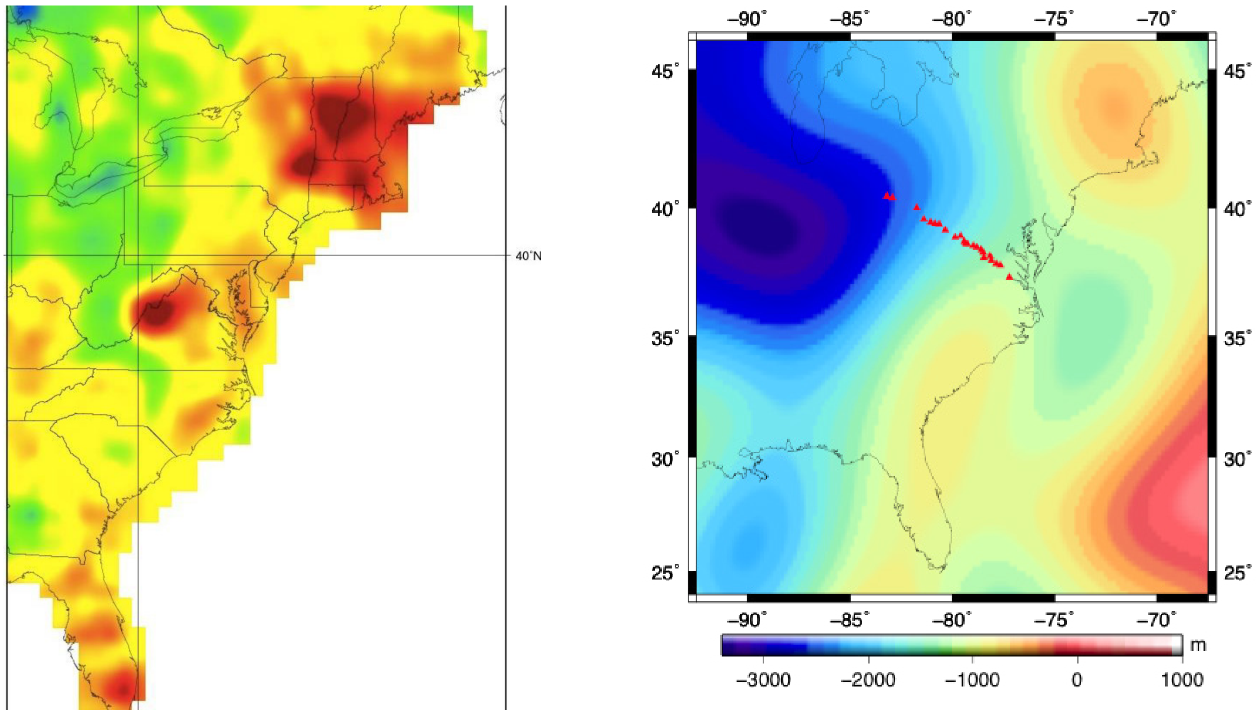


Figure 3.4. Left: Tomographic image of S wave velocities in the upper mantle at a depth of 125 km, from the model of Schmandt & Lin (GRL, 2014). Pronounced low velocity anomalies are visible beneath the Eocene volcanics in Virginia (Mazza et al., 2014) and beneath New England. Figure generated using the IRIS DMC Earth Model Collaboration viewer. Right: Predicted dynamic topography obtained by converting S40RTS velocities (Ritsema et al., 2011) to density and predicting resulting mantle flow. The red triangles indicate the stations in the MAGIC deployment (from nugget by King et al.).

3.2.2 The East Africa Rift System (EARS) Primary Site

GeoPRISMS research at the East African Rift System (EARS) Primary Site launched after the EARS Implementation Planning Workshop in October 2012. The phased funding model allowed for funding opportunities for large field projects only for FY14 and FY15. To date only a few projects have been funded, although related projects have built upon ongoing efforts supported through NSF and NASA (discussed in 3.2.2.1).

EARS exhibits a wide variety of rift processes and characteristics, making it an ideal target for GeoPRISMS goals. Aspects of all of the four key rift initiation and evolution (RIE) questions defined in the GeoPRISMS draft science plan can be addressed in part or entirely in this primary site, given the great variety of rift processes and characteristics expressed in this setting. Proposed GeoPRISMS research at this primary site is organized around the primary focus area of the Eastern Rift, which encompasses the rift from the Tanzanian divergence in the south to Lake Turkana and southern Ethiopia to the north. It also has several secondary focus areas in the Afar and Main Ethiopian Rift, and the Western Rift and SW branch, in which collaborative and international efforts could be leveraged (Figure 3.5). Synoptic investigations across the entire rift are also deemed important and will help to constrain and characterize the consequences of rift-wide variations in the origin, composition, and timing of volcanism, the rate and distribution of strain along and across the rift systems and large scale pre-rift structure and dynamics underpinning the rift system. Components of EARS science thus could include broad and open data assimilation efforts, strategic infilling of climatic, geochemical, and geophysical observations, and modeling and experimental work, which would provide a framework for the focused investigations along the rift.

