## 3.2. East African Rift System - Primary Site

*(Replaced May 15, 2013; revised December 23, 2013)*

### 3.2.1. Overview of the East African Rift System

The 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 (DSP) can be addressed in part or entirely in this primary site, given the great variety of rift processes and characteristics expressed in this setting.

The northern end of the EARS, in Ethiopia and the Afar region, is highly extended and appears to be strongly influenced by the Afar Plume. This northern region experienced voluminous volcanism during the initiation of rifting in the Red Sea and Gulf of Aden as Arabia separated from Africa at ~30 Ma. The timing of onset of volcanism varies, but within Afar, Ethiopia, and the Eastern rift, bimodal volcanism has been and remains an active process. These voluminous extrusive volcanic rocks have blanketed the earth's surface, and dramatically altered drainage basins and landscapes. Ongoing volcanic activity is manifest at about 100 centers active in the Holocene in the EARS through ground deformation, earthquakes, gas emissions and effusive and explosive volcanic eruptions. In contrast, the Western and Southwestern rift segments show little surface expression of magmatism and appear to be less extended. Instead, this part of the rift zone is characterized by deep, narrow rift basins bound by ~100-km-long border faults and by deep earthquakes (> 30 km).

At deeper levels, the entire EARS overlies an asthenosphere with the largest mantle low-velocity zone on Earth, the African Superplume. The pre-rift lithosphere includes deeply-rooted Archean cratons ringed by Proterozoic to Pan-African orogenic belts (Figure 3.1). Initial rift stage fault systems commonly lie along lithospheric-scale structures such as the boundaries of deeply rooted cratons and Proterozoic-Pan-African suture zones. Earthquakes, monitored teleseismically or by temporally and or spatially sparse local arrays, may occur throughout the crust and possibly the upper mantle, including moderate-sized earthquakes (e.g., the 2006 $M_w$ 7.0 event in Mozambique), or in the upper 10 km in areas of incipient plate rupture. Present-day rift opening velocities along the length of the rift system are poorly constrained except in the Afar rift where extensional velocities are 20 mm/yr and the Main Ethiopian rift with velocities of 6 ± 3 mm/yr; outside this zone, rigid-plate models predict velocities of < 3 mm/yr.

A fundamental property of the EARS is the along-axis segmentation of both magmatic and tectonic systems. In the youthful SW, Western, and southern parts of the Eastern rift arms, pronounced tectonic segmentation at the surface is defined by ~100 km long border faults linked via obliquely-oriented accommodation zones. In these early-stage zones, fault reconstructions indicate that most of the extension appears to occur along the border faults, with intrabasinal faults accommodating hanging wall collapse. As extension progresses, strain along border faults may migrate to magma intrusion zones within the central basin. In highly evolved rift zones, fault-controlled segmentation is replaced by ~50 km-scale tectono-magmatic segmentation.

Along-axis segmentation patterns, superimposed on broad plateau uplifts, exert strong controls on drainage and deposition patterns. Short-wavelength footwall uplifts associated with discrete border faults influence regional drainage evolution and intra-basinal sediment pathways. Fault-bounded basins along the length of the rift contain an extensive and, in some regions, continuous sedimentary record of deformation and East African climate change at all stages of rift evolution. Feedbacks between faulting, flank uplift, sedimentation, and subsequent deformation are recorded. Widespread tephra deposits, and their vertical succession, provide valuable controls for constraining rifting and climate histories on a variety of temporal scales. Sedimentary basins spanning 30° latitude preserve high-resolution histories of climate belt fluctuations from the mid-Miocene through the late-Quaternary, and document the high-frequency and high-amplitude hydrologic variability of the region, driven by the evolving East African monsoon system.

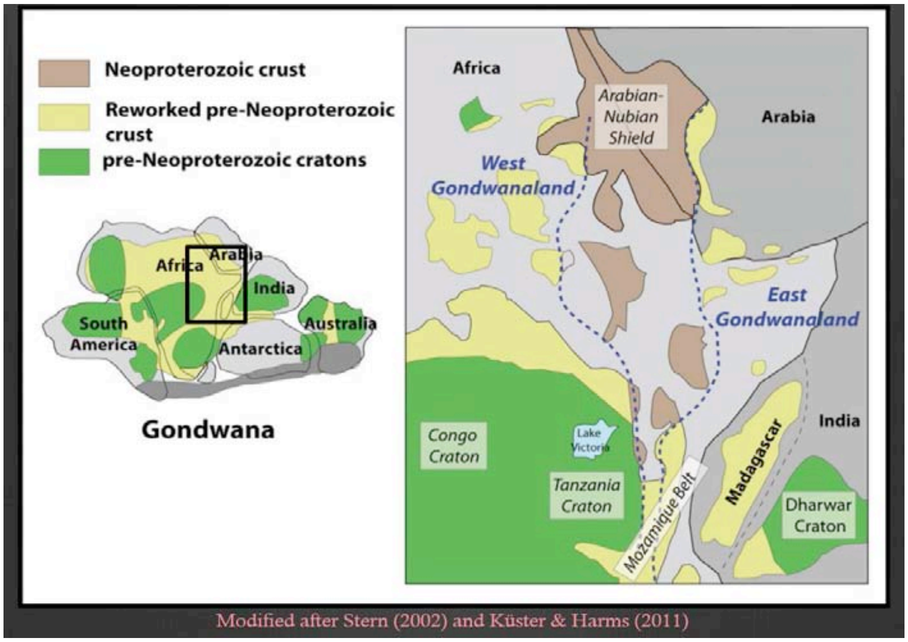


Figure 3.1. Construction of the regional lithosphere during the Pan-African Orogeny, modified after Stern (2002) and Küster and Harms (2011). Courtesy of Wendy Nelson.

