Relocating aftershocks of the 2017 Moiyabana, Botswana earthquake

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INTRODUCTION

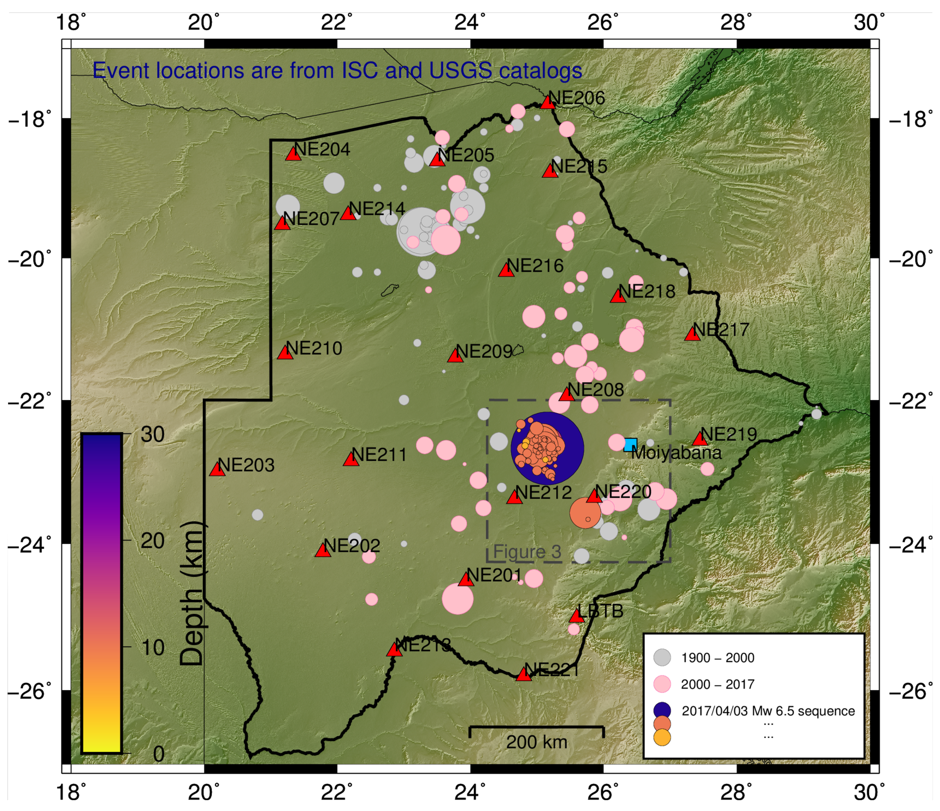

Figure 1: Earthquake event location map. Brighter colored circles represent the 2017 Moiyabana earthquake sequence. Magnitudes are given by the size of the circles. The seismic stations are shown as red triangles.

Botswana has been known for its low historical seismic activity. On April 3, 2017 a magnitude 6.5 earthquake occurred in southeast Botswana. Because the 2017 Moiyabana earthquake occurred more than 300 km away from the East African Rift System, the event has been classified as an intraplate seismic event. Large intraplate earthquakes can cause severe damage to buildings and infrastructure, but their seismic hazard is hard to assess.

A sequence of 79 aftershocks was recorded with magnitudes between 2.5 and 5.0. The majority of these earthquakes occurred in the Paleoproterozoic Limpopo-Shashe (LS) orogenic belt, whereas two aftershocks are located in the Kaapvaal Craton.

The LS belt was formed during collision between the Kaapvaal Craton and Zimbabwe Craton, resulting in northeast dipping thrust faults in the southern part of the belt. A 30 - 120 meter thick layer of Kalahari sand challenges the investigation on the structures that slipped during the earthquake sequence. Relocations of the aftershocks give insight in the geometries of these structures and how they relate to the local geology.

