STRUCTURAL CONTROL ON STRESS VARIABILITY AT FORSMARK

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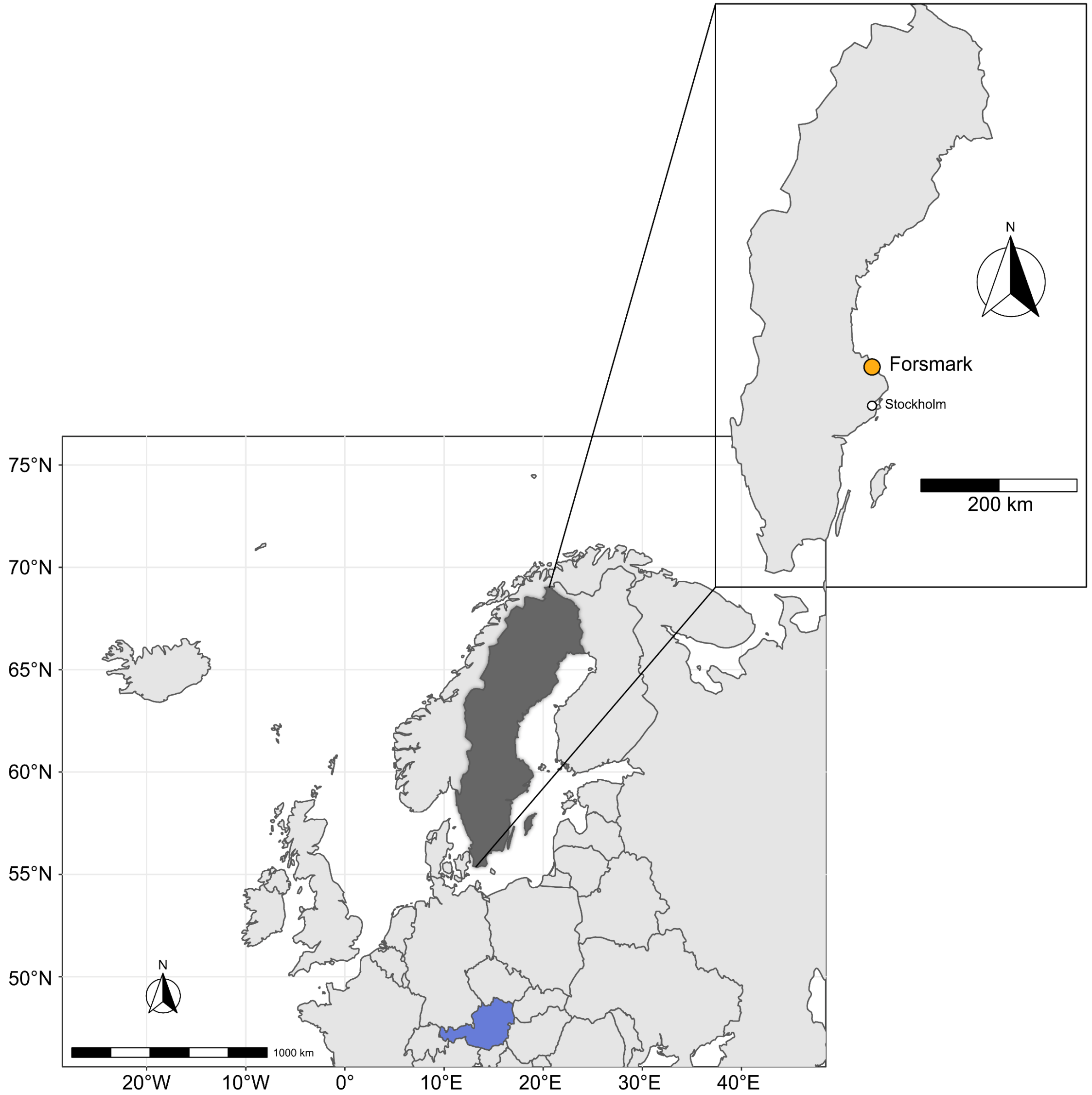
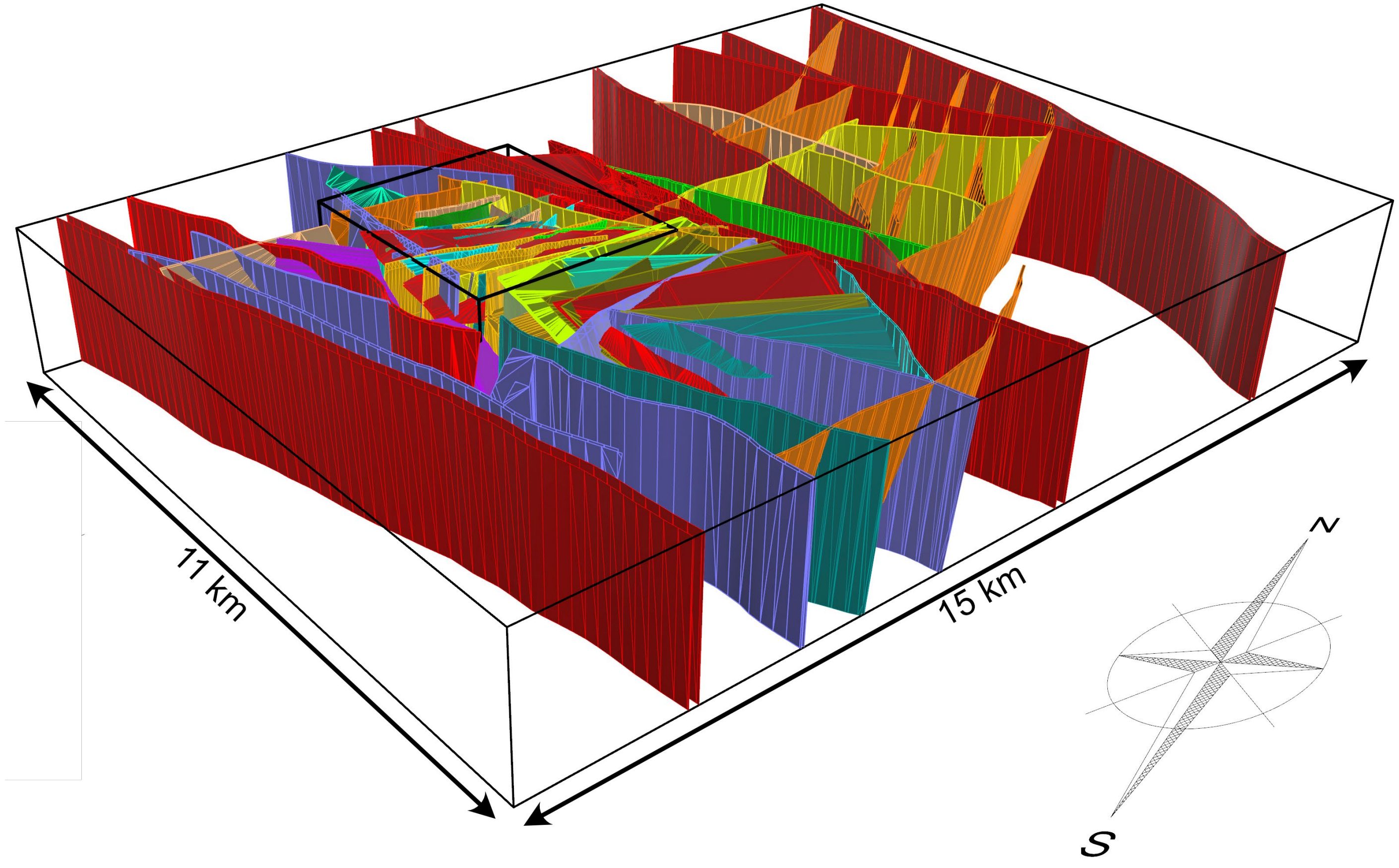
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

- SKB is the Swedish Nuclear Fuel and Waste Management Company
- Responsible for management and safe final disposal
- Site selected in 2009
- Construction application for repository submitted in 2011
- Located in Forsmark, Sweden
- Construction to take ca. 10 years
- Ca. 6000 canister capacity
- Depth ca. 470 m



