



Acquisition of a Unique Onshore/Offshore Geophysical and Geochemical Dataset in the Northern Malawi (Nyasa) Rift

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ABSTRACT

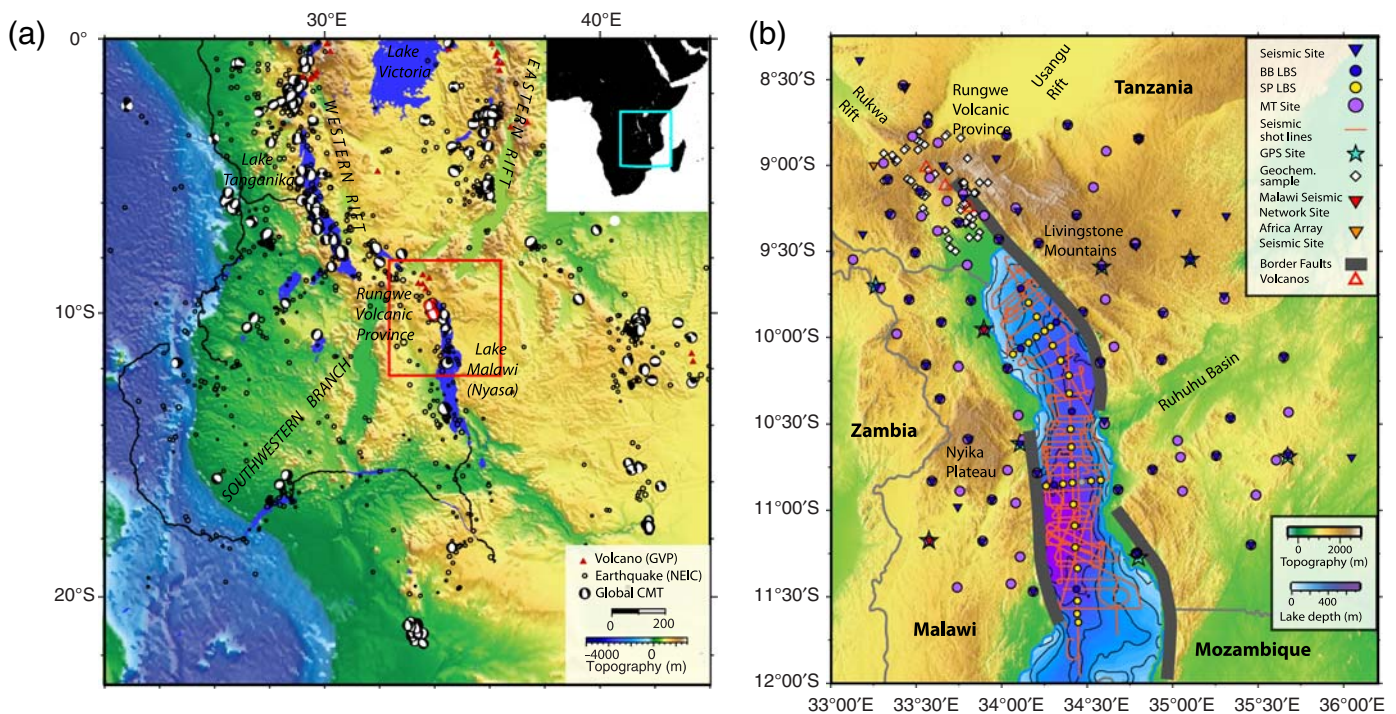
The Study of Extension and magmatism in Malawi and Tanzania (SEGMeNT) project acquired a comprehensive suite of geophysical and geochemical datasets across the northern Malawi (Nyasa) rift in the East Africa rift system. Onshore/offshore active and passive seismic data, long-period and wideband magnetotelluric data, continuous Global Positioning System data, and geochemical samples were acquired between 2012 and 2016. This combination of data is intended to elucidate the sedimentary, crustal, and upper-mantle architecture of the rift, patterns of active deformation, and the origin and age of rift-related magmatism. A unique component of our program was the acquisition of seismic data in Lake Malawi, including seismic reflection, onshore/offshore wide-angle seismic reflection/refraction, and broadband seismic data from lake-bottom seismometers, a towed streamer, and a large towed air-gun source.

SCIENCE MOTIVATION AND EXPERIMENT SUMMARY

The primary scientific goal of the Study of Extension and magmatism in Malawi and Tanzania (SEGMeNT) project

is to examine the emergence and early evolution of two fundamental features of all divergent plate boundaries: magmatism and segmentation. Magmatism accommodates a significant percentage of plate separation at most midocean ridges and late-stage continental rifts. Likewise, transform faults demarcate discrete spreading segments in midocean ridges, which are broadly characterized by more robust magmatism at their centers than at their edges (Macdonald *et al.*, 1988; Lin *et al.*, 1990). Well-developed magmatic and tectonic segmentation is also observed in late-stage continental rifts and new ocean basins (Taylor *et al.*, 1995; Ebinger and Casey, 2001; Keir *et al.*, 2009), but little is known about the controls on the initiation and development of magmatism and segmentation in immature rifts. Our project is focused on addressing the following questions:

- When, where, and why does magmatism initiate in rifts, and what is its role in accommodating extension?
- What controls the development of tectonic segmentation in early-stage rifts? How is it manifested in 4D patterns of magmatism and deformation?