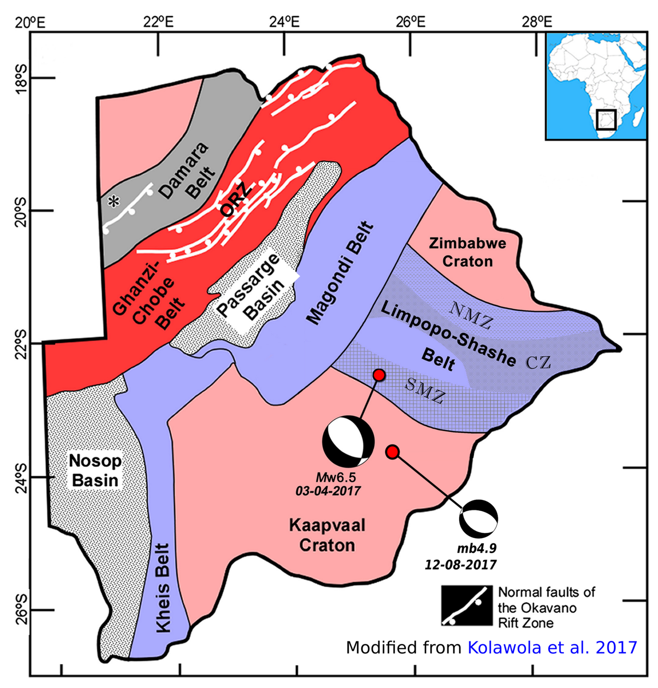

Figure 2: Tectonic map of Botswana. The focal mechanisms are from the USGS catalog and H. Paulssen (personal communication).

DATA & METHODS

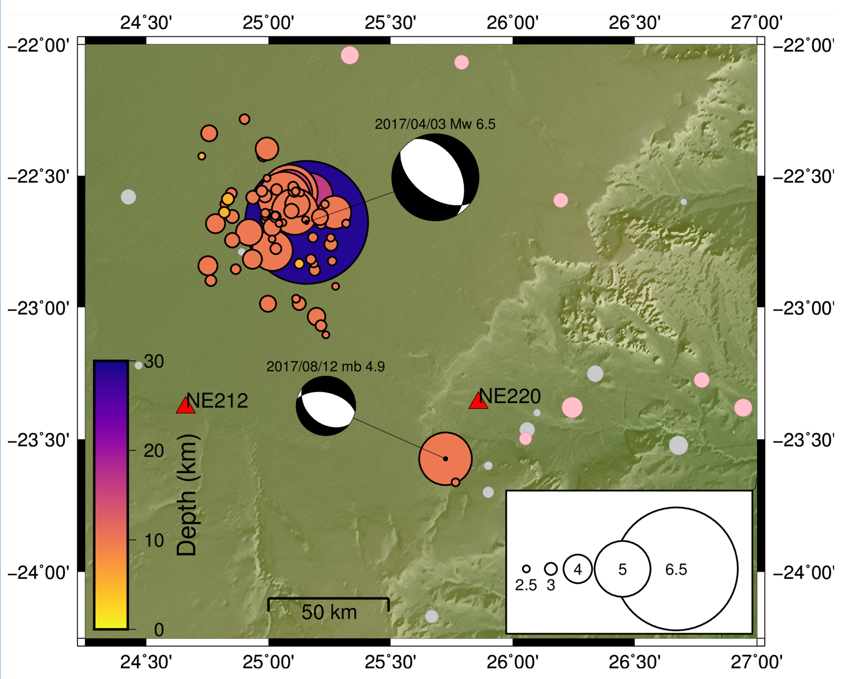

Figure 3: Initial locations of the 2017 Moiyabana earthquake sequence.

Data

The earthquakes used for the relocation occurred between April 3, 2017 and November 9, 2017. The arrival time picks are from station LBTB and stations of the NARS Botswana seismic network.

HypoDD

HypoDD[1] is used to determine the relocations. Double-difference residuals are calculated by taking the differences in travel times between pairs of events.

Double-difference residual:

$$dr_k^{ij} = (t_k^i - t_k^j)^{obs} - (t_k^i - t_k^j)^{cal}$$

When the distance between two events is small compared to the event-station distance, then the travel time difference between the events can be attributed to the spatial offset.

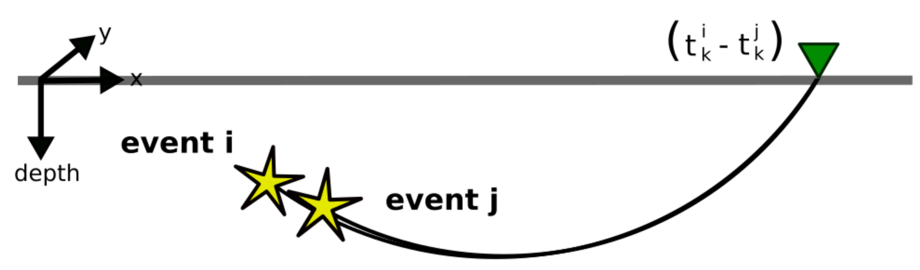

Figure 4: Sketch of the double-difference method. The travel time of event i at station k is given by t_k^i.