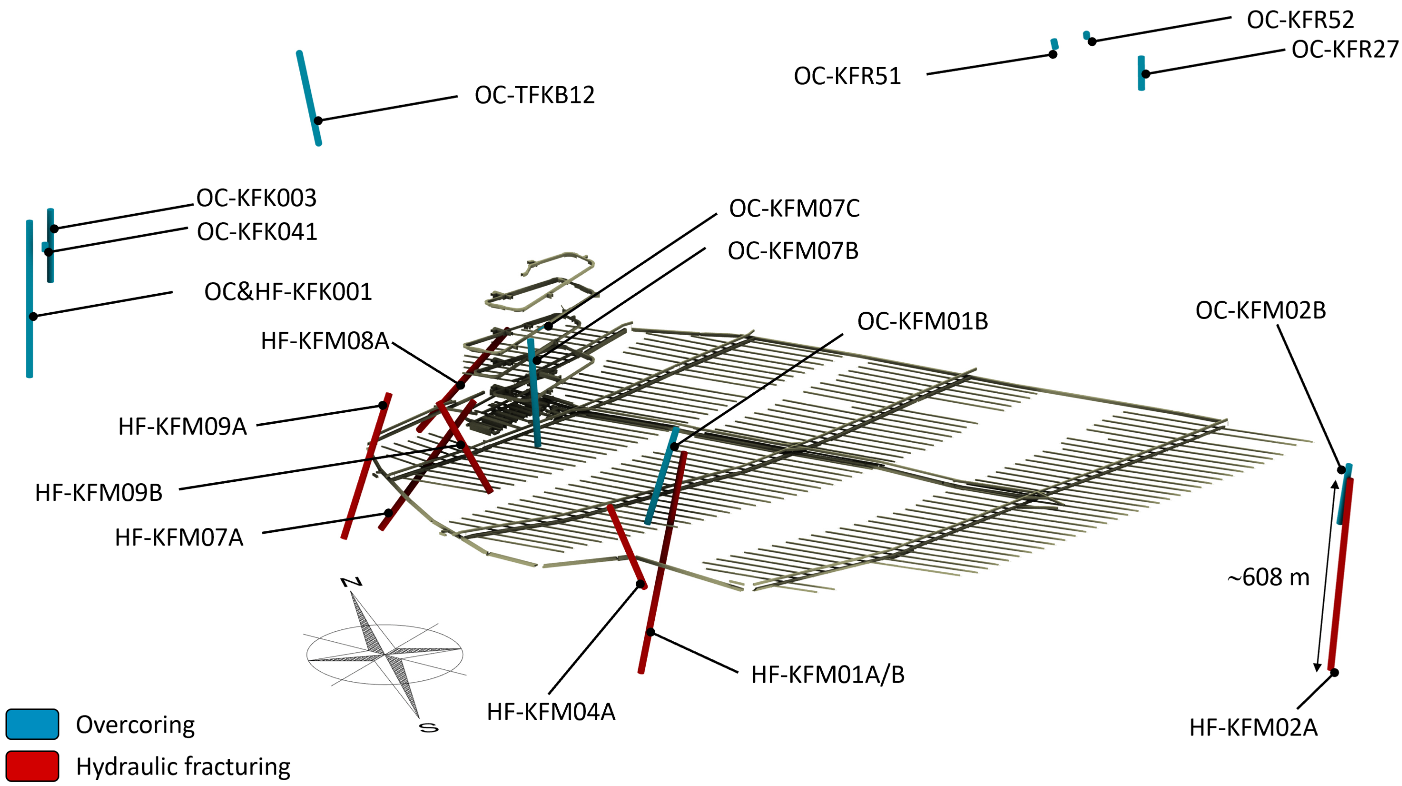
SITE CHARACTERIZATION

- Began in the 1970's
- Geological, hydrological, ecological and social impacts studied
- On-going investigations include:
  - Geology
  - Thermal properties
  - Rock Mechanics
  - Hydrogeology
  - Hydrogeochemistry
  - Transport properties
- Resulted in regional and local geological models
- Rock mass quality good, stiff, strong and homogeneous
- Lower quality largely related to fault zones (110)



IN SITU STRESS STATE

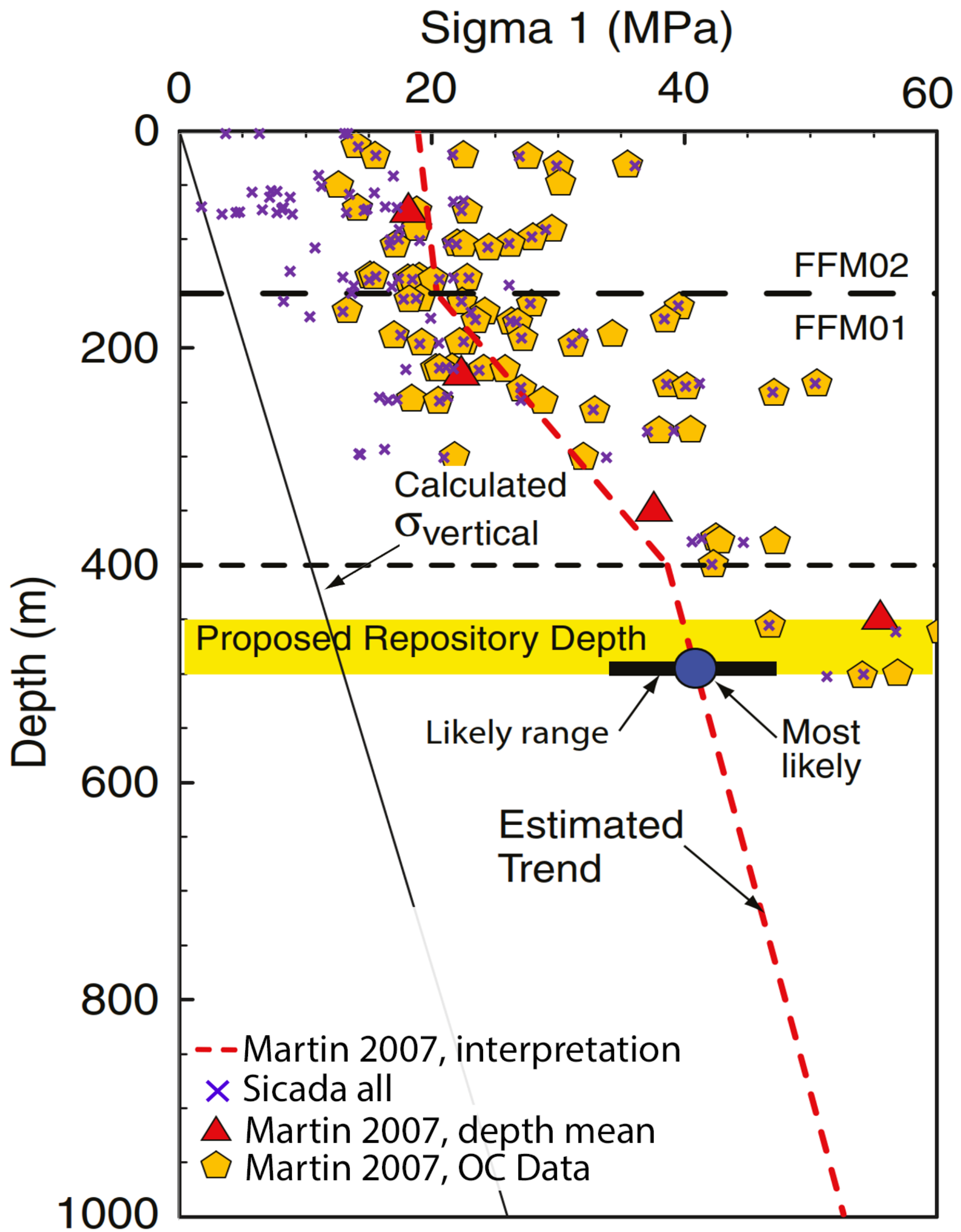
- Good understanding required for safe final disposal
- Fennoscandian area dominated by plate tectonics:
  - Mid-Atlantic ridge-push
  - Collision of the Eurasian and African plates in the alps
- Glaciation effects significant
- Thrust fault conditions promoted shear of brittle fault zones
- Stress state affected



