Schatzalp Workshop on Induced Seismicity (organized by SSS ETH Zurich)

Drilling to probe quasi-static and dynamic seismic ruptures in deep South African gold mines (DSeis) from cm- to km- scale

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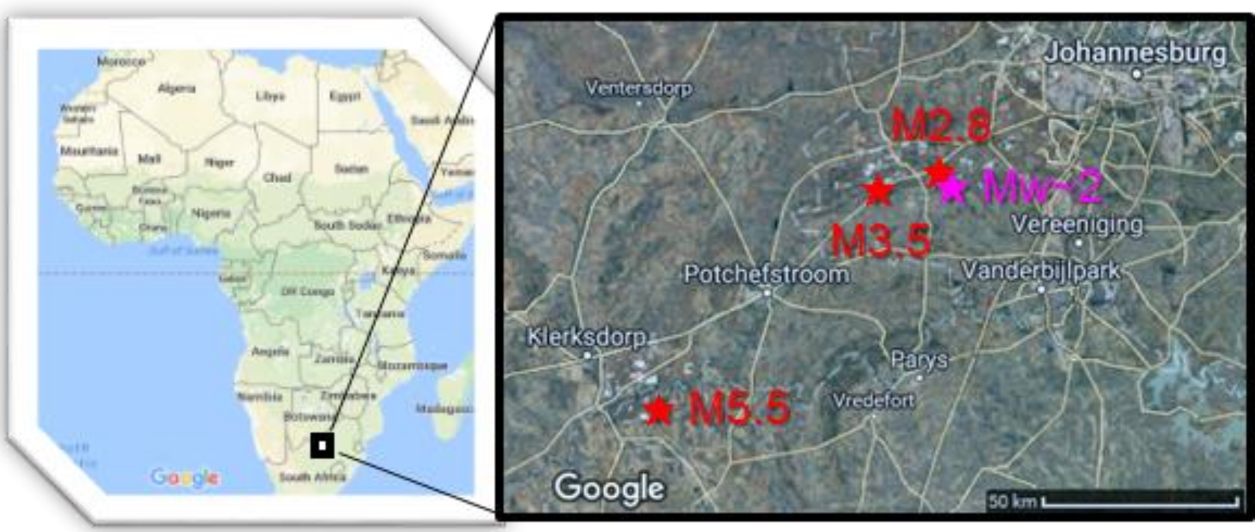
Thursday, 16 March 2017 10:30- (18 min talk) in the session Scaled Experiments



icdp

INTERNATIONAL CONTINENTAL SCIENTIFIC DRILLING PROGRAM

DSEIS

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2015 ICDP-Ritsumeikan Workshop (70 people from 7 countries)

Outline

- Background
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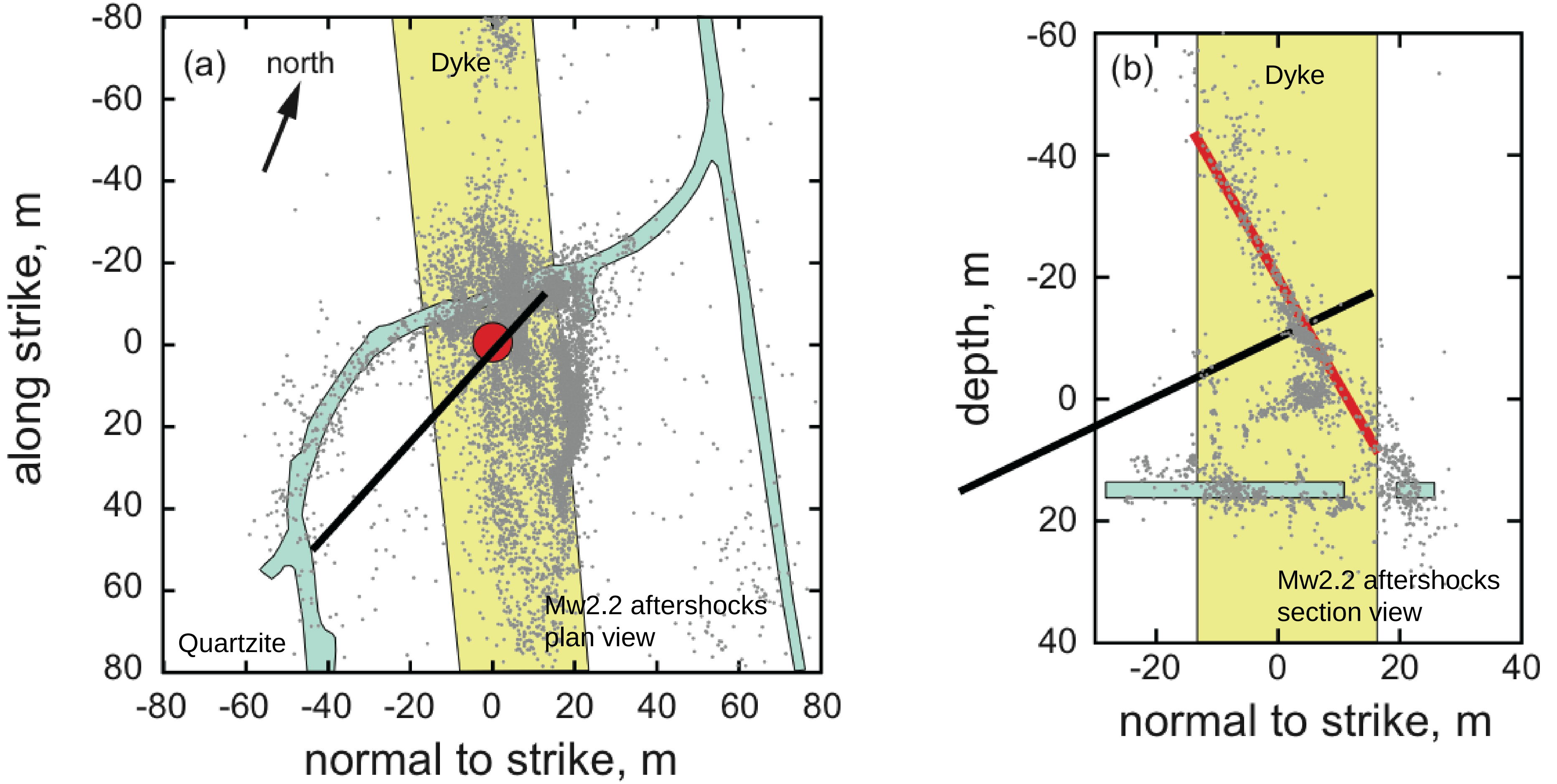
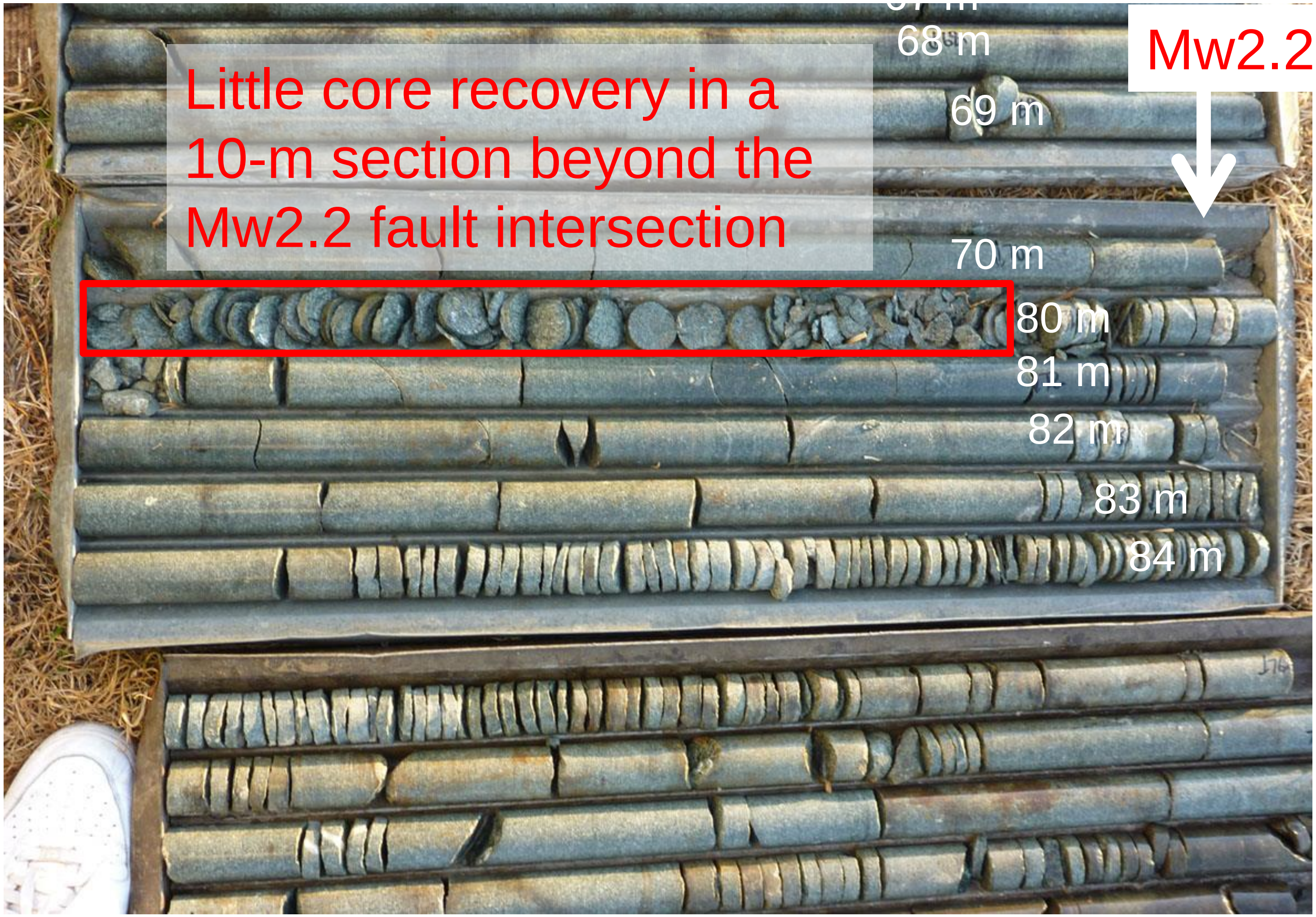
Background project (JAGUARS chaired by Masao 2006-2008):
Yasuo detailed the Mw2.2 nucleation in the 2015 Schatzalp WS.
He drilled into the 2007 Mw2.2 hypocenter at 3.3 km depth.



