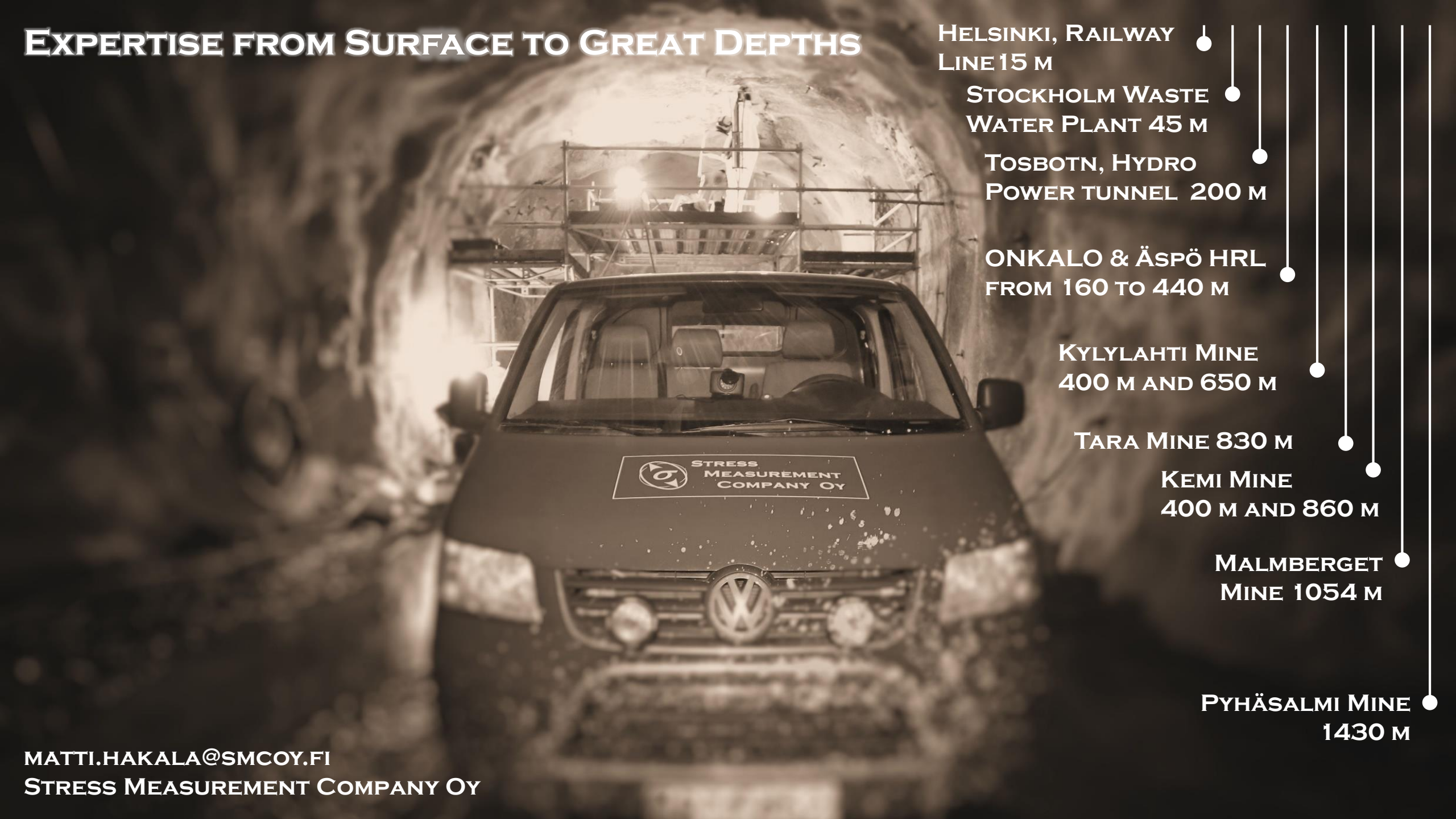
Expertise from Surface to Great Depths



Helsinki, Railway
Line 15 m

Stockholm Waste
Water Plant 45 m

Tosbotn, Hydro
Power tunnel 200 m

ONKALO & Äspö HRL
from 160 to 440 m

Kylylahti Mine
400 m and 650 m

Tara Mine 830 m

Kemi Mine
400 m and 860 m

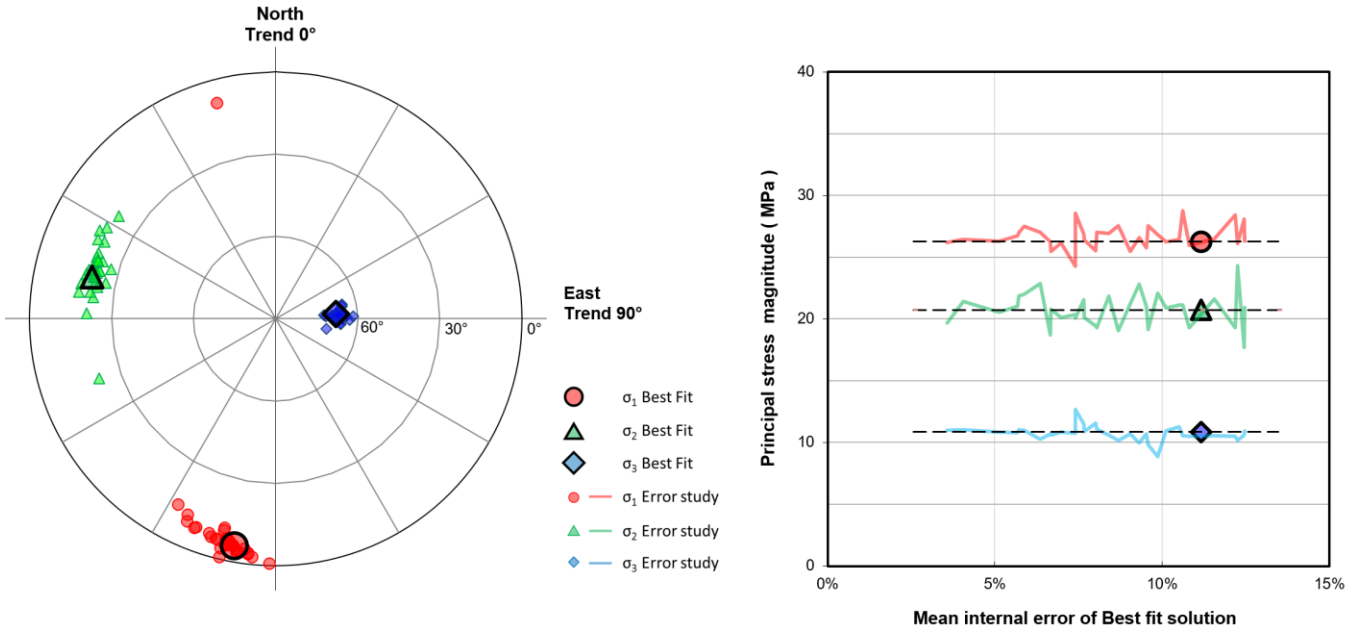
Malmberget
Mine 1054 m

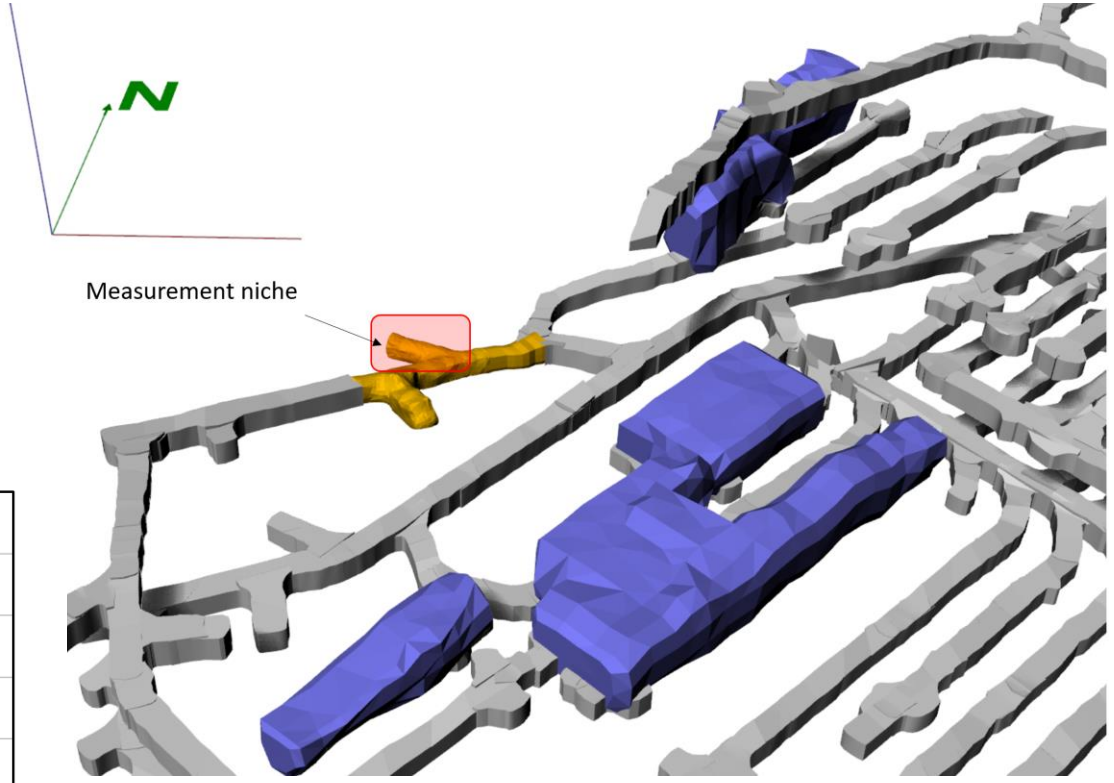
Pyhäsalmi Mine
1430 m

matti.hakala@smcoy.fi
Stress Measurement Company Oy

LVDT-CELL METHOD

- FROM EXISTING EXCAVATIONS OR SHAFTS
- WE FOCUS ON QUALITY AND KNOWN VARIABILITY



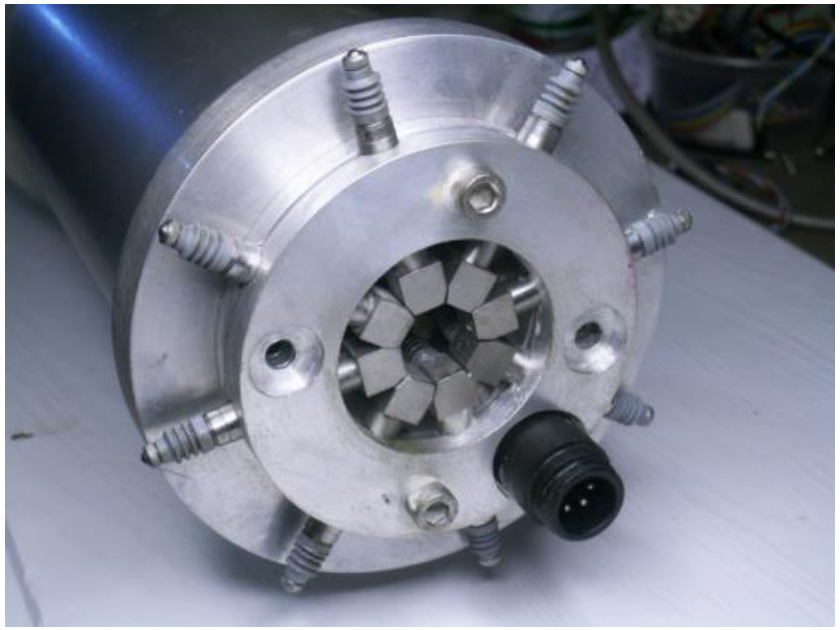


NEW BOLIDEN TARA MINE, IRELAND

