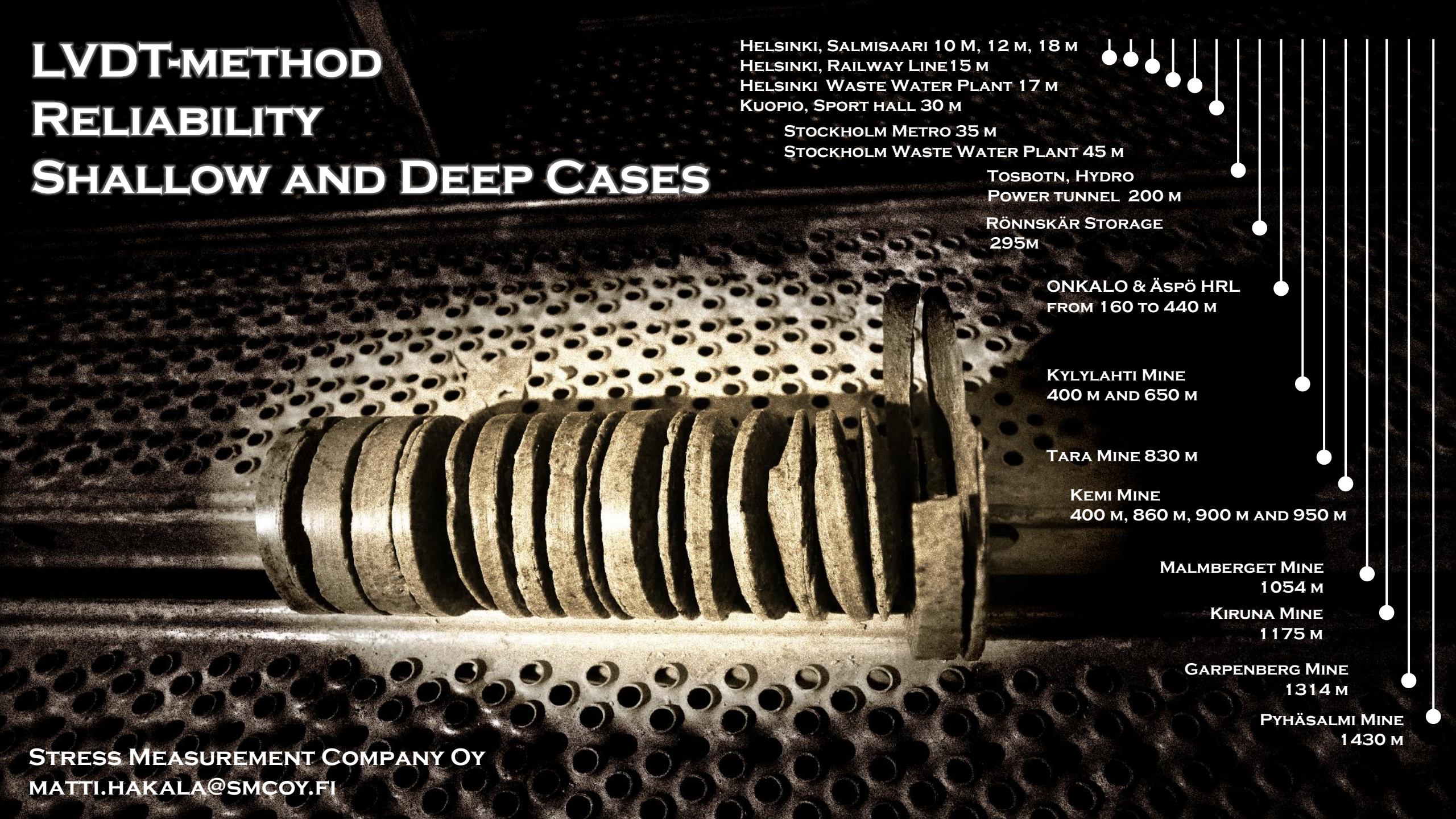
LVDT-method Reliability Shallow and Deep Cases



Helsinki, Salmisaari 10 m, 12 m, 18 m
Helsinki, Railway Line15 m
Helsinki Waste Water Plant 17 m
Kuopio, Sport hall 30 m

Stockholm Metro 35 m
Stockholm Waste Water Plant 45 m

Tosbotn, Hydro Power tunnel 200 m

Rönnskär Storage 295m

ONKALO & Äspö HRL from 160 to 440 m

Kylylahti Mine 400 m and 650 m

Tara Mine 830 m

Kemi Mine 400 m, 860 m, 900 m and 950 m

Malmberget Mine 1054 m

Kiruna Mine 1175 m

Garpenberg Mine 1314 m

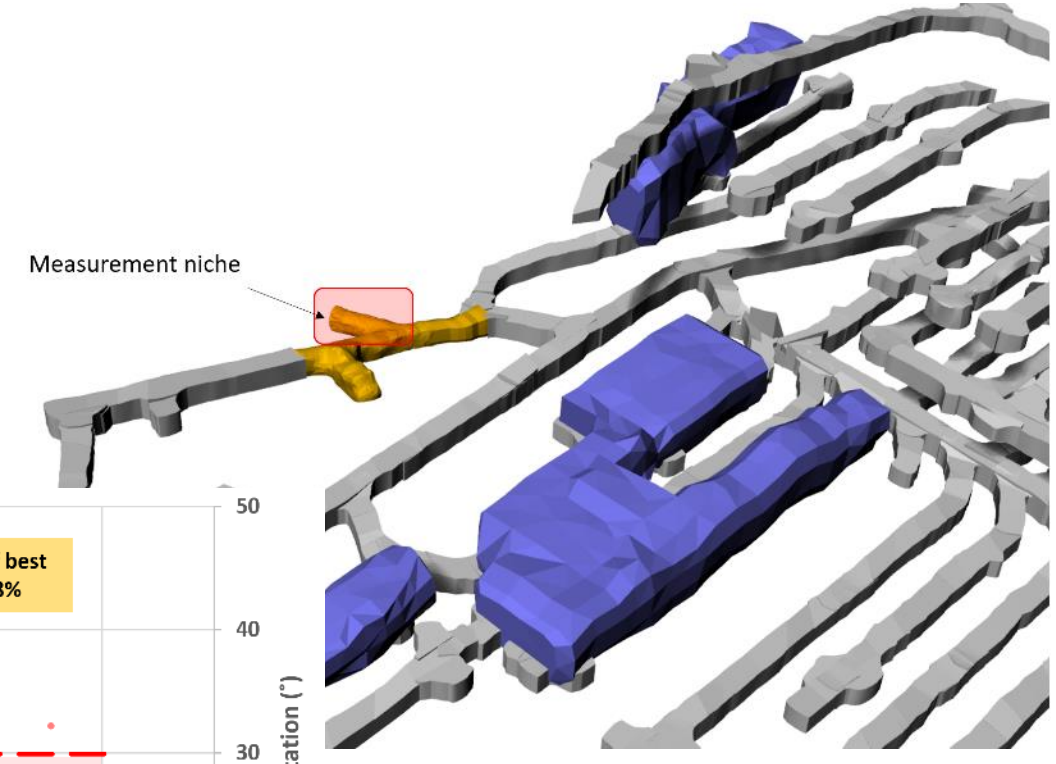
Pyhäsalmi Mine 1430 m

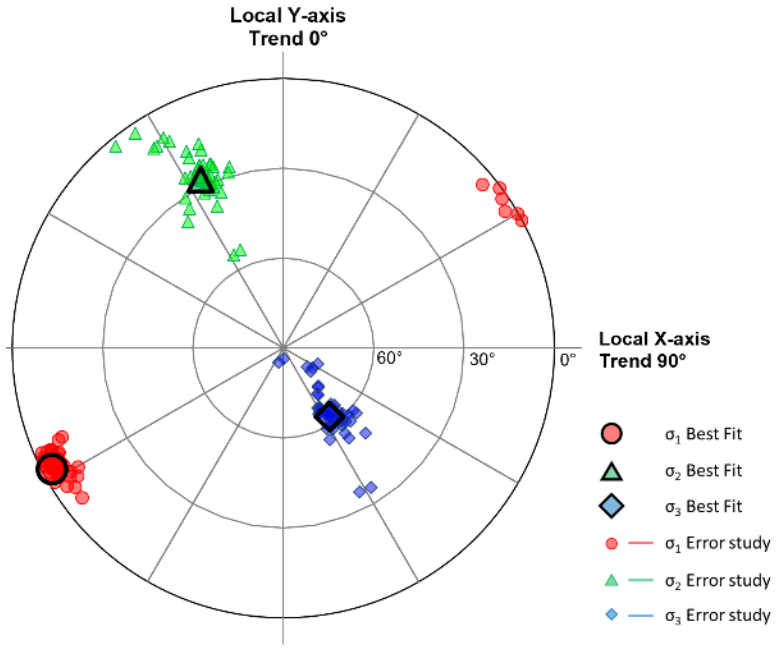
Stress Measurement Company Oy
matti.hakala@smcoy.fi