▲ **Figure 1.** (a) Southern part of East Africa rift system with topography from Shuttle Radar Topography Mission (SRTM; [Farr et al., 2007](#)), Centroid Moment Tensors from the Global Centroid Moment Tensor (Global CMT) project ([Ekström et al., 2012](#)), earthquakes from the National Earthquake Information Center (NEIC), and volcanoes from the Smithsonian Volcanism Program ([Global Volcanism Project, 2013](#)). The 2009 Karonga earthquake sequence is indicated with lighter colored symbols. Box shows location of study area in (b). Inset shows Africa with location of (a) shown with a box. (b) Data acquisition map for the Study of Extension and magmatism in Malawi and Tanzania (SEGMeNT) project with topography from SRTM ([Farr et al., 2007](#)) and lake depth from [Lyons et al. \(2011\)](#). Key defines symbols. Circles with gray outlines show lake-bottom seismometers (LBSs) that were lost or had no data. Lake depth contoured at 100 m. The color version of this figure is available only in the electronic edition.

To address the questions above, we acquired an integrated geophysical and geochemical dataset across the northern Malawi (Nyasa) rift in the southern part of the East Africa Rift system (EARS). Our team included universities and geological surveys in the United States, Malawi, and Tanzania. The following datasets were acquired as a part of the SEGMeNT project: onshore/offshore active and passive seismic data, long-period and wideband magnetotelluric (MT) data, continuous Global Positioning System (GPS) data, and geochemical samples. This is the first integrated geophysical and geochemical dataset acquired across and within any of the great African rift lakes that can constrain rift architecture and processes at a range of scales.

TECTONIC BACKGROUND

The northern Malawi (Nyasa) rift in the Western Branch of the EARS is an excellent locality to examine the early stages of rifting in strong, cold lithosphere; only a small amount of stretching has occurred (<15%; [Ebinger, 1989](#)). Sparse constraints suggest that the extension is proceeding relatively slowly at ~ 3.5 mm/yr ([Stamps et al., 2008](#)). The length scales of border faults, the flexure associated with faulting ([Ebinger et al., 1991](#)), the occurrence of deep seismicity ([Jackson and Blenkinsop, 1993](#); [Foster and Jackson, 1998](#)), and the inference of mafic lower crust ([Nyblade and Langston, 1995](#)) suggest

that rifting is occurring in relatively strong lithosphere. Volumetrically minor volcanism is observed in this region, providing a serious test for recent models that require intrusive magmatism to initiate rifting in cold strong continental lithosphere ([Buck, 2004](#)). Strikingly, the only surface expressions of magmatism in the western rift occur in accommodation zones between discrete segments rather than in segment centers ([Fig. 1a](#)), in clear contrast to midocean ridges and mature rifts. The Rungwe volcanic province, the most southerly volcanism in the EARS, occurs in a complex accommodation zone between the northern basin of Lake Malawi, the Rukwa rift, and the Usangu basin ([Fig. 1b](#)). Seismic tomography with existing sparse seismic data indicates a localized low-velocity zone in the mantle below Rungwe ([O'Donnell et al., 2013](#)), and isotopic analyses of recent volcanic rocks suggest a deep plume-influenced source, at least for the youngest magmatism ([Hilton et al., 2011](#)). However, the original cause of magmatism, the distribution of elevated temperatures and magma at depth beneath the Malawi rift, and the relationship between magmatism and extension remain unknown.

The Malawi rift exhibits pronounced tectonic segmentation, which is defined in the upper crust by ~ 100 -km-long border faults ([Ebinger et al., 1987](#); [Specht and Rosendahl, 1989](#); [Flannery and Rosendahl, 1990](#); [Fig. 1b](#)). The border faults are often thought to account for most of the cumulative extension ([Specht and Rosendahl, 1989](#)) and host many of the earth-

quakes. However, a number of intrabasin faults are present as well. The occurrence of a sequence of earthquakes in 2009 with magnitudes up to M_w 6 on one or more west-dipping intrabasin faults near Karonga in northern Malawi clearly indicates that some of these faults remain active (Biggs *et al.*, 2010; Fagereng, 2013; Macheyeke *et al.*, 2015; see Fig. 1a for locations).

The absolute timing of the onset of extension in the Malawi rift and magmatism in the Rungwe volcanic province and their relative timing with respect to one another are poorly known. Although relatively little total extension has occurred, some authors suggest that rifting or magmatism could have started as early as 24 Ma (Roberts *et al.*, 2012).

Finally, and very importantly, the rifting process is associated with significant seismic and volcanic hazards for the densely populated rift valley (e.g., Fontijn *et al.*, 2011; Hodge *et al.*, 2015). The long border faults within thick strong crust may be capable of producing $M_w \sim 8$ earthquakes (Jackson and Blenkinsop, 1997; Hodge *et al.*, 2015). As demonstrated by the Karonga earthquake sequence (Biggs *et al.*, 2010; Fagereng, 2013; Macheyeke *et al.*, 2015), active intrabasin faults also pose a hazard to people living near the lakeshore; such faults could potentially be associated with near-field tsunamis.

