Above or Below the Moho? Contentious Earthquakes in the Southern East African Rift

Kimberly Espinal[1,1], Shiqi (Axel) Wang[1,1], Brian Chen[1,1], and Simon Klemperer[1,1]

[1]Stanford University

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Abstract

We studied seven earthquakes in the southern East African Rift System (EARS) with catalog depths of 10 to 33km, in locations where the Moho is thought to be at ~32 km depth (CRUST 1.0). Our earthquakes include three relocated by Yang and Chen (JGR, 2010) to be significantly deeper and to be below the Moho. We independently assessed whether the events occurred above or below the Moho using the Sn/Lg method (Wang et al., AGU Fall Meeting 2019; see also adjacent poster by Chen et al.). In a 1D earth, sub-Moho earthquakes produce strong Sn and weak Lg signals, and intra-crustal earthquakes produce weak Sn and strong Lg arrivals. All seven events we studied were characterized by low Sn/Lg, including the three earthquakes interpreted as upper-mantle events by Yang and Chen (2010) (their events M3 and M5 in Malawi and T12 in Zambia). Although low Sn/Lg is elsewhere associated with crustal events we suspect that, in the East African Rift, events in the shallow upper mantle that produce strong Sn at the source may be recorded at regional distances with low Sn/Lg due to Sn-to-Lg conversion at the deepening Moho at the rift margins. CRUST 1.0 suggests crustal thicknesses reach 45 km beneath the cratons adjacent to the East African Rift, with average Moho dips of 5-10°. Hence even the deepest earthquake reported by Yang and Chen (JGR, 2010), at 44±4 km, could undergo significant Sn-to-Lg conversion. Our findings highlight the importance of careful interpretation of Sn/Lg ratios and motivates our ongoing work to model 2D propagation effects.

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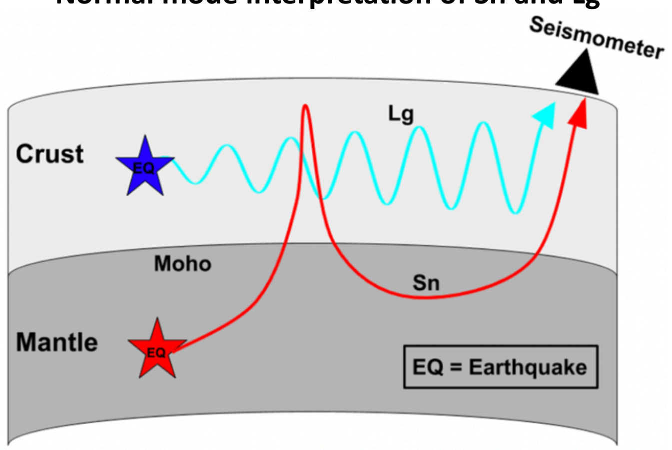
(1) Stanford University (2) Franklin & Marshall College (3) The Harker School

1) Introduction

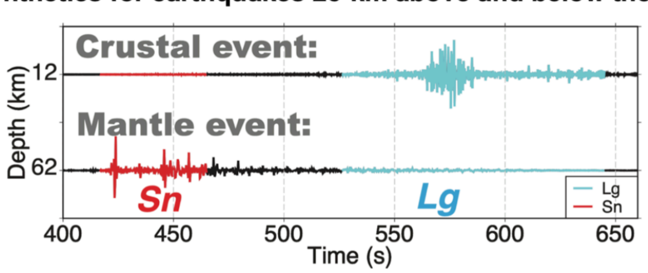
- Yang & Chen (2010) [1] claim there are mantle earthquakes beneath the East African Rift.
- Craig et al. (2011) [2] claim they are all in the crust or at the Moho.

Normal mode interpretation of Sn and Lg



- We use the ratio of Sn and Lg amplitudes (Sn/Lg) to determine whether an earthquake is above or below the Moho. In a 1-D earth, Sn/Lg >> 1 indicates a mantle earthquake and Sn/Lg << 1 indicates a crustal earthquake [3].

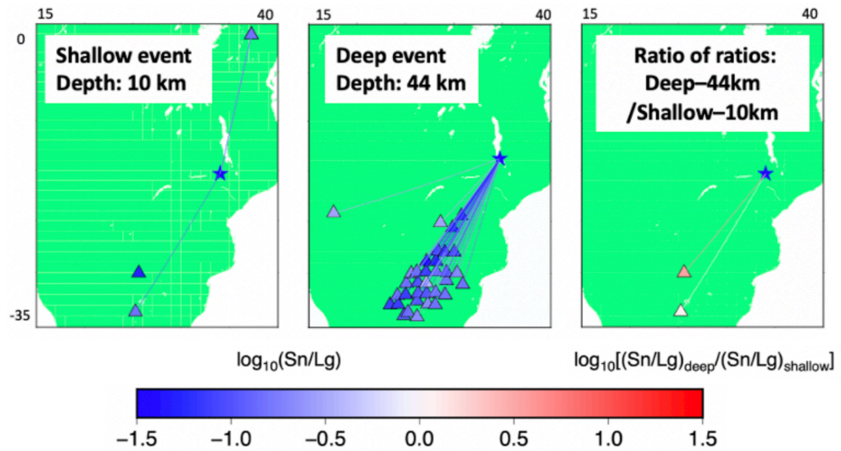
1-D synthetics for earthquakes 25-km above and below the Moho

