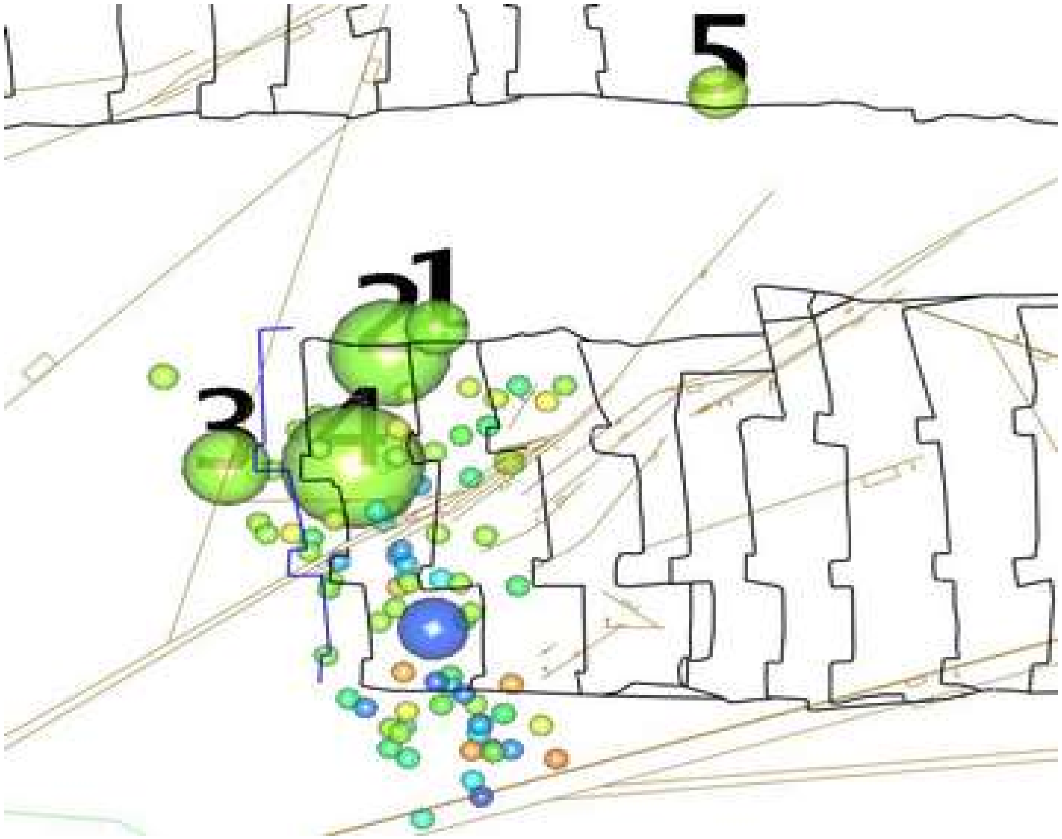
Forensic rock mechanics for the analysis of rockbursts and seismicity in mines – Session II

Part C

Contents

6.6 tau20061023



Preparing for the webinar, I revisited of a fatal rockburst case of 2006 (TauTona 97W3, 20061023). Aspects of this case are described in van Aswegen (2013) and Murphy (2012). Reviewing the data (photographs) with the aid of building 3D models of parts of the site and re-interpreting the damage mechanisms, I conclude that these papers have the fundamental mechanisms wrong because of my incorrect interpretation at the time.

Events 3 and 4 are the rockburst events

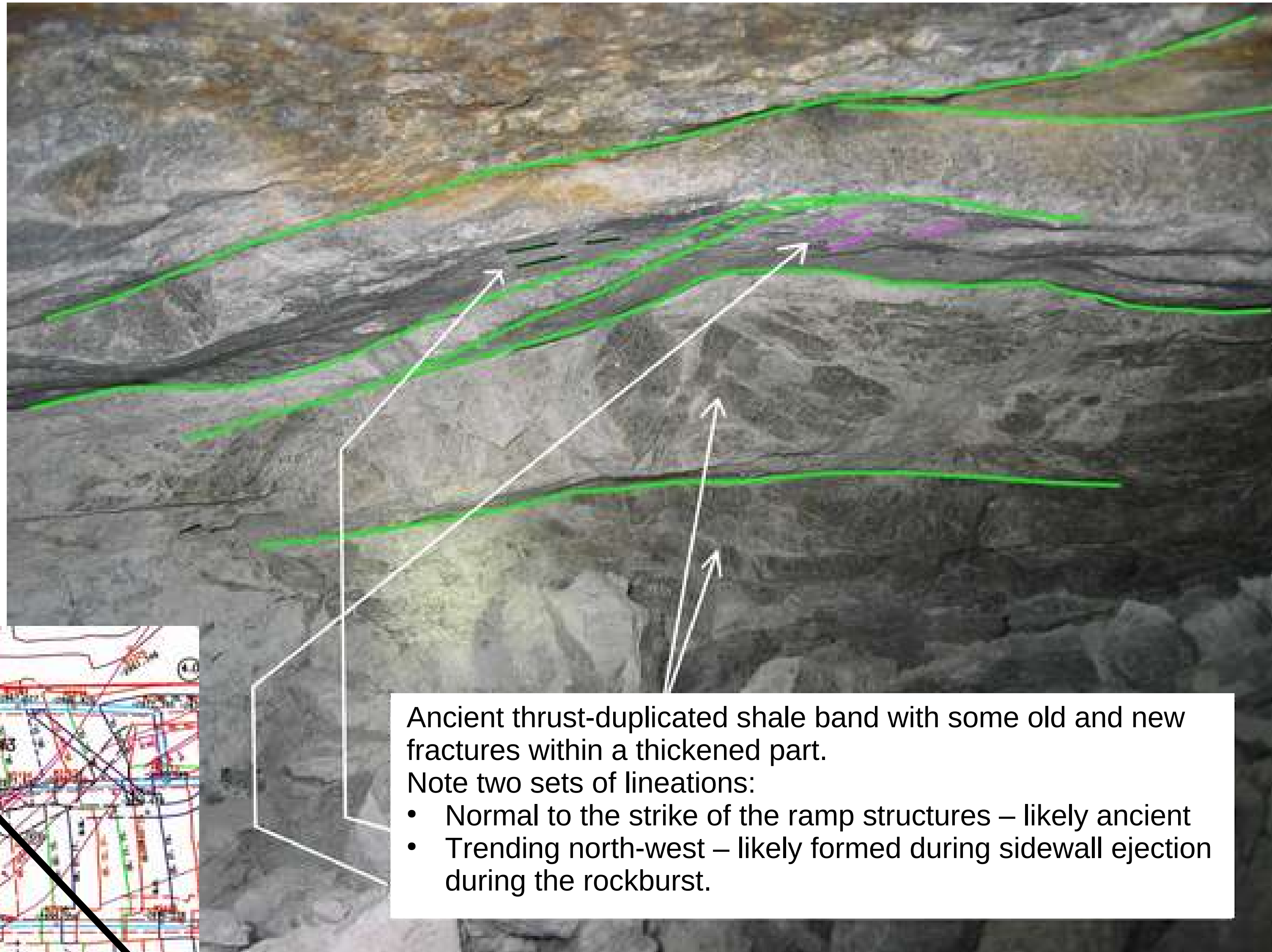
In the following slides it is shown how a combination of pre-existing geological weaknesses and a high stress field combined to yield a complete, dynamic collapse of the 97W3 face, TauTona shaft pillar, on 23 October 2006.

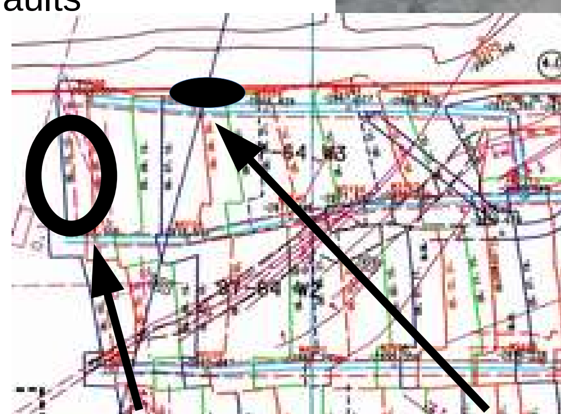
Murphy. S.K. (2012). *Linear elastic numerical modelling prediction failure assessment.* Southern Hemisphere International Rock Mechanics Symposium SHIRMS 2012. The Southern African Institute of Mining and Metallurgy.
van Aswegen, G (2013). *Forensic rock mechanics, Ortlepp shears and other mining induced structures.* Key-note lecture, Eighth International Symposium on Rockburst and Seismicity in Mines (RaSiM8).

Old bedding-parallel faults

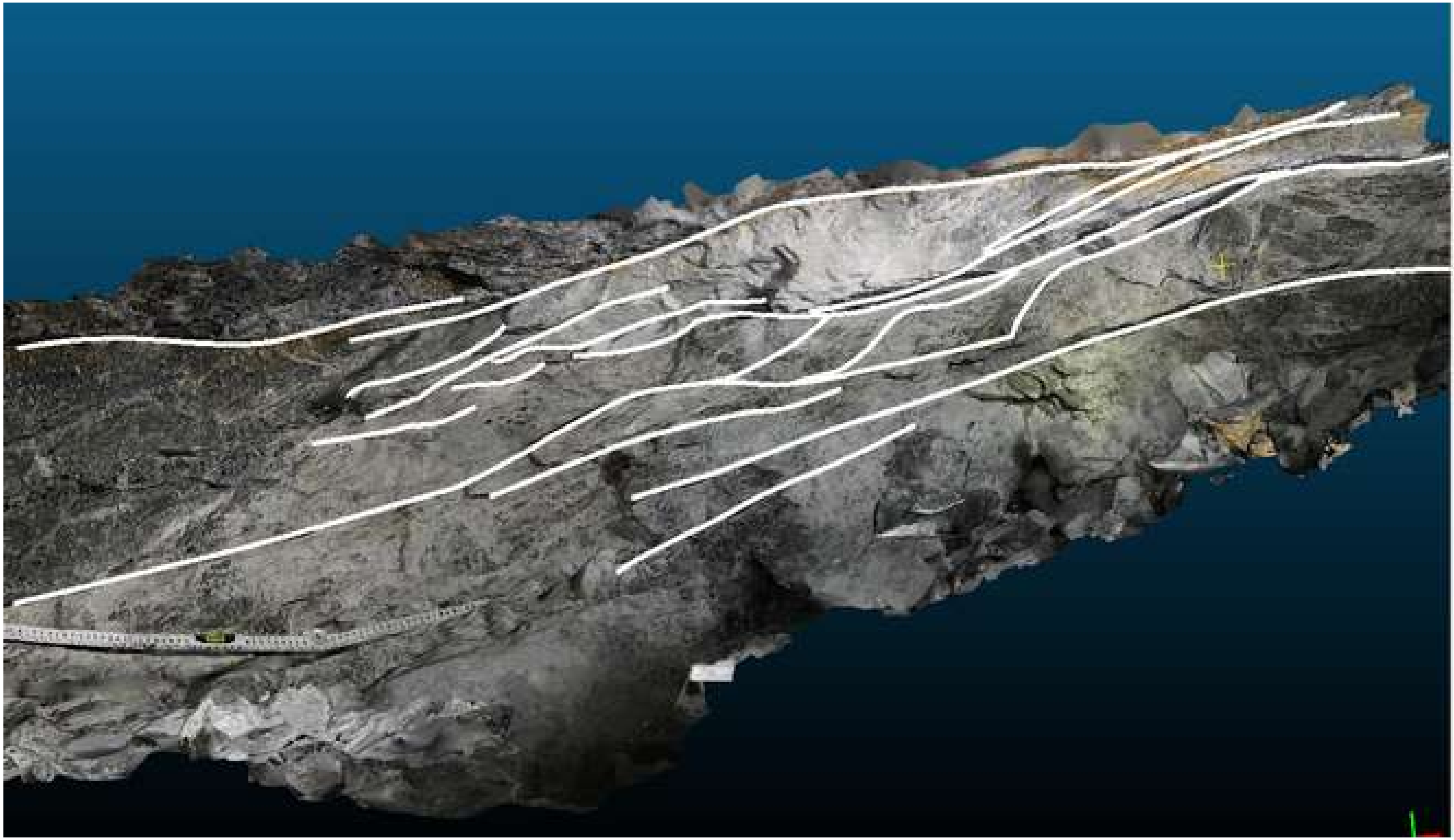
Along the top strike gully a set of low-angle thrust faults are visible

We do not have a "before and after" view of the damaged panel, so we have to imagine the state prior to the dynamic failure. Here I try to set the scene, mainly from a geological structure perspective.
We note the presence of small bedding (sub) parallel thrust faults



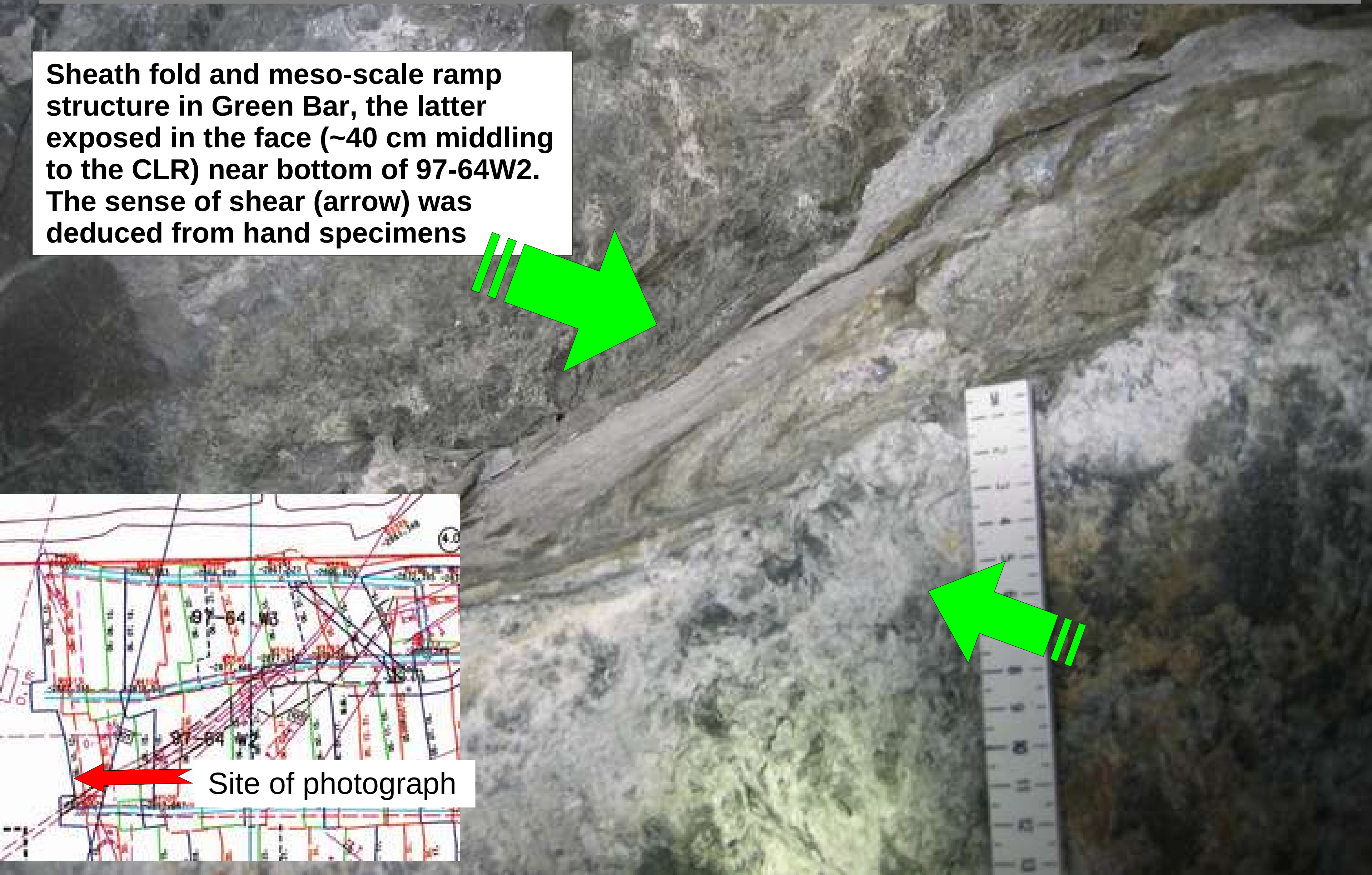


Another view of the small thrust faults sub-parallel to bedding



Old bedding-parallel deformation – syn Vredefort?