Yabe et al. (2013)

Background project (JAGUARS 2006-2008)
Drilling reveled that the Mw2.2 was not on the dyke-hostrock contact but on a pre-existing weakness. However, the drilling direction was not ideal for good core recovery.



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During the following Jpn-SA project (2009-2015), Ogasawara et al. (2012) optimized an overcoring technique suitable for working condition at highly stressed ground in SA gold mine,
demonstrating that core recovery with minimum damage even at earthquake-prone ground is feasible with great care for drilling direction.

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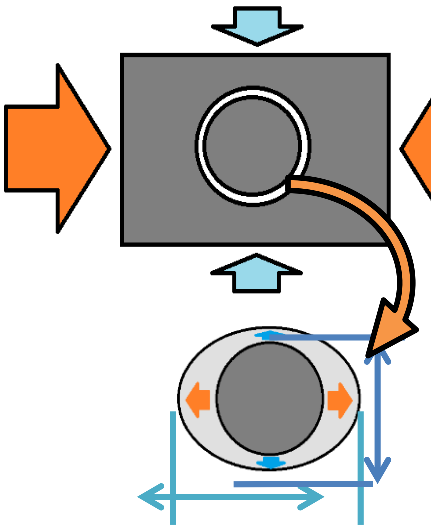
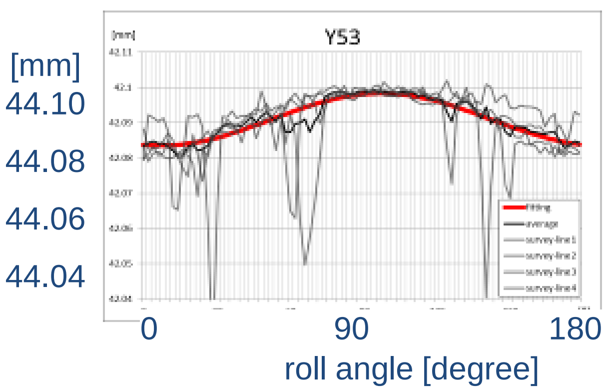
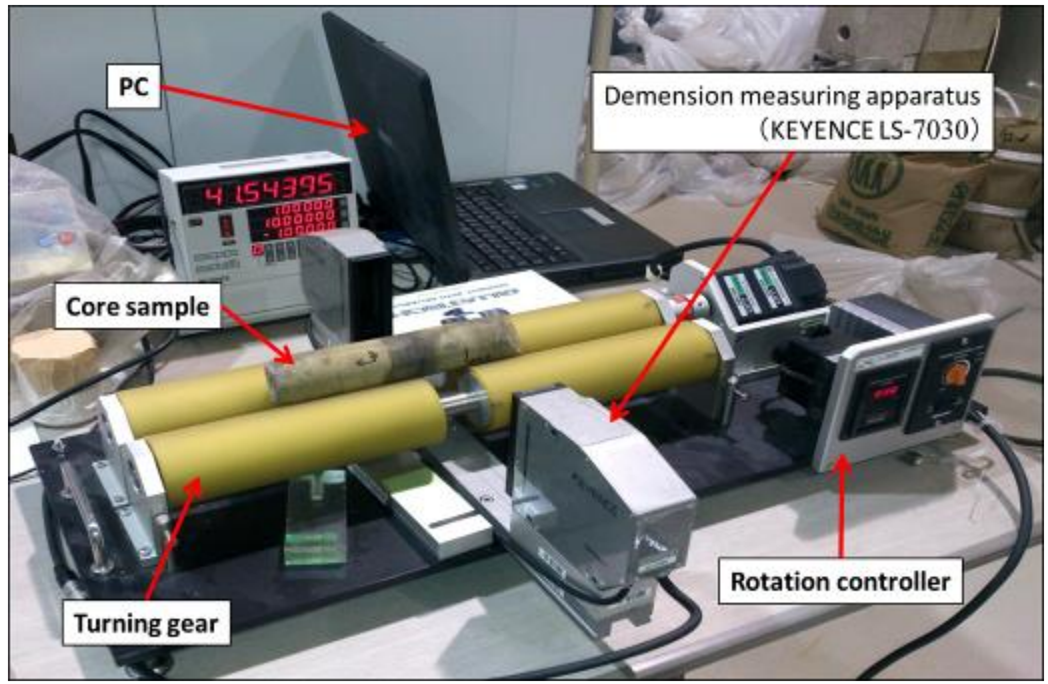
With a new method (Funato and Ito, 2011; Funato et al., 2016), we measure shade width variation to measure τ_{max} without overcoring, hydrofracturing, borehole scoping, or conventional time-consuming lab testing.

