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ORIGINAL PAPER

Rupture process of the April 2017 Mw 6.5 Botswana Earthquake: deepest earthquake observed in continental Africa

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Abstract
On April 3, 2017, an earthquake of magnitude Mw 6.5 ruptured in Botswana in a region where there was no significant recent tectonic activity and where present-day deformation is believed to be negligible. The event was followed by several aftershocks distributed along NW-SE direction with NE-SW extension direction. We focused on the determination of reliable source parameters for the Mw 6.5 main shock using moment tensor inversion, in both time and frequency domains from regional, broadband waveform data. We retrieve the source depth at 38.4 km, probably the deepest earthquake observed in continental Africa. The estimated hypocentral depth of this earthquake is roughly about the Moho depth beneath the region, reflecting a deep source that is relatively rare in stable continental regions. The result may suggest that the seismogenic depth is as deep as the average global Moho thickness indicating the upper mantle and lower crust region is actively deforming due to a reactivation of the preexisting fault oriented in the NW-SE direction. The resulting focal mechanism of the event shows normal faulting with NE-SW extension direction. The result may provide useful information for contemporary geodynamic investigation of the area.

Keywords East African Rift System · Okavango Delta Region · Okavango Rift Zone · Moment tensor inversion

Introduction

The African continent is a tectonic plate with diverse geological domains that include seismically active and aseismic regions where the seismic activity is mainly characterized by shallow depth earthquakes (Adagunodo et al. 2018). The East African Rift System (EARS) is active with seismicity of small to large magnitude earthquakes (Shudofsky 1985; Nyblade and Langston 1995; Nyblade et al. 1996; Foster and Jackson 1998; Langston et al. 2002; Weeraratne et al. 2003; Kim et al. 2009; Yang and Chen 2010; Albaric et al. 2010, 2014; Ayele et al. 2007, 2016; Isola et al. 2014) and the distribution of earthquakes is mainly confined to the active rift zones (Fairhead and Girdler 1972; Iranga 1992; Nyblade et al. 1996; Langston et al. 2002). Majority of the earthquakes occur at plate boundaries (e.g., Sykes 1978) where the earthquake energy budget is dominated by stress loading of well-defined active faults (Calais et al. 2016). Unlike earthquakes at plate boundaries, the stable continental earthquakes are rarely localized on well-defined active faults or poor surface expressions of causative structures (Crone et al. 1997). Intra-plate earthquakes in stable continental regions are infrequent and occur in regions with low strain rates (Calais et al. 2006; Tregoning et al. 2013). Despite their rare occurrence, earthquakes with larger magnitudes affect several continents (Calais et al. 2016). Most of the present-day intra-plate earthquakes are followed by an intense aftershock sequences (Boyd et al. 2015). Thus, the April 3, 2017, Botswana main shock is an example of the intra-plate earthquake in a stable continental region that exhibits hundreds of aftershock sequences and occurred in the region with low seismicity.

The Botswana region has been the site of several small to moderate earthquakes (Fig. 1; Nthaba et al. 2018) with different tectonic settings which hosts the third arm of the EARS

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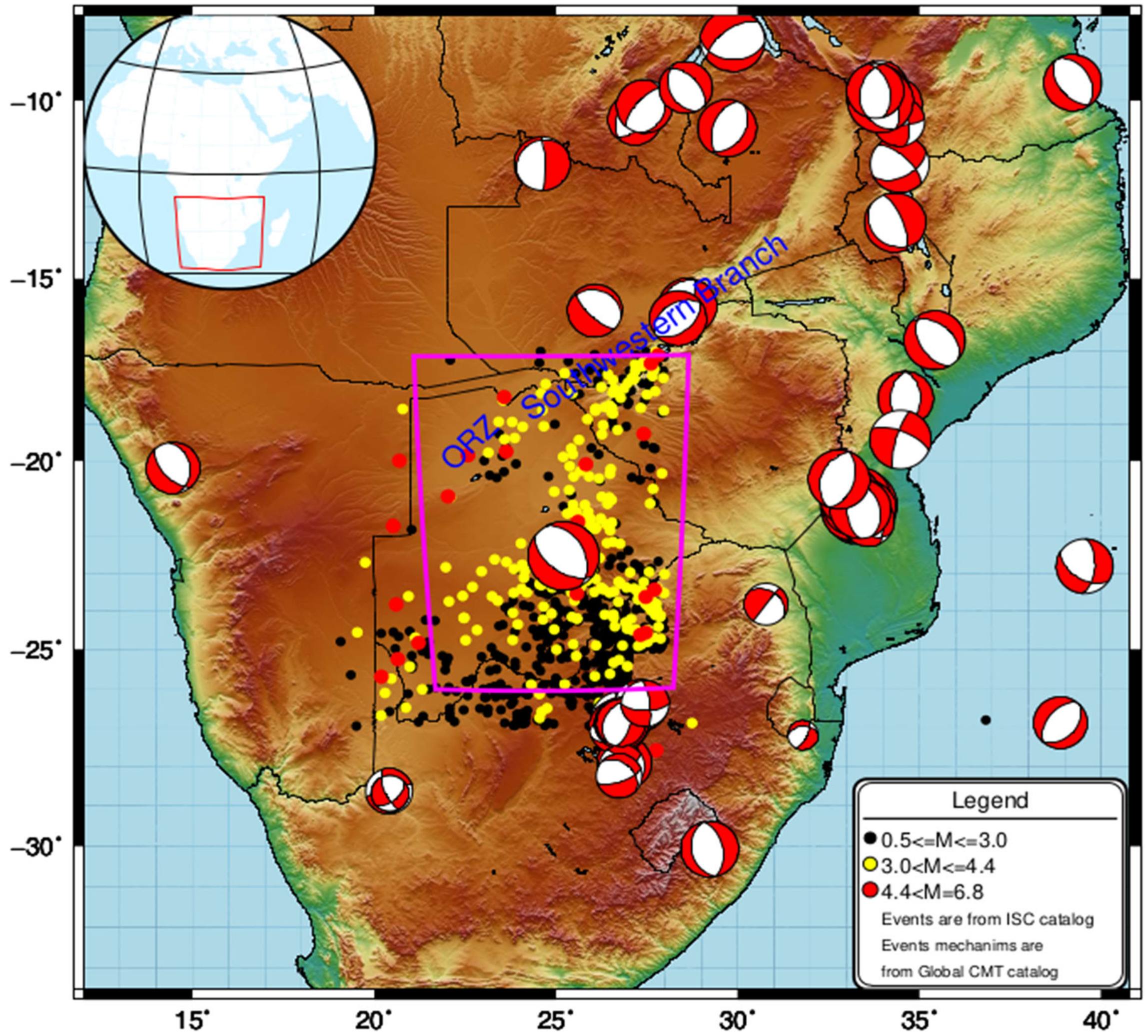