The EARS provides a rare, yet accessible window into actively occurring rift events. These events present significant natural hazards to local communities and to regional infrastructure and commerce. GeoPRISMS research in East Africa will focus on the following set of research questions, specific to the EARS site:

- *How does the presence or absence of an upper-mantle plume influence extension?*
- *How does the mechanical heterogeneity of continental lithosphere influence rift initiation, morphology, and evolution?*
- *How is strain accommodated and partitioned throughout the lithosphere, and what are the controls on strain localization and migration?*
- *What factors control the distribution and ponding of magmas and volatiles, and how are they related to extensional fault systems bounding the rift?*
- *How does rift topography, on either the continental- or basin-scale, influence regional climate, and what are the associated feedback processes?*.

Sections of the rift system were identified that could best address the five overarching science questions and that would also maximize the potential for success within the timeframe of the program (Figure 3.2). Additional considerations taken into account when picking focus areas included: safe and relatively easy access (some sections of the rift present logistical and geopolitical difficulties to fieldwork); leveraging and collaborative opportunities, ongoing or planned efforts at various sections along the rift; and support of budding research groups in those regions. With this in mind, one section of the rift was identified to be the primary target of new GeoPRISMS efforts. Two other areas, for which there are substantial leveraging and collaborative opportunities, were also identified, and highlighted as such below. Finally, there are opportunities presented by identifying and filling system-wide data gaps to improve our ability to constrain key processes common to the system as a whole (e.g., the role of plume dynamics on shaping the rift evolution). The chosen sites and their attributes are summarized below. Updated information on current and planned projects in the region also will be made available through the GeoPRISMS website (http://www.geoprisms.org/) so that prospective PIs can use this information to structure their own efforts and to foster collaborations.

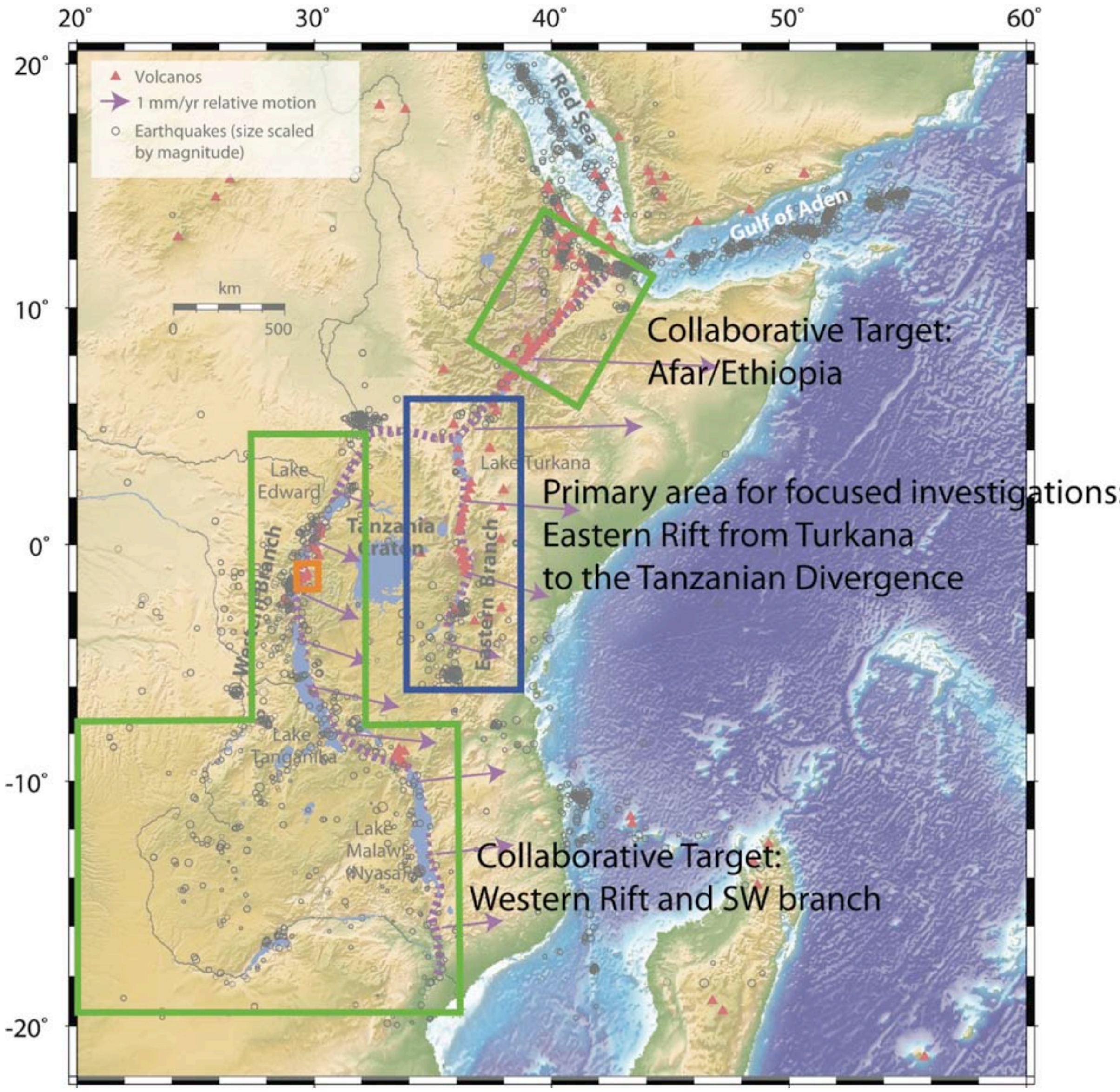


Figure 3.2. Map of the East African Rift System (EARS) highlighting the primary focus area and the collaborative targets of opportunity discussed in the text.