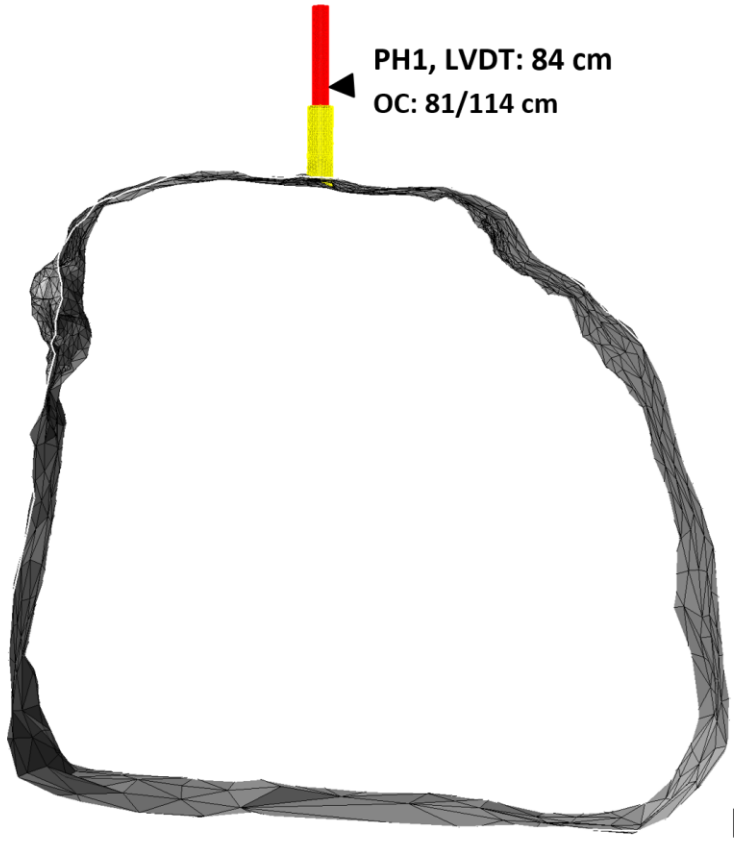
The cell

- 2D-cell, which measures four diametric deformations with eight LVDT-sensors

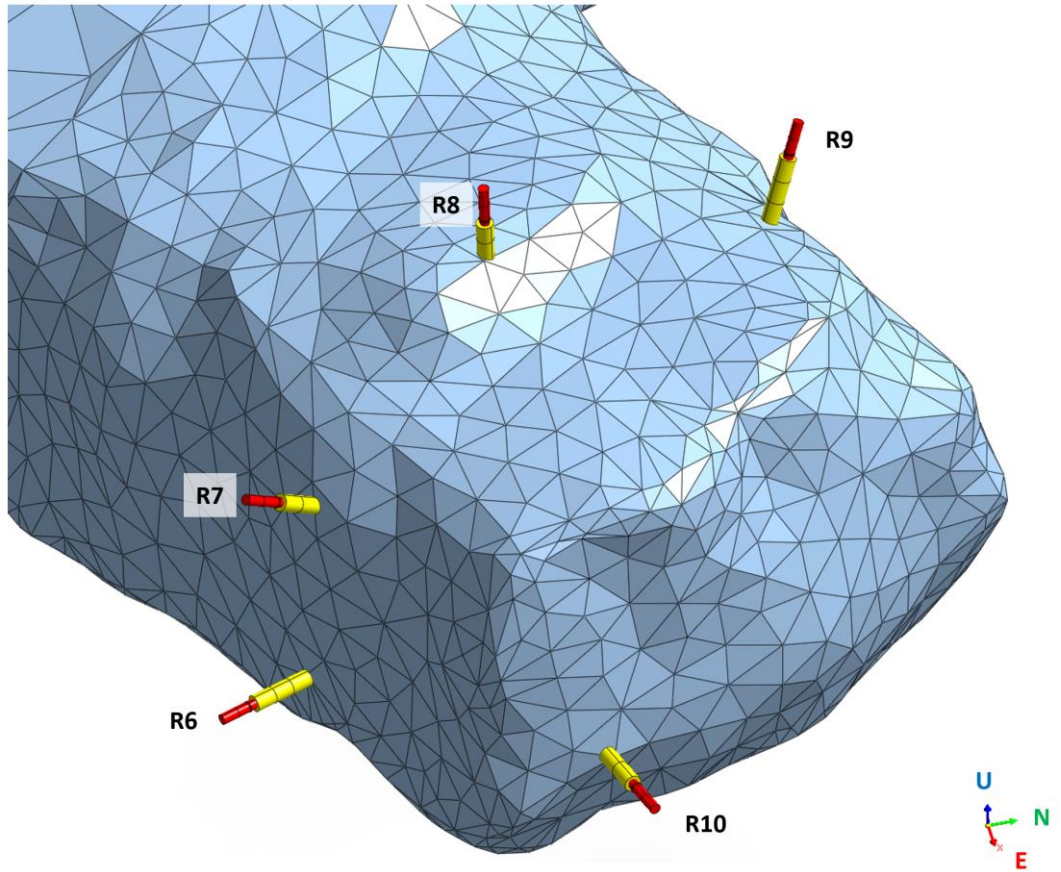
- Pilot hole diameter 126 mm

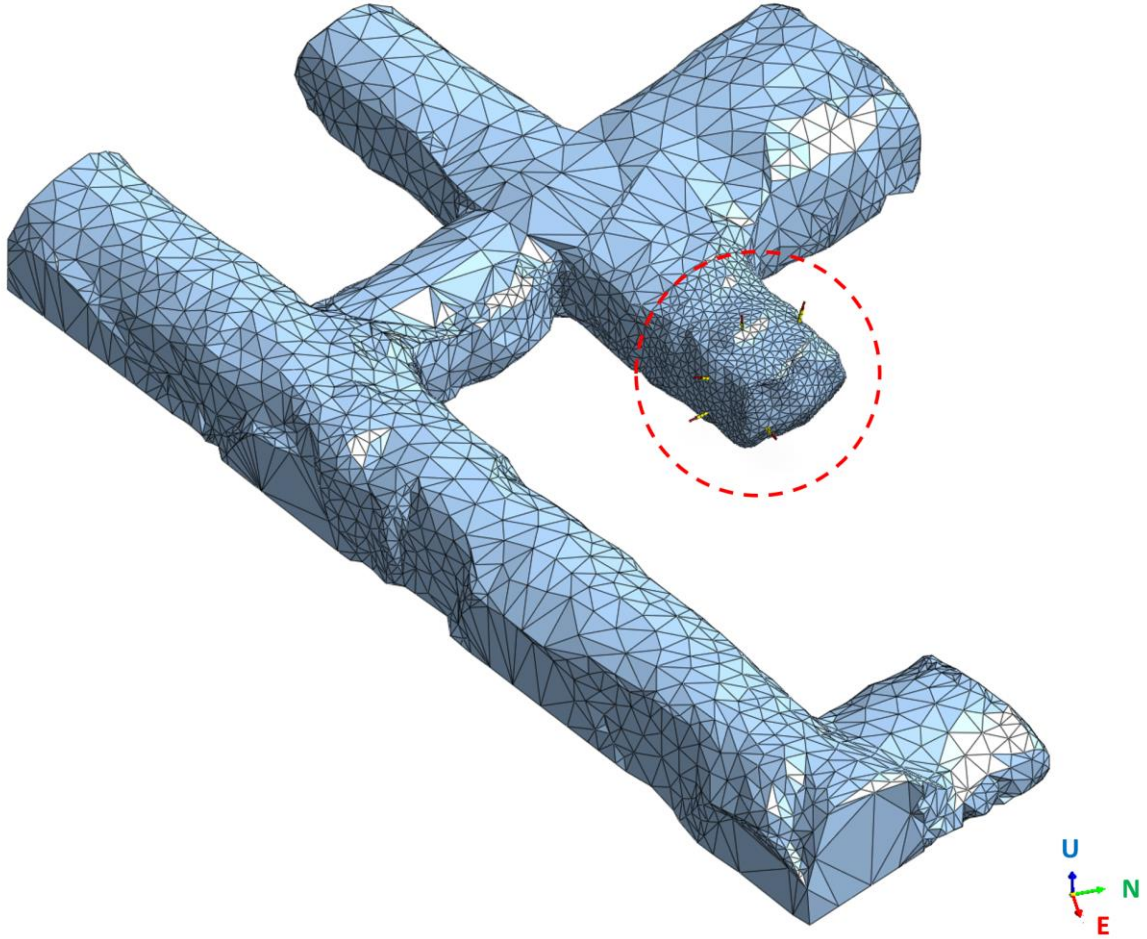


- One crown measurement gives horizontal stress magnitudes and orientations

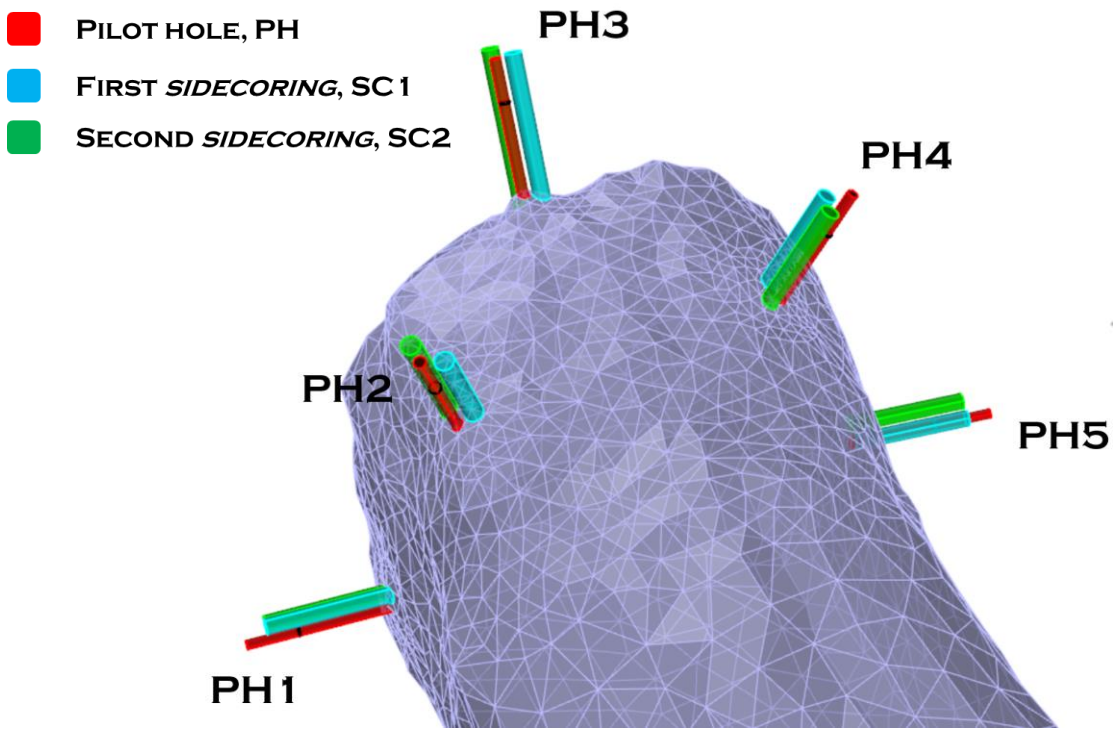


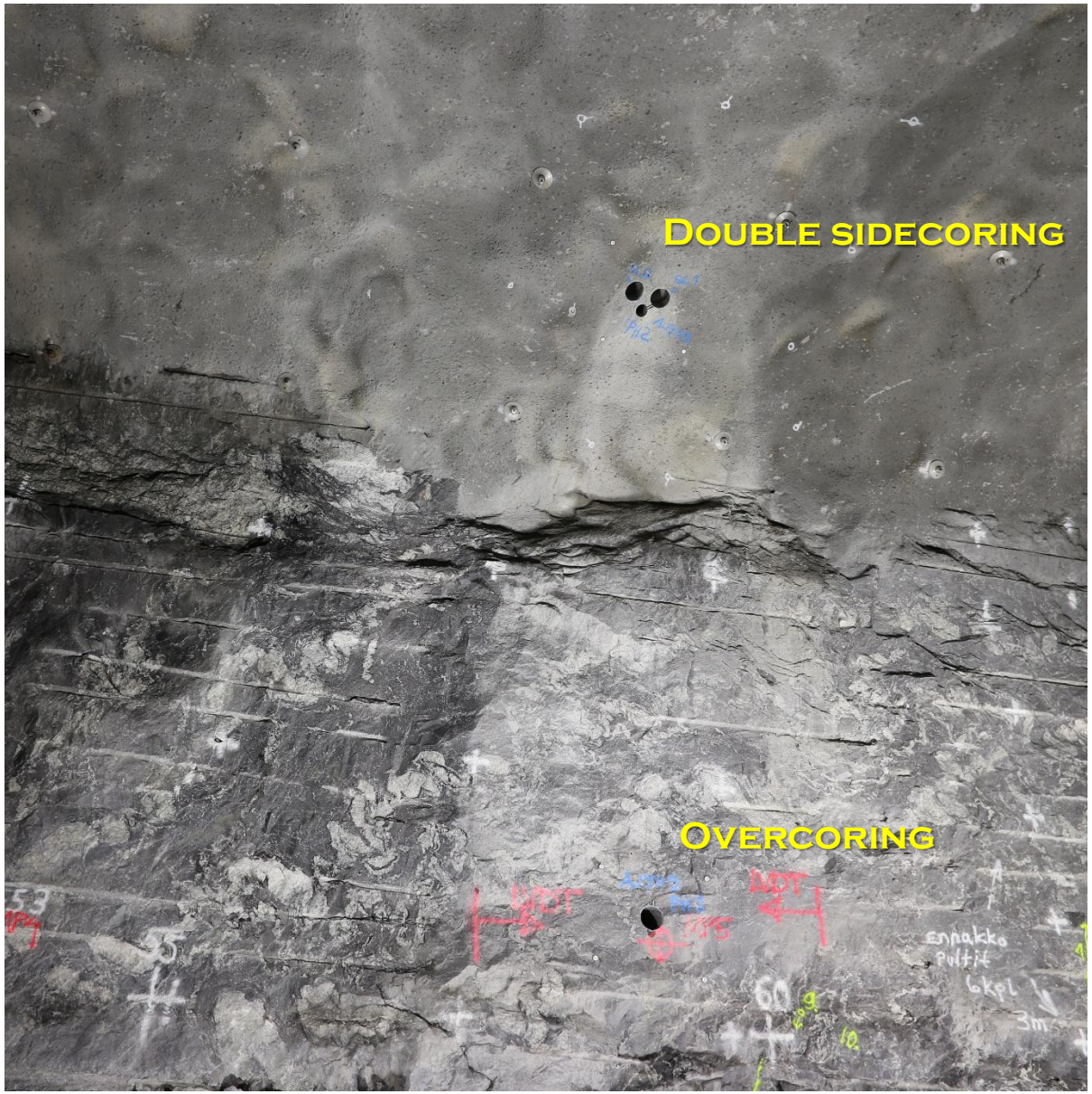
- Four to five measurements around excavation profile gives full 3D stress tensor





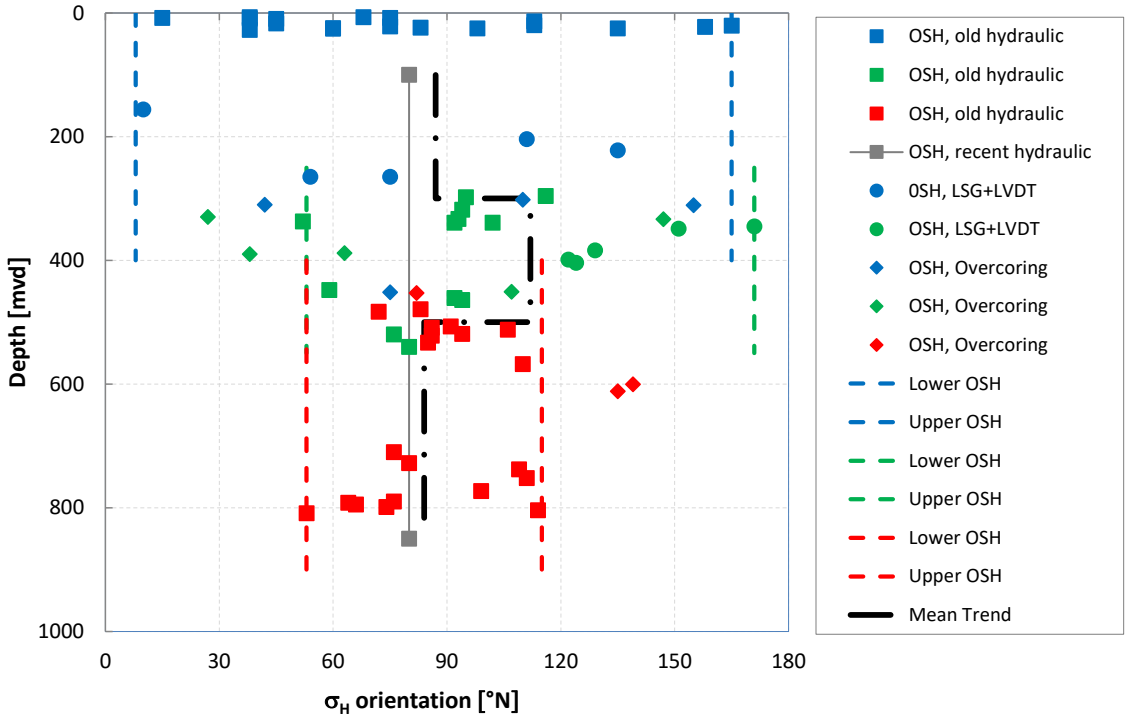
- **Inverse solution method enables partial stress realease - both *overcoring* or *sidecoring* techniques can be used**