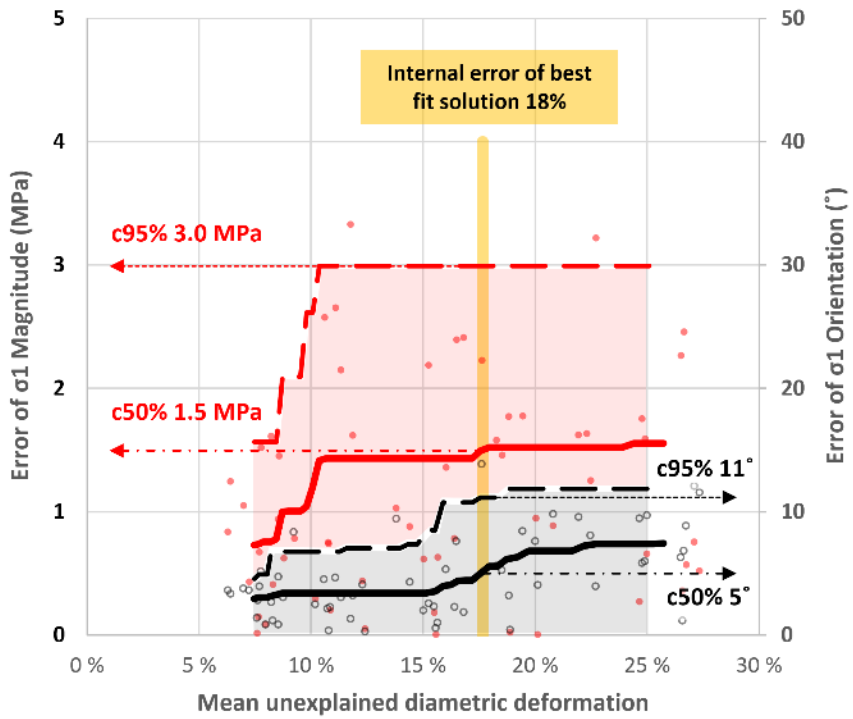
LVDT-cell Method

LVDT-CELL METHOD

- FROM EXISTING EXCAVATION OR SHAFT
- FOCUSED ON KNOWN QUALITY AND RELIABILITY



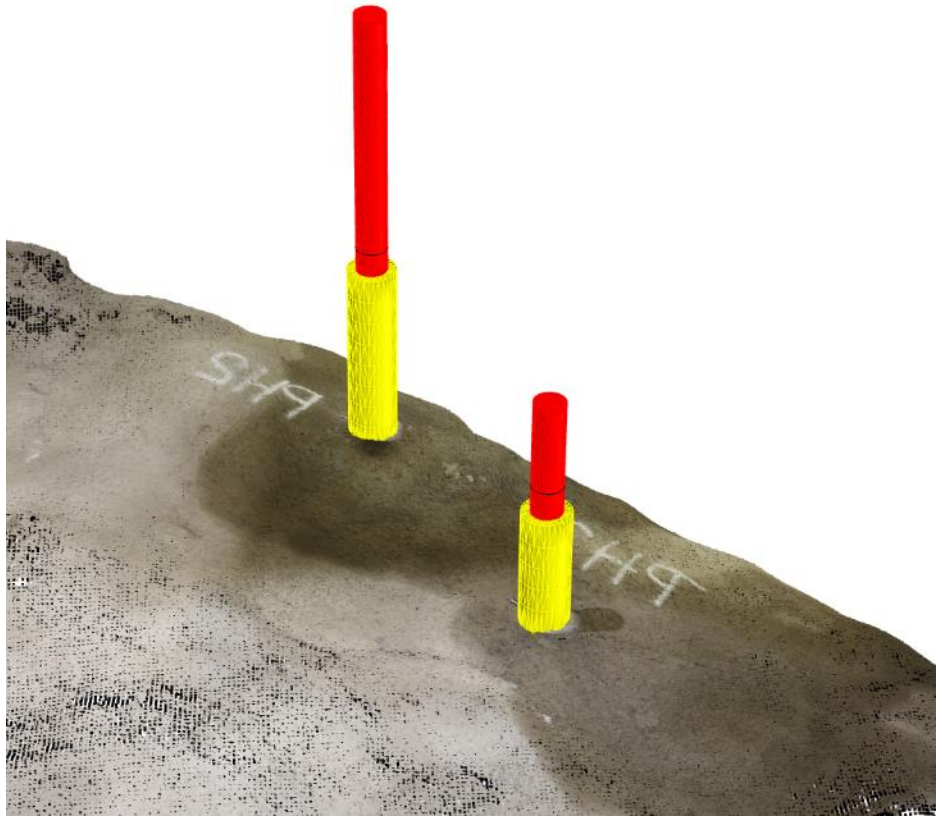


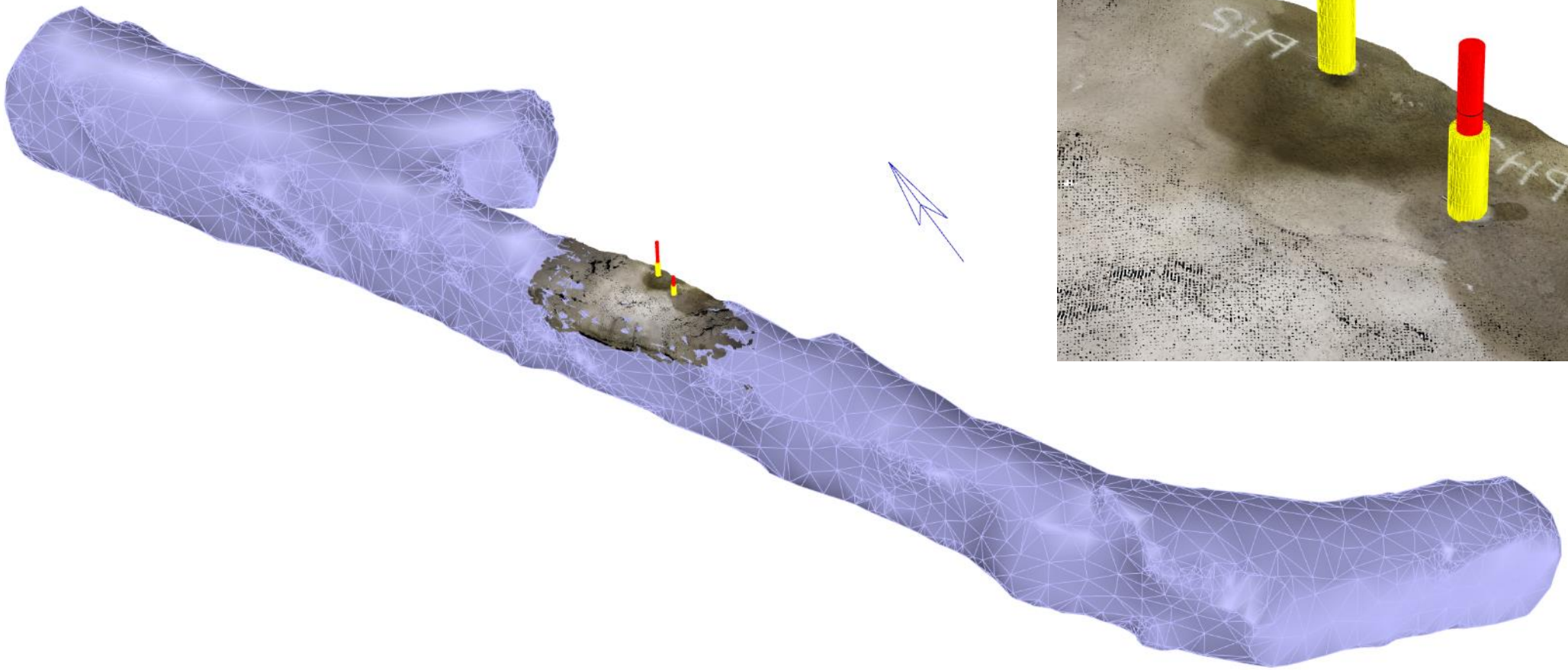


The cell

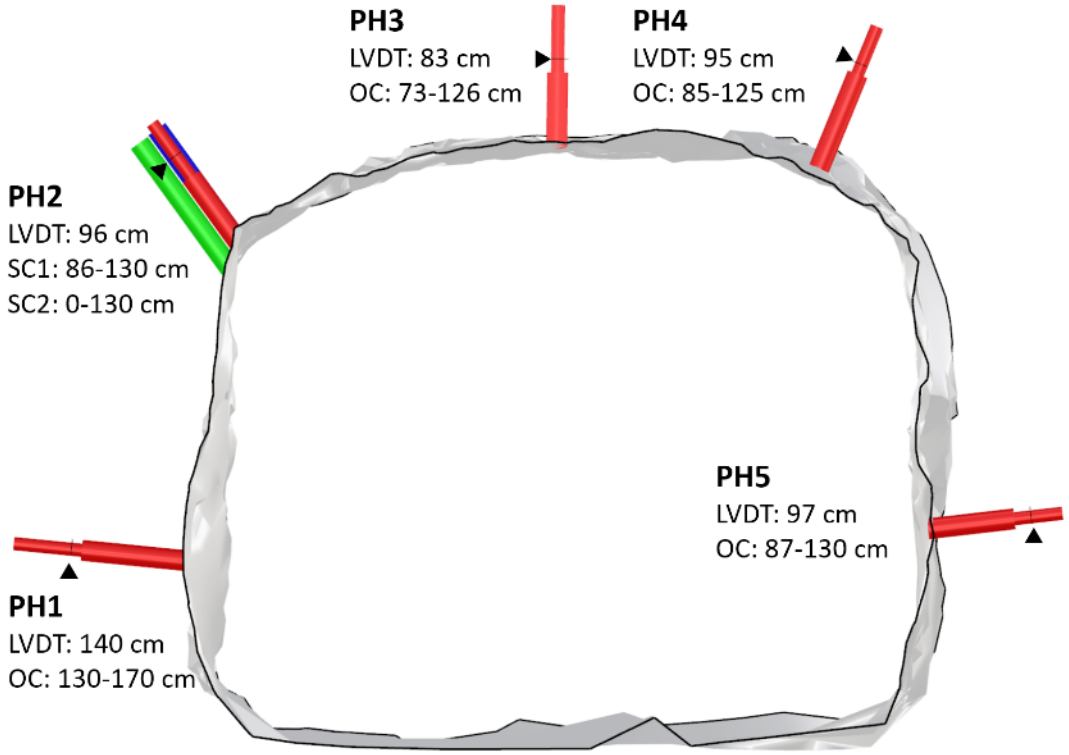
- Robust 2D-cell, which measures four diametric deformations with eight LVDT-sensors
- Mechanically mounted with expandable o-rings
- Pilot hole diameter 126 mm
- Overcoring or sidecoring diameter 200 mm
- <u>2021: New wireless version in prototype testing</u>

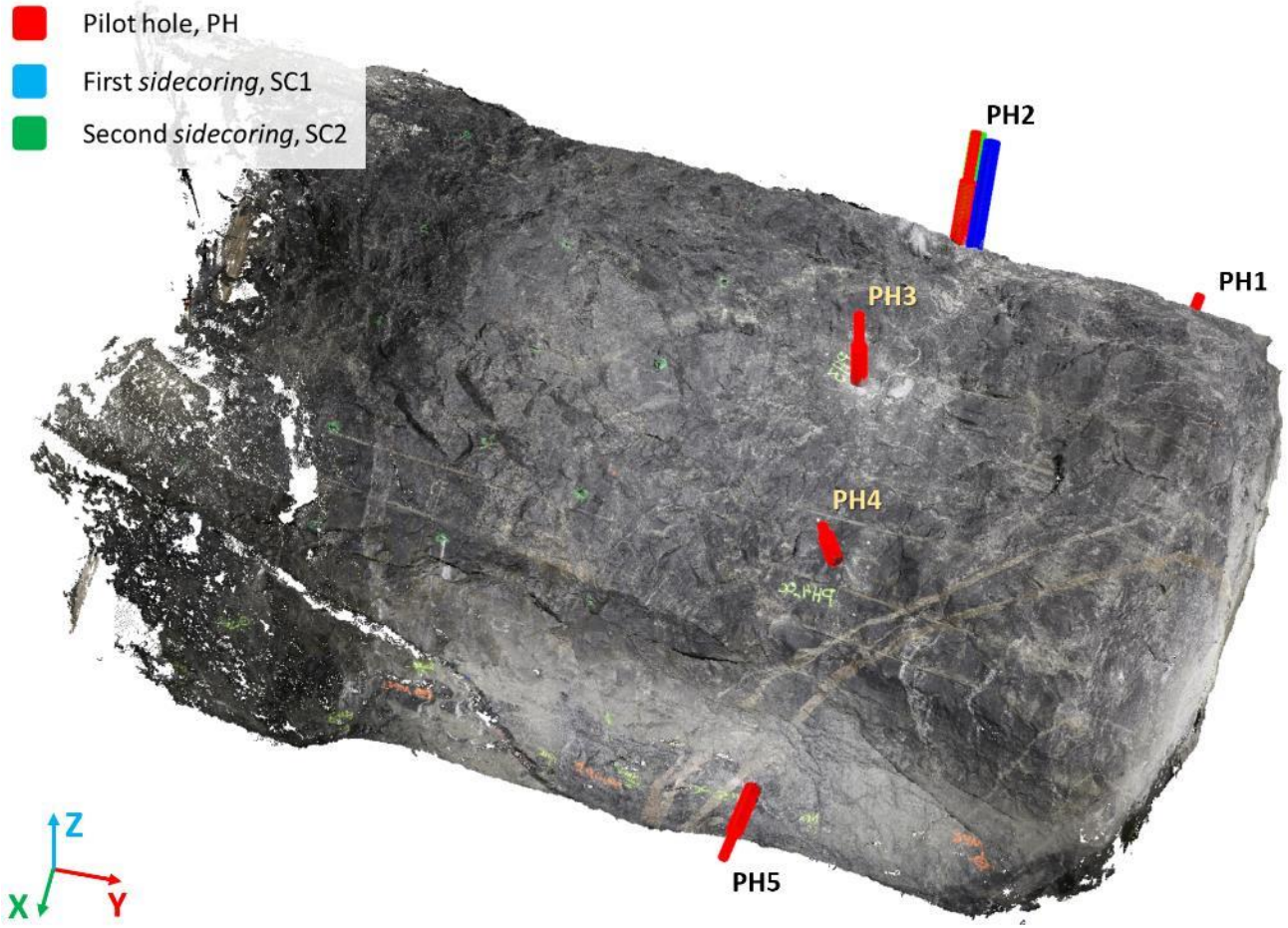
- Horizontal in situ stress magnitudes and orientation with one or two crown measurements
- two increases reliability





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





In high stress

- Overcoring doesn't work when disking takes place
- Applied inverse solution enables use of *sidecoring* -> partial stress relief
- Sidecoring works, as far as pilot hole remain stable

