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Deep Rupture Process of the April 3, 2017 Earthquake in Stable Continental Region, Botswana

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Abstract. On April 3, 2017 an earthquake of magnitude Mw 6.5 occurred in Botswana in a region where there was no recent tectonic activity and where present-day deformation is believed to be negligible. The event was followed by several aftershocks distributed along in NW-SE direction with NE-SW extension direction. We focused on determination of a reliable source parameters for the Mw 6.5 earthquake using moment tensor inversion both in time and frequency domains from regional and broadband waveform data. We obtained the rupture source at the depth of 38.4 km deeper than the previous results. The estimated reliable source depth of this study is approximately estimated at the boundary between lower crust and Moho depth beneath the region, reflecting a deep source that is relatively rare in stable continental regions. This source depth may suggest the continental-rift initiation between weak upper mantle and weak lower crust or due to reactivation of the pre-existing faults with NW–SE geological structure beneath the region at deep. Focal mechanism of the event resulted from moment tensor inversion shows normal faulting with NE-SW extension. The results of this study will provide useful information for future seismicity of the region in such stable area where rare large magnitude and deep earthquake occurs.

Keywords: East African Rift System, Okavango Delta Region, Okavango Rift Zone.

1 Introduction

The African continent is a tectonic plate with diverse geological domains that include seismically active and aseismic region. The East African Rift System (EARS) has been the site occurrence of small to large magnitude earthquakes for many years [5]. The Botswana region in particular has been the site of several small to moderate earthquakes [13]. The April 3, 2017 Botswana earthquake struck the central Botswana and the shaking was felt in different neighboring countries and Modified Mercalli intensities of VI [10] was estimated. Major historical earthquakes recorded in Botswana are mainly located in the northern part of the April 2017 Botswana main shock location, in Okavango Delta Region (ODR) where young arm of the EARS is developing thus, the region thought to be an incipient rift. Previously the region has been rocked by the 11th of September and 11th of October 1952 earthquakes with magnitudes of 6.1 and 6.7 ML [13], respectively.

Several studies on the April 3, 2017 Botswana earthquake have been published. [1] used InSAR interferograms, classified the event as a natural intraplate earthquake. On the other hand, from geodetic data [6] proposed deep fluid migration for the event. [12] suggested the event may be controlled by the collocation of a weak upper mantle and weak crustal structure, between otherwise strong Precambrian blocks. Moreover, [9] used teleseismic broadband waveform data to generate synthetic waveforms in the time domain. Studying such large earthquake in the region helps to refine and estimate source parameters and expands our understanding of reliable rupture source of the event in a region where there is no direct evidence for observed surface deformation related to fault plane, which implies unusually deeper source. Seismicity of EARS is mainly characterized by shallow depths however, the April 3, 2017 Botswana earthquake is relatively deep which has never been observed before. Depth estimation of an earthquake is usually the most difficult to nail down with great accuracy thus, techniques used to determine earthquake depth [8] should be improved. Therefore, we applied a mixed approach moment tensor inversion using regional broadband waveform data that provide reliable source parameters of the event.

2 Data and Method

Three-component broadband waveform data and instrument response information were obtained from the IRIS DMC for all stations at regional distances which successfully recorded the April 3 2017 Botswana earthquake (Fig. 4).

In this study we applied the approach developed by [2] to estimate source parameters of the event using moment tensor inversion both in frequency and time domains. We selected six broadband seismic stations with high quality waveform data located at various azimuths and distances from the source. We generated synthetic seismograms both in time and frequency domain and fitted synthetic seismograms with the observed seismograms for three-component seismic waveform data and the reliable source parameters of the event were extracted at the best fits (Figs. 2 &3) using the band-pass filtering in the range of 0.02-0.05 Hz.

3 Results

After conducting the moment tensor inversion for the April 3 2017 Botswana earthquake, rupture source depth of 38.4 km has been estimated with an error misfit of 0.296. Moment magnitude Mw 6.5 is estimated for the event. A good waveform fit is obtained for the observed and synthetic seismograms in both cases (Figs. 2 & 3), thus the source parameters are selected.

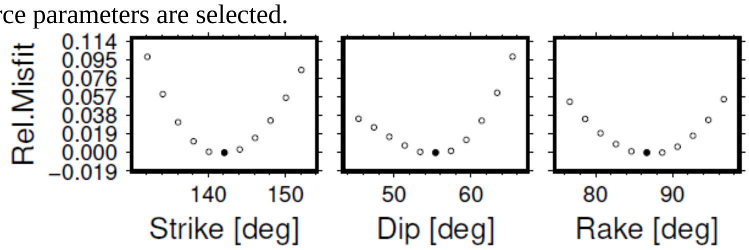

Fig. 1. The misfit versus Strike, Dip and Rake angles for fault plane solution of the April 3 2017 Botswana earthquake estimated using moment tensor inversion and obtained at source

depth of 38.4 km. The bold black dots represent the value at which three angles are selected from the minimum variance.