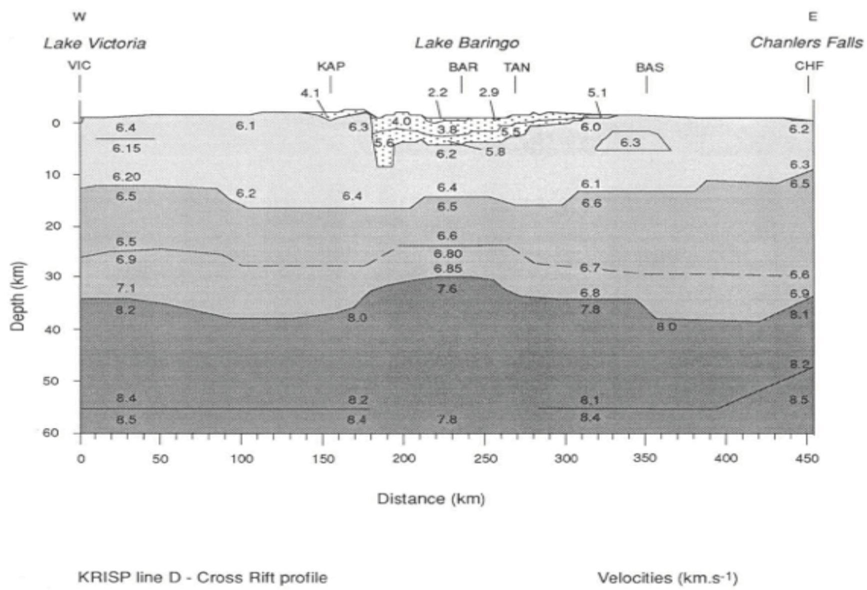


Figure 3.3. P-wave velocity cross-section from the KRISP experiment across the Kenya Rift (modified after Maguire, 1994).

### 3.2.2. Primary Focus Area: The Eastern Rift

The Eastern Branch of the EARS (Figure 3.2) was identified as a location where a focused interdisciplinary effort could substantially impact our understanding of rift processes and effectively address the majority of the science questions that form the core of the science plan. This region would encompass the rift from the Tanzanian divergence in the south to Lake Turkana and southern Ethiopia to the north. Particular opportunities highlighted by discussion include (but are not limited to) the role/origin of a plume in this part of this rift; the interaction of the rift and plume with major lithospheric structures; an active magmatic system; along-strike variations in the amount of cumulative extension and lithospheric thickness (thin in the north; thick in the south); the preservation of a record of the interplay of climate and tectonics. Existing studies in this region (e.g., Figure 3.3) provide a rich framework upon which GeoPRISMS science can build.

- *How does the presence or absence of an upper-mantle plume influence extension?*

  This site offers the possibility of testing the hypothesis that two upper mantle plumes, rather than one whole mantle plume influence rifting. Questions remain as to the distribution of plume material in the upper mantle in this region, the potential distinctive composition of plume material, and the extent of the plume when compared to that inferred for Afar/Ethiopia. Additional observations are needed to resolve the plume contribution to magmatism in the focus area and understanding how, where and why melts are generated in this region remains a key unknown. additional geochemistry (isotopic studies, volatile characterization, experimental melting), and geophysics (upper mantle and lithospheric structure) will constrain the absence or presence of plume material in the regional upper mantle and conditions of melt generation.

- *How does the mechanical heterogeneity of continental lithosphere influence rift initiation, morphology, and evolution?*

  The presence of the Tanzania Divergence within the study area, and the intersection of the rift with the Tanzania Craton (Figure 3.1), allows for the study of mechanical lithospheric heterogeneity on the rifting process. Specifically, comparisons can be made between rifting that occurs within mobile belts and that which may impinge on a deeply-rooted craton. Within the study region, the rift appears to be taking advantage of pre-existing structures, but questions remain as to how this strain and magmatic localization has evolved in terms of fault kinematics and the influence of magma. Existing observations, that there is variation in earthquake depth from north to south, raise further questions as to along-axis variability in structures and processes. To address the questions related to existing mechanical heterogeneity, needed studies include: xenoliths and basement exposures, fault kinematics, geophysical imaging of the lithospheric density contrasts (e.g., at the Moho), geodetic surveys, geochemical studies of lithosphere-derived magmas, structural mapping of the relationships between rifts, magma and pre-existing structures, and borehole stress or other stress measurements.

- *How is strain accommodated and partitioned throughout the lithosphere, and what are the controls on strain localization and migration?*

  This more weakly extended, but magmatic rift, provides a comparison in terms of strain with the more highly extended Afar/Ethiopian segment. The upper crustal diking event in thick continental lithosphere associated with the July-August 2007 seismo-volcanic sequence in the weakly extended Natron rift and Oldoinyo Lengai volcano, seems surprising and so understanding how faulting and magma intrusion contribute to strain accommodation within a youthful continental rift could facilitate the development of coupled thermo-mechanical models of extension in rheologically-layered continental lithosphere.

- *What factors control the distribution and ponding of magmas and volatiles, and how are they related to extensional fault systems bounding the rift?*

  Satellite Interferometric Synthetic Aperture Radar (InSAR, Figure 3.4) and other studies provide evidence of active inflation and deflation of volcanoes along the length of the Eastern rift (e.g., Paka, Menengai, Longonot, Suswa, Oldoinyo Lengai). Understanding the generation, migration and storage of magmas and the magmatic plumbing through time using, for example, geochemical and geochronological studies, experimental studies, fault length-displacement studies adjacent to and distant from volcanoes, and the imaging of magma bodies would be compelling.