DATA ACQUISITION

To address these science questions, the SEGMeNT experiment aims to constrain several fundamental characteristics of the northern Malawi rift:

- 3D patterns of cumulative deformation and magmatism with depth through the crust and upper mantle and along multiple rift segments and the Rungwe volcanic province;
- variations in active deformation along and across the rift, encompassing the full width of deformation;
- origin and age of magmatism in the Rungwe volcanic province.

To provide this critical information, we acquired a suite of geophysical and geochemical observations across the northern Malawi rift between 2012 and 2016 (Fig. 1b). Given that the core of the Malawi rift is covered by the ~ 70 -km-wide, ~ 650 -km-long Lake Malawi, it was necessary to collect data in and around the lake. The collection of multiple seismic datasets in Lake Malawi is a unique part of our project. We summarize each component below.

Onshore/Offshore Broadband Seismic Array

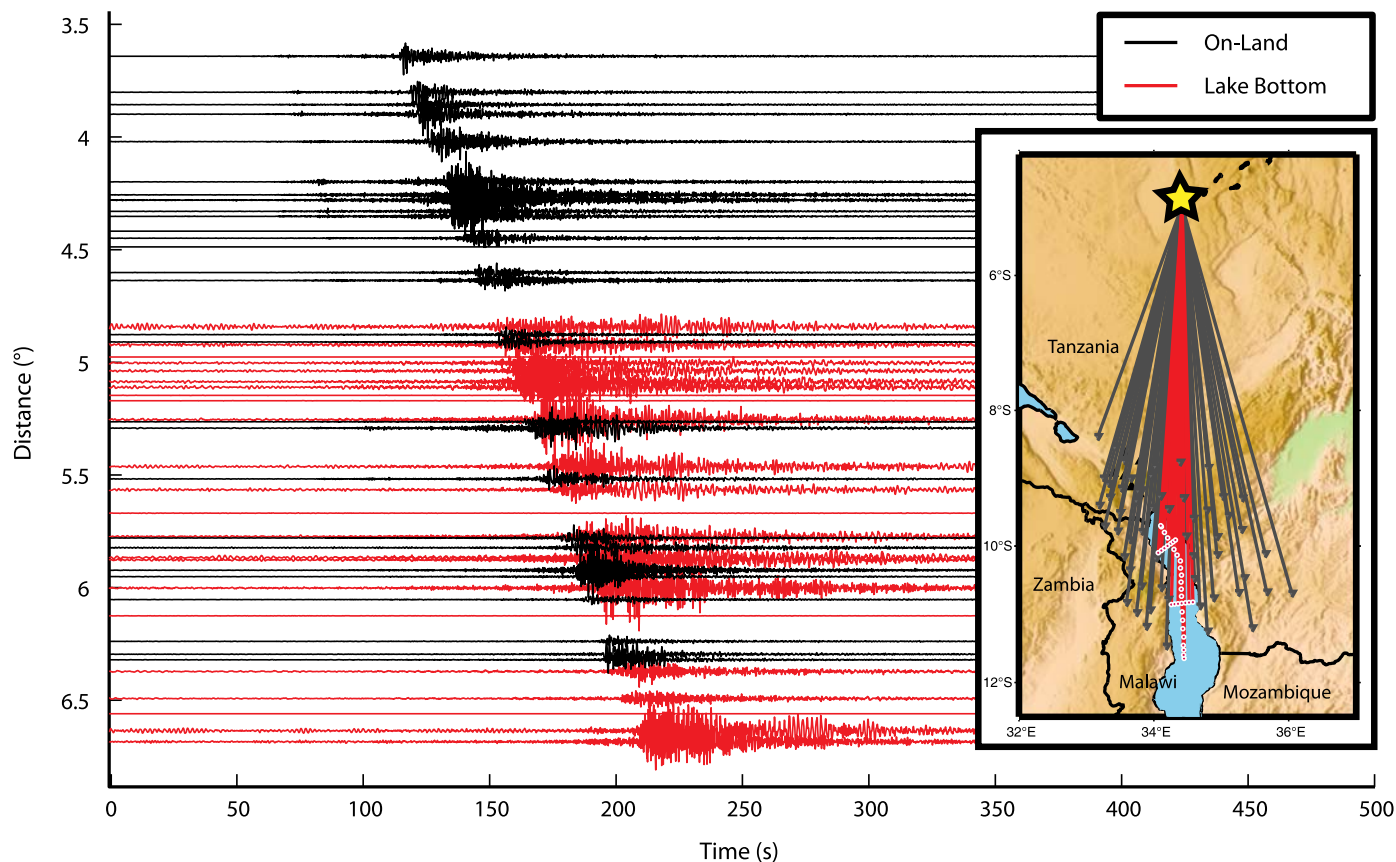
The goals of this component of the SEGMeNT project are to record local seismicity to constrain patterns of deformation in the rift, and to record ambient noise and local, regional, and teleseismic earthquakes for seismic imaging of crustal and upper-mantle structure inside and outside the rift. The passive seismic network is composed of 63 stations spanning a ~ 350 km \times 250 km footprint encompassing the northern two segments of the Malawi rift and the Rungwe volcanic province (Fig. 1b). This network includes 43 broadband onshore seismic stations, 14 onshore intermediate-period stations, and 7 broadband (BB) lake-bottom seismometers (LBSs). Most of the onshore seismic equipment is