Sheath fold and meso-scale ramp structure in Green Bar, the latter exposed in the face (~40 cm middling to the CLR) near bottom of 97-64W2. The sense of shear (arrow) was deduced from hand specimens



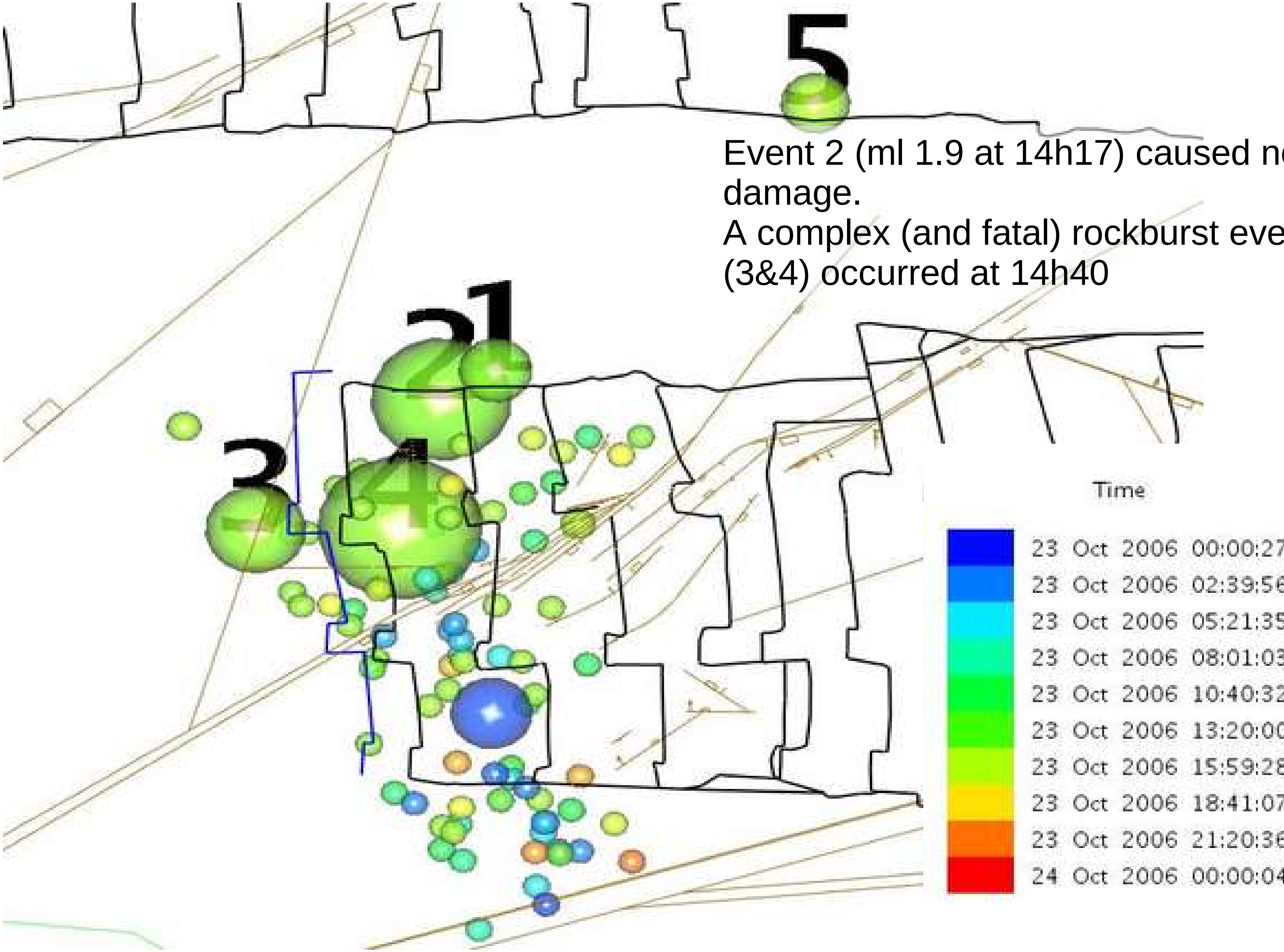
Westerly dipping fault

some distance back from the face – to illustrate the presence of structures dipping ~30° westerly

Rockburst

.. so we note several geological structures sub-parallel to the stope and of varying dips that could act as weak discontinuities during dynamic deformation ..

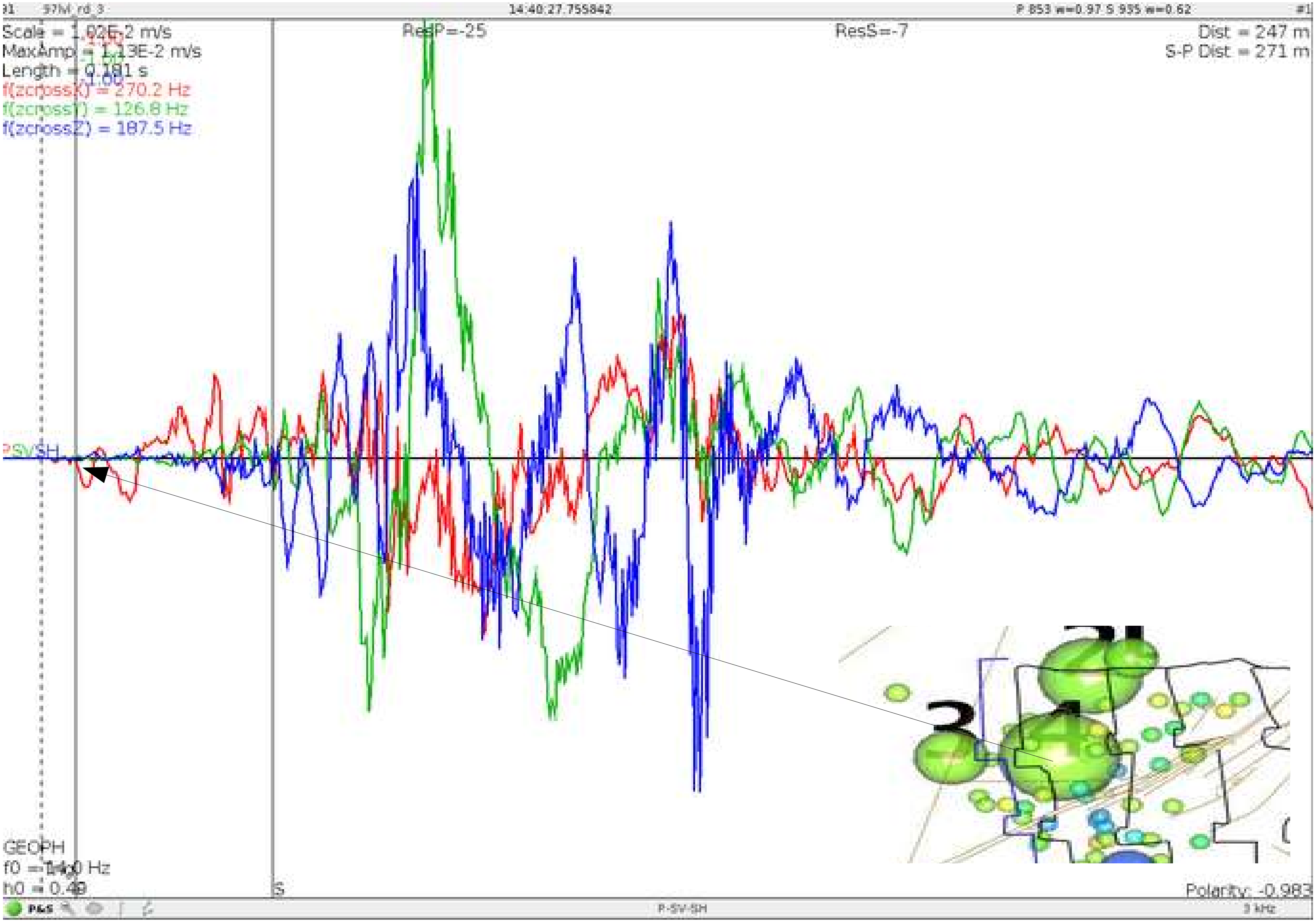
6.6 tau20061023 – the events

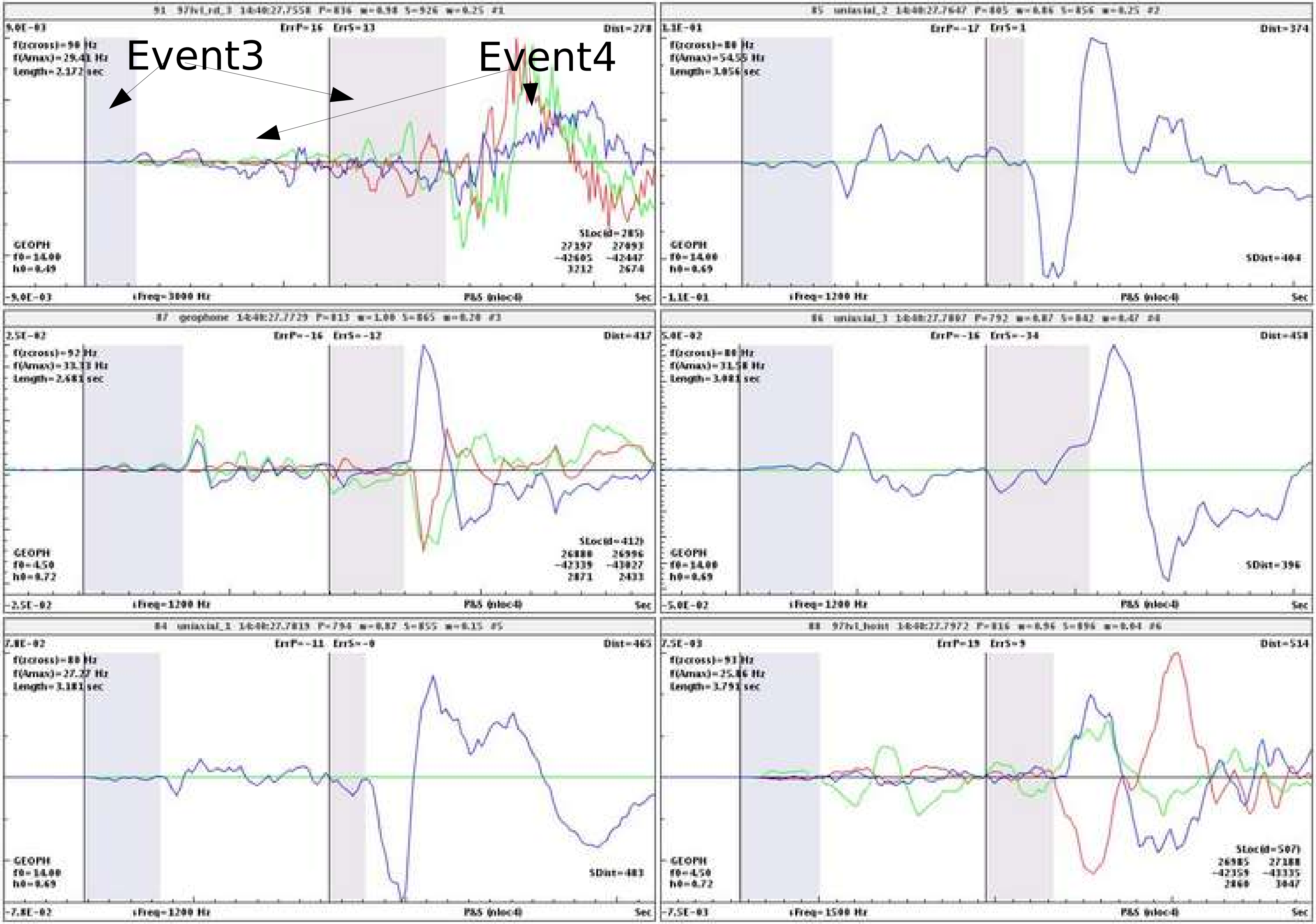


Event 2 (ml 1.9 at 14h17) caused no damage.

A complex (and fatal) rockburst event (3&4) occurred at 14h40

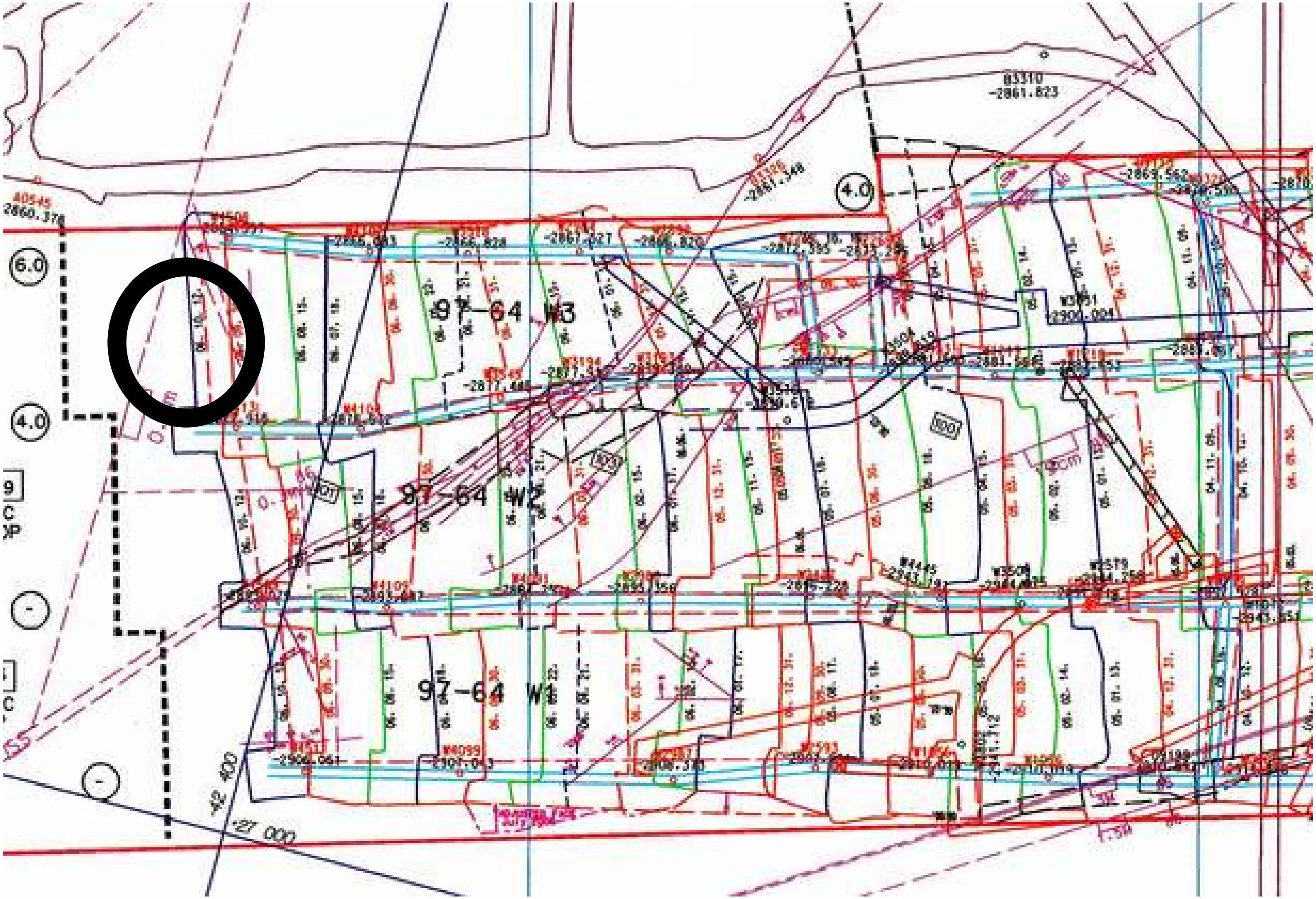
Tau20061023 – complex – as all large events



