# Investigating Source Properties of Mining-Induced Earthquakes and the Resulting Seismic Hazard in TauTona Gold Mine, South Africa

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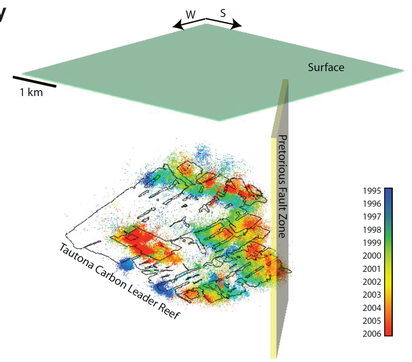
## Why study mining-induced microseismicity at TauTona Gold Mine, South Africa

- TauTona is the deepest gold mine in the world with mining to depths of ~4 km
- Hundreds of earthquakes are recorded each day (-4 < M < 4) triggered by active mining
- Seismicity contributes to hazardous conditions within the mine where even small earthquakes are very dangerous
- Seismic stations placed at depth create a natural laboratory to study earthquake sources and relate laboratory seismic experiments to complex tectonic fault systems


TauTona Gold Mine ~80 km west of Johannesburg, South Africa (from *Heesakkers et al.*, 2011a)




Seismicity throughout TauTona Gold Mine along the mined portion of the Carbon Leader Reef. Each colored dot represents an earthquake. Approximately ~300,000 earthquakes are shown.

Fencing erected to stabilize a fault in TauTona mine in a region where the tunnel collapsed during a M1.8 earthquake on 12 December, 2004. (Photo provided by V. Heesakkers and Z. Reches)

Left: A miner and a scientist inspect a fault in a tunnel in TauTona Gold Mine.

## Is the rupture process of mining-induced microearthquakes the same as that of large earthquakes in tectonic fault systems?

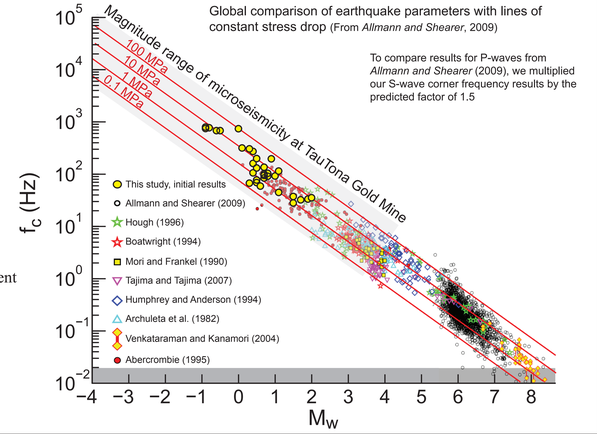
- Stress drop results based on the Madariaga (1976) source model for an initial set of earthquakes recorded at TauTona Gold Mine:

  No. of earthquakes: 32
  Magnitude range: -1 < M < 2
  Stress drop range: 0.2 to 119 MPa
  Mean stress drop: 12 MPa
  Median stress drop: 5 MPa

- The mean stress drop for earthquakes at TauTona Gold Mine is consistent with other studies of both large and small magnitude earthquakes (e.g. *Allmann and Shearer*, 2009; *Baltay et al.*, 2011)
- A constant stress drop for earthquakes over a wide magnitude range suggests that intraplate mining-induced microearthquakes have the same rupture processes as large earthquakes in tectonic fault systems

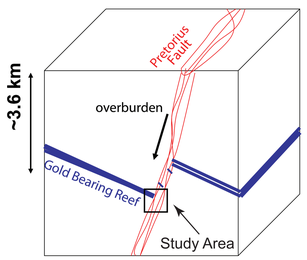
Global comparison of earthquake parameters with lines of constant stress drop (From *Allmann and Shearer*, 2009)

To compare results for P-waves from *Allmann and Shearer* (2009), we multiplied our S-wave corner frequency results by the predicted factor of 1.5

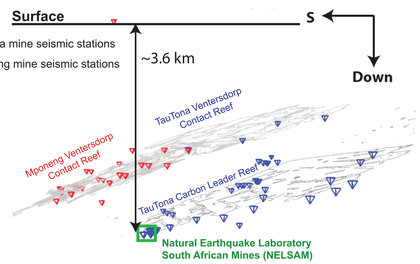



## Recording microseismicity in the vicinity of an ancient intraplate fault

- Mining has reactivated the Pretorius fault, the largest fault system in the mine, which was last active over 2 billion years ago
- Seismic stations have been placed throughout the mine to monitor the abundant seismic activity
- The Natural Earthquake Laboratory South African Mines (NELSAM) seismic network is installed within the Pretorius fault zone in the deepest part of the mine to provide high-quality and high-sample rate records of very small earthquakes (*Z. Reches*, 2006)




Block diagram of the TauTona study area and the Pretorius fault off-setting the gold-bearing reef. The mine environment allows for seismic stations to be placed in the seismogenic zone next to hundreds of earthquakes that occur everyday.