- *How does rift topography, on either the continental- or basin-scale, influence regional climate, and what are the associated feedback processes?*

  The development of significant topographic relief associated with the EARS evolution has been suggested as a significant influence on regional air mass interactions and climate over the African continent. There may also be feedback mechanisms whereby changing climate influences local rift margin tectonics and exhumation rates. The Eastern rift is also an area of great interest for understanding Earth surface/tectonic interactions in the EARS because of its important paleoanthropological record, which may have been impacted by these Earth history events. Topographic changes allow testing models of how local and regional topography feeds back into climate and to test how much tectonic change is needed to have a climatic influence. Specific opportunities for looking at climate/tectonics interactions could come from some focused studies of erosion/accumulation rates in the context of paleoclimate records from targeted sites with good continuous stratigraphic records. Probably the most continuous for the Kenya rift is in the Tugen Hills section, but other long records could come from the Turkana Basin. Both of those sites, as well as sites in the Chew Bahir Basin, Magadi Basin and Koora Graben have or will be drilled in the context of the Hominin Sites and Paleolakes Drilling Project (*http://www.icdp-online.org/front_content.php?idcat=1225*).

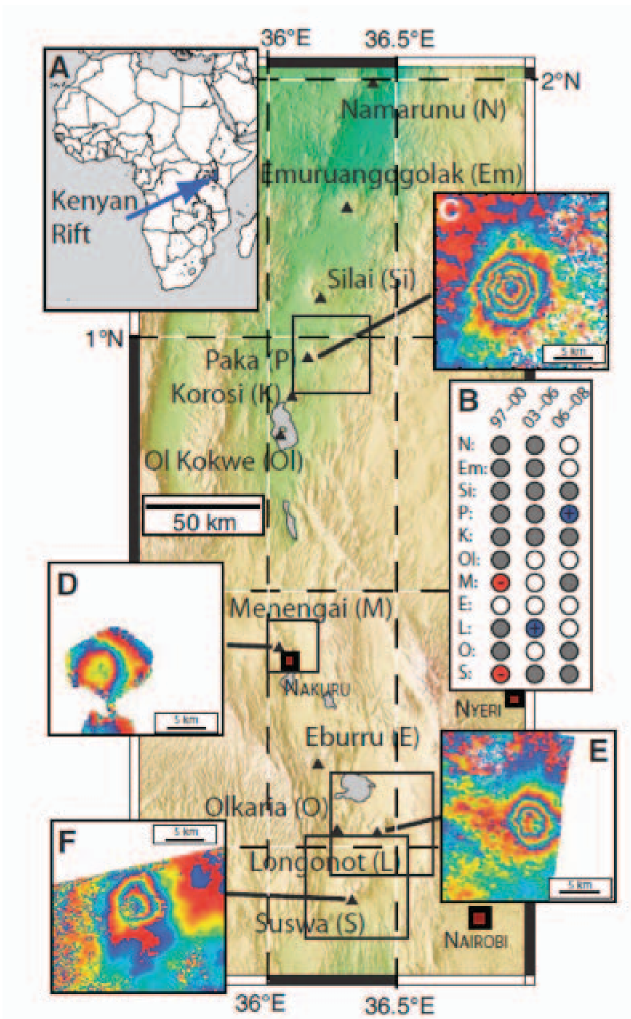


Figure 3.4. Interferograms of active volcanoes in Kenya showing geodetic activity (Biggs et al., 2009).

### 3.2.3 Collaborative Targets of Opportunity: The Afar and Main Ethiopian Rift

This part of the rift system is the focus of intense recent and ongoing international and US efforts. Further GeoPRISMS studies that could enhance our understanding of rifting processes include (but are not limited to) efforts that examine strain localization and studies probing the origin and role of a plume in rifting. The recent rifting and multiple volcanic eruptions in this region allow studies of active processes. Despite the large amount of geodetic and geophysical work done by the Afar Rift Consortium (*http://www.see.leeds.ac.uk/afar/*), there is still a need for further geophysical, geochemical and geological observations in the Afar region.

- *How does the presence or absence of an upper-mantle plume influence extension?*

  This site features geophysical images of the plume through a variety of seismic methods, and so the plume and its interaction with the lithosphere are well characterized. However a central question remains as to how melts are created and the relationship of these melt generation processes to ongoing extension. Such questions can be addressed by utilizing the long magmatic record present in this area, allowing for the analysis of the temporal and chemical evolution of the plume magmatism and the identification of the contribution of such magmatism to the evolving rift system.

- *How does the mechanical heterogeneity of continental lithosphere influence rift initiation, morphology and evolution?*

  The region contains the boundary between the Nubian and the Ethiopian plates in addition to a triple junction. Magmatic underplating identified beneath the western Ethiopian plateau, and other compositional heterogeneities in the lithospheric mantle may equally influence the heterogeneity and structure of the lithospheric plates. This region thus encompasses a variety of lithospheric structures through which the rift has cut and provides a rich template to examine the possible impact of lithospheric heterogeneity on rift development.

- *How is strain accommodated and partitioned throughout the lithosphere and what are the controls on strain localization and migration?*

  Archived and ongoing seismic monitoring throughout the study region provide perhaps the longest records of seismicity north of S. Africa. For example, Ethiopia has 8 broadband seismic stations in the national network. The high extension rates throughout this region make it an ideal environment to study seismic and aseismic strain partitioning through combined seismic and geodetic monitoring. Sparse GPS data have been collected throughout the region, although there could be benefit in re-occupying critical sites and creating new sites to fill gaps. There is extensive documented diking and faulting through the region.

- *What factors control the distribution and ponding of magmas and volatiles and how are they related to extensional fault systems bounding the rift?*

  This region is highly magmatic with well-documented and -imaged volcanic centers. Seismic studies reveal multiple active eruptive centers localized near the centers of rift segments, but with other magma chambers in off-axis and inter-segment zones. Combined geochemical and geophysical studies have successfully created a framework for understanding the crustal distribution of magmatism and its relationship to strain within in the Ethiopian Rift and Afar. However, little information exists as to the volatile flux and the potential linkage of such volatiles with the activation of faults and volatile concentration in the zone of active magma intrusion, or in areas with the highest fault density. Magneto-telluric studies when combined with seismic and geochemical evidence have been successful in delineating the geometry of magma bodies in the crust and mantle lithosphere.