from the Incorporated Research Institutions for Seismology-Program for the Array Seismic Studies of the Continental Lithosphere (IRIS-PASSCAL) instrument center. Sensors include CMG 3Ts, STS-2s, and Trillium 40s. RefTek RT130 dataloggers recorded data at 50 samples per second at 39 stations in Tanzania, and Quanterra Q330 loggers recorded at 100 samples per second for 15 stations in Malawi. These stations were complemented by one AfricaArray station in Tanzania (MBEY), and two stations of the recently established Malawi national network operated by the Malawi Geological Survey department (KARM, VWZM). Data from these stations have been archived with the SEGMeNT network for the duration of the experiment. Onshore stations were deployed in two phases: 15 stations were deployed around the Rungwe volcanic province in August 2013, and the remaining stations were deployed in June–July 2014. We serviced the stations every 3–6 months, and recovered all stations in October–November 2015. Field teams typically included one to two U.S. scientists or students and one to two Tanzanian or Malawian scientists or students, who used 4WD field vehicles to reach sites. Access to the sites was highly variable, with some sites requiring long drives on very rough roads. Deployments were staged from temporary field centers in Karonga and Mzuzu in Malawi and from Mbeya, Njombe, and Songea in Tanzania. We deployed the stations near schools, hospitals, and churches. Besides being advantageous for the security of the stations, this deployment strategy provided excellent opportunities for education and public outreach (Fig. 2d).

The Scripps Institution of Oceanography Institutional Instrument Contributor within the Ocean Bottom Seismograph Instrument Pool supplied seven BB LBSs that were deployed in Lake Malawi. To our knowledge, this is the first time that LBSs were placed within any of the African rift lakes. The Scripps BB LBSs have Trillium 240 seismometers, a differential-pressure recorder and sampled at 100 samples per second. To use these instruments in freshwater, the normal burn-wire release systems- which rely on the conductivity of salt water- were replaced with a new release system developed for this project by the Scripps ocean-bottom seismometer (OBS) group and called the Multi Environment Low-power Trigger (MELT) release. This system uses a plastic-like polymer that melts when heated, but can be reformed at lower temperatures (see [Data and Resources](#)). We chose the sites with water depths > 230 m for all instruments to improve noise characteristics and to minimize danger to the instruments from fishing. All stations were deployed in February 2015 using the F/V *Ndunduma*, a fishing vessel operated by the Malawi Fisheries Department. The instruments were lowered over the side using the *Ndunduma's* trawl winch (Fig. 2a). The working conditions were challenging due to the limited deck and lab space and the use of a simple low-tonnage boom for deployments, and hence required significant improvisation and creativity from our team. We staged the cruise from the Chilumba port in southern Lake Malawi, > 250 km south of the field area, because this is the only port in Malawi with a gantry crane capable of moving containers. For this same reason, Chilumba was also the chosen port for mobilization for the active-source work (see the [Offshore](#)



▲ **Figure 2.** Pictures from various components of data acquisition. (a) Deployment of broadband LBS in Lake Malawi from the F/V *Ndunduma* by Ernest Aaron, Mark Gibaud, and Martin Rapa (out of frame). (b) Recovery of outer sections of 1500-m-long streamer aboard the M/V *Katundu* by science party and ship's crew. (c) Patrick Chindandali (Malawi Geological Survey Department) acquiring MT data. (d) Godson Kamihanda (Geological Survey of Tanzania) describes seismic station to high-school students. (e) Nelson Boniface (University of Dar es Salaam) and Gary Mesko (LDEO) acquiring samples from Rungwe volcanic province. (f) M/V *Katundu* in port in Chilumba following mobilization. The color version of this figure is available only in the electronic edition.



▲ **Figure 3.** Example of seismograms recorded on the vertical channels of land stations (black) and lake-bottom stations (lighter colored symbols) from the SEGMeNT project from an M_w 4.3 event at a depth of 14.9 km located 105 km northwest of Dodoma, Tanzania. The color version of this figure is available only in the electronic edition.

