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Abstract. The MOZART experiment consisted of a deployment of 30 stations in central and southern Mozambique and north-eastern South Africa. The overall goal was to study the signature of nascent rifting at the southernmost extent of the East African Rift. The particular goals were to record local seismicity and record teleseisms. Both operational goals were successful, though only about 25 stations in all yielded usable data. We faced severe operational diff culties due to the logistics of deployment and due to unanticipated f ooding of some sites, which led to equipment damage and reduced network operational capacity. However the data yield was suff cient to yield preliminary results on the trend of active rifting and for the crustal structure throughout central and southern Mozambique. We f nd that the rifting trend appears to be following the southern African cratonic margin rather than heading seaward, and that the crust thins signif cantly (>35 km to <15 km) from the cratonic margin to the Mozambique Coastal Plain.

Background

Project MOZAmbique Rift Tomography (MOZART) investigated the seismicity and the crustal structure of central Mozambique with four main goals:

1. to delineate the active structures of the East African Rift System (EARS) in this region;
2. to characterize the imprint left in the crust and upper mantle by the tectonic history of the study area;
3. to identify any crustal and upper mantle signature of continental rifting at an incipient stage, thus shedding light on the still obscure processes of rift initiation;
4. to understand the role of inherited structures in the development of continental rifting.

The project was funded by the Portuguese research foundation FCT, Lisbon, under contract PTDC/CTE-GIX/103249/2008. Through the author's participation in that grant, equipment was available through SEIS-UK.

The study area was the southern end of the EARS in Mozambique. Here the Rift's location becomes unclear beyond the southern end of Lake Malawi, thus allowing it to be delineated by local seismicity. The study area also provides a way to explore the structure of the shallow mantle in a nascent rifting setting with no surface volcanic expression and to contrast it to Ethiopia, that has an active volcanic zone bounded by the escarpments of the Rift. In particular, in Ethiopia it is clear the the magmatism is facilitating rifting. However in the south it is not obvious whether any subsurface magmas are acting to thin the lithosphere, thus assisting rifting, or whether magmatic focusing arises after rifting is developed. The southern EARS is a good place to test this idea.

Deployment details

We deployed instruments in three phases: 1) S. African stations; 2) N. Mozambique stations; 3) S. Mozambique stations. Phases (1) and (2) took place in Mar. 2011 and (3) in Nov. 2011. We expected that site security requirements would be our principal problem. Consequently site selection was dictated by security considerations. We attempted to put stations in areas of existing protected infrastructure. The best examples were sites in Kruger National Park, where we obtained permission from the South African National Parks authority to put stations inside their camping compounds. Similarly, in Mozambique, we sited stations in existing facilities (geophysical observatories, national parks, churches, schools, medical clinics), and hired guards to monitor sites not co-located with any other facility. We also engineered a solar panel frame that could be built from local materials (soft iron concrete reinforcing rods) that would protect the panels, batteries and dataloggers from theft. A sketch of the deployment strategy to prevent water damage to the sensors is shown in Figure 1. We were not so diligent in similarly protecting the dataloggers because we felt that access for data recovery was the main concern. However after a disastrous set of floods in Jan. 2012 that damaged dataloggers in SA and MZ, we redeployed the dataloggers in similarly overturned plastic storage containers to prevent future water damage.

Figure 2 shows a map of the deployment sites in MZ and SA. We collaborated with both the Direcção Nacional de Geologia (DNG) of the Mozambique government and with the Council for Geosciences, S. Africa. Our SA counterparts were straightforward to deal with because we collaborated with their seismic group who not only runs the SA national seismic network but also contracts out time to install, service and maintain nearby national seismic facilities (Botswana, Zimbabwe, Malawi). DNG collaboration was more complex on account of its structure, influenced by the resolution of the civil war in Mozambique. The agreement between the parties (RENAMO and FRELIMO) established regional zones of control by one group or another. Consequently, our DNG partners always required a national level representative to be with us in addition to a regional representative. Though inefficient, the arrangement was workable except during the recovery phase when return of equipment marshalled at a northern DNG regional site (Beira) to the capital (Maputo) was delayed due to lack of coordination between the regional and national representatives.

Avoidance of fees for import and export of equipment into and from Mozambique was a major consideration for the deployment. This required a bond to be left with Customs in Maputo, the recovery of which was fraught. The customs arrangement made it impossible to shift equipment in SA to MZ and vice-versa when we had equipment failures due to site flooding in South Africa and Mozambique.