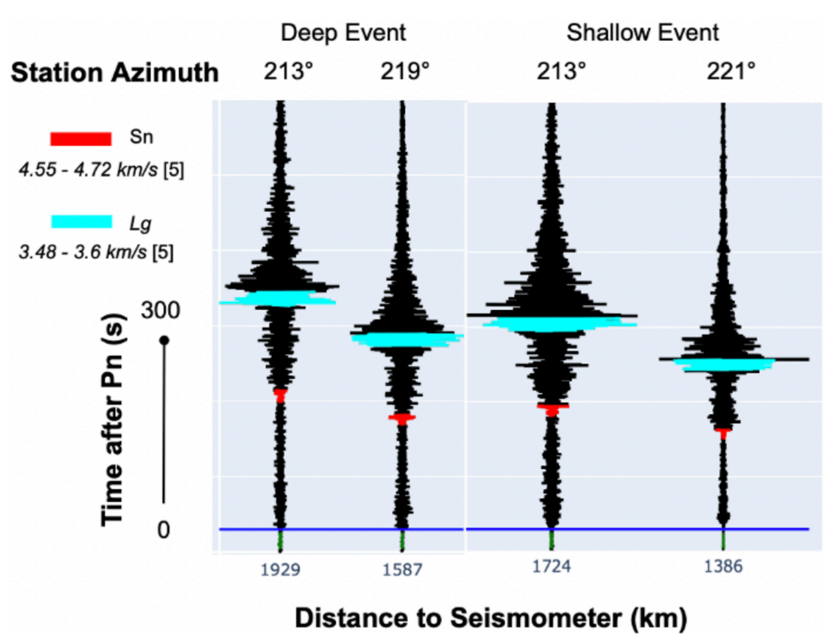


- Large Sn indicates mantle earthquakes, large Lg indicates crustal earthquakes.
- Absolute Sn/Lg ratios are sensitive to raypath and receiver effects, so we compare Sn/Lg of a target deep earthquake to Sn/Lg of a nearby shallow earthquake recorded at the same station ('ratio of ratios').
- *See Brian Chen's iPoster for details [4].*

2) Data

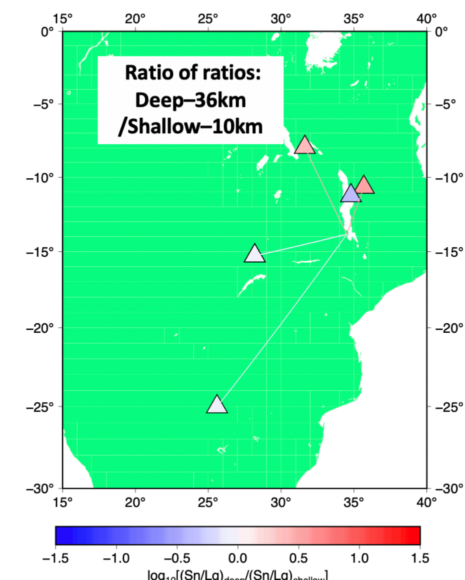
- Africa's deepest event (mb=4.7, 1998-08-24) was beneath Lake Malawi at 44 km, either "within error of the Moho" [2] or "well below the crust" [1].
- We compared this 44-km event to a 10-km deep event (mb=4.7, 1996-08-30) located 208 km distant. Sn/Lg < 1 on all traces for both earthquakes, so 1-D theory suggests both are in the crust.
- However, our 'ratio-of-ratios' plot shows (Sn/Lg)deep/(Sn/Lg)shallow > 1 at two stations that recorded both earthquakes.