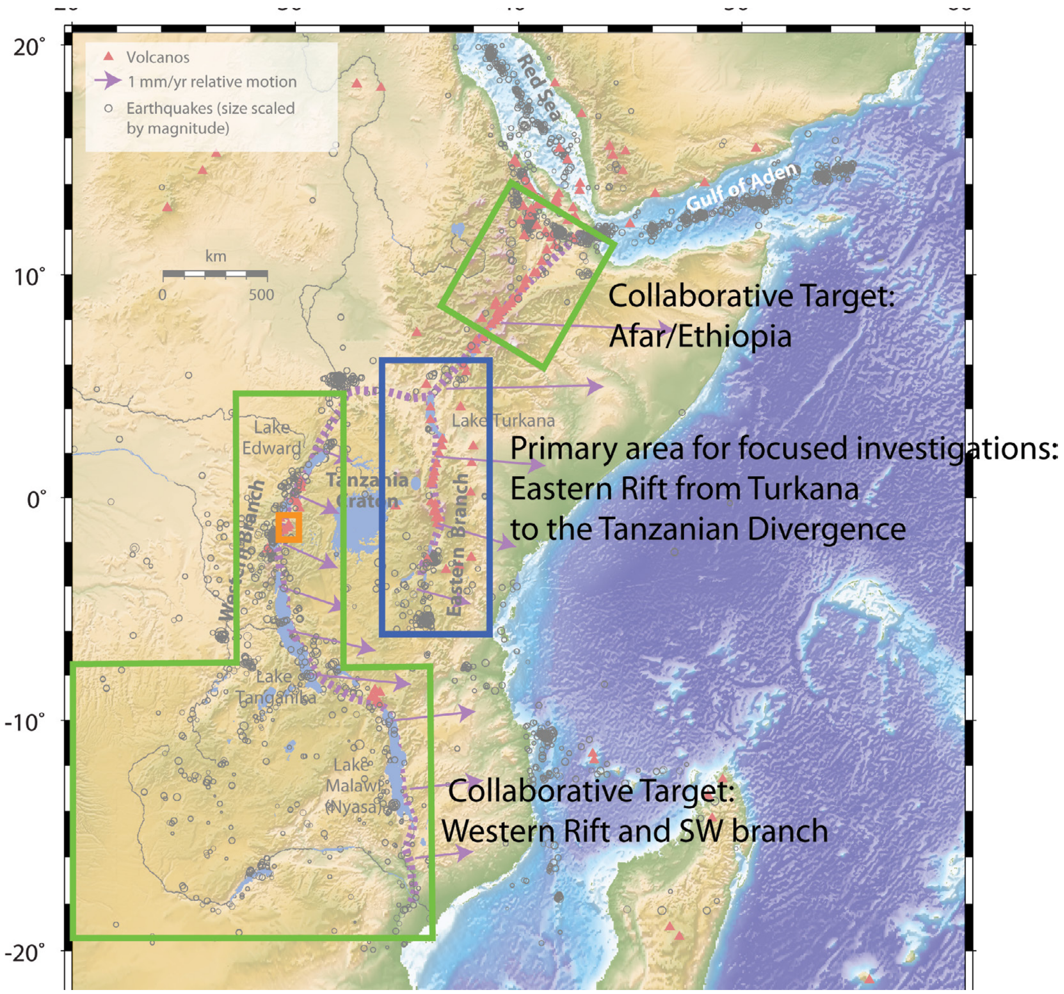


Figure 3.5. A map of the East African Rift System (EARS) highlighting the primary focus area and the collaborative targets of opportunity (from GeoPRISMS Implementation Plan).

The earliest project funded for the EARS Primary Site was to PIs Gaherty, Shillington, Pritchard, and Nooner. In this project a rare 2009 sequence of earthquakes in the northern Malawi rift valley and the associated geodetic response was analyzed (Figure 3.6; see nugget by Gaherty et al.). The Karonga events are far removed from the border fault and instead appear to have taken place on one or several previously unknown shallow hanging wall faults. There is no evidence for magmatic control on earthquake occurrence. The conclusions of this study have significant implications for earthquake hazards in this setting. The project engaged the Malawi Geological Survey Department in both data collection and research. It also led to Malawi government funding of the country's first national seismic network.