Disking

Two double sidecoring measurements


Borehole breakout

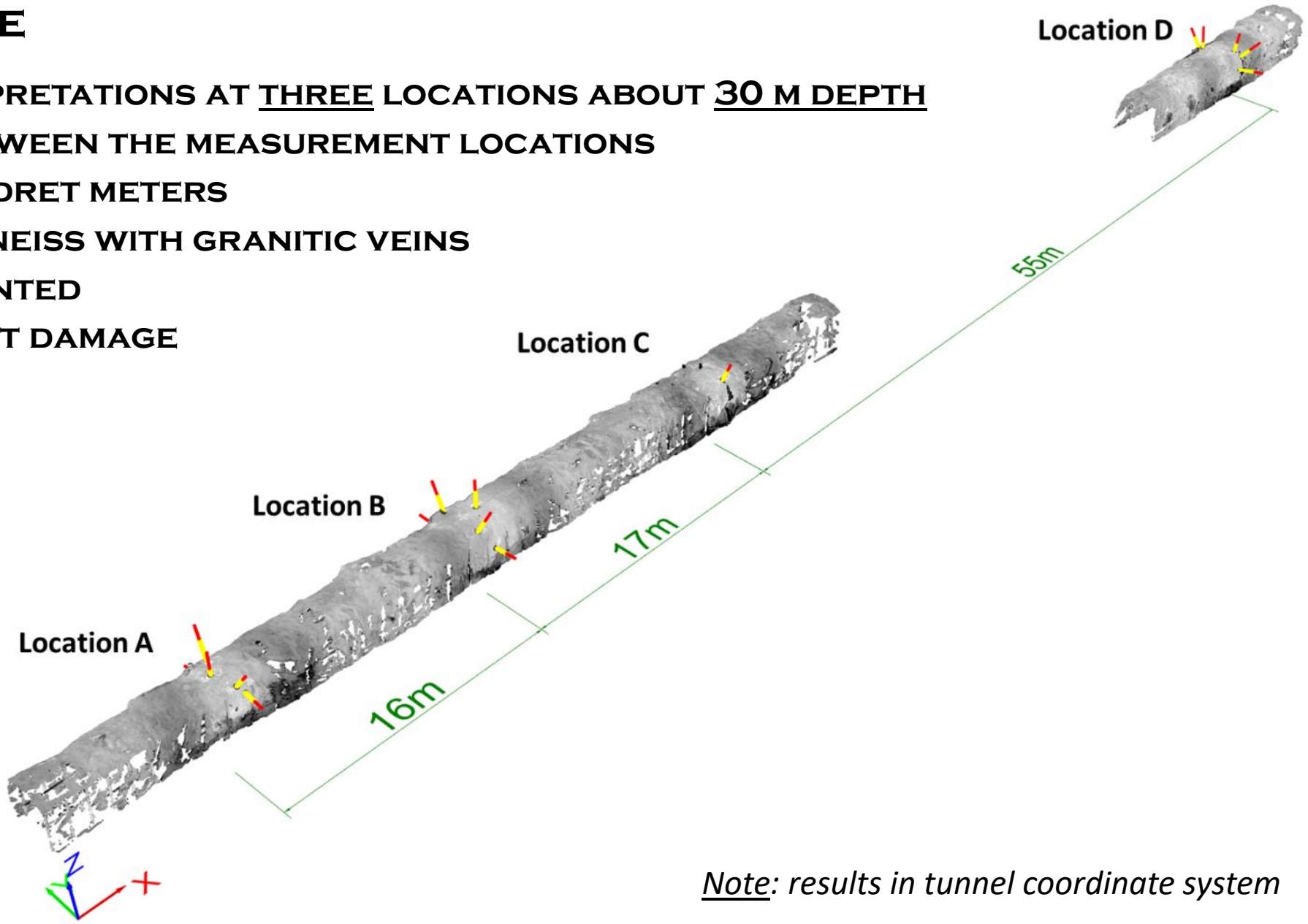
Compact drill rig

Case 1 –Shallow Measurement

Note: photo from Helsinki

Shallow depth case

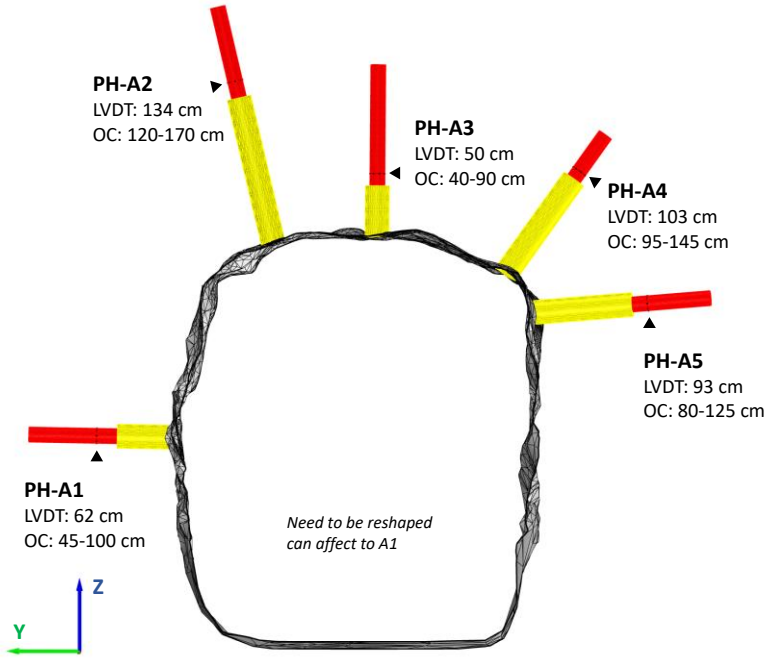
- 3D in situ stress interpretations at <u>three</u> locations about <u>30 m depth</u>
- Maximum distances between the measurement locations was less than one hundret meters
- Domiant rock type is gneiss with granitic veins
- Rock is moderately jointed
- Depth of exvation blast damage was less than 20 cm



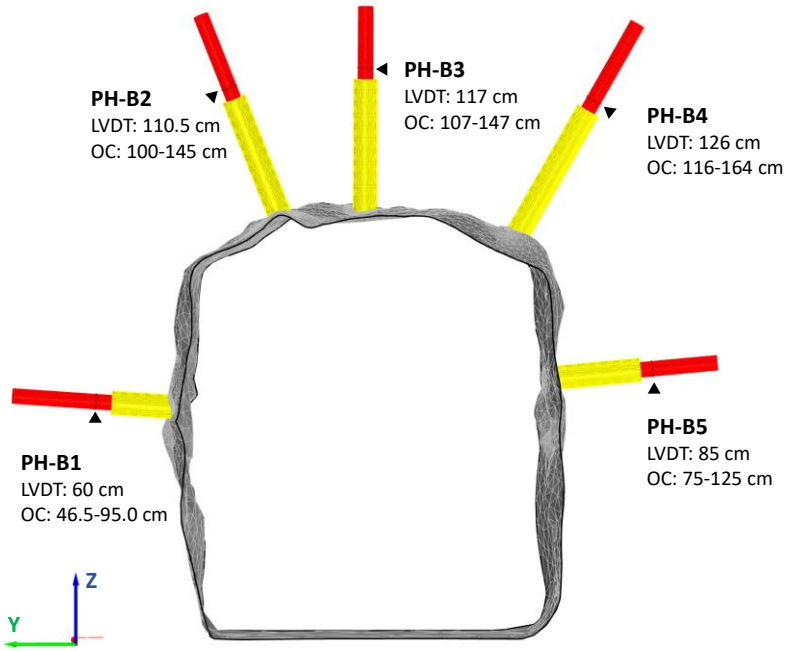
<u>Note</u>: results in tunnel coordinate system

Five overcoring measurements at each location

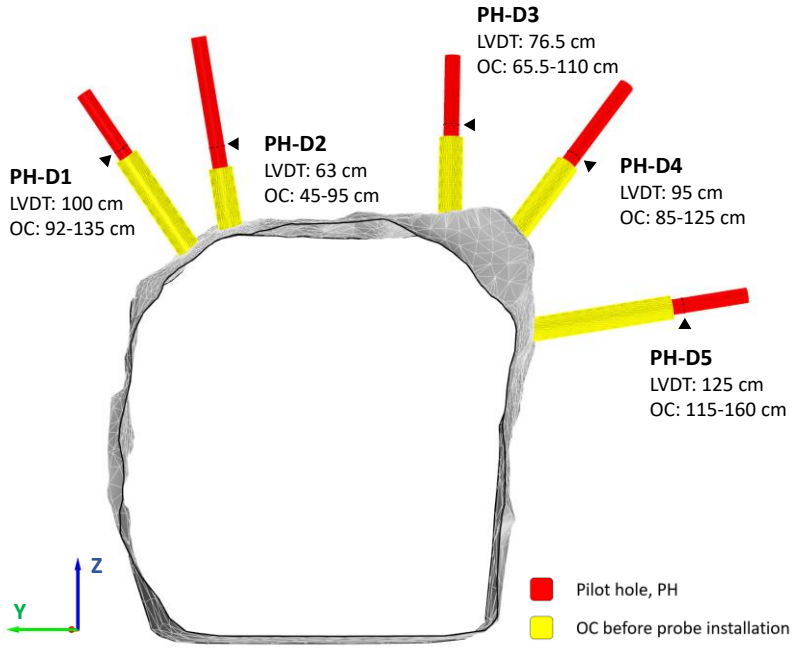
Location A



Location B

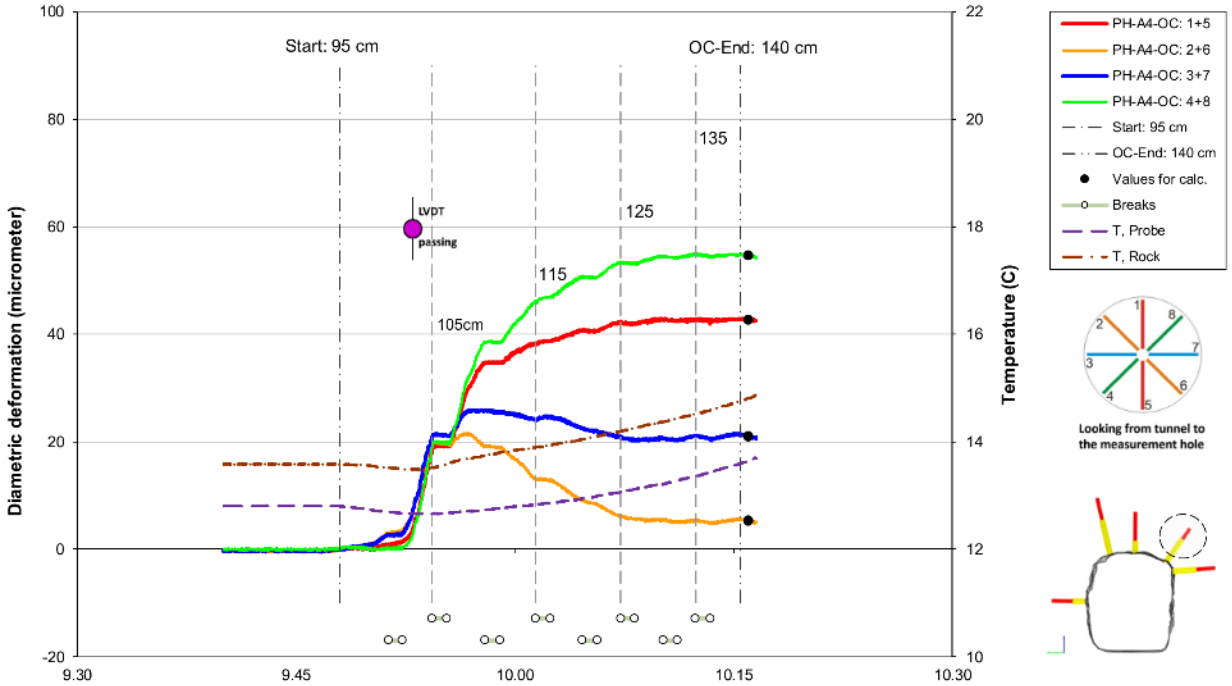


Location D



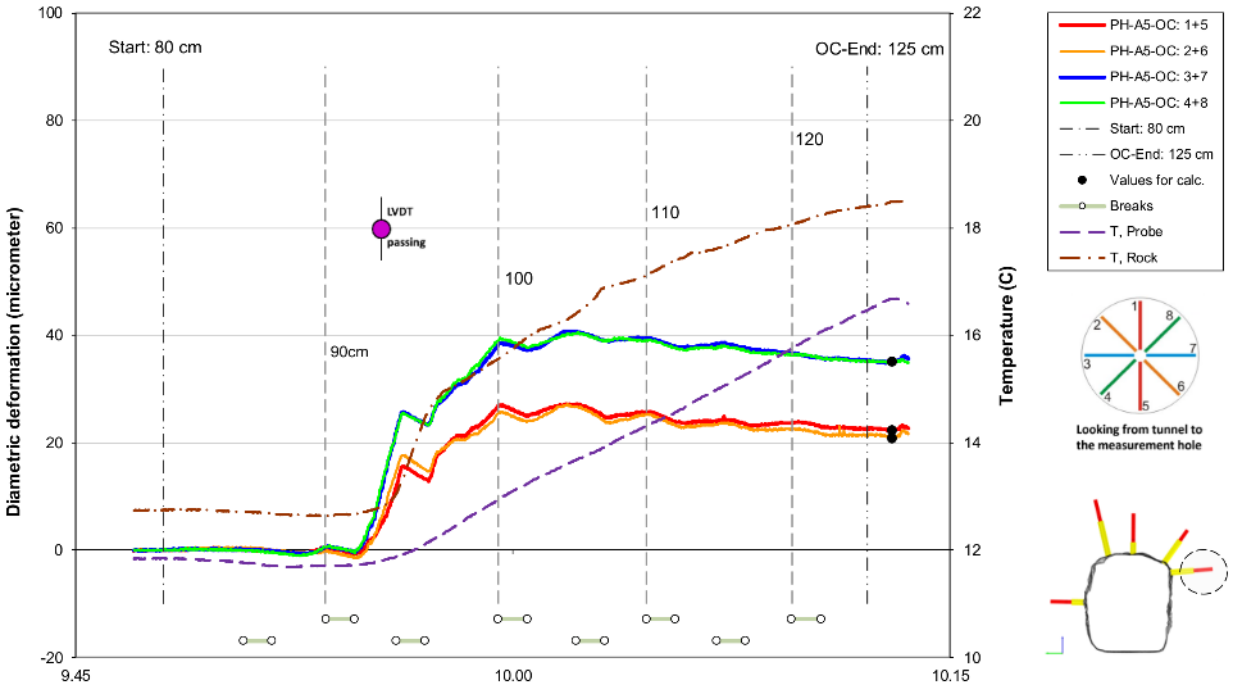
Overcoring responce: typical and the worst one

PH-A4



Time	Observation
9:48	cell stable, overcoring started, advance 95 cm = 0
9:51-10:13	8 * coring advance recording
10:16	OC finished, advance 140 cm
10:37	logging paused for data saving
10:50	logging restarted, 'warming' of electronics during next 15 min
16:30	logging stopped

PH-A5

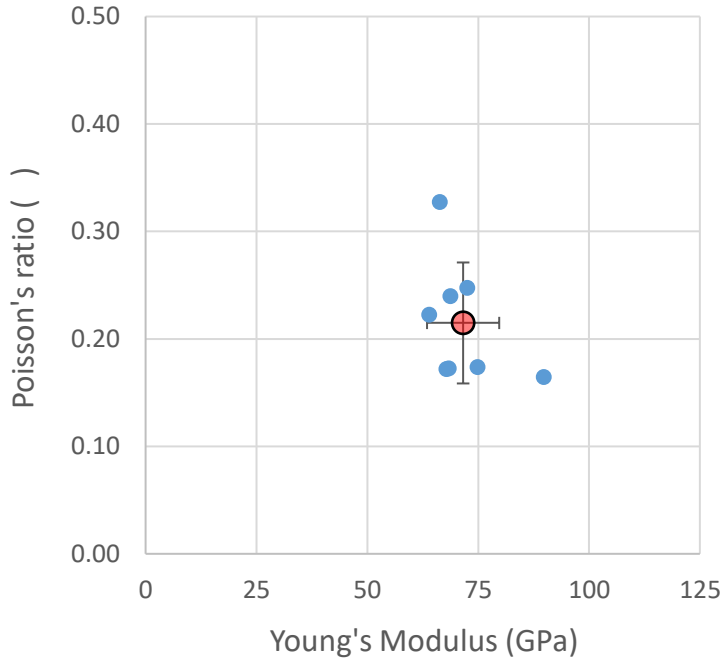


Time	Observation
9:48	cell stable, overcoring started, advance 80 cm = 0
9:50-10:10	8 * coring advance recording
9:50 +	High rate drifting initiated in all convergences, drifting rate decreases with advancing coring, most probable due to high temperature increase
10:13	OC finished, advance 125 cm
10:32	logging paused for data saving
10:44	logging restarted 'warming' of electronics during next 15 min
9:16 +1d	logging stopped on next morning

