Geochemical and petrographic approaches for the study of rifting in the EAR

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The growing recognition that magma can play a critical role in the initiation and evolution of continental rifting, even in seemingly magma-poor environments, has highlighted the fundamental need to focus on magmatic processes in studies of rifting. Magmas and volatiles found in rift environments are the result of many overlapping processes, and they may therefore be used to examine the thermo-chemical state of the mantle, dispersion of materials beneath the rift, lithospheric heterogeneity, magmatic differentiation, and many other critical processes that depend on magmas. Perhaps one of the most utilitarian aspects of the geochemical and petrologic study of magmas is the opportunity to develop a temporal understanding of the evolution of these rifting processes by leveraging currently active regions with the wide array of products preserved in the East African Rift (EAR) over the past 45 Ma. In the context of GeoPrisms RIE science plan as it relates to the EAR, the application of geochemical, geochronological and petrographic techniques are central to establishing a new model of rift development.

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

Decompression melting has been typically linked with magma production in rift environments. However, the temperature and composition of the mantle exert a fundamental control on melt production. The presence of a mantle plume can have a profound impact on the thermo-chemical conditions of the mantle beneath a rift and therefore represent a significant perturbation of melting conditions in the ambient upper mantle. Plumes may contain lithologies characterized by a solidus that exists at lower temperatures and pressures than "background" mantle. Furthermore plumes are perhaps more volatile-rich than the surrounding mantle material, and such volatiles lower the melting point of mantle rocks. Similarly, elevated mantle potential temperatures associated with plumes result in enhanced melt production. Enhanced melting associated with plumes can in turn affect extension.

Plumes can be identified geochemically using several approaches; one of the most unambiguous being helium isotopes. To date, there are 2 main manifestations of high (plume-like) $^3He/^4He$ ratios along the EAR: Afar/MER/Red Sea and Rungwe Volcanic Province. Studies volatiles in both along and across rift axis investigations of erupted rocks, volcanic gas discharges and fault related conduits would provide valuable insights into the lithospheric and sub-lithospheric nature of volatile distribution below the rift. Radiogenic isotope systems (e.g., Pb-Sr-Nd-Hf-Os) further constrain contributions from a potential mantle plume but also reveal the role of the ambient upper mantle and continental lithosphere in magma production and modification. Constraining the thermobaric conditions of melt generation beneath the rift and discerning the contributions from a plume are best approached by geochemical modeling techniques. Current models have shown elevated mantle potential temperatures centered beneath Afar and the Tanzania craton, though further sampling throughout the EAR is necessary to refine these observations. The degree of contamination of the EAR upper mantle by plume materials remains uncertain. Such contamination may introduce pyroxenites that can be probed by high precision olivine studies. In addition the impact of a plume on the oxygen fugacity of the mantle (a principle thermodynamic property), has the potential to shift the position of the mantle solidus, promoting or prohibiting the formation of melts rich in carbon, hydrogen and sulfur.

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

The EAR system has developed across a continent that is characterized by widely heterogeneous lithosphere. From the Tanzania craton to the Pan-African mobile belt, lithospheric heterogeneity can impact the nucleation and evolution of the rift. Isotopic geochemical techniques are vital in deducing the antiquity of the lithosphere through which the rift passes and how this lithosphere has been modified by rifting processes. The direct geochemical analysis of basement rocks, and investigating lithospheric contamination of rift magmas provides an important record of the rift lithosphere and possible discontinuities not evident at the surface.

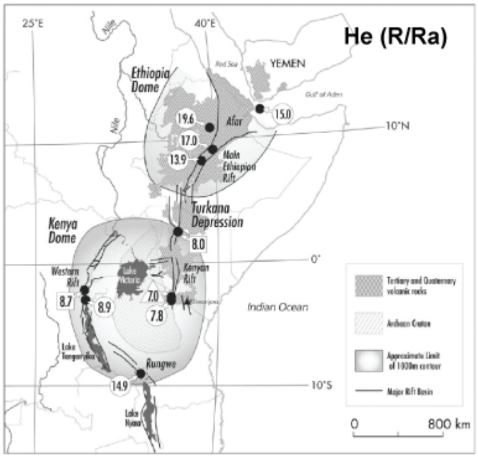
The long history of magmatism in the EAR has led to widespread modification of the lithosphere through intrusion, underplating, and metasomatism. Lithospheric modification can promote melt generation from within the lithosphere, and magmatic intrusion can lead to the focusing of extensional strain. Geochemical analysis of mantle xenoliths provides constraints on the characteristics of the pre-rift lithosphere and the impact of subsequent modification. Repeated magma injection into the continental lithosphere facilitates strain migration. Geochemical investigation of the magmatic plumbing system in zones of focused magma intrusion is therefore important in assessing the evolution whereby extension migrates from lithospheric thinning processes towards magmatic intrusion.