- *How does rift topography on either continental- or basin-scale influence regional climate and what are the associated feedback processes?*

  This site offers an extensive stratigraphic and sedimentary record interpreted within a thermo-chronological framework. These existing data make it possible to undertake much needed paleo-landscape reconstructions. The paleo-anthropological record along the Awash River is well studied, but further delineation of its paleo-environmental and tectonic context is need. The triple junction offers the possibility to understand the influence of this major tectonic feature on climate.

### 3.2.4. Collaborative Targets of Opportunity: The Western Rift and SW branch

These sites provide the opportunity to examine the role of magmatism in rifting by comparing this comparatively less magmatic system with the highly magmatic Eastern Rift. The Southwestern rift zone contains the most weakly extended and youngest portions of the rift and thus can be used to tackle questions concerning incipient rifting. Finally, deep lakes along the Western Rift contain the longest continuous record of climate/tectonic/geomorphic interactions available for the EARS. There is an obvious opportunity to contrast this young rift with the more established fault and magmatic systems in the Afar and Eastern rift sectors, as well as offering a comparison to ultra-slow spreading ridge systems.

- *How does the presence or absence of an upper-mantle plume influence extension?*

  The possible influence of a mantle plume on the Western Rift is unknown, though some recent geophysical and geochemical studies suggest that there is a plume influence (e.g., from Helium isotopes) even though the surface expression of magmatism is limited. Further studies characterizing the distinctive composition of the plume as well as lithosphere in this region, the extent and nature of their interactions will be necessary to address these questions. This area offers the chance to examine how far south a plume may be participating in rifting and how it relates to other plumes proposed in this rift system.

- *How does the mechanical heterogeneity of continental lithosphere influence rift initiation, morphology and evolution?*

  There is some broad-scale geophysical evidence of heterogeneity in lithospheric structure through this region, particularly between Proterozoic-Precambrian orogenic belts and Archean cratons. The incipient nature of rifting in the Southwestern rift allows testing of models of how pre-existing lithospheric structure guides rift initiation. These early stage processes include strain localization and onset of magmatism, influenced by preexisting lithospheric features, e.g., zones of weakness and lithosphere-asthenosphere topography.

- *How is strain accommodated and partitioned throughout the lithosphere and what are the controls on strain localization and migration?*

  Incipient segments of the rift provide the opportunity to examine how strain is distributed at the early stages of breakup. Studies will also enable an examination of processes throughout the lithosphere during the initiation of rifting, including the formation and growth of fault systems, the importance of lithospheric thinning versus magmatic assistance, and the possible role of small-scale mantle convection.

- *What factors control the distribution and ponding of magmas and volatiles and how are they related to extensional fault systems bounding the rift?*

  Volcanism along this part of the rift system is limited to a few small provinces, which exhibit diverse geochemistry and indicate metasomatism, or introduction of significant volumes of volatiles, to the mantle lithosphere. Almost all of them are located within transfer zones between rift segments, but the distribution of magmatism at depth (and its relationship to border faults and accommodation zones) is poorly known. The Western Rift offers the opportunity to examine magmatic plumbing systems in a weakly extended region thought to have relatively thick, cold, strong lithosphere with those in the highly magmatic eastern rifts and Afar.

- *How does rift topography on either continental or basin scale influence regional climate and what are the associated feedback processes?*

  Lakes along the Western Rift contain a rich record of tectonic and climatic events. Studies in this region should permit integrating landscape studies of erosion, exhumation and uplift rates with stratigraphic records. There is an existing drill core from Lake Malawi (Nyasa), which covers the last ~1.25Ma and strong paleoclimate community backing for obtaining a similar but much longer record from Lake Tanganyika. The region offers the possibility of examining the influence of rifting on hydrology and climate.

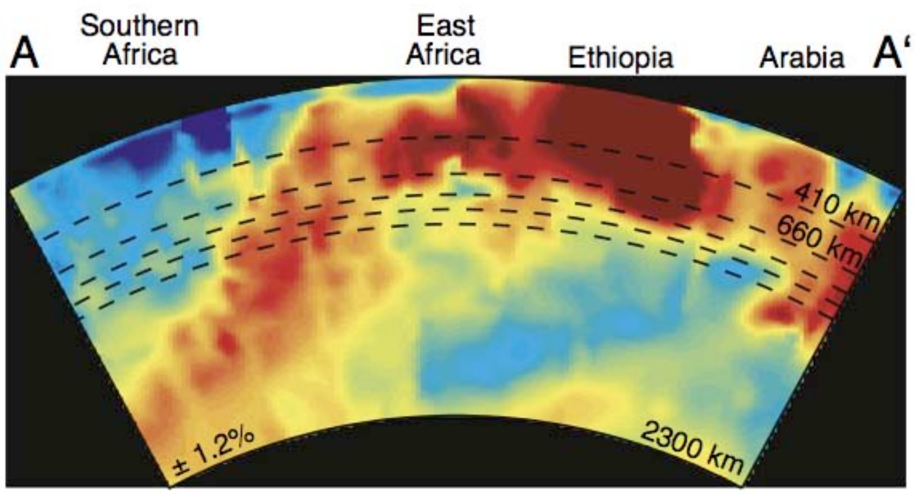


Figure 3.5. Cross sectional P-wave velocity model through the African and Arabian mantle. Dashed lines mark the 410 and 660 km discontinuities as well as depths of 800, 900 and 1000 km (Hansen et al., 2012).

### 3.2.5. Collaborative Targets of Opportunity: Synoptic Investigations Along the Entire Rift

There are also questions in the science plan that are best addressed by examining the rift as a whole. These concern 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 (Figure 3.5). Thus, components of EARS science 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.

One of the driving factors behind this target is the wealth of data that already exist across the rift system but with the knowledge that there are spatial (and in some cases temporal) gaps in coverage. This effort is expected to consist of the accumulation, integration, and quality assessment of existing data, re-processing of data where feasible and necessary, and the identification of data gaps with the intent of filling in these gaps through targeted field campaigns. It was specifically noted that reoccupying critical geodetic sites can have a big payoff by extending existing time series, whereas new sites require a long duration and so may need to begin as soon as possible.