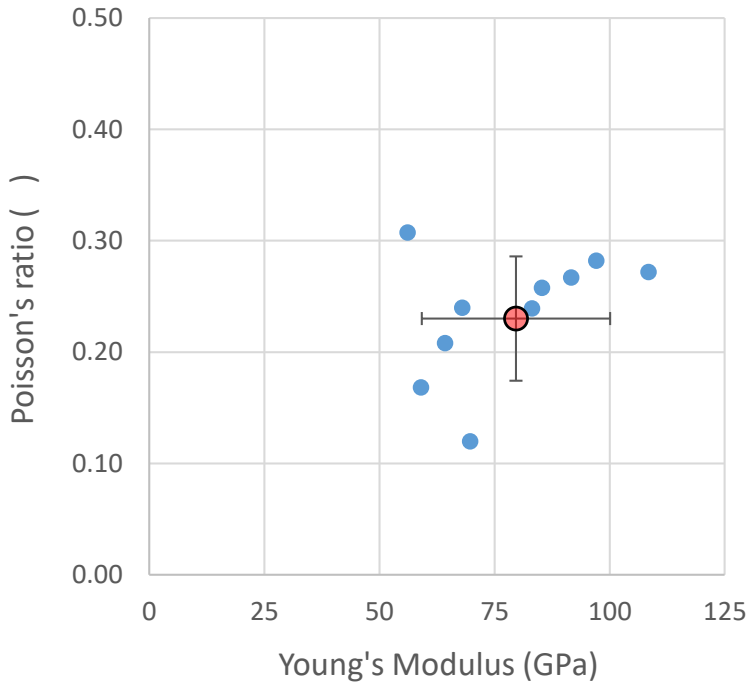
Testing for elastic properties

- Uniaxial compression of 120 mm pilot cores
- Generally, as here, heterogeneous approach is preferred

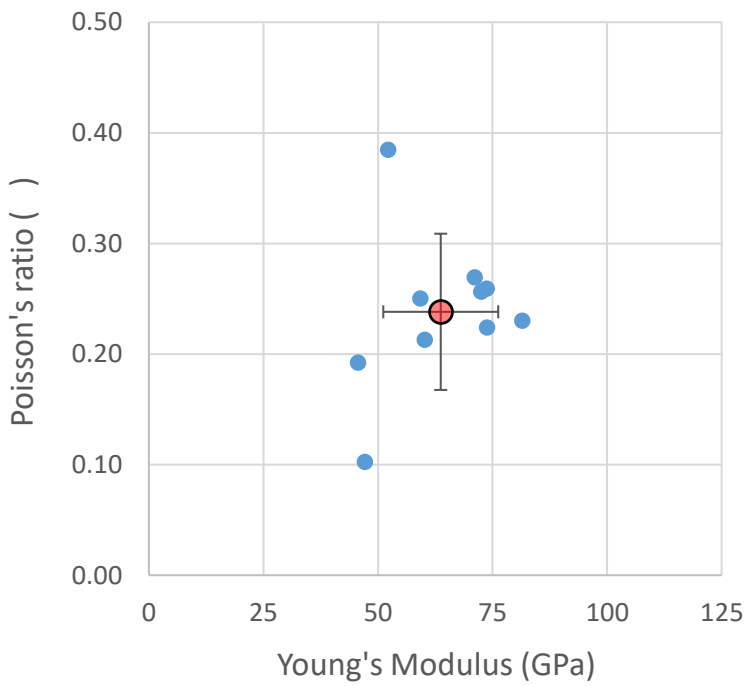
Location A



Location B

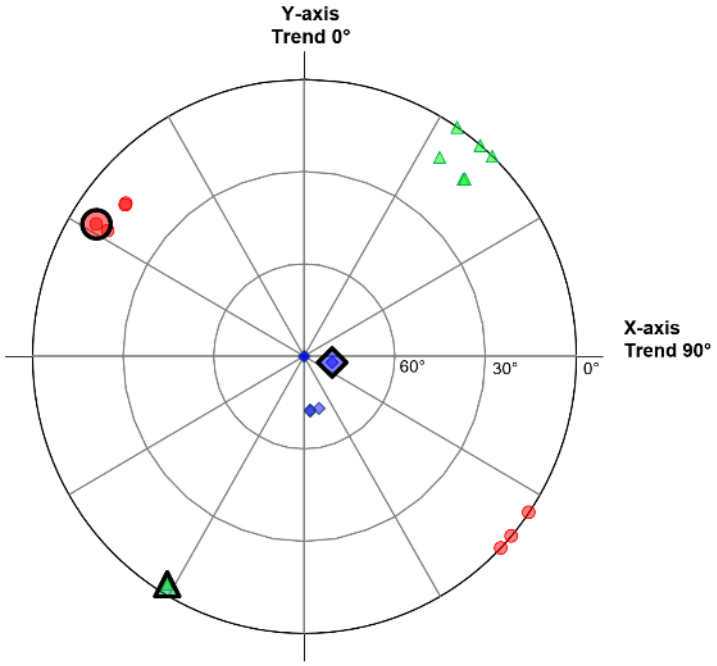


Location D



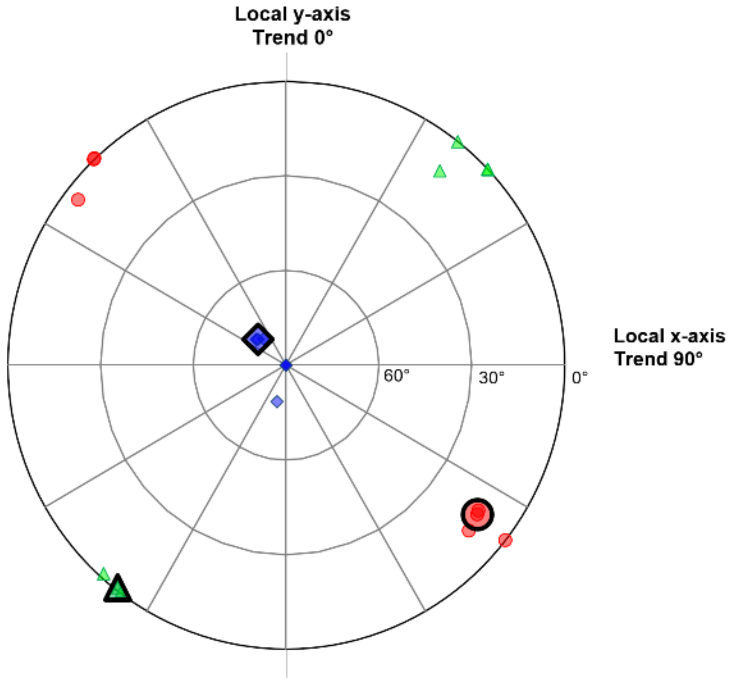
Results – Best fit and other solutions for principal Stresses

Location A



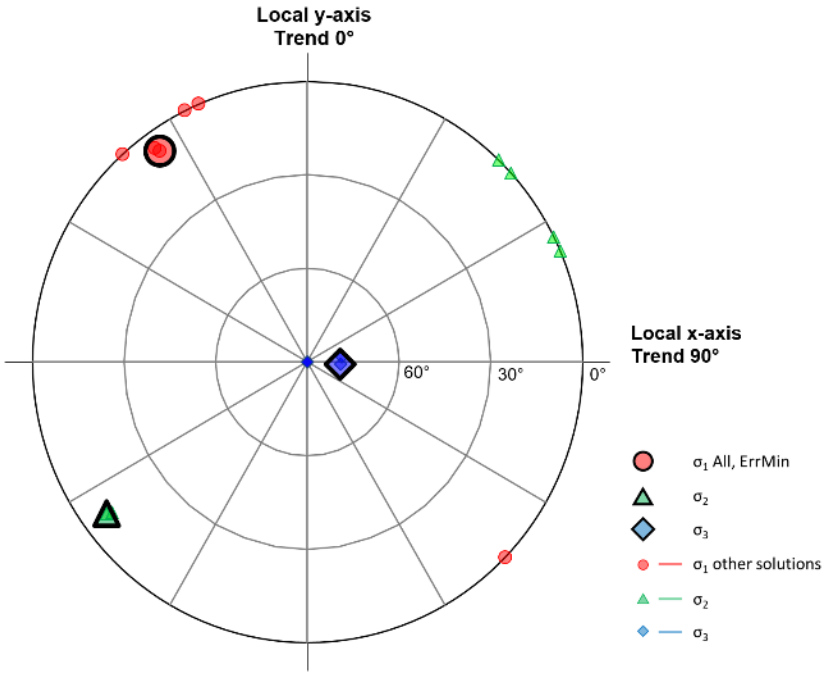
	mag	bear.	dip
σ1	13.7	302	9
σ2	8.0	212	3
σ3	3.3	102	80
σH	**13.4**	**122**	
σh	**8.0**	**212**	

Location B



	mag	bear.	dip
σ1	15.5	127	12
σ2	8.3	218	1
σ3	1.4	312	78
σH	**14.9**	**127**	
σh	**8.3**	**217**	

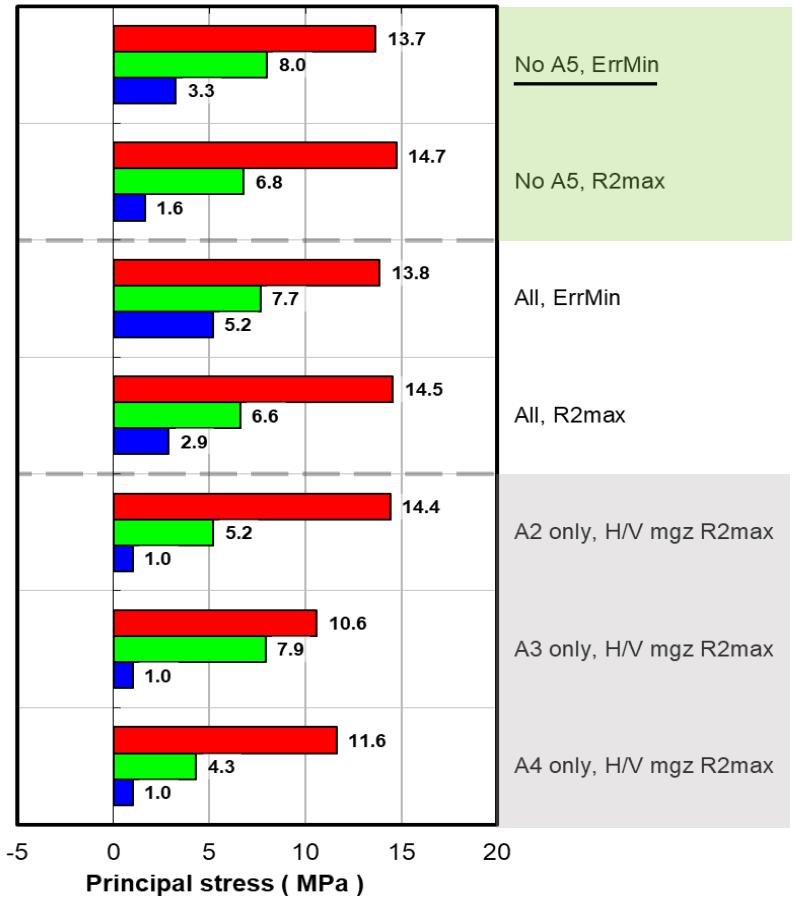
Location D



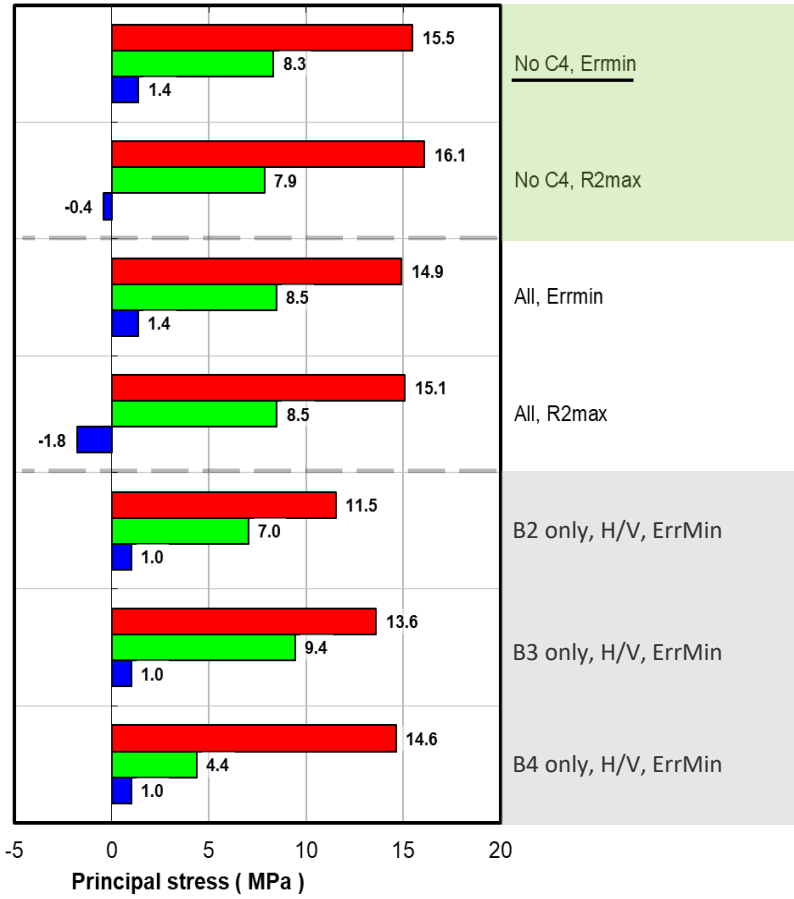
	mag	bear.	dip
σ1	14.1	325	7
σ2	7.0	233	8
σ3	0.4	94	79
σH	**13.9**	**145**	
σh	**6.8**	**235**	

