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Interactive comment on "Statistics of the Seismic Sequence and Rupture Directivity of the M5.5 Earthquake in Orkney, South Africa" *by* Carsten Dinske et al.

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SE-2020-58 REFEREE COMMENTS

GENERAL COMMENTS

The paper analyses 70,000 events that occurred in a three year period in the vicinity of Moab-Khotsong gold mine, South Africa. The data set includes the main shock and aftershocks of the M5.5 Orkney earthquake of 5 August 2014, as well as mining-induced earthquakes. The rupture has been drilled under the auspices of the ICDP project, DSeis. The study is an important component of this multi-disciplinary international

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Discussion paper

project.

The authors have used standard techniques to analyse the frequency-magnitude statistics of the data and to image the rupture.

I do, however, have two major concerns. Firstly, regarding the classification of 48,000 of the 70,000 events as ‘fluid-induced’. This has a major impact on the interpretation of the data. Secondly, the lack of local knowledge, especially the failure to acknowledge relevant prior work. I expand on these points in the ‘specific comments’ section below.

I have attached an annotated version of the pdf file in which I have highlight some grammatical and spelling errors.

Professor Ray Durrheim Johannesburg 9 June 2020

SPECIFIC COMMENTS

(1) Fluid-induced earthquakes

On Line 163 the authors report that 48,000/70,000 earthquakes are fluid-induced, 15,000 aftershocks of the Orkney M5.5 earthquake, and 7,000 are mining-induced. However, they do not adequately explain how they reached this conclusion. I find this statement very surprising, as I am not aware of any previous study in a South African mining district that has attributed such a large proportion of seismicity to fluids.

Figure 2 does not differentiate between the classes, so I could not detect whether these were related to the controlled flooding of the worked out Buffelsfontein mine immediately to the north of the M5.5 rupture.

Nevertheless, there is a body of work that has investigated the effect of changes of pore-fluid pressure caused by the controlled flooding of worked-out mines in South Africa, for example East Rand Proprietary Mine in the East Rand Gold Field, Libanon Gold Mine in the West Rand Gold Field, and Buffelsfontein Gold Mine. These observations at have been presented in local conferences and workshops, and published in various reports commissioned by the Mine Health & Safety Council. I include several references below and am happy to supply the authors with copies, should they so desire. However, the observations have not, to my knowledge, been published in the international refereed literature. The authors make no mention of this work in their paper. See, for example: Ali, S., 20-16, Evaluation of flooding induced mining seismicity with a view to characterize safety margins for surface structures under existing and flooded conditions in the Central Rand, Johannesburg, PhD thesis, University of the Witwatersrand, 2016. Birch, D.J., 2014. Identifying instability in the rock mass caused by water ingress into abandoned mines, Masters dissertation, University of Pretoria. Fowkes, N., Hocking, G., Mason, D.P., Please, C.P., Kgatle, R., Yilmaz, H. and van der Merwe, N., 2015, Models for the effect of rising water in abandoned mines on seismic activity. International Journal of Rock Mechanics & Mining Sciences, 77, pp.246-256. Goldbach, O.D., 2009, Flooding-induced seismicity in mines. In 11th SAGA Biennial Technical Meeting and Exhibition (pp. cp-241). European Association of Geoscientists & Engineers. Liebenberg, K., Smit, A., Coetzee, S. and Kijko, A., 2017. A GIS approach to seismic risk assessment with an application to mining-related seismicity in Johannesburg, South Africa. Acta Geophysica, 65(4), pp.645-657.

(2) Lack of local knowledge and failure to acknowledge prior work

Line 3: The authors write, "We aim to address these questions with a comprehensive study of seismicity in deep South African gold mines."

In my view, this is not a comprehensive study. It is a detailed study of a large and unusual event and its fore- and aftershocks and events induced by mining at Moab-Khotsong mine during a three-year period (August 2014 – September 2017). I think that this is important work, but it certainly cannot claim to be a 'comprehensive study of seismicity in deep South African mines'.

Lines 19-20: The authors state that the M5.5 Orkney earthquake '. . . was the second largest recorded seismic event in South Africa'. This is not true. Three events with M>6 have been recorded since 1900, viz the ML6.2 Koffiefontein event of 20 February 1912; the ML6.3 St Lucia event of 31 December 1932; the ML6.3 Ceres-Tulbagh earthquake of 29 September 1969. Ssee, for example, Durrheim, 2015 Earthquake seismology, In: J.H. de Beer (ed.), The History of Geophysics in Southern Africa, SUN MeDIA, Stellenbosch, pp. 22-52, ISBN 978-1-920689-80-3.