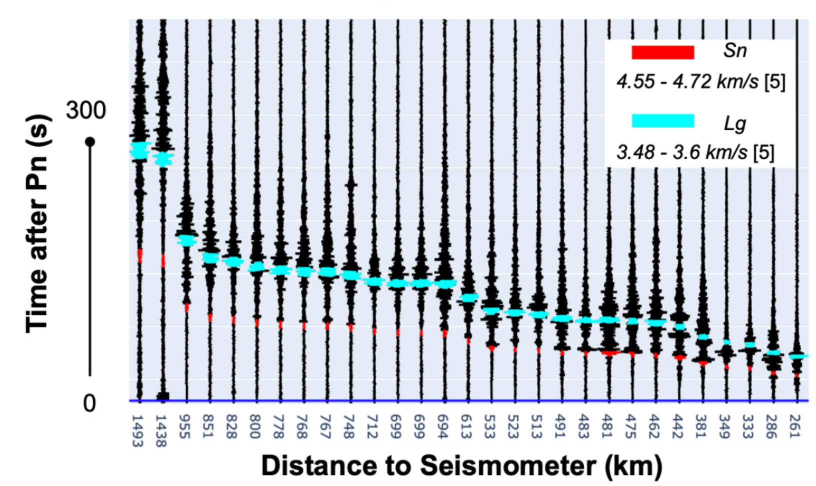
3) Results

- We plot the 44-km event on the Lake Malawi receiver-function image [6] (Panel 4). If the 44-km event is indeed beneath the rift, it is below the Moho.
- Lg amplitude >> Sn suggests a crustal source, but (Sn/Lg)deep/(Sn/Lg)shallow > 1 for all stations allows a sub-Moho origin for the 44-km event.
- We also examined the mb=4.4, 2015-08-15 event beneath Lake Malawi at 36 km and compared it to the mb=4.7, 2010-01-12 shallow event 10 km beneath Lake Malawi. The 36-km event has the same low Sn/Lg as the 44-km event, and our ratio-of-ratios plot shows 4 of 5 stations that recorded both events have $(Sn/Lg)_{deep}/(Sn/Lg)_{shallow} > 1$.



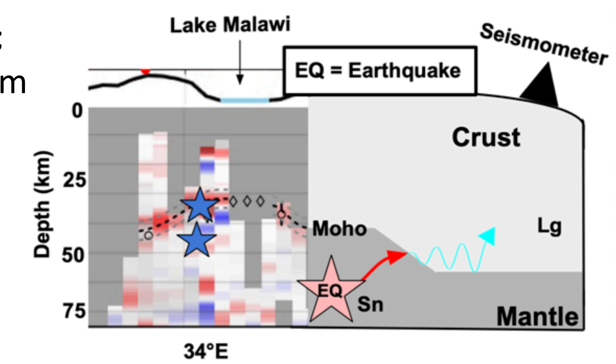
- We think this earthquake occurred below the Moho because of the very sharp onset of Sn.

Deep Event–36km



4) Conclusions

- Sn/Lg < 1 for some sub-Moho events because of 2-D Earth structure.
- Upper-mantle earthquakes beneath thin rift exhibit Sn-blockage as energy propagates into adjacent thicker crust, while crustal-earthquakes show Sn-to-Lg conversion as energy propagates into thinner crust.
- We suspect the 44-km event was 'at the Moho' at the rift edge; and the 36-km event was below the Moho within the rift.



- The Sn/Lg method that works very well for a 1-D Earth [3] must be applied with much greater care in regions of significant Moho topography.
- Plots of $(Sn/Lg)_{deep}/(Sn/Lg)_{shallow}$ remove path and station effects. We believe some earthquakes occur in the mantle beneath the East African Rift, suggesting a 'jelly-sandwich' rheological model.
- We are developing 2-D synthetics to formally model the effects of Sn to Lg conversion.

5) References

- Stanford's Summer of Undergraduate Research in Geoscience and Engineering (SURGE) program and Stanford Earth Young Investigators (SEYI) program sponsored the participation of KE and BC, respectively.
- Seismic data acquisition with IRIS and USGS Earthquake Catalogues.

1. Yang, Z., & Chen, W. P. Earthquakes along the East African Rift System: A multiscale, system-wide perspective. J. of Geophysical Research 115(12), 1–31 (2010).
2. Craig, T. J., Jackson, J. A., Priestley, K., & Mckenzie, D. Earthquake distribution patterns in Africa: Their relationship to variations in lithospheric and geological structure, and their rheological implications. Geophysical. J. Intl. 185, 403-234 (2011).
3. Wang, S. and Klemperer, S.L., 2019. Quantitative study on the relative excitation of guided seismic waves Sn and Lg as a function of source depth. AGUFM, 2019, pp.S31D-0554.
4. Chen, B., Wang, S., Klemperer, S.L. and Espinal, K., 2020, December. Above or Below the Moho? Depth analysis of continental US earthquakes using Sn/Lg ratio. In AGU Fall Meeting 2020. AGU.
5. Gumper, F., & Pomeroy, P. W. (1970). Seismic Wave Velocities and Earth Structure on the African Continent. 60(2), 651–668.
6. Hopper, E., Gaherty, J. B., Shillington, + 9 co-authors. Preferential localized thinning of lithospheric mantle in the melt-poor Malawi Rift. Nature Geoscience, page 16. (2020).