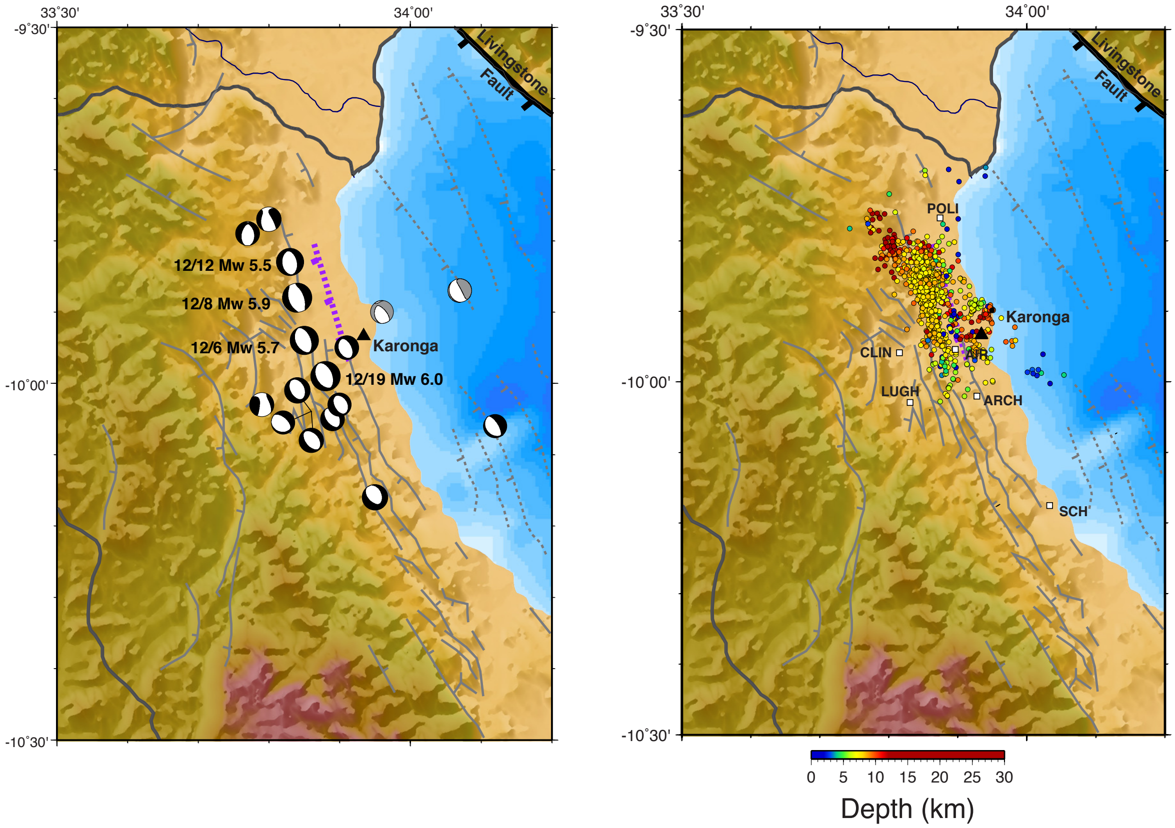


Figure 3.6. Left: Focal mechanisms of the largest 17 events of the 2009-2010 Karonga sequence. Surface projection of the buried St. Mary's fault, inferred from InSAR, is shown with purple line. Fault locations from PROBE and geologic data shown in grey lines. Right: Epicenters of ~1000 aftershocks relocated using HypoDD, with depth shown by color. The earthquake distribution north of Karaonga is consistent with events on the west-dipping St. Mary's fault. The earthquakes beneath and south of Karonga earthquake clusters suggest multiple west-dipping faults.

A one-year project begun in 2014 (see nugget by Bendick and King), encompasses two activities: deployment of new GPS stations across the presumed actively spreading region of the Turkana Depression and compilation and analysis of existing geodetic data over all of East Africa to develop a community velocity model. This latter effort will facilitate systematic comparisons of different structural rift segments, providing a synoptic framework for other active tectonics research in the area. This effort is still underway and results are not yet available.

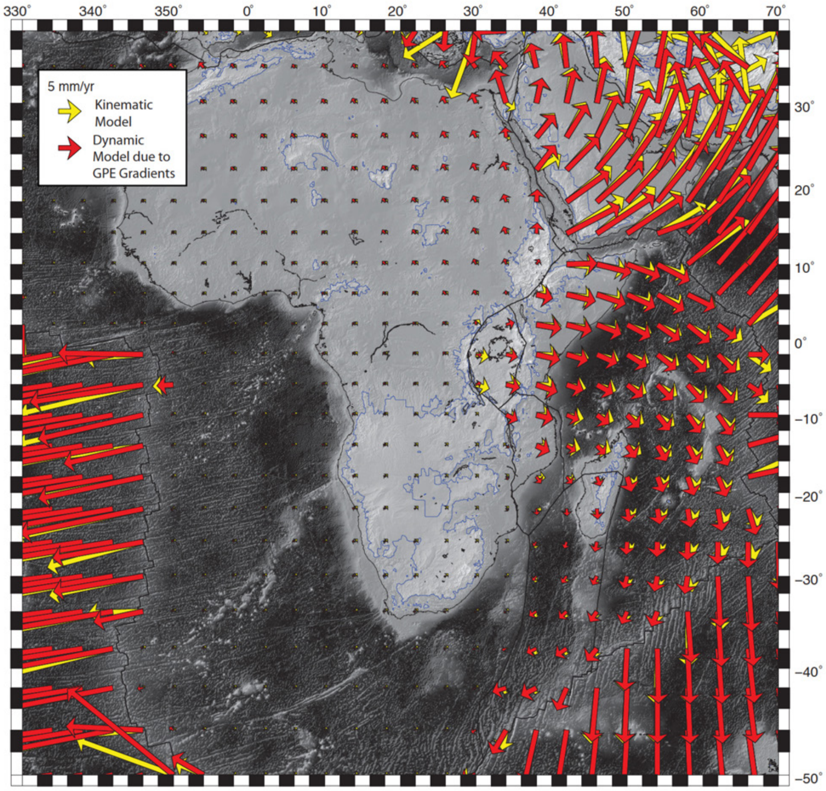
A new project for FY15 to PI Mittelstaedt supporting postdoc Sybrandt (see nugget by Mittelstaedt) will use coupled laboratory and numerical experiments to quantitatively assess the contribution of both melt production and melt extraction processes on the distribution of volcanic activity along the three main branches of the actively spreading East African Rift System. Initial work has been focused on determining appropriate modeling fluids and laboratory set-ups; modeling work will start this fall.