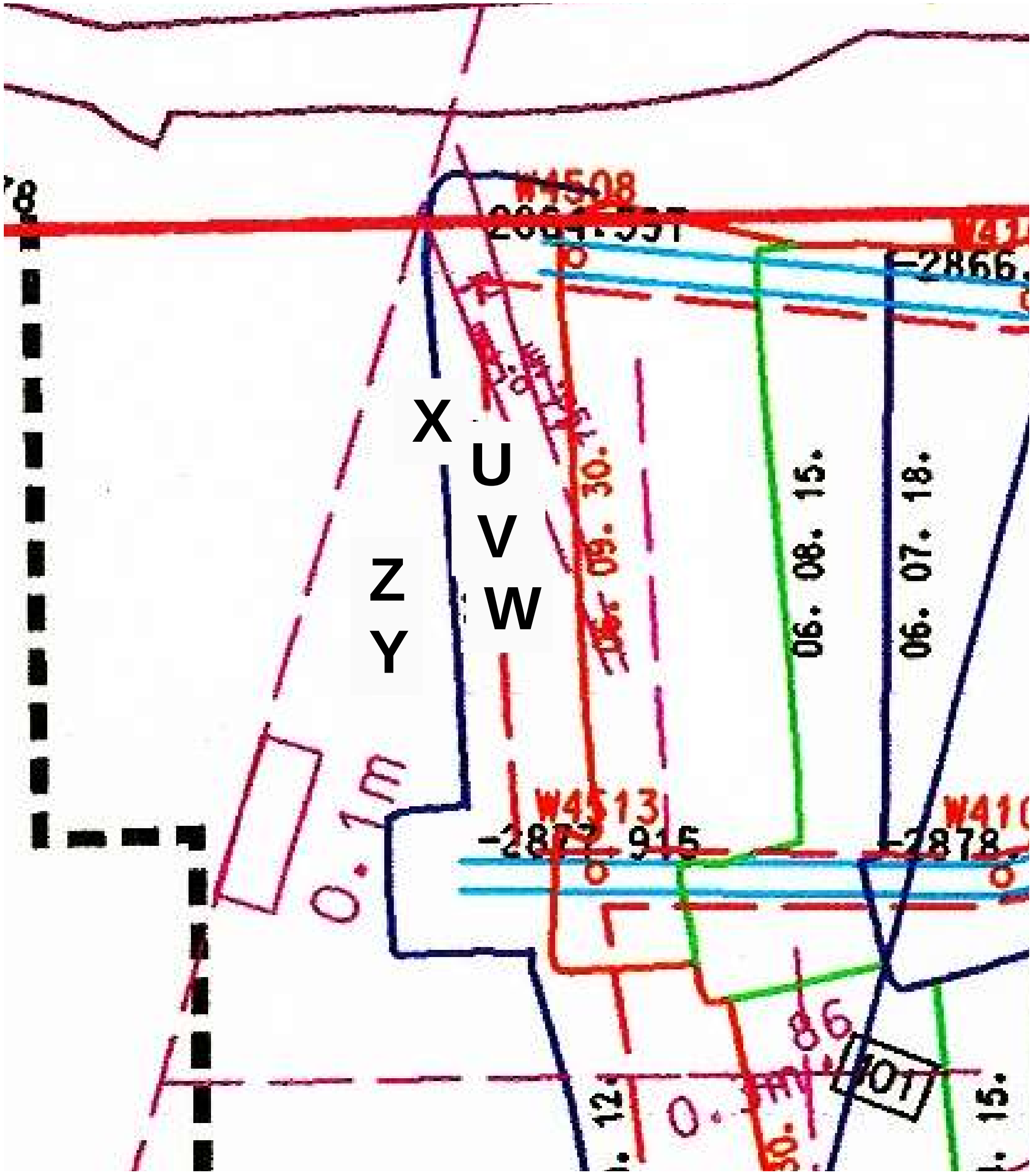


Event3
Event4
GEOPH
P&S (nloc4)
Sec

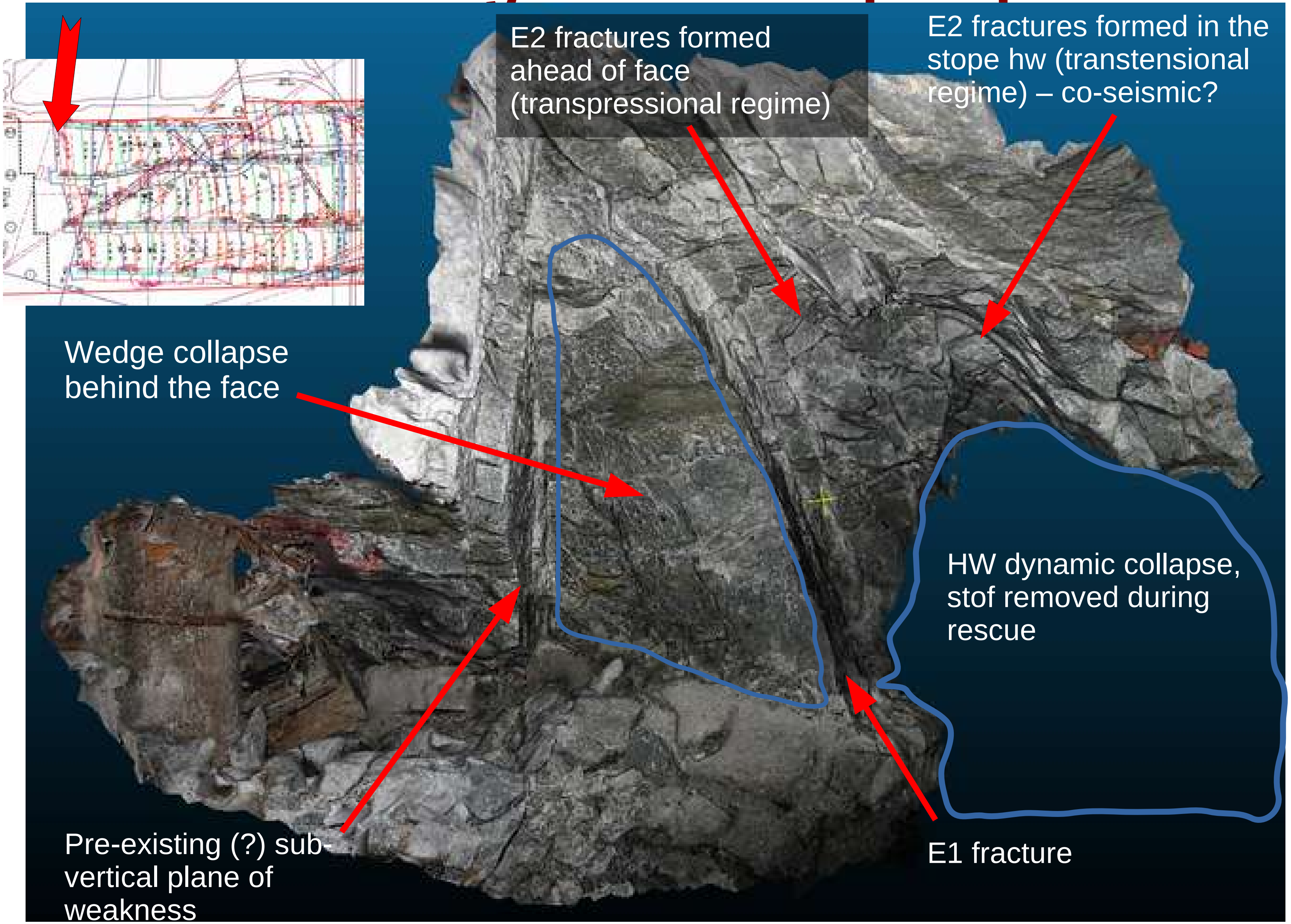
Photographs of damage
... in the area indicated



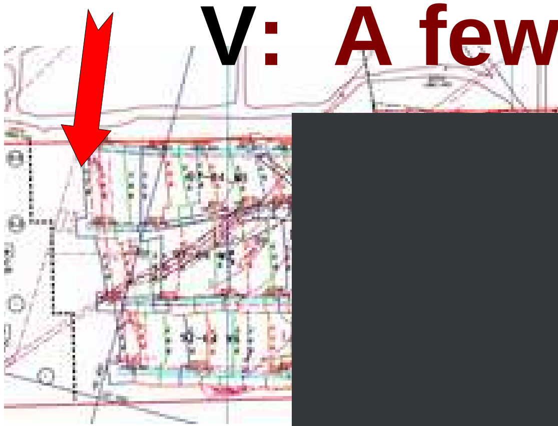
Sites of the photographs of damage

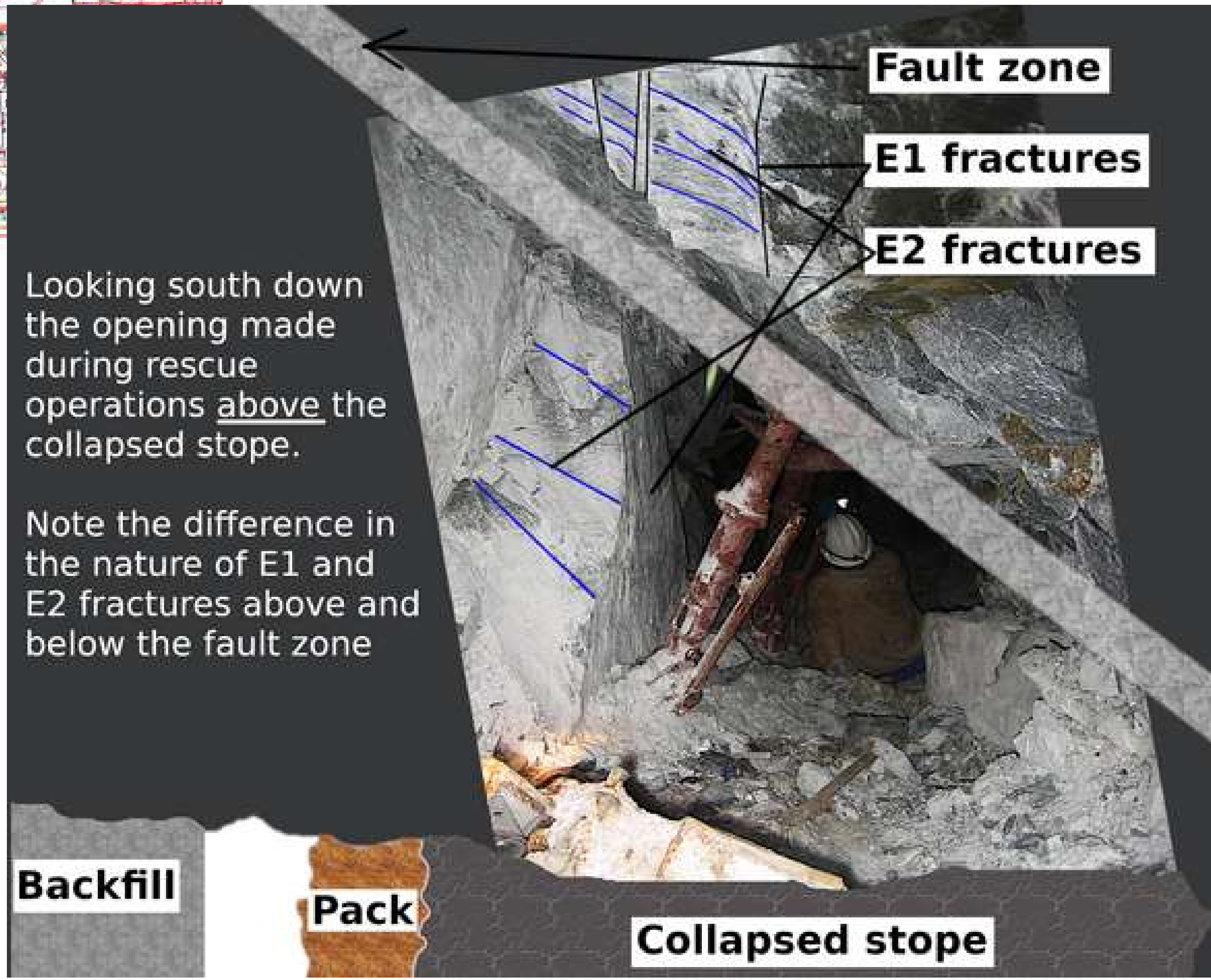


U: Looking south at top of panel



V: A few metres further down the panel

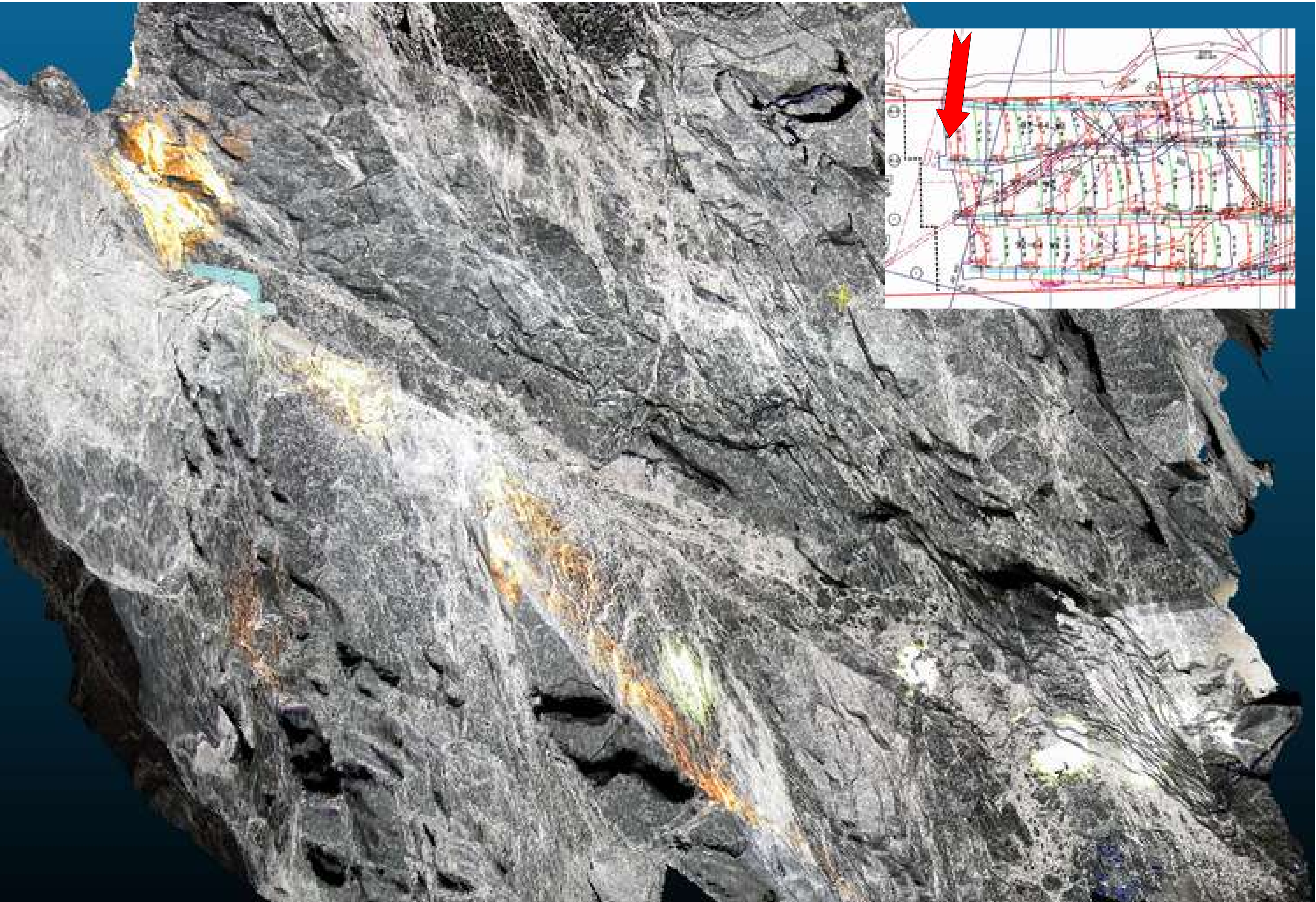




Looking south down the opening made during rescue operations above the collapsed stope.

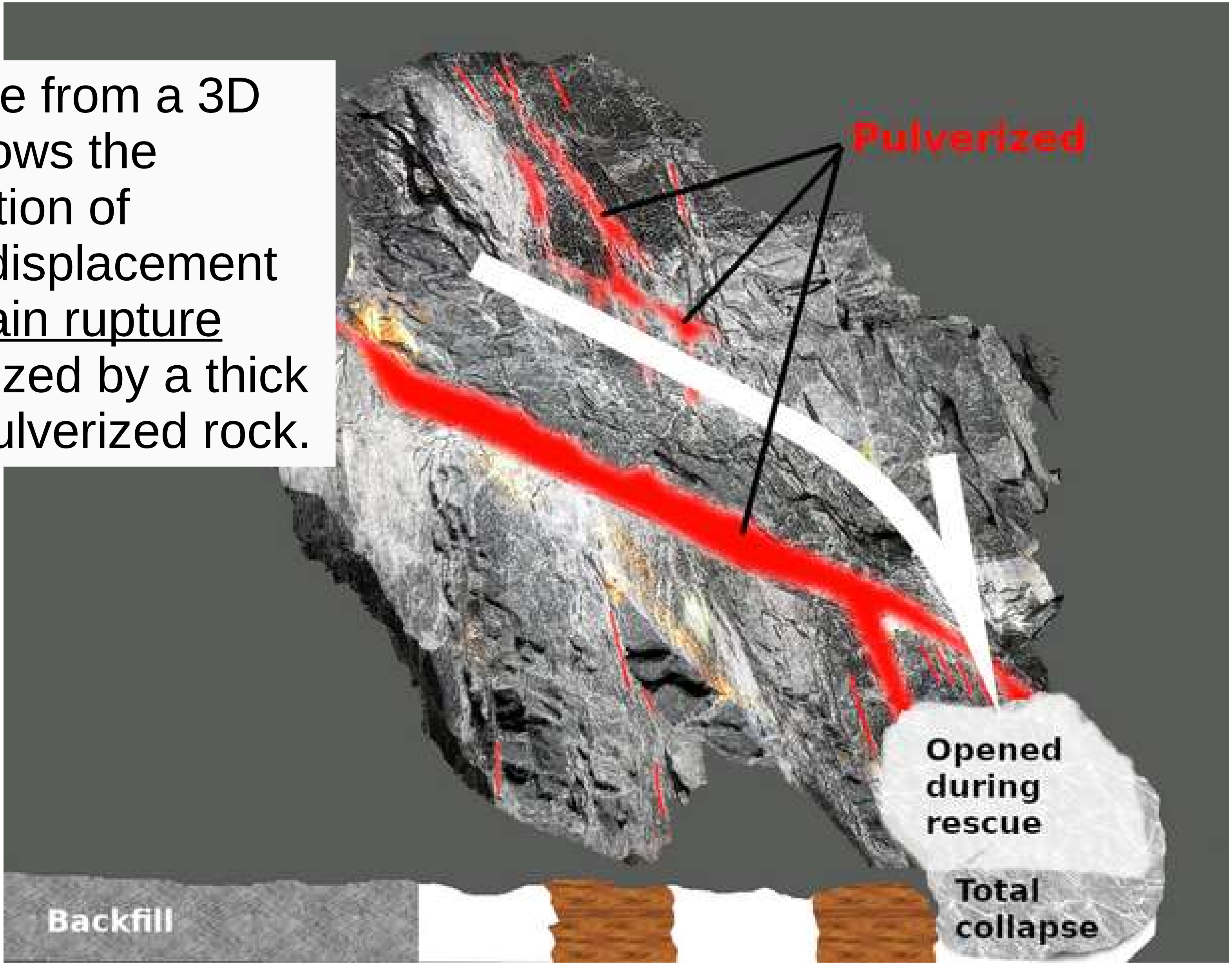
Note the difference in the nature of E1 and E2 fractures above and below the fault zone

W: few metres further down – pulverized shear zone



W: Some interpretation

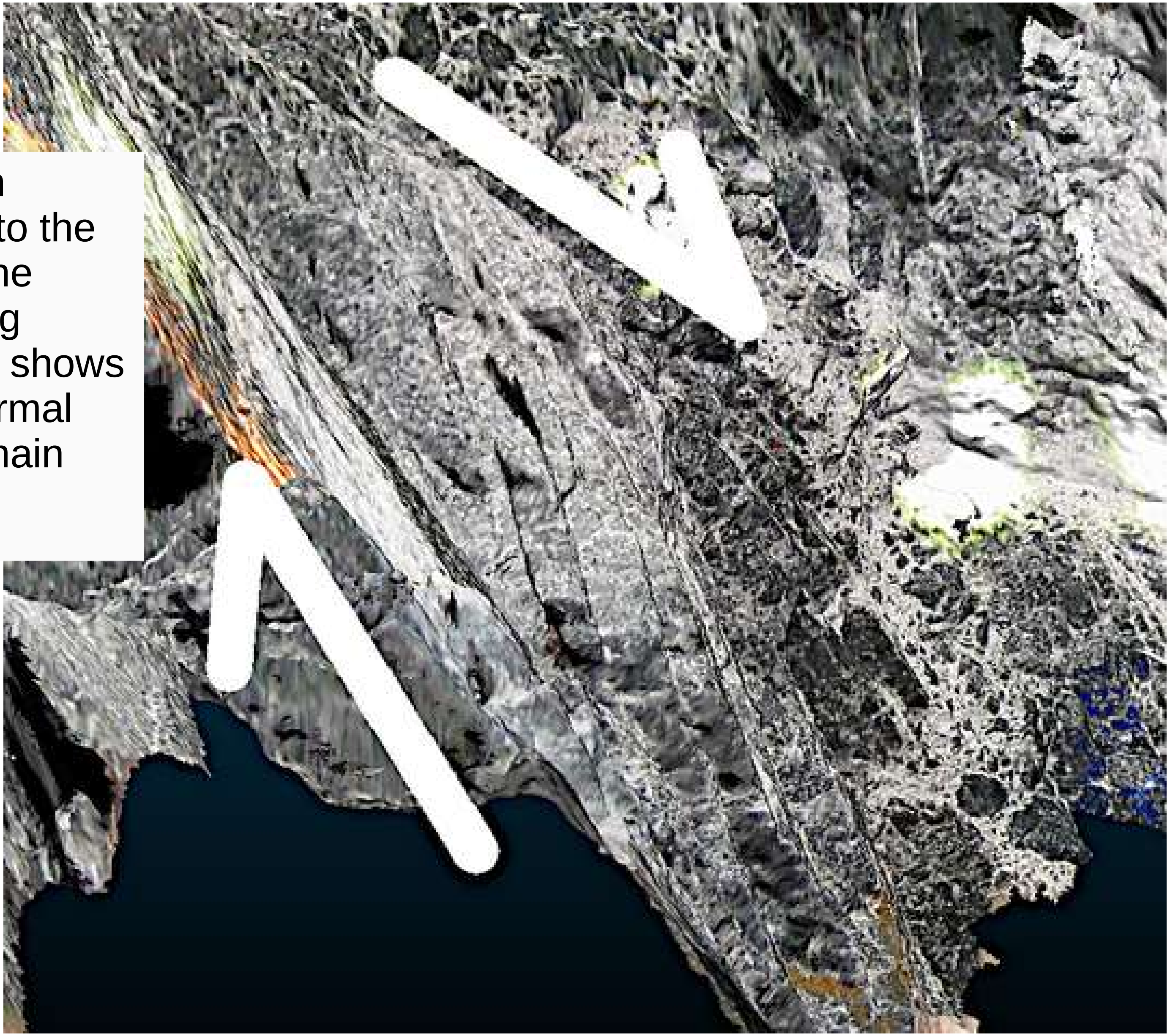
This image from a 3D model shows the interpretation of dynamic displacement wit the <u>main rupture</u> characterized by a thick zone of pulverized rock.