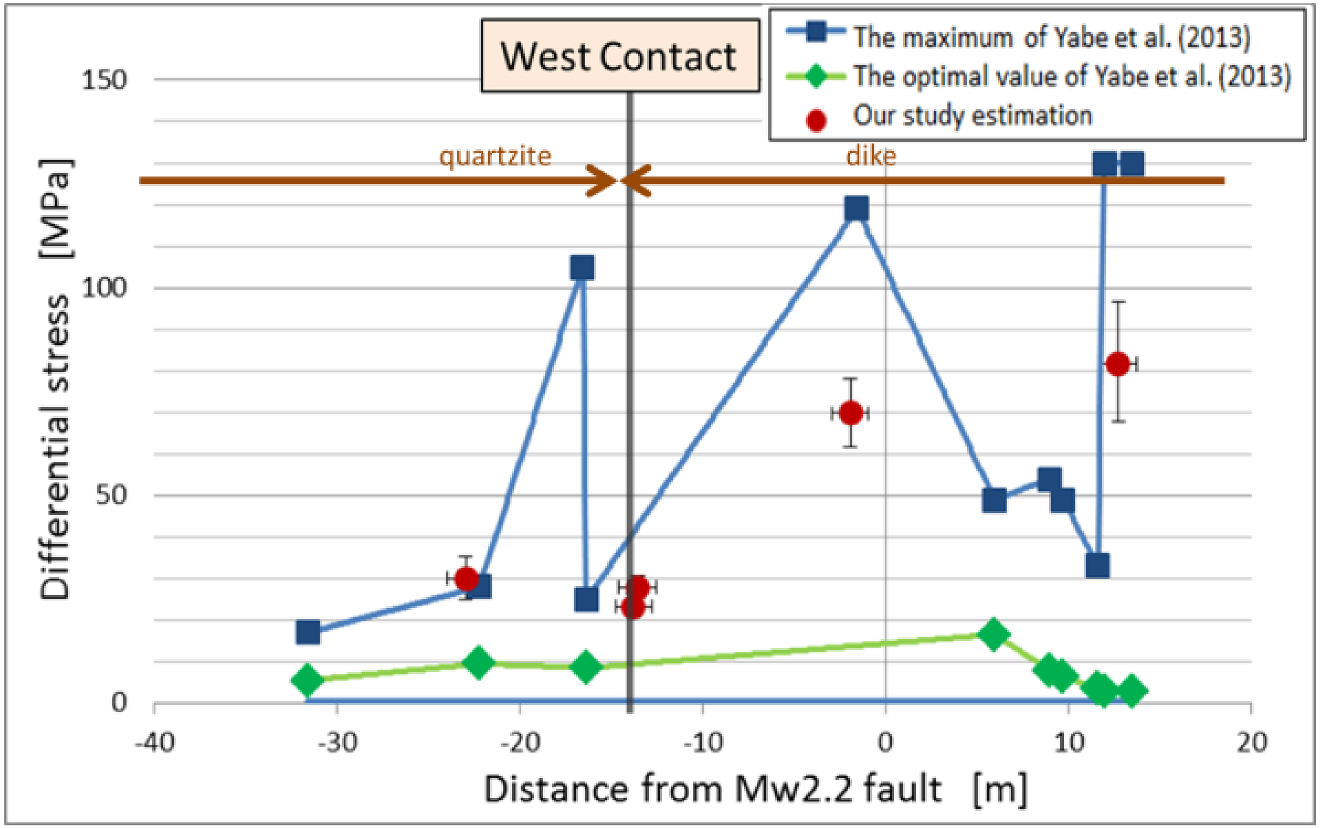


Elastic unaxisymmetric expansion





Diameter variation of the core corresponding to τ_{max} of several tens of MPa at the Mw2.2 seismogenic zones.



Abe et al. (2017)

The measured differential stress was

- much better constrained than those by analyses of b/h breakout and core discing (blue and green).
- consistent with stress model calibrated by overcoring measurements.

At the other sites, consistent with an overcoring measurement results.

Effective in the ground where stress is too high for hydrofracturing method.

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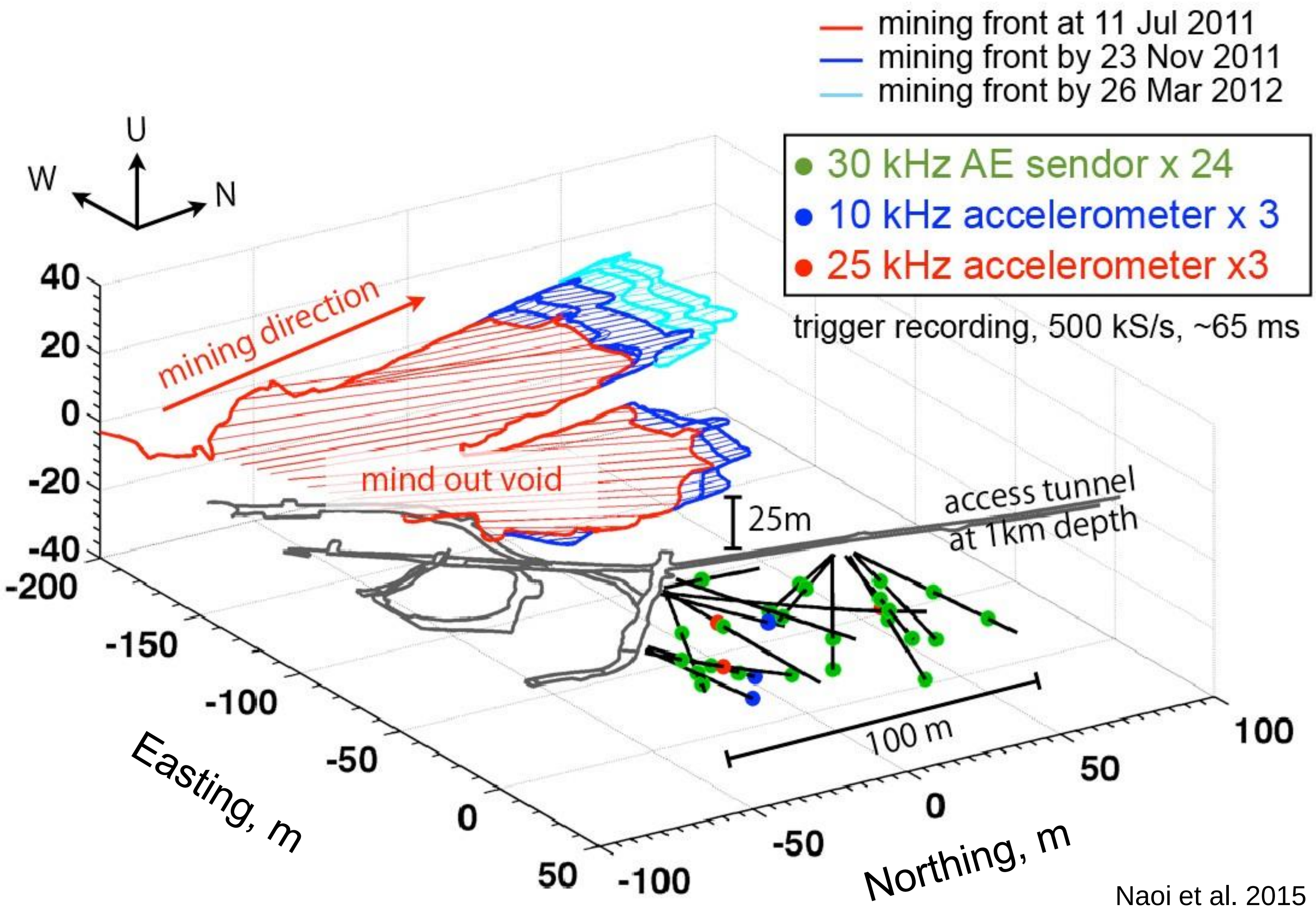
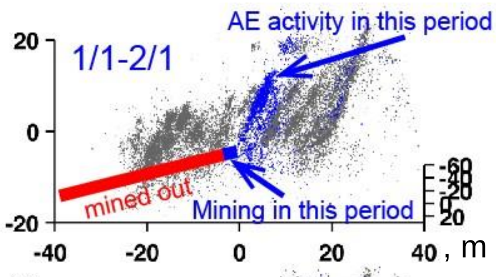
Target A: observation network of M~2 quasi-static rupture evolution ahead of stopes in Cooke 4



Naoi et al. 2015

Target A: Migration of planar activity

- ✓ Regularly spacing ~10 planer structures
- ✓ Dipping by 60~70◦ to south
- ✓ Sub-parallel to the mining edge



24404 events
-3.3 < Mw < -0.5

Naoi et al. 2015

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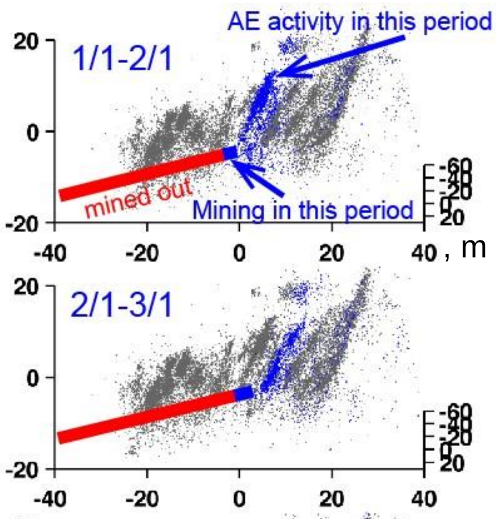

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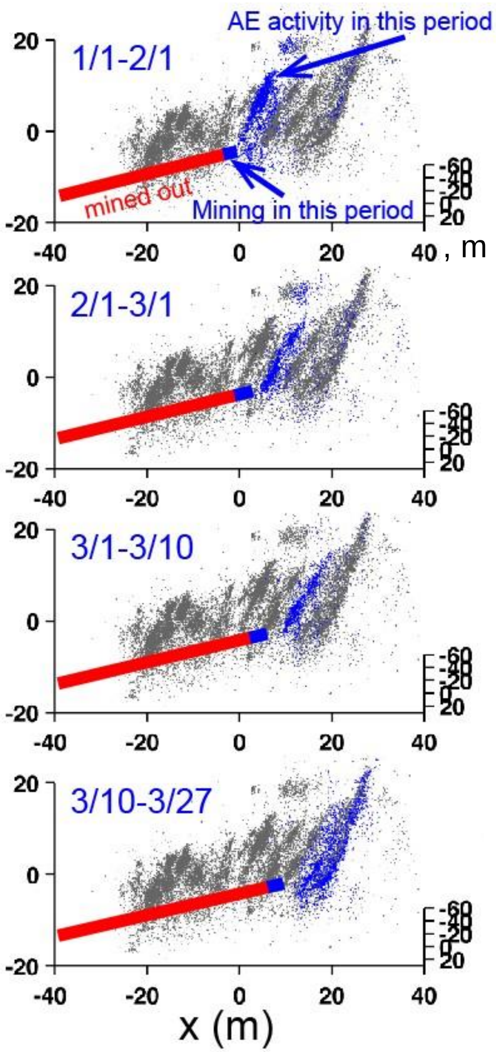