3.2.2.1 Related work at the East African Rift System

Recent advances in our understanding of the RIE East Africa primary site have also come from projects funded through NSF (including EAR Core and the Continental Dynamics program) and NASA. This work features many of the PIs who have been active in the RIE community and lays the groundwork for upcoming field deployments in the EARS.

Plate motions across East Africa derived from permanent GPS stations within the Africa Array and temporary GPS stations deployed over several decades have now been modeled as part of an EAR postdoctoral fellowship to PI Stamps to constrain the driving forces responsible for present-day rifting. The models show that density variations within the lithosphere are enough to explain current rifting velocities, but rift initiation would have required an additional source of forcing or lithospheric weakening (Stamps et al., 2014).

Figure 3.8. Measured vs. modeled GPS velocities across Africa, showing that velocities can be largely explained by gravitational potential energy (Stamps et al., 2014).



From a grant funded by the NASA Planetary Geology and Geophysics program in 2011, PI Rooney and others have studied the distribution of volcanism in the Central Main Ethiopian Rift and its relationship with lithospheric structures (Figure 3.9). Results from this project show that the transition from mechanical thinning towards magmatic intrusion may be more protracted than originally predicted and that pre-existing lithospheric structures may control the intrusion of magma into the lithosphere (Rooney et al., 2014).

From a collaborative award made through the NSF Tectonics program in 2011, PIs Ebinger, Kattenhorn, Roecker and Fischer examined the role of magma and

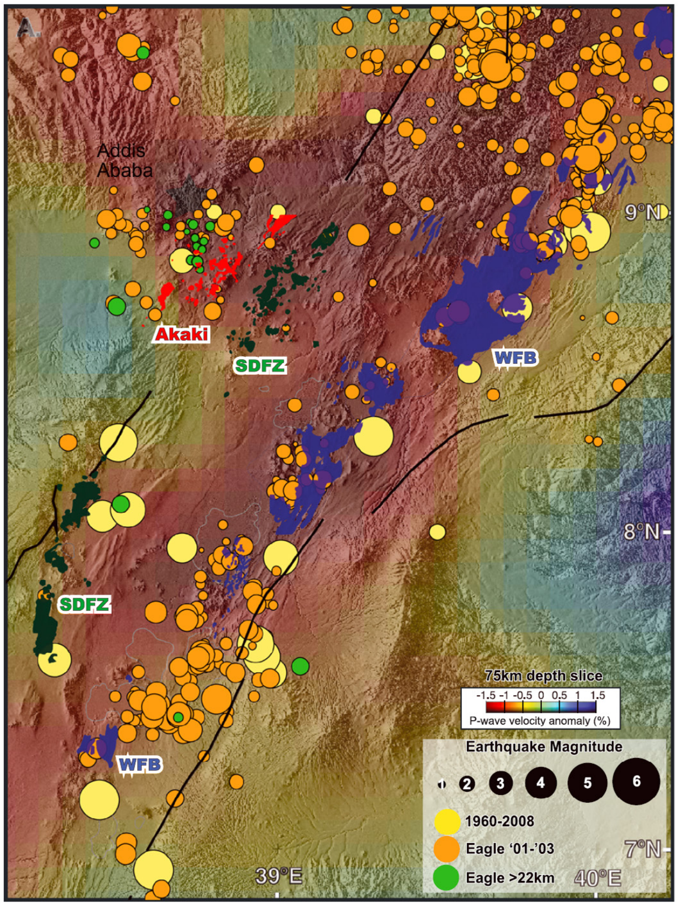


Figure 3.9. Region of the Central Main Ethiopian Rift (border faults shown as black lines) showing the distribution of Pliocene-Quaternary volcanism of the Akaki Magmatic Zone, Silti Debre Zeyit Fault Zone (SDFZ), and Wonji Fault Belt (WFB) overlain on topography. Also shown are earthquakes and their magnitudes recorded in the region. Color background represents P wave velocity anomalies at 75 km in the region of study. The Akaki Magmatic Zone and adjacent northern SDFZ lie above a very pronounced low velocity seismic anomaly that continues broadly along the rift axis to the south. See Rooney et al., (2014) for details and citations.

related fluids in early stage rifting within the focus site. Early results from this project show that the mechanism of upper crustal extension varies with rift maturity such that in early-stage rifts, upper crustal dikes are not a significant mechanism for accommodating extension, as they are confined to areas in and around transfer zones. In contrast more evolved rift basins exhibit more rift-parallel dikes and thus accommodate upper crustal extension by diking along the full length of the basin (Muirhead et al., 2015).

An award from the NSF Petrology & Geochemistry program in 2010 to PI Hilton and others has been used to examine noble gas characteristics along the East African Rift system. Results of this work indicate the potential of a common mantle plume source along the entire rift system (Halldorsson et al., 2014). A study of noble gases, H_2O and CO_2 in basalts from the Gulf of Aden, funded by NSF Marine Geology and Geophysics in 2013 to PIs Graham and Michael, has resulted in new constraints on the composition of the regional lithospheric mantle (Sgualdo et al., 2015).

Through an award made through the NSF Tectonics program in 2011, PIs Bendick, Keranen, and Flesch have been examining how extension may be accommodated beyond the confines of the defined rift valley in Ethiopia. Results to date (Kogan et al., 2012) have suggested that lithospheric extension may be accommodated over a significantly greater area than is occupied by the rift valley.