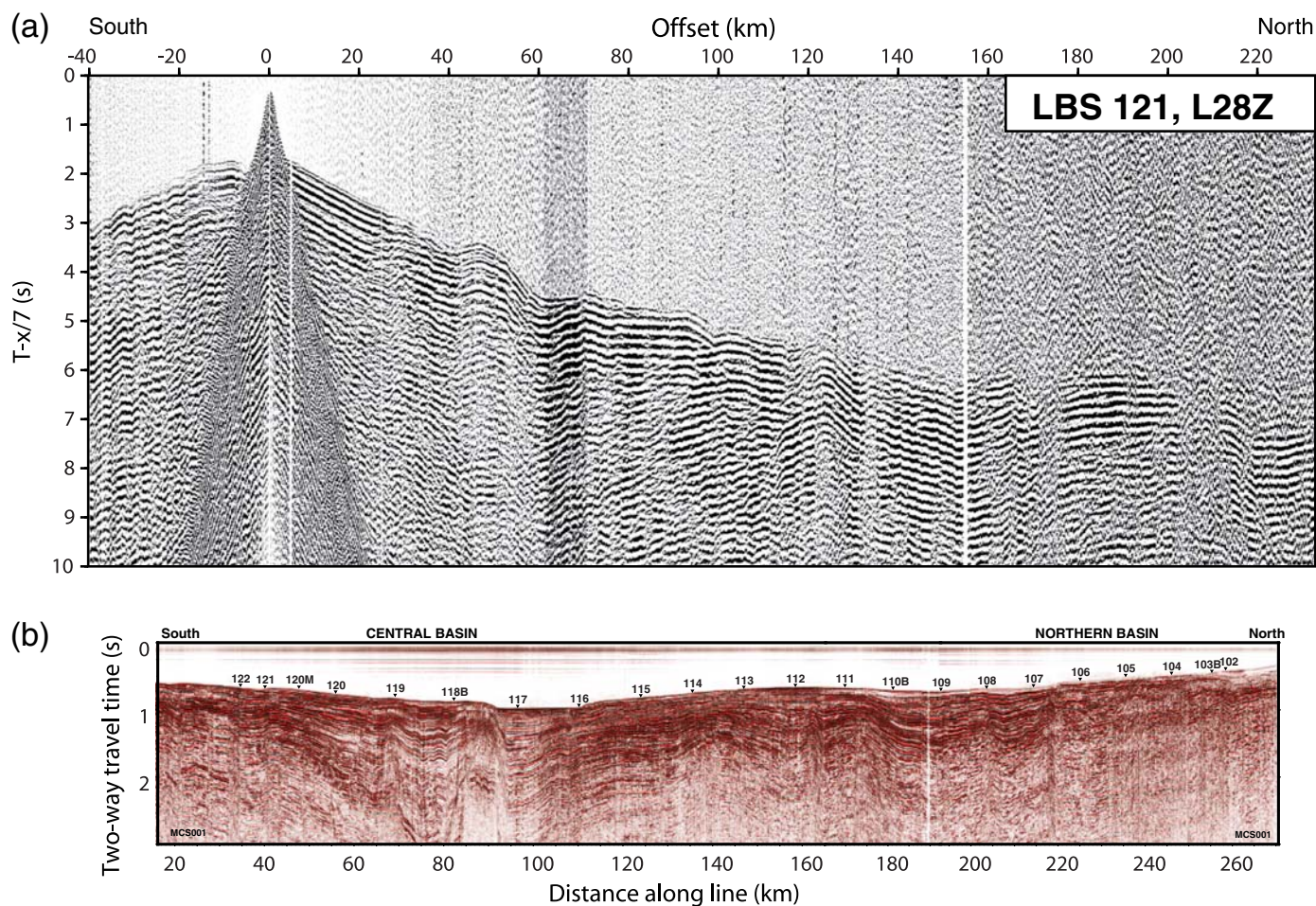
Active-Source Seismic Experiment section). Instruments were recovered during a 3-day cruise in late October 2015 using the *M/V Chilembwe*, which is operated by Malawi Shipping Company/Mota Engil and was briefly used as a fast ferry. The advantages of the *Chilembwe* for our program were that it could make up to 23 kt, has a large deck space, and a small articulated crane capable of handling the heavy broadband equipment, whereas the disadvantage was that there were not enough cabins for the ship's crew and the science party.

The overall data quality from the onshore/offshore seismic deployment is high, with excellent coherence between onshore and LBS recordings (e.g., Fig. 3). Failures of several RefTek GPS clocks resulted in timing uncertainty during the time interval July–November 2013 (Rungwe stations only). One BB LBS (304B) had a bad flash disk and failed to record any data (indicated with gray circle in Fig. 1b), and another BB LBS had problems with the horizontal channels. Malawi network stations KARM and VWZM had equipment problems that were fixed during the course of the experiment. A handful of the PASSCAL stations experienced data logger and/or sensor failures. However, given the conditions, the overall data return is excellent, with a network uptime of 96.3%. This number does not include the lost short-period (SP) LBS (see following sec-

tion), which was never archived, or periods of time with compromised timing or data quality.