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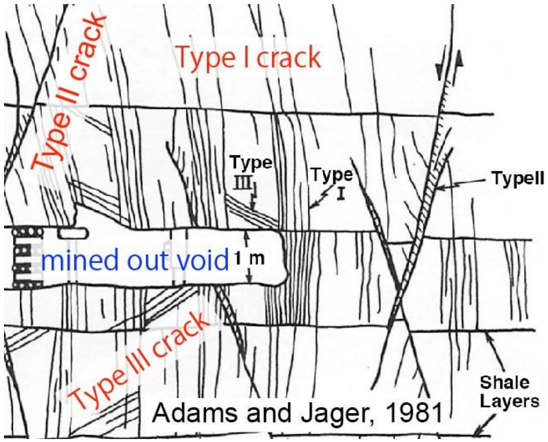
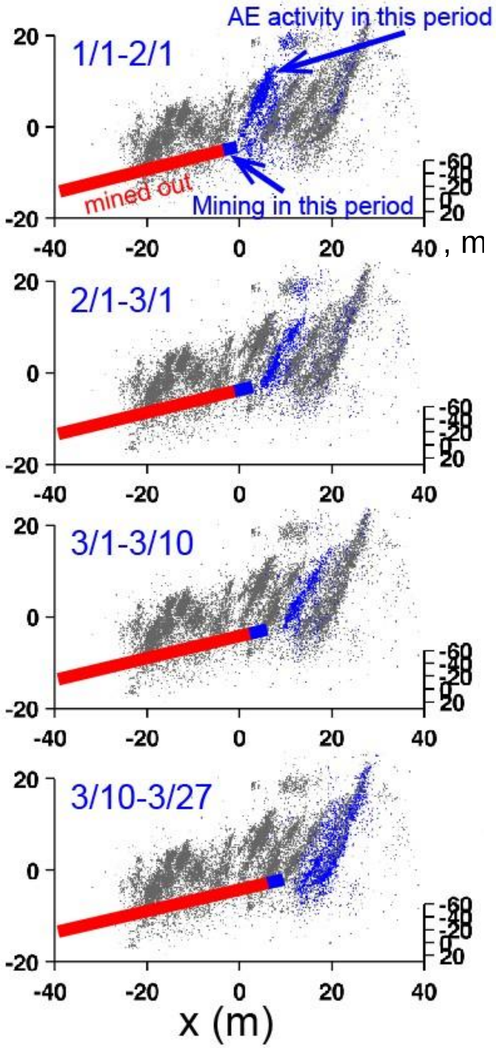
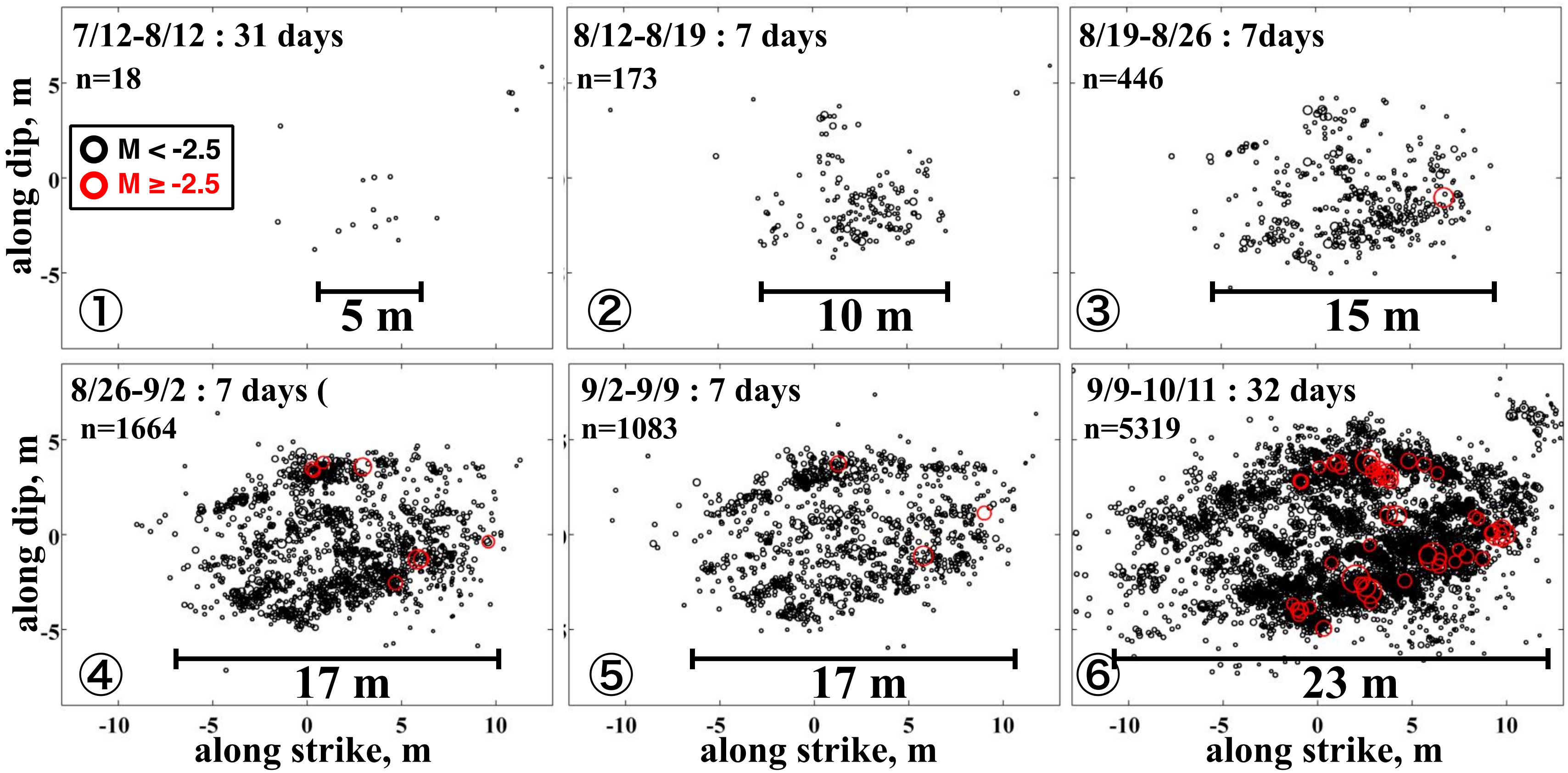




24404 events
-3.3 < Mw < -0.5

Naoi et al. 2015

Target A: Quasi-static rupture evolution which we drill a ~50m hole to probe



Naoi et al. 2015

Naoi et al. (2013 and 2015) have already investigated in detail the temporal variation in b-value and repeating earthquakes.

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Skip this slide because of time shortage

- Target B and C were the seismogenic zones of the events that the strong motion damaged infrastructure considerably.

- Target B: a 2014 M2.8 dynamic rupture*
  - σ_1 > 130 MPa was measure before the M2.8 event.
  - Originally, AE monitoring and multiple drilling were planned. The rupture was to be exhumed by future mining to compare.
  - As it turned out that the mine was closed down and is to be flooded in 2018 because of mine closure, drilling to deploy AE network was abandoned.

- Target C: a 2016 M3.5 dynamic rupture at 3.3 km depth
  - A site alternative to Target B
  - Low σ_1 was measured after the M3.5
  - Geology Department drilled a hole although seriously disked.
  - We drill holes with much better core recovery and deploy AE network.