The kinds of geophysical data sets that exist already with varying degrees of coverage include seismic (for example, through Africa Array, EAGLE, Afar Rift Consortium), magnetotelluric, geodetic, and very limited and relatively old heat flow stations. There is also an extensive geochemical data set including analyses of lavas, helium, and volatiles. sedimentary data sets from long cores could also be augmented through strategic coring under this effort.

Climate studies under this target might include running the NOAA Geophysical Fluid Dynamics Laboratory's (GFDL) Earth Systems Model (http://www.gfdl.noaa.gov/earth-system-model) (correctly parameterized for early and later rifting topography) which would offer a good way to see more accurately the dynamical effects of elevation on climate and climate/tectonic feedbacks.

### 3.2.6. Numerical and Experimental Studies

The development of a theory of continental rifting also depends on numerical investigations of loss of thickness and mechanical competence under extensional boundary conditions as well as surface processes. However, in comparison to regions of continental collision such as Tibet, the range and specificity of numerical investigations remains much more limited, and much progress in the description of rift related processes can be anticipated from numerical studies.

Focus of the modeling studies may range from surface processes (erosion, sedimentation) to crustal scale deformation- and upper mantle scale convection. Conceptual approaches may include plate-asthenosphere flow interactions, 2D and 3D dynamical models of crust and lithosphere deformation, magma generation and migration models, and regional-scale convection models. Fully coupled regional atmospheric flow, surface process, and lithospheric dynamics models can be applied to explore the development of drainage networks, mass flux across the landscape and into depositional systems, and any feedbacks between erosion and mechanical responses (which are seen in collisional systems and are expected to be modest but evident in extension). Some of this work has been done, but could be much expanded.

Simulations that overlap in time with the various data-campaigns will provide support for interpretations and may direct ongoing acquisition of field data. Recently developed 3D models suggest that the time and length scales of surface deformation during rifting are related to lithosphere rheology and layering, and efforts have started to understand earthquake patterns and other observables by comparing them with numerical model predictions.

Abundant evidence for lateral variations in EARS lithospheric competence exists, especially the loss of the mantle lithosphere northward toward the Afar triple junction. Numerical simulations of fully 3D mechanics are rare for any setting, with just a few results from compressional regimes such as Tibet and even fewer for rift settings. Such models require data for initial and boundary conditions that may not yet have been collected or documented. A longer-term goal of GeoPRISMS will be the development of such an integration of new data and new simulations

Experimental studies can help us to understand the effect of volatiles on the evolution of magmas erupting along the rift, constrain source lithologies, and examine the impact of volatile elements in melt production. These approaches are of utility in examining the evolution of magmas as they relate to plume-induced and decompression-induced magmatism (Figure 3.6). In particular experimental studies can have great utility in placing constraints on the possible volatile contents of magmas, in the absence of melt inclusion bearing tephras.

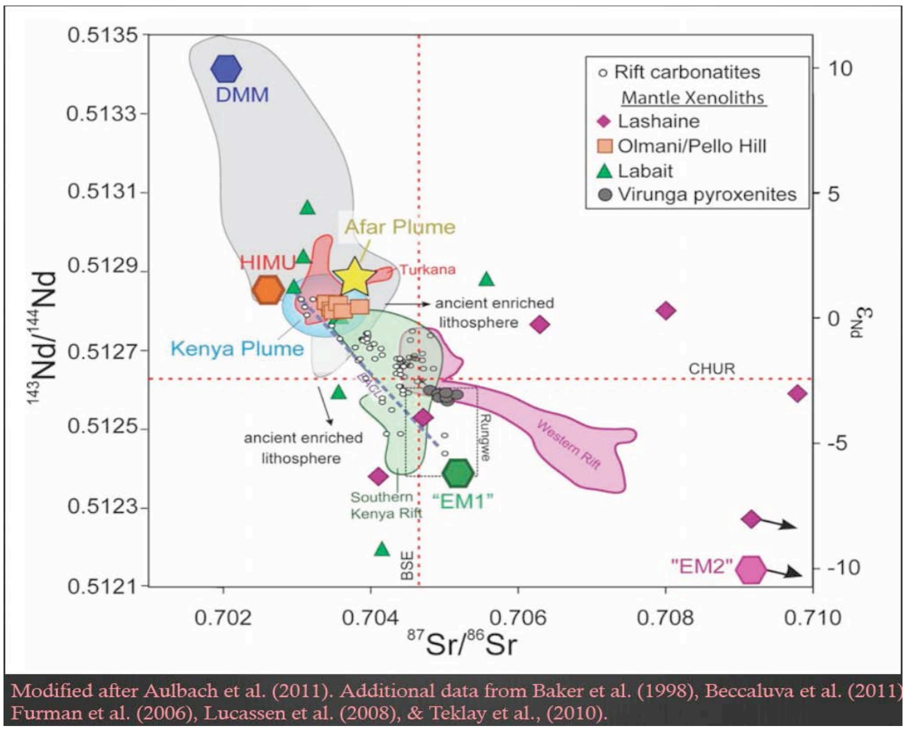


Figure 3.6. Isotopic variation of selected lavas and xenoliths from the East African Rift System, modified after Aulbach et al., 2011 with data from Baker et al. (1998), Beccaluva et al. (2011), Furman et al. (2006), Lucassen et al. (2008), and Teklay et al. (2010). Courtesy of Wendy Nelson.

### 3.2.7. Research Strategies and Partnerships

Given the limited program resources, leverage and collaboration with international partners is expected to play a key role in successful GeoPRISMS proposals to work on the EARS. There are also additional sources of potential funding, both within NSF and also at other US and foreign agencies. Below are a few of these possibilities. This list is likely incomplete and readers should refer to the GeoPRISMS website for an updated list.