Fig. 1 Seismicity of the Botswana region with earthquake magnitudes in the range of 0.5 to 6.8 for the time period of 2000 to 2017 compiled from the International Seismological Center (ISC) catalog. The region is dominated by lower magnitude earthquakes within the range of 0.5 to 3.0 and the southern part of the study area is seismically more active as compared to the other parts of the region. Different color circles (black, yellow, and red) show the epicenters of earthquakes where circle size is proportional to earthquake magnitude as shown in the legend. The magenta box on the map shows the study area

(Figs. 1 and 2). The April 3, 2017, Botswana earthquake of magnitude Mw 6.5 occurred within the Paleoprotozoic Limpopo Orogenic Belt, a tectonic area dominated by a collisional suture zone located between the Kaapvaal and Zimbabwe Cratons (Khoza et al. 2013), with historically low seismic activity (Stamps et al. 2014).

The April 3, 2017, Botswana earthquake struck central Botswana and the shaking was felt in different neighboring countries with Modified Mercalli Intensity of VI (Midzi et al. 2018). The event is unique and drew attention as its epicenter is quite far from the frequent locations of earthquakes in the EARS. Major historical earthquakes recorded in Botswana are mainly located north of the April 3, 2017, event near Okavango Delta Region (ODR) where the young arm of the EARS is developing and thought to be an incipient rift (Modisi, 2000). Previously, the region has been rocked by the 11 September and 11 October 1952 earthquakes with magnitudes of 6.1 and 6.7 ML, respectively (Nthaba et al. 2018).

The April 3, 2017, Botswana earthquake has been investigated by several researchers using various methods which ended with different interpretations. The geometric and kinematic characteristics of the causative fault were estimated from the modeling of Sentinel-1 InSAR interferograms and the best-fit solution for the main shock was represented by a normal fault located at a depth greater than 20 km and classified the event as a natural intra-plate earthquake (Albano et al. 2017). Gardonio et al. (2018) proposed a reservoir of elastic stress that can be released episodically, as a result of deep fluid migration for the event at the depth of 29 ± 4 km which proposed to require a transient pulse of fluids from a deep source to activate brittle faulting. On the other hand, Moorkamp et al. (2019) suggested the event may be a sign