Offshore Active-Source Seismic Experiment

The objective of the multichannel seismic (MCS) reflection and wide-angle reflection/refraction component is to constrain deformation and magmatism in the crust, from faults and sediments in the basin to overall variations in crustal structure. To enable deep seismic-reflection imaging and long-offset arrivals for refraction work, we required a much larger seismic source than has been used in previous seismic-reflection experiments in Lake Malawi and other African rift lakes (up to 120 inch³ during the PROBE project, e.g., Rosendahl *et al.*, 1992, and to 15 inch³ during high-resolution surveys, e.g., Scholz *et al.*, 1993). Active-source data acquisition with a large air-gun array requires significant deck space for the streamer reel, compressors to supply compressed air to the array, lab space for prepping or repairing equipment and monitoring acquisition, and generators to power the compressors, labs, and other gear. Identifying a ship in Lake Malawi that was in good working order with sufficient deck space to hold all of our equipment proved to be a long, but ultimately successful, odyssey that led us to the container ship *M/V Katundu*. Like the *Chilembwe*, this ship was operated by



▲ **Figure 4.** Example of receiver gather from (a) LBS 121 with shots from along-strike profile shown with (b) a water-velocity FK-migrated brute stack of coincident seismic reflection data from MCS001/001C. LBS positions indicated with triangles and numbers. The color version of this figure is available only in the electronic edition.

Malawi Shipping Company/Mota Engil. Extensive planning and a 1-month-long refit of the M/V *Katundu* in the Chilumba port in southern Lake Malawi were required to transform this ship into an active-source seismic vessel. The mobilization was an extraordinarily complex undertaking that involved placing and welding six containers, two generators, a streamer winch, and a fuel tank onto the deck of the *Katundu* (Fig. 2b,f). The source was a series of G-guns from Geological Survey of Denmark and Greenland/Aarhus University in Denmark, and the streamer was a ~1500-m-long Hydrosience digital streamer with 12.5-m channel spacing from Syracuse University. Additional equipment to support the seismic source was provided by the Geological Survey of Canada. An unconventional towing strategy was conceived and implemented due to the absence of aft deck space, requiring us to deploy gear from midships (Fig. 2b).

Following mobilization, we conducted three cruises to acquire active-source data. Two cruises were aboard the F/V *Ndunduma* to deploy and recover 27 SP LBS provided by the Scripps Instrument Center for the wide-angle reflection/refraction experiment. These instruments have a three-component geophone and a hydrophone sampling at 200 samples per second. The SP LBSs were deployed during the same cruise as the BB LBS in February

2015 using the boom of the *Ndunduma*, as described in the previous section. Two trips were required from Chilumba to deploy the instruments because there was not space for all 34 instruments on the *Ndunduma*. All SP and BB LBSs were deployed for the duration of the active-source seismic cruise aboard the M/V *Katundu* (see following paragraphs). These instruments employed the same MELT releases as the BB LBS described in the previous section. The SP LBSs were recovered with the F/V *Ndunduma* during a second cruise in April 2015, which also required multiple trips. One SP LBS 102 could not be recovered from the lake bottom (gray circle at northern end of lake in Fig. 1b), and voltage problems rendered the hydrophone recordings of nine SP stations unusable. Otherwise, the data quality was high (e.g., Fig. 4). We observed refractions and wide-angle reflections at all shot-receiver offsets (> 200 km) on most instruments. Besides recording the active-source experiment, the SP LBS also recorded local seismicity.

Following the mobilization and the deployment of the LBS, we conducted a successful 29-day cruise aboard the M/V *Katundu* from 8 March to 5 April 2015, during which we acquired ~2000 km of MCS reflection data with a variety of acquisition parameters and fired the air-guns along an additional ~1500 km

of lines at longer (250 m) shot intervals to be recorded by LBS and land seismometers (Fig. 1b). The science party comprised members from project partner institutions in the United States, Malawi, and Tanzania. Personnel from the Malawi Department of Fisheries were present for environmental monitoring and assisted in communicating with fishing communities onshore. The MCS lines included a series of dip and strike profiles in the northern and central basins intended to be orthogonal to structures or well suited for along-strike correlations (Fig. 1b). Several sets of acquisition parameters were tested during the cruise to optimize the trade-offs between source volume, shot interval, and recording time with the goal of reflection imaging of the top of basement and structures in the deep sediments and upper crust, and refraction imaging of the entire crust and uppermost mantle. We used a streamer up to 1500 m long with a group interval of 12.5 m and a sample rate of 2 ms. We used shot volumes between 500 and 1540 inch³ at a pressure of 135 bar, shot intervals of 25–50 m, and recording times of 6–14 s.

We also shot a series of profiles intended as sources for refractions and wide-angle reflections to be recorded on seismometers deployed on the lake bottom and onshore (Fig. 1b). For OBS shooting, we used a volume of 2580 inch³ firing at a pressure of 180 bar at a longer shot spacing of 250 m to avoid previous shot noise for long-offset recordings. We also fired the air-guns at larger shot intervals (and at larger volumes when possible) during turns and streamer deployments, recoveries, and repairs to provide additional ray coverage for wide-angle reflection/refraction study.

The cruise aboard the *Katundu* was divided into four legs by port calls to refuel/re-provision and for repairs/replacements of equipment. This part of the program came with numerous challenges: our streamer was struck by lightning (twice!), our seismic gear became tangled with fishing gear, and we experienced failures in nearly every piece of equipment needed for our operation, including both generators providing power for the operation. However, we were able to overcome the majority of these challenges thanks to the extraordinary tenacity and creativity of our excellent technical crew, ultimately leading to a very successful cruise. The data quality from both the MCS and OBS work is very high (Fig. 4).