W: Extreme pulverization

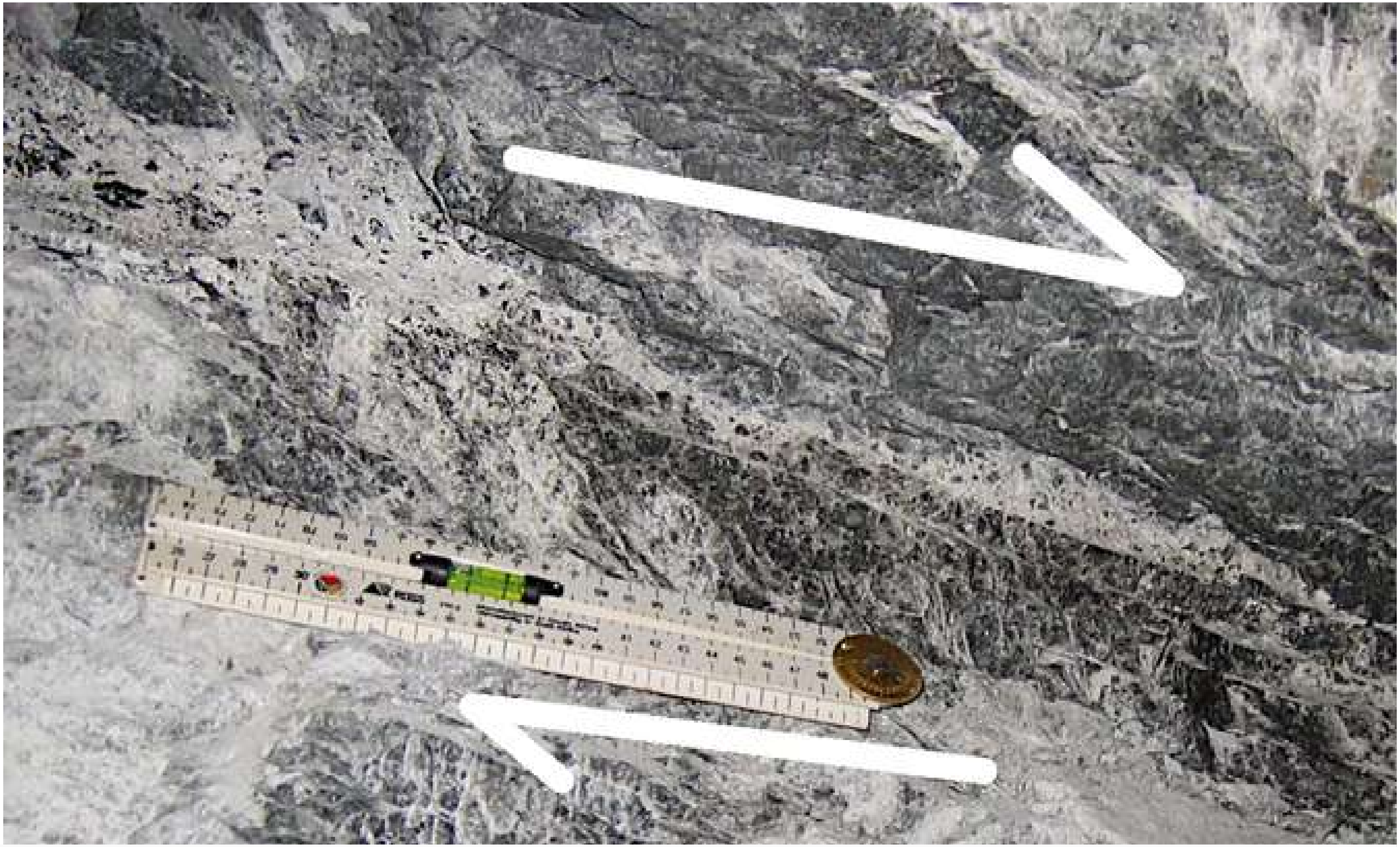
The bent arrow shows normal shear as the rockmass violently ejects into the stope below along the main rupture.
The pattern of steeply dipping pulverization below the main rupture indicates reverse shear. One possible explanation could be that the moving rockmass experience local resistance (maybe an elongate) as suggested by the fat arrow

W: Normal shear



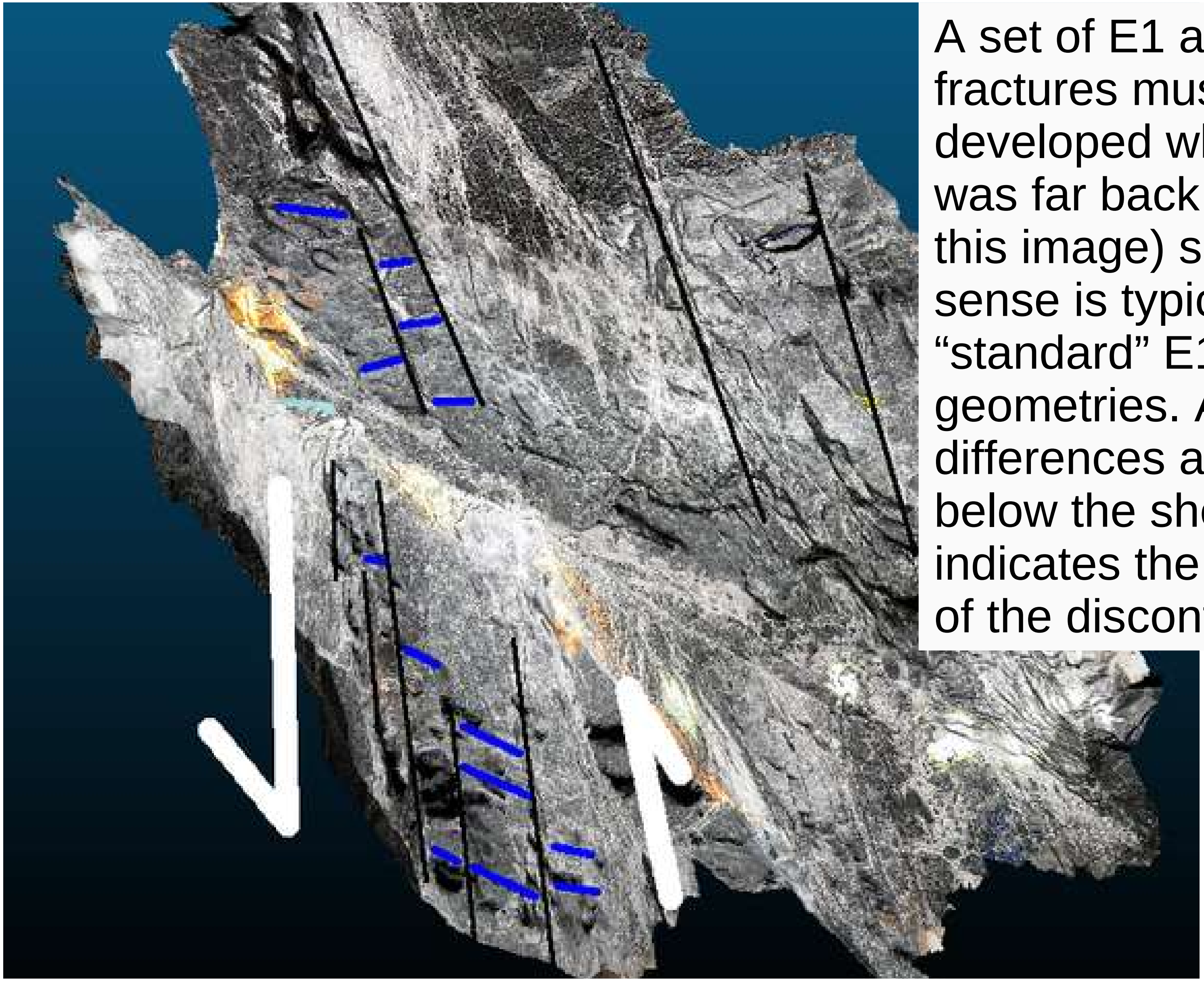
The extension fractures just to the east (left) of the steeply dipping reverse shear shows the overall normal shear of the main rupture

W: Extreme pulverization further updip along the main rupture



The pulverized material shows no flow structure (foliation) – consistent with transtensional shear as indicated by the arrows – note the arrows are not parallel to the rupture zone

W: E1 and E2 fractures

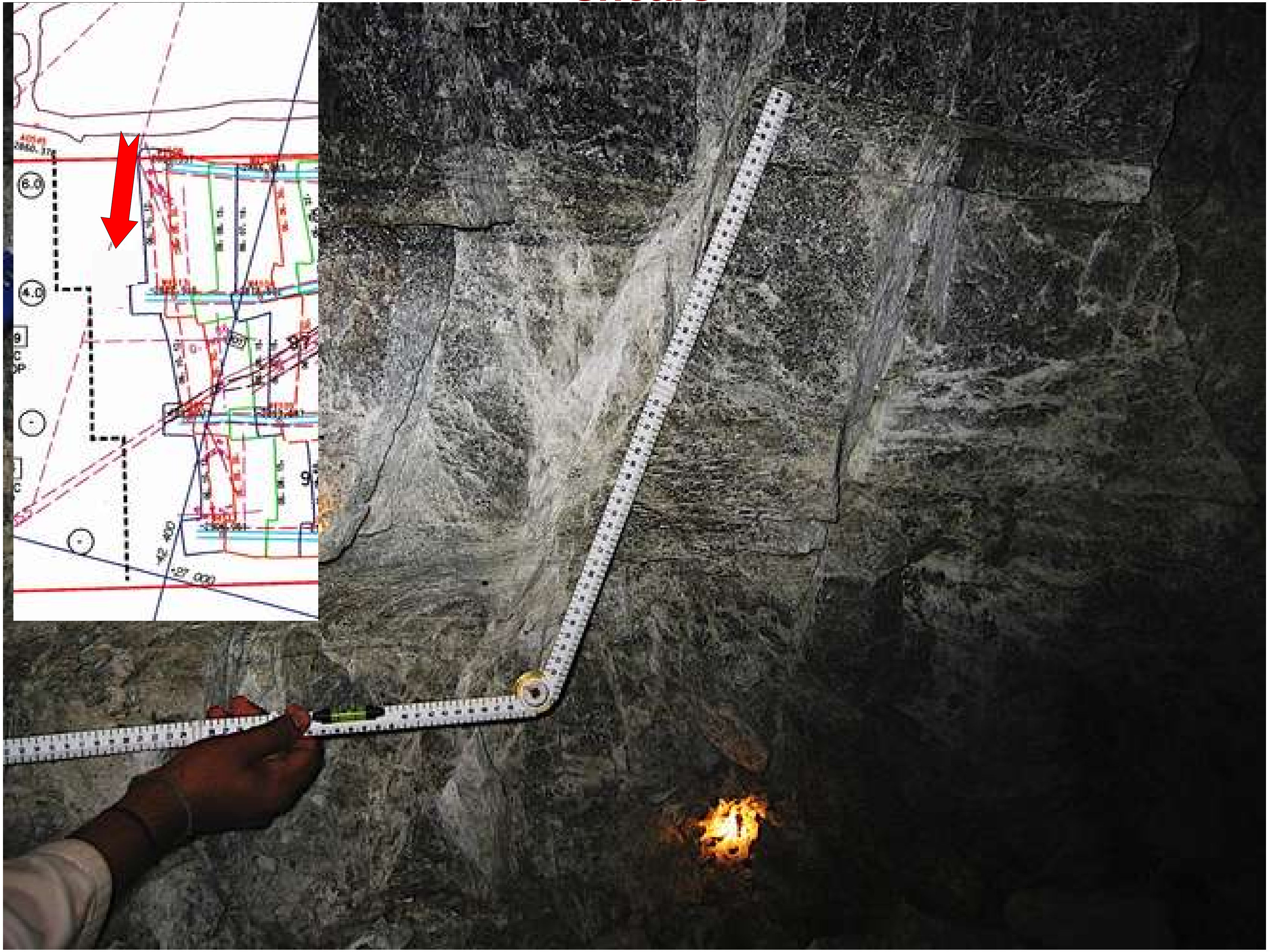


A set of E1 and E2 fractures must have developed while the face was far back (to the left in this image) since the shear sense is typical of “standard” E1-E2 geometries. Again, the differences above and below the shear zone indicates the pre-existence of the discontinuity

X: An Ortlepp shear

X: An Ortlepp shear

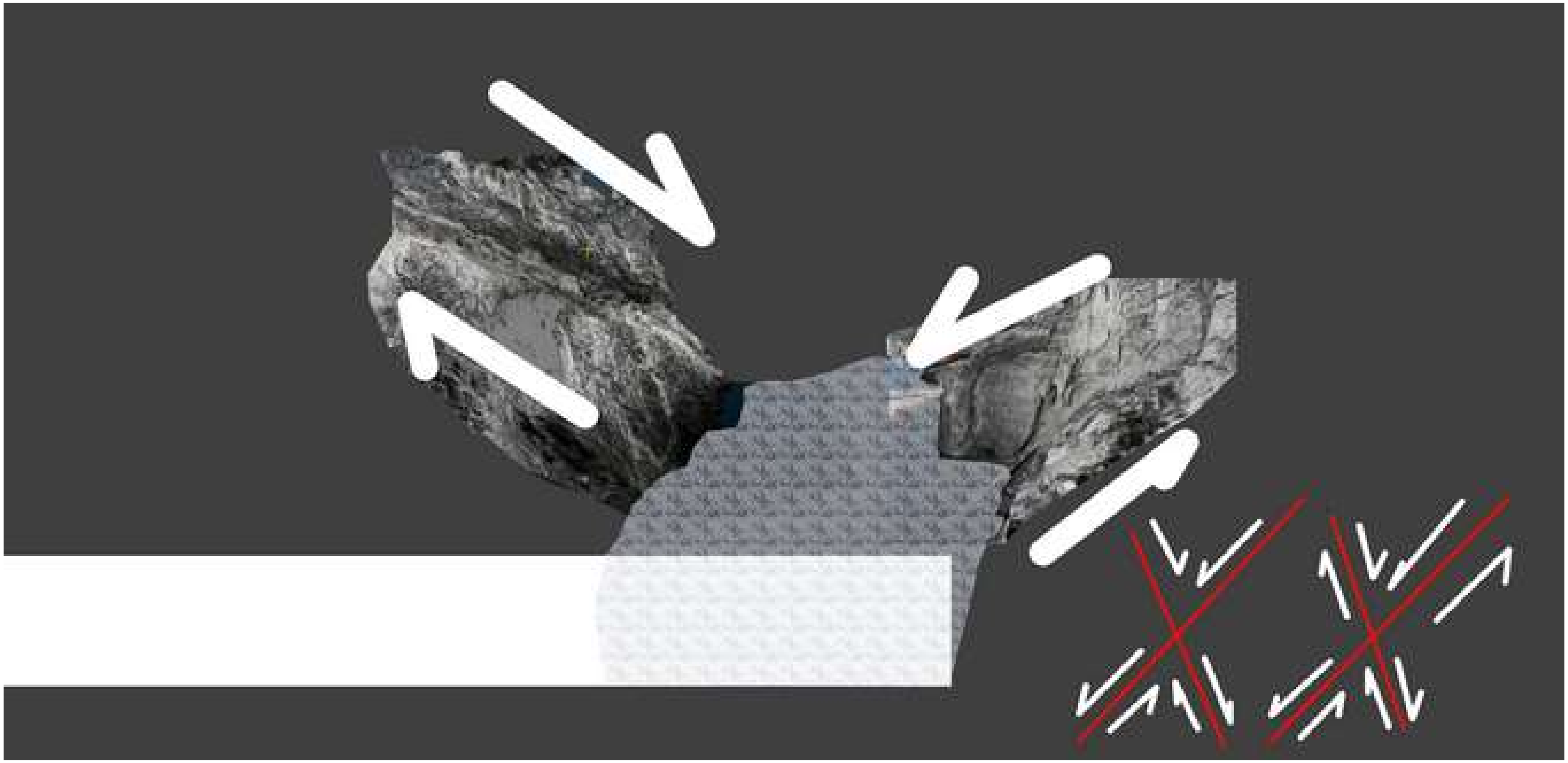
Y: After the rockburts, updip mining exposed several Ortlepp shears



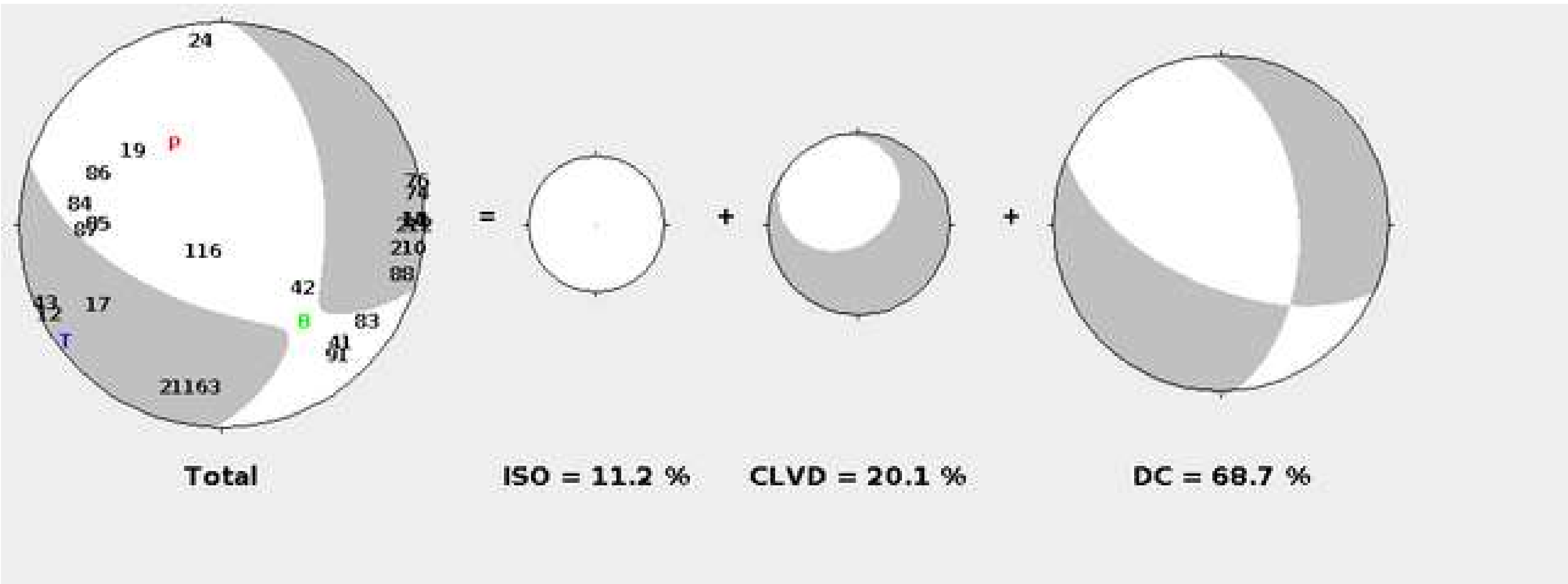
Z: Subsequent updip mining exposed several Ortlepp shears