Largely to deal with the import complexities, the Portuguese PI, Prof. Joao Fonseca, moved to Maputo for six months to facilitate them and liaise with DNG.

Delays from prior SEIS-UK loan returns forced us to deploy in two phases, in Mar. 2011 and again in Nov. 2011. Recovery took place in July 2013 (MZ instruments) and Sep. 2013 (SA instruments). Return of the MZ equipment was delayed on account of DNG structural problems related earlier. SA equipment return was delayed because we

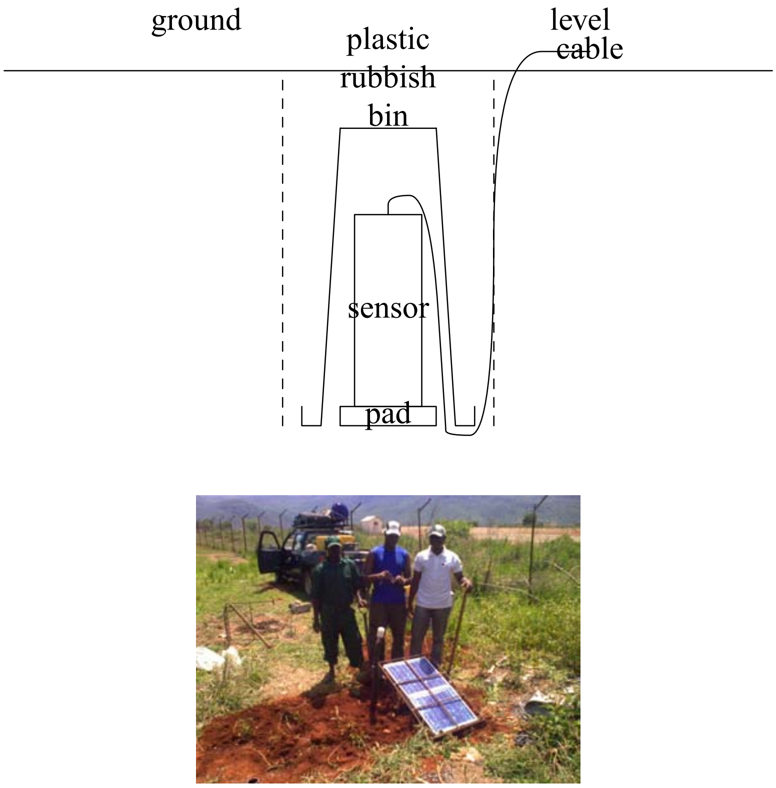

Figure 1. Sketch of pit construction in MOZART experiment and typical deployment method. (top) Overturned plastic rubbish bin forms a bell jar over sensor preventing ingress of water. Cables to sensor leave bottom of pit next to pad and then lead up through the back-f lled hole (dashed lines) to the surface datalogger. Sensor was also wrapped in foam insulation (not shown) to prevent tilt from differential heating due to convection inside the bin. (bottom) Photo of site deployed at Catandica. Solar panel frame made from welded rebar and set into ground with cement footings to prevent theft of panel. Battery under panel is also protected from theft by support frame. Sensor is buried in pit to left of solar panel and datalogger buried in a shallower pit in between. GPS antenna f xed to frame.

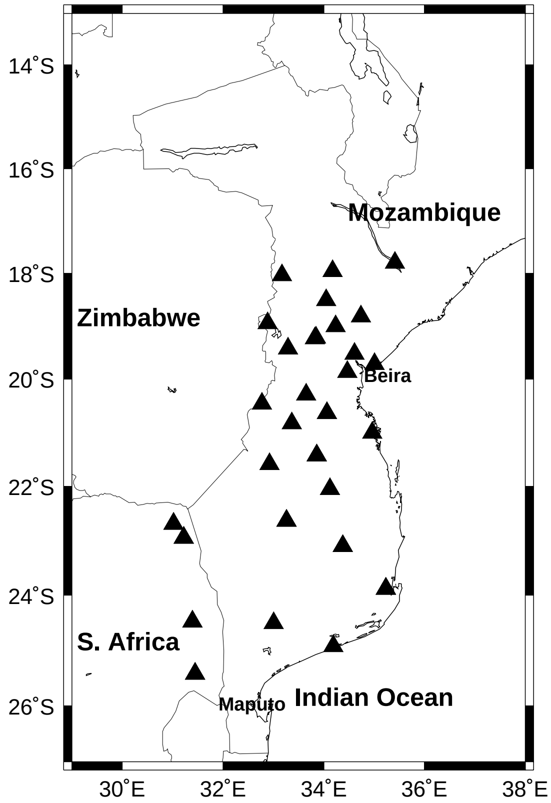

Figure 2. Map showing deployment region and political boundaries. Regional equipment marshalling points in Mozambique, Maputo (capital) and Beira also shown.