- # Results – Best fit and other solutions for principal Stresses

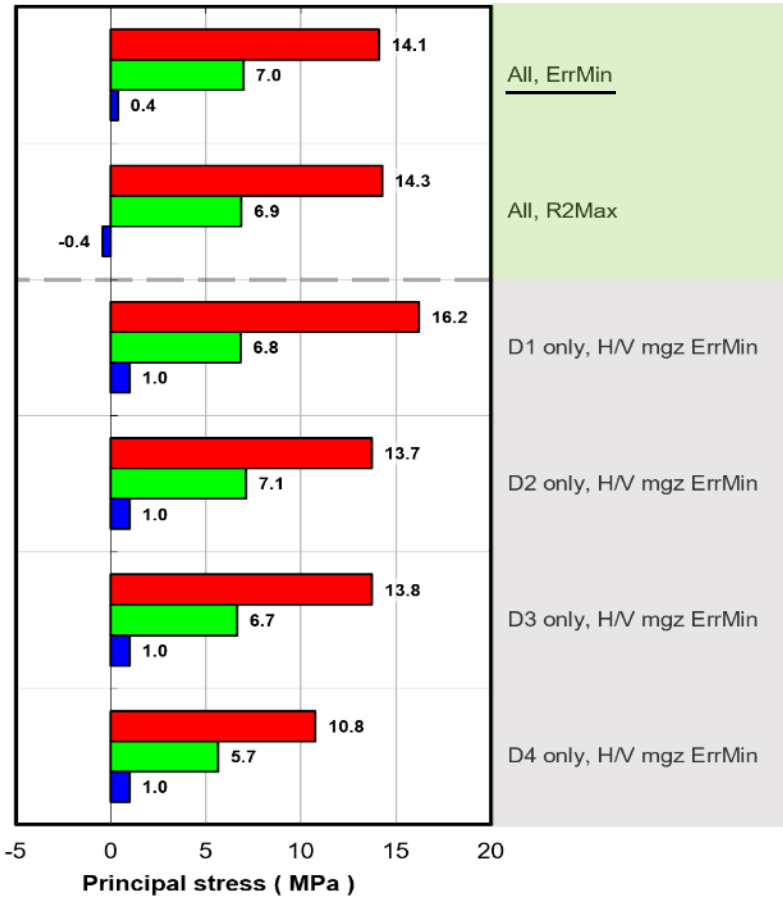
Location A



Location B



Location D



ErrMin: *best fit solution minimizing error between measured and simulated convergences*
R2max: *best fir solution maximizing the coefficient of determination*
H/V: *best fir solution for horizontal stress components only*

Error study

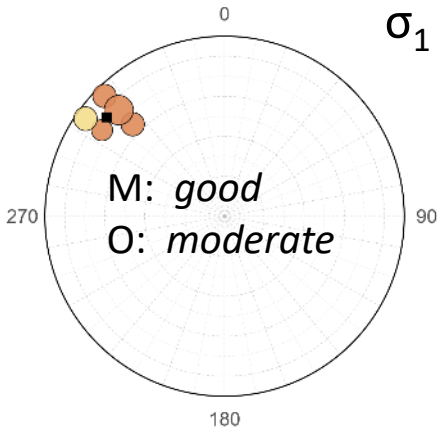
- Reliability of resulting stress state based on 60-100 realizations with internal error less than or equal compared to best fit solution
- Magnitude (MPa)
  - [−5,0]
  - (0,5]
  - (5,10]
  - (10,15]
  - (15,20]

Principal stress

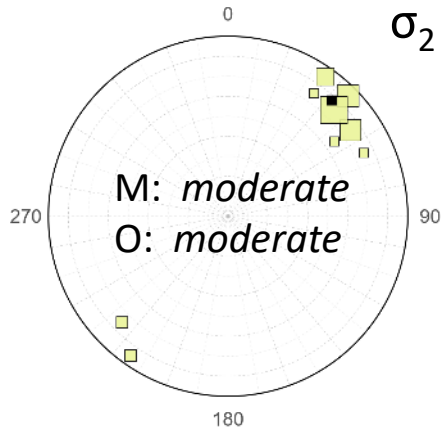
- S1
- S2
- S3

Location A

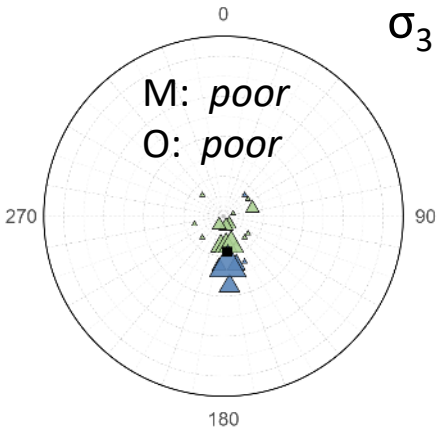
Percentile, %
10
20



σ_1



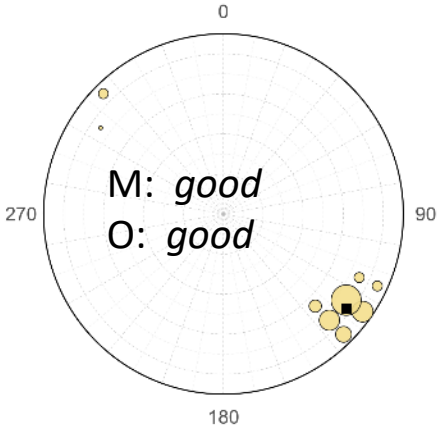
σ_2

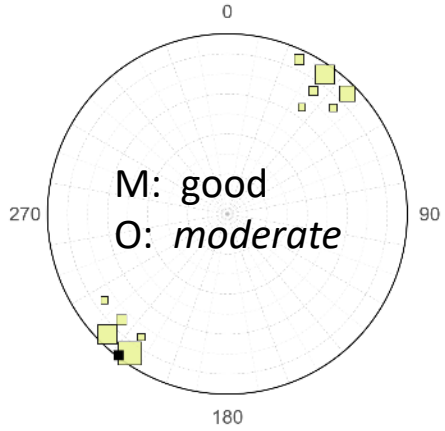


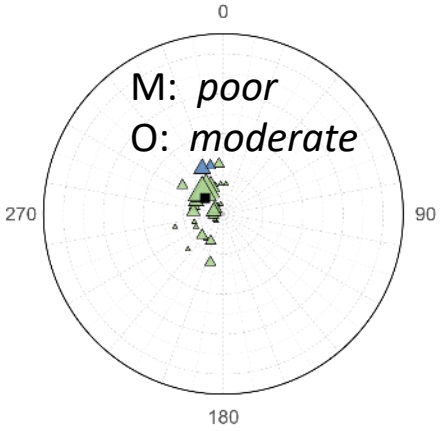
σ_3

Location B

Percentile, %
10
20
30

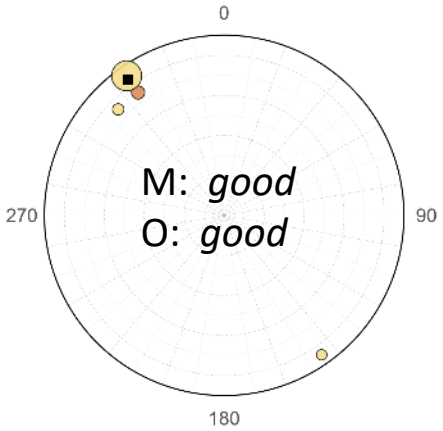


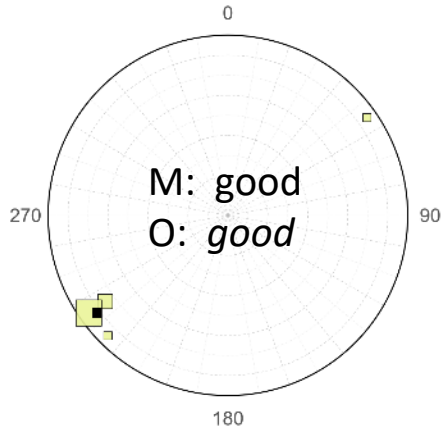


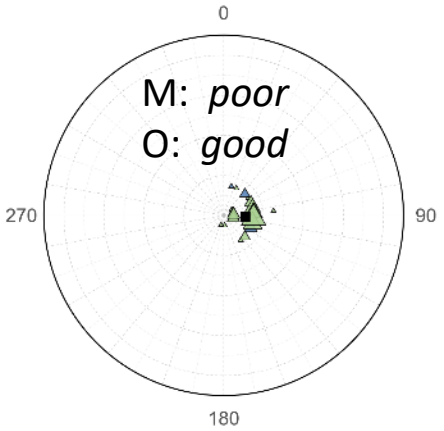


Location D

Percentile, %
20
40
60







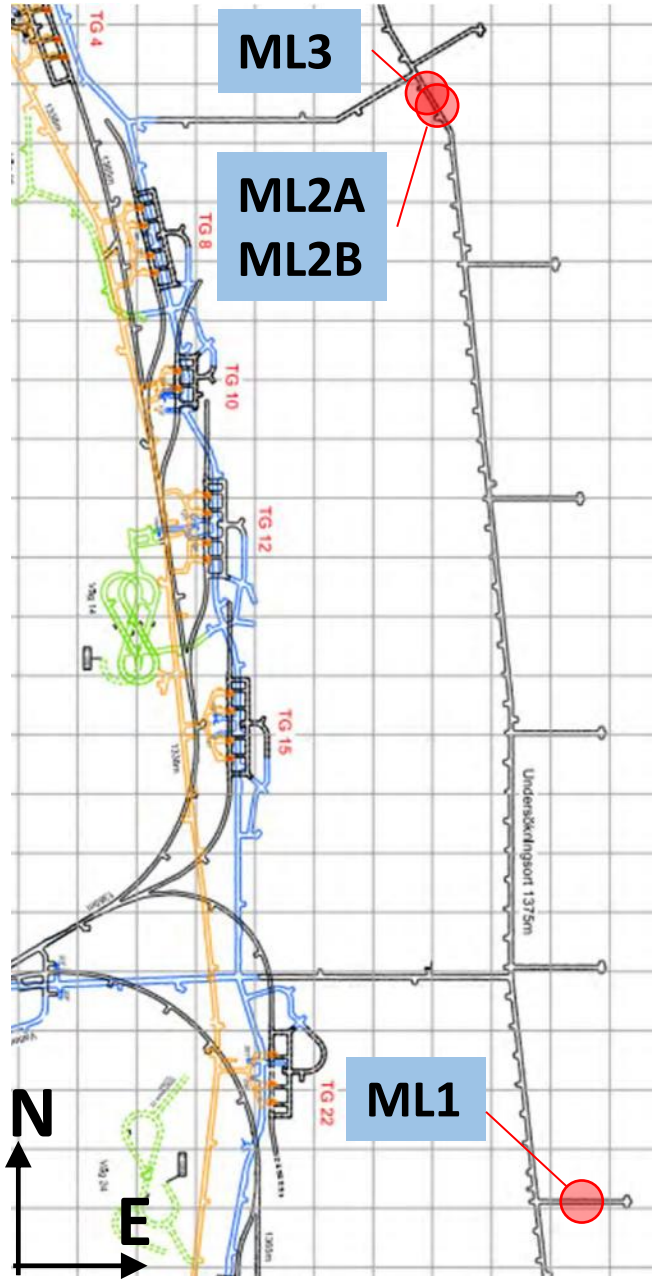
Result– recommendation for future use

- Horizontal/vertical aligned in situ stress state
- Vertica stress equal to weight of overburden
- 95% confidence limits for horizontal stress magnitudes and orientations

σ_1 =	σ_H =	13.9 MPa ±2.8 MPa,	trend 145° ± 7°, *clockwise from local y-axis*
σ_2 =	σ_h =	0.5 σ_H, 0.43 σ_H to 0.56 σ_H,	trend = trend(σ_1)-90° and
σ_3 =	σ_V =	mgz = 0.9 MPa	= 0.027 MPa/m * 35 m

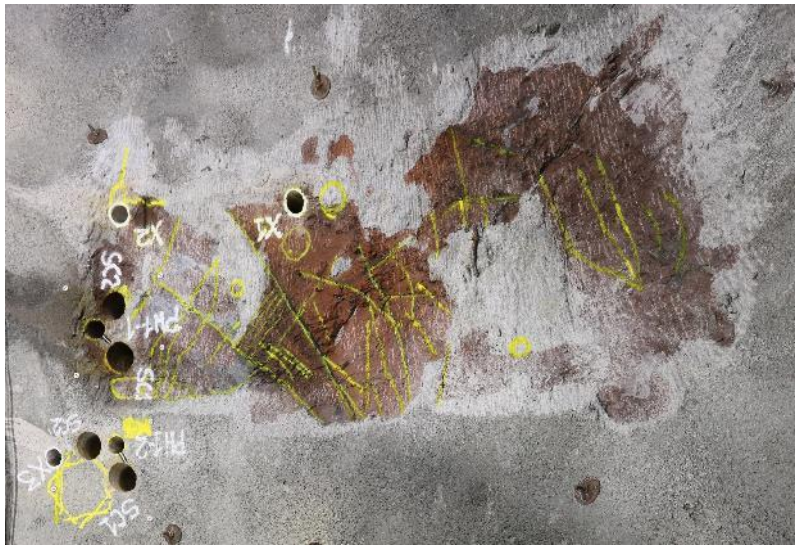
Case 2 – Deep measurement

Measurements for horizontal in situ stresses at three loactions in LKAB Kiruna mine at 1375 level