Z: Subsequent updip mining exposed several Ortlepp shears

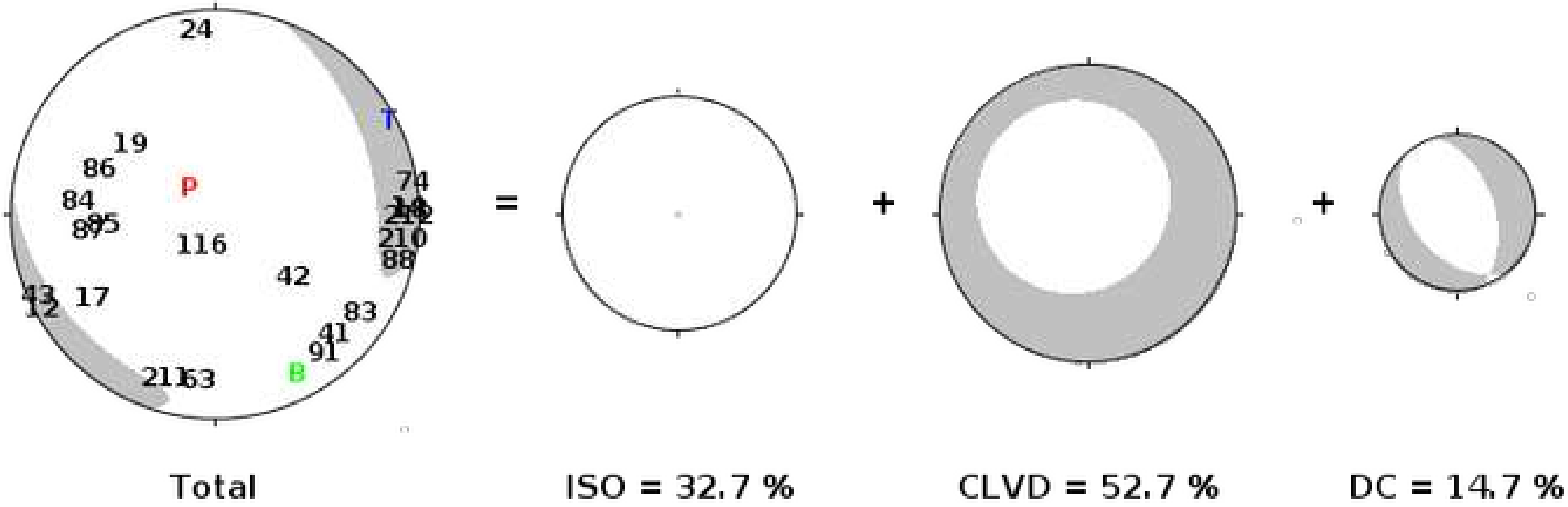
Observations



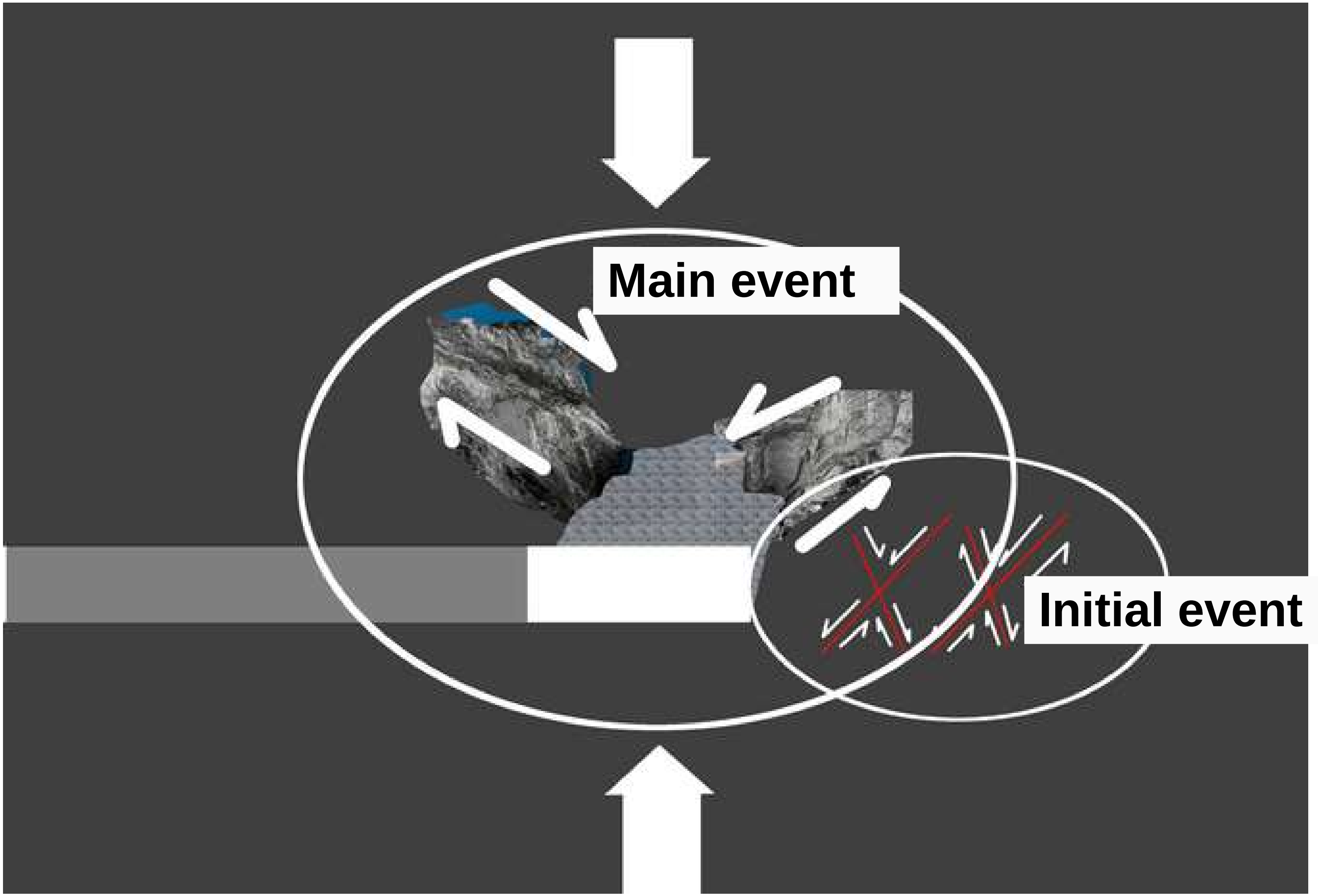
Moment tensor – based on amplitudes and polarities of the first dominant displacements



Full waveform moment tensor, i.e. taking the full history of deformation into account as reflected by the waveforms



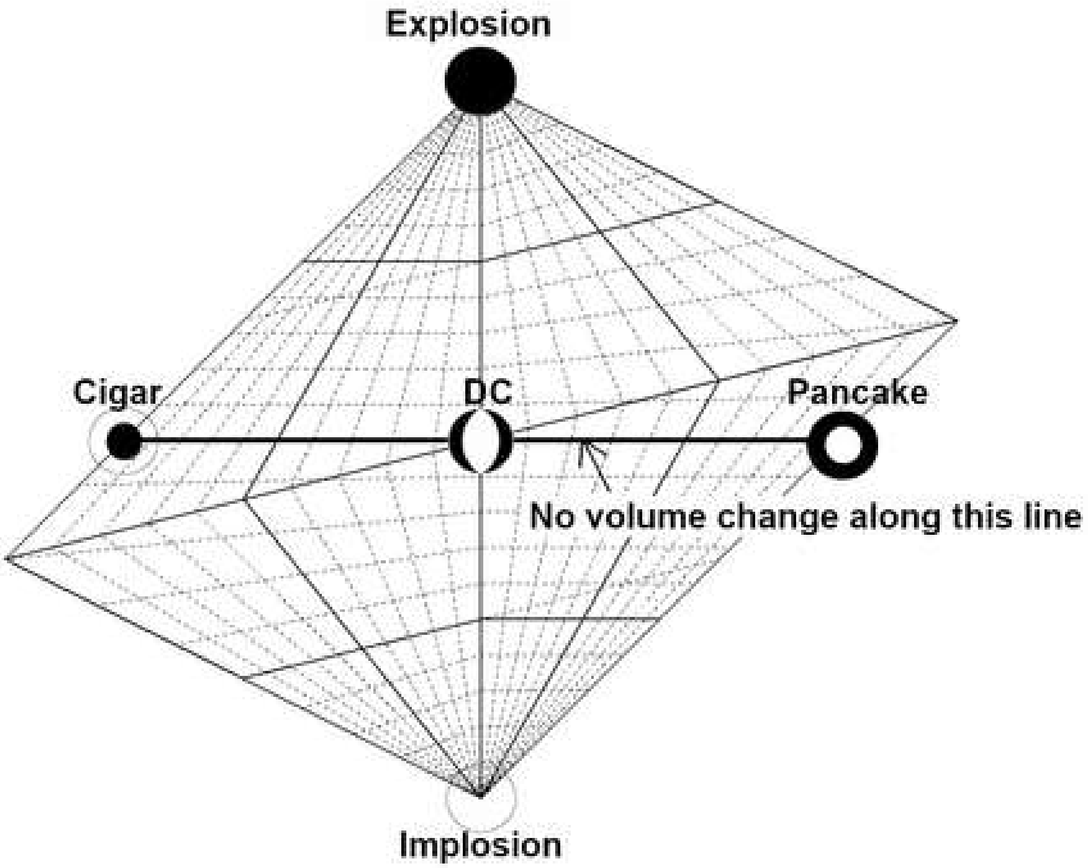
Interpretation



7. Seismic Moment Tensor

Do we know what it means?

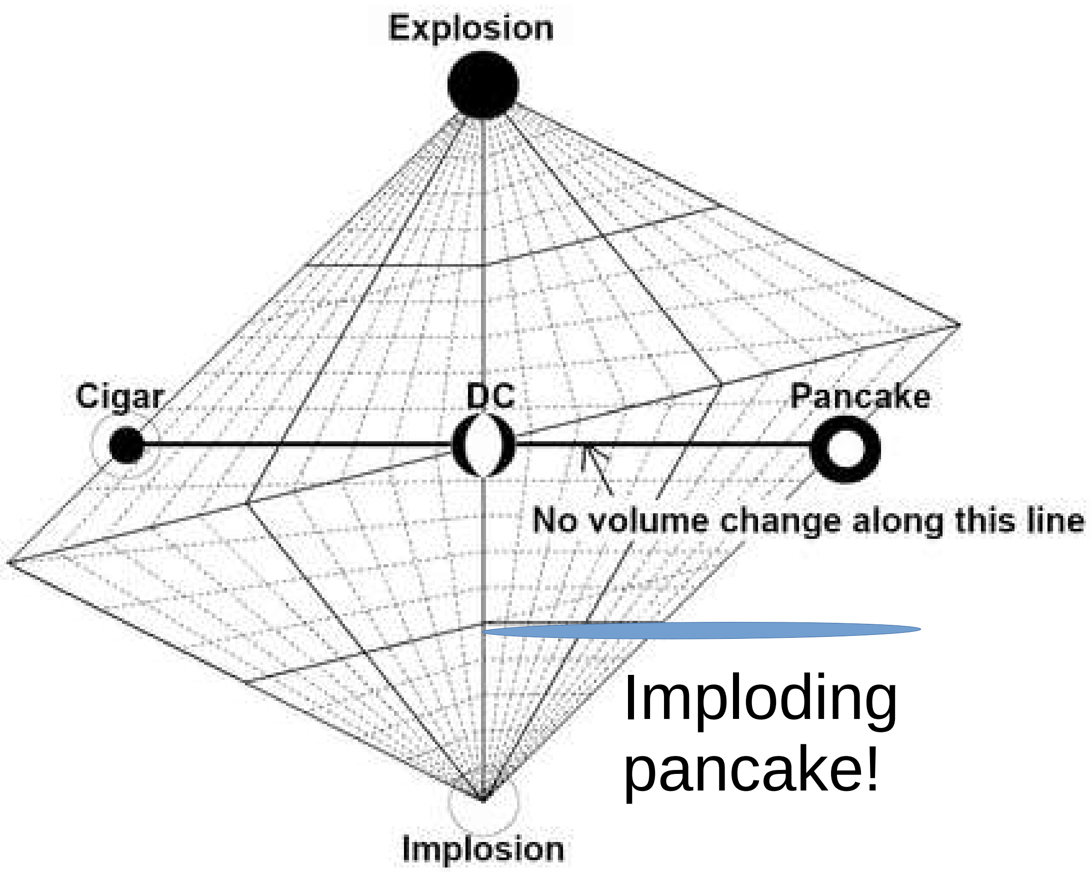
Seismic moment tensor



Hudson diagram: Moment pure explosion at the top corner, pure implosion at the bottom corner. Zero volume change plot along the bold centre line, prolate (cigar-shaped) at the left end of this line, oblate (pancake shaped) at the right end of the line. Double couple (simple shear) source plot at the centre of the diagram.

Hudson, J.A., Pearce, R.G., and Rogers, R.M. (1989). Source type plot for inversion of the moment tensor. Journal of Geophysical Research, 94, 765–774.

Seismic moment tensor



Hudson diagram: Moment pure explosion at the top corner, pure implosion at the bottom corner. Zero volume change plot along the bold centre line, prolate (cigar-shaped) at the left end of this line, oblate (pancake shaped) at the right end of the line. Double couple (simple shear) source plot at the centre of the diagram.

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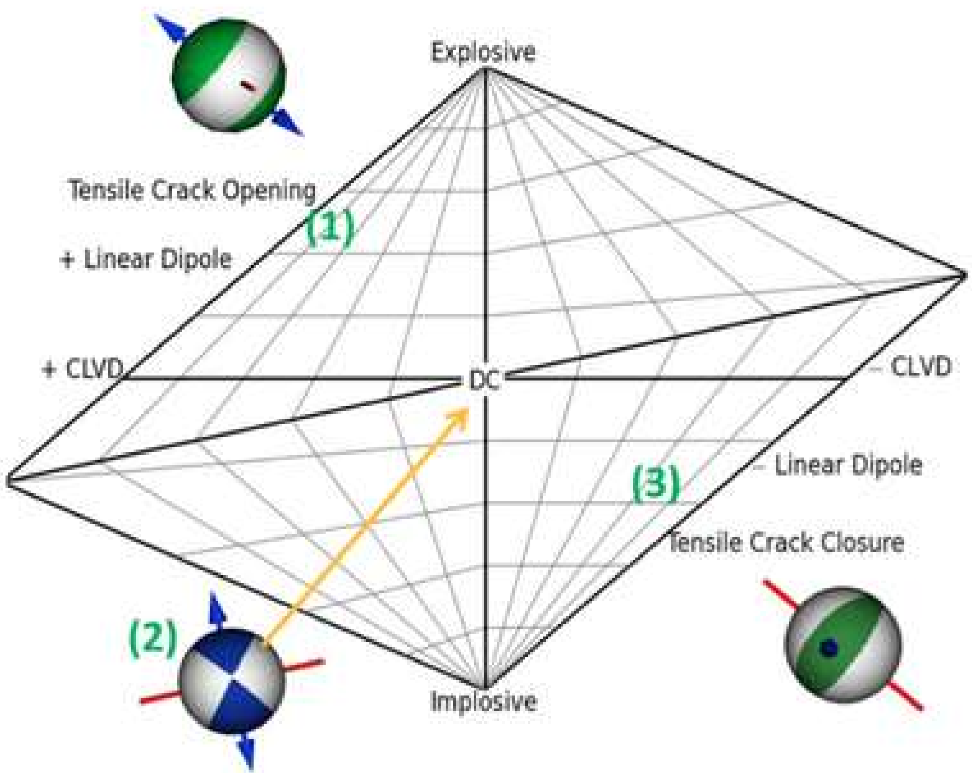
Seismic moment tensor

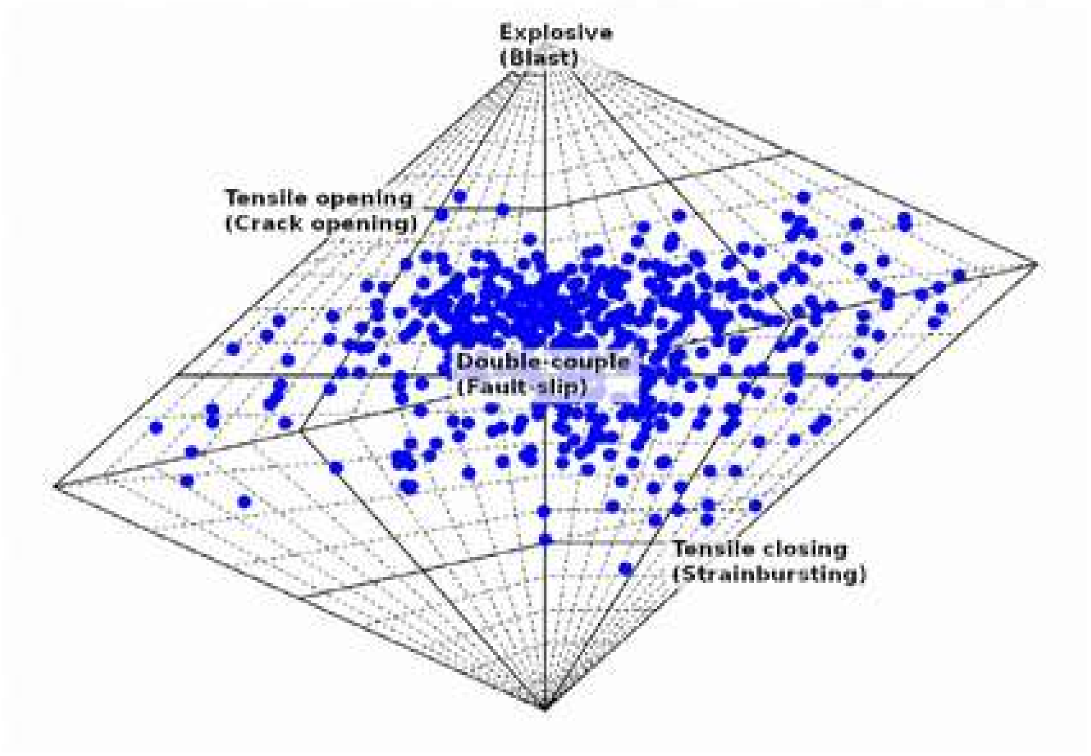


Interesting explanation of the pancake-implosive mechanism:
tensile crack closure

How much must the tensile crack close to be detectable by a distant seismometer??