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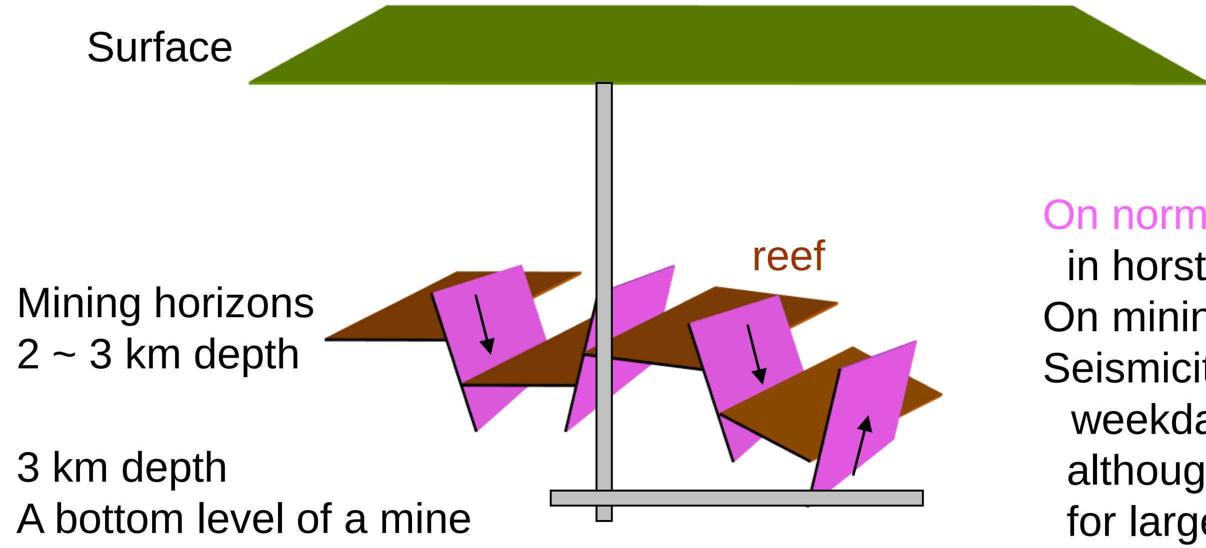
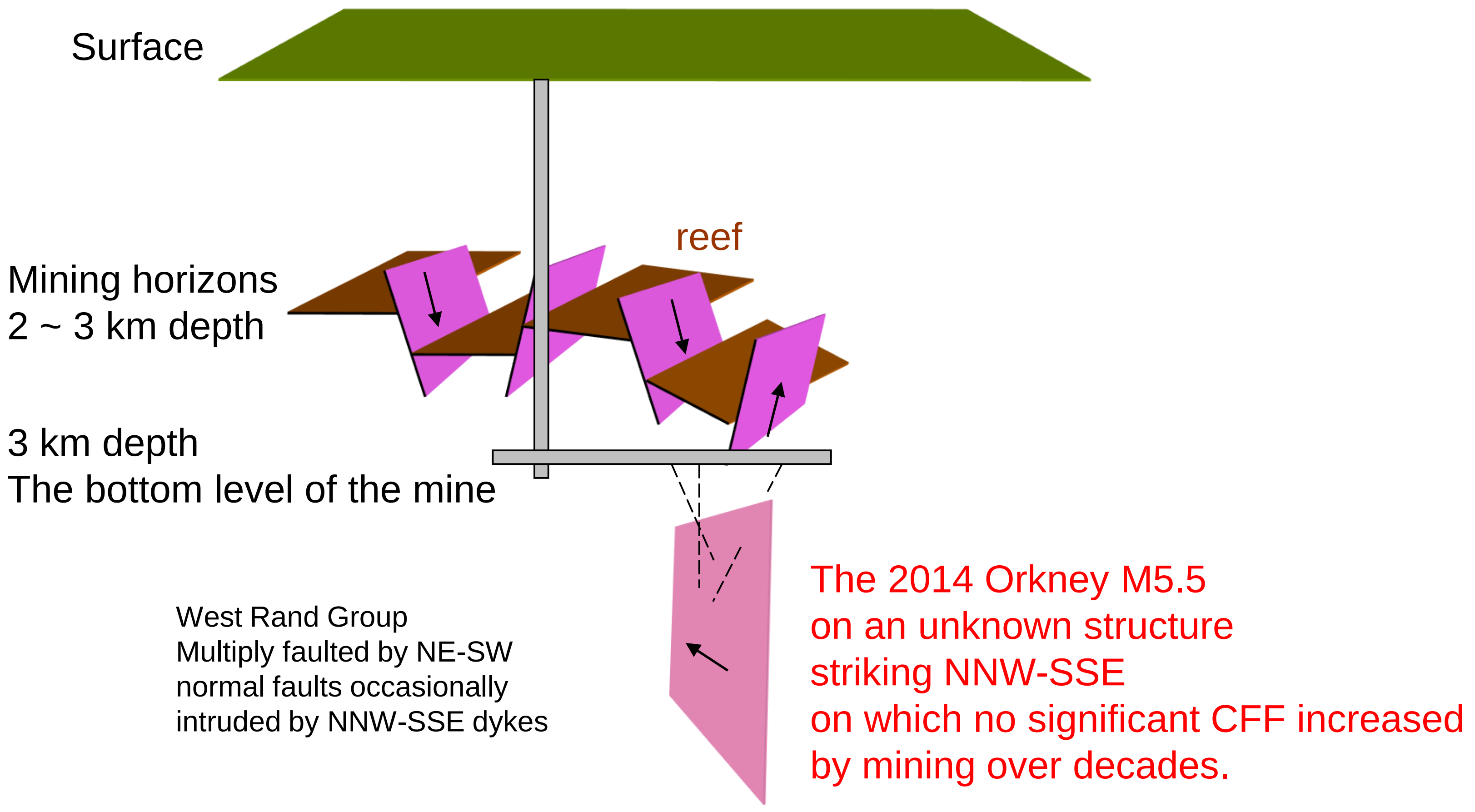
Target A-C: Usual mechanism at usual depth



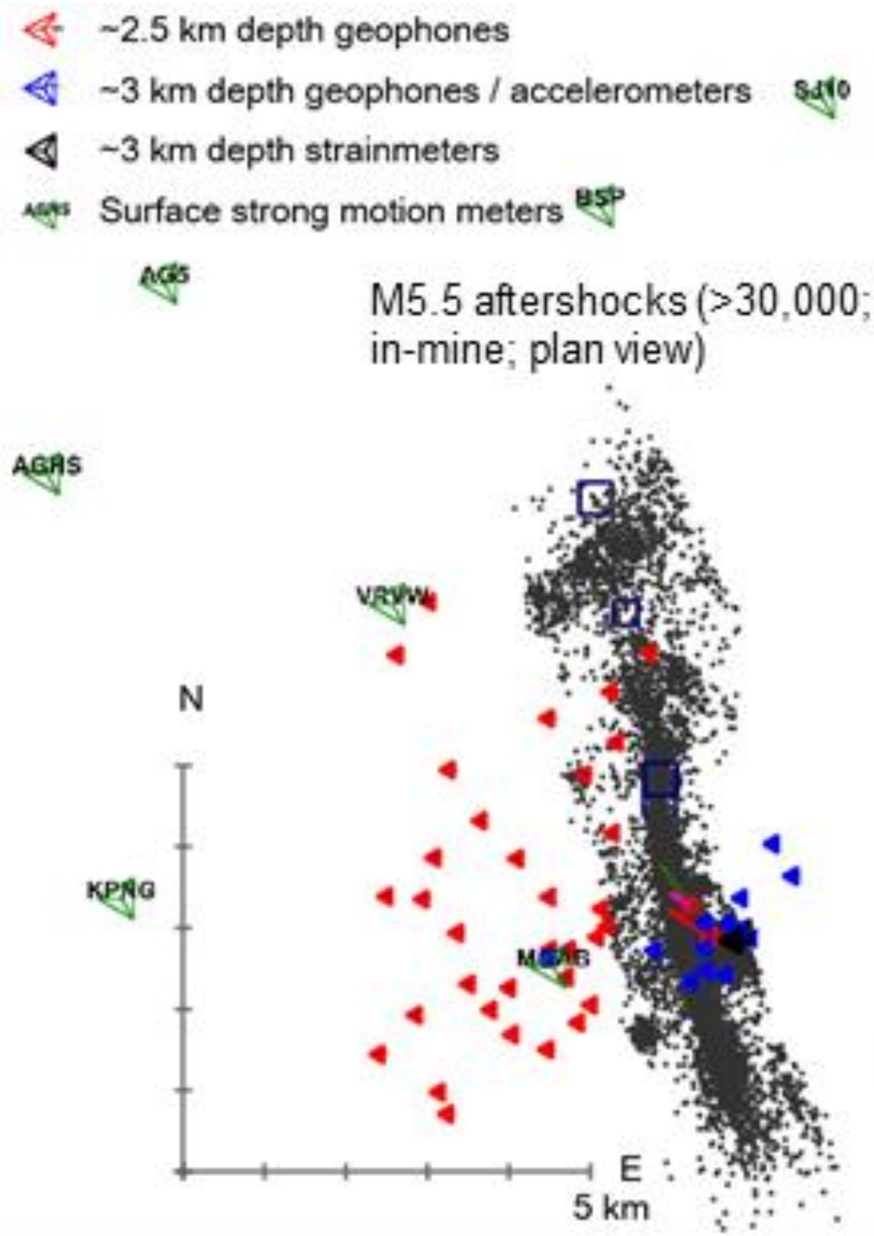
On normal faults (striking NE-SW)
in horst/graben structure.
On mining horizons
Seismicity follows
weekday afternoon blasting
although not the case
for larger events.