Line 27-28: The statement that "Earthquakes induced by activities and operations in deep-level mines are a topic of research since decades starting with the pioneering works of Spottiswoode and McGarr (1975) and Gay and Ortlepp (1979)". While these certainly are landmark studies, the authors omit a huge body of foundational work done prior to this, beginning in 1908. For reviews of mine seismology research in SA, see for example:

Durrheim, RJ, 2010, Mitigating the rockburst risk in the deep hard rock South African mines: 100 years of research. In Extracting the Science: a century of mining research, J. Brune (editor), Society for Mining, Metallurgy, and Exploration, Inc., ISBN 978-0-87335-322-9, pp. 156-171. Durrheim, R.J., 2015, Geophysical laboratories in deep gold mines: earthquakes, neutrinos, extremophiles and the origin of the Earth's magnetic field, In: J.H. de Beer (ed.), The History of Geophysics in Southern Africa, SUN MeDIA, Stellenbosch, pp. 116-138. ISBN 978-1-920689-80-3 Durrheim, R.J. and Riemer, K.L., 2015, The history of mining seismology, In: J.H. de Beer (ed.), The History of Geophysics in Southern Africa, SUN MeDIA, Stellenbosch, pp. 85-110. ISBN 978-1-920689-80-3. Riemer, KL and RJ Durrheim, 2012, Mining seismicity in the Witwatersrand Basin: monitoring, mechanisms and mitigation strategies in perspective, Journal of Rock Mechanics and Geotechnical Engineering, 4, 228-249.

Lines 70-73, 84-87: The paucity of large aftershocks and deviation from Båths law was previously reported by Kgarume, TE, SM Spottiswoode and RJ Durrheim, 2010, Statistical properties of mine tremor aftershocks, Pure and Applied Geophysics, 167, 107-117.

Lines 205-208: The authors conclude, “Our findings and conclusions have basically the potential to contribute to an improved assessment and a possible mitigation of seismic hazard in active mining districts. In particular, we think that the Lower Bound model combined either with the Omori-Utsu model for aftershock productivity or with a Poissonian model for induced earthquakes would be a first step towards more realistic hazard estimations of mining operations.”

The authors ignore as substantial body of innovative work by South African seismologists on the statistical analysis of seismicity with regard to both mining-induced and tectonic seismicity. For example:

Kijko A. 2004. Estimation of the Maximum Earthquake Magnitude mmax. Pure and Applied Geophysics, 161:1-27. Kijko A. 2012. On Bayesian procedure for maximum earthquake magnitude estimation. Research in Geophysics, 2(1):46-51. Kijko A & Graham G. 1998. “Parametric-Historic’ Procedure for Probabilistic Seismic Hazard Analysis. Part I: Assessment of Maximum Regional Magnitude mmax. Pure and Applied Geophysics, 152:413-442. Kijko A & Graham G. 1999. ‘Parametric-Historic’ Procedure for Probabilistic Seismic Hazard Analysis. Part II: Assessment of Seismic Hazard at Specified Site. Pure and Applied Geophysics, 154:1-22. Kijko A & Sellevoll MA. 1989. Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part I: Utilization of Extreme and Complete Catalogues with Different Threshold Magnitudes. Bulletin of the Seismological Society of America, 79:645-654. Kijko A & Sellevoll MA. 1992. Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part II: Incorporation of Magnitude Heterogeneity. Bulletin of the Seismological Society of America, 82:120-134. Kijko A & Singh M. 2011. Statistical tools for Maximum Possible Earthquake Magnitude Estimation. Acta Geophysica, 59:674-700. Kijko A & Smit A. 2012. Extension of the Aki-Utsu b-value estimator for incomplete catalogs. Bulletin of the Seismological Society of America, 102:1283-1287. Kijko A, Smit A & Sellevoll MA. 2016. Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part III: Incorporation of uncertainty of earthquake-occurrence model. Bulletin of the

Seismological Society of America, 106: 1210-1222. Kgarume TE, Spottiswoode SM & Durrheim RJ. 2010. Statistical properties of mine tremor aftershocks. Pure and Applied Geophysics, 167:107-117. Kgarume, TE, SM Spottiswoode and RJ Durrheim, 2010, Deterministic properties of mine tremor aftershocks, Proceedings of the Fifth International Seminar on Deep and High Stress Mining, M Van Sint Jan and Y Potvin (editors), Australian Centre for Geomechanics, ISBN 978-0-9806154-5-6, pp. 227-237.

Please also note the supplement to this comment:
https://se.copernicus.org/preprints/se-2020-58/se-2020-58-RC1-supplement.pdf

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