The earliest stages of continental extension in EARS are under investigation with funding from a grant from the NSF Continental Dynamics program in 2011 to PIs Buck, Gao, Harder, Canales, and Atekwana. In a recent publication by Leseane (2015) it is hypothesized that strain localization at continental rift initiation could be achieved through fluid-assisted lithospheric weakening without asthenospheric involvement.

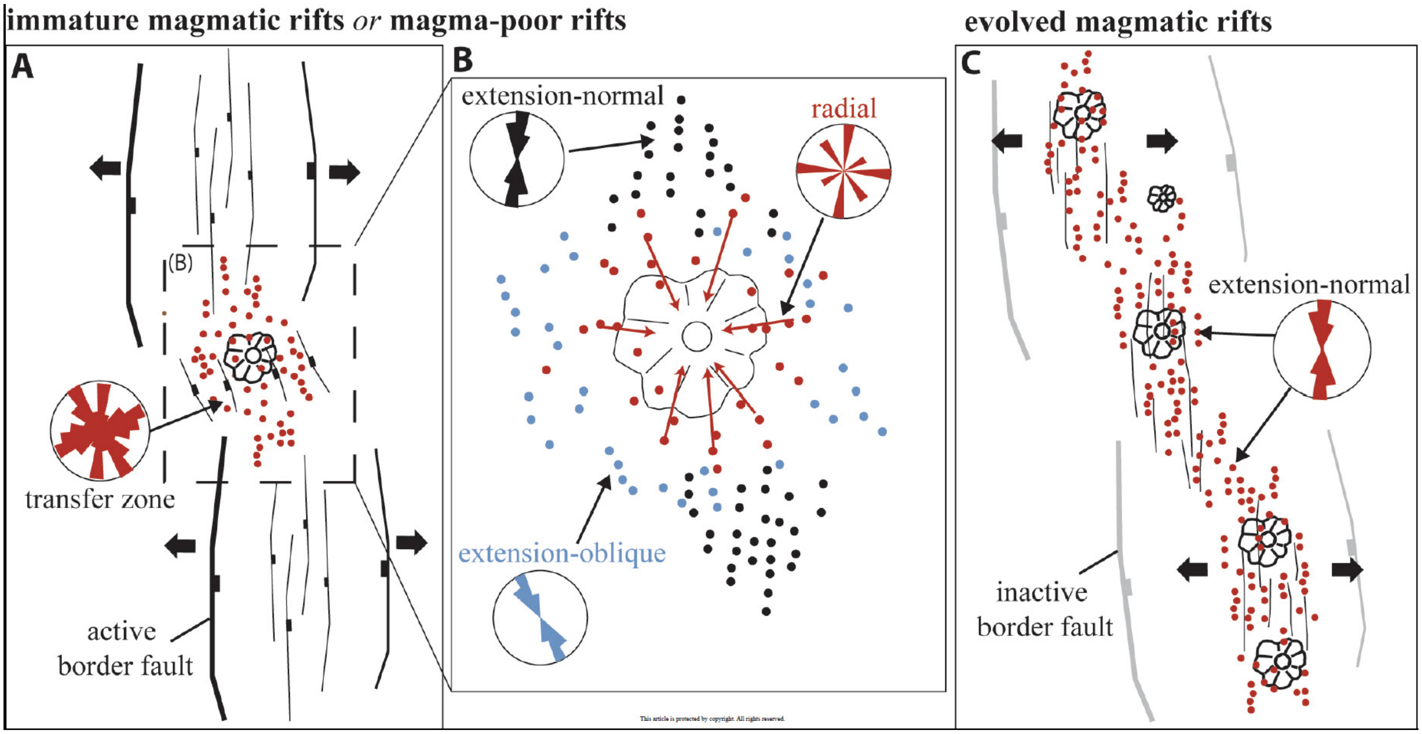


Fig. 3.10. Results of Muirhead et al., (2015) showing the relationship between strain accommodation and diking. A: In immature magmatic rifts and magma-poor rifts. B: The range of cone trends distributed within transfer zones in immature magmatic rifts and magma-poor rifts. C: Distribution of extension-normal cone lineament trends along evolved magmatic rifts.

3.2.3 Thematic Studies of Rifting and Passive Margins

To date, the GeoPRISMS program has funded one thematic study in RIE that is not aimed at a particular primary site. PI Straub focused on the stratigraphic evolution of passive margins (see nugget by Straub). This work aims to understand the evolution of deltas and in particular how the cycles of relative sea level (RSL), itself a function of climate and tectonics, are stored in deltaic stratigraphy. This project encompasses laboratory experimental work (Figure 3.11) that demonstrates that RSL cycles with magnitudes and periodicities less than the spatial and temporal scales of the internal (autogenic) dynamics of deltas cannot be extracted from the physical stratigraphic record of passive margins. The set of experiments carried out under this project defines quantitative limits on the range of paleo-RSL information that can be extracted from passive margin stratigraphy, which could aid the prediction of deltaic response to climate change. Results from this work (Kim et al., 2014; Armstrong et al., 2014) will play a role in placing quantitative limits on the fidelity of the stratigraphic record at passive margins.

A small number of other GeoPRISMS- and late MARGINS-funded projects from Appendix A1 should also have provided updates on thematic studies, but we have not been able to describe these due to lack of contributed nuggets or results in the primary literature.