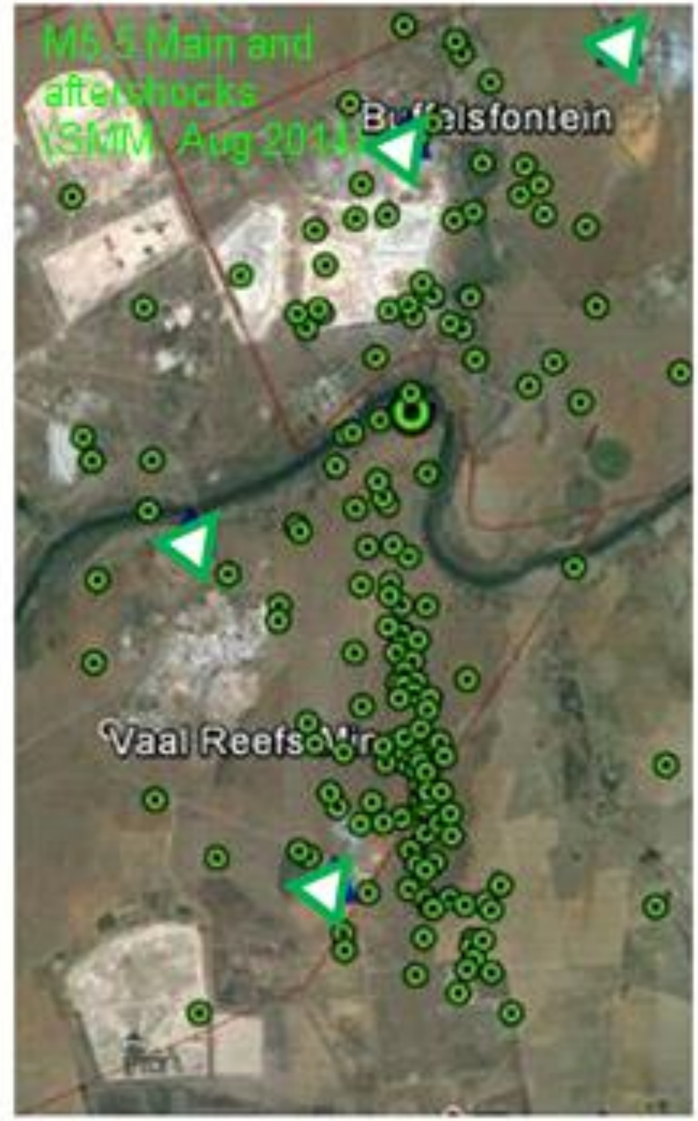
No background M>0 seismicity
beneath mining horizons
before the 2014 M5.5 event



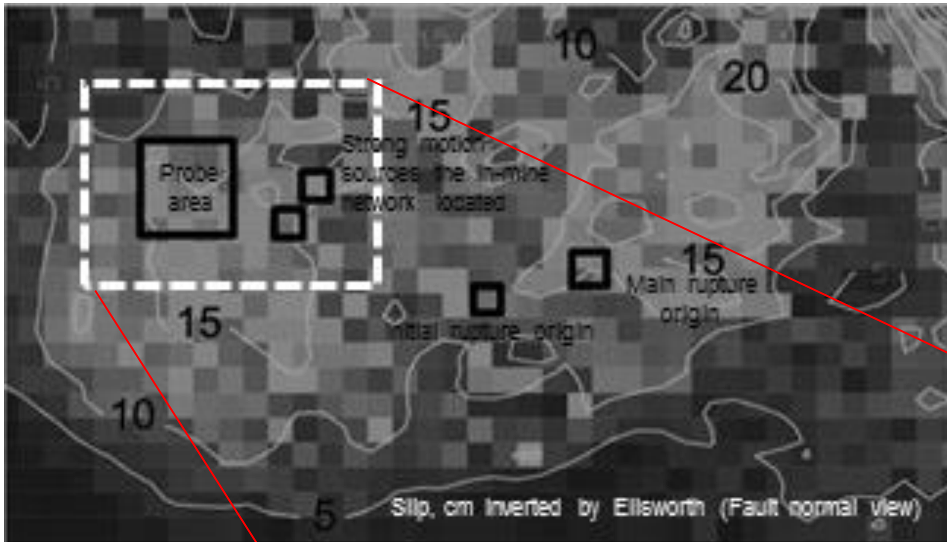
Target D: Unusual mechanism at unusual depth

Target D





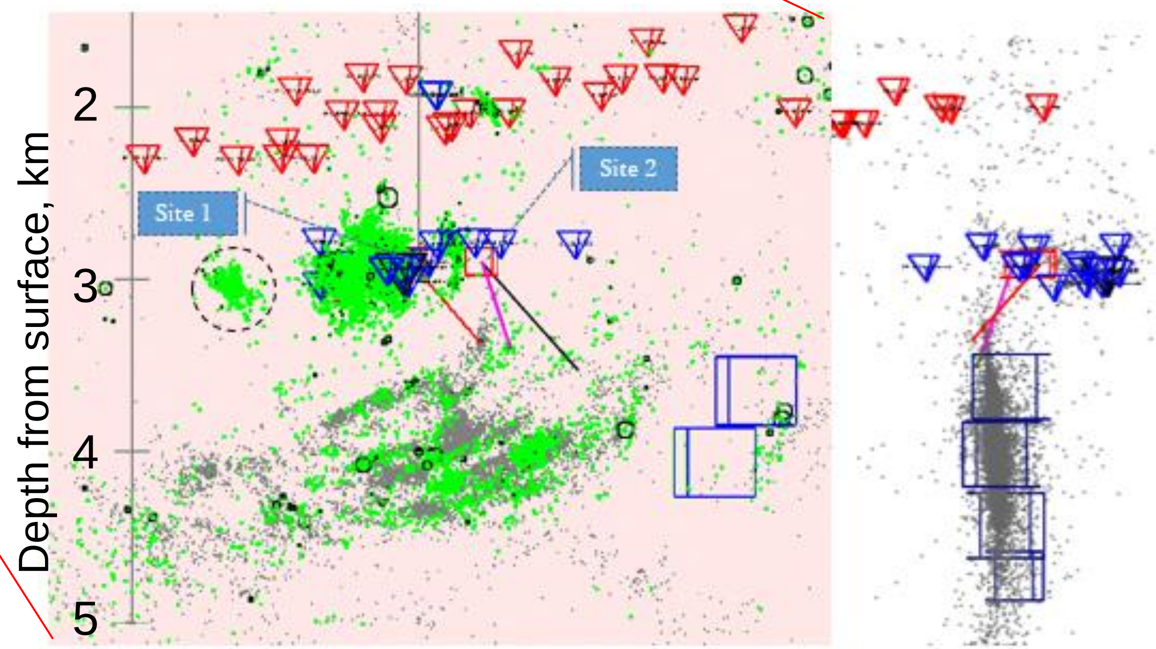
On the mining horizon, lots of NE-SW normal faults are mapped, hosting normal-faulting induced events. Dykes are only NNW-SSE structures, but too minute on the mining horizons to host a M5.5 earthquake.



The ICDP 1st NQ 750m hole from Site 1 is to locate the M5.5 rupture precisely, followed by logging and in-hole geophone array installation.

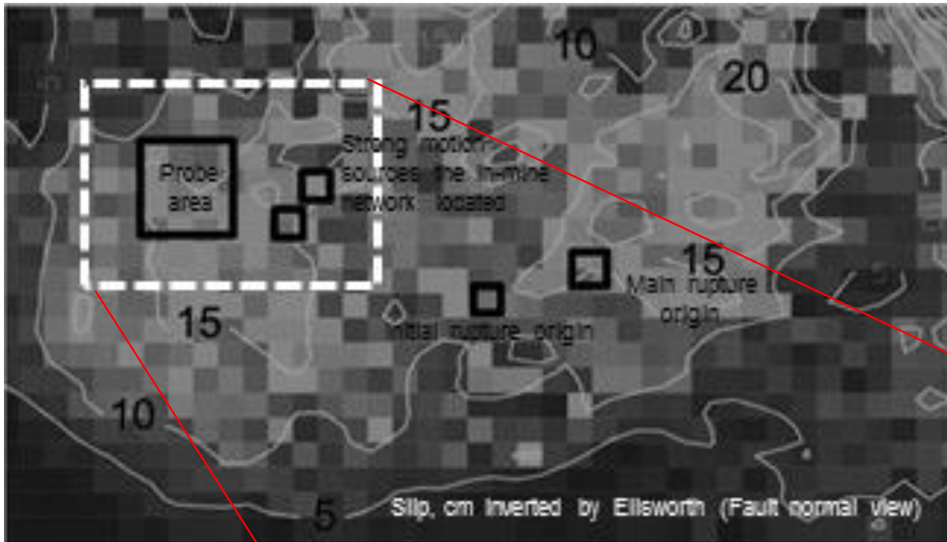
The ICDP 2nd NQ 600m hole intersects the fault at greater depth, dedicated for hydrological and geomicro-biological monitoring.