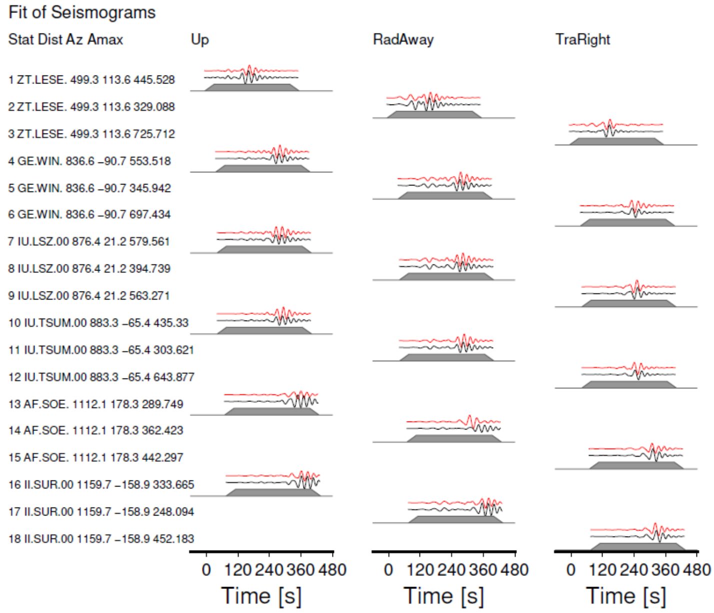

Fig. 2. Regional waveform fits of the April 3 2017 Botswana mainshock from six three-component broadband seismic stations using moment tensor inversion in the time domain. The panel is dedicated to waveform comparison (red color is for data, black is for synthetics). Stations are sorted according to epicentral distances, with station name, distance, azimuth and maximal amplitudes provided on the left side.

4 Discussion

The distribution of aftershocks (Fig.4) of the April 3 2017 Botswana earthquake show NW-SE trending, consistent with the trend of focal mechanism of the mainshock. The southward propagation of the EARS extends to the southwest into Botswana where it forms a southwestern branch [11] towards the northern Botswana in the Okavango Rift Zone (ORZ) and weakness zones initiate strain location, when coupled to favorable plate kinematics can lead to continental break-up [3]. The Gumare and Nare faults appear to represent the NW and SE extent of recognized rift related faults and a zone of extension [7]. Thus, we interpreted that the extension of EARS towards Botswana may be the main cause of the 2017 Botswana earthquake occurrence. The focal mechanism of the event is purely normal faulting with NW-SE extension.

The well-constrained rupture source depth is estimated to be 38.4 km, which is near to be the lower crust and upper mantle boundary, reflecting a deep source which is rare in the earthquake occurrence tradition of the EARS. In northwestern ORZ serves as the stage development of continental rifts and the structures bounding and linking rift basins are strongly controlled by pre-existing rift structures [14]. The development of continental rifts is controlled by deep-seated structures within the lithosphere [4]. Therefore, the deep rupture source result of this study may suggests the reactivation of a deep weak preexisting NW–SE trending geological structure or from the early rift faults within the stress region during rift initiation beneath the area.

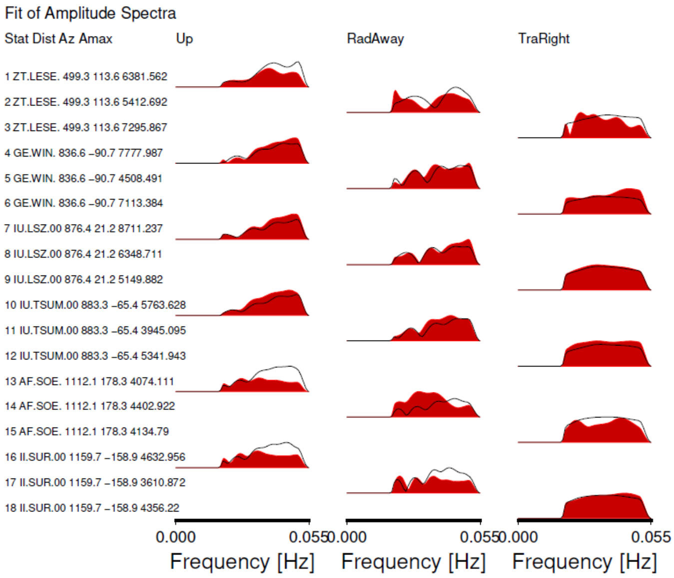

Fig. 3. Spectra amplitude fits of the April 3 2017 Botswana mainshock from six three-component broadband seismic stations using moment tensor inversion in frequency domain. The panel is dedicated to spectra comparison (red color is for data, black is for synthetics). Stations are sorted based on epicentral distances, with station name, distance, azimuth and maximal amplitudes provided on the left side. Source parameters are selected at this fit.