*NSF Science, Engineering, and Education for Sustainability (SEES):* The goal of this program is to advance understanding of fundamental processes associated with specific natural hazards and technological hazards linked to natural phenomena, and their interactions. Proposals should be multi-disciplinary with the goal of improving capabilities for forecasting or predicting hazards, mitigating their effects, and enhancing capacity to respond to and recover from resultant disasters. The very nature of the EARS with its associated rift related earthquakes, volcanic eruptions and volatile emissions provides a natural laboratory for the GeoPRISMS-EARS community to take advantage of this funding opportunity.

*NSF Integrated Earth Systems (IES)*: This new program in the Division of Earth Sciences (EAR) focuses specifically on the continental, terrestrial and deep Earth subsystems of the whole Earth system. Overall, the goals of IES are to: (a) provide opportunity for collaborative, multidisciplinary research into the operation, dynamics and complexity of Earth systems at a budgetary scale between that of a typical project in the EAR Division's disciplinary programs and larger scale initiatives at the Directorate or Foundation level; (b) support study of Earth systems that builds on process-oriented knowledge gained from EAR programmatic research and enables systems-level hypothesis testing and analysis of coupled processes; and (c) provide a "bridge" among the EAR disciplinary programs in order to foster the exchange of questions, ideas, and knowledge between disciplinary discovery and system-level investigations.

*NASA* has several programs relevant to EARS science. In addition to these potential sources of funding, there are upcoming missions that, subject to budgets, could potentially provide important data sets including deformation, atmospheric volatile concentrations and altimetry.

*ROSES* program (http://nspires.nasaprs.com/external/) supports projects that use data from NASA satellite or airborne platforms to study a variety of earth processes relevant to the EARS program. For example, the Earth Surface and Interior program (http://solidearth.jpl.nasa.gov/) funds projects that asess, mitigate and forecast the natural hazards that affect society, including earthquakes, landslides, coastal and interior erosion, floods and volcanic eruptions.

*SERVIR* program (https://www.servirglobal.net/EastAfrica.aspx) aims to integrate satellite observations, ground-based data and forecast models to monitor and forecast environmental changes and to improve response to natural disasters.

*Africa Array (http://www.africaarray.psu.edu)* was started in 2004 as a vehicle to create new geoscientific research and training programs and rebuild existing ones in Africa. While the long-term vision for *AfricaArray* is to support training in many geoscience fields, initial efforts have focused on geophysics. Specific undertakings have included the development of new geophysical training programs and also the expanded support of existing ones; promotion of geophysical research; and design and establishment of a network of geophysical stations. The program has been particularly responsible for installing and maintaining a seismic network which, among other goals, has assisted in imaging the African superplume. It has also collected GPS and weather data.

*Hominin sites and the Paleolakes Drilling Project (http://www.icdp-online.org/front_content.php?idcat=1225):* Five drilling areas spanning late Tertiary/Quaternary lakes and paleoanthropology questions. Cores will provide high-resolution archives of environmental history (including local tectonics, erosion and exhumation history) with the potential to test hypotheses of the relationship of human evolution, extinction events and demography to environmental history. Projects established as a result of this effort have synergies with GeoPRISMS goals including studies of: basin tectonics, watershed reconstruction and paleogeomorphology-cosmogenic Isotopes and low temperature detrital thermochronology; seismite records/earthquake recurrence; landscape modeling; global and nested regional climate modeling; climate-tectonic-surface process feedbacks.

*Lake drilling projects:* There are a series of drill cores either collected or planned in East African Rift Lakes. Long cores are aimed at addressing the dynamics of the last ~7Myrs of African climate and assessing the sensitivity of east African hydrology and temperature to orbital scale climate forcings. The long cores also plan to address issues related to fault kinematics, earthquake recurrence intervals and the volcanic history of EAR volcanoes such as Rungwe.

*International efforts:* Below is brief information on international efforts, where readers can seek information on completed or ongoing projects or find potential partners for collaborative efforts. Again, this list is not complete, and we encourage viewing the GeoPRSISMS website for updated information:

*Afar Rift Consortium* (ARC) (http://www.see.leeds.ac.uk/afar/) is a project funded by the UK Natural Environment Research Council (NERC). It is made up of scientists from the Universities of Leeds, Bristol, Oxford, Edinburgh, and Cambridge, and Project Partners at the British Geological Survey, Universities of Addis Ababa, Auckland, Brittany, Rochester, Purdue, and Columbia (LDEO). The linked NSF-funded SEARIFT project supports the US partners (http://www.ees.rochester.edu/ebinger/SEARIFT). These projects, nearing completion, aimed to capture in 4D the partitioning of magmatic and tectonic strain, and the geodynamic conditions for the onset of along-axis segmentation at plate rupture. The ARC has conducted geophysical experiments in Afar using seismology, geodesy, gravity, and magnetotellurics; it has used geology and petrology to map and understand the magmatic history of the Dabbahu rift segment; it has used high-resolution LiDAR topography to understand the history of faulting; and it has used numerical models to understand the evolution of the region and the response to the diking episode.

The French government has funded, through Agence Nationale pour la Recherche (ANR), a large number of projects focused on or around the EARS. L'Institut National des Sciences de l'Univers (INSU) has also funded a seismic experiment in the Eastern Afar, and a project looking at volcanism and structure during extension.

The GEOBSNET program of the Royal Central African Museum of Belgium targets scientific efforts for assessing geo- and environmental hazards *(http://www.africamuseum.be/GEORISCA)*

The Global Earthquake Model (http://www.globalquakemodel.org/) aims to construct a global framework of data that permits enhanced risk assessment at the local scales and which fosters international collaboration.

ICTP (http://africa.ictp.it/) has a long tradition of scientific capacity building in Africa by facilitating exchange visits for African scientists. The science fields cover a broad range of physics, mathematics, geophysics and climatology.