If JSPS approves a fund, we drill **the 3rd or more holes** > 900m traversing both denser and sparser aftershock areas.



Initial 1-month; latest 1-year; 1-month in July 2016.

Target D



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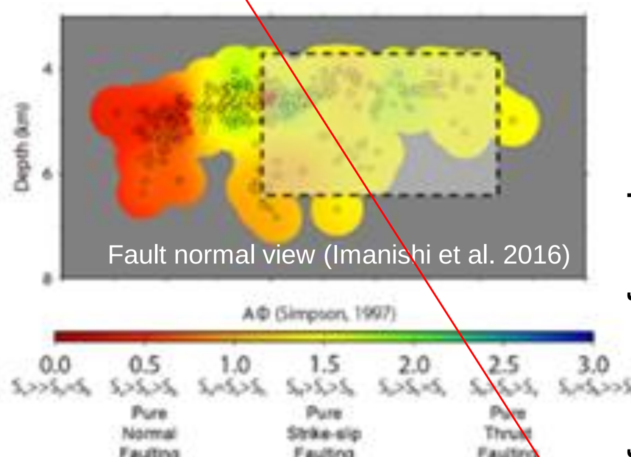
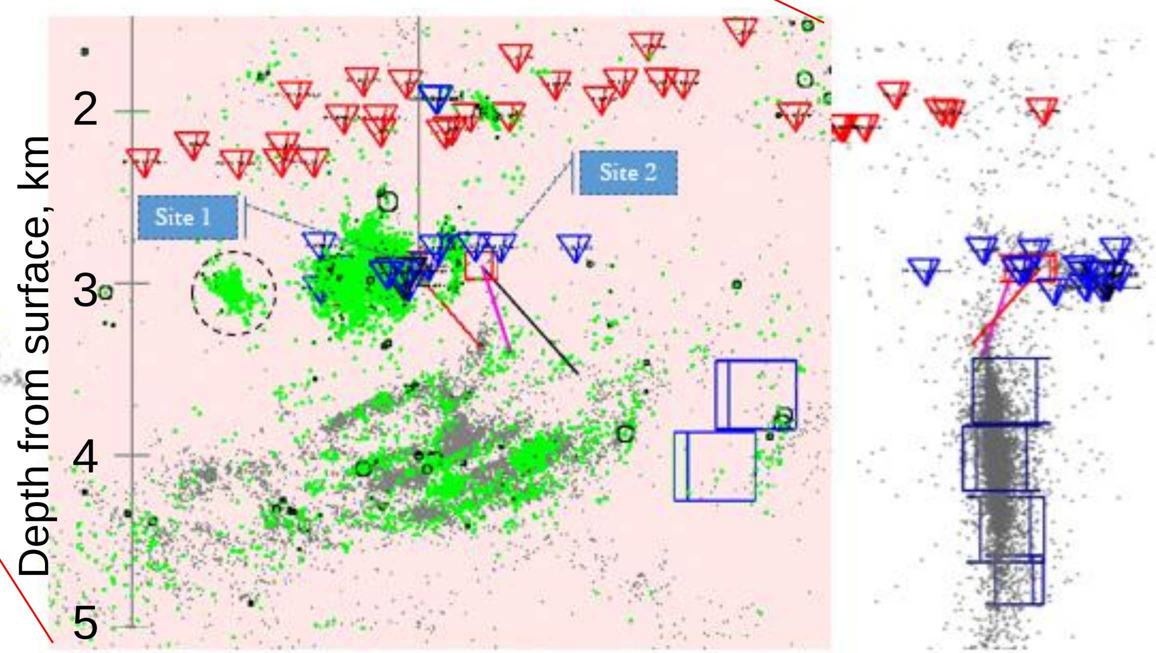


Fault normal view (Imanishi et al. 2016)



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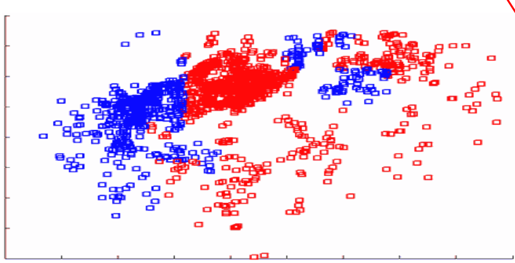
Higher and lower stress drop

Target D

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Conclusions

We aim
to probe ruptures with ~2 < M < 5.5,
seismologically spatio-temporary well elucidated
which evolved both quasi-statically and dynamically,
to recover cores fully (partly oriented and with a triple-tube barrel)
by drilling in line with σ_1 direction, and
to measure stress and log boreholes and cores
followed by in-hole monitoring to elucidate seismicity further.

Geomicrobiologists compare seismicity with water and gas
to see if there is any change in H2 generated by seismicity
that suggests microbiological activity fueled by the H2.

The above allows us to address open questions
- in seismology (what controls ruptures or seismicity), and
- in geomicrobiology (what fuels deep underground life),

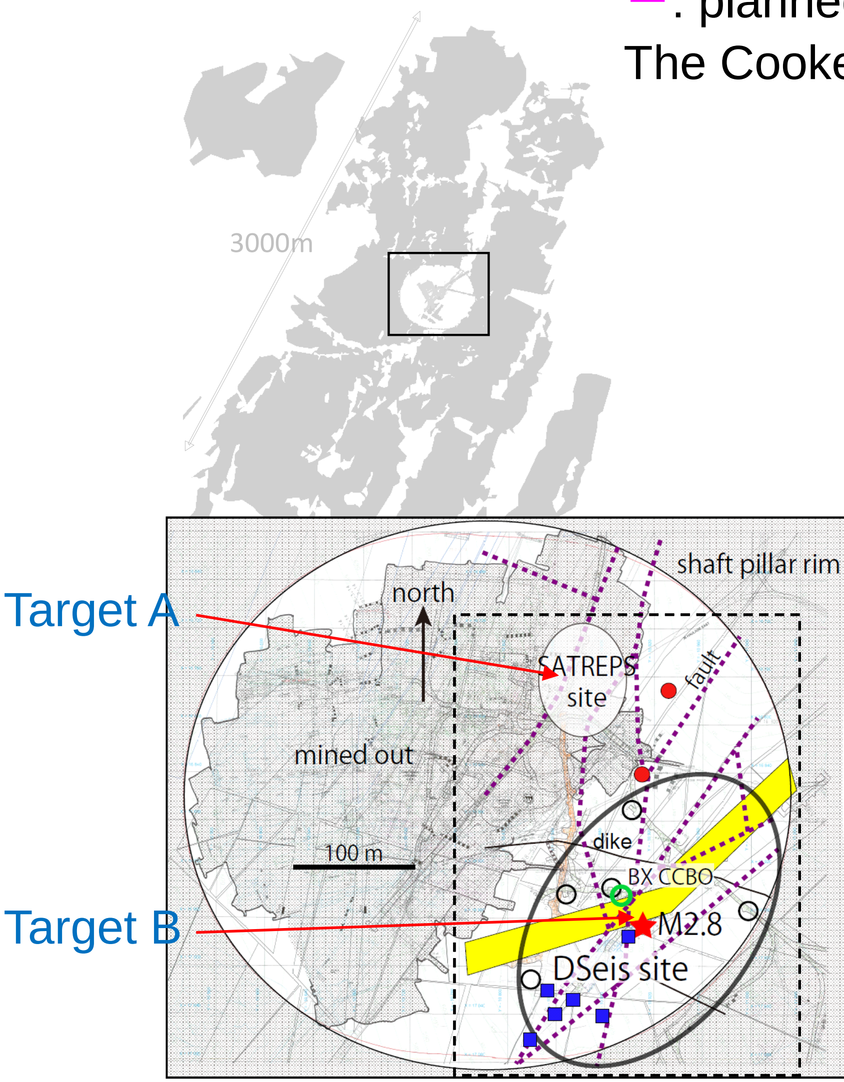
to discuss the robustness and reliability of seismological inversion,
to foster international early-career researchers.