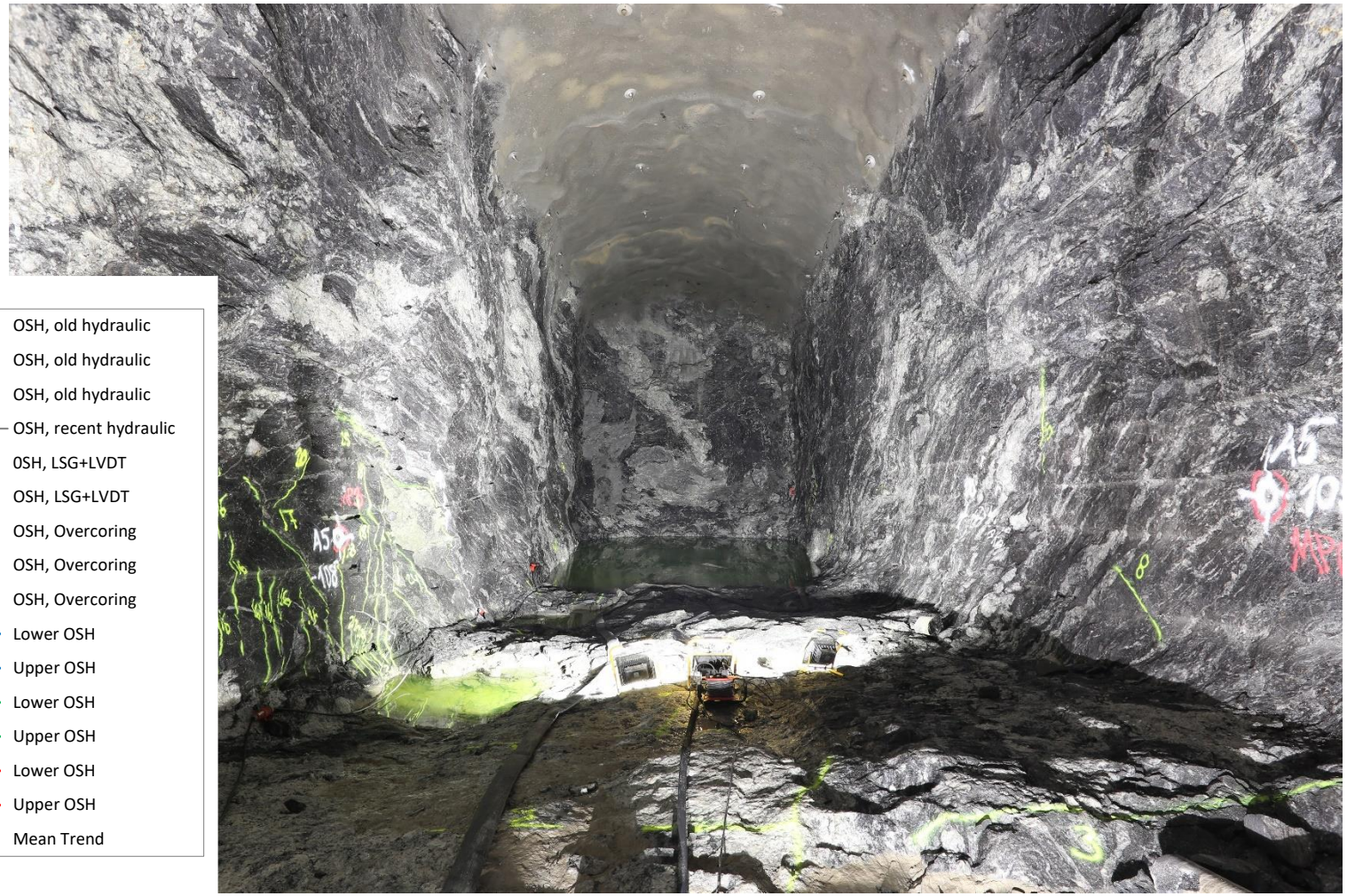




Why LVDT-method

- All started from heterogeneous and foliated migmatitic rock

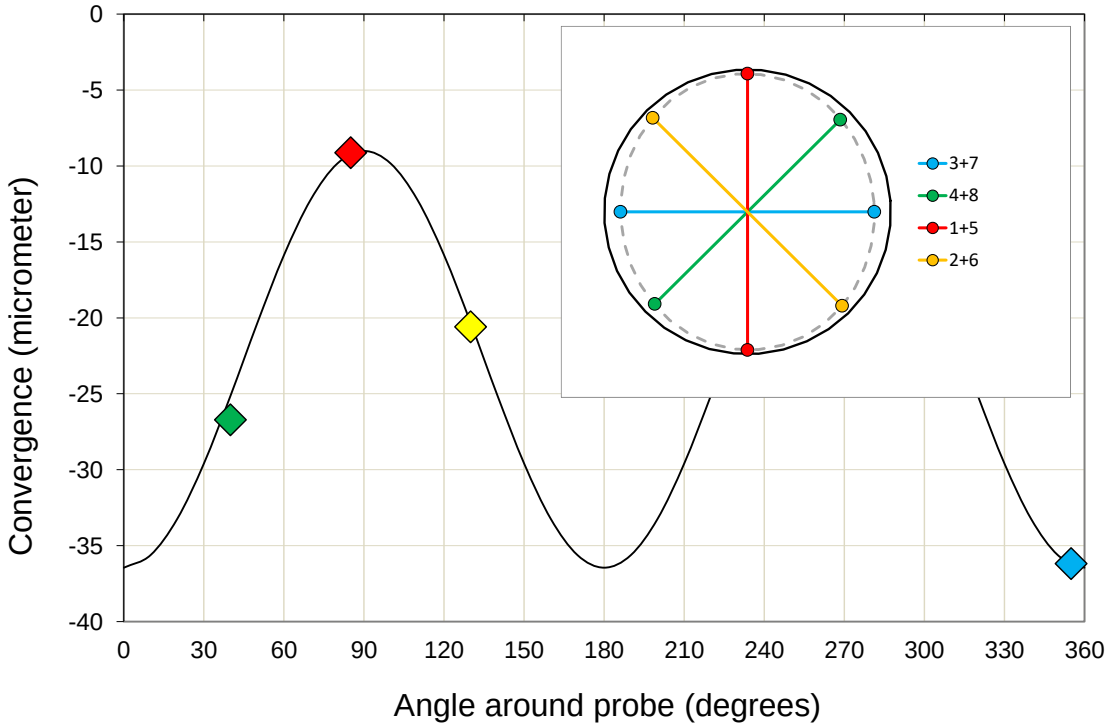


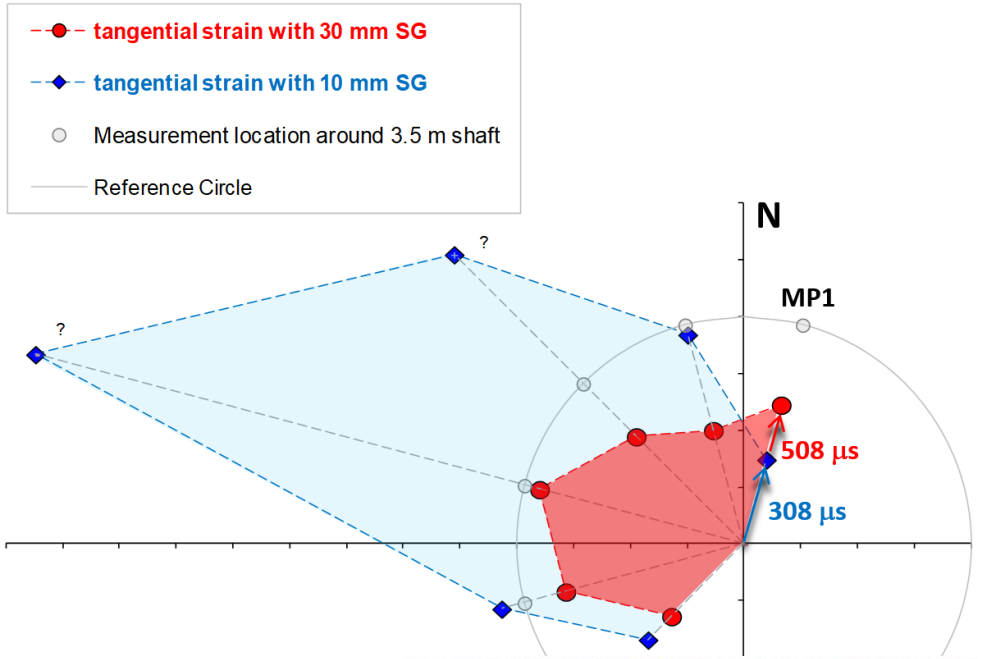


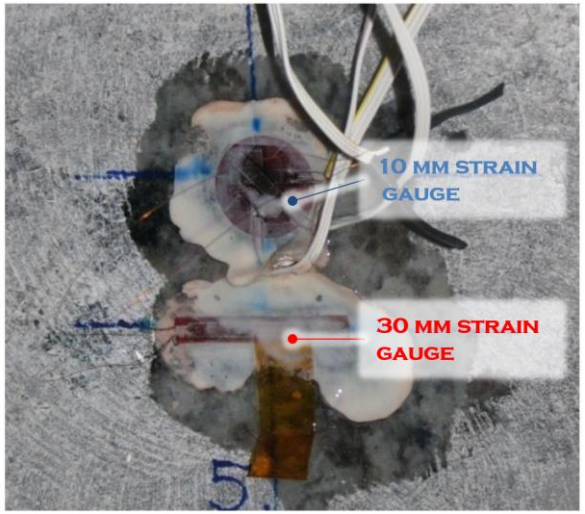
Posiva Oy's ONKALO facility, Finland

SIZE

- STRAING GAUGE STUDY ->
- BIG 126 MM PILOT GIVES MORE TO MEASURE AND IS LESS SENSITIVE FOR HETEROGENEITY

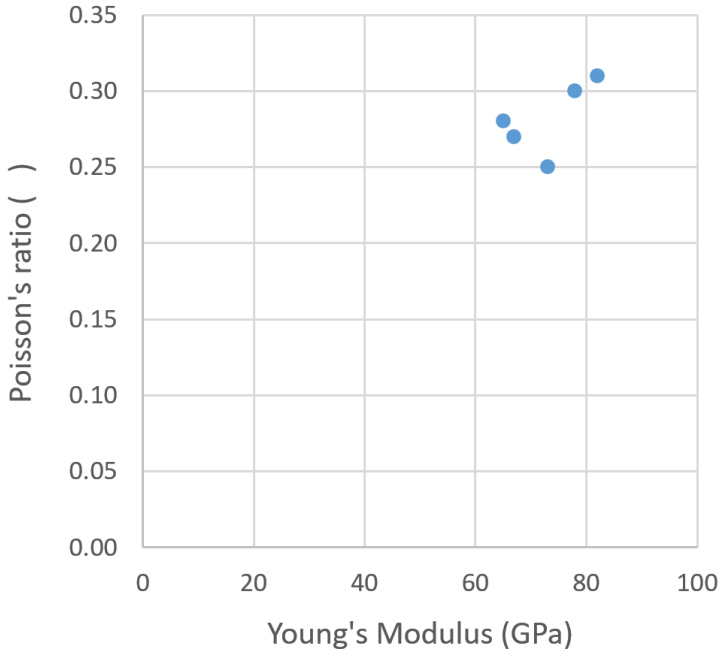


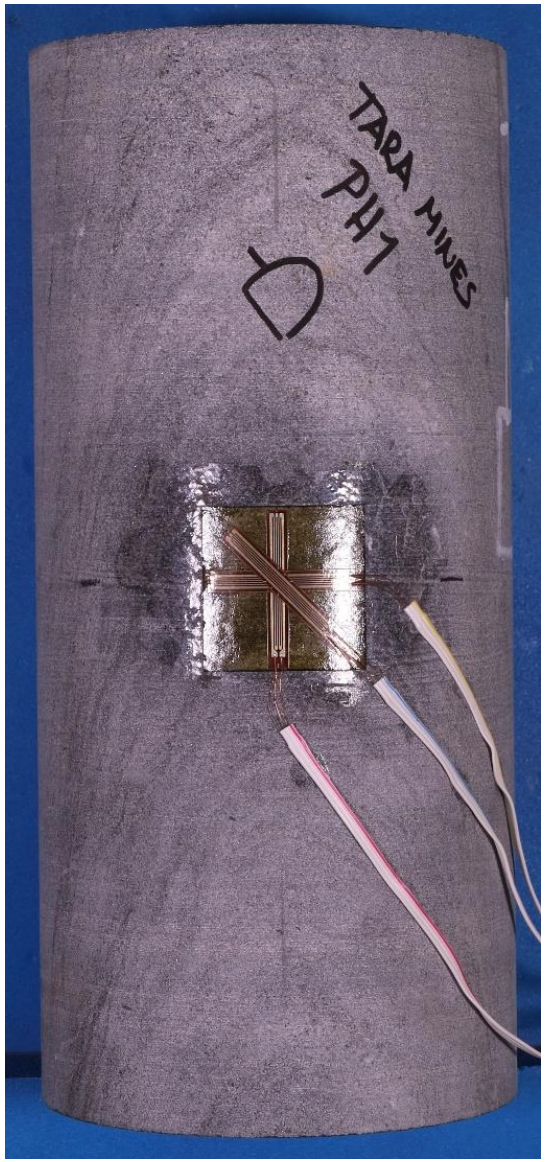




Size

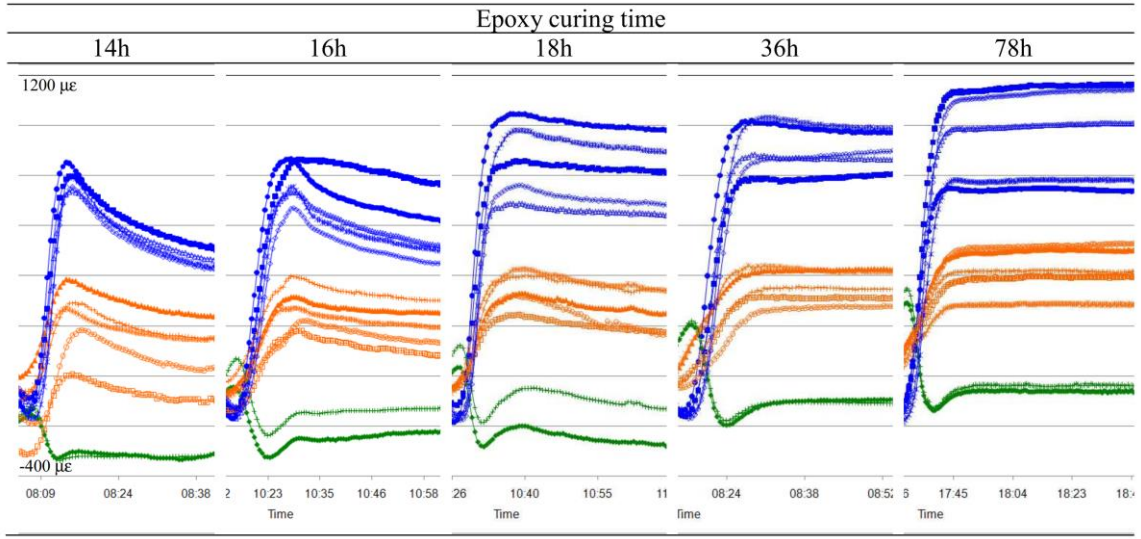
- The same applies for definition of elastic parameters needed for stress solution
- Note that modulus defines principal stress magnitudes in ratio 1:1
- Effect of Poisson's ration is reversed and 40% compared to. It has biggest effect on minor principal stress



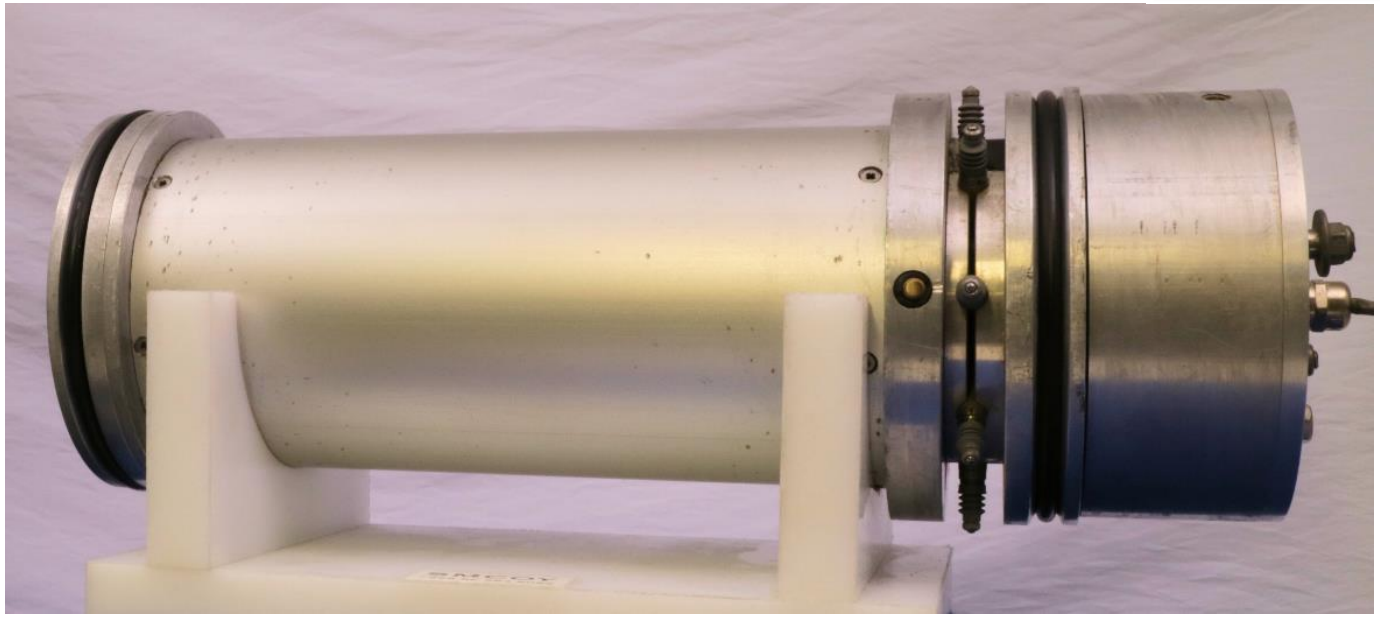


GLUE

- Glue related problems, specially in low rock temperatures ->
- LVDT-cell is mechanically mounted ->
- No hardening time, no drift