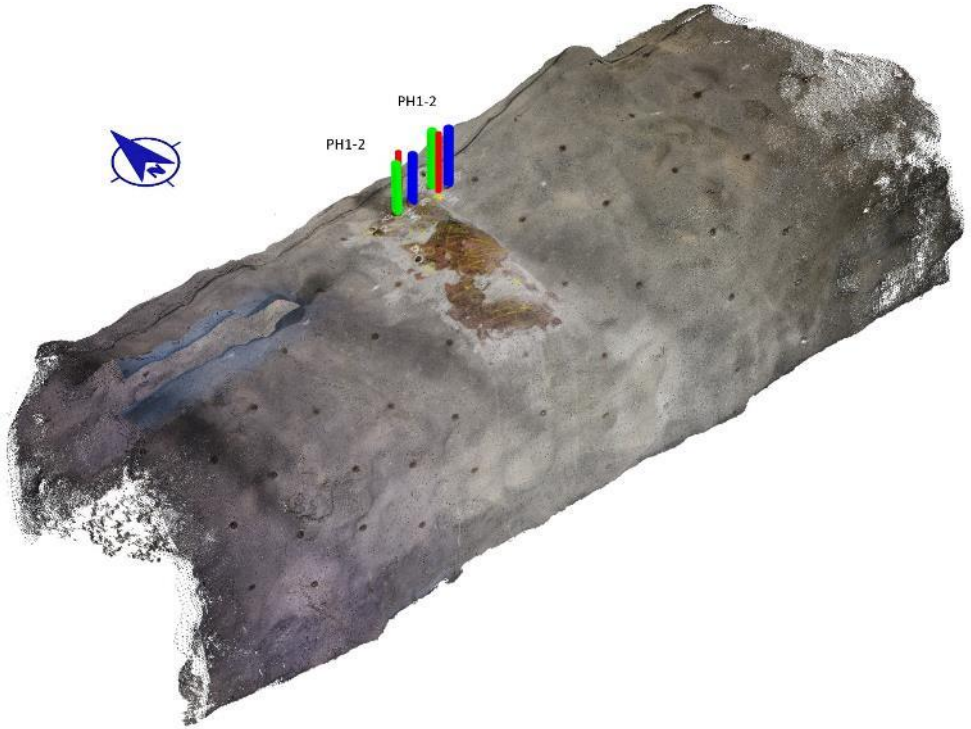
ML3: thin sprayed concrete, easy to find installation locations

ML1: Densely fractured
- *very hard to find installation location*



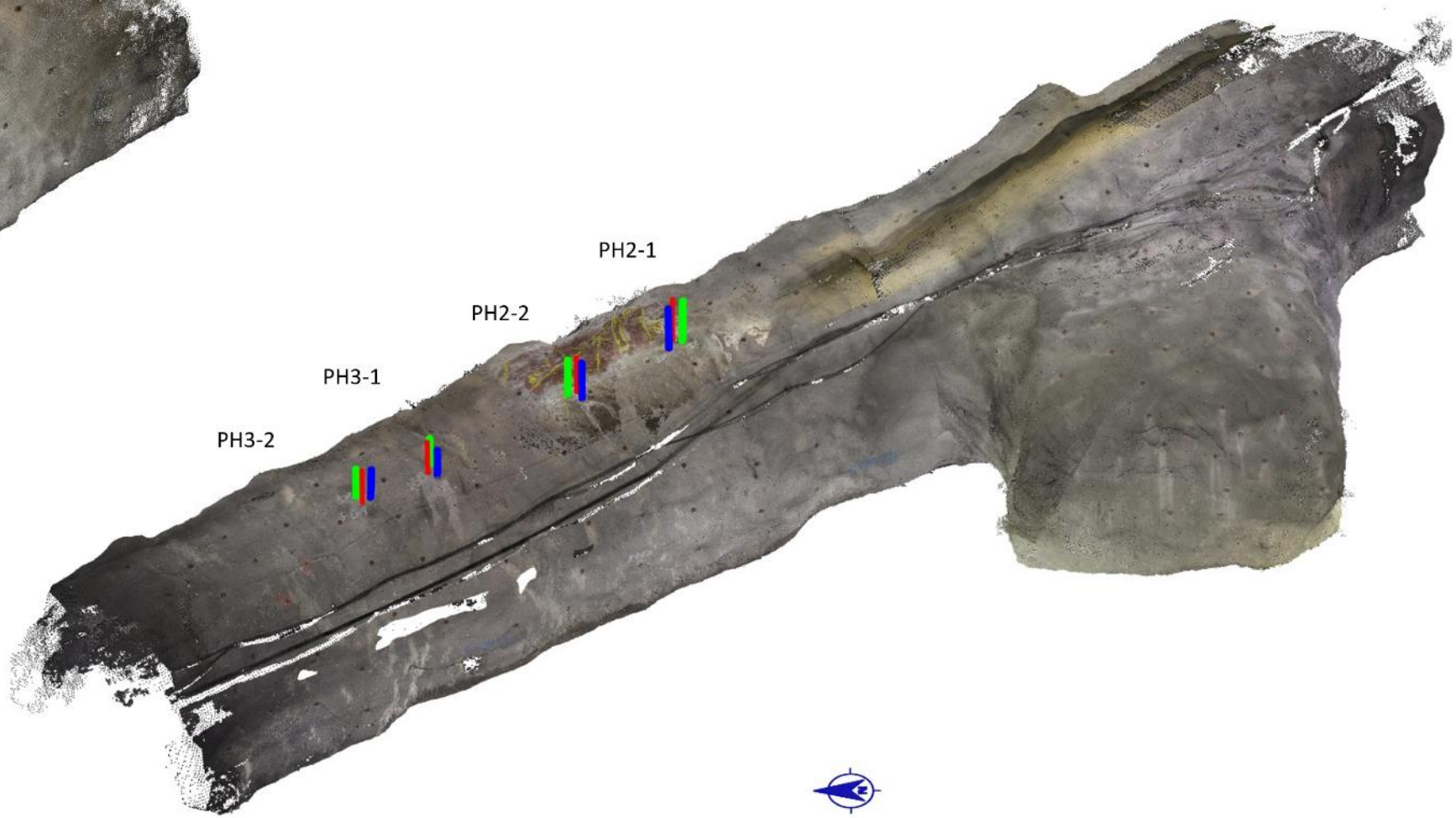
ML2: Sparse to moderate fracture spacing, easy to find installation locations

ML1: two *doble sidecoring* measurements

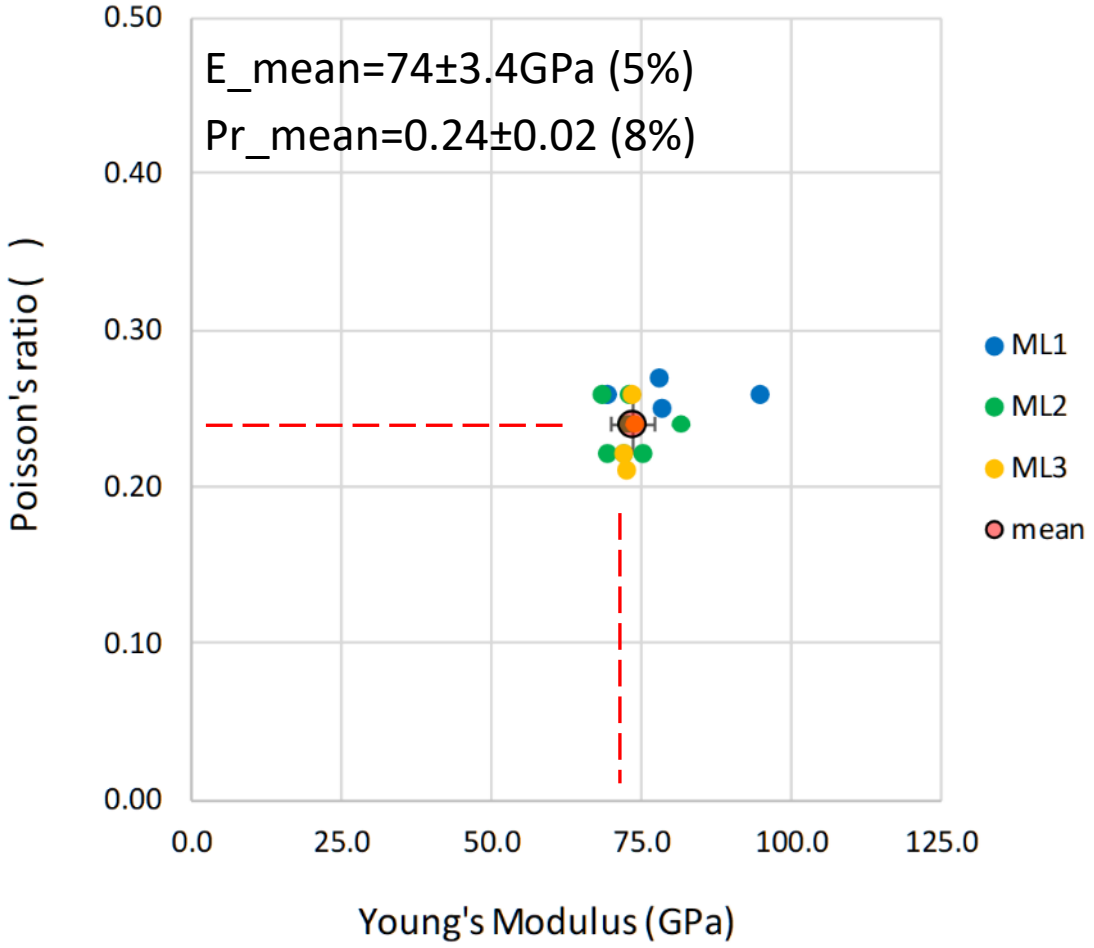


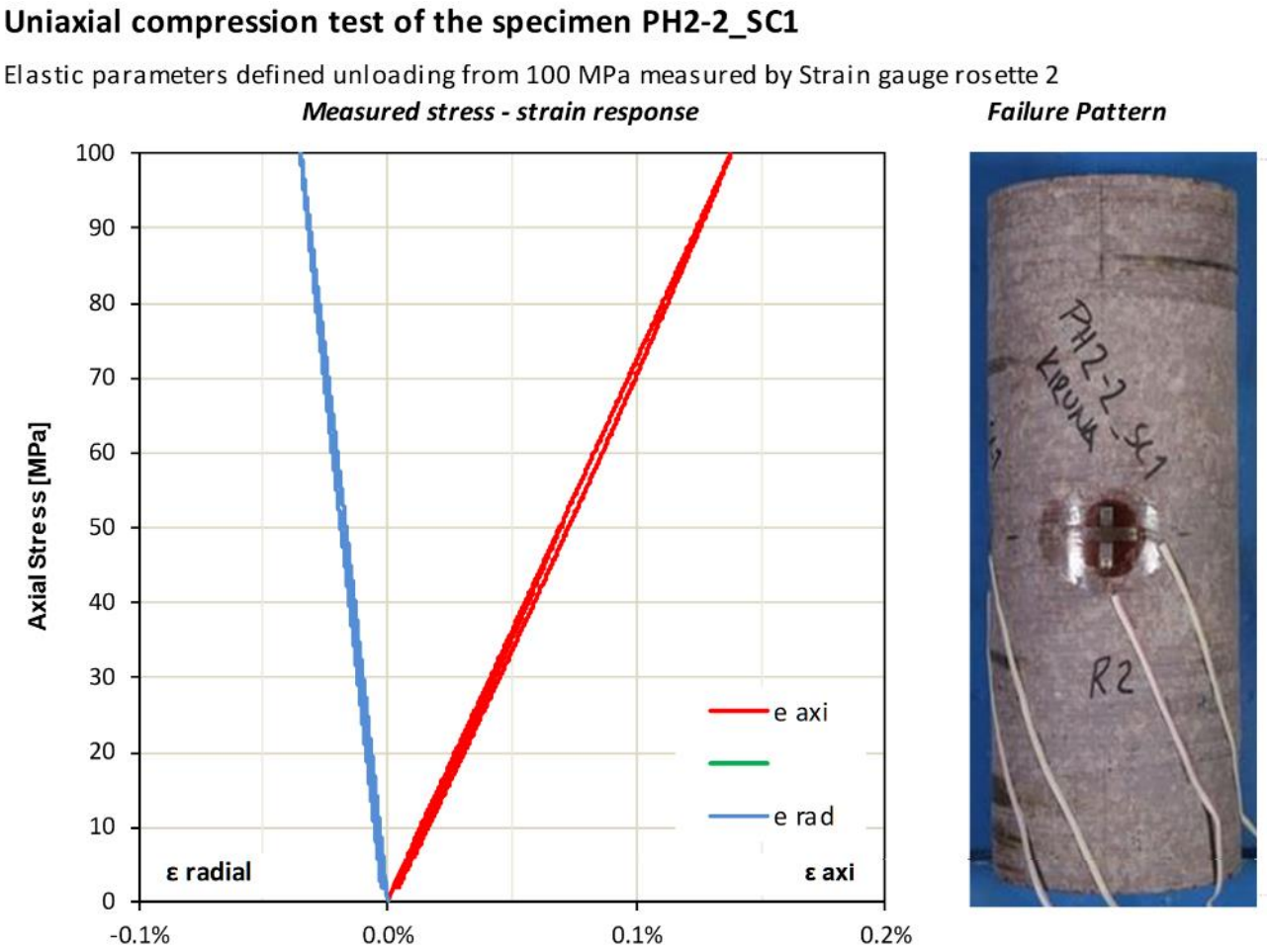
ML2: four *doble sidecoring* measurements, at two depths