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 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?

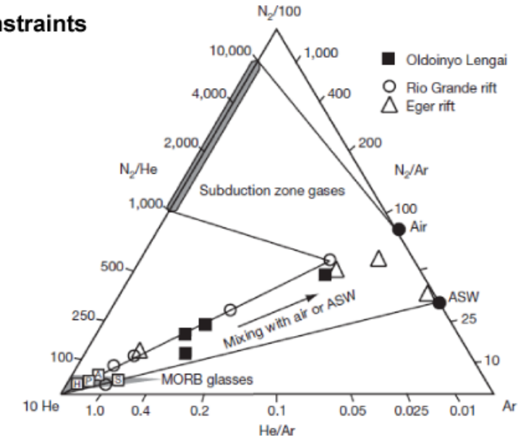
We believe these two questions to be closely related. Volatile release and magmatic activity are spatially and temporally influenced by the presence of faults, which may act as channels or barriers to flow. The location of magma bodies in the crust is strongly dependent on buoyancy forces and the crustal stress regime. Direct geochemical approaches can evaluate where magmas pond in the crust, how long they reside in the crust before eruption, and at what rates they move through the crust. Geochemical modeling can further inform us regarding the volumes, configurations, and geometries of magma storage reservoirs, and plumbing, all of which are dependent on the crustal stress regime and the availability of pathways for migration of melt and other deep fluids. New and precise geochronology combined with sophisticated P and T constraints based on isotopes, mineral assemblages and volatile contents provides these insights.

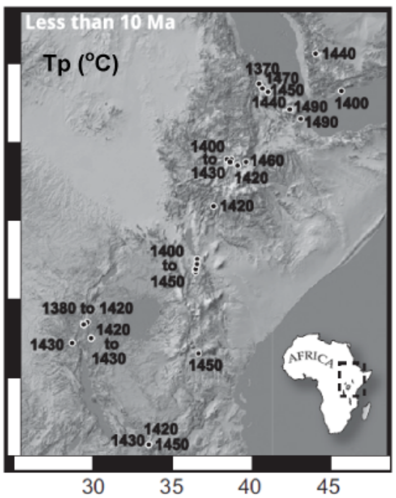
How does rift topography, on either the continental- or basin-scale, influence regional climate, and what are the associated feedback processes?

Eastern Africa has long been recognized for its significant deviation from the geoid as well as for some of the most dynamic topography on the African continent. The high Ethiopian plateau, which exerts a fundamental control over the monsoonal rains, is constructed of flood basalts and associated shield volcanoes. However, the origin of this first-order control on EAR topography is controversial, when did this plateau become elevated? Geochemical tools such as (U-Th)/He thermochronometry are indispensible for such studies. Magmatism also has direct and indirect effects on the global carbon budget. Injection of magmas into rift sedimentary basins can release greenhouse gases (CO_2 and CH_4) due to breakdown of organic C rich sediments. Weathering of crustal and mantle rocks exposed at the surface in some extensional environments consumes CO_2 and modulates the greenhouse effect. Understanding the spatial and temporal distribution of these processes in the rift environment is critical to understanding the overall effect of continental rifts on climate though earth's history.

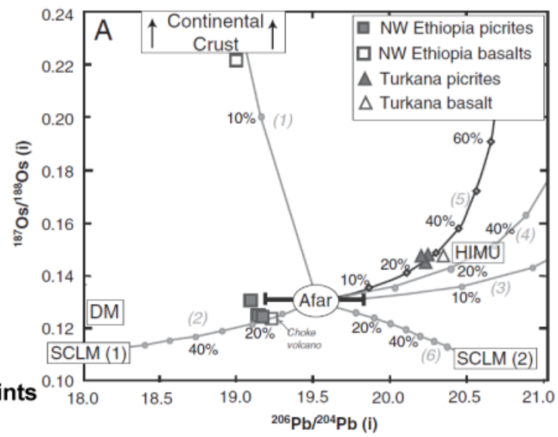


Noble gas constraints

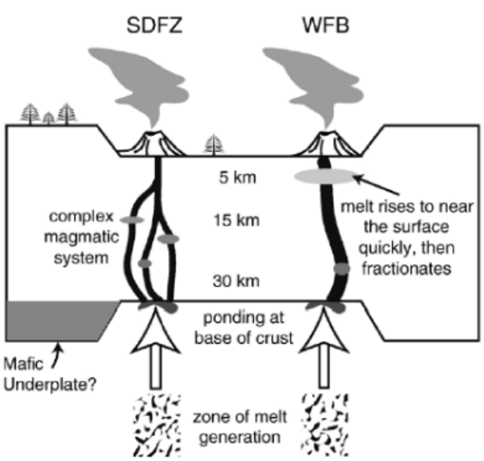




Thermal constraints



Isotopic constraints



Magmatic differentiation constraints