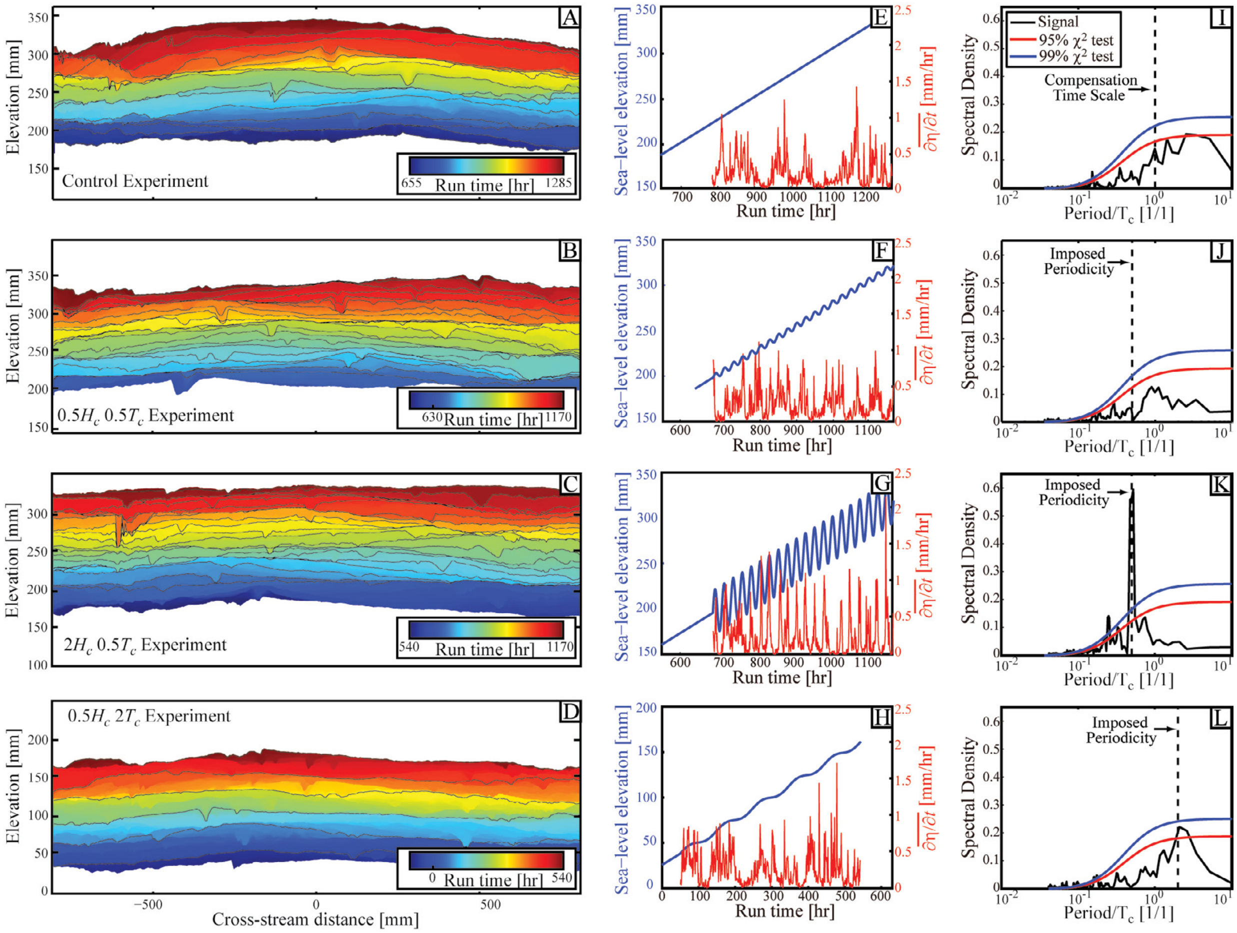


Figure 3.11 (courtesy of Kyle Straub). Time series analysis of mean deposition rate calculated from preserved stratigraphy for all experimental deltas with comparison to sea level time series. A-D) Synthetic stratigraphy. Solid black lines represent time horizons; in B-D the lines demarcate the start of each RSL cycle. E-H) Sea level and mean deposition rate time series along proximal transects; I-L) Power spectra of mean deposition time rate series (with c2 confidence limits).

3.3 Summary of Progress to Date and Future Directions

The highly successful ENAM CSE data collection effort has resulted in high-quality datasets, suitable for imaging structure across a range of scales and interrogating a range of processes in a single shoreline-crossing footprint, that are now publicly available. While the science that takes advantage of this unique dataset for the most part remains to be carried out, the data are now in place within the central part of ENAM to address the full suite of science goals articulated by the GeoPRISMS implementation plan, including those related to tectonic inheritance, the role of magmatism in rifting, along-strike segmentation of rifting processes, controls on offshore landslides, and post-rift evolution from the surface to the deep mantle. Geochemical and petrological study of the ENAM Eocene volcanics is yielding new clues about the post-rifting evolution of the passive margin and the links between deep mantle processes and the surface. Multidisciplinary projects such as MAGIC, which combines constraints from seismology, geodynamics, and geomorphology and which complements the geochemical and petrological investigations of the ENAM Eocene volcanics, are integrating constraints across disciplines to address GeoPRISMS science goals. In general, efforts to take advantage of synergies between ENAM GeoPRISMS initiatives and those of other programs and agencies, particularly EarthScope, have been successful. It is important to note, however, that science investigations using the ENAM CSE data are only just getting underway. Furthermore, ENAM projects funded by GeoPRISMS to date have focused exclusively on the central portion of the margin, with comparatively little attention paid so far to the southern ("Charleston corridor") and northern ("Nova Scotia corridor") focus areas.