RESULTS

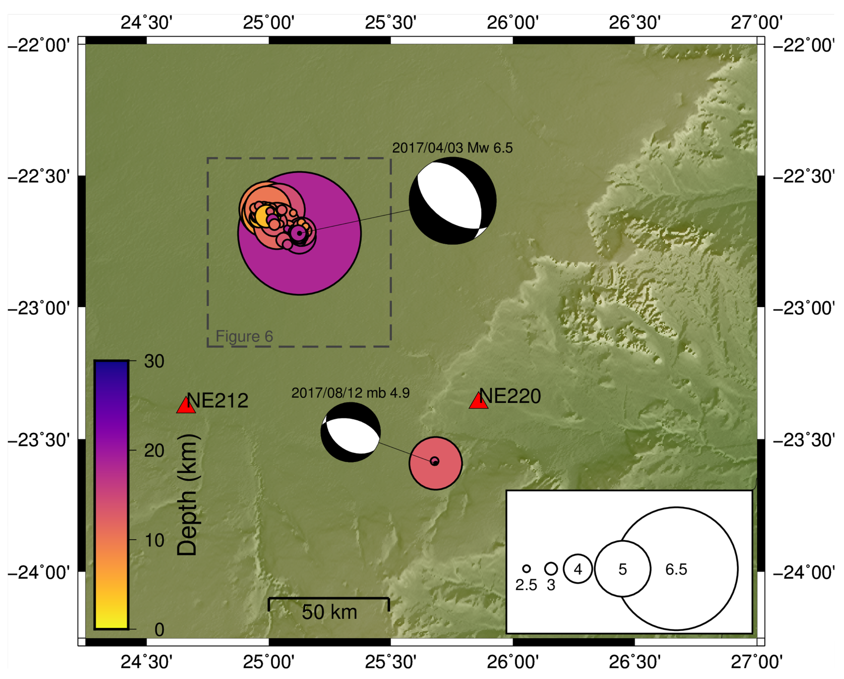

Figure 5: Relocated earthquake hypocenters.

After relocation:

- The hypocenters are located closer together
- The events in the large cluster are located along a plane with NW-SE strike, dipping towards the northeast
- The depth of the aftershocks decreases towards the northwest
- The depth range is from 0.1 ± 0.6 km to 18.4 ± 0.7 km