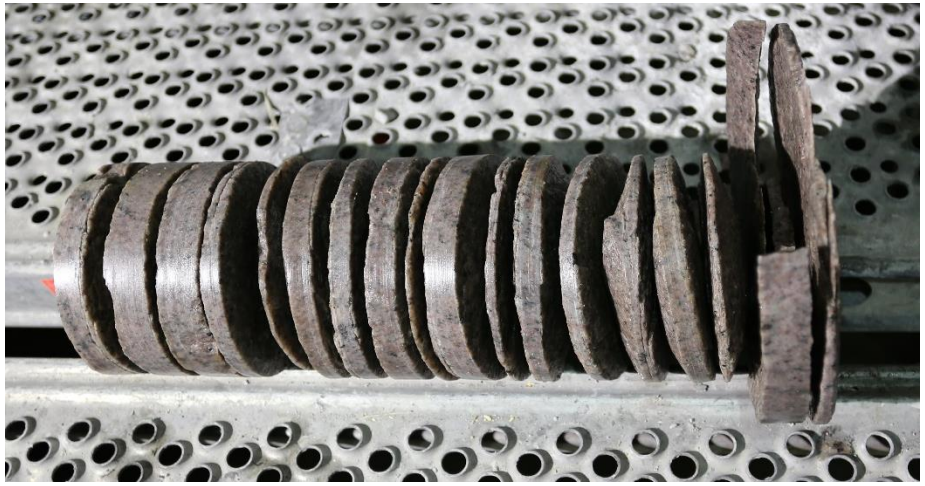


F. Lahaie et al. 2010
CSIRO-HI cell



Core damage

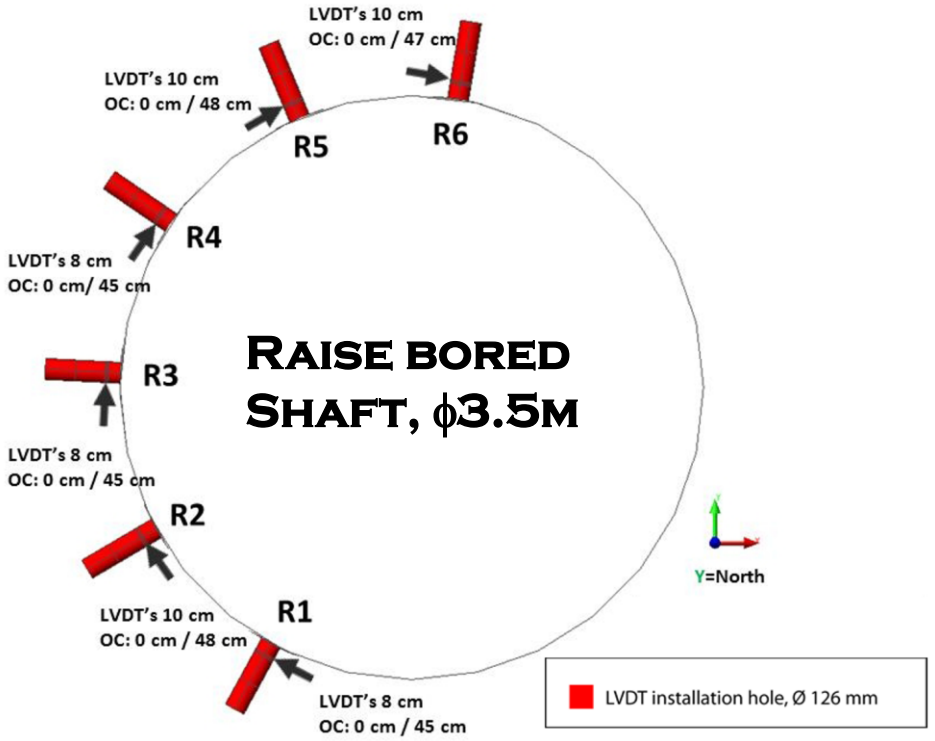
- Overcoring doesn't work in high stress-strength ratio -> core disking
- Sidecoring works,
  as far as pilot is stable



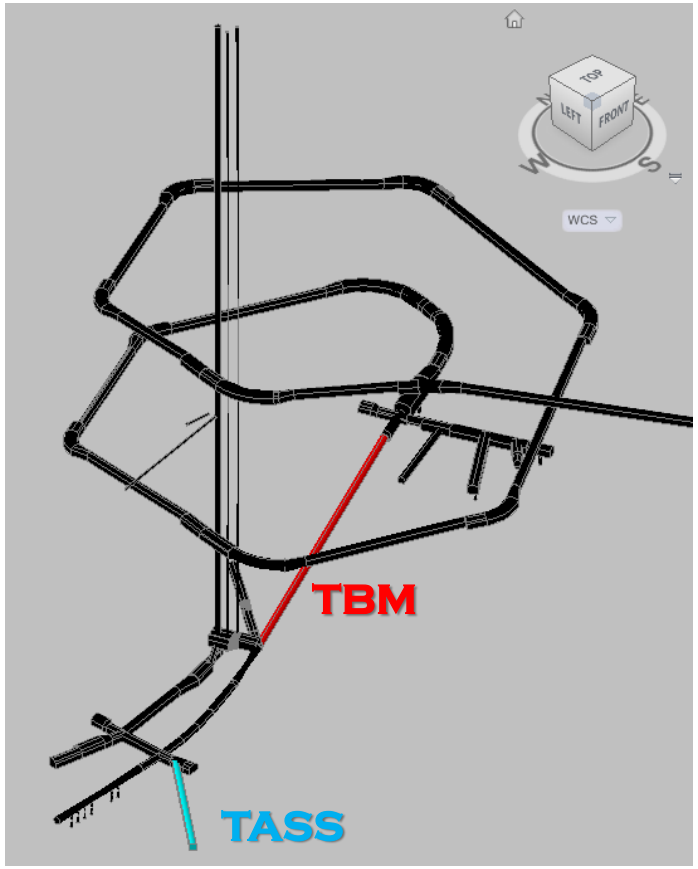
Photos from LKAB Malmberget mine, Sweden

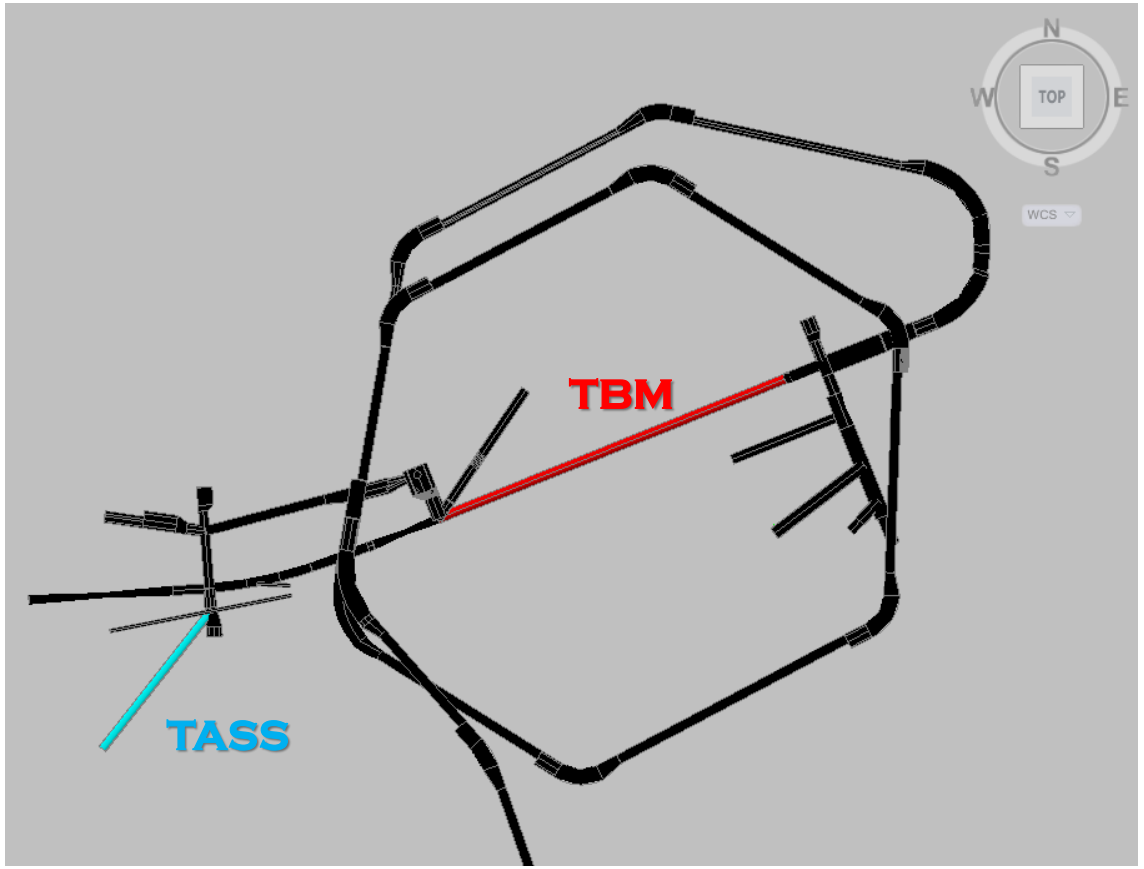
Compact drill rig

- Measurements can be done from limited spaces like shaft
- Two or more drills can be used at the same time