engaged the Council for Geosciences in a contract to recover the instruments and they were too busy on other projects to devote people to the recovery.

Issues and recommendations

The main technical problem that we had with the instruments were the datalogger behavior across the leap second on 1 July, 2012. Only one of the dataloggers worked properly when this happened: a Guralp whose GPS was locked when the leap second occurred. All the other dataloggers introduced time tears in the data in various forms that had to be fixed by relabeling the headers in the MSEED blockettes. See Table 1 that summarizes the problems and remedies. I am astonished that datalogger manufacturers cannot handle leap seconds better. I suggest that future tendering of datalogger purchases specifically specify performance criteria around leap second introductions, and in particular relax the requirement that the GPS clocks be continuously locked at the time of a leap second for proper functionality.

The other technical problem we had was damage to equipment due to heavy flooding in central Mozambique in Jan. 2012. SA National Park contacts reported a 4-6 inches of water on the ground at the northern 3 sites (one of whose dataloggers was damaged;

Table 1. Datalogger performance across leap second.

Type	Failure	Remedy
Taurus v2	When GPS satellite constellation began broadcasting a future leap-second, in mid-Jan. 2012, the clocks were jerked back by one second immediately.	Repair time stamps in ~6 months of MSEED blockettes.
Taurus v3	When the leap second occurred, the datalogger clock did not introduce an extra second. Time correction did not occur until the next GPS lock.	Repair time stamps in ~1 hour of MSEED blockettes.
Guralp	Same as above, except for one system whose GPS was locked at time of leap second.	Repair time stamps in ~1 hour of MSEED blockettes.

Figure 2). The Limpopo river overf owed its banks and inundated the town of Chokwe, submerging the school where one instrument was located under two meters of water. All told, there was no damage to sensors, but three dataloggers were rendered unusable. Due to insuff cient spares we had to shrink the network and redeploy some functioning sites ensure suff cient coverage to detect local seismicity.

One Taurus datalogger appears to have failed due to a power overload at a site which had mains power delivered (a Catholic mission). We do not know if the overload arose due to a short in the datalogger or due to a surge in the external power.

One sensor was damaged in transit after recovery from its site and return to Beira and thence to Maputo. Due to the urgent need for return of the equipment to SEIS-UK we opted to forego a huddle test of all the equipment in Maputo prior to its return to the UK. Consequently, we don't know at which stage of transport the damage occurred.

We also had one datalogger stolen. We filed a police report in order to facilitate a future insurance claim and offered a reward for return of the datalogger, but without success.

Preliminary results

Due to the low levels of cultural noise, data quality was generally excellent. Figure 3 shows a record section of a teleseismic earthquake that occurred in South America at a range of about 85° from the center of the MOZART network. Teleseisms such as this form the basic dataset for the receiver function analysis component of the MOZART work package.

Preliminary work to locate the local seismicity delineating the rift extension shows that it turns southward and follows the S. African cratonic margin rather then heading east