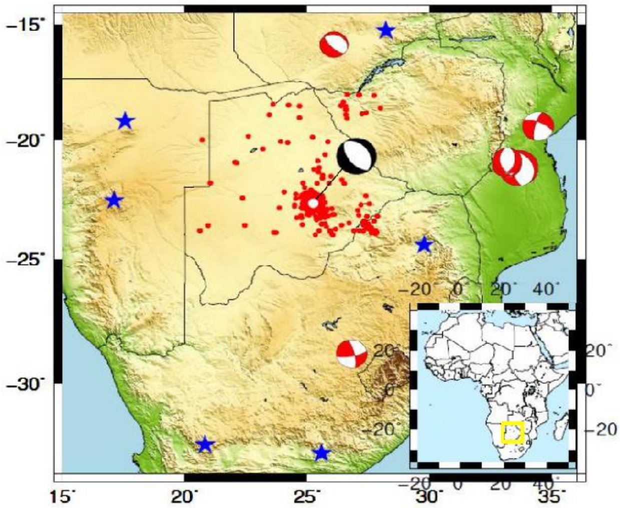

Fig. 4. Focal mechanism of the April 3 2017 Botswana mainshock and its aftershocks distribution. The red dots represent the epicentre location of aftershocks. The blue stars represent the

seismic stations used in moment tensor inversion. The black and white color beach ball is for fault plane solution of the 2017 Botswana mainshock, while the red and white beach balls represent the GCMT solutions. Inset map shows the study area.

5 Conclusions

We applied time and frequency domains moment tensor inversion techniques from regional waveform data to determine reliable source parameters of the April 3 2017 Mw 6.5 Botswana earthquake. The moment magnitude of Mw 6.5 is estimated using broad bandpass frequency range of 0.02-0.05 Hz in contrast to the GCMT solution relatively narrow frequency range of 0.025-0.02 Hz. Our fault plane solution shows normal faulting on a NW-SE trending fault and NE-SW extension direction, thus, the southward propagation of EARS towards Botswana may be the main cause for the occurrence of this rare event. We obtained the rupture source depth of 38.4 km, deeper than the previous results in this study which is unusually deep source. The source may suggest the reactivation of a deep weak pre-existing NW–SE geological structure or from the early rift faults within the stress region during rift initiation beneath the area**.**

References

1. Albano, M., Polcari, M., Bignami, C., Moro,M., Saroli,M., & Stramondo,S. Did anthropogenic activities trigger the 3 April 2017 Mw 6.5 Botswana earthquake? *Remote Sens.* **9**, 1–12 (2017).
2. Cesca, S., Heimann, S., Stammler, K. & Dahm, T. Automated procedure for point and kinematic source inversion at regional distances. *J. Geophys. Res. Solid Earth* **115**, 1–24 (2010).
3. Corti,G., Wink, J,V., Bonin, M., Sokoutis, D., Cloetingh,S., Innocenti, F., Manetti, P.Transition from continental break-up to punctiform seafloor spreading: How fast, symmetric and magmatic. *Geophys. Res. Lett.* **30**, 1–4 (2003).
4. Delvaux, D., Fronhoffs, A., Hus, R. & Poort, J. Normal fault splays, relay ramps and transfer zones in the central part of the Baikal rift basin: insight from digital topography and bathymetry. *Bcredp* 341–358 (1998).
5. Foster, A. N. & Jackson, J. A. Source parameters of large African earthquakes: implications for crustal rheology and regional kinematics. *Geophys. J. Int.* **134**, 422–448 (1998).
6. Gardonio, B., Jolivet, R., Calais, E. & Leclère, H. The April 2017 Mw6.5 Botswana Earthquake: An Intraplate Event Triggered by Deep Fluids. *Geophys. Res. Lett.* **45**, 8886–8896 (2018).
7. Kinabo, B. D., Atekwana, E.A., Hogan, J.P., Modisi, M.P., Wheaton, D.D., Kampunzu, A.B. Early structural development of the Okavango rift zone, NW Botswana. *J. African Earth Sci.* **48**, 125–136 (2007).

8. Maggi, A., Jackson, J. A., McKenzie, D. & Priestley, K. Earthquake focal depths, effective elastic thickness, and the strength of the continental lithosphere. *Geology* **28**, 495–498 (2000).
9. Materna, K., Wei, S., Wang, X., Heng, L., Wang, T., Chen,W., Salman, R., Bürgmann, R. Source characteristics of the 2017 M w 6.4 Moijabana, Botswana earthquake, a rare lower-crustal event within an ancient zone of weakness. *Earth Planet. Sci. Lett.* **506**, 348–359 (2019).
10. Midzi, V., Saunders, I., Manzunzu, B., Kwadiba, M., T., Jele, V., Mantsha, R,. The 03 April 2017 Botswana M6.5 earthquake: Preliminary results. *J. African Earth Sci.* **143**, 187–194 (2018).
11. Modisi, M. P. Fault system at the southeastern boundary of the Okavango Rift, Botswana. *J. African Earth Sci.* **30**, 569–578 (2000).
12. Moorkamp, M., Fishwick, S., Walker, R. J. & Jones, A. G. Geophysical evidence for crustal and mantle weak zones controlling intra-plate seismicity – the 2017 Botswana earthquake sequence. *Earth Planet. Sci. Lett.* **506**, 175–183 (2019).
13. Nthaba, B., Simon, R. E. & Ogubazghi, G. M. Seismicity Study of Botswana from 1966 to 2012. *Int. J. Geosci.* **09**, 707–718 (2018).
14. Ring, U. Urema graben. **13**, 313–326 (1994).