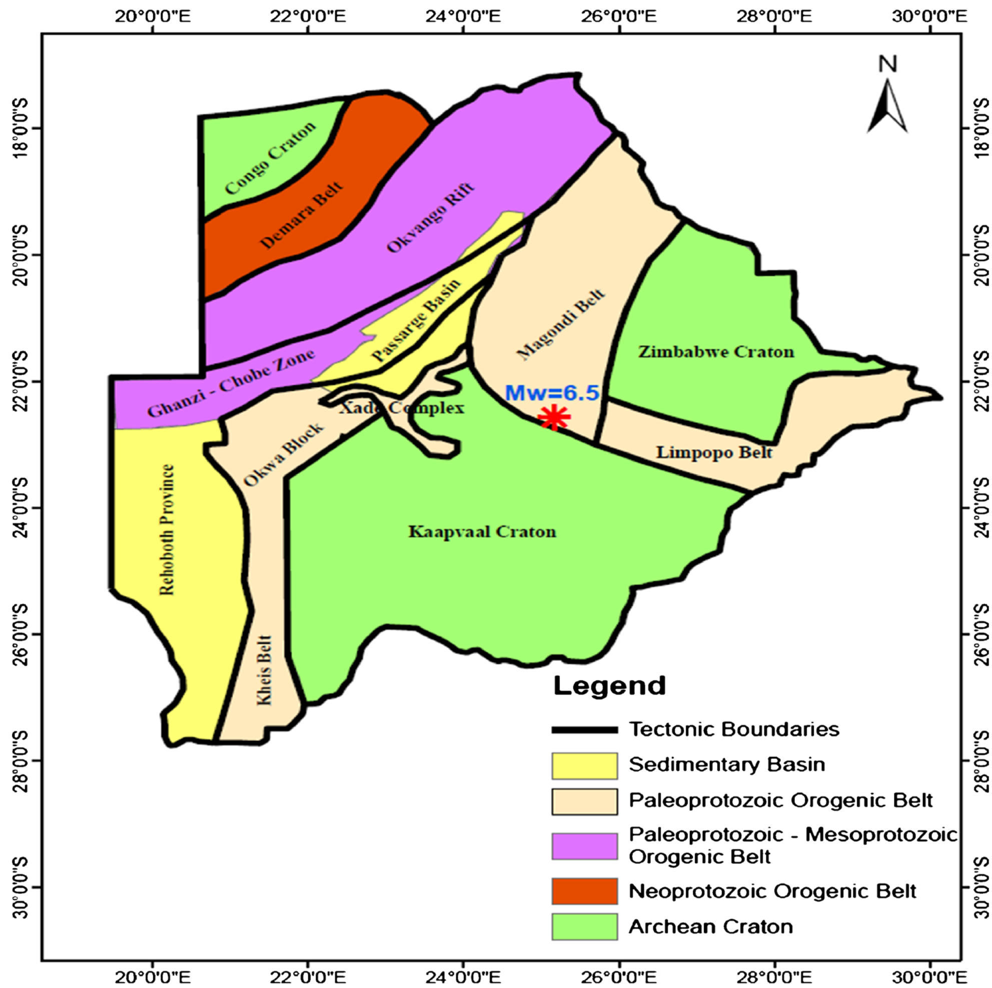

Fig. 2 An overview of the tectonic and geologic map of Botswana and its surroundings. The epicetral location of the April 3, 2017, Botswana main shock of Mw 6.5 is shown by red asterisk. Black lines represent the tectonic boundaries from Fadel et al. (2018) modified after Singletary et al. (2003) and McCourt et al. (2013). Geologic map of Archean cratons and Proterozoic orogenic belts in Botswana and surroundings is after Leseane et al. (2015)

of future activity, controlled by the collocation of a weak upper mantle and a weak crustal structure using a result of an integrated geophysical study. Moreover, Materna et al. (2019) attempted to generate synthetic seismograms in the time domain from teleseismic broadband waveform, and suggested that the event appears to have occurred in an ancient zone of weakness. Furthermore, Midzi et al. (2018) estimated quite a low value of maximum intensity of VI for such a large event.

Earthquake source characterization in the stable regions like Botswana is challenging due to poorly understood earthquake source investigation in the past. Thus, studying such a large earthquake of 3 April 2017 of Mw 6.5 Botswana earthquake may help to refine estimates of source parameters and expand our understanding of reliable hypocentral depth of the event in a region where present-day deformation is believed to be negligible. An accurate hypocentral depth estimation of an earthquake is a critical parameter for understanding the tectonics and evaluating earthquake hazards of a region in the context of the occurrence of a great earthquake. However, hypocentral depth estimation of an earthquake is usually the most difficult to nail down with great accuracy. Therefore, the main purpose of this effort is to obtain reliable source parameters of the April 3, 2017, Botswana main shock using a mixed approach moment tensor inversion in both time and frequency domains from regional broadband waveform data that require few number of station in contrast to P-wave first motion focal mechanism study.

Geologic and tectonic setting

The East African Rift System (EARS) is a well-developed continental rift with major geodynamic feature splitting the African continent into the Nubian and Somalia plates. The EARS propagates in the southward direction through Ethiopia (Beyene and Abdelsalam, 2005) and then forms two main rift segments; the eastern and western branches. When we go further south, the third arm of the EARS is called the southwestern branch (e.g., Girdler 1973; Chapman and Pollack 1974; Ballard et al. 1987; Modisi 2000; Scholz and Koczynski 2007; Mosley et al. 2012). This rift branch is dominated by NE-SW trending faults that have similar orientation with Lake Kariba (Figs. 1 and 8) and the localized seismic activity led many authors that have been working in the region since the late 1960s to believe that this area is the final extension of the EARS. Therefore, the southwestern branch of the EARS is believed to be an incipient rifting zone (Modisi 2000; Scholz and Koczynski 2007; Mosley et al. 2012).

The basement of the Botswana geology is dominated by complex tectonic inheritance of early Archean cratonic blocks and belts (Fig. 2). The well-known three major cratons are the Congo, Zimbabwe, and the Kaapvaal Cratons. Thus, the diverse tectonic features of the region encompass these cratons (Fadel et al. 2018) with several mobile belts found in the region: the Limpopo, Magondi, and Damara Belts (Key and Neil, 2000). The main provinces of the ORZ and the current study area are sandwiched between the Neoproterozoic Congo Craton to the northwest (Yu et al. 2015), the Kaapvaal Craton in the south, and Zimbabwe Craton in the east-southeast (Fig. 2; Kinabo et al. 2008; Begg et al. 2009). Most of the Botswana region is dominated by the basement rocks of the Kaapvaal and Zimbabwe Cratons that are extending in the east and southeast with metamorphic rocks of Archaean age and Limpopo Belt (McCourt et al. 2004). The collision between the Kaapvaal and Zimbabwe Cratons during late Archean caused the dominant planar surface along the Limpopo Belt (Roering et al. 1992). The Limpopo Paleoproterozoic Orogenic Belt encloses a lithospheric scale suture zone resulted from the collision of these two cratons. It is a Neoarchean orogenic belt which has a width of ~250 km and ~600 km length located between the Zimbabwe Craton to the north and the Kaapvaal Craton to the south (Ranganai et al. 2002). The current study focuses on the April 3, 2017, Botswana earthquake of Mw 6.5 that occurred within the Paleoprozoic Limpopo Orogenic Belt (Fig. 2). The cratonic margins and some intra-cratonic domain boundaries may have a major role in the tectonics of the region. Boundaries may have localized successive cycles of extension, rifting, and the ongoing development of the East African Rift while uplifted topographic feature of the region has been affected by the African Superswell (Brandt et al. 2012). Thus, the African Superswell is responsible for the cratonic movement resulted in the formation of the southern African tectonic region (Begg et al. 2009).

The southwest branch of the EARS and the Botswana region are one of the least studied areas in the African continent as compared to the other parts in the region with diverse tectonic features and several mobile belts which may be the cause of earthquakes in the region. Earthquake distributions can be found in several parts of the region mainly in the mobile belt area like ODR. The historical earthquakes of 1952 occurred within the Okavango Rift Zone at the end of the southwestern branch of the EARS (Fig. 8; Modisi, 2000). A relatively high level of seismicity distribution within the Okavango Rift Zone suggests rifting in the Bostawana is due to the extension of the EARS. The initiation and early-stage development of the rift are mostly due to lithospheric stretching resulted from the relative motion between the Archean Congo and Kalahari cratons along preexisting ancient orogenic zones (Yu et al. 2016).