Verification in Äspö HRL, Sweden
- Well known stress state at 450 m depth



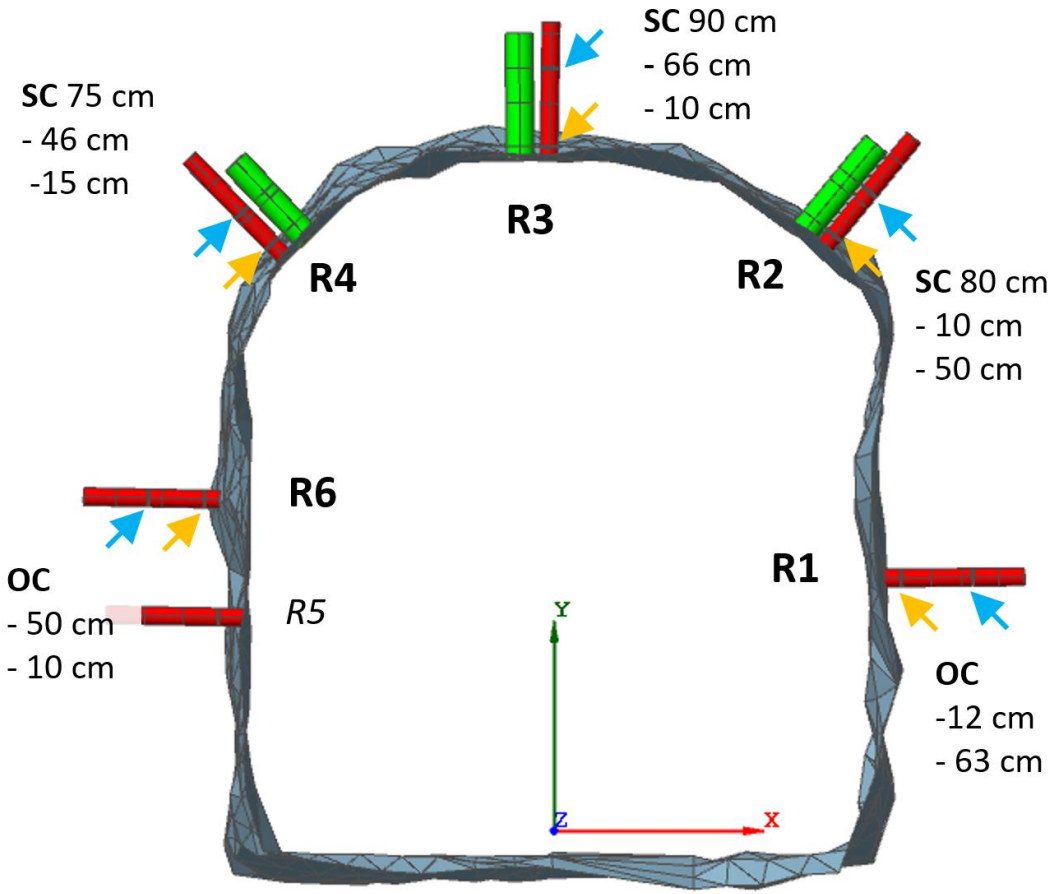


TASS
- BEARING 218°, PLUNGE 0.6° (UP)
- DRILL AND BLAST

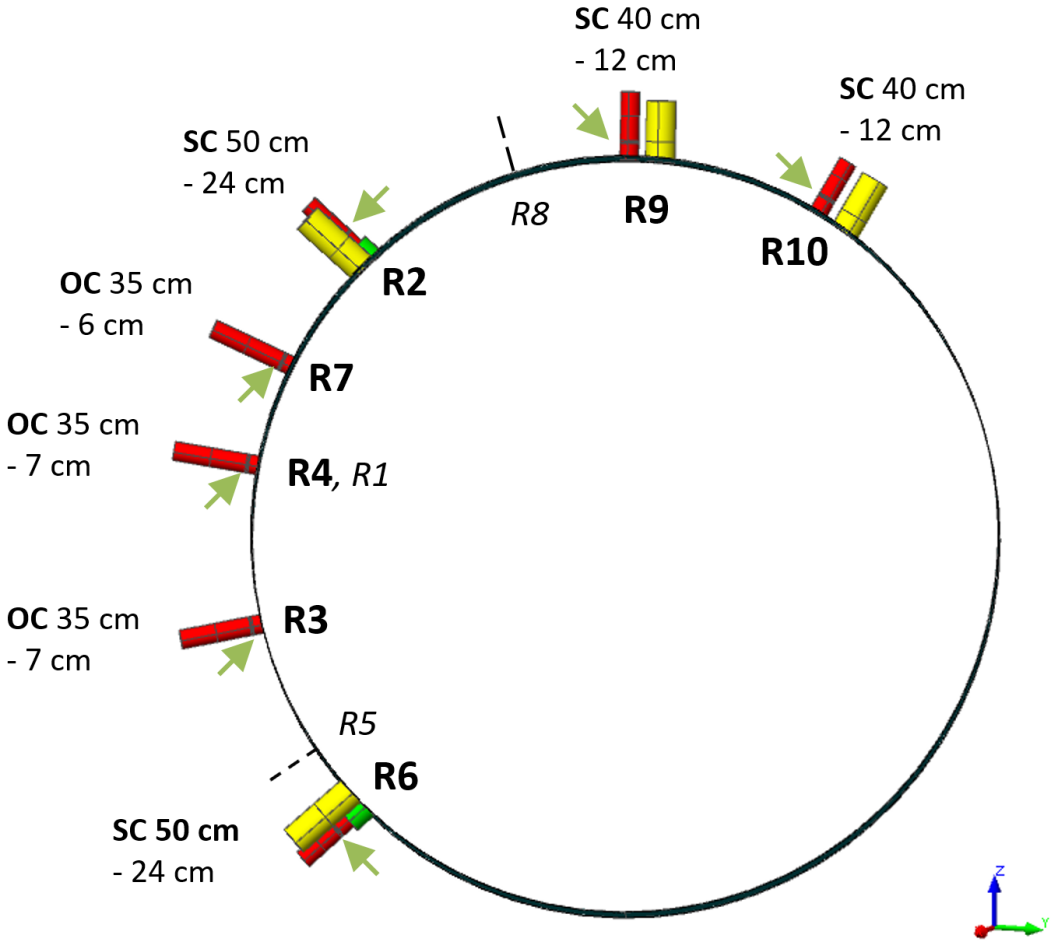
TBM
- BEARING 248°, PLUNGE 8°

ÄSPÖ - *IN SITU* STRESS ORIENTATION

TASS — IN EDZ AND DEEPER

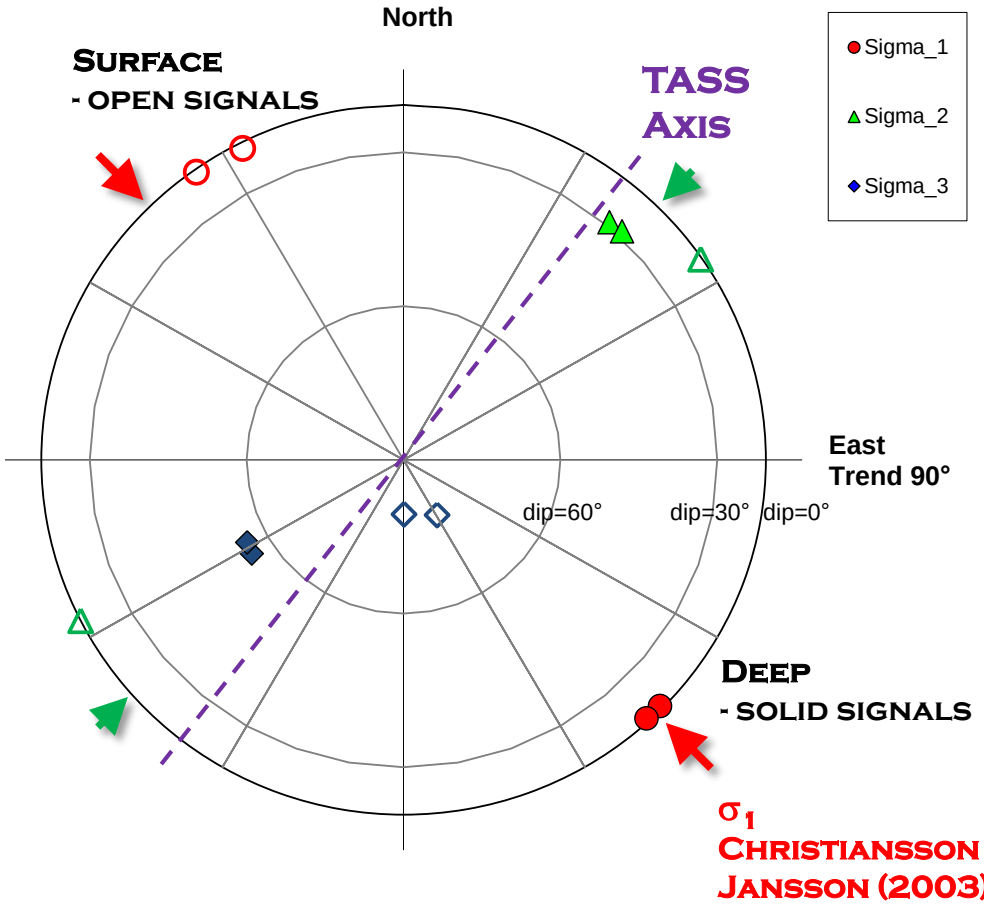


TBM — CLOSE TO SURFACE

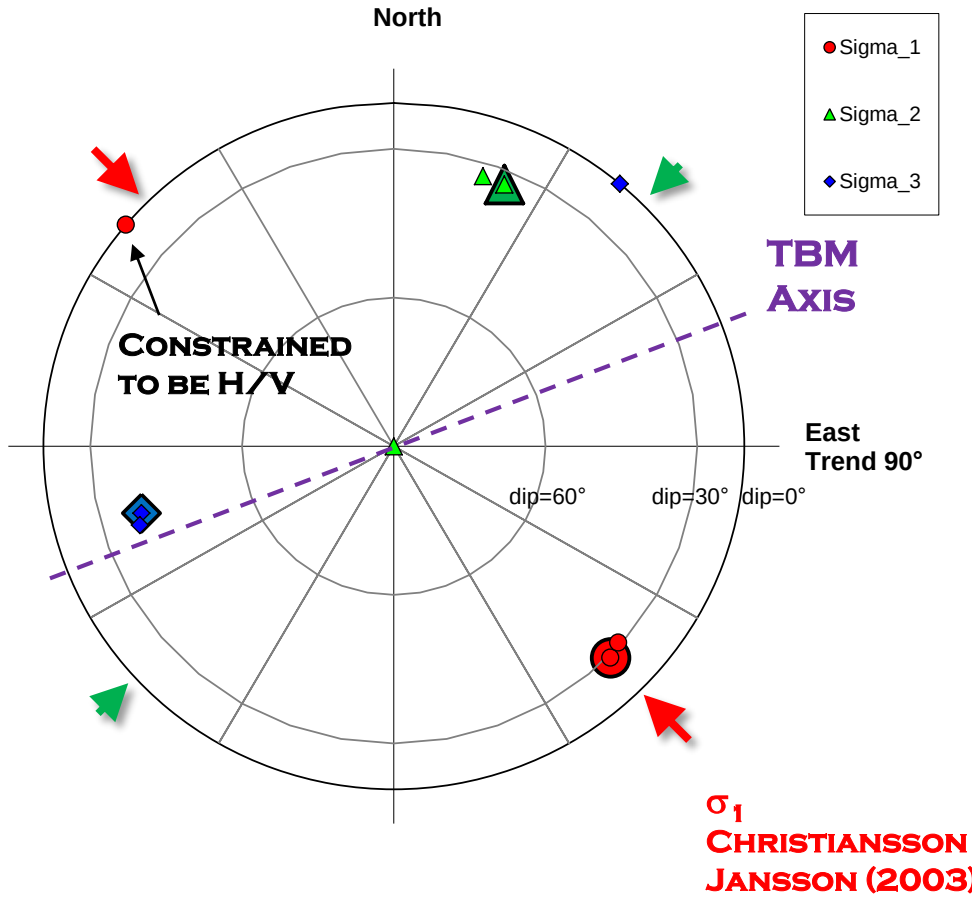


ÄSPÖ - *IN SITU* STRESS ORIENTATION

TASS – IN EDZ AND DEEPER



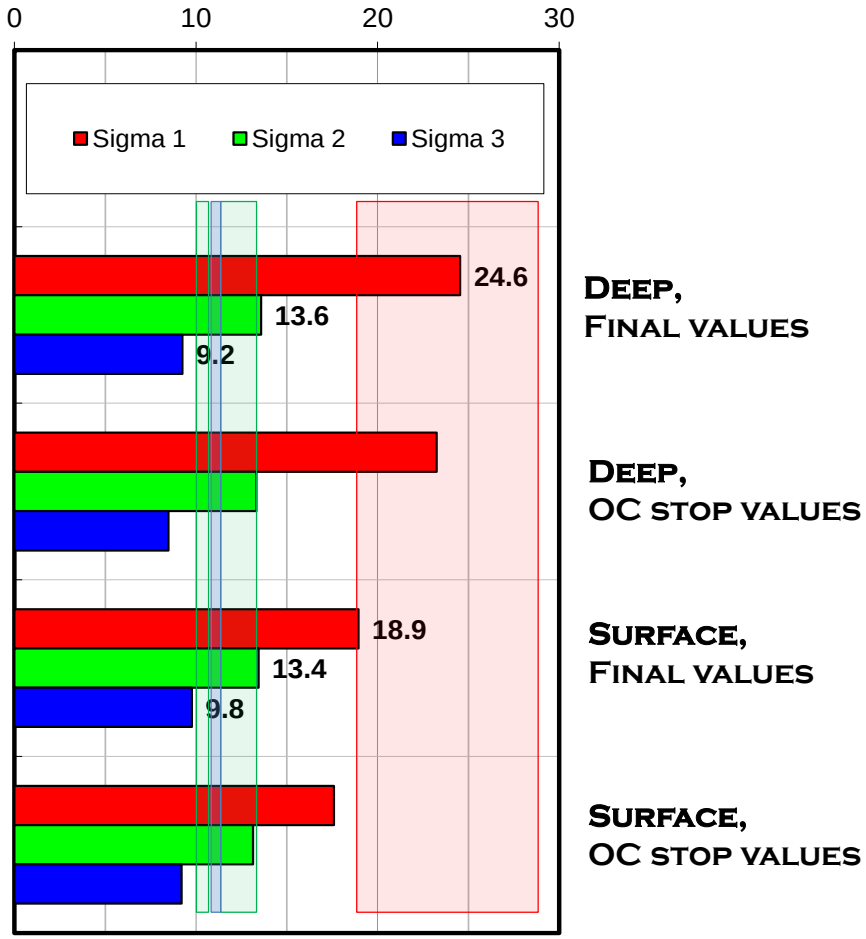
TBM – CLOSE TO SURFACE



ÄSPÖ - *IN SITU* STRESS MAGNITUDE

NOTE, VERTICAL BARS ARE FOR S_H, S_H AND S_V ACCORDING TO CHRISTIANSSON & JANSSON (2003)

TASS – IN EDZ AND DEEPER



DEEP, FINAL VALUES

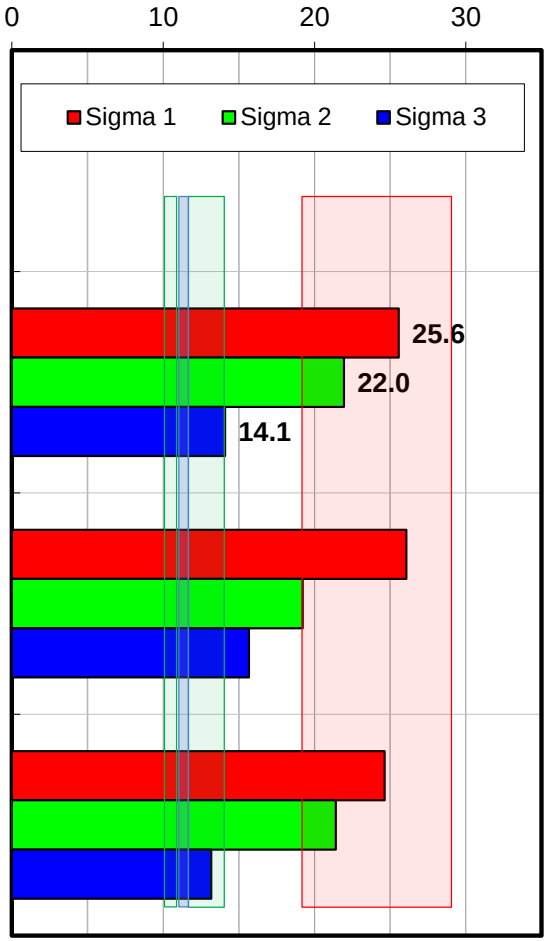
DEEP, OC STOP VALUES

SURFACE, FINAL VALUES

SURFACE, OC STOP VALUES

PRINCIPAL STRESS (MPA)

TBM – CLOSE TO SURFACE



FINAL VALUES

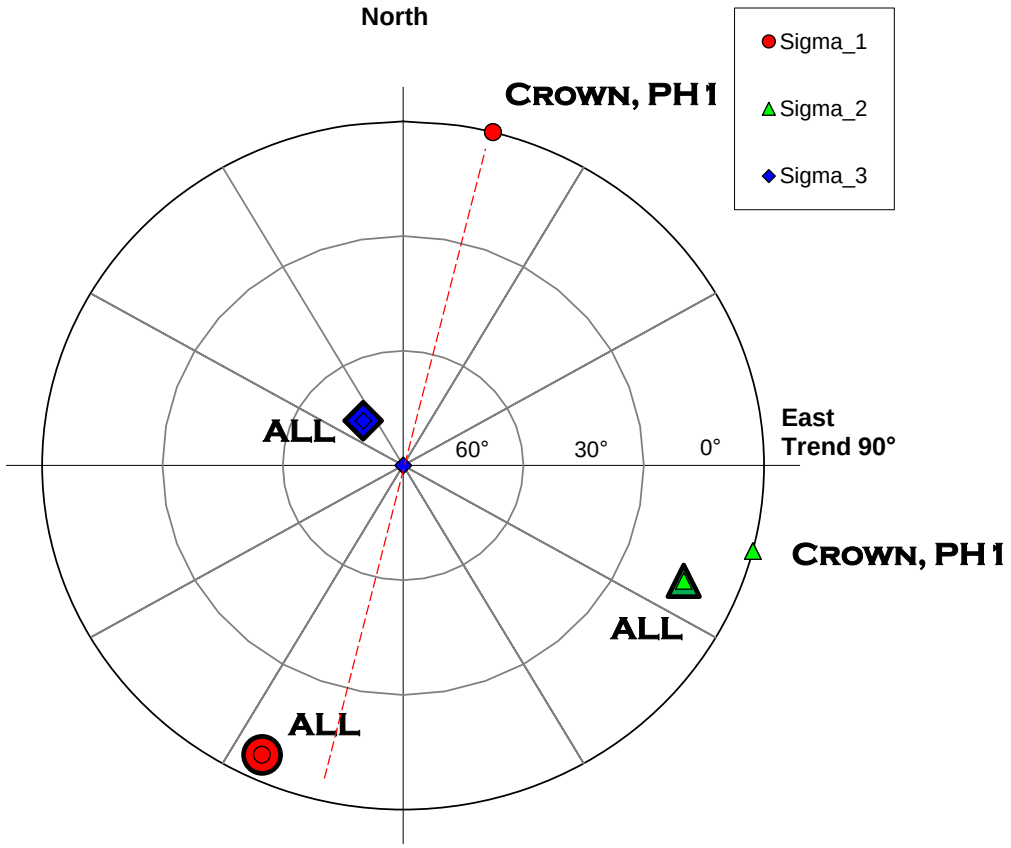
FINAL VALUES, CONSTRAINED TO BE H/V

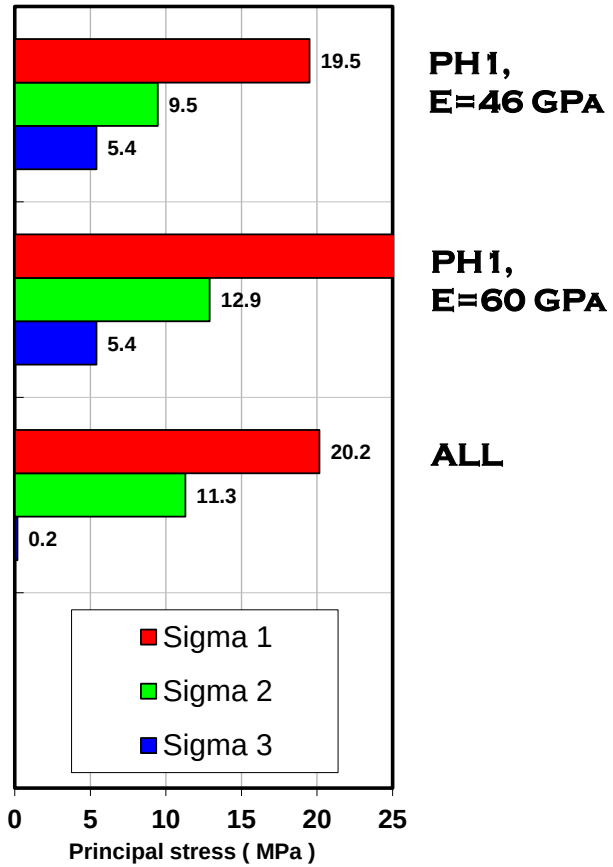
OC STOP VALUES

PRINCIPAL STRESS (MPA)

Case 1 – @ 200 m depth

- Horizontal stress from one crow measurement vs full 3D-stress tensor from five measurements at the same location
- Note the effect of estimated modulus (60 GPa) and measured (46 GPa)