ML3: two *doble sidecoring* measurements

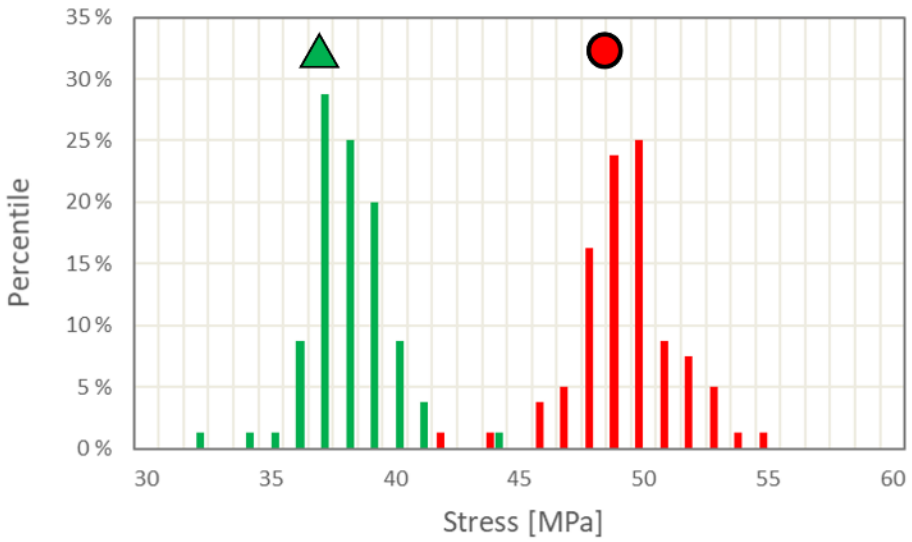


Elastic parameters

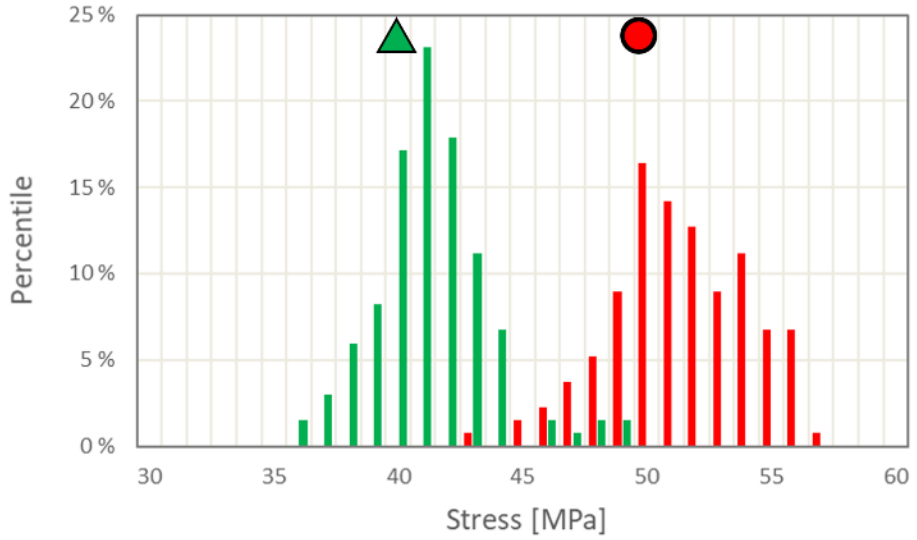




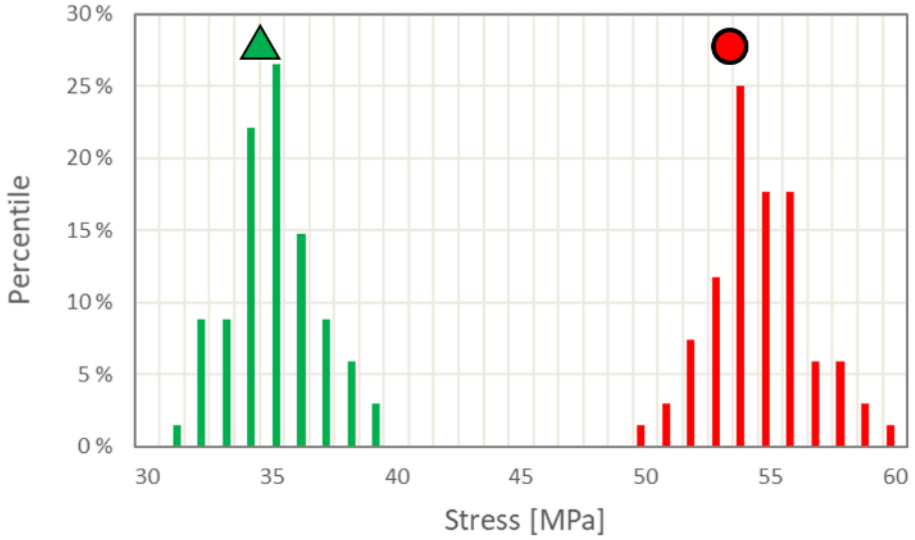
ML2A - measurement depth: 85-87 cm



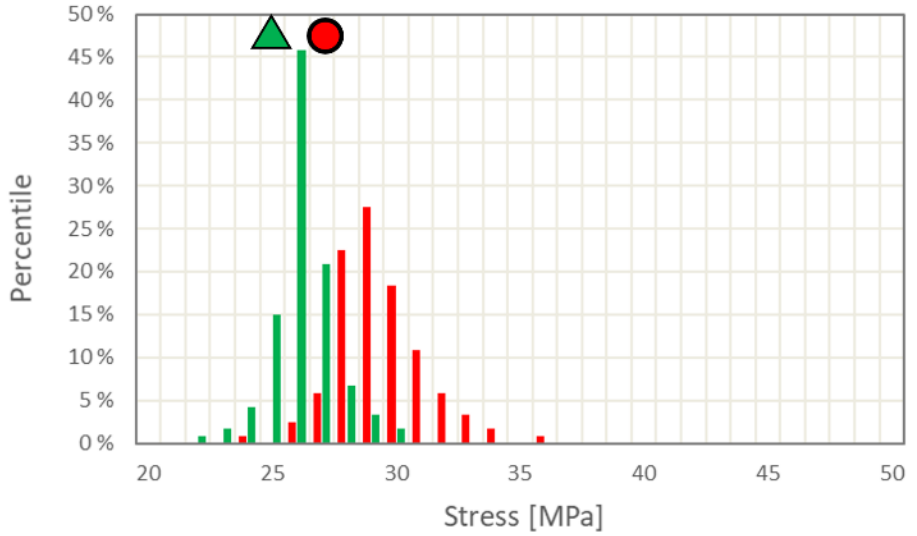
ML2B - measurement depth: 132-145 cm



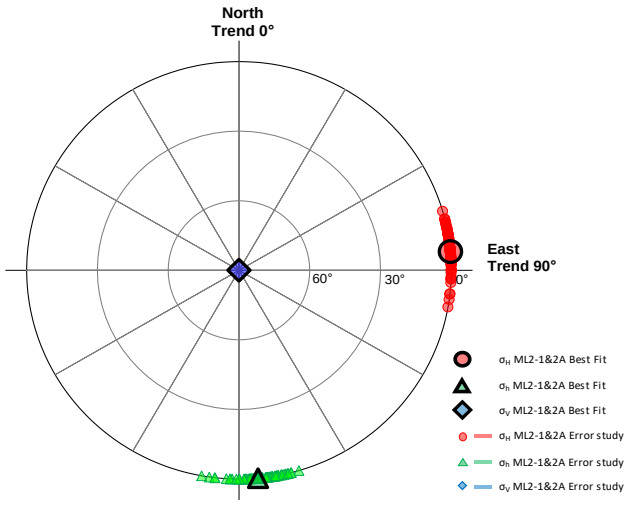
ML3 - measurement depth: 88-93 cm



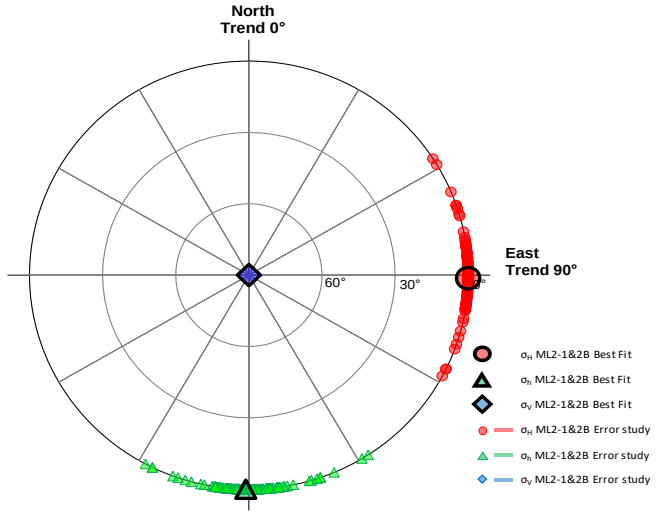
ML1



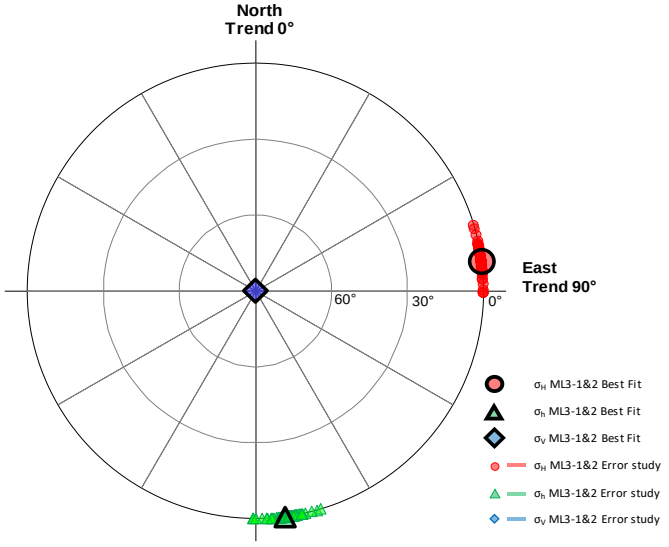
ML2A - measurement depth: 85-87 cm



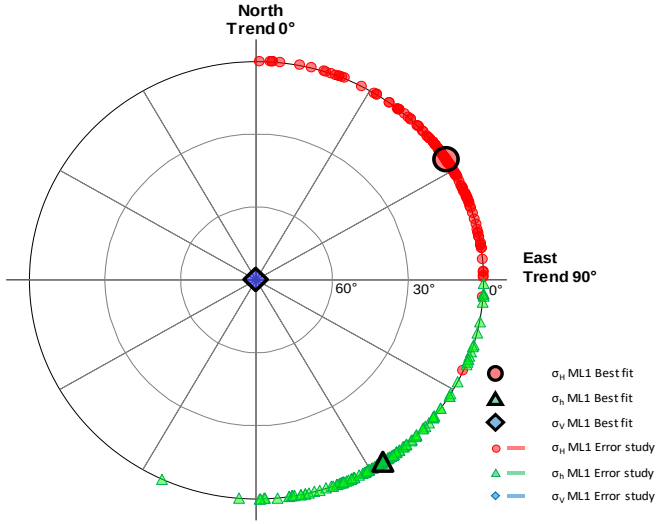
ML2B - measurement depth: 132-145 cm



ML3 - measurement depth: 88-93 cm



ML1



RANKING OF DATA AND SOLUTIONS

ML2A - measurement depth: 85-87 cm

	Value	95% C.L.	*Reliabilitity*
Field data			*good*
Elastic parameters			*good*
Stress solution			
σ_H [MPa]	48.3	±5.8	*good*
σ_h [MPa]	37.1	±5.9	*good/moderate*
Trend of σ_H [˚]	85	±13	*good*
CoD	0.97		
Overall			***good***

ML2B - measurement depth: 132-145 cm

	Value	95% C.L.	*Reliabilitity*
Field data			*good*
Elastic parameters			*good*
Stress solution			
σ_H [MPa]	49.9	±6.4	*good*
σ_h [MPa]	40.4	±7.6	*moderate*
Trend of σ_H [˚]	91	±33	*poor*
CoD	0.92		
Overall			***moderate - poor***

ML3 - measurement depth: 88-93 cm

	Value	95% C.L.	*Reliabilitity*
Field data			*good*
Elastic parameters			*good*
Stress solution			
σ_H [MPa]	54	±5.3	*good*
σ_h [MPa]	34.6	±3.7	*good*
Trend of σ_H [˚]	83	±8	*good*
CoD	0.99		
Overall			***good***