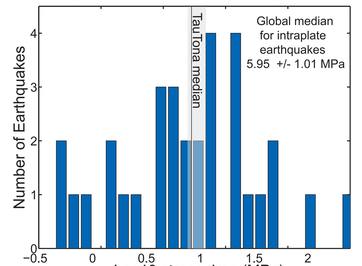



Cross-section of TauTona Gold Mine and the location of seismic stations at depth including the high-sample rate NELSAM network. The TauTona and nearby Mponeng mines are well instrumented to monitor the abundant seismic activity within the mines.

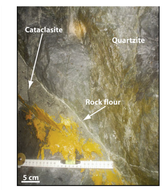
## Are ancient intraplate faults in a mining environment strong or weak?

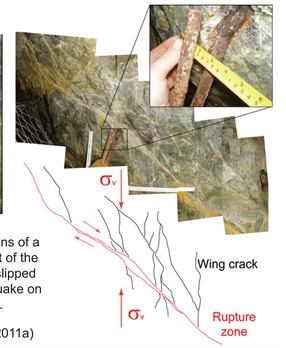
- Stress drop distribution for earthquakes at TauTona Gold Mine show a median value comparable to the global median for intraplate earthquakes
- Mining-induced microearthquakes have a stress drop similar to that of natural faults and show no evidence for a weak fault system
- Combined geophysical evidence suggests that large normal stresses due to nearby mining result in earthquakes with high stress drops

(*Z. Reches*, 2006; *Heesakkers et al.*, 2011a; *Lucier et al.*, 2009; *Boettcher et al.*, in prep.; *Heesakkers et al.*, 2011b)




Stress drop distribution of 32 microearthquakes recorded at TauTona Gold Mine (global median from *Allmann and Shearer*, 2009)



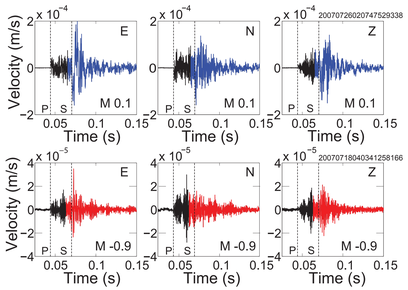




Geologic observations of a subparallel segment of the Pretorius fault that slipped after a M2.2 earthquake on 12 December, 2004.

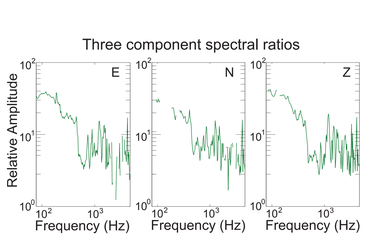
*Heesakkers et al.* (2011a)

## How is spectral analysis used to obtain stress drop for microseismicity at TauTona Gold Mine?

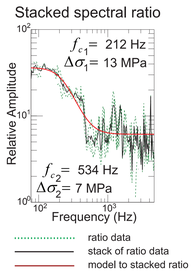
Seismic data can be used to obtain stress drop, an earthquake source parameter related to the energy of an earthquake, and may be linked to crustal strength. (e.g. *Fletcher and McGarr*, 2006; *Baltay et al.* 2011)




1. Earthquakes less than 100 m apart, with at least one order of magnitude difference, and have similar waveforms are paired and used for analysis




2. Earthquake records for each pair are converted to the frequency domain and divided to obtain a spectral ratio




3. The spectral ratios for each component and station are stacked and modeled to find the corner frequency

Stress drop calculated from S-wave corner frequency

$$\Delta\sigma = \left(\frac{7}{16}\right) M_0 \left(\frac{f_c}{0.21\beta}\right)^3$$

where

$\Delta\sigma$ = stress drop
$M_0$ = seismic moment
$f_c$ = corner frequency
$\beta$ = S-wave velocity

4. Stress drop for each earthquake is calculated using the corner frequency from spectral analysis and a catalog seismic moment

## Continuing work and analysis

- Obtain stress drop and additional source parameters for hundreds more earthquakes in the vicinity of the Pretorius Fault and throughout TauTona Gold Mine using spectral analysis techniques
- Compare source parameters of earthquakes occurring in the vicinity of the Pretorius Fault to earthquakes occurring near other natural and manmade structures throughout the mine (such as dikes and stopes)
- Investigate in detail source parameters of large (M > 2) earthquakes recorded in TauTona Gold Mine and thought to have anomalously high stress drop
- Compare source parameter results throughout the mine with faulting type

## Acknowledgements and References

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