Riftlink (http://www.riftlink.de/) is a research program studying rift dynamics uplift and change in Africa, through a consortium of German and African institutions

*African collaborations*: Collaborations with local scientists are essential to the success of any project launched within Africa. This collaboration is typically facilitated with the signing of a memorandum of understanding (MoU). Collaboration should be a two way street. For the European and American scientists, the importance of local knowledge, language and logistical assistance cannot be overstated. The monetary value of logistical assistance can be substantial – reliable vehicles are often hard to come by, for example. The type of institution available for collaboration is dependent on the country: in some cases, the pertinent geological survey is the first point of contact, in others a university is. Strong collaborations with local scientists can also serve to enhance the educational experience of GeoPRISMS students especially those looking for study abroad opportunities as well as short-term exchange visits. For the local scientists, sustainable relationships with their US and European peers can help with capacity building in several areas: through training of staff, particularly early-career faculty; providing scientific input into the long-term strategic planning for sustainable resources management and hazards evaluation/mitigation for the countries transected by the rift; the development of geophysical and geochemical skills that are valuable for mineral and water resources exploration; and for future scientific investigations in the host countries.

*Industry collaborations*: There are numerous examples of where industry has partnered with academia to facilitate the collection of data in Africa. For example, the SAMTEX consortium collected a large number of MT stations that were, in part, funded with a partnership with several mining companies (DeBeers, BHP and RTZ). World Bank and African Development bank loans support geothermal research throughout the proposed study regions, and many have been trained through alternative energy programs. Gold and other economic mineral exploration companies continue to support geophysical, geochemical, and geological research in East Africa. The petroleum industry has interests and active exploration programs in Afar, and the Eastern and Western rift, many of which could be leveraged through science/industry partnerships.

### 3.2.8. Broader Impacts

#### *3.2.8.1 Capacity building, education and outreach in Africa*

Working in Africa creates potential for capacity building through collaboration with local scientists. Collaborations are essential to the success of any project. NSF offers some avenues to facilitating capacity building. For example, the African partners of funded NSF projects can seek funding via the PEER program is an NSF partnership with USAID (http://sites.nationalacademies.org/PGA/dsc/PEERscience/index.htm). Some capacity building can be included as part of normal NSF awards, depending on the program. Africa Array has been carrying out capacity building and its website (http://www.africaarray.psu.edu) offers concrete examples of capacity building exercises, including workshops and summer schools, visiting scientist programs and student exchanges.

Capacity building through individual projects can be a challenge, and successful approaches will depend on the science being completed. African colleagues at the Morristown meeting emphasized the importance of engaging the local community in the science. They also highlighted the need to have an awareness of the different expectations of the local stakeholders involved in the effort. Governments have community development interests to consider, whereas the local community itself might want to understand how a project will address daily problems they encounter. Universities will look for educational and research opportunities, within the scope of their limited faculty staff and students. Individual scientists might look for training experiences that can advance their careers and that provide them with knowledge they can in turn pass onto their colleagues and students. Examples of approaches to successful capacity building that have been used successfully include:

- Sandwich programs that enable African students to get degrees at their home institutions but spend a significant amount of time abroad being co-supervised by someone at a foreign institution. This is much cheaper than bringing the student to the foreign institution for a degree, and helps the student keep connections back home, which in turn helps to address the brain drain problem.

- Technical training in country, formally and informally, on equipment operation and maintenance, data archiving, and data processing. Support for these activities can be built into budgets and are relatively inexpensive.

- Long term (post-project) commitment to helping scientists keep research equipment operating. This is really more a time commitment issue on the part of the PI rather than a financial commitment. Often, local scientists simply need advice on what to do when things break down.

- Providing ownership of a component of the project to local scientists. This can be done by providing opportunities for reduced-cost equipment purchase, support and training in secure data archiving, opportunities for data sharing across political boundaries, and support of existing networks, such as the SADCC seismic network operators training courses, and access to regional training workshops (e.g., Potsdam seismic training, ICTP geophysics courses, IAVCEI workshops). It can also involve training the scientists to collect their own data set and assisting with the data reduction, analysis and interpretation. The survey design and goals can be up to the local scientists and can be tailored to meet the larger aims of their institution (governmental or academic). Exchange programs wherein the scientists visit US institutions to carry out part or all of the analysis can accelerate the training process.

GeoPRISMS projects in Africa also offer tremendous educational opportunities for American students and young scientists. The active EARS is particularly well suited to interdisciplinary studies, providing young scientists with exceptional opportunities to interact with other American and African scientists doing complementary work. Besides the obvious scientific learning that comes through close international collaboration, working closely with African scientists and in the field in Africa is an invaluable cultural experience for students. Internationalization of young American scientists will serve them well in whatever field they chose.

Executing GeoPRISMS science in the EARS also enables an international outreach effort. Field programs in Africa offer the chance for abundant interaction and outreach to people living within and near the rift system on the fundamental earth processes at work and the associated geohazards. Outreach opportunities that combine field work and outreach could include deploying instruments near schools, and giving presentations in local communities during field work.

*3.2.8.2. Hazards*

The EARS can produce damaging earthquakes (Mw > 7), fatal landslides with frequency increasing with land denudation, potential anoxic lake overturns and seiche/lake tsunamis, and also presents volcanic hazards (eruptions with Volcano Explosivity Index > 4 along with lahars, lava flows, landslides, etc.) to the growing population of the region. In some places, these hazards are not fully appreciated by the government or the local scientists lack funding, local instrument networks or training to better document them. Comparatively small natural disasters can have substantial long-term societal effects in these developing economies, and the growing body of knowledge indicates that volcanic hazards are grossly underestimated in many rift sectors.. Thus, there are many opportunities for broader impacts by better understanding the hazards through collaborating with local geological surveys or NGOs for risk assessment, community education, or multi-disciplinary collaborations through programs such as NSFs Hazards SEES or NASA's SERVIR program (see above).