The majority of the largest earthquakes in the African continent are concentrated near tectonic plate boundaries where the continent is pulling apart in an approximately east-west direction because of the presence of the EARS; thus earthquakes with normal faults are dominating the deformation pattern in the region. The Botswana region does not show any strong earthquakes activity in the instrumental era. The clustering of small magnitude events in the Okavango Delta has led to speculation of an incipient rift in the Okavango Rift Zone (ORZ) (Leseane et al. 2015) which may represent the southwestern continuation of the EARS (Fadel et al. 2018). However, the April 3, 2017, Botswana main shock shows normal faulting with extensional direction roughly in the NE-SW which seems to differ from the common trends of earthquakes focal mechanism within the EARS.

Data and method

In this study, three-component broadband waveform data are obtained from the Data Management Center of the Incorporated Research Institutions for Seismology (IRIS DMC). We use broadband data from six permanent seismic stations at epicentral distances in the range of roughly 500–1160 km which successfully recorded the April 3, 2017, Botswana earthquake shown in Fig. 8. We selected broadband seismic stations with a high signal-to-noise ratio (e.g., Fig. 3) located at various azimuths and distances from the source. The quality of all three-component broadband waveform data was checked and decided to use prior to the inversion.

Several methods are employed over the years for detailed study of the rupture process of a large magnitude earthquake. Accordingly, the source parameters of the April 3, 2017, Botswana main shock have been routinely processed and reported by several agencies like the National Earthquake Information Center (NEIC), Institut de Physique du Globe de Paris (IPGP), International Seismological Centre (ISC), and the Global Centroid Moment Tensor (GCMT). Here, we have critically examined the source parameters of the event from waveform inversion using the regional broadband data. A regional and global 1D velocity models are used in a moment tensor inversion (e.g., Dreger et al. 2000; Zahradnık et al. 2005). Hence, the 1D velocity model is an adequate approximation that reveals a successful inversion results. In this study, the displacement records of the April 3, 2017, Botswana main shock are retrieved after removing the instrument response. For better characterizing the source parameters of the event, we have used 1D local velocity model (Qiu et al. 1996) developed near the source of the event. The source

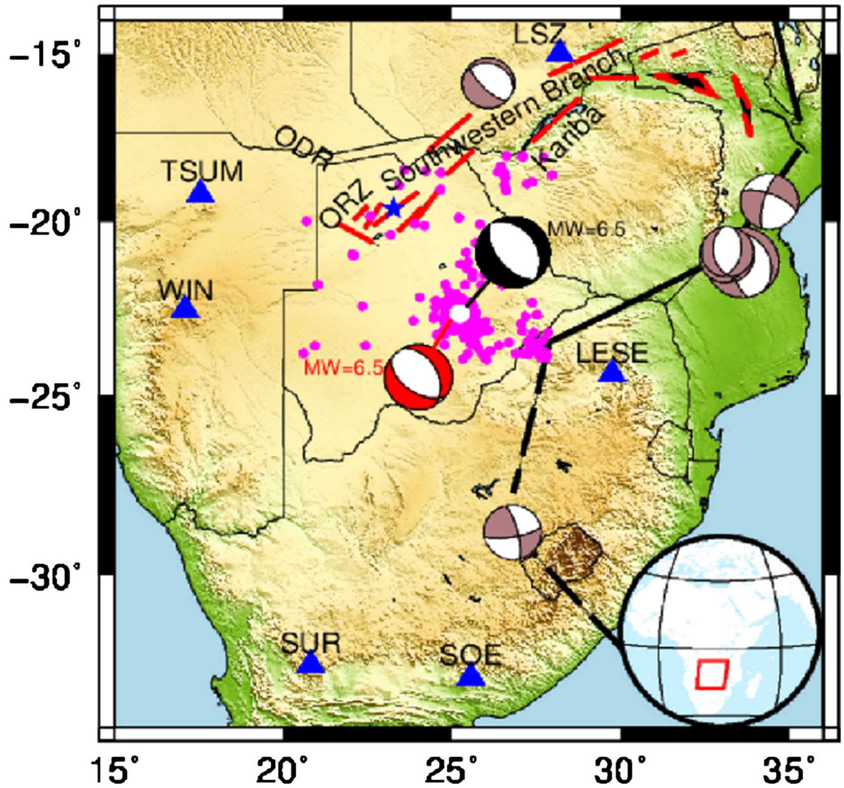

Fig. 8 Focal mechanism of the April 3, 2017, Botswana main shock (black and white color beach ball) and its aftershock distribution. The white dot represents the location of main shock and magenta dots represent the epicenter location of aftershocks. The blue triangles represent the seismic stations used and the blue star is the location of historical earthquakes of the 11 September and 11 October 1952 earthquakes with magnitudes of 6.1 and 6.7 ML. The red and white beach ball is the focal mechanism for 2017 Botswana main shock from GCMT solution while pink and white are for some earthquakes from GCMT solutions. Broken red lines represent the fault system of the Okavango Rift Zone (ORZ) and southwestern branch; ODR represents Okavango Delta Region modified from Kinabo (2007). Heavy black lines represent plate boundaries modified from Bird (2003). Inset map shows the study area

parameters of the event were estimated based on this velocity model.

We applied the approach developed by Cesca et al. (2010) to estimate the source parameters of the event under discussion with magnitude Mw 6.5. In the inversion procedure, synthetic seismograms are generated and fitted with observed seismograms through a bandpass filtering in the range of 0.02–0.05 Hz. We calculated our uncertainty with an error misfits of L2 norm which is equal to sqrt((d - s)**2), where d are data and s are synthetics. The L2 norm method is used to minimize the difference between the observed and synthetic seismograms. Two indicators were identified and considered in the evaluation of the quality of solutions. The first indicator was misfit value that reflects the quality of the solutions. The second indicator was a relative misfit curves for hypocentral depth, strike, dip, and rake perturbations. This stability indicator prefers solutions, for which a common perturbation of strike, dip, or rake angles that will induce a major variation of the misfit values and find the source depth at smallest misfit (see Figs. 6 and 7) based on the L2 norm calculation. The reliable source parameters of the event were extracted at the best fits between synthetic and waveform data.