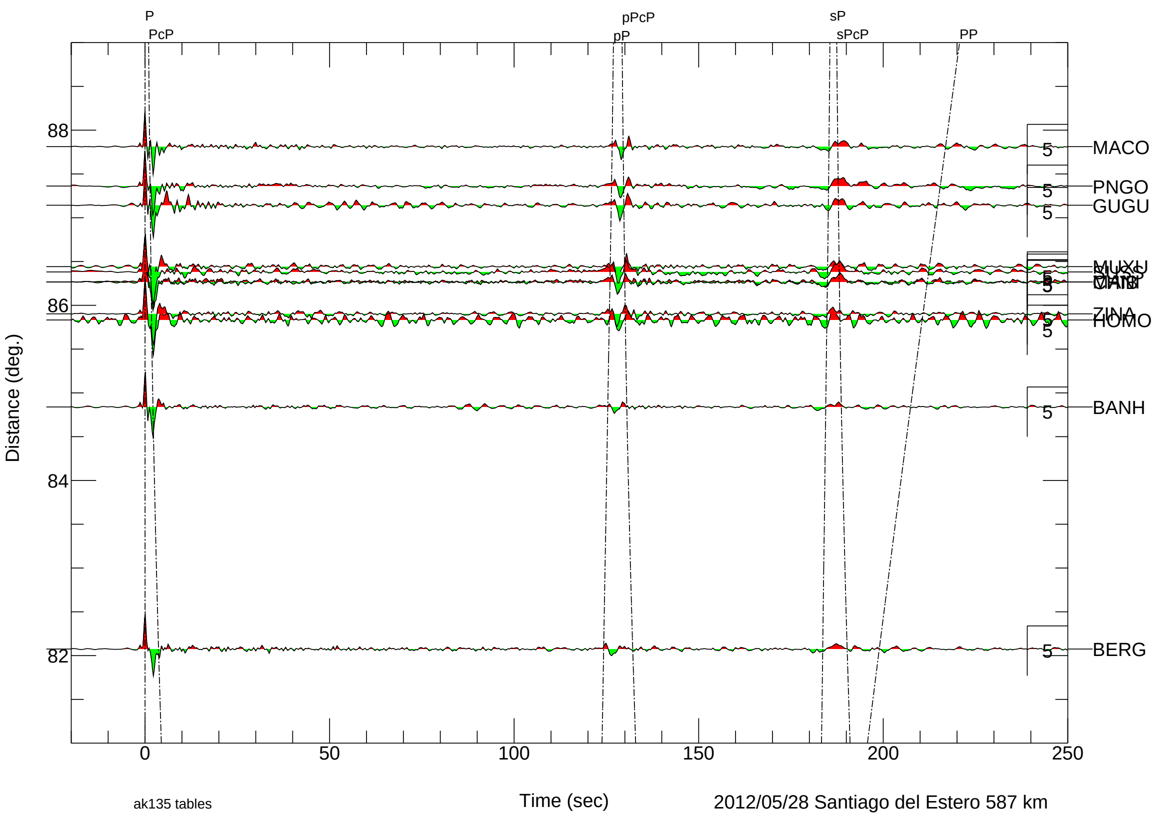

Figure 3. Record section of 11 MOZART stations recording deep teleseismic earthquake of 2012/05/28 in S. America, in the distance range of 82-85° from Mozambique. Time window shows direct P and core-ref ected PcP along with depth phases. Predicted phase arrival times are labeled at top and shown as vertical dotted lines.