OBJECTIVES & METHODS

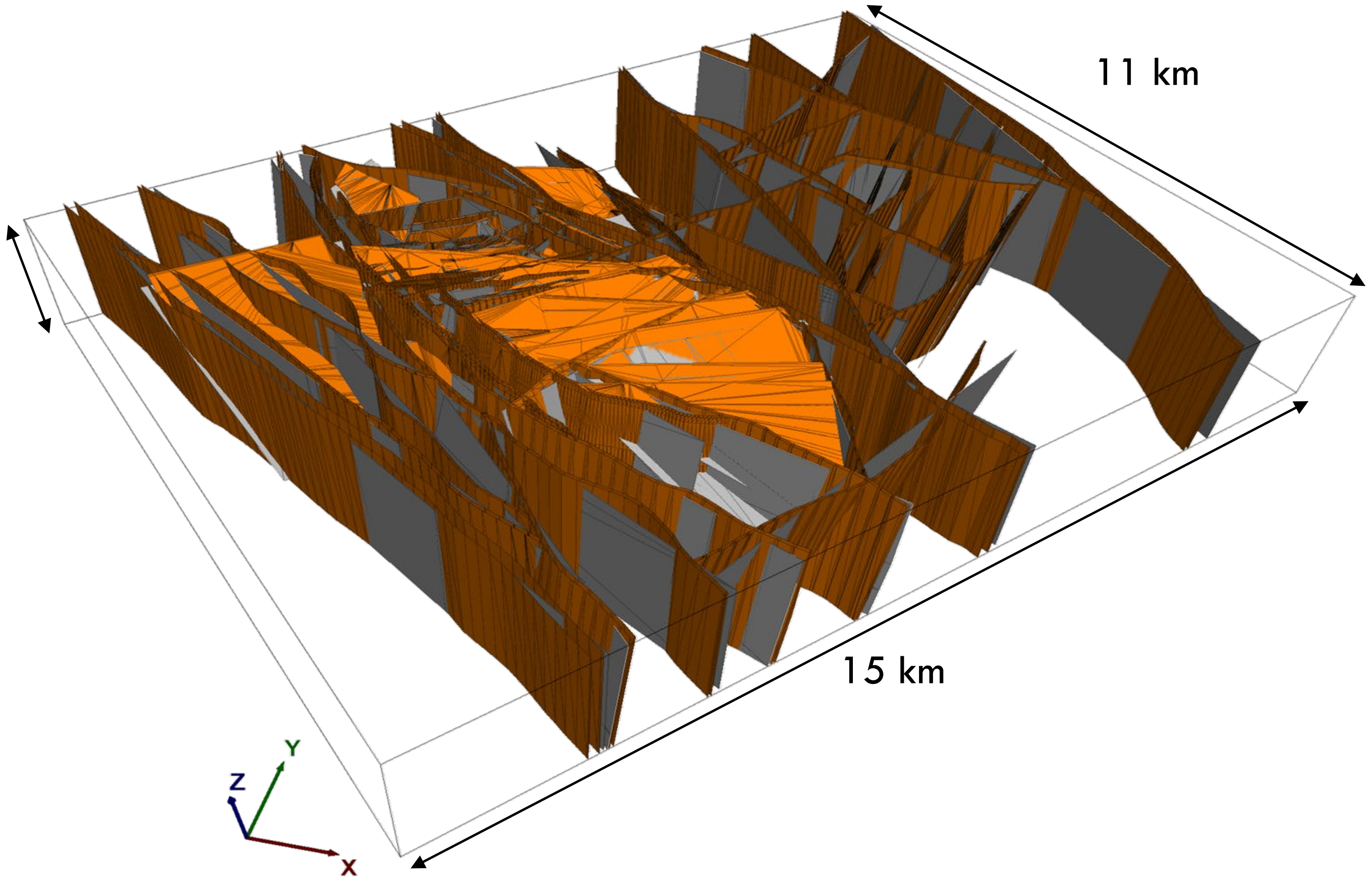
- Better understanding of observed variation
- Verification of rock and fault parameters

- Current stress interpretation (Martin 2007) based on 130 overcoring and 240 hydraulic stress measurements
- Indicates NW-SE orientation of σ_H
- Mean magnitudes of σ_H and σ_h 41 and 23 MPa, respectively

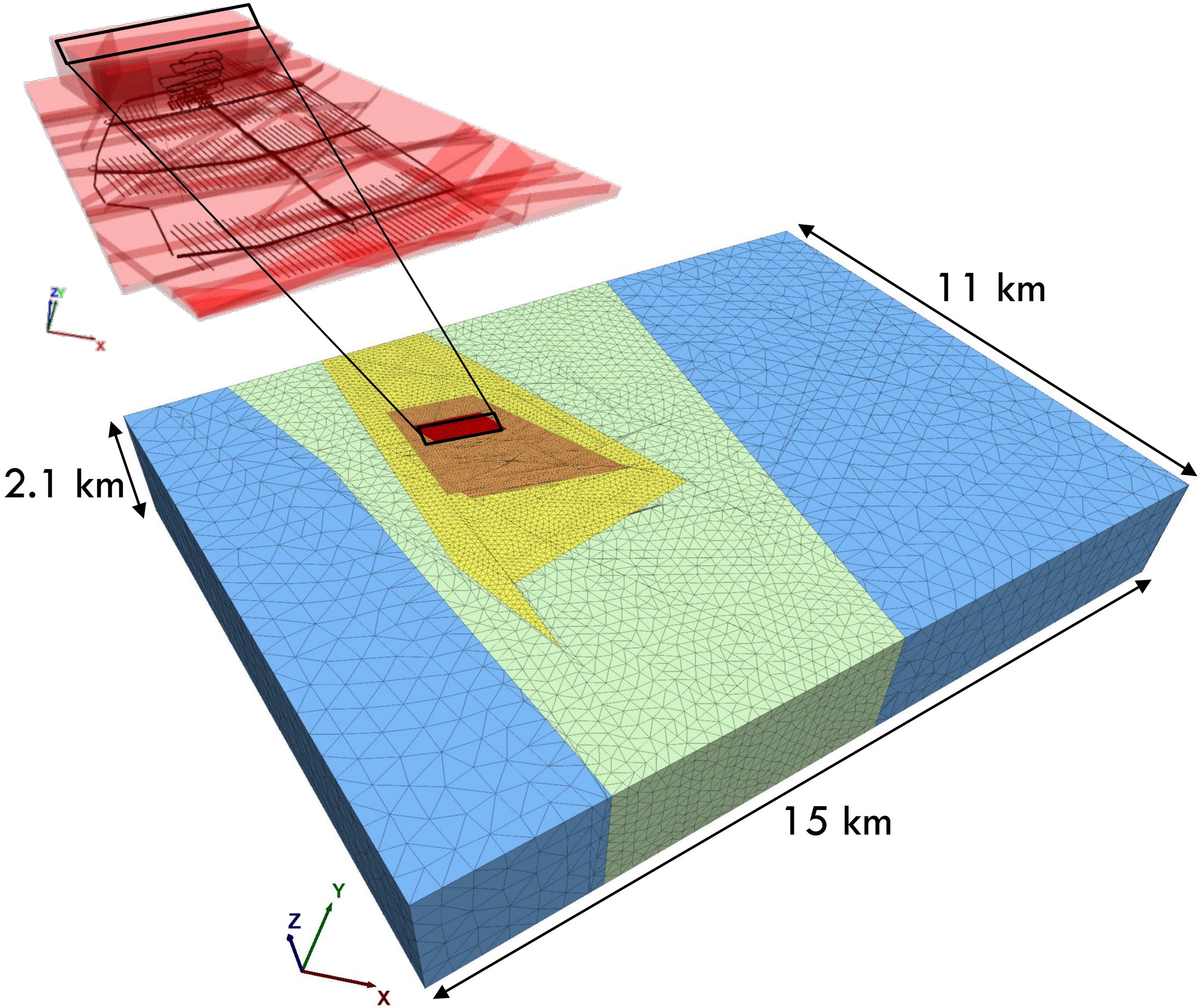


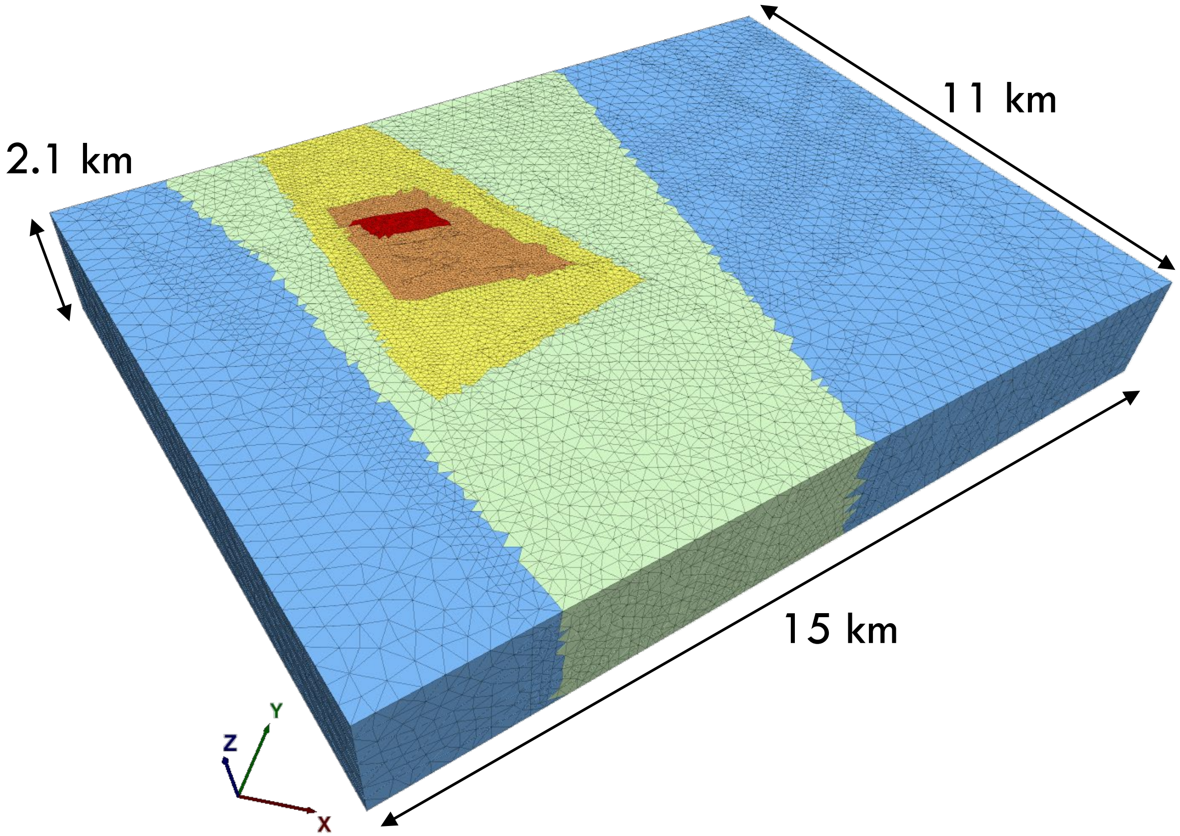
GEOMETRY

- Simulations performed using 3DEC
- Performed in two phases
- Phase 1:
  - Planar & undulating fault zone geometry
  - Shear strength
- Phase 2:
  - Affect of thrust simulation
  - Thrust orientation varied
  - Glaciation simulated



GEOMETRY / ZONING

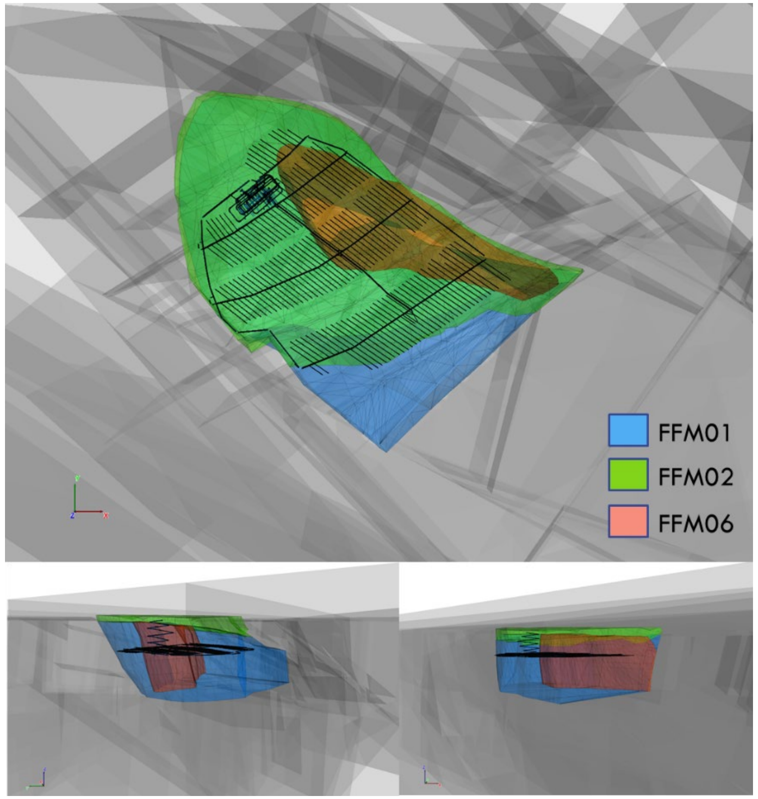




SIMULATION PARAMETERS

- Isotropic and elastic rock mass
- Divided into four domains
  - Main rock mass
  - Three fracture domains
- Fault zone parameters varied in individual cases
- Friction and cohesion maintained after failure

Parameter	kn (MPa/mm)	ks (MPa/mm)	coh (MPa)	fric (°)	ten (MPa)
Deformation zone					
All, except Singö	80	20	0.7	36	0.001
Singö	0.2	0.01	0.4	31.5	0.001

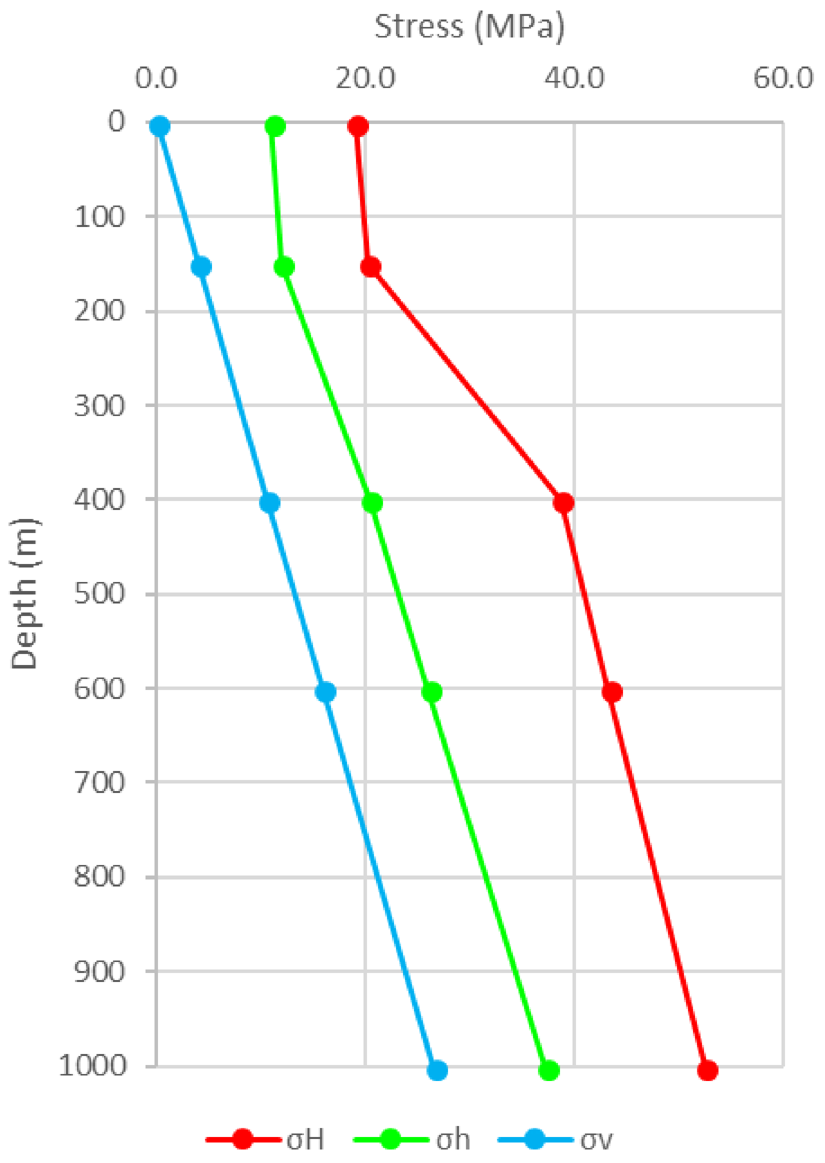


TARGET *IN SITU* STRESS STATE

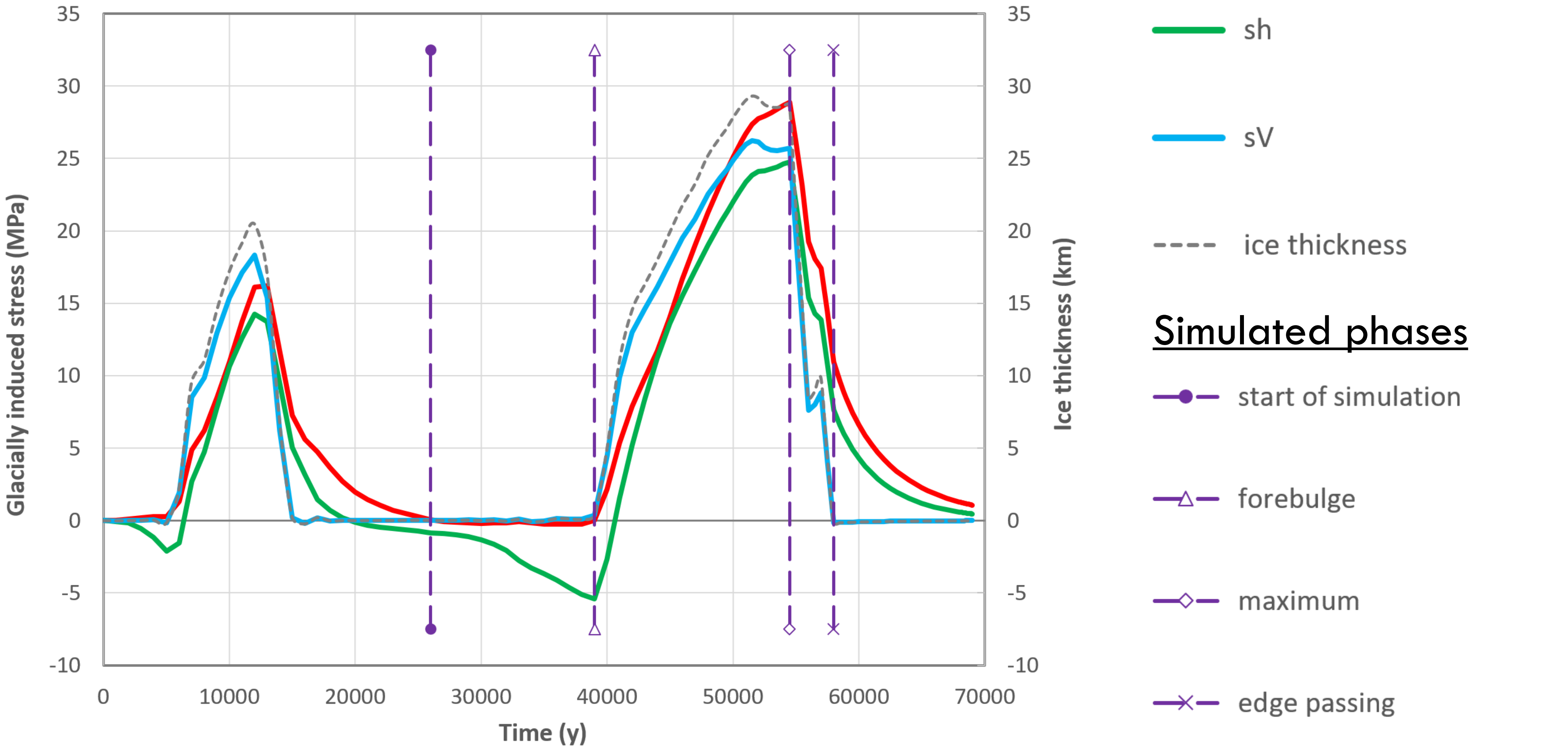
- Full gravitational water pressure applied
- Variable excess pore pressure applied when simulating glaciation

Depth range (m)	σ_H (MPa)	σ_H trend (°)	σ_h (MPa)	σ_h trend (°)	σ_V (MPa)
0-150	19+0.008z	145	11+0.006z	55	0.0265z
150-400	9.1+0.074z	145	6.8+0.034z	55	0.0265z
400-600	29.5+0.023z	145	9.2+0.028z	55	0.0265z

z is depth below rock surface in metres



GLACIATION



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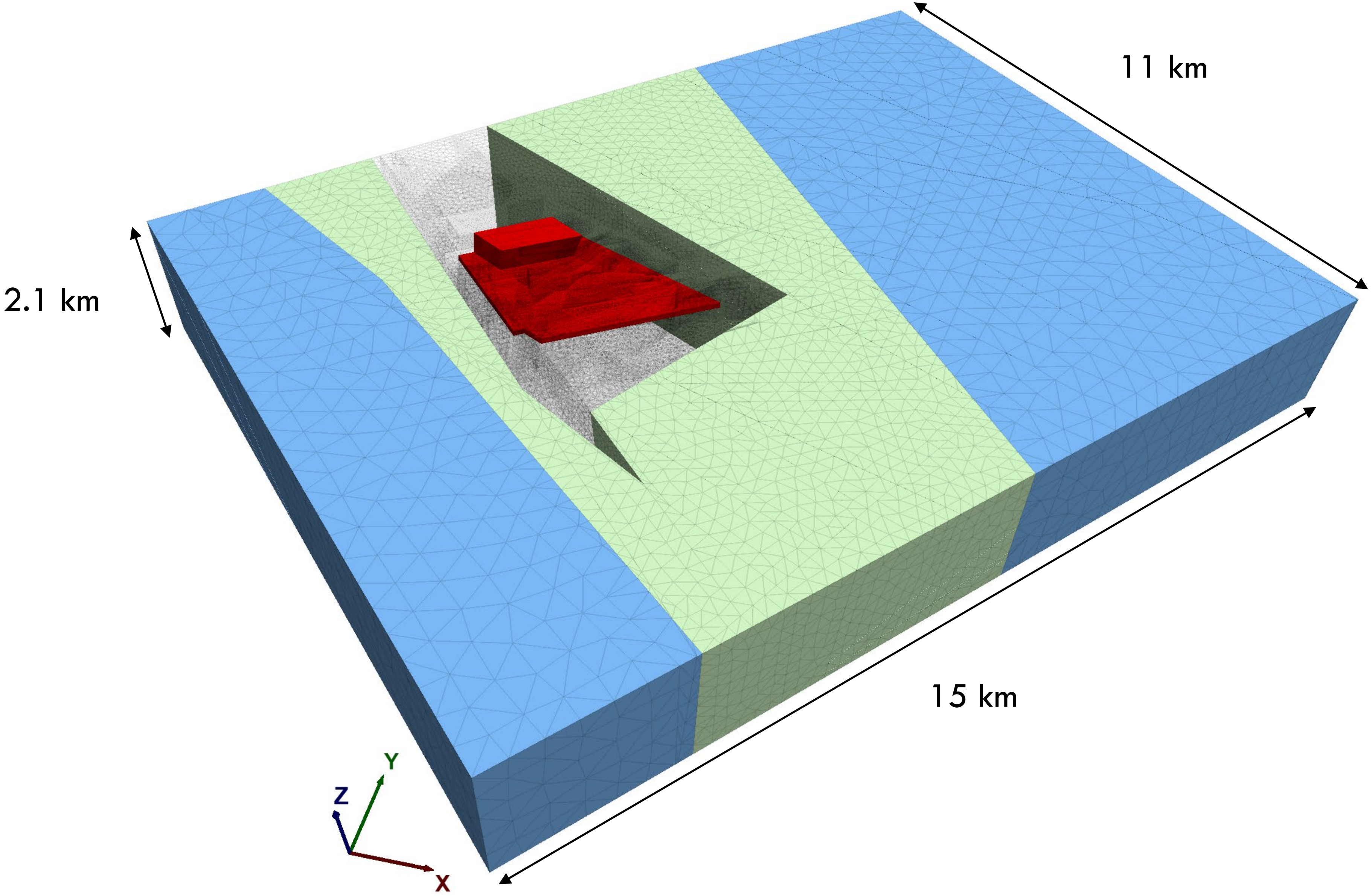
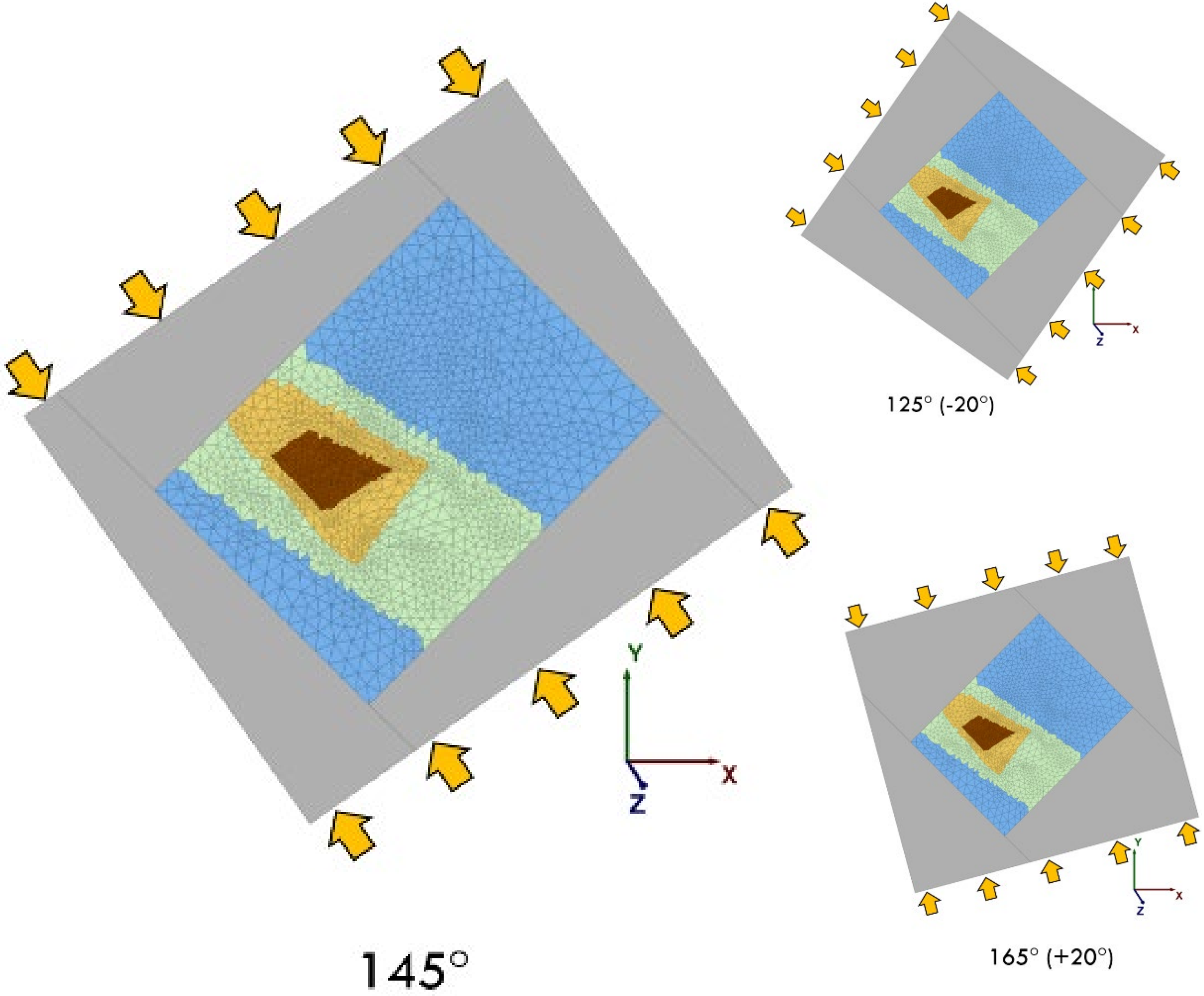
PHASE 1

- Seven cases as both undulating and planar = 14 cases
- Largely varied fault zone shear strength: $\phi = 10 - 36°$, c = 0.3 – 0.7 MPa
- Applied *in situ* stress directly

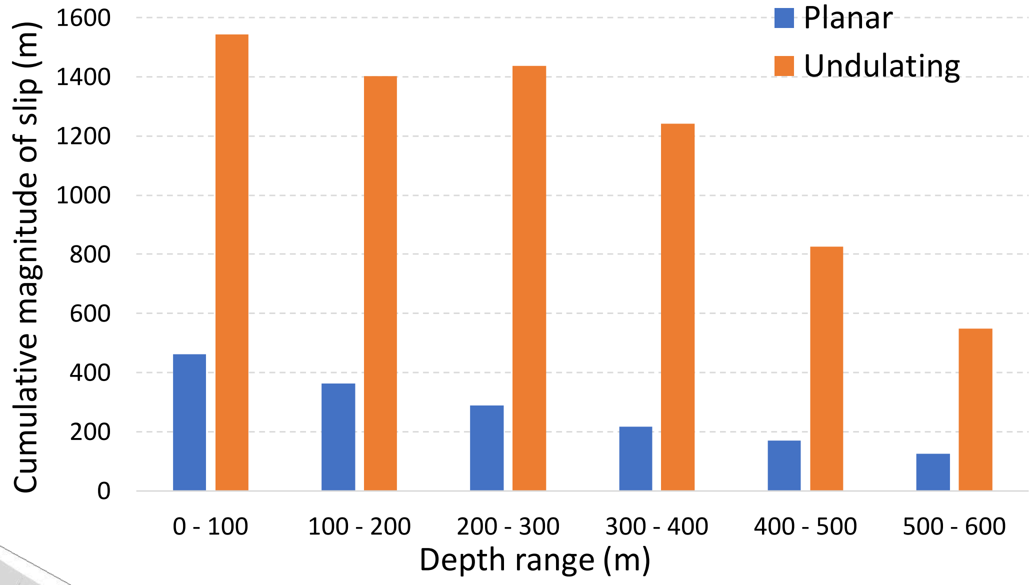


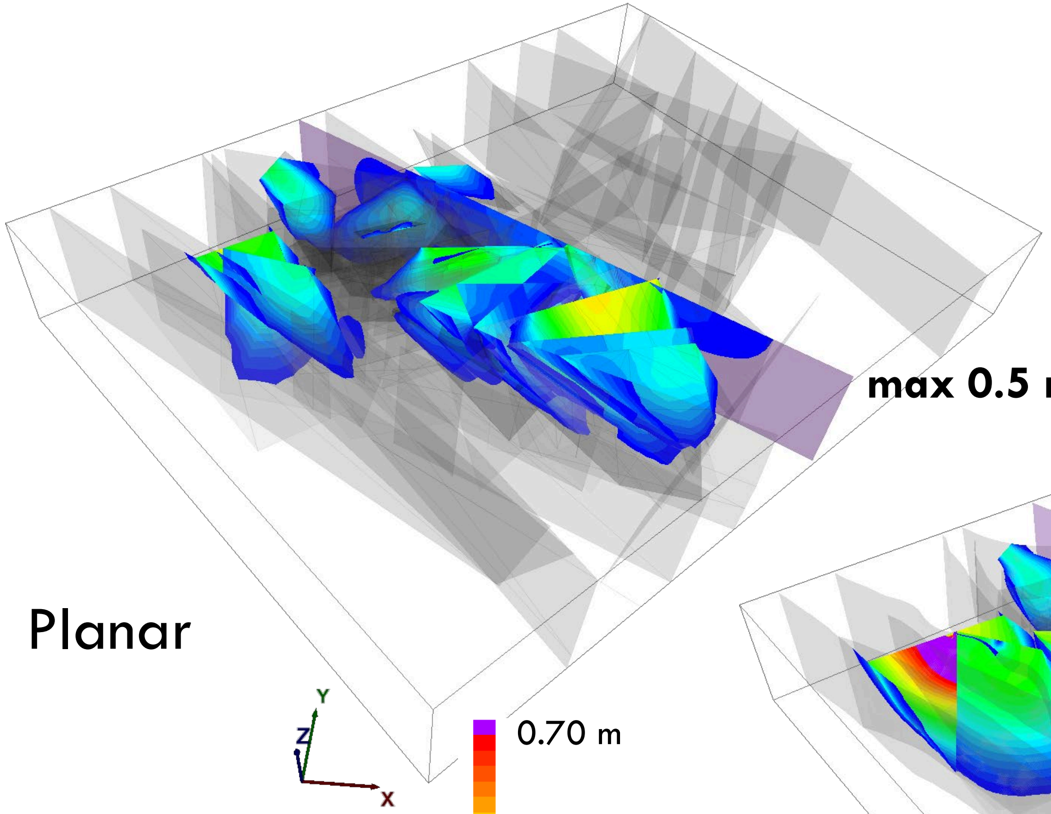
PHASE 2

- Lower stress values with narrow variation in Phase 1 -> boundary thrust
- Glaciation cycle also added
- Only undulating geometry
- 15 cases



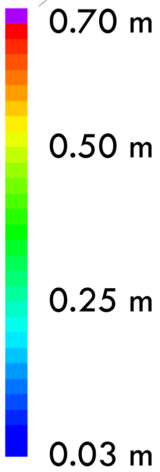
RESULTS: PHASE 1

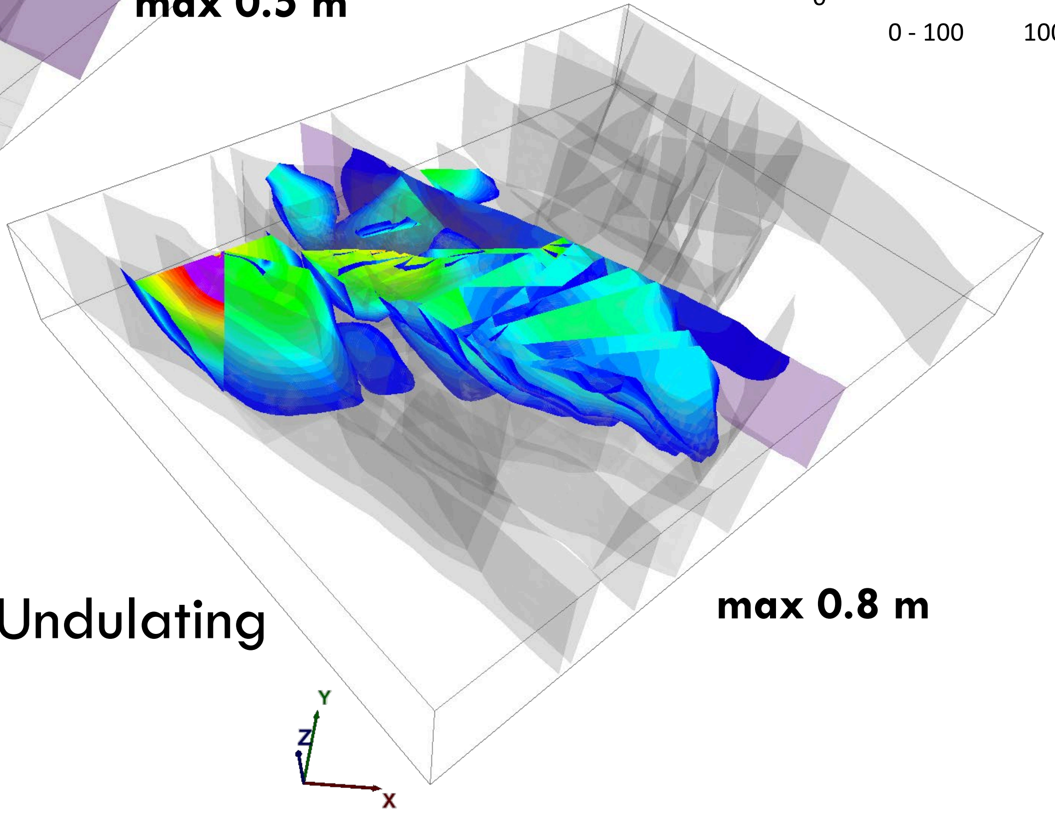




max 0.5 m

Planar



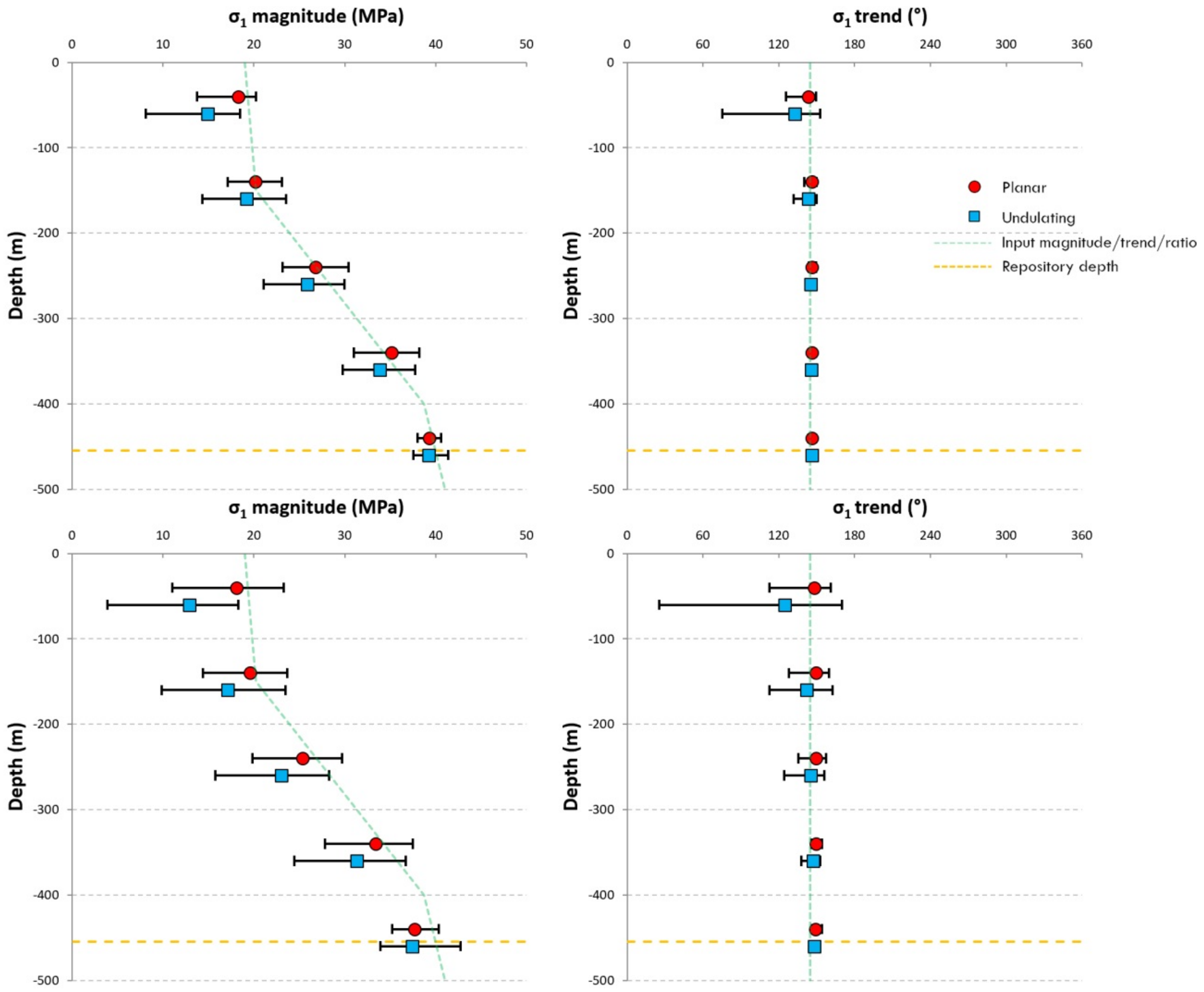


Undulating

max 0.8 m

RESULTS: PHASE 1

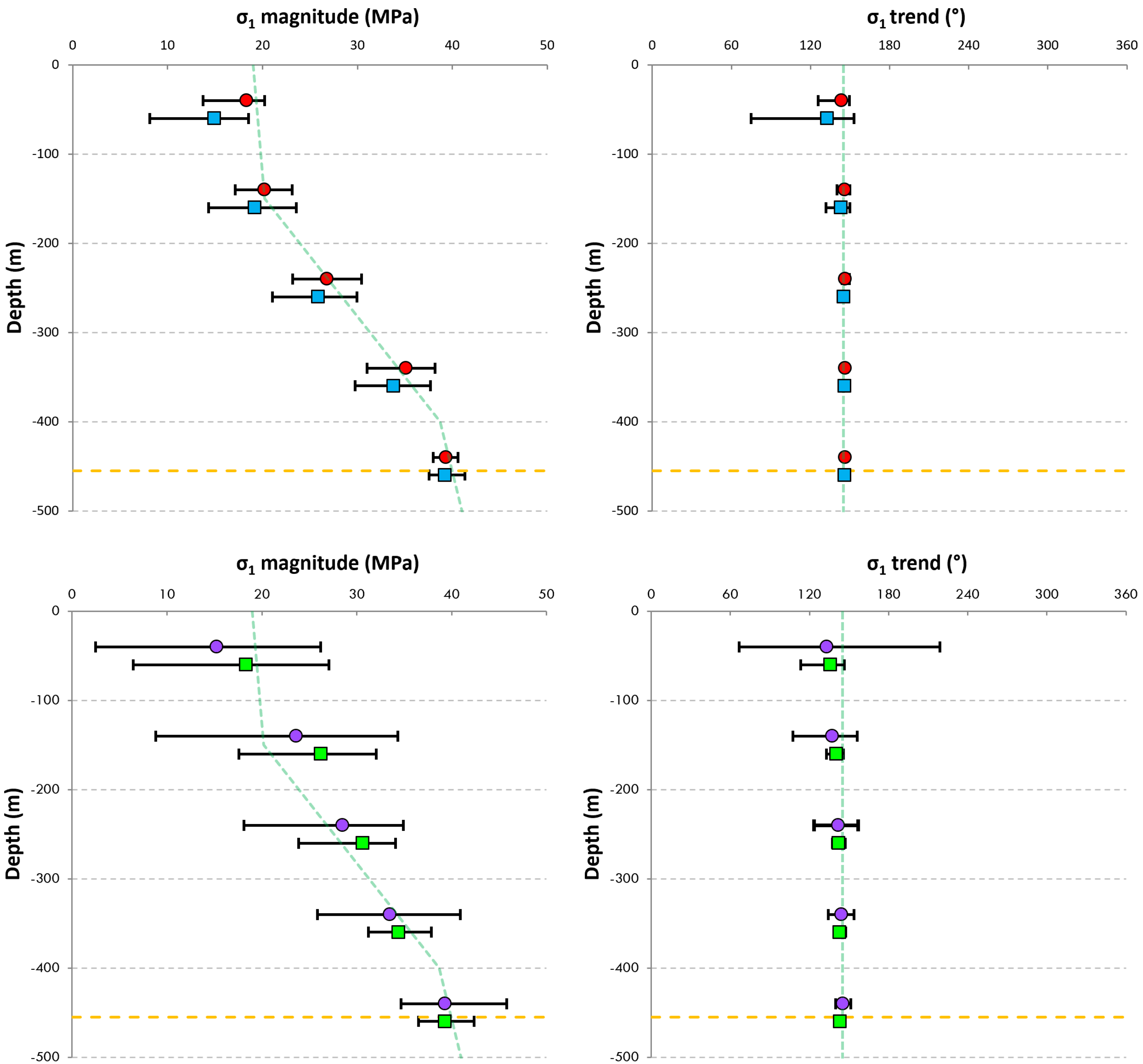
- ϕ 36° & 0.7 MPa
- ϕ 20° & 0.3 MPa



RESULTS: PHASE 2

- Planar vs Undulating geometry

Planar
Undulating
Pre-glacial
Post-glacial
Input magnitude/trend/ratio
Repository depth



- Effect of glaciation with undulating geometry

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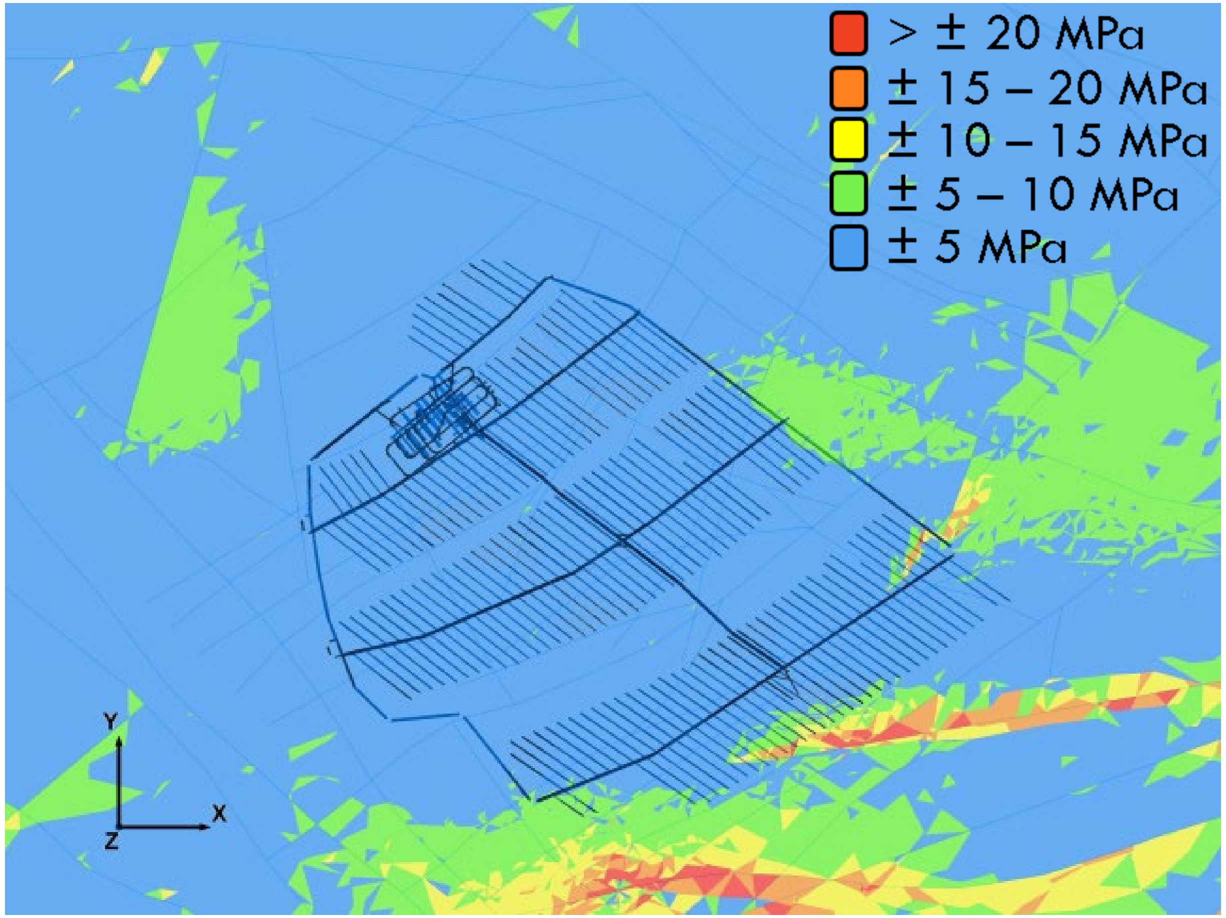
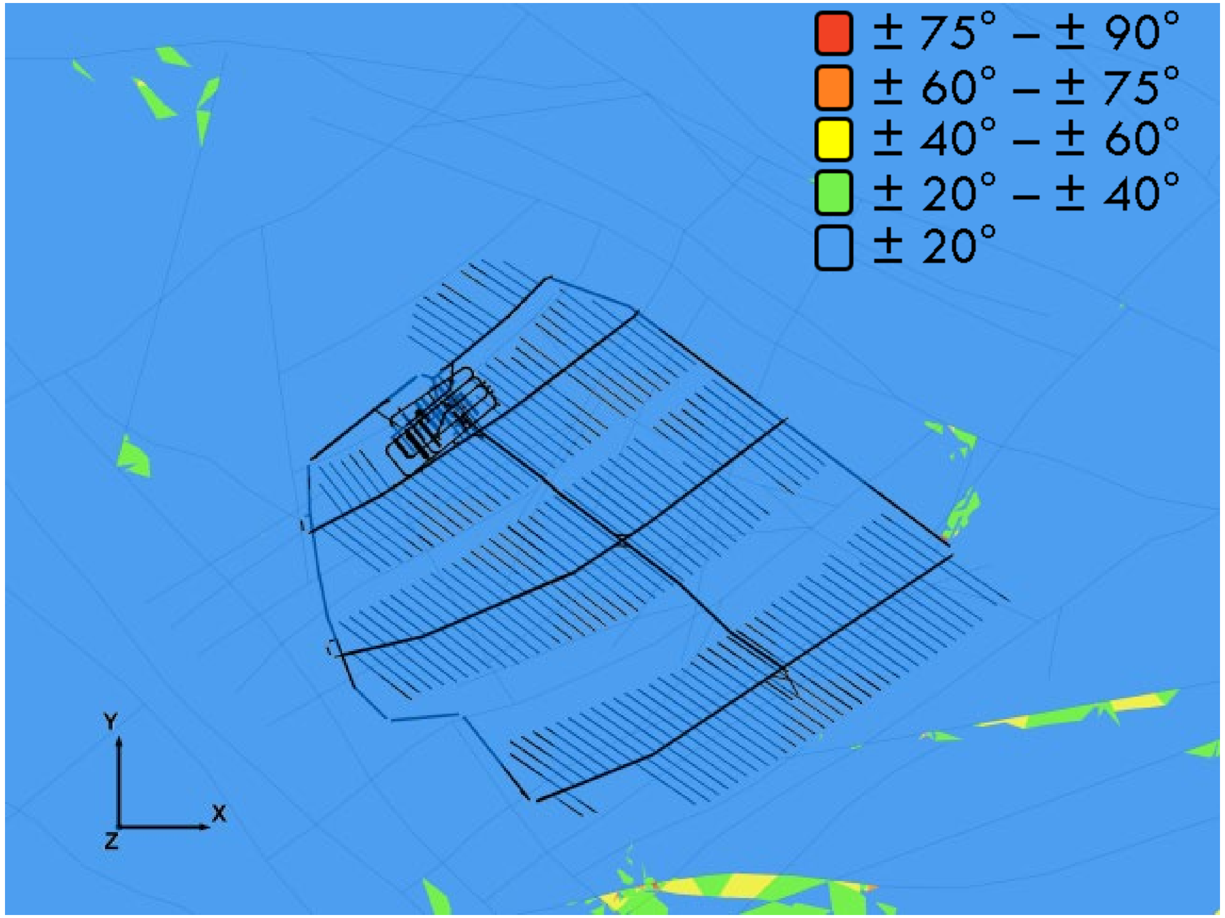
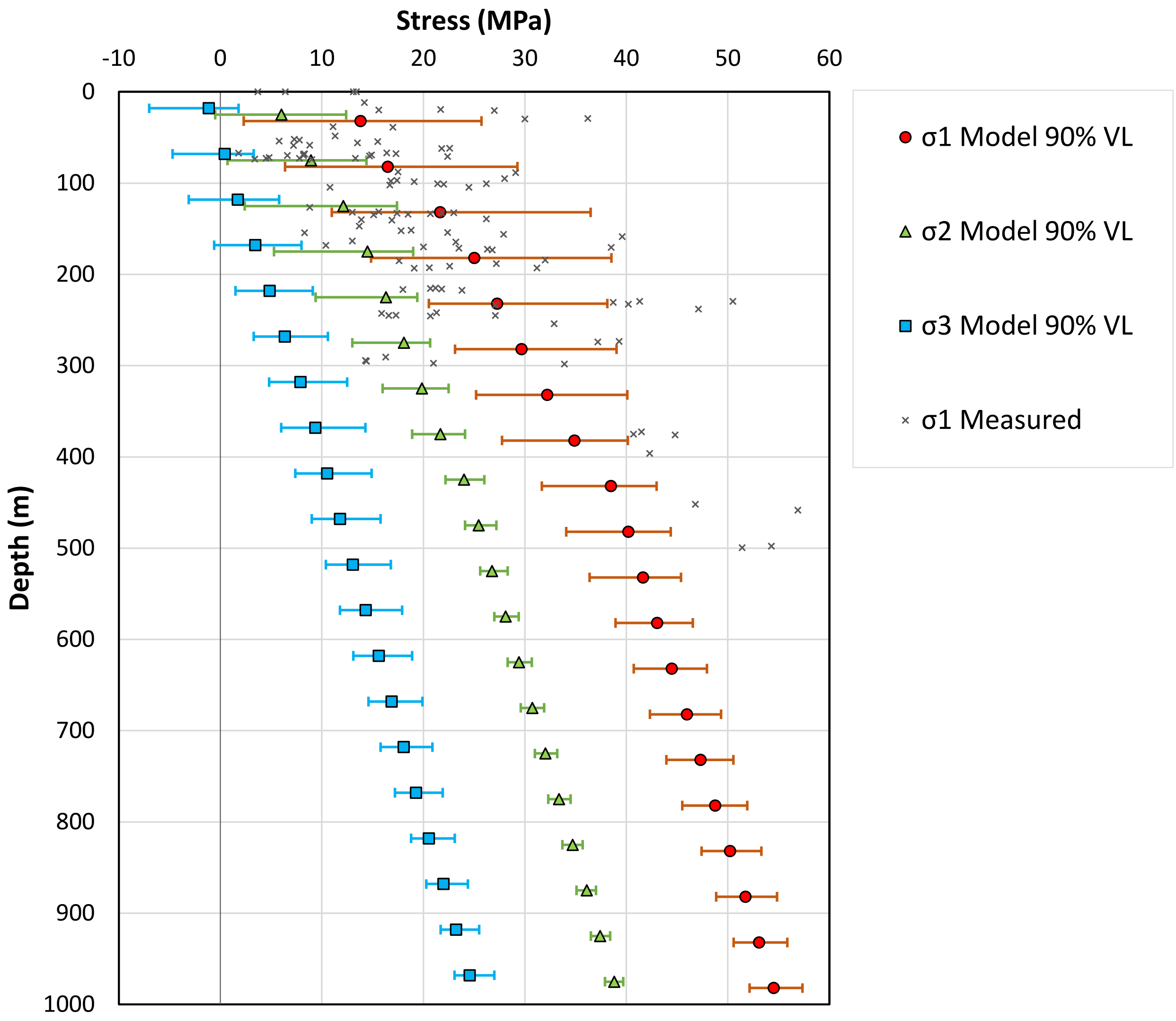