Smith-Boughner, L., Baig, A.M., Urbancic, T.I. Resolving the Behavior of the Rock Mass in the Sill Pillar through Dynamic Parameters. RaSiM9

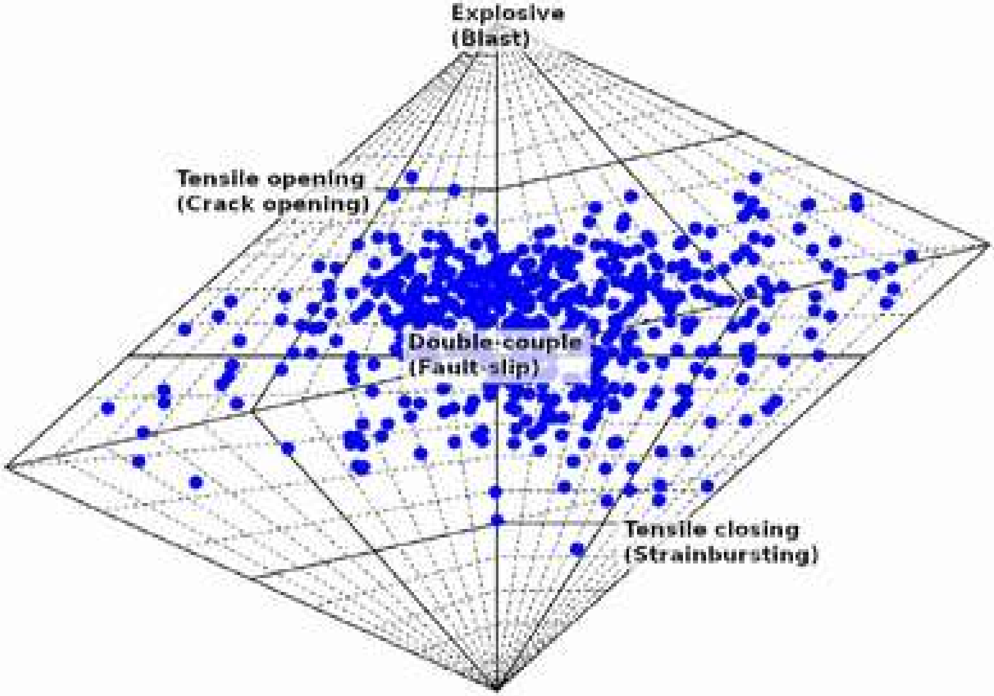
Seismic moment tensor



Here the suggestion is that

- "tensile closing is associated with strainbursting
- Seismic events associated with hydrofracturing are explosive

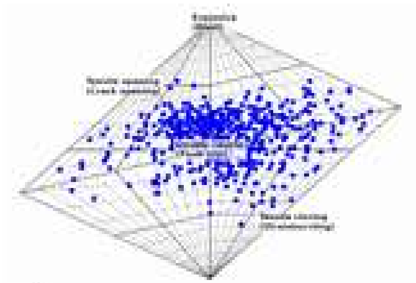
Seismic moment tensor

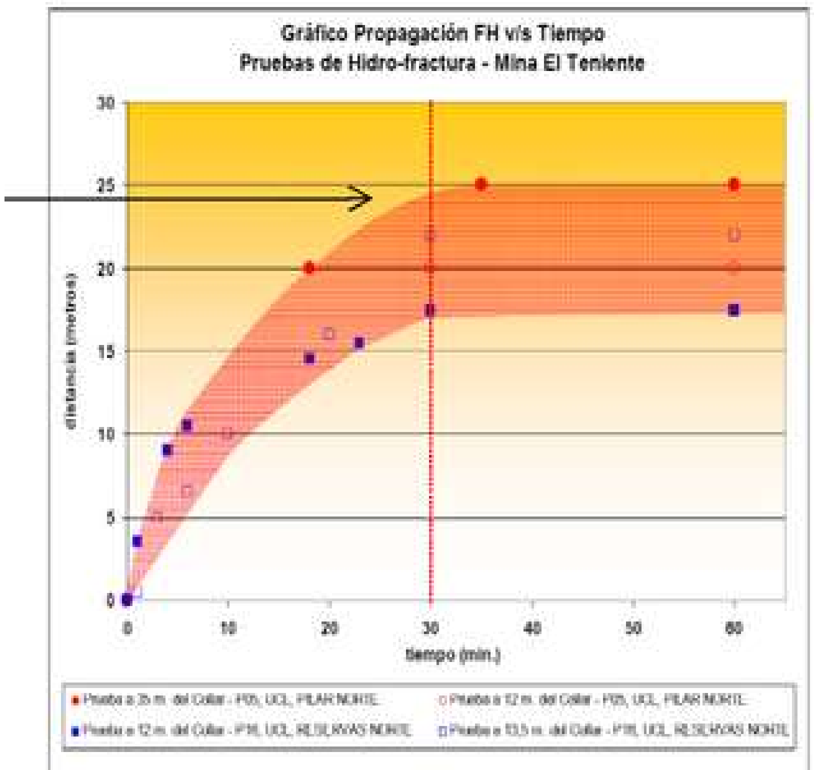


However:

- <u>Strainbursting</u> causes failure of the excavation wall which yield some implosive deformation of the excavation.
- <u>HF:</u> Seismic events are triggered by the stress disturbance caused by HF. The actual fracture formed by the process of HF (maybe 30m radius) does not form in one go – rather millions of undetectable acoustic emissions are associated with the process zone ...

Seismic moment tensor



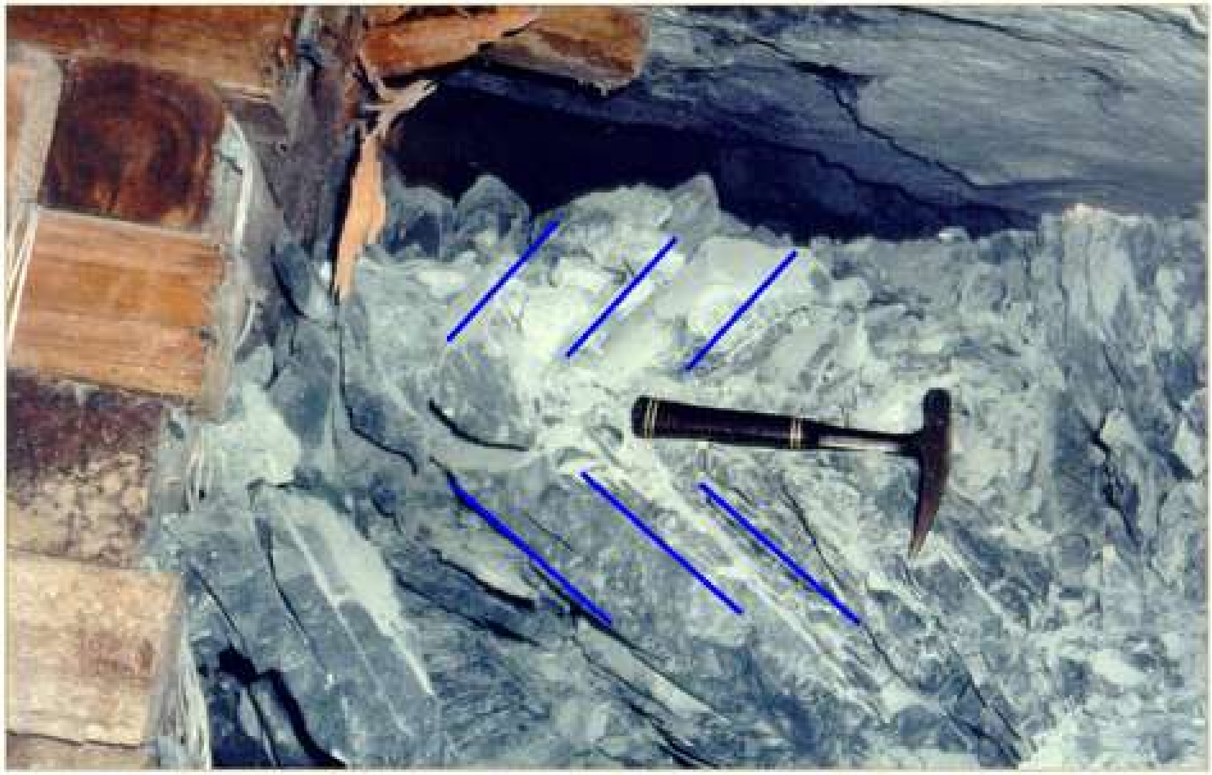


"Explosive" events associated with HF

- Seismic events are triggered by the stress disturbance caused by HF.
- The actual fracture formed by the process of HF (maybe 30m radius) does not form in one go – see time graph here – rather millions of undetectable acoustic emissions are associated with the process zone and the crack evolves over many minutes – as long as the pump can maintain the pressure
- Behind the crack front, the fracture is closed – broken and wet, but closed.

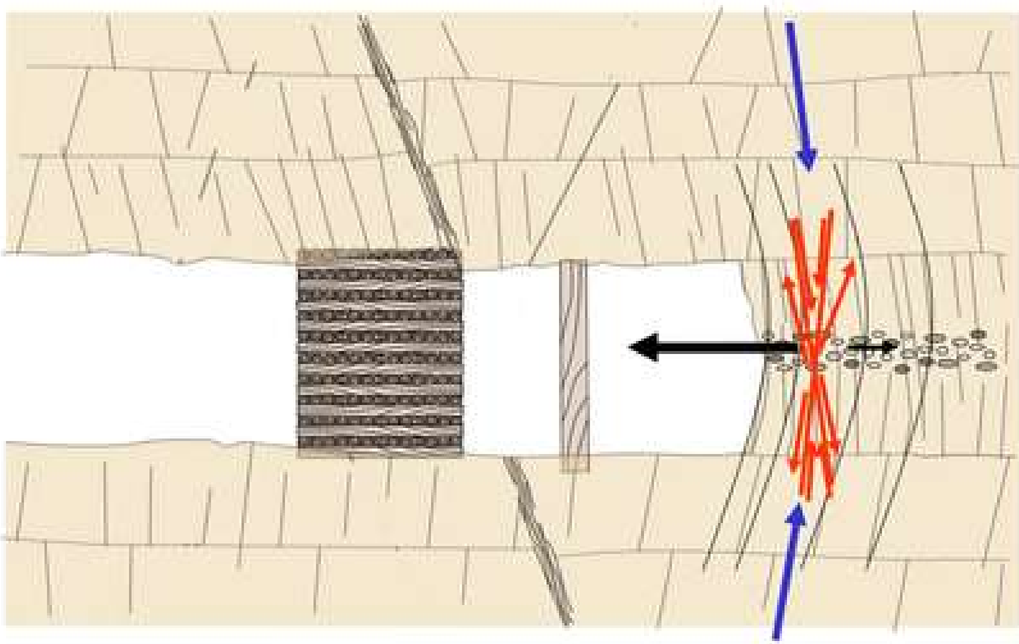
Faceburst in a Wits stope

- .. <u>while the drama you see is not even in the seismic record</u>...

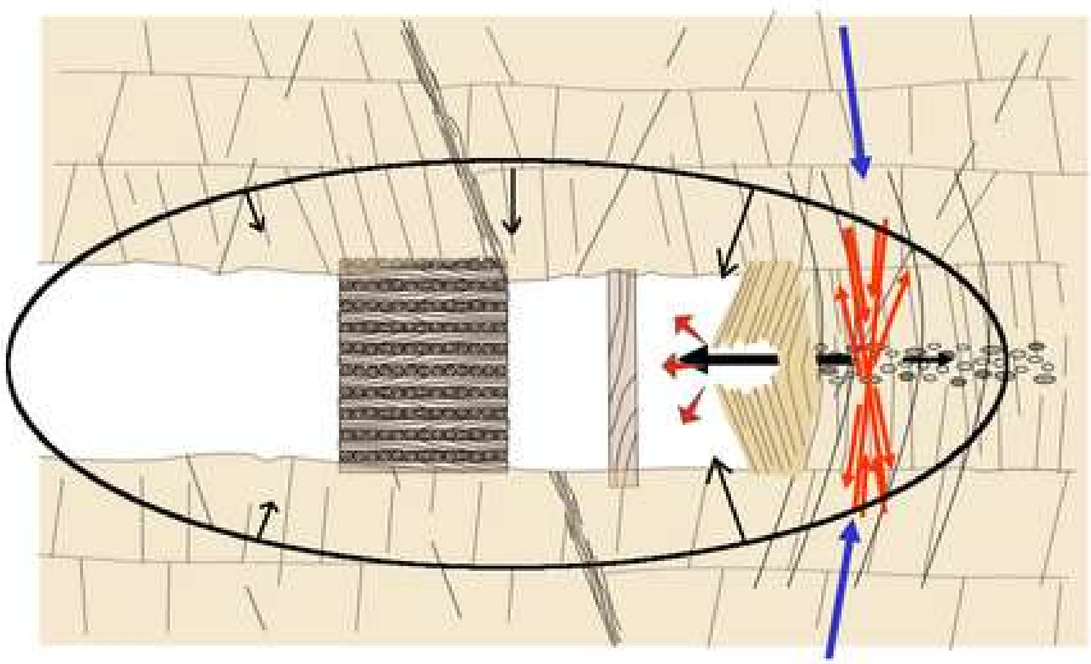


From Riaan Carstens – presentation at the 2007 ISS International Seminar, Stellenbosch

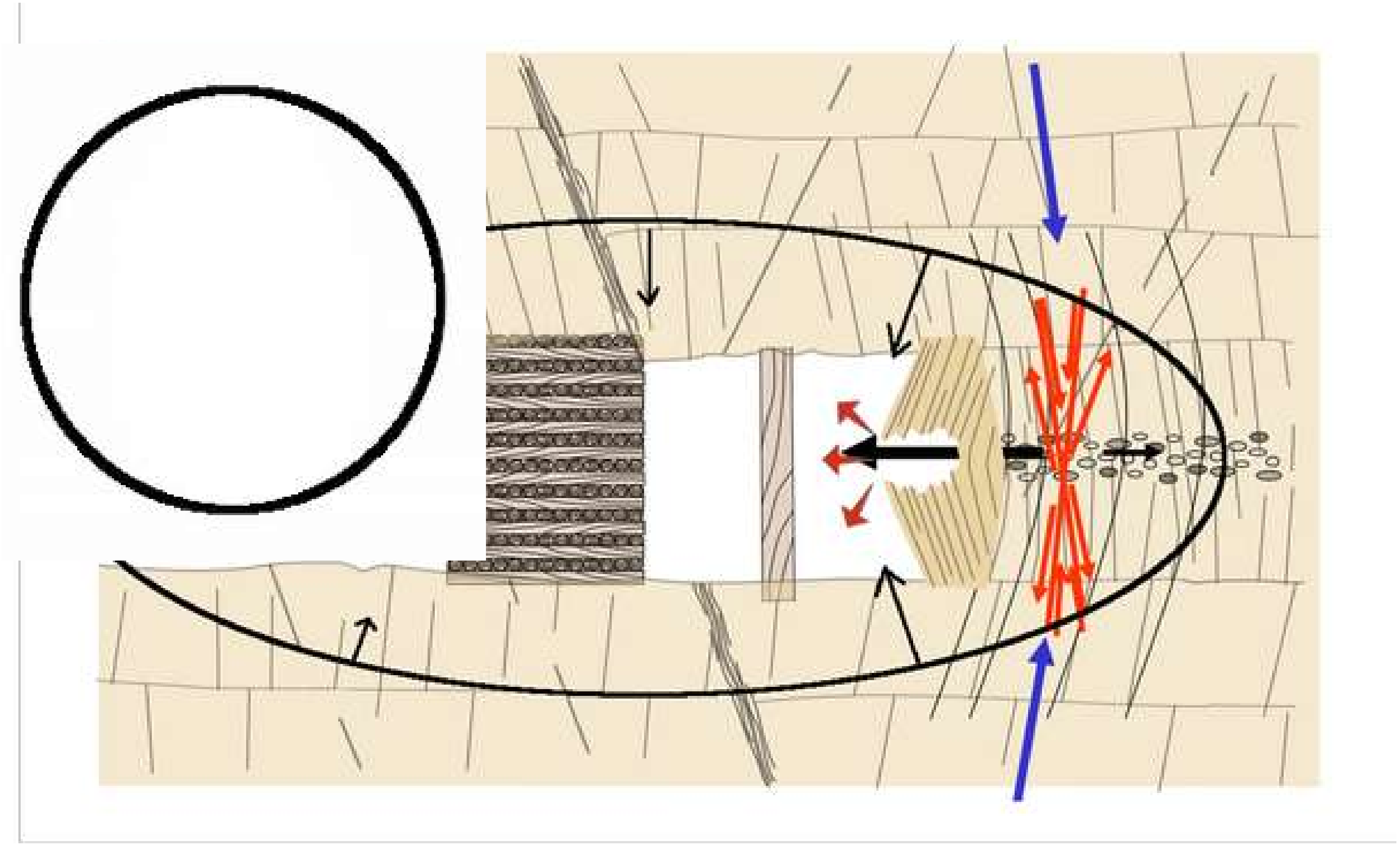
- The initial source could be relatively small
  - Near uni-axial loading
  - Buckling of slabs at the face between extension fractures
- The total source could, however, be huge