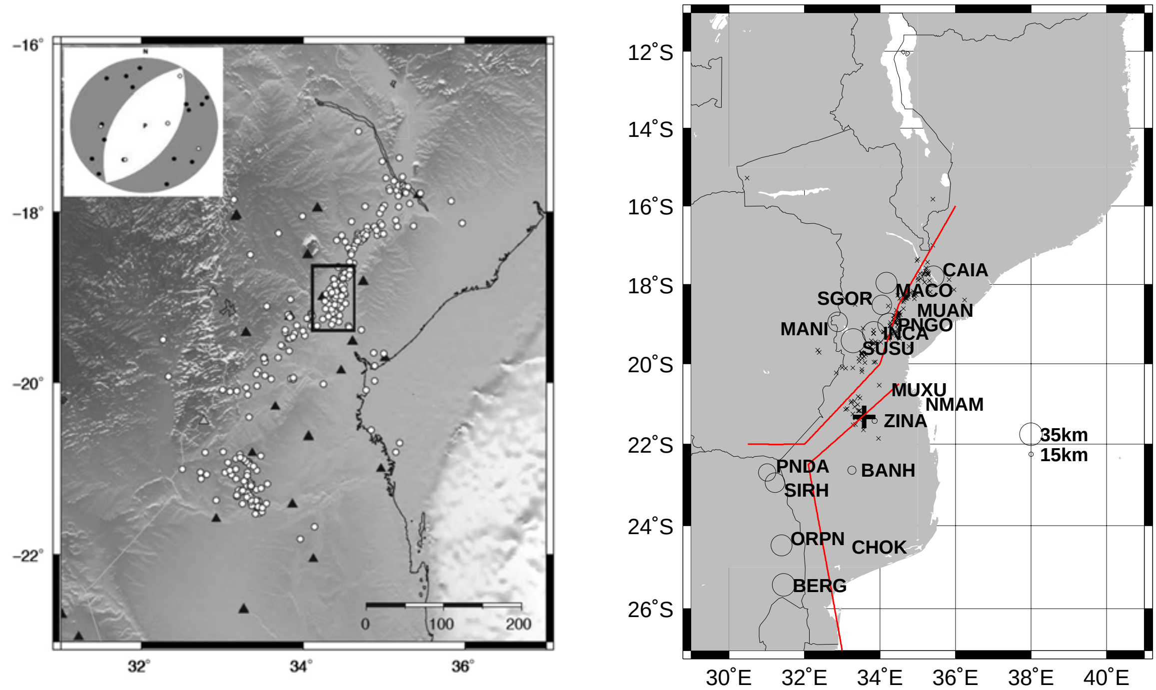

Figure 4. (left) Local seismicity located with MOZART data Apr. 2011-July 2012. Inset shows joint focal mechanism from four events with Ml > 2.4 indicating normal faulting along a NNE-SSW trend and suggesting the direction of rift propagation. (Figure from Fonseca et al. (2014)). (right) Preliminary receiver function results from Apr. 2011-July 2012 data. Crustal thickness along S. African margin is quite thick, but crust in Mozambique coastal plain is very thin, perhaps even sediment-covered oceanic crust. Red lines outline Urema Graben/Sabi Monocline and Kapvaal Craton margin. Cross shows location of 2006 M7 Machaze earthquake.

towards Madagascar (Figure 4).

A preliminary receiver function study shows that the crust is thickest to the west against the S. African cratonic margin (Fig. 4). Crust in the Mozambique Coastal Plain is much thinner, and with 4 km of sediment under the plain, suggests a non-sedimentary crustal thickness of ~10 km -- thin enough to be oceanic. The thick sedimentary cover makes it diff cult to see below the Moho to the mantle structure; some technical development work will be required to fully exploit this dataset for receiver function study.

A tomographic study of the region using body waves in collaboration with James Hammond (Imperial College) is anticipated, as well as incorporation of surface wave data into all-African tomography by Stewart Fishwick (U. Leicester).

Preliminary publication list.

- MOZART - A seismological investigation of Central Mozambique (talk) Ana Domingues, Jose Chamussa, George Helffrich, Stewart Fishwick, Ana Ferreira, Susana Custódio, Graça Silveira, Vladimiro Manhiça, and João Fonseca, EGU 2013 Meeting, Vienna.

- Ambient Noise Tomography of the East African Rift System in Mozambique (talk) Ana Domingues, Susana Custódio, José Chamussa, Graça Silveira, Sung-Joon Chang, Sergei Lebedev, Ana Ferreira, and João Fonseca, EGU 2014 Meeting, Vienna.
- Fonseca, J.F.D.B., Chamussa, J.P., Domingues, A.L., Helffrich, G.R., Antunes, E., van Aswegen, G., Pinto, L. V., Custódio, S.I., Manhiça, V. J. MOZART - a seismological investigation of the East African Rift in central Mozambique, Seismological Research Letters, v. 85, p. 108-116, 2014.

Conclusions and recommendations

Despite facing severe logistical and environmental problems, the MOZART group managed to collect data from ~25 sites in southern Mozambique and NE South Africa. The data suggest that the extension of the EARS system is towards the SSW, with no suggestion of an active link to Madagascar. Thus the triple junction separating the Nubian and Somalian parts of Africa and the Antarctic plate appears to be evolving to a position south of the Mozambique Channel.

Rifting also seems to be taking advantage of existing structures, following the trend of the Urema Graben and the cratonic margin of S. Africa. This suggests that pre-existing structures are guiding the progress of early rifting.

In future, SEIS-UK should consider recommending the practice followed here for buried sites, which use the bell-jar approach to prevent water ingress into buried sensor pits and into buried datalogger vaults. We found no water damage to instrumentation protected in this way.

Future datalogger procurement should include specif ed behavior when leap seconds occur. Present generation dataloggers do not respond well when these arise, which causes diff culty when large amounts of recorded data need to be reprocessed to correct invalid time stamps.