DISCUSSION

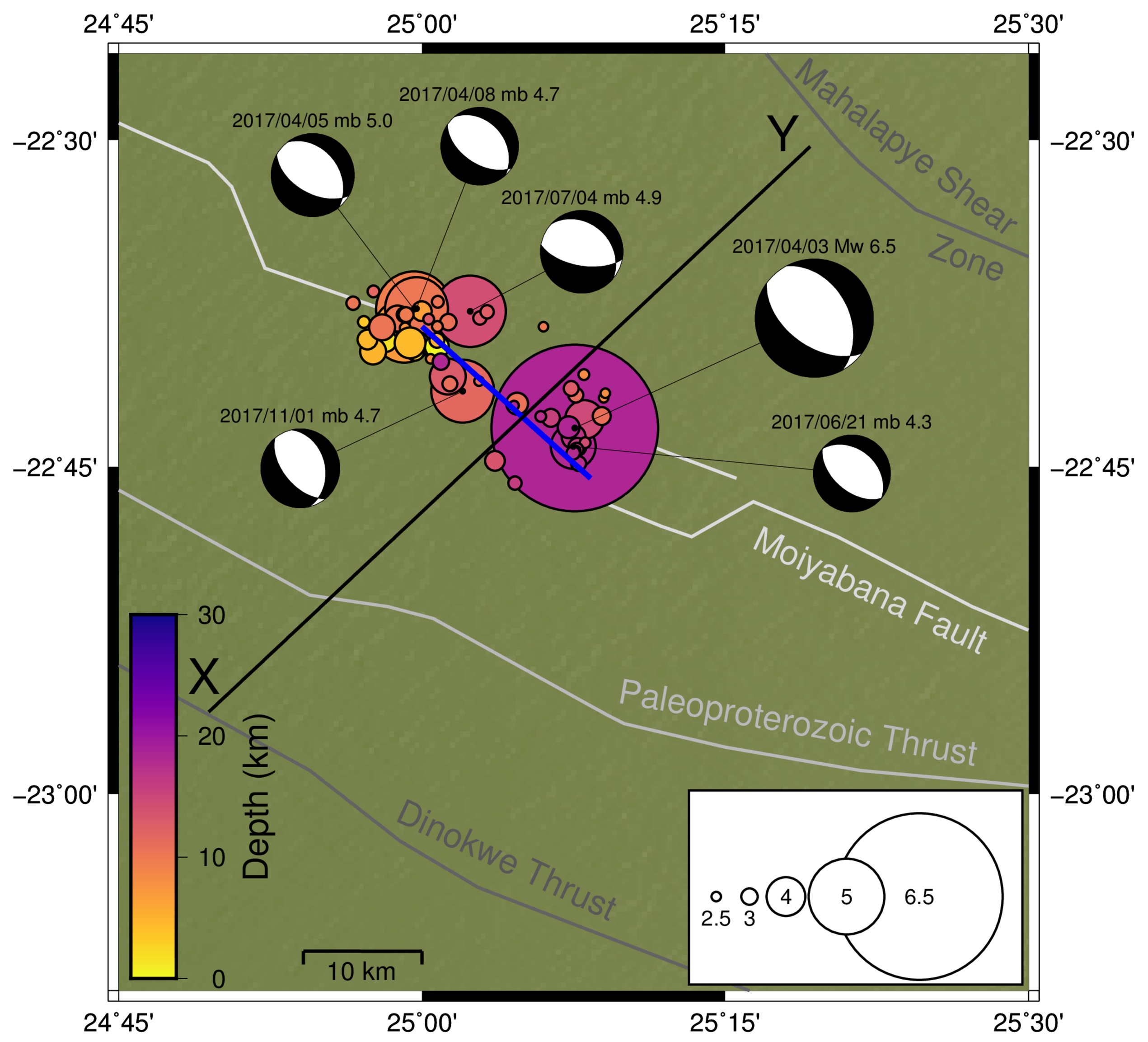

Figure 6: Relocated hypocenters for the 2017 Moiyabana earthquake sequence. Fault structures are interpreted and the blue line is the Moiyabana Fault trace determined by InSAR measurements[2]. The focal mechanisms of the main event and a few aftershocks are displayed [H. Paulssen, personal communication].

The strike and dip, along which the hypocenters are located, are consistent with the interpreted fault structures[2] and the focal mechanisms of the main event and several aftershocks. A few smaller aftershocks align along a southwest dipping structure. These events may have occurred on an antithetic fault.

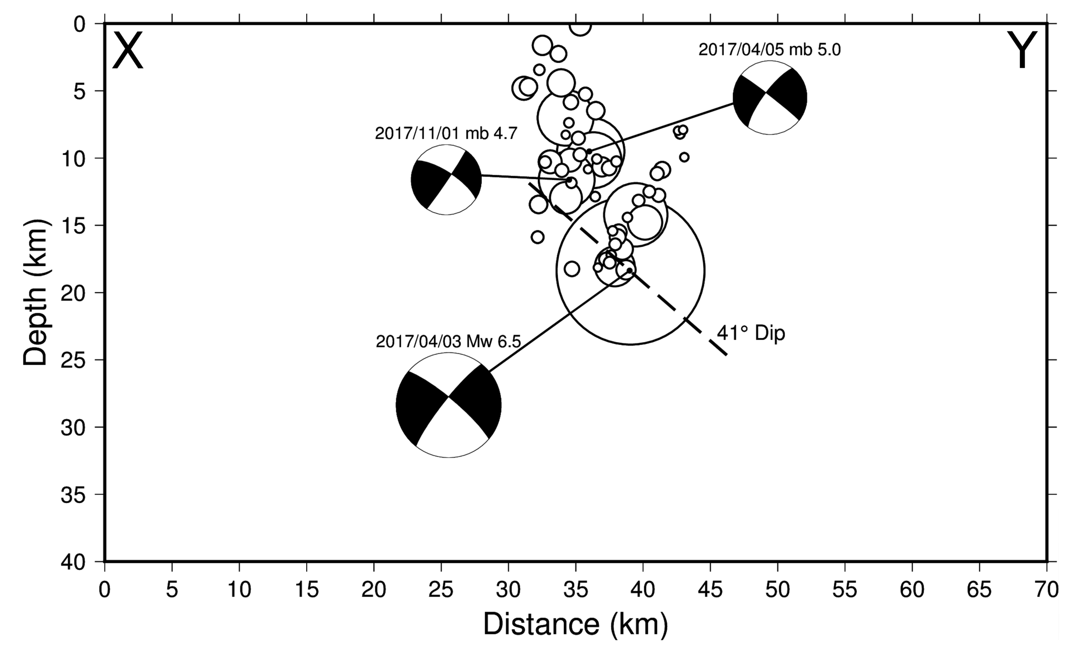

Figure 7: Cross-section X-Y. The dip of the main event is shown as a dashed line.

Comparing our results with the cross-section of aeromagnetic data with interpreted fault structures[2] shows that our relocated hypocenters align well with the interpreted Moiyabana Fault.