In comparison to ENAM, GeoPRISMS efforts in the EARS primary site are somewhat less developed. Numerical and analog modeling aimed at understanding the regular spacing of volcanic centers within EARS is in its very early stage. New constraints on faulting in early-stage rifts have been obtained from the study of the unusual earthquake sequence in northern Malawi using seismic and InSAR data. In terms of new data collection, efforts in EARS are building on several projects that are funded by other NSF programs. Some new GPS data has been collected, and a new community GPS velocity model for East Africa has been produced, constraining the kinematics of extension. According to the phased funding schedule, proposals for large data collection efforts were scheduled to be accepted for the summer 2015 proposal competition and we expect significant future work on major data collection efforts in EARS.

We anticipate that key RIE efforts over the remaining years of the GeoPRISMS Program will entail detailed analysis and interpretation of the rich ENAM data sets and acquisition and analysis of focused data sets (including field studies) in EARS. Synthesis and integration within and across the two primary sites will be critical to achieving the goals of the RIE initiative, in particular, comparison between the early stages of rifting (EARS) and mature rifting (ENAM). Experimental and numerical investigations will probably play a significant role in this latter analysis.

3.3.1 RIE: Related GeoPRISMS-funded publications

Influence of growth faults on coastal fluvial systems: Examples from the late Miocene to Recent Mississippi River Delta - Armstrong et al., 2014

Galicia bank ocean-continent transition zone: new seismic reflection constraints – Dean et al., 2015.

Active features along a 'passive' margin: the intriguing interplay between Silurian-Devonian stratigraphy, Alleghanian deformation, and Eocene magmatism of Highland and Bath Counties, Virginia – Haynes et al., 2014.

Investigating the autogenic process response to allogenic forcing - Kim et al., 2014

Volcanoes on the passive margins: the youngest magmatic event in eastern North America – Mazza et al., 2014.

The Cryogenian intra-continental rifting of Rodinia: evidence from the Laurentian margin in eastern North America – McLellan and Gazel, 2014.

Influence of water and sediment supply on the stratigraphic record of alluvial fans and deltas: process controls on stratigraphic completeness – Straub and Esposito, 2013.

3.3.2 RIE: Related MARGINS-funded publications (2009 and beyond)

Modern sediment dispersal and accumulation on the outer Poverty continental margin – Alexander et al., 2010.

Geodetic constraints on present-day motion of the Arabian plate: implications for Red Sea and Gulf of Aden rifting – ArRajehi et al., 2010.

Oblique rifting ruptures continents: example from the Gulf of California shear zone – Bennett and Oskin, 2014.

Transtensional rifting in the proto-Gulf of California near Bahia Kino, Sonora, Mexico – Bennett et al., 2013.

How sediment promotes narrow rifting: application to the Gulf of California – Bialas and Buck, 2009.
How much magma is required to rift a continent? – Bialas et al., 2010.
New insights into deformation along the North America-Pacific plate boundary from Lake Tahoe, Salton Sea and southern Baja California – Brothers, 2009.
Tectonic evolution of the Salton Sea inferred from seismic reflection data – Brothers, 2009.
Estimation of the spectral parameter kappa in the region of the Gulf of California, Mexico – Castro and Avila-Barrientos, 2015.
Location of moderate-sized earthquakes recorded by the NARS-Baja array in the Gulf of California region between 2002 and 2006 – Castro et al., 2011.
The long lasting aftershock series of the 3 May 1887 Mw 7.5 Sonora earthquake in the Mexican Basin and Range Province – Castro et al., 2010.
Geometry and Quaternary slip behavior of the San Juan de los Planes and Saltito fault zones, Baha California Sur, Mexico – Coyan et al., 2013.
Late Oligocene to middle Miocene rifting and synextensional magmatism in the southwestern Sierra Madre Occidental, Mexico: the beginning of the Gulf of California rift – Ferrai et al., 2013.
Report on the August 2012 Brawley earthquake swarm in Imperial Valley, Southern California – Hauksson et al., 2013.
The 2010 Mw 7.2 El Mayor-Cucupah earthquake sequence, Baja California, Mexico and Southernmost California, USA: Active seismotectonics along the Mexican Pacific margin – Hauksson et al., 2011.
Late Pleistocene cyclicity of sedimentation and spreading-center structure in the Central Gulf of California – Kluesner et al., 2014.
Lithospheric strength and strain localization in continental extension from observations of the East African Rift - Kogan et al., 2012.
Frequency-dependent shear wave splitting and heterogeneous anisotropic structure beneath the Gulf of California region – Long, 2010.
Thick deltaic sedimentation and detachment faulting delay the onset of continental rupture in the northern Gulf of California: analysis of seismic reflection profiles – Martin-Barajas et al., 2013.
Kinematics of the southern Red Sea – Afar triple junction and implications for plate dynamics – McClusky et al., 2010.
Viscous dissipation, slab melting, and post-subduction volcanism in south-central Baja California, Mexico – Negrete-Aranda et al., 2013.
Seismic evidence of a ridge-parallel strike-slip fault off the transform system in the Gulf of California – Ortega and Quintanar, 2010.
A comparison between P-wave and S-wave propagation characteristics in the southern part of the Gulf of California, Mexico – Ortega and Quintanar, 2011.
Rayleigh wave dispersion measurements reveal low-velocity zones beneath the new crust in the Gulf of California – Persaud et al., 2015.
(U-Th)/He zircon and archaeological ages for a late prehistoric eruption in the Salton Trough (California, USA) – Schmitt et al., 2013.
Oceanic magmatism in sedimentary basins of the northern Gulf of California rift – Schmitt et al., 2013.
The mechanisms of earthquakes and faulting in the Southern Gulf of California – Sumy et al., 2013.
Middle Miocene to early Pliocene oblique extension in the southern Gulf of California – Sutherland et al., 2012.
Why did the Southern Gulf of California rupture so rapidly? Oblique divergence across hot, weak lithosphere along a tectonically active margin – Umhoefer, 2011.
Late Quaternary faulting history of the Carrizal and related faults, La Paz region, Baja California Sur, Mexico – Umhoefer et al., 2014.
An attenuation study of body waves in the South-Central Region of the Gulf of California, Mexico – Vidales-Basurto et al., 2014.
Convective upwelling in the mantle beneath the Gulf of California – Wang et al., 2009.
Seismic tomography in the crust and upper mantle of the Gulf of California region – Wang et al., 2012.