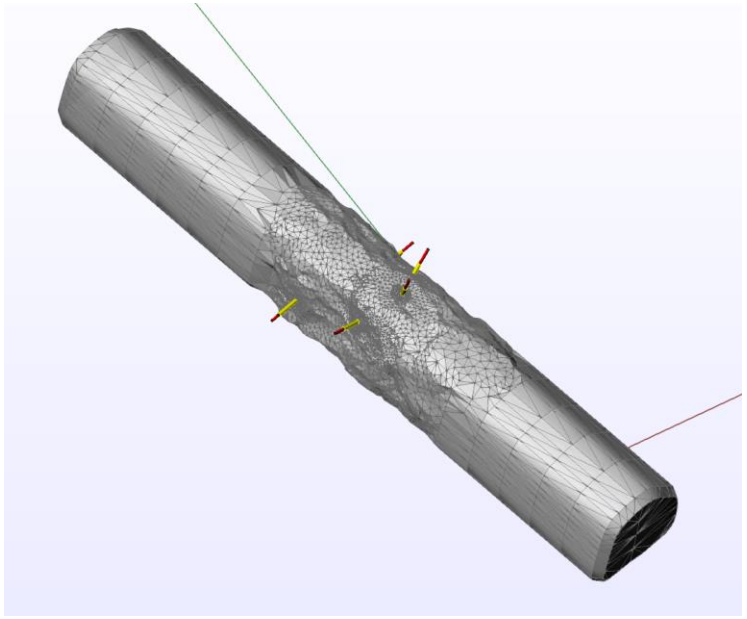


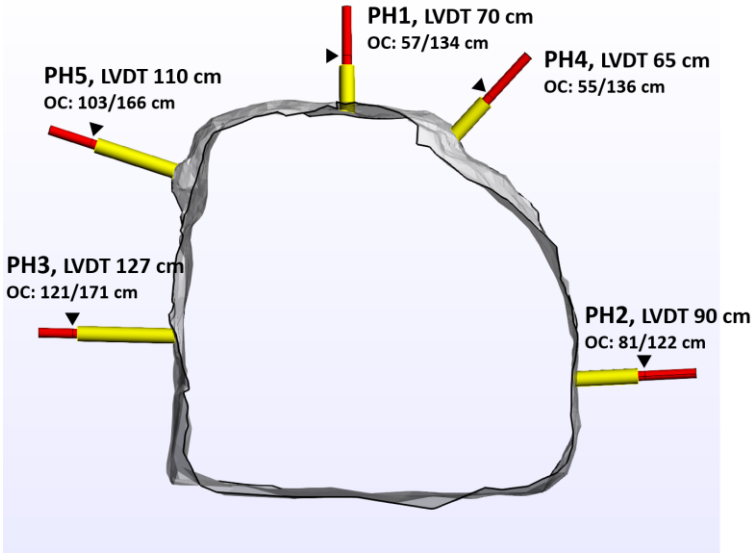


PH1, E=46 GPa

PH1, E=60 GPa

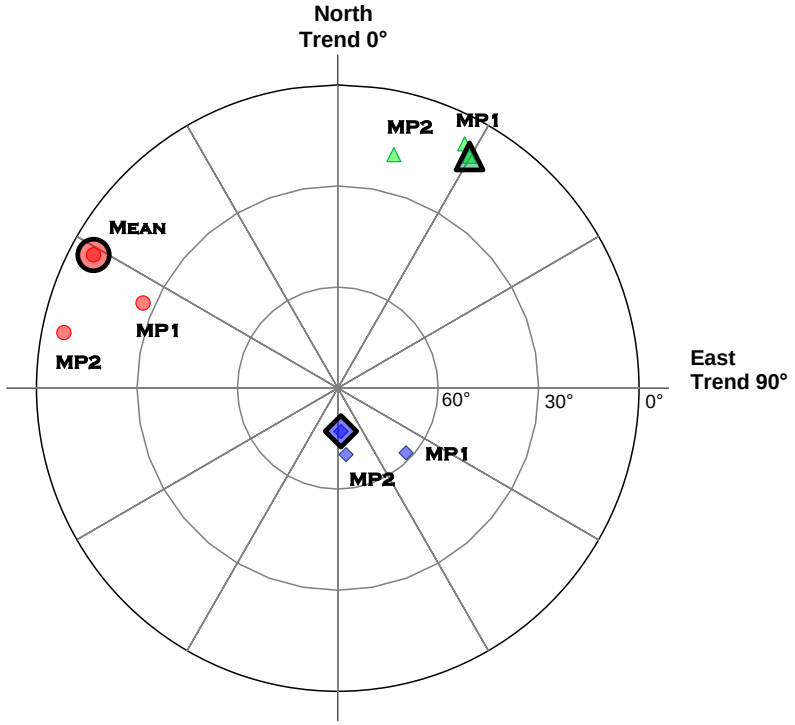
ALL

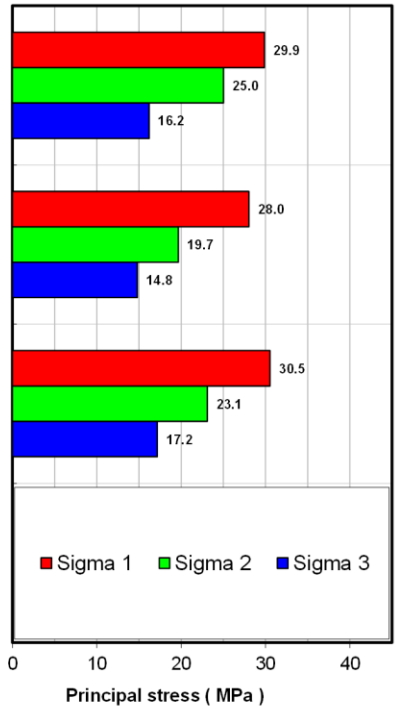




Case 2 – @420 m depth,

- measurements in three tunnels nearby with different orientations

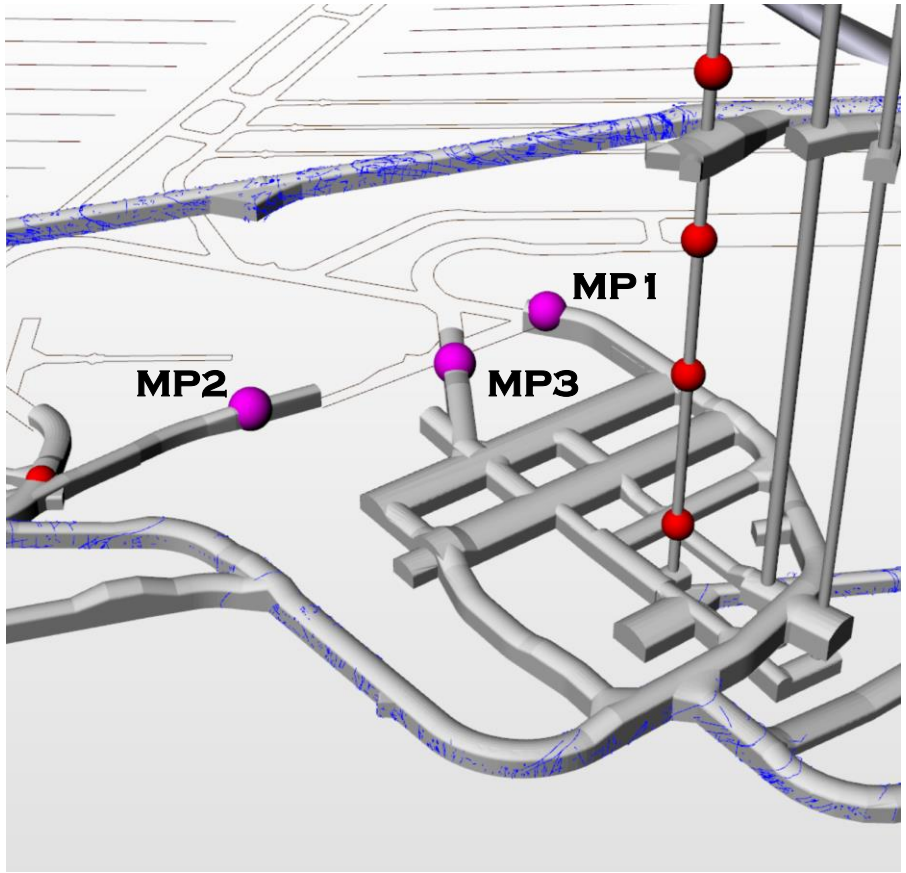




MP1

MP2

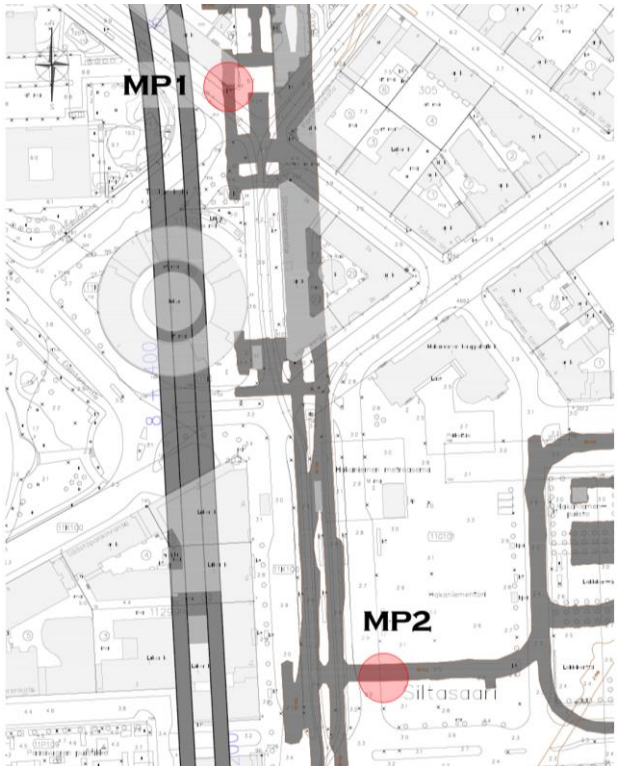
Mean of previous measurements



MP3 under work

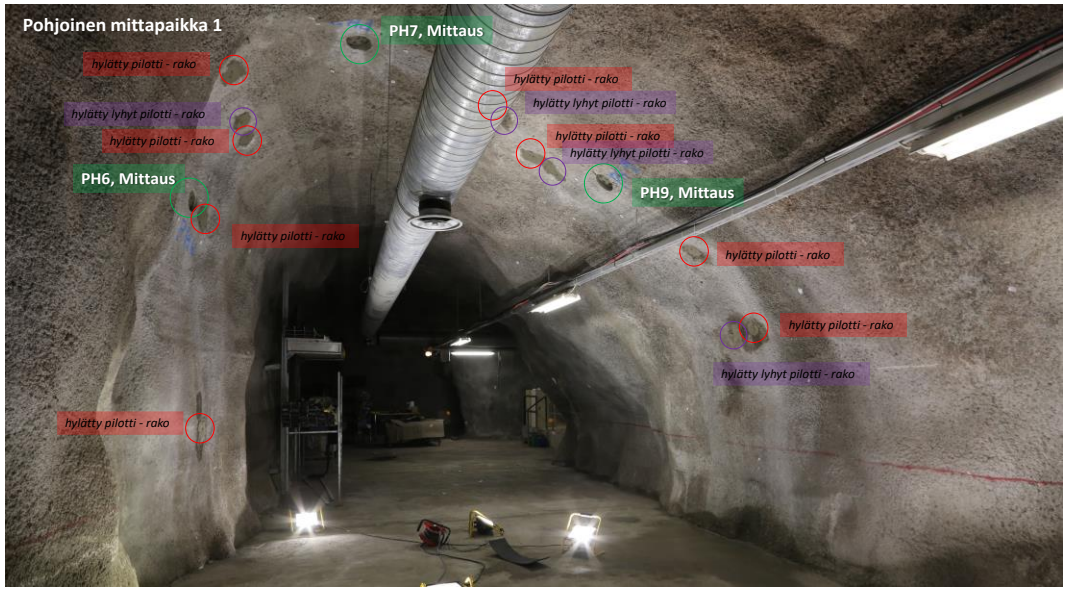
Case 3, rock cover 16 m

- Tunnels excavated 40 years ago
- Effects of unknown brittle fault zones through MP1



Case from Helsinki, Finland
Hakaniemi metro station

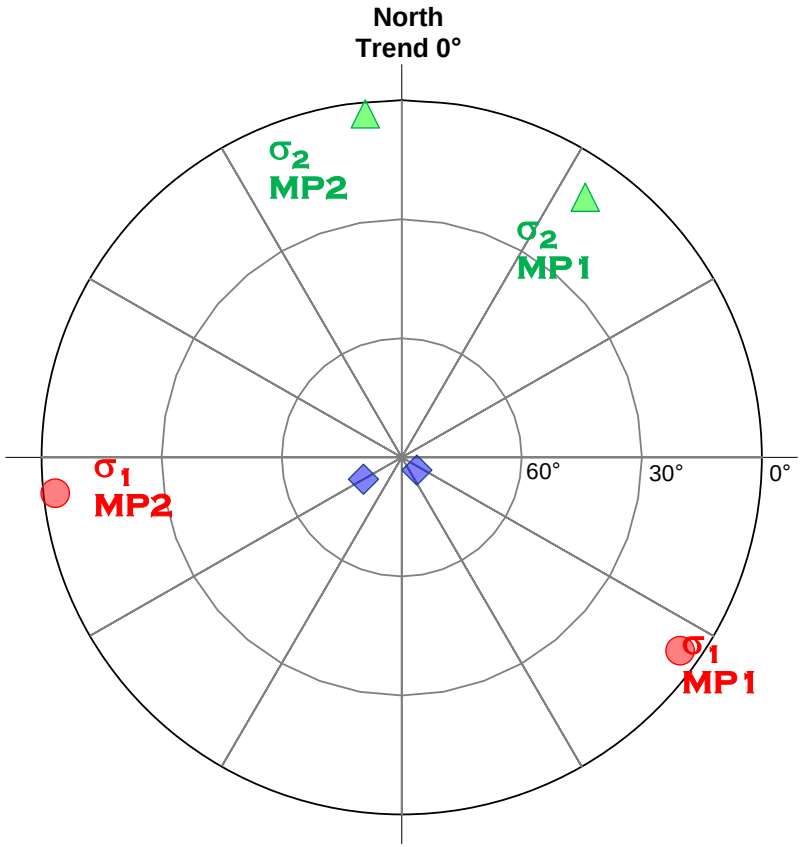
MP1

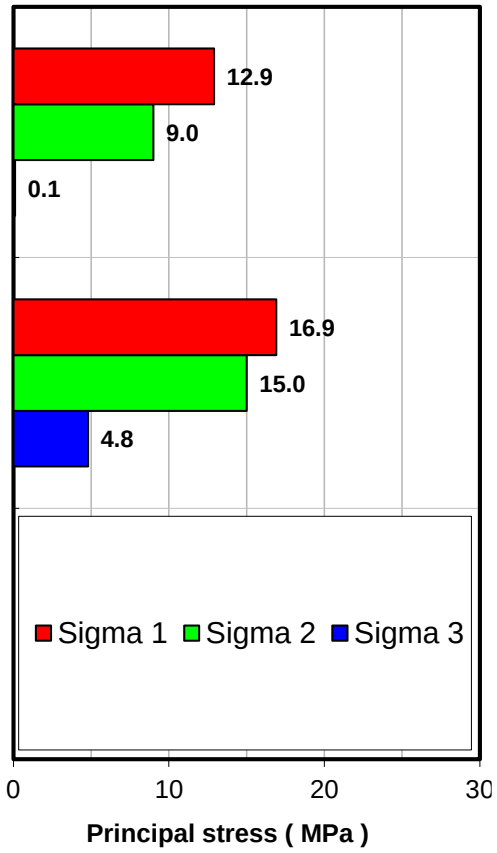


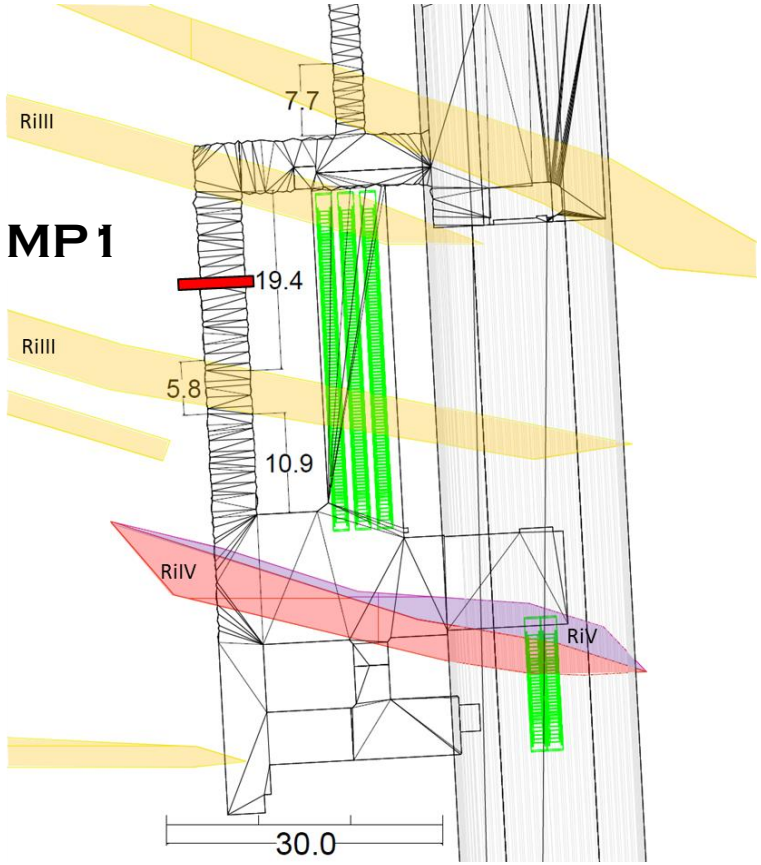
MP2

Case 3

- Effects of unknown brittle fault zones through MP1







Case from Helsinki, Finland, Hakaniemi metro station

Reliability

Before further use following four elements of each measurement are reliability ranked:

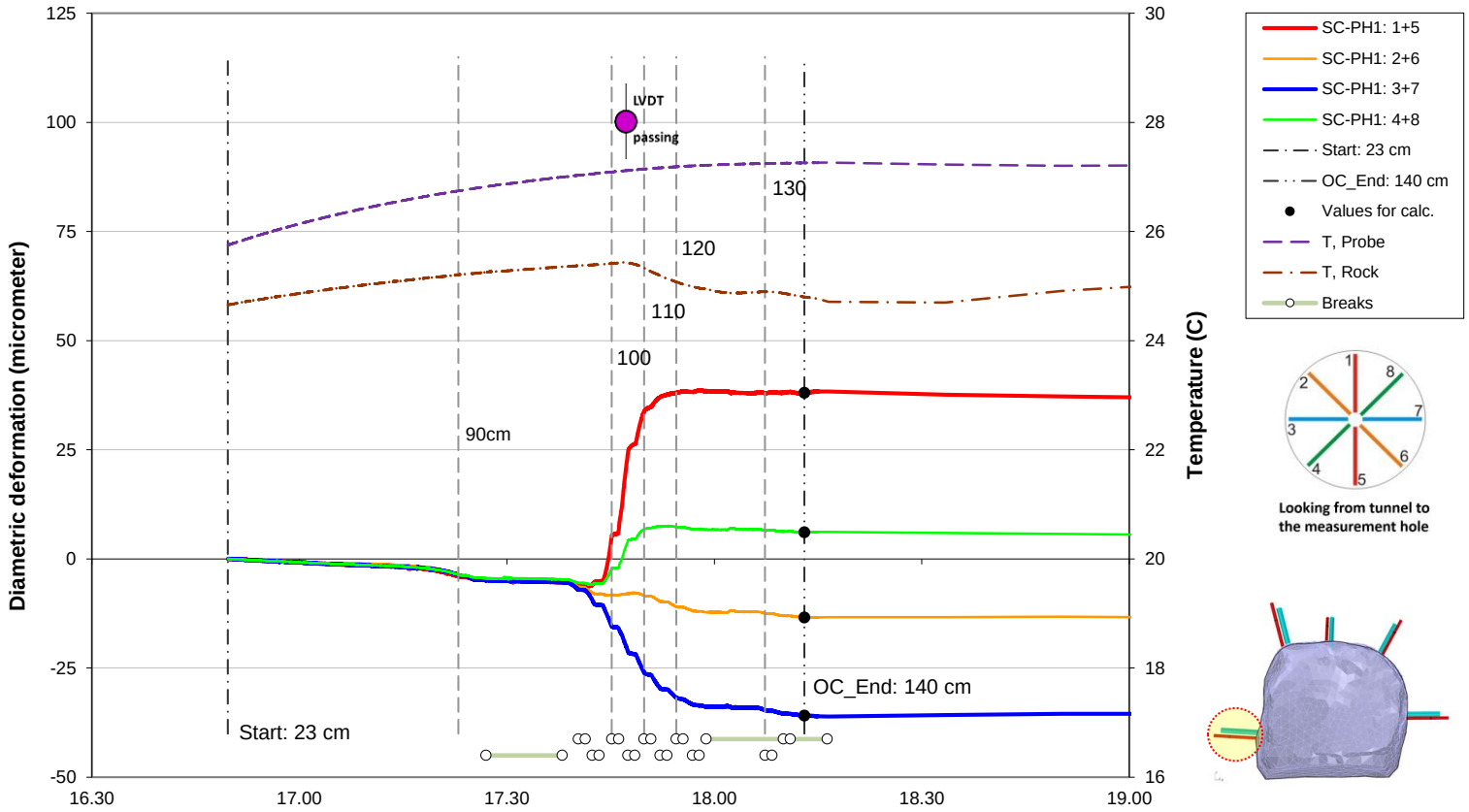
1) field measurement data
2) Uniaxial test results of pilot cores
3) error of the solution
4) geology at the measurement location

In general, the overall reliability can' be better than for field measurement or elastic parameters

RANKING OF FIELD DATA

	3 good	2 moderate	1 poor	-1 rejected	0 N/A
1) Calibration, before *Deviation from 1000* µm *calibration value, which indicates sensor reading linearity, normally a measurement is not started if it is not below 40* µm.	<40µ	<50µ	<100µ	>100µ	
2) Stability before drilling *Relative amount of unreturnable or uncorrectable shift in micrometers per 15 minutes. Weighting is minor as drilling is not started if the cell is unstable.*	<5µ/15'	<10µ/15'	<20µ/15'	>20µ/15'	
3) Stability during drilling, LVDT's passed by 15 cm *Relative amount of unreturnable or uncorrectable shift. Weighting is high as the majority of convergences take place when the LVDT-section is passed by 15 cm.*	<5% <5µm	<10% <10µm	<20% <15µm	>20% >15µm	
4) Stability during drilling breaks *Relative amount of unreturnable or uncorrectable shift. Weighting is high because this indicates damage in the pilot hole wall and if encountered, normally leads to the rejection of the measurement.*	<5% or <5µm /15 min	<10% or <10µm /15 min	<20% or <15µm /15 min	>20% or >15µm /15 min	
5) Stable final readings *Change in value during the last 2.5 cm of coring compared to the final value or relative amount of unreturnable or uncorrectable shift. Ranking cannot be better than ranking according to criterion 3). Weighting is high as this defines the final reliability of the values used in the inverse calculation, but if the readings are not fully stable, more stable values that were obtained earlier can be used instead.*	<5% <5µm	<10% <10µm	<20% <15µm	>20% >15µm	
6) Overcoring length after LVDT-section *The majority of the convergence takes place when coring has passed the LVDT section by 15 cm and stable values should observed after 30 cm, high weighting.*	>25cm	>20cm	>15cm	< 15 cm	
7) Order of convergence magnitudes *Pilot hole deformation should always be elliptical or circular --> result either accepted or disqualified*	ok			not ok	
8) Temperature change at calculation readings *magnitude error of approximately 3 MPa. The effect of an even higher temperature increase can be estimated at an acceptable accuracy.*	<2C	<10C	<20C	>20C	
9) Calibration, after *and weighting is higher than criterion 1) as this affects the stress calculation and cannot be traced and fixed.*	<40µ	<60µ	<100µ	>100µ	

RANKING OF FIELD DATA

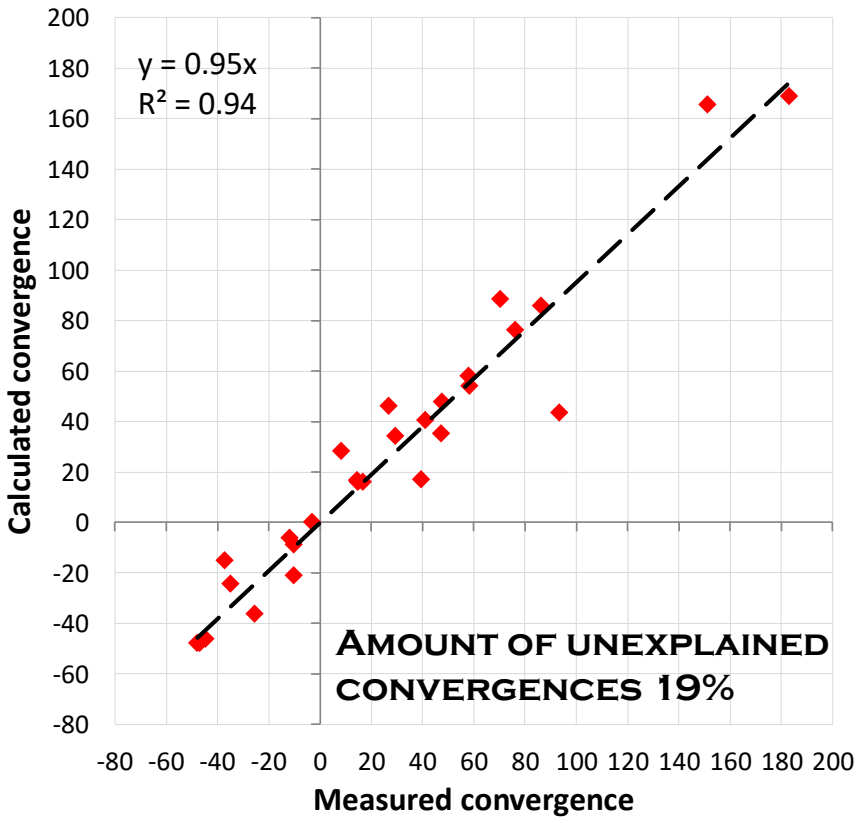


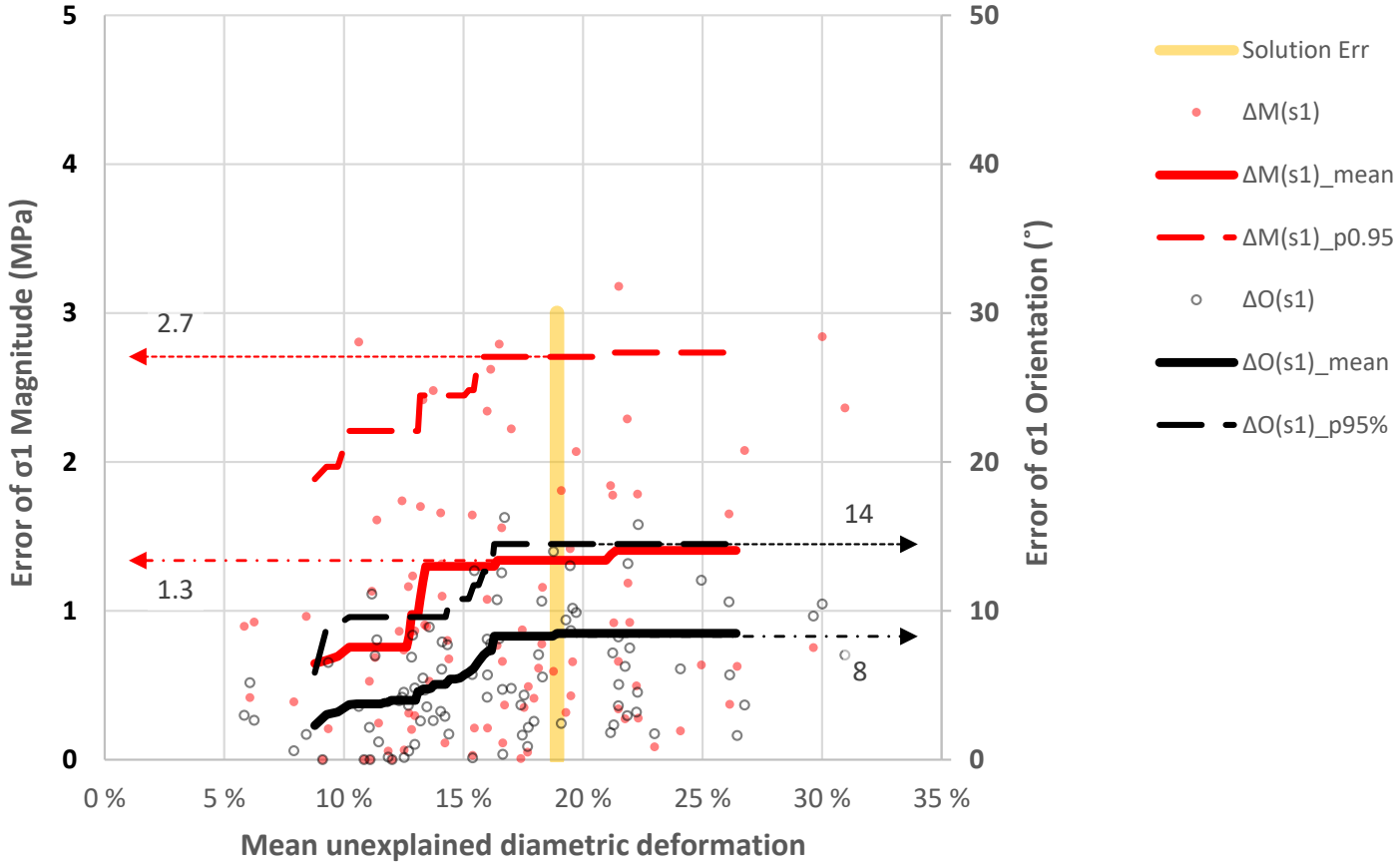
Time	Observation
16:30	sidecoring started
16:46	cell stable, ok for measurement, SC1 advance 23 cm
17:25-17:26	coring advance recording
17:27-17:38	drill bit full, core removal
17:40-17:57	8 * coring advance recording
17:58-18:16	drill bit full, core removal
18:07-18:12	2 * coring advance recording
18:13	SC1 finished, coring stopped
18:15	logging stopped and restarted for data copying
+1d 10:50	logging stopped

	1-5	2-6	3-7	4-8
1) Calibration, before	3	3	3	3
2) Stability before drilling	3	3	3	3
3) Stability during the drilling, LVDT's passed by 15 cm	3	3	3	3
4) Stability during the drilling breaks	3	3	3	3
5) Stable final readings, can't be better than 3)	3	3	3	3
6) Overcoring length after LVDT-section	3	3	3	3
7) Order of convergence magnitudes	3	3	3	3
8) Temperature change at calculation readings	3	3	3	3
9) Calibration, after	3	3	3	3
Convergense weighted grading	3.0	3.0	3.0	3.0
LVDT-Measurement weighted grading for accepted values	*3.0*			
LVDT-Measurement quality	*good*			