MT Dataset

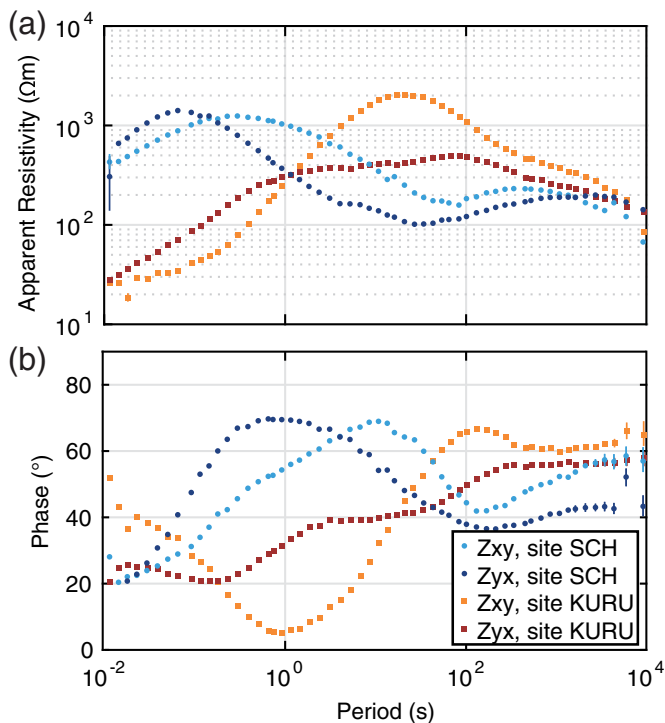
The goal of the MT component of the project is to image crustal and lithospheric structure across the rift system. MT data image electrical conductivity of the Earth, which is a distinct and complementary physical property to what seismic imaging provides. In particular, MT data are much more sensitive to magma and fluids than seismic data and are therefore essential to the goal of constraining the distribution of magmatism along and across the rift. Combined interpretation of MT and seismic data also provides better resolution of lithospheric temperature and composition than is possible with one methodology alone.

MT data were collected across the same footprint as the onshore seismic deployment (Fig. 1b). We collected both long-period data, which can image deep into the upper mantle, and wideband data, which provide better crustal resolution. Wideband data were collected for at least 1 day using Electromagnetic Instruments, Inc.

(EMI) MT24LF data loggers coupled with EMI induction coil sensors, whereas long-period data were collected for at least 7 days, and typically 14 days, using NIMS data loggers and fluxgate magnetometers from Narod Geophysics. Electric field measurements were made using nonpolarizable Ag/AgCl₂ electrodes and ~100-m-long dipoles. All instruments were loaned by the U.S. Geological Survey. We had three key criteria for site selection. The first was to avoid cultural noise, such as power lines, or features that cause the sensors to vibrate, such as roads or milling machines. We sought to avoid such features, which was often difficult because the field area is densely populated. The second was to avoid galvanic distortion. Surface features such as steep topography, riverbeds and abrupt changes in soil type can distort the electric field measurements; so we looked for site locations that were large enough to deploy the electric dipoles while avoiding such features. The third was that we required station locations that could be easily guarded to ensure instrument safety. We buried all instrumentation (including cables) at all sites to help keep them hidden from view. With these criteria in mind, we deployed 52 collocated wide- and long-period stations at close proximity to the onshore seismic stations. Generally, we were able to deploy the station within the same school, church, or hospital that housed the seismic station; where this was not possible, we found an alternate site at most a few kilometers away. In addition, we deployed 30 stand-alone wideband stations in the gaps between the long-period stations in order to improve lateral resolution. In total, data was collected at 56 sites in Tanzania and 26 sites in Malawi (Fig. 1b). Acquiring these data required two exceptionally long field seasons by an individual field team: 2 months in 2013 and 4 months in 2014. In general, only one to two stations could be deployed each day due to long driving times between stations and the time required to find a suitable site and gain permission for deployment. In almost all cases, two or more stations were synchronously recording, to assist in signal/noise separation via remote-reference processing. Although cultural noise was encountered at some sites, the ionospheric and magnetospheric sources of signal upon which the MT method relies were strong during both the 2013 and 2014 surveys. In general, high-quality data were collected, with well-defined wideband (long-period) impedance data to 1000 s (10,000 s). Figure 5 shows a comparison between sounding curves from station KURU, located on the eastern side of Lake Malawi (Nyasa), and station SCH, located on the western side of the lake. Strong variations in the data at periods shorter than 100 s provide an indication of complex conductivity structure within and surrounding the rift basin.