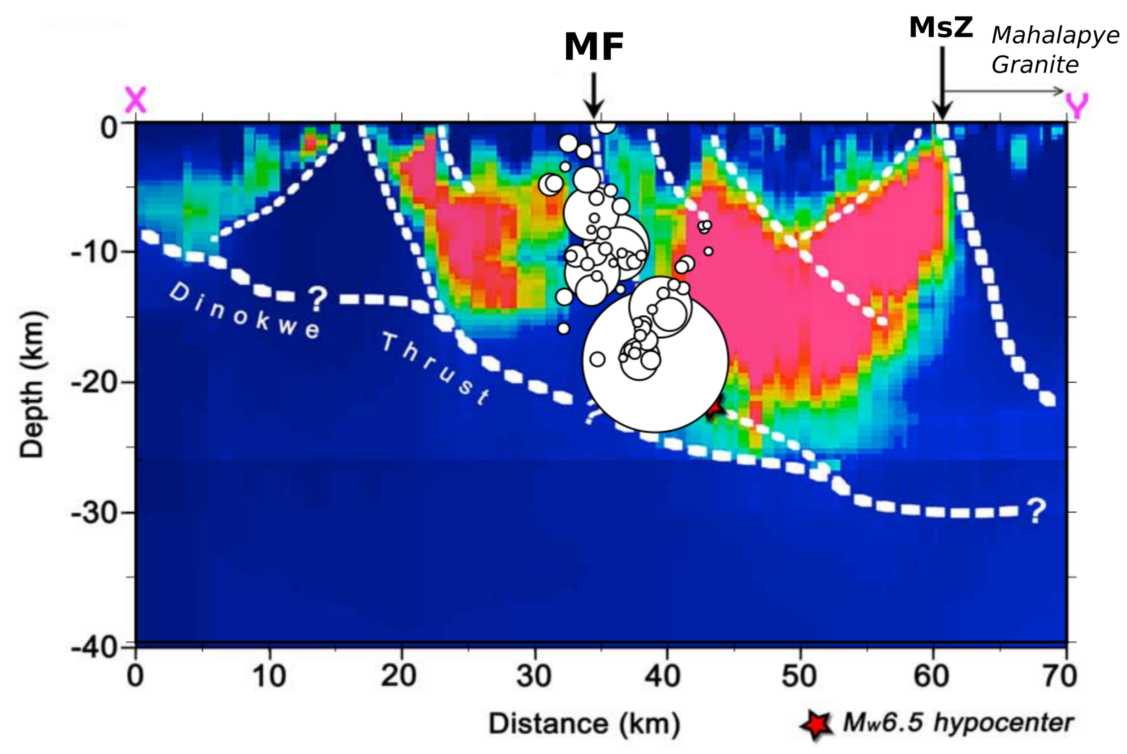

Figure 8: Cross-section X-Y of the relocated seismicity superimposed on the cross-section of aeromagnetic data[2]. The scale for magnetic susceptibility (SI) is given in blue to red (0 - 0.003). MF = Moiyabana Fault; MsZ = Mahalapye Shear Zone.

The earthquake locations and focal mechanisms are consistent with the stress field in Botswana[3, 4].

CONCLUSION

The relocations of the 2017 Moiyabana earthquake sequence resulted in aftershocks being located closer together along a NW-SE normal fault, consistent with the focal mechanisms of the main event and several aftershocks. The depth of the events decreases towards the northwest and the hypocenters align well with the northeast dipping Moiyabana Fault. This fault is part of a Proterozoic zone of weakness, containing ancient thrust faults associated with the collision of the Kaapvaal and Zimbabwe Cratons, that responded to large scale extensional forces present in southern Africa.

References

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[2] Kolawole, F., Atekwana, E. A., Malloy, S., Stamps, D. S., Grandin, R., Abdelsalam, M. G., Leseane, K., and Shemang, E. M. (2017). Aeromagnetic, gravity, and Differential Interferometric Synthetic Aperture Radar analyses reveal the causative fault of the 3 April 2017 Mw 6.5 Moiyabana, Botswana, earthquake. Geophysical Research Letters, 44 (17):8837–8846.

[3] Stamps, D., Flesch, L., Calais, E., and Ghosh, A. (2014). Current kinematics and dynamics of Africa and the East African Rift System. Journal of Geophysical Research: Solid Earth, 119(6):5161–5186.

[4] Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D., and Müller, B. (2010). Global crustal stress pattern based on the World Stress Map database release 2008. Tectonophysics, 482(1-4):3–15.