Geodynamics of the Gulf of California from surface wave tomography – Zhang and Paulssen, 2012.
3D shear velocity structure beneath the Gulf of California from Rayleigh wave dispersion – Zhang et al., 2009.

3.3.3 Other S2S/RCL MARGINS-funded publications (2009 and beyond)

Storm and fair-weather driven sediment transport within Poverty Bay, New Zealand, evaluated using coupled numerical models – Bever and Harris, 2010.
Hydrodynamics and sediment transport in the nearshore of Poverty Bay, New Zealand: observations of nearshore sediment segregation and oceanic storms – Bever et al., 2011.
A 1-D mechanistic model for the evolution of earthflow-prone hillslopes – Booth and Roering, 2011.
Topographic signatures and a general transport law for deep-seated landslides in a landscape evolution model – Booth et al., 2013.
Restoration of the contact surface in FORCE-type centered schemes II: non-conservative one- and two-layer two-dimensional shallow water equations – Canestrelli and Toro, 2012.
A mass-conservative centered finite volume model for solving two-dimensional two-layer shallow water equations for fluid mud propagation over varying topography and dry areas – Canestrelli et al., 2012.
One-dimensional numerical modeling of the long-term morphodynamic evolution of a tidally-dominated estuary: the lower Fly River (Papua New Guinea) – Canestrelli et al., 2014.
Quantifying temporal variations in landslide-driven sediment production by reconstructing paleolandscapes using tephrochronology and lidar: Waipaoa river, New Zealand – Cerovski-Darriau et al., 2014.
A numerical exploration of time and frequency-domain marine electromagnetic methods for hydrocarbon exploration in shallow water – Connell and Key, 2013.
Formation and preservation of sedimentary strata from coastal events: insights from measurements and modeling – Corbett et al., 2014.
Variable styles of sediment accumulation impacting strata formation on a clinoform: Gulf of Papua, Papua New Guinea – Crockett et al., 2009.
The influence of sea level and tectonics on late Pleistocene through Holocene sediment storage along the high-sediment supply Waipaoa continental shelf – Gerber et al., 2010.
Chute channel dynamics in large, sand-bed meandering rivers – Grenfell et al., 2012.
Sediment transport and event deposition on the Waipaoa river shelf, New Zealand – Hale et al., 2014.
Sediment accumulation patterns and fine-strata formation on the Waiapu River shelf, New Zealand – Kniskern et al., 2010.
Characterization of a flood-associated deposit on the Waipaoa river shelf using radioisotopes and terrigeneous organic matter abundance and composition – Kniskern et al., 2014.
Exploring the transfer of Earth materials from source to sink – Kuehl and Nittrouer, 2011.
Steady state reach-scale theory for radioactive tracer concentration in a simple channel/floodplain system – Lauer and Willenbring, 2010.
Shelf sedimentation on a tectonically active margin: a modern sediment budget for Poverty continental shelf, New Zealand – Miller and Kuehl, 2010.
Thick evaporites and early rifting in the Guaymas Basin, Gulf of California – Miller and Lizarralde, 2012.
A hydrodynamic and sediment transport model for the Waipaoa Shelf, New Zealand: sensitivity of fluxes to spatially-varying erodibility and model nesting – Moriarty et al., 2014.
Recent sedimentation patterns and facies distribution on the Poverty Shelf, New Zealand – Rose and Kuehl, 2010.
Siliciclastic influx and burial of the Cenozoic carbonate system in the Gulf of Papua – Tcherepanov et al., 2010.
Spatial and temporal variability in sediment deposition and seabed character on the Waipaoa River margin, New Zealand – Walsh et al., 2014.
Understanding fine-grained river-sediment dispersal on continental margins – Walsh and Nittrouer, 2009.
Coastal progradation and sediment partitioning in the Holocene Waipaoa sedimentary system, New Zealand – Wolinsky et al., 2010.