In the first step, time domain inversion was performed through a bandpass filtering in the range of 0.02–0.05 Hz. Both waveforms and Green's functions are filtered using bandpass filtering of 0.02–0.05 Hz. The amplitude and phase fits of the seismograms have been considered in this inversion technique. We generated synthetic seismograms and compared with the observed waveform data. The solution is solved by calculating synthetic seismograms for the possible solutions by shifting to the best fits with observations by evaluating the L2 norm misfits. The inversion is conducted until a reasonable waveform fit is achieved between the observed and synthetic seismograms. Due to some small misfits, the generated synthetic seismograms are shifted relative to the observed in phases and amplitudes. The best solutions are searched and the corresponding required parameters are estimated (Fig. 4). The results of strike, dip, and rake angles are extracted (Fig. 6). In addition, solution for source depth is computed (hypocentral depth versus relative misfits) and the best solution has chosen at the smallest misfits (e.g., Fig. 7) in this inversion technique.

In the second step, we applied the amplitude spectra inversion. In this inversion technique, we used the same bandpass

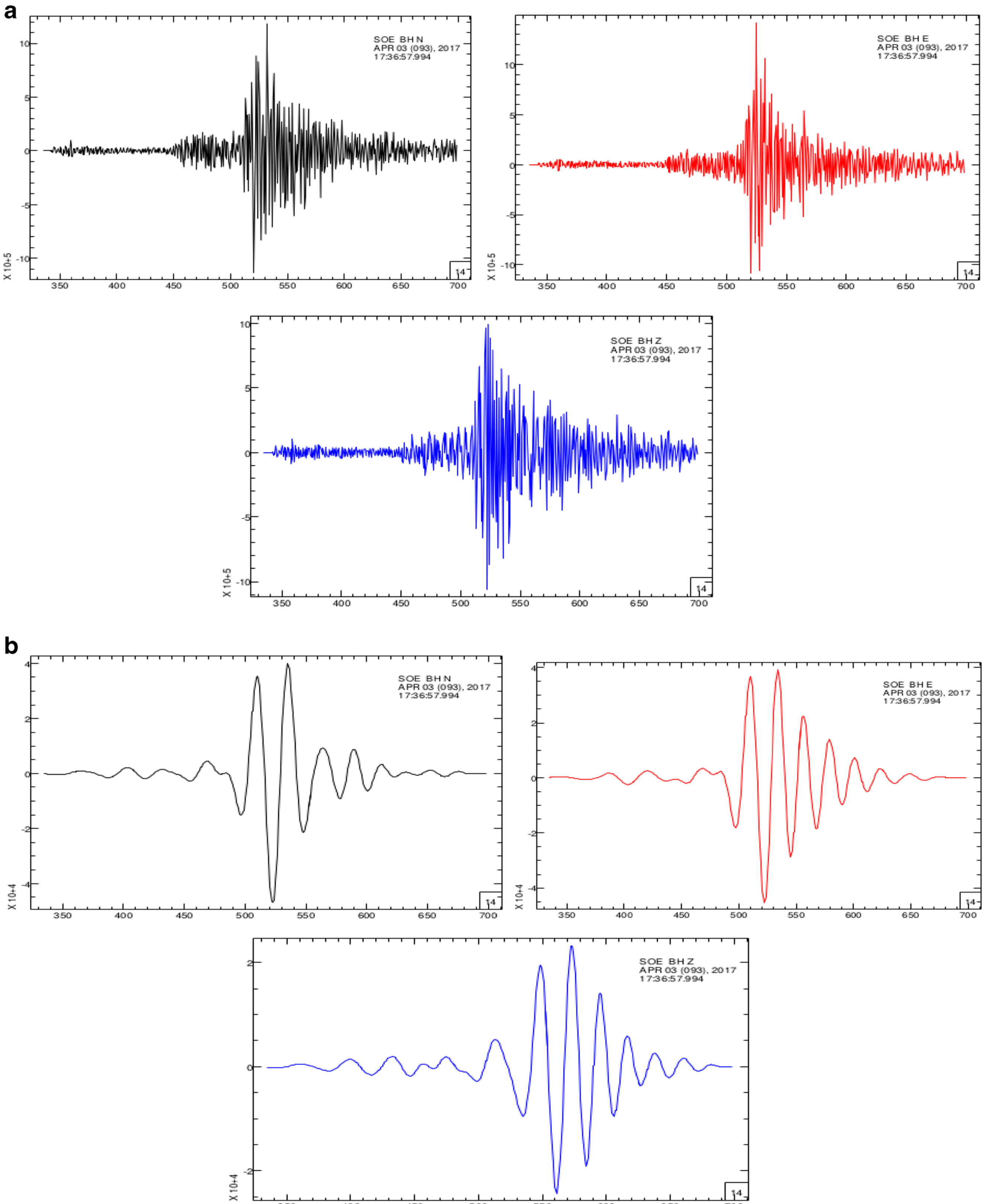

Fig. 3 Seismograms of the April 3, 2017, Botswana main shock recorded at the SOE seismic station. **a** The raw data for three-component seismograms. **b** The three-component seismograms filtered at bandpass filtering range from 0.02 to 0.05 Hz (after instrument response removed) which are used in the inversions process of this study. E, N, Z indicate (E-W), (N-S) and vertical components respectively