Targets A and B at Cooke 4

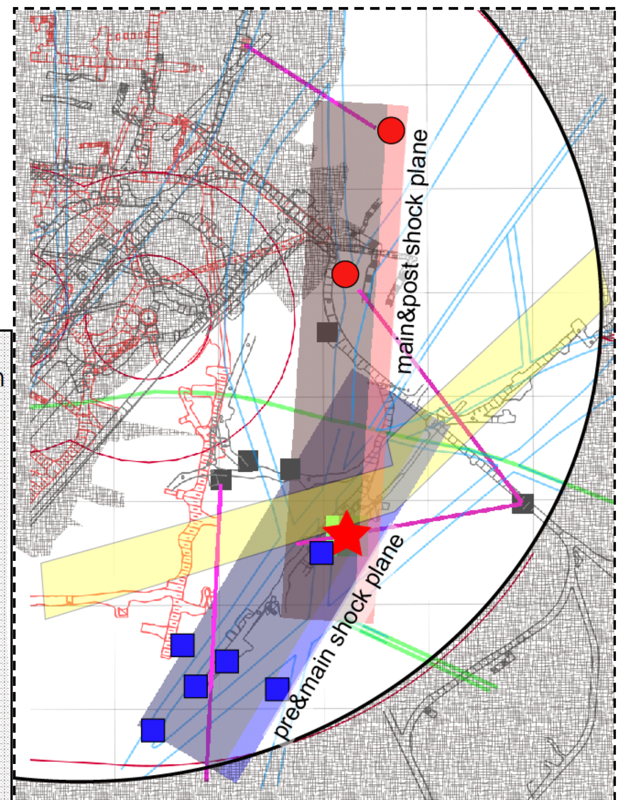
Although it is only 1km depth, stress is high at the remnant.
The M2.8 rupture (Target B) was to be exhumed by mining from yellow band.

—: planned ICDP drilling.

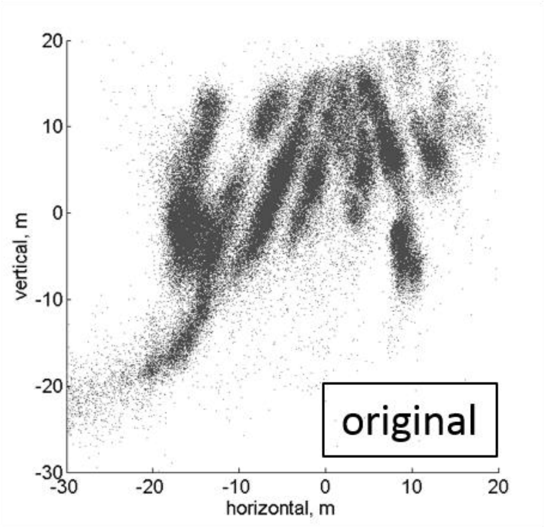
The Cooke 4 mine gave up mining the eastern remnant.

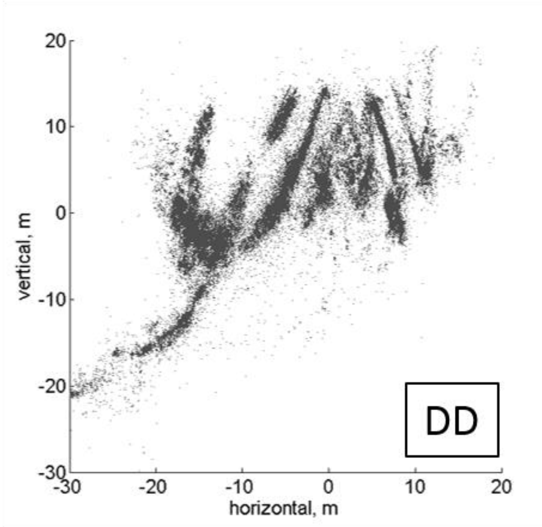


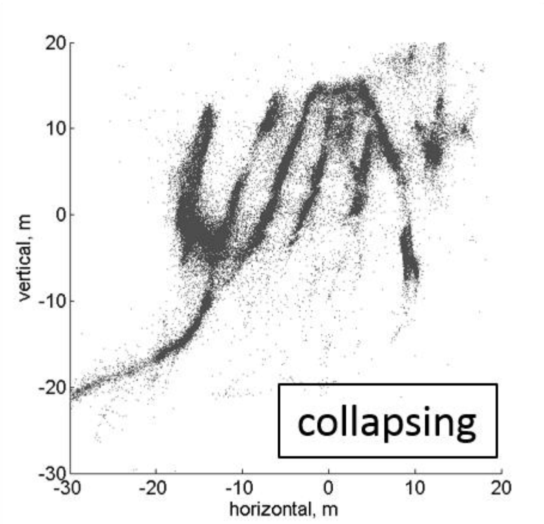
Target B (enlarged)



Target A (Target B was to be elucidated as well as Target A)



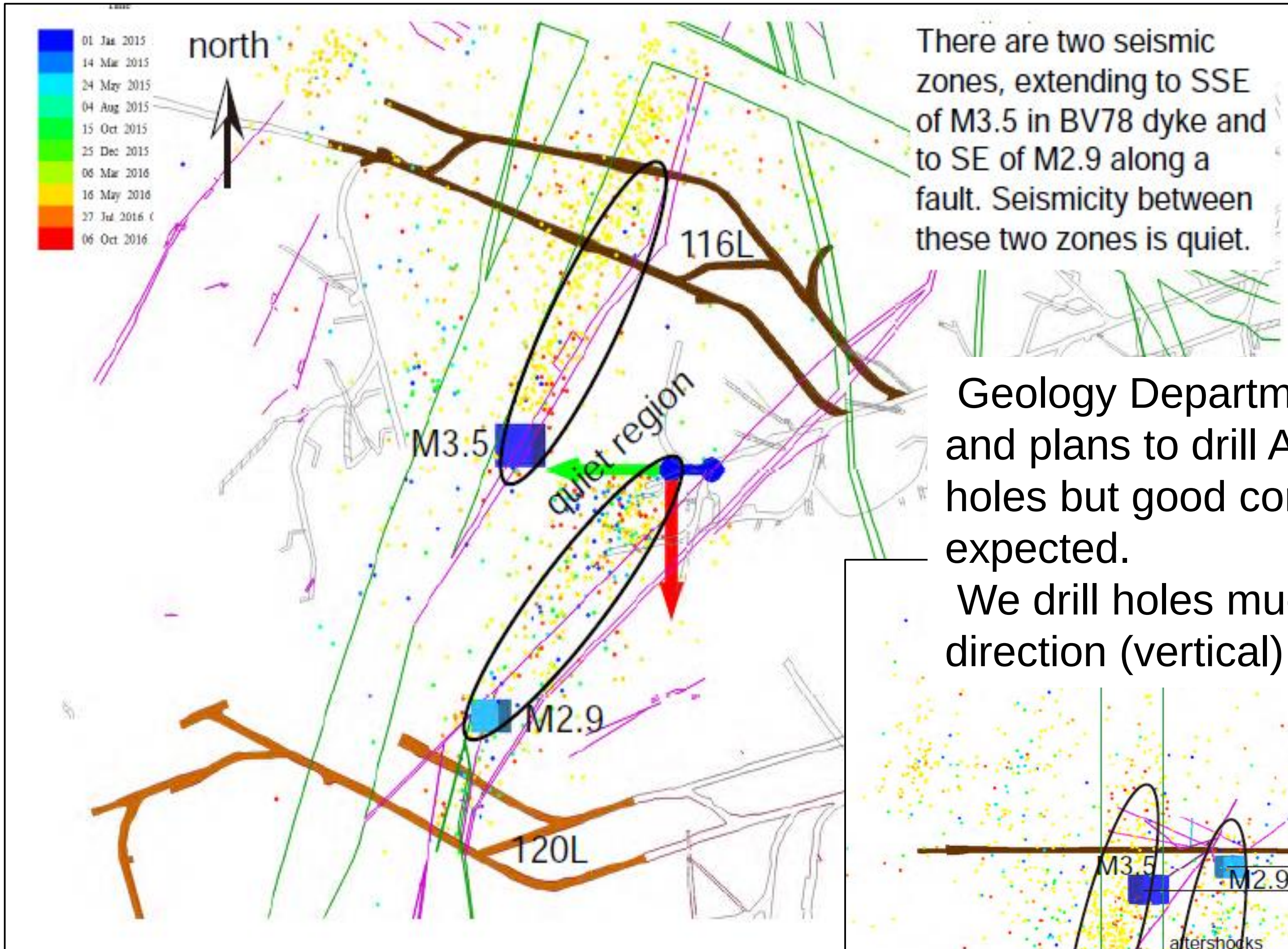




Will be able to compare our drilling with seismological inferred structure.

Drilling enriches our understanding of seismogenic zones because seismic events only convey information of the locality where the events took place.

Target C (A M3.5 fault in a dyke)



There are two seismic zones, extending to SSE of M3.5 in BV78 dyke and to SE of M2.9 along a fault. Seismicity between these two zones is quiet.

Geology Department has drilled and plans to drill AX sub-horizontal holes but good core recovery is not expected.

We drill holes much in line with σ_1 direction (vertical)