RELIABILITY

MEANING OF INTERNAL ERROR OF STRESS SOLUTION



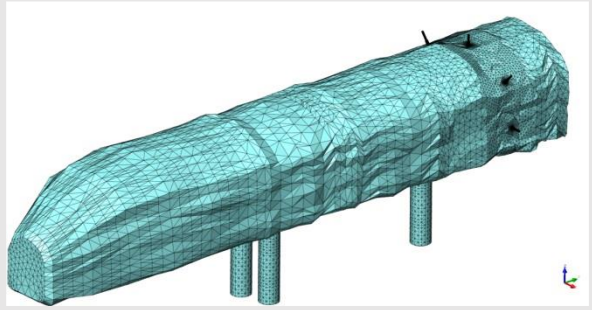


Various Inversion modelling approaches

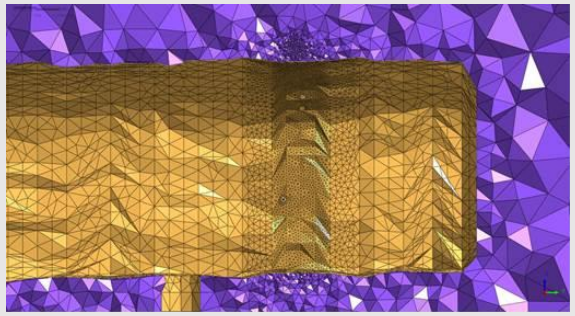
BEM
- Examine3D

Others
- Midas GTS NX

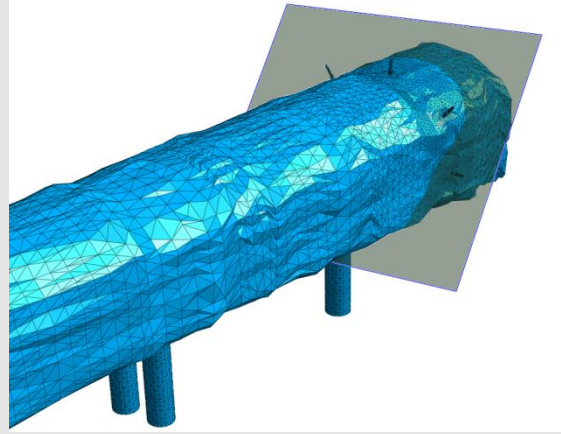
BEM



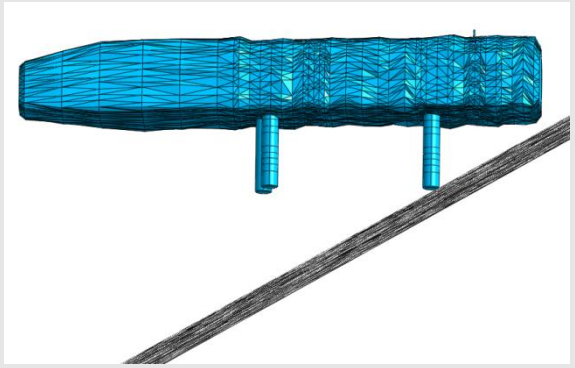
FEM



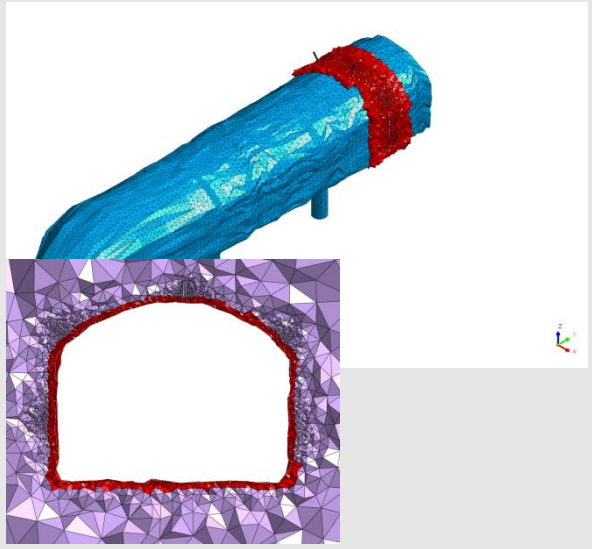
FEM – transversely isotropic



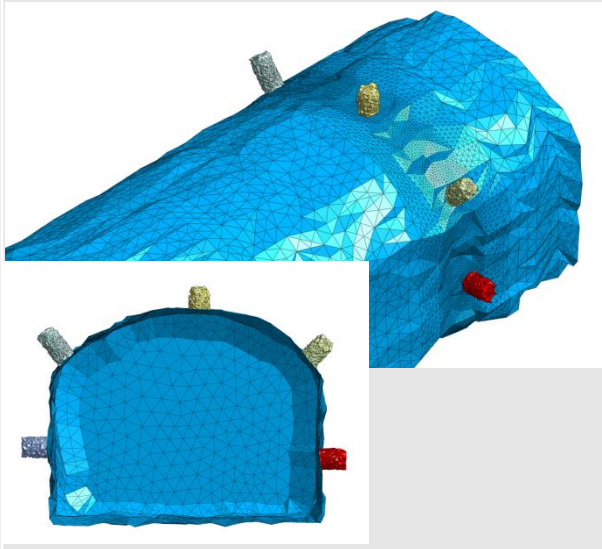
FEM – brittle fault zone



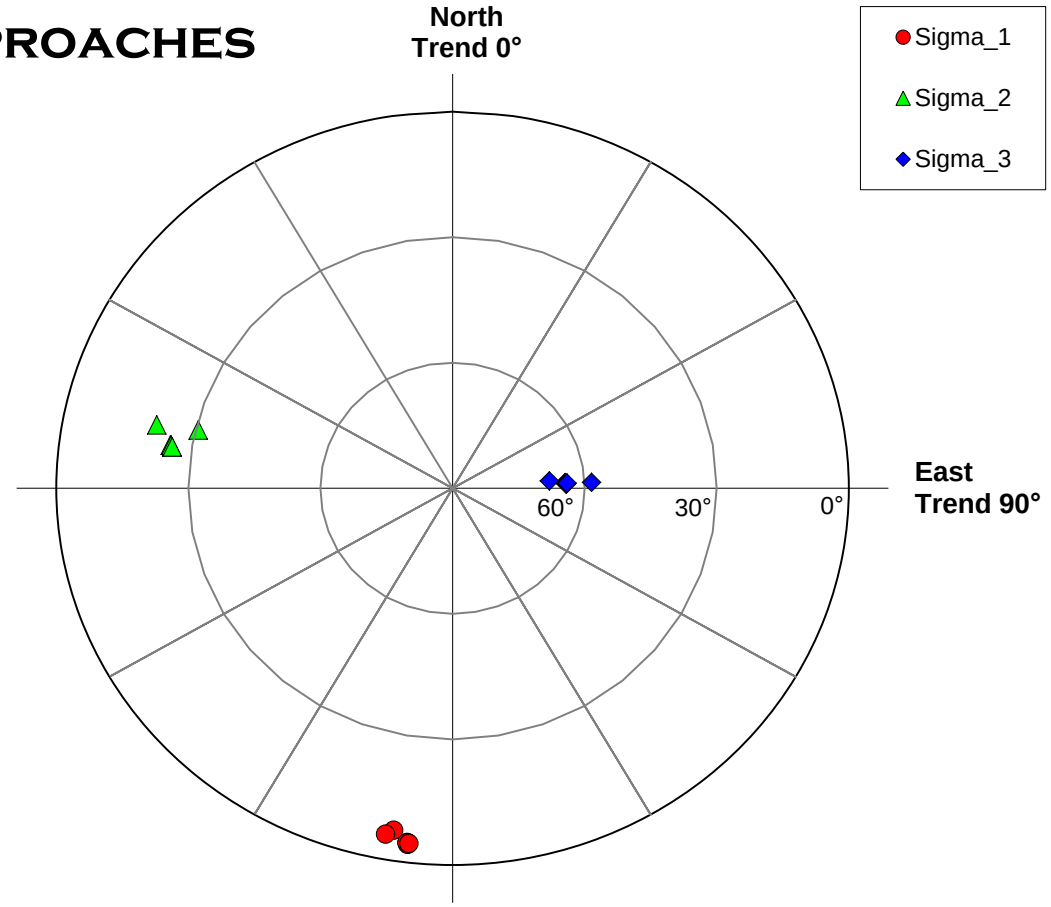
FEM - EDZ

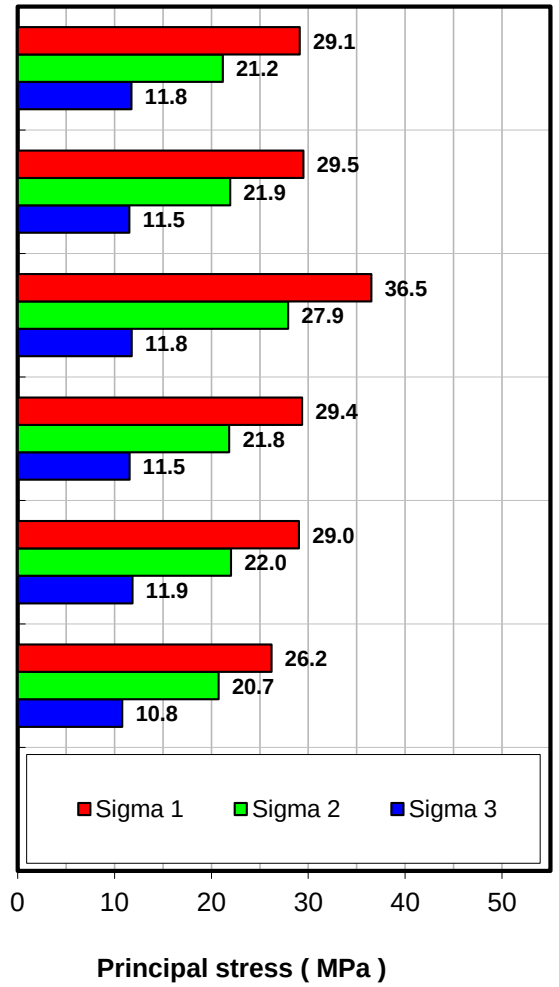


FEM Heterogeneity



Various Inversion modelling approaches





BEM

FEM

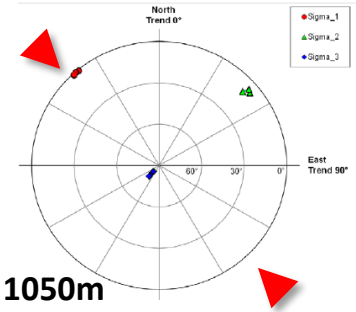
Transverse isotropy E/E'=1.4

Effect of BFZ below floor

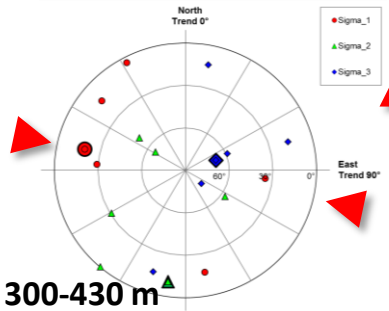
EDZ, E_{EDZ}/E=0.8, r=0.25 m

Heterogeneity, E_i=31-68 GPa

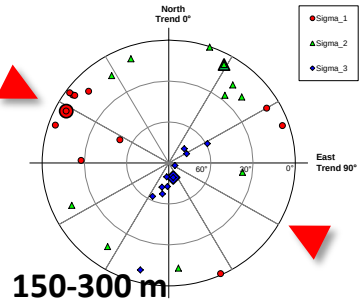
LVDT Measurements 2009 - 2015



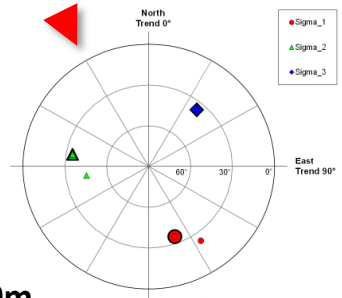
1050m



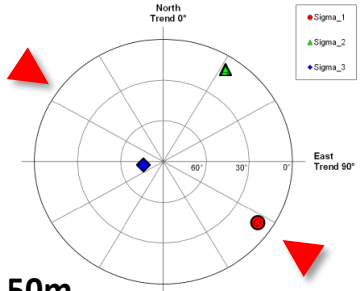
300-430 m



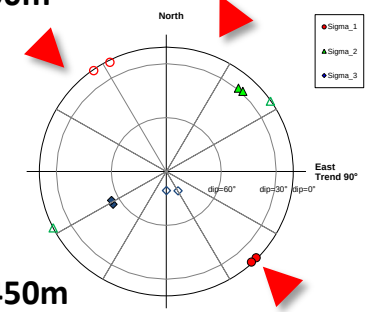
150-300 m



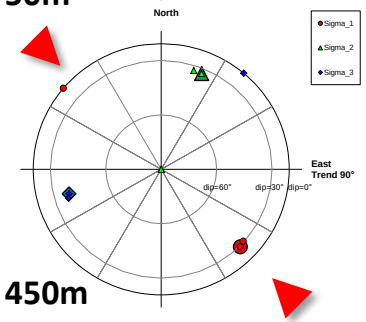
50m



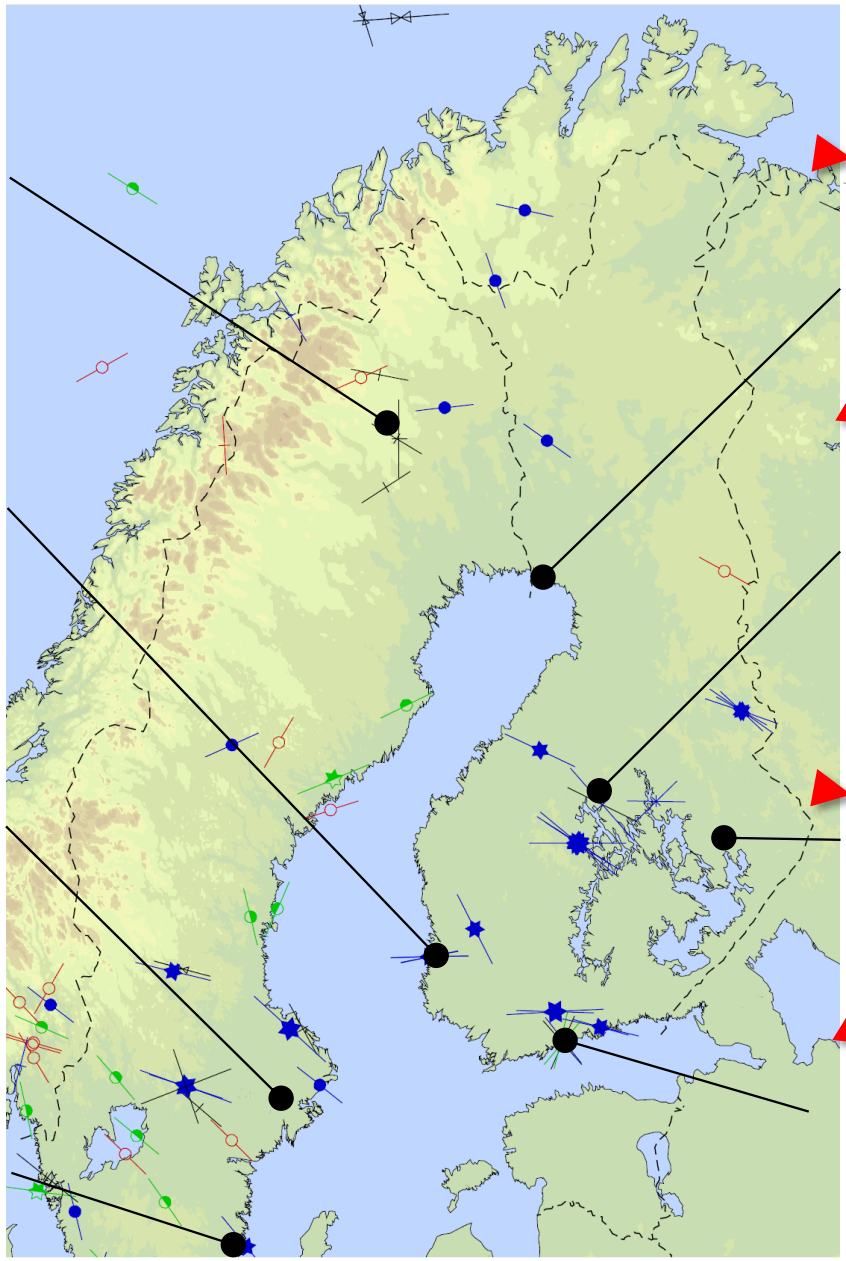
50m

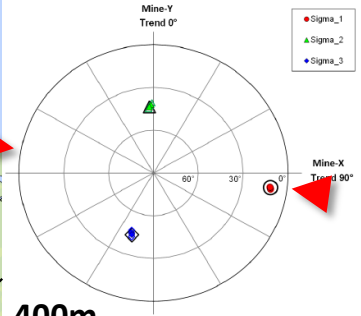


450m

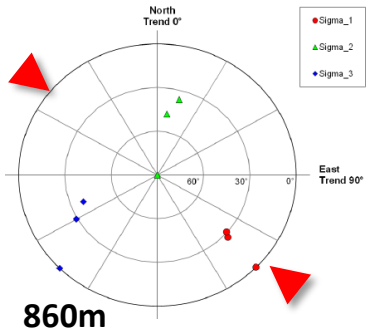


450m

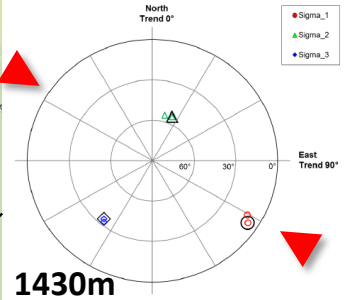




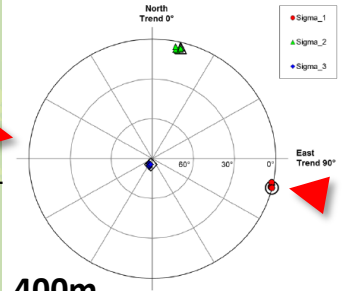
400m



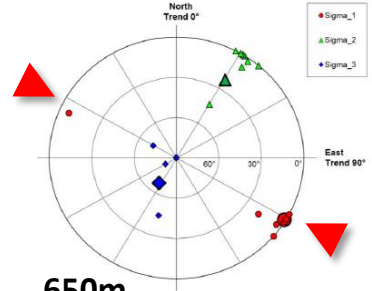
860m



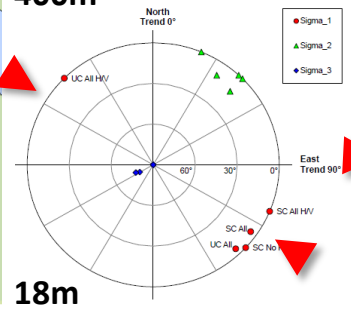
1430m



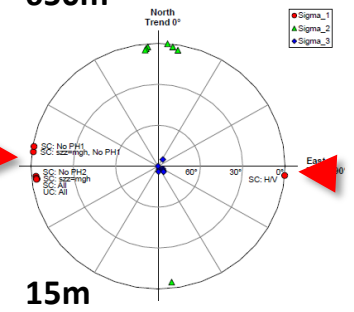
400m



650m



18m



15m

Thank you for your attention

Stress Measurement Company Oy
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