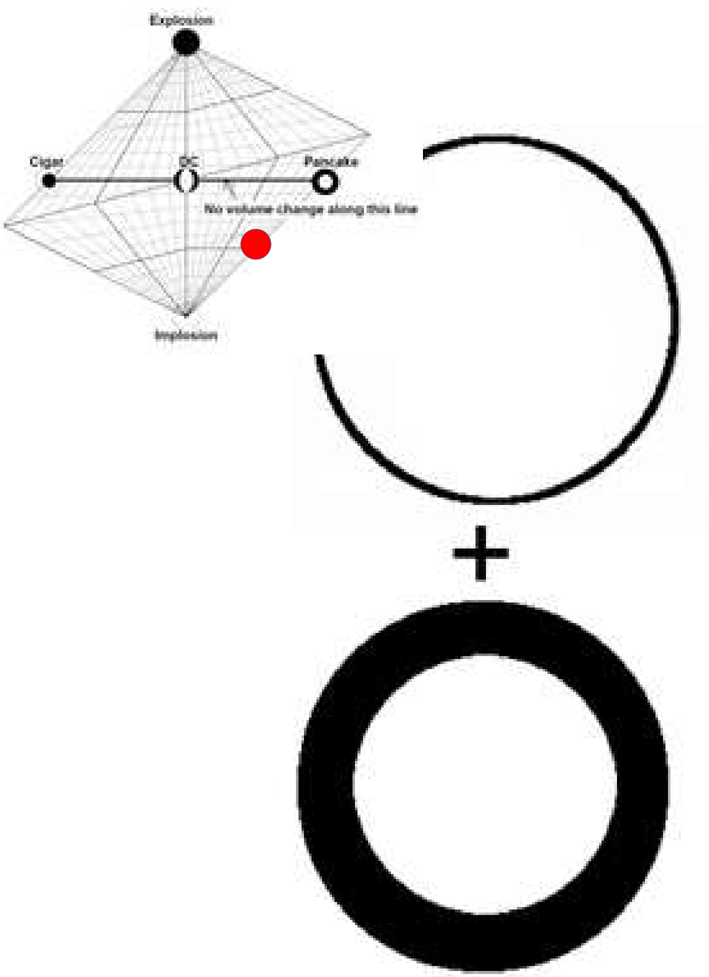
- **The total source can be huge, being partial stope closure – note that the seismic waves recorded reflect only the sudden, elastic part of the deformation, the total strain within the seismic source being small, maybe 1E-4**

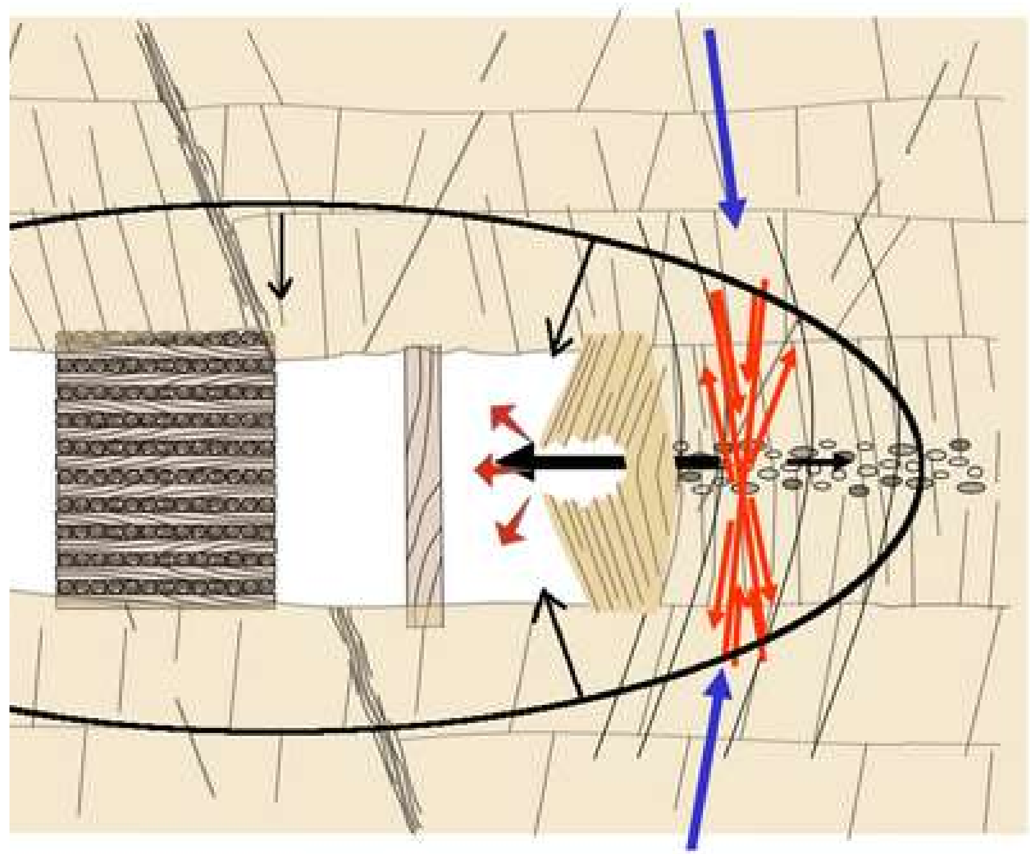


- **The source mechanism could be simple implosion … rather boring beach-ball**

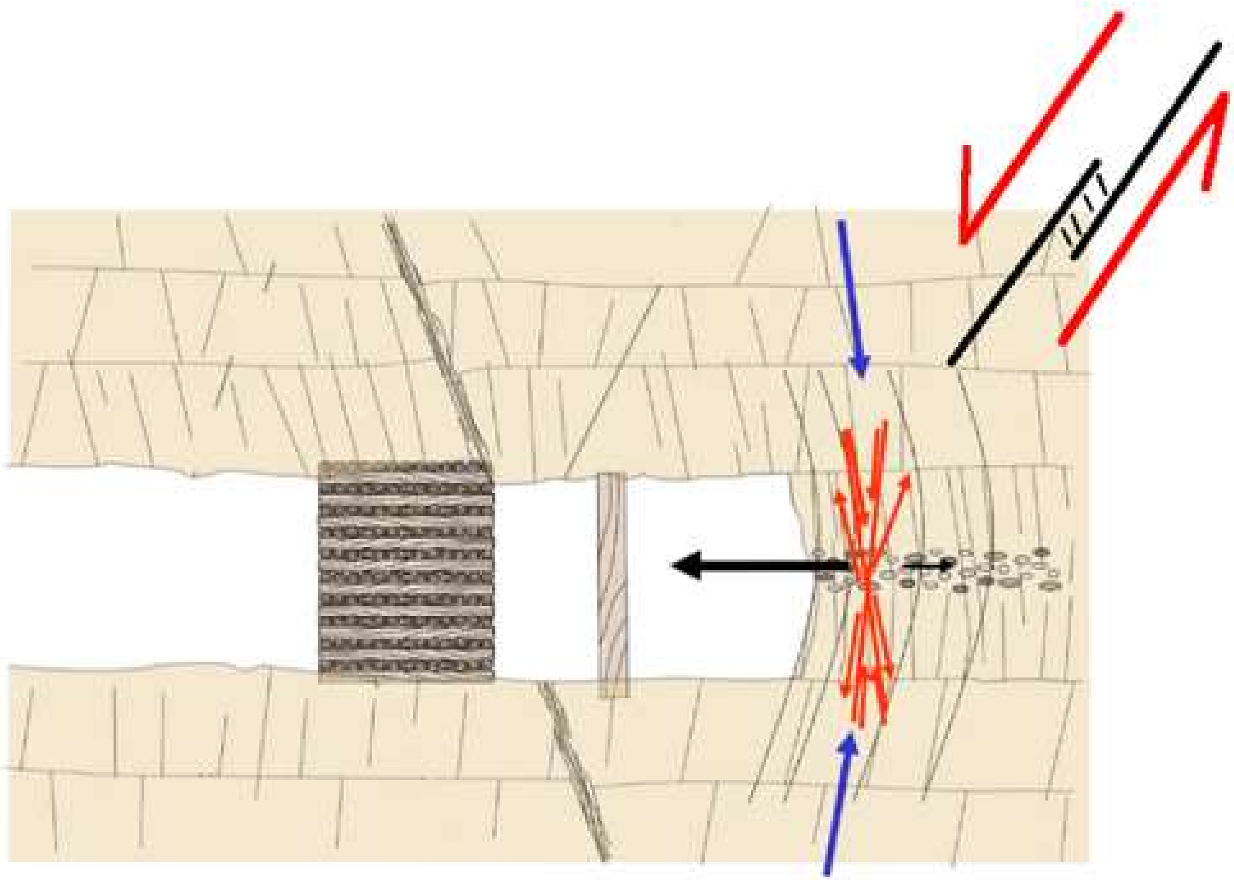


- **Or implosion plus pancake type CLVD - not because the CLVD is physical, <u>but because the algorithm used is based on a method that does not understand simple planar stope closure</u> .**

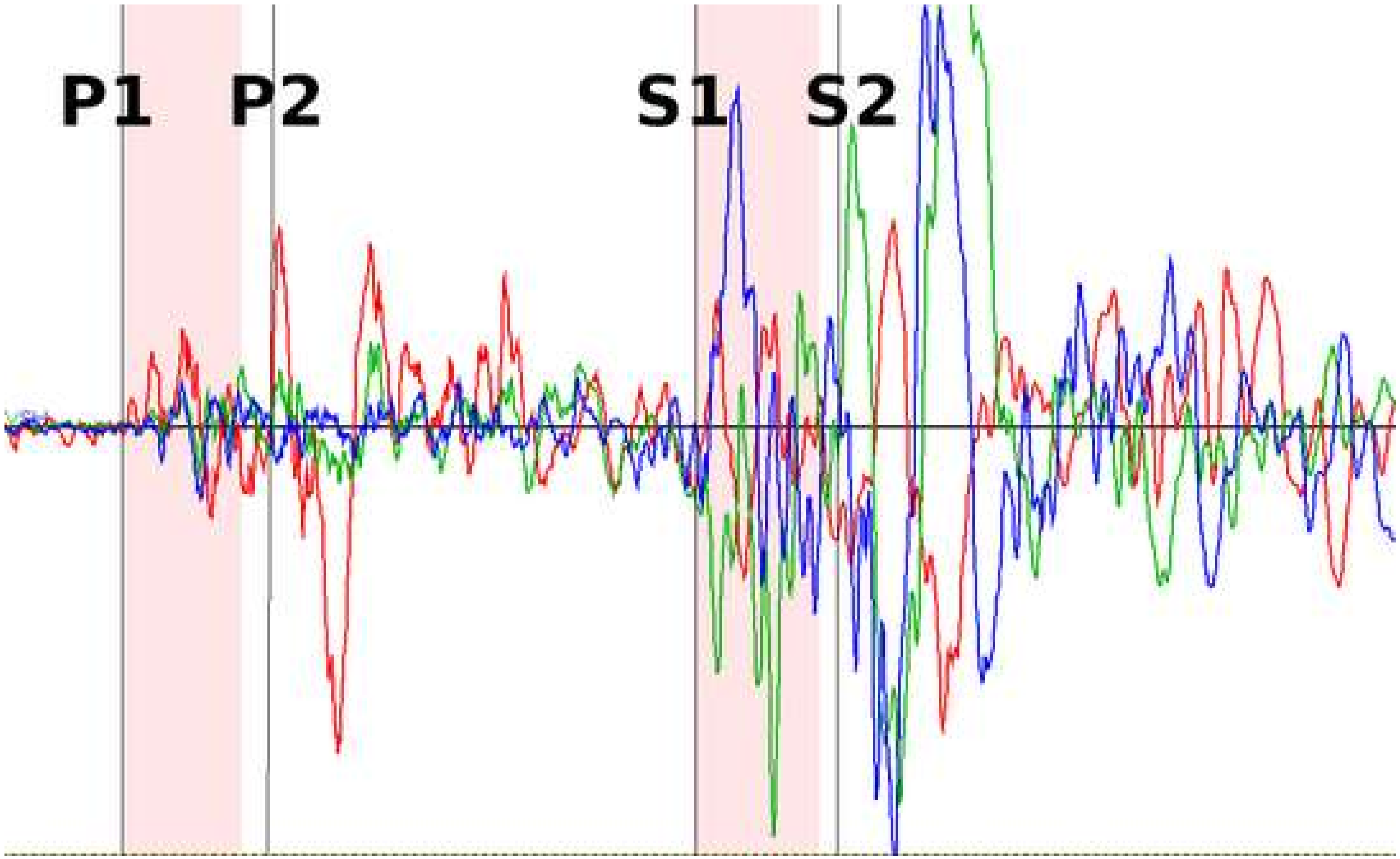




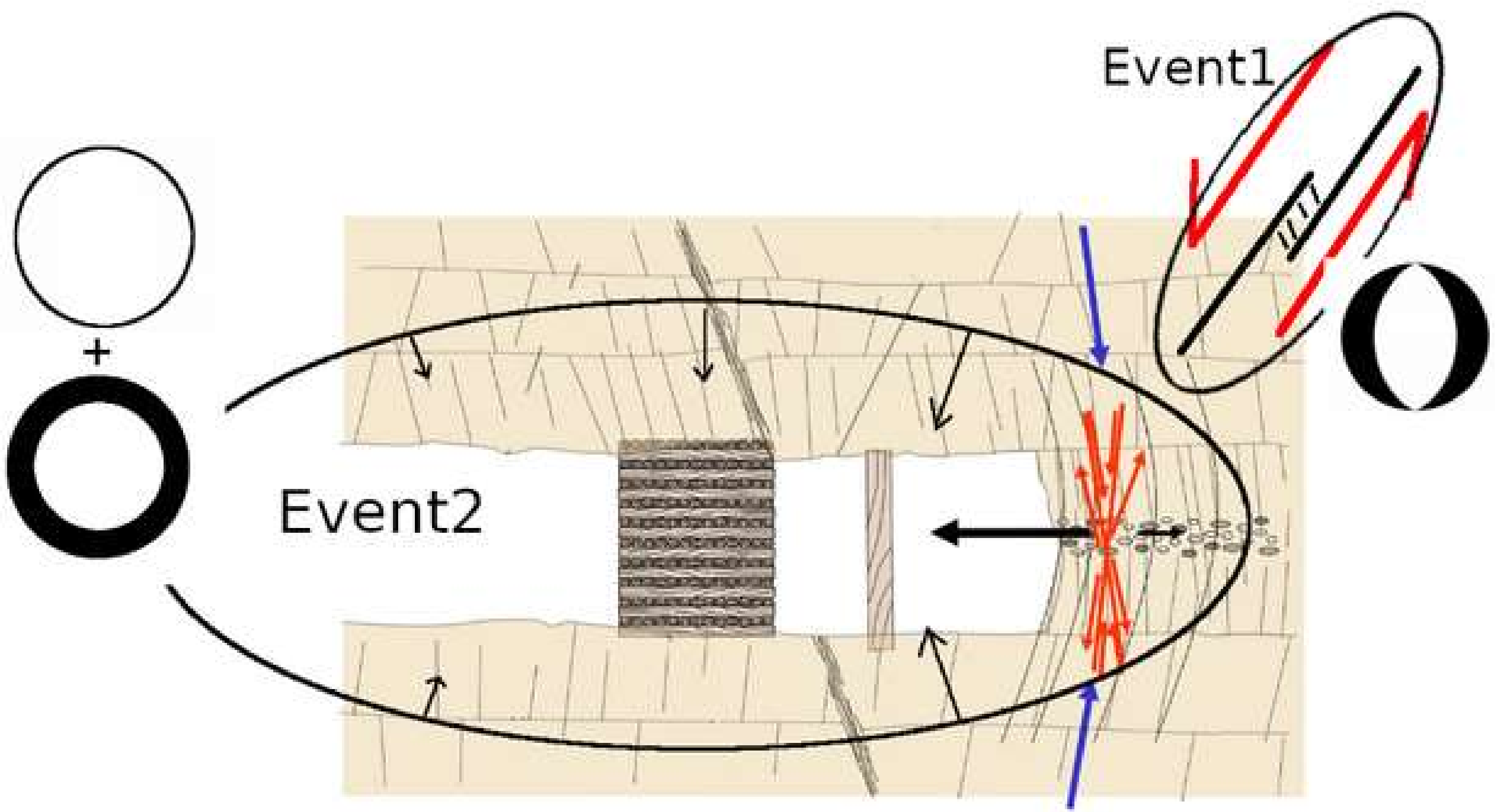
- **Or the burst could be <u>triggered</u> by an smaller <u>Ortlepp shear type failure not daylighting in the stope, adding complications to the source</u>**



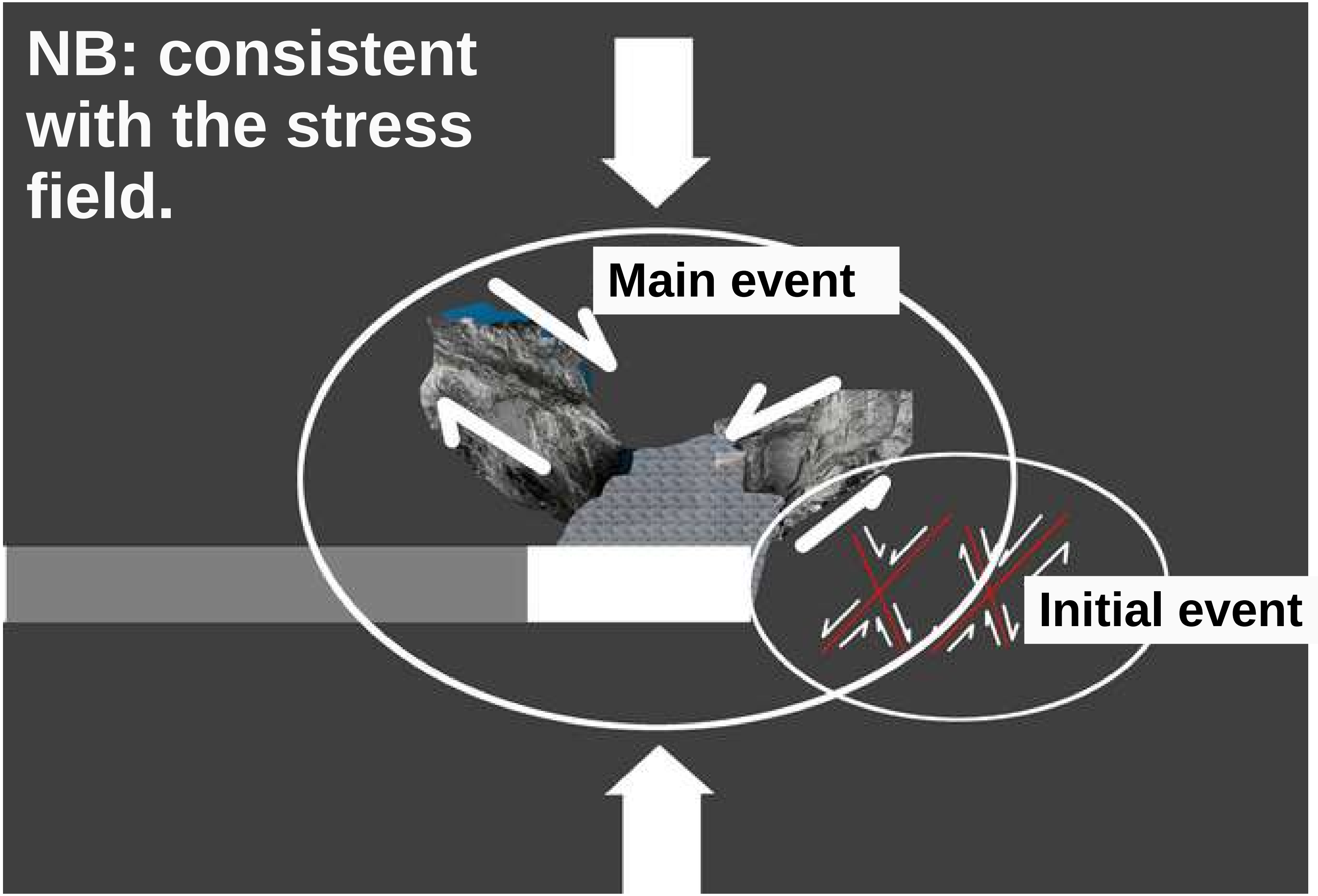
- **… possibly yielding waveforms that look like this:**