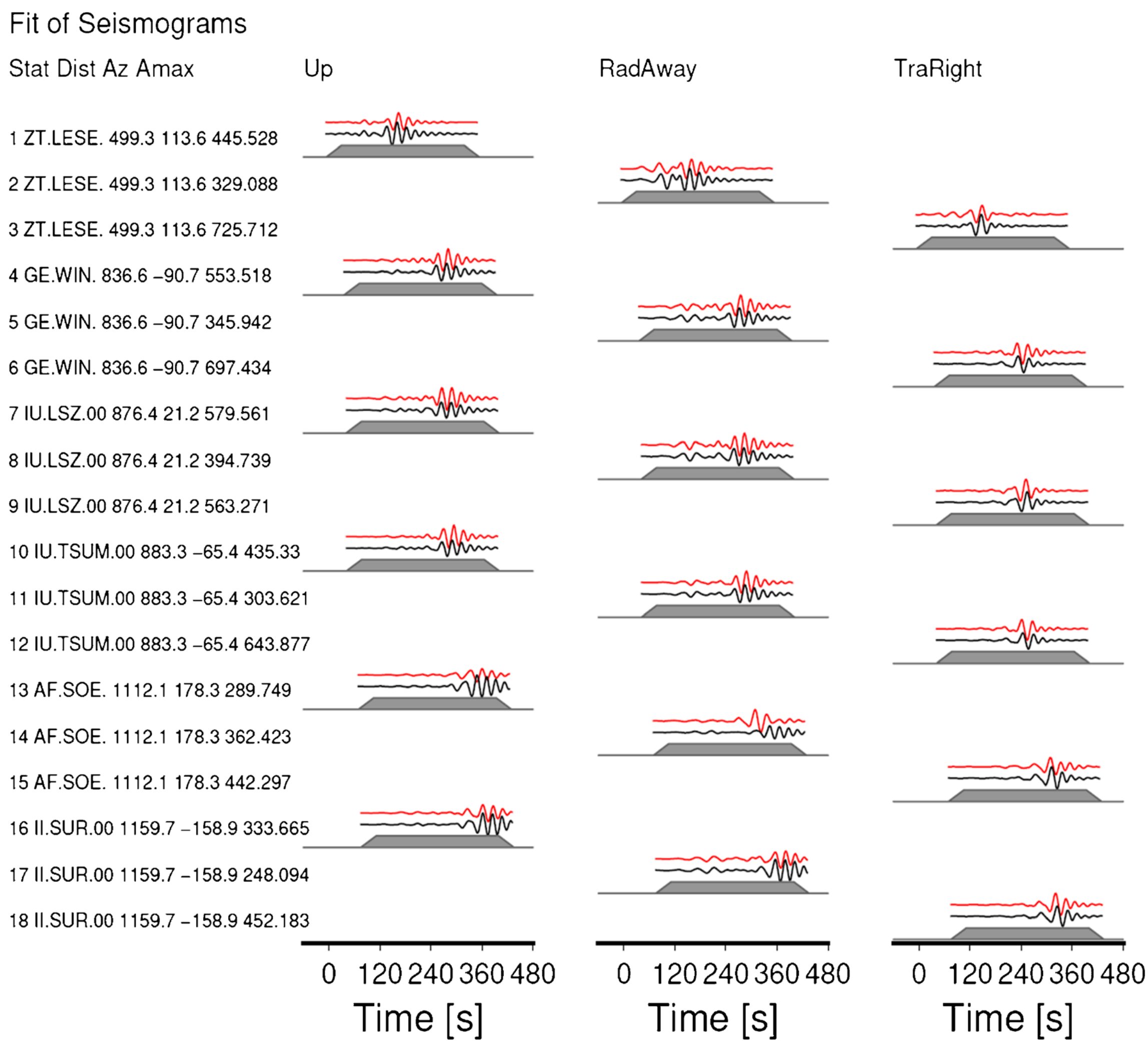

Fig. 4 Regional waveform fits of the April 3, 2017, Botswana main shock using moment tensor inversion in the time domain. The panel is dedicated to waveform comparison (the red color is for data, black is for synthetics). Stations are sorted according to epicentral distances, with station name, distance, azimuth, and maximal amplitude provided on the left side

filtering range and regional waveform data that we used for the time domain inversion. This technique is less sensitive to a precise trace alignment and phase shifting owing to mismodeling of the crustal structure (Cesca et al. 2010) and it is very helpful to search the source parameters with small misfits because in the inversion procedure the fitted result is only amplitude spectra. Therefore, an amplitude spectral inversion has advantages over the time domain inversion (Dahm et al. 1999; Cesca et al. 2006). After the inversion, the values of strike, dip, rake, and hypocentral depth are estimated.

The best solutions are accepted with errors misfits of 0.572 and 0.296 (L2 norm misfit sense) for time and spectral domains, respectively. As we compare the fits of time domain

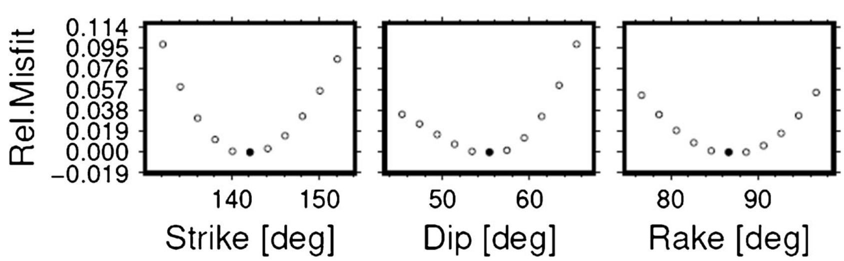

Fig. 6 The relative misfits (illustrate how our misfit increases when we perturb one single parameter) versus strike, dip, and rake angles for the fault plane solution estimated using a moment tensor inversion and obtained at a hypocentral depth of 38.4 km. The bold black dots represent the values at which the three angles are selected from the minimum variance