GPS and Interferometric Synthetic Aperture Radar (InSAR)

The goal of the GPS and InSAR component of SEGMeNT is to constrain deformation associated with active rifting and volcanism in our study area, which will strongly complement the seismicity information provided by the seismic array. InSAR data are collected over the region infrequently by most satellites, and some satellites have made no useful observations. But sufficient data from several satellites exist to observe ground deformation—principally from the European Space Agency's Envisat and Sentinel-1 satellites and the Japanese Space Agency's ALOS-1 satellite (Biggs *et al.*, 2010; Hamiel *et al.*, 2012). The GPS network includes 12 con-



▲ **Figure 5.** Comparison of magnetotelluric impedance data from two sites: SCH (on western side of Lake Malawi) and KURU (on eastern side of Lake Malawi). (a) Apparent resistivity, and (b) impedance phase. The color version of this figure is available only in the electronic edition.

tinuous GPS stations deployed in Malawi, Tanzania, and Zambia (Fig. 1b). Ten of these stations were installed between July 2012 and March 2013 by U.S., Tanzanian, and Malawian scientists along with UNAVCO engineers, and two stations were deployed in Zambia in March 2013 by Zambian partners and UNAVCO engineers. This network is complemented by nearby AfricaArray stations in Malawi (MZUZ), Tanzania (MBEY and MTVE), and Zambia (KASM). The SEGMeNT GPS stations have Trimble receivers (either NetR9 or NetR8) and Trimble Zephyr GNSS Geodetic II antennas. Sites were chosen near schools, hospitals, churches, national parks, and other secure locations, and guards have been hired for the duration of the experiment. Several GPS and seismic stations were collocated during the deployment of the onshore broadband seismic array. Monumentation varies with local conditions; antenna mounts include stainless steel masts attached to bedrock, threaded rods attached to concrete pillars, and building mounts that bolt directly to rooftops.

Four of these stations are located outside the core footprint of the seismic/MT experiment to ensure that we encompass the full width of deformation zone, including across the seismically active southwest branch of the EAR and the intervening craton, which lies to the west of the Malawi rift (Fig. 1). All GPS stations are still active and are being serviced every 6 months by Malawian, Tanzanian, and Zambian collaborators. Vandalism at the Isoka (ISOK) Zambia station and Kifanya (KFNY) Tanzania station has resulted in loss of some data at those sites, but both have since been repaired. Campaign mea-

surements were also made during July 2012 at Iringa (IRI2) and Makambako (MAK2) in Tanzania and future measurements are being considered. Data are made publicly available immediately after collection through the UNAVCO archive; users of these data need to abide by the UNAVCO Data and Attribution Policies (Pritchard *et al.*, 2012) and should contact the Principal Investigator before using unpublished data in a scientific publication.

Geochemistry

The objective of the geochemical portion of the SEGMeNT program is to determine the origin and evolution of magmas at Rungwe volcanic province. The timing and geochemistry of magmatism is essential to understand the role of magmatism in early-stage rifts as well as how this relationship evolves as extension, particularly lithospheric thinning, matures. A secondary goal is to better characterize the mantle source(s) in both a regional and global context through geochemical and isotopic fingerprinting.

During a 5-week-long field campaign in July–August 2012, a team of U.S. and Tanzanian scientists and students collected 117 volcanic rock samples (total weight of 550 kg) from the Rungwe volcanic province for analysis (Figs. 1b and 2e). The team focused on sampling distal flows and edifices to obtain and geochemically constrain the earliest eruptions in the sequence. Samples were described in the field to evaluate freshness and note any phenocrysts.

SUMMARY AND FUTURE WORK

The acquisition of the geophysical and geochemical datasets described above was enormously successful, albeit challenging, and has produced a unique dataset for understanding the early stages of continental rifting. Analyzing and integrating these data will enable the development of a complete picture of this early-stage rift and extract valuable constraints on continental rifting processes. We expect that our study will strongly complement previous, ongoing, and future studies in this and other parts of the EAR, including the Project for Rift Initiation Development and Evolution (PRIDE) (Bufford *et al.*, 2012; Leseane *et al.*, 2015; Yu *et al.*, 2015).

DATA AND RESOURCES

The data acquired by the Study of Extension and magmatism in Malawi and Tanzania (SEGMeNT) program are being archived at the appropriate databases described below. The Global Positioning System (GPS) data are open now, and the other datasets will be open following the customary two-year moratorium.

- Active and passive seismic data from onshore/offshore network: Incorporated Research Institutions for Seismology Data Management Center (IRIS-DMC; http://www.fdsn.org/networks/detail/YQ_2013/, last accessed August 2016).
- Seismic reflection data: Marine Geoscience Data System (<http://www.marine-geo.org/index.php>, last accessed August 2016).
- GPS data: UNAVCO (<http://www.unavco.org/data/doi/doi:10.7283/T5J38QW6>, last accessed August 2016).

- MT data: U.S. National Geoelectromagnetic Facility (ngf.oregonstate.edu) archive located at the IRIS-DMC (www.iris.edu, last accessed August 2016).
- Geochemistry: Samples are International Geo Sample Number (IGSN) registered and are to be made searchable at <http://www.earthchem.org/portal> (last accessed August 2016).
- The Multi Environment Low-power Trigger (MELT) release (<https://scripps.ucsd.edu/news/new-invention-advances-freshwater-seismology-research>, last accessed August 2016). ✉

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