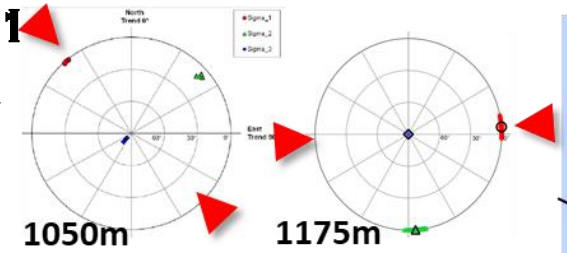
ML1

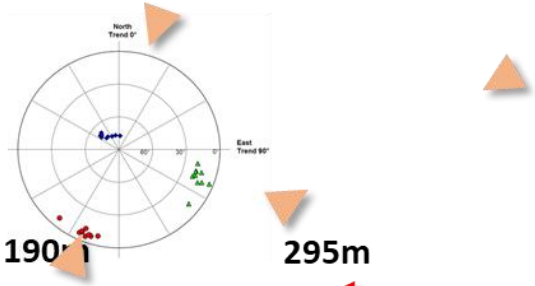
	Value	95% C.L.	*Reliabilitity*
Field data			*good/moderate*
Elastic parameters			*good*
Stress solution			
σ_H [MPa]	27.6	±6.4	*moderate*
σ_h [MPa]	25.3	±4.2	*moderate*
Trend of σ_H [˚]	56	±61	-
CoD	0.96		
Overall			***moderate***

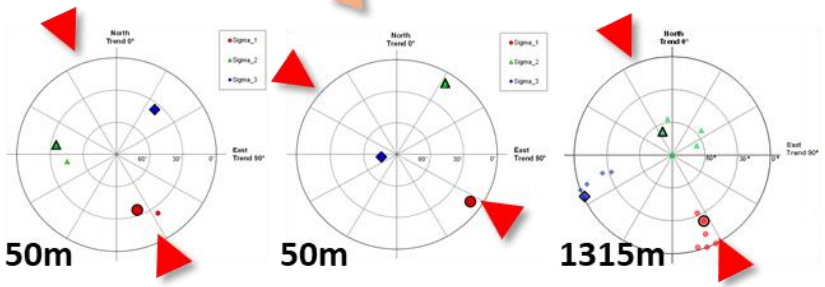
Major princial stress orientation in Scandinavia based on LVDT-measurements

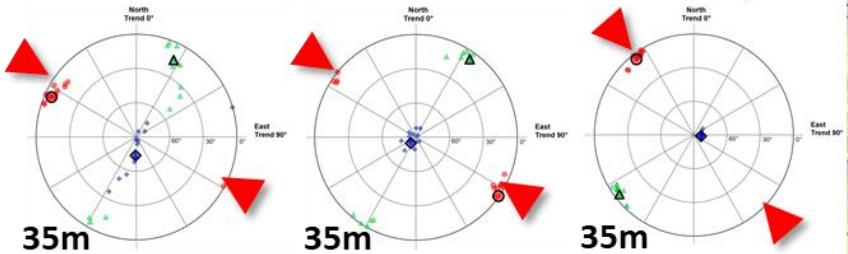
LVDT Measurements 2009–2021

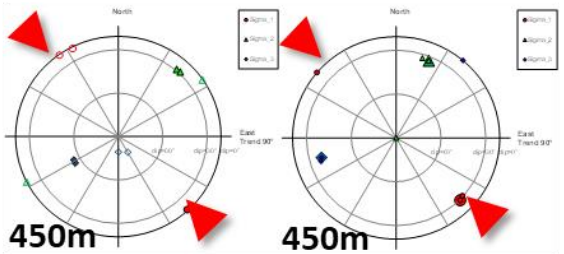
- *Few Helsinki measurements missing*

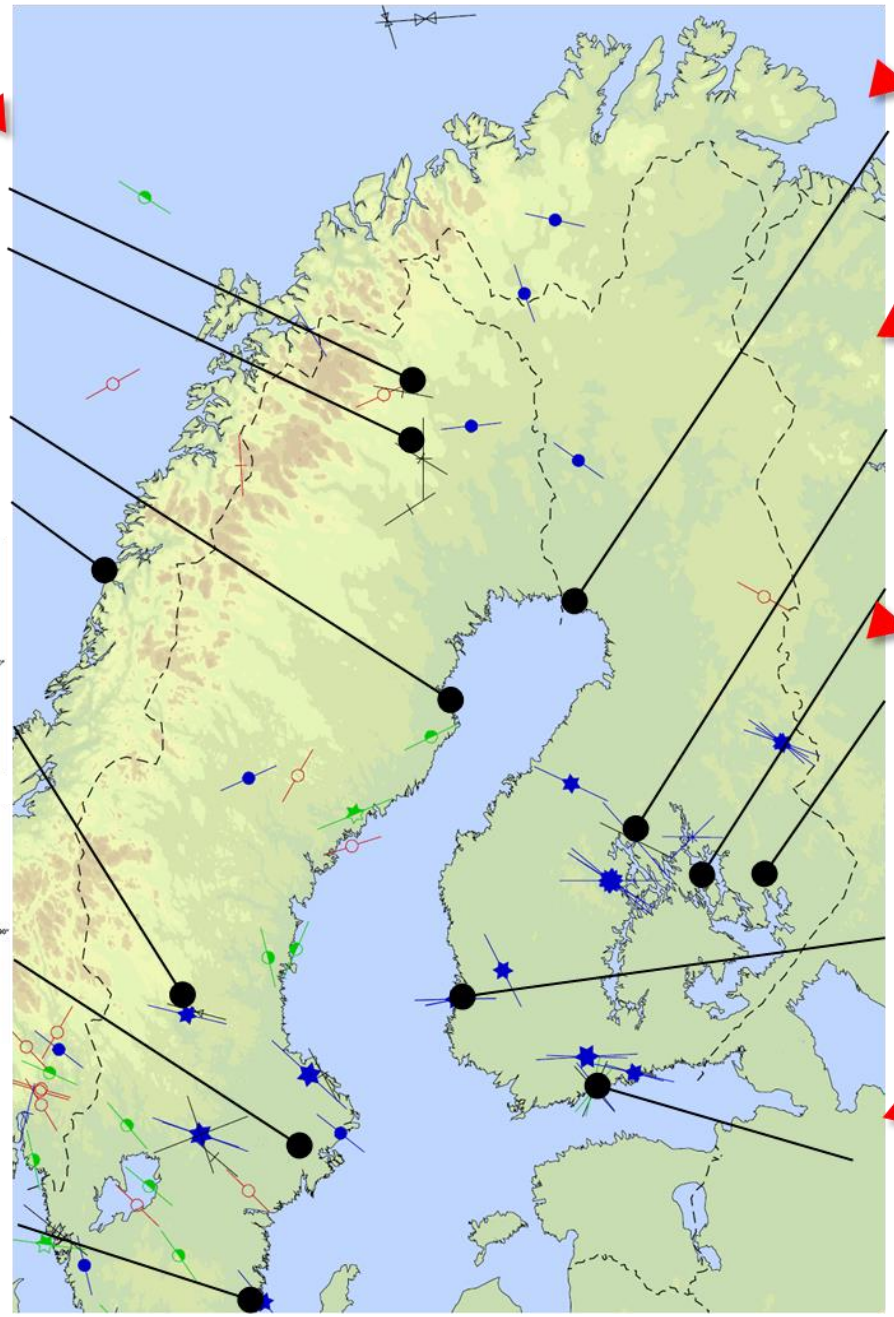


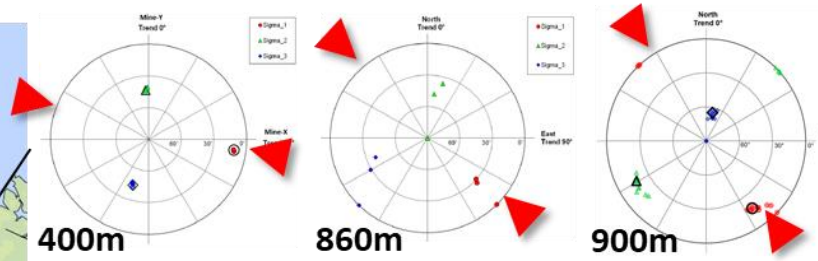


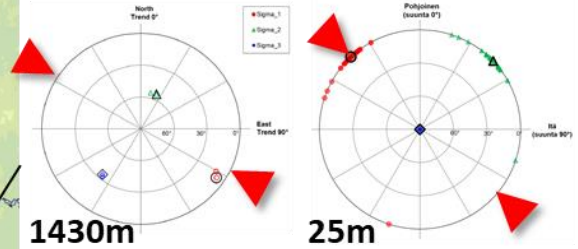


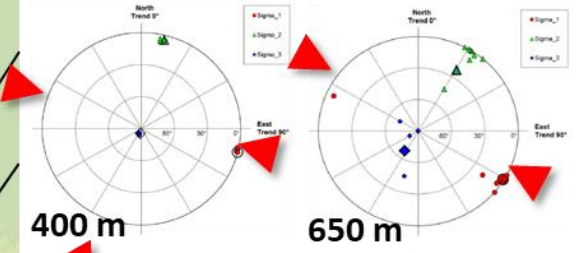


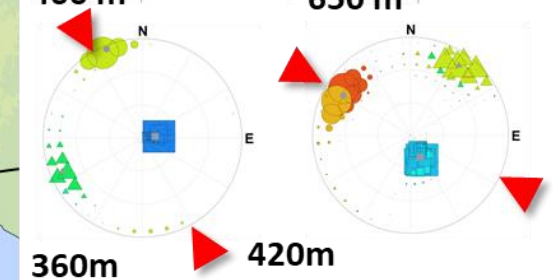


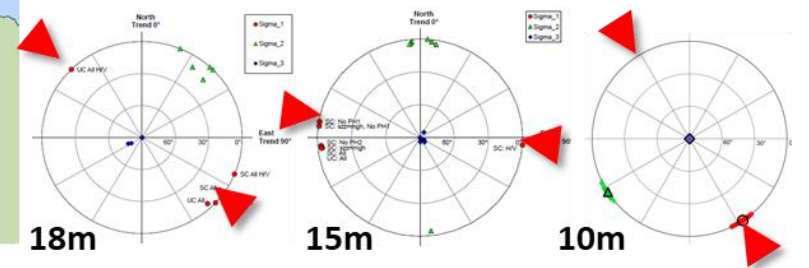








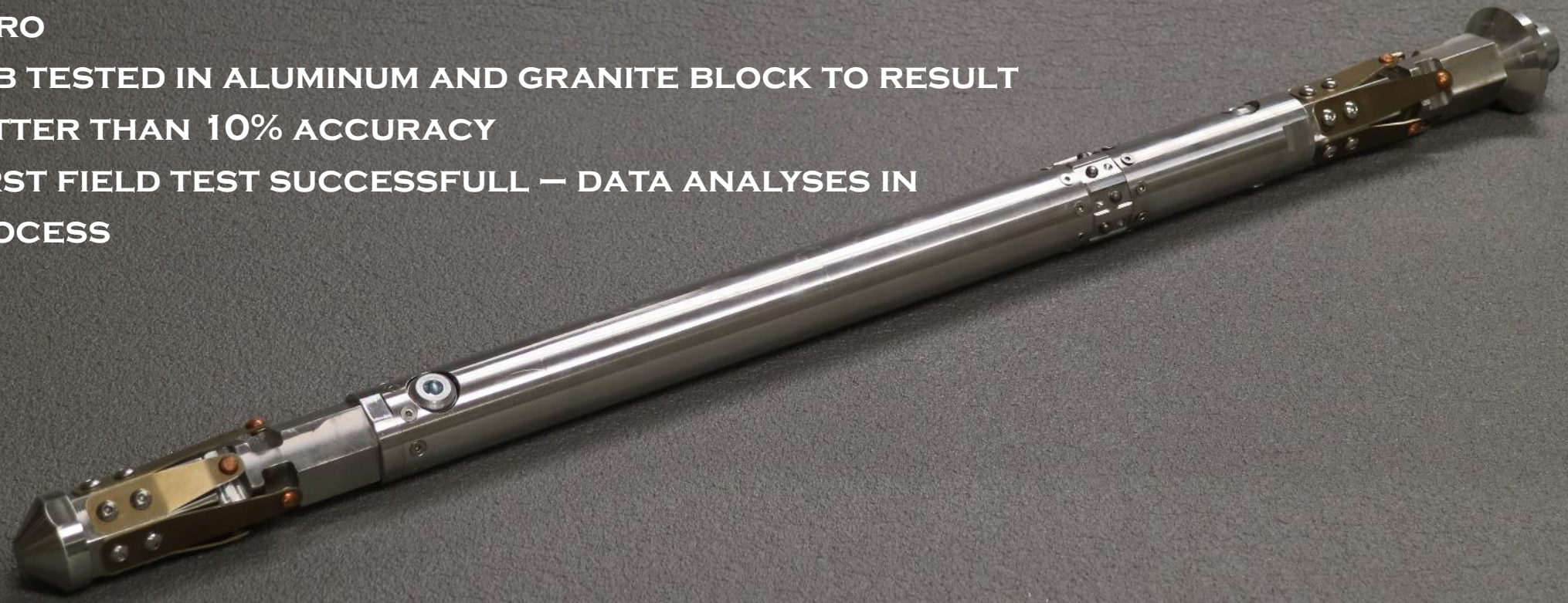




Something new

New 2D downhole probe – DDP36

- 36 mm pilot hole
- Mechanically mounted
- Four convergences with eight sensors
- Rock temperature
- Gyro
- Lab tested in aluminum and granite block to result better than 10% accuracy
- First field test successfull – data analyses in process



Thank you for your attention

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