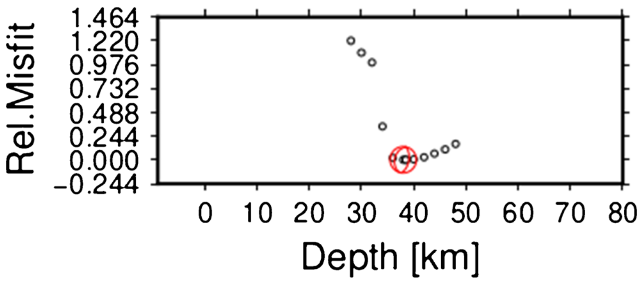

Fig. 7 Relative misfits versus hypocentral depths of the April 3, 2017, Botswana earthquake of magnitude Mw 6.5 computed from the moment tensor inversions. The best solution has been chosen at the smallest misfit for the hypocentral depth (38.4 km)

and spectral domain inversions, error with small misfit is obtained in spectral inversion than the time domain, because in the time domain inversion procedure fits in both phase and amplitude are required. The spectral fit is less sensitive to a precise trace alignment because only amplitude spectra fit is required. An example of the three-component waveform data recorded on seismic station SOE that were used in the inversion for the April 3, 2017, Botswana earthquake of magnitude Mw 6.5 is plotted in Fig. 3.

Here, we use six three-component seismic stations (a total of 18 phases), thus full waveform or spectral inversion for 18 components of ground motion gave us a reasonable fit for a generic 1d crustal model. We are confident that the final source parameters obtained in this study are robustly determined where the fault plane parameters are also in good agreement with the GCMT solutions. In fact, it is not uncommon to use single station full waveform inversion to get a reasonable estimate of fault plane solutions (Delouis and Legrand, 1999; Zahradník et al. 2015).

Results

After conducting the moment tensor inversion for the April 3, 2017, Botswana earthquake, hypocentral depth of 38.4 km has been estimated with an error misfits of 0.572 and 0.296 (L2 norm misfit sense) for time and spectral domain inversions, respectively. The moment magnitude of Mw 6.5 was estimated for the event which is consistent with the value obtained by the Global CMT solution (Table 1). Normal fault plane solution is obtained from the inversion in time and frequency domains. A good waveform fit is obtained for the observed and synthetic seismograms in both inversion techniques (Figs. 4 and 5).

Discussion

An interest to study earthquakes in the stable continental regions was increased after the 1968 Meckering, 1986 Marryat Creek, and 1988 Tennant Creek earthquakes in Australia. These events had formed scarps up to 30 km long and 2 m height were which reactivated preexisting faults within Precambrian crust (Calais et al. 2016). In the stable part of the African continent, the M6.3 1969 Ceres earthquake occurred in the region with no evidence of significant previous seismicity (Smit et al. 2015). On the other hand, the recent April 3, 2017, Botswana earthquake has occurred in the stable continental region that had probably no earthquake occurrence in the past and poorly developed neotectonic features. The event has occurred likely in the stable African continent near the northeast margin of Kaapvaal Craton within the Limpopo Belt and significant number of aftershock sequences (Figs. 2 and 8).

The overall distribution of aftershocks (Fig. 8) of the April 3, 2017, Botswana earthquake roughly shows NW-SE trending, consistent with the trend of the focal mechanism of the main shock (purely normal faulting). The southward propagation of the EARS extends to the southwest into Botswana where it forms a southwestern branch (Modisi, 2000) towards the Okavango Rift Zone (ORZ) and weak zones initiate strain when coupled with favorable plate kinematics which will eventually lead to continental breakup. Thus, the ORZ comprises a rift related faults and a zone of extensional regime (Kinabo 2007) that might be responsible for seismicity of the region. On the other hand, the low velocity anomaly observed at the upper mantle beneath the EARS (Adams et al. 2012) seems to affect the crust through weak low velocity zones at the Okavango Rift Zone and the border of the Kaapvaal Craton. Therefore, we believe that the extension of the EARS until the border of the Kaapvaal Craton (Yu et al. 2016) might be the cause for the occurrence of the large April 3, 2017, Botswana earthquake of magnitude 6.5 Mw with its NE-SW extension direction.

Table 1 Source parameters of the April 3, 2017, Botswana main shock from the moment tensor inversion of this study and reported by global agencies (GCMT, NEIC, IPGP, and ISC)

Agency	Strike (°)	Dip (°)	Rake (°)	Depth (km)	Magnitude (Mw)
GCMT	126/332	51/41	−107/−70	30	6.5
NEIC	139.46/336.7	54.29/36.96	−100.25/76.08	29	6.5
ISC	138.47/350.70	67.48/26.12	−103.58/−60.49	20.5	–
IPGP	133/333	57/35	−101/−74	30	6.5
This study	142/328	55/35	−93/−85	38.4	6.5