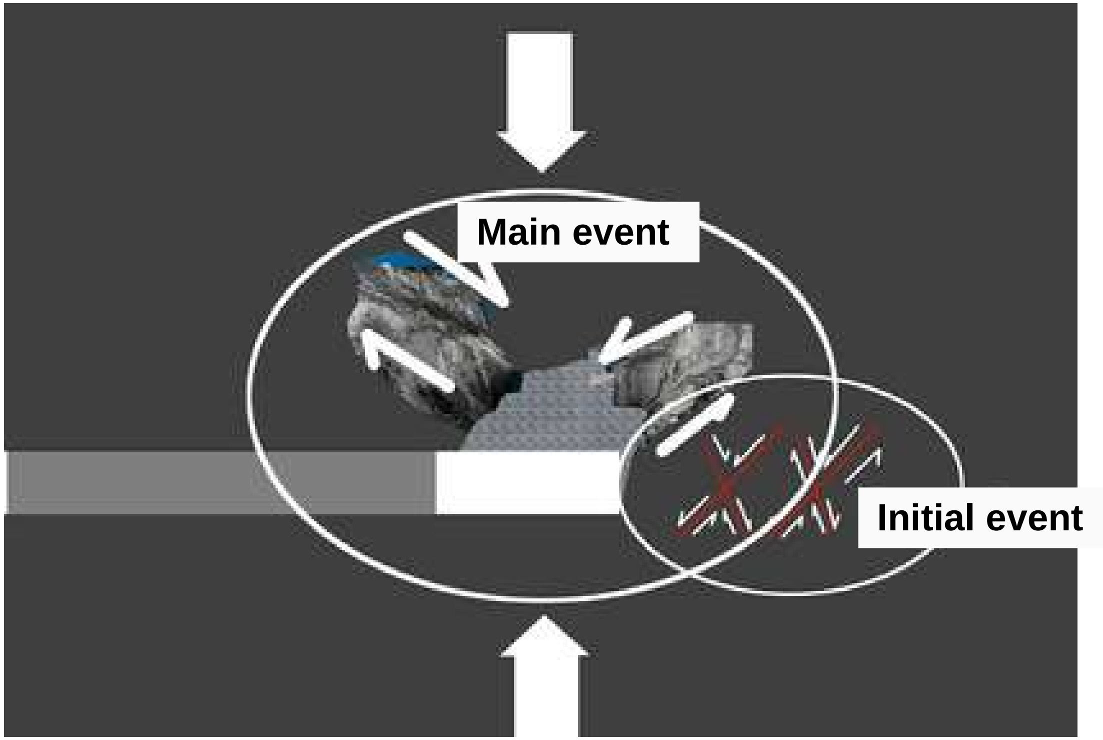
- .. so now we’ve made a complex event with simple components: the event1 mechanism is largely DC while the main event is mainly implosive (plus perhaps some nonsensical pancake type CLVD) …



Interpretation

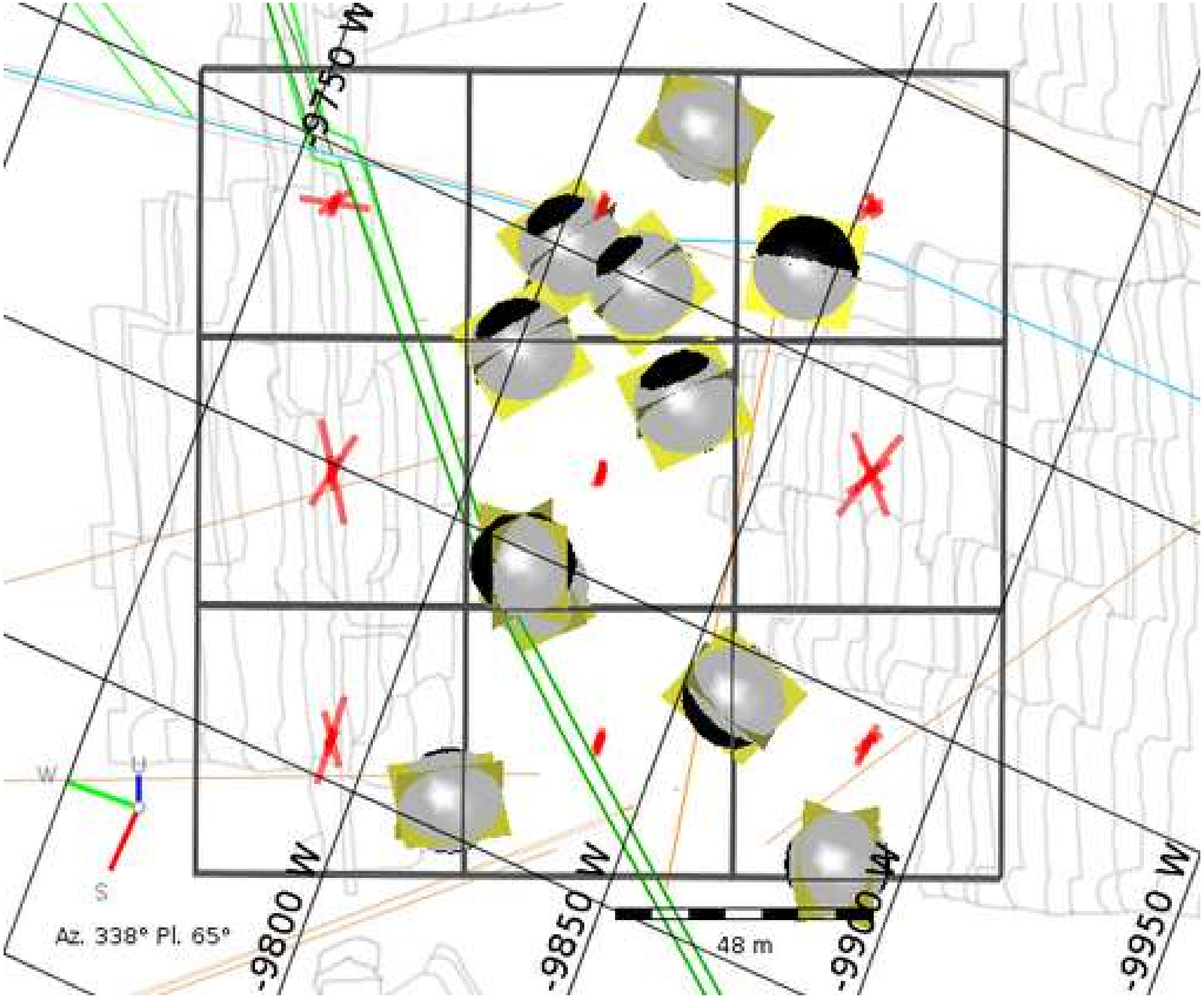


Interpretation



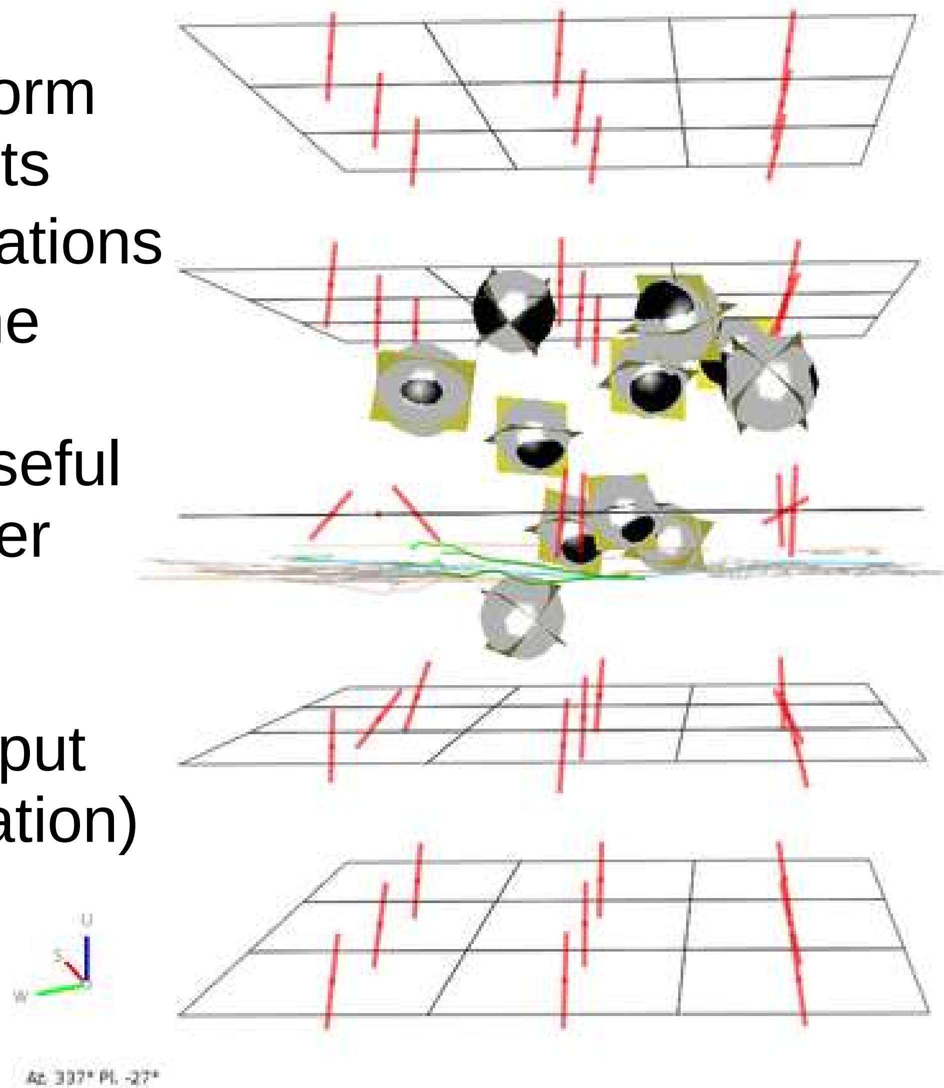
The dynamic deformation is controlled by the stress field, the mine opening (nature wants to close it) and the local rock fabric (faults, joints, stress fractures ...) - actually very simple after all.

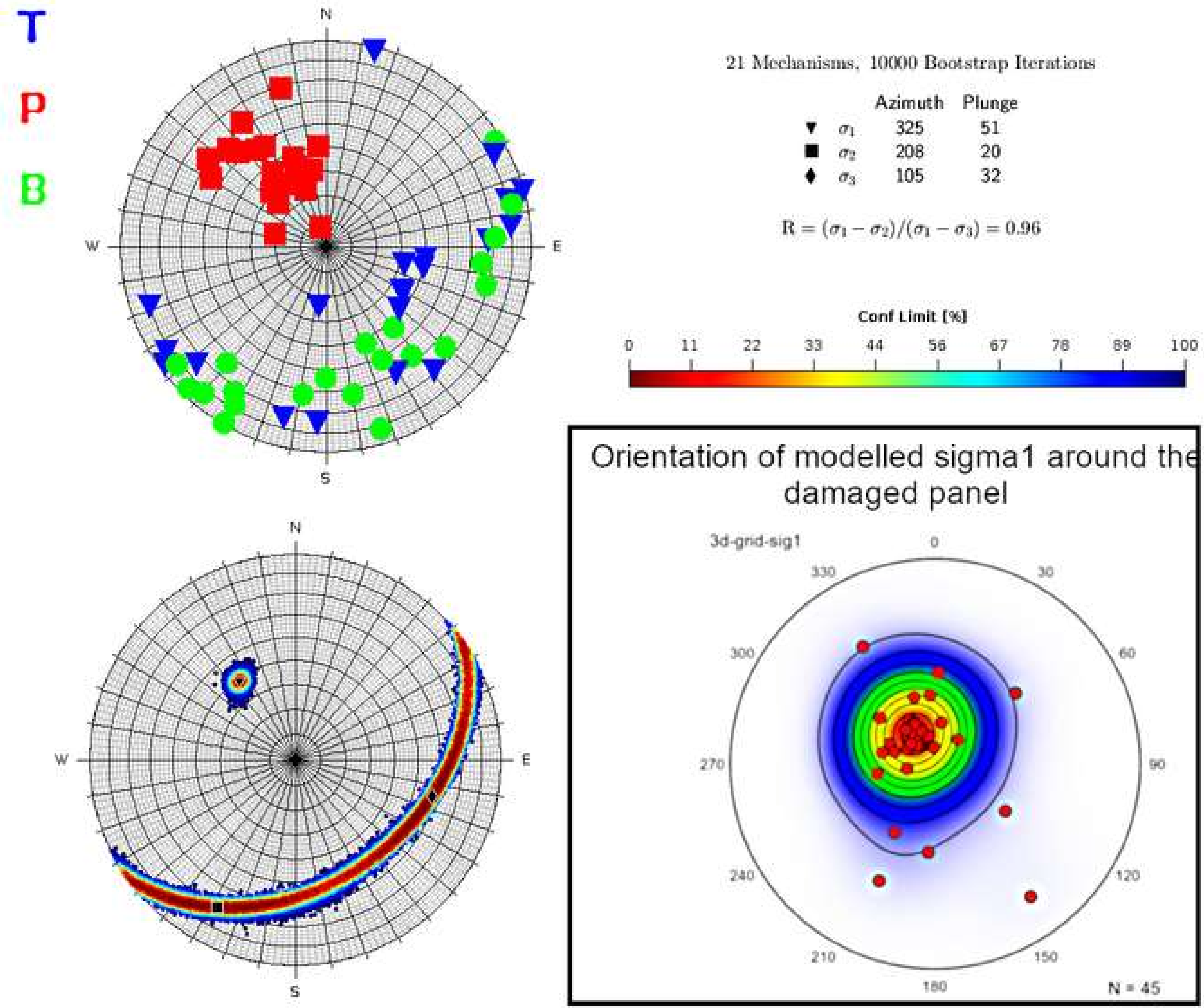
Stress inversion – very useful



Stress inversion

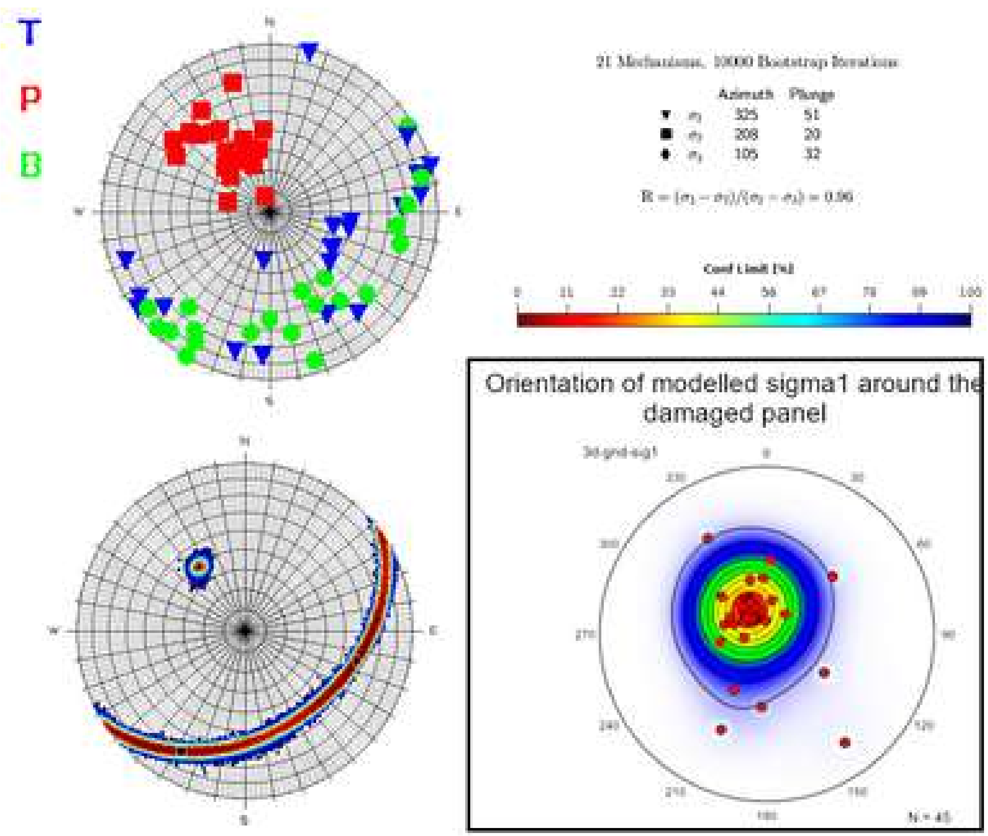
Plot p-axes form seismic events and δ_1 orientations form the same volume and compare – useful to test whether boundary conditions of model (i.e. input stress orientation) is correct





T
P
B
N
W
E
S
21 Mechanisms, 10000 Bootstrap Iterations
Azimuth Plunge
σ1 325 51
σ2 208 20
σ3 105 32
R = (σ1 − σ2)/(σ1 − σ3) = 0.96
Conf Limit [%]
0 11 22 33 44 56 67 78 89 100
Orientation of modelled sigma1 around the damaged panel
3d-grid-sig1
0 30 60 90 120 150 180 210 240 270 300 330
N = 45

Stress inversion



NB: The larger the implosive components, the more reliable the stress inversion