

## Nearly completion of ICDP drilling into M2.0 –M5.5 seismogenic zones in South African gold mines (DSeis)

\*Hiroshi Ogasawara<sup>1</sup>, Yasuo Yabe<sup>2</sup>, Tullis C Onstott<sup>3</sup>, Bennie Liebenberg<sup>4</sup>, Michael Rickenbacher<sup>5</sup>, Akimasa Ishida<sup>1</sup>, Shuhei Abe<sup>1</sup>, Kosuke Sugimura<sup>1</sup>, Takatoshi Ito<sup>2</sup>, Akio Funato<sup>6</sup>, Siyanda Mngadi<sup>7</sup>, Hiroyuki Ogasawara<sup>1</sup>, Musa Manzi<sup>7</sup>, Tatsunari Yasutomi<sup>8</sup>, Taku Noda<sup>1</sup>, Raymond J Durrheim<sup>7</sup>, Martin Ziegler<sup>5</sup>, Neta Wechsler<sup>9</sup>, Gerrie van Aswegen<sup>10</sup>, Anthony K Ward<sup>11</sup>, Sifiso Bucibo<sup>12</sup>, Zamaswazi Nkosi<sup>13</sup>, Dave Roberts<sup>13</sup>, The DSeis team<sup>14</sup>

1. Ritsumeikan Univ., 2. Tohoku Univ., 3. Princeton Univ., USA, 4. AngloGold Ashanti, South Africa, 5. ETH Zurich, Switzerland, 6. Fukada Geological Institute, 7. Univ. Witwatersrand, South Africa, 8. Kyoto Univ., 9. Tel-Aviv Univ., Israel, 10. Inst. Mine Seismol., South Africa, 11. Seisogen CC, South Africa, 12. Council for Geoscience, South Africa, 13. CSIR, South Africa, 14. ICDP

The last ICDP DSeis drilling (Hole B) is on target to intersect aftershock zone of the 2014 M5.5 Orkney earthquake, South Africa in a few hundred meters. The M5.5 event took place on an unknown geological structure, nearly vertical and striking NNW-SSE below the mining horizon. This was delineated by over 20,000 aftershocks located by in-mine seismic network. An NQ hole was collared in November 2017 at a depth of 2.9km from surface at the Moab Khotsong gold mine, at 593m depth from the collar as of 16 February 2018. Once the aftershock zone is reached, a 1.5m triple-tube core-barrel will be used to recover fragile fault materials and ruptures as completely as possible; a 3m double-tube core-barrel is used for full-core drilling with core orientation for the remainder of the hole. The aftershock zone is expected to be intersected in Hole B in March or April 2018. This will be followed by geophysical logging, and installation of a Kinetically Activated Subsurface Microbial Sampler (KASMS, funded by the US NSF). KASMS automatically samples water and gas in order to investigate whether deep microbial life is associated with seismic activity in any way. The KASMS project also installs a water pressure transducer at the intersection. Geochemical and structural geological studies also follow. If JSPS grant-in-aid is approved, we will deploy an in-hole geophone array.

This on-going drilling is designed taken into account the deflection of the 1st 817m drilling (Hole A) that commenced in June 2017 and was terminated in September 2017 because of little chance to intersect the aftershock zone. Borehole Full Wave Sonic logging confirmed approximately the same velocities used for the M5.5 aftershock location in the in-mine seismic network. Core is logged (Ziegler et al. EGU 2018), imaged, and cataloged in the ICDP Digital Information System. Ishida et al. (JpGU 2018) carried out Diametrical Core Deformation Analysis (Funato and Ito, 2017) to measure elastic deformation of cores during drilling to calculate stress at 50 m intervals in Hole A, finding a systematic decrease in differential stress with increase in distance from mine workings, followed by systematic increase below the Crown lava or below the upper edge of the M5.5 aftershock zone. Hole B, together with Hole A, will allow us to better model geology and stress 3-dimensionally.

Hiroyuki Ogasawara et al. (JpGU 2018) reprocessed seismic reflection data, finding a nearly vertical fault zone striking NNW-SSE below the mining horizon as a capable structure. They also delineated cross-cutting relationships of the major normal fault that dislocated gold reefs by 1km both horizontally and vertically and limited the extent of the M5.5 aftershocks.

Using these datasets, a Source Inversion Validation (SIV) workshop, funded by the Southern California Earthquake Centre, will be held in 2018 to determine the best rupture model for the M5.5 earthquake.

The depletion of gold reserves has led to changes in mine ownership and mine closures. Sibanye Gold has already closed Cooke 4 shaft, site of a hole into the source zone of a M2 earthquake. Irrespective of this difficulty, we could complete a DSeis drilling to recover ruptures ahead of mining front, which will be studied in detail (Wechsler et al. 2018 EGU). We had to abandon drilling into M3 seismogenic zones at the Savuka and the Tau Tona mines, which were also closed down. However, Ishida et al. and Abe et al. (JpGU2018) could measure stress at the sites with existing core and borehole breakout measurements. AngloGold Ashanti Ltd is finalising the sale of Moab Khotsong mine, site of the hole intersecting the M5.5 seismogenic zone, to Harmony Gold Ltd in the second quarter of 2018. We anticipate that we will be able to complete DSeis drilling without additional difficulty.

Keywords: ICDP fault drilling, Seismogenic zones, Earthquake and geomicrobiology