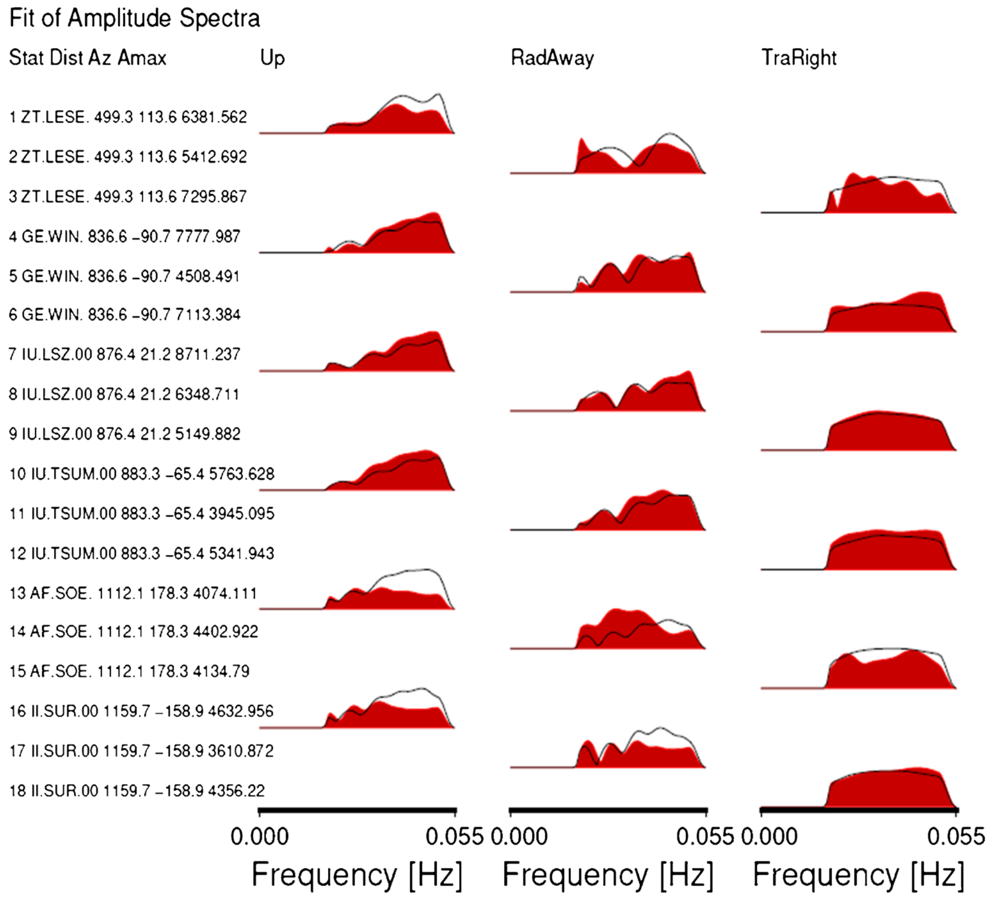

Fig. 5 Spectra amplitude fits of the April 3, 2017, Botswana main shock using moment tensor inversion in the frequency domain. The panel is dedicated to spectra comparison (the red color is for data, black is for synthetics). Stations are sorted based on epicentral distances, with station name, distance, azimuth, and maximal amplitude provided on the left side

Relatively deeper event (> 25 km) in stable continental region has been reported by Johnston, (1996). Various mechanisms have been proposed for deeper earthquakes that occurred in a stable continental region (Zhan et al. 2016). The mechanisms do not seem to be common for all of deeper source seismicity. For instance, a hypocentral depth of an earthquake may correlate with heat flow and tectonic age which may generally be valid for most cratons. The mechanism of an earthquake might be associated with a preexisting rift structures. A reactivation of preexisting rift fault is likely to take place due the stress perturbation and it appears to be a plausible mechanism associated with an earthquake in the intra-cratonic zones.

The well-constrained hypocentral depth of the event is estimated to be at 38.4 km, near the lower crust and the upper mantle boundary. The source is reflecting relatively deepest hypocentral depth that is rare in the occurrence of earthquakes along the EARS. In the previous study, Moorkamp et al. (2019) suggests the crustal and mantle weak zones control seismicity of the 2017 Botswana earthquake sequence using the result of geophysical evidence. The Okavango Rift Zone is at the initial stage of continental breakup in which the preexisting rift structures are strongly controlling the linking rift basins (Ring 1994). Therefore, we suggest a relatively deep hypocentral depth for intra-plate earthquake in stable continental region of the April 3, 2017, Botswana main shock might be associated to a reactivation of preexisting NW-SE trending geological rift beneath the margin of the Kaapvaal Craton and Limpopo Belt. Thus, we are disagree for the event origin that constitutes a reservoir of elastic stress that can be released episodically as a result of deep fluid migration suggested by Gardonio et al. 2018.

On the other hand, the large magnitude earthquakes that occur at plate boundaries and sometimes close to populated areas may pose a significant threat to human lives and infrastructure. However, such a large magnitude of the April 3, 2017, of Mw 6.5 Botswana earthquake is typically occurred on previously unknown faults. The Mw 6.5 Botswana earthquake is one of the largest instrumentally recorded events within the Botswana territory, though the event caused little to no damage, but its effect was felt over a wide area.

The source parameters of the event estimated in this study and the one reported by global agencies are summarized in Table 1. We estimated a magnitude of Mw 6.5 and normal faulting that are in agreement with solutions from other global agencies (GCMT, NEIC, IPGP, and ISC). But our solution for the hypocentral depth of the event is slightly deeper than the others (Table 1). As we compare an average of the two nodal planes with the other agencies, small variations are observed between our solution and the

NEIC, and IPGP. On an average, the differences of rake angles are 5.62° and 7°, dip angles are 1.335° and 1°, and rake angles 8.085° and 9.5° for NEIC and IPGP, respectively. Therefore, the source parameters of the event in this study are more in agreement with the solutions reported by NEIC and IPGP.

It is difficult to model aftershock sequences by using the techniques used in this study. The techniques need high quality of data (data with a high signal-to-noise ratio) for large magnitude earthquakes. We suggest an alternative method such as the first polarity reading for aftershock sequences with larger magnitudes. However, focal mechanisms of some of these aftershock sequences with larger magnitudes have been computed by the Council for Geoscience (PRE) using polarity method and available on ISC catalog.

Conclusions

We applied time and frequency domain 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 the broad bandpass frequency range of 0.02 to 0.05. Our fault plane solution shows normal faulting on NW-SE trending fault and NE-SW extension direction.

The well-constrained hypocentral depth of this event is estimated at 38.4 km, which is relatively deeper than previous results. The mechanism for relatively deep hypocentral depth, which is near to the lower crust and the upper mantle boundary, may suggest the reactivation of preexisting fault. The result of the inversion for the focal mechanism of the event is in agreement with the previously reported global solutions with extensional nature consistent to the majority of the focal mechanism in the East African Rift System. Indeed, we believe that the earthquake epicenter is located in an extensional area, where a new rifting zone is developing due to active deformation of lower crust and upper mantle. The results of this study is intriguing and exciting which will provide useful information for modeling geodynamics of the region.

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Declarations

Conflict of interest The author(s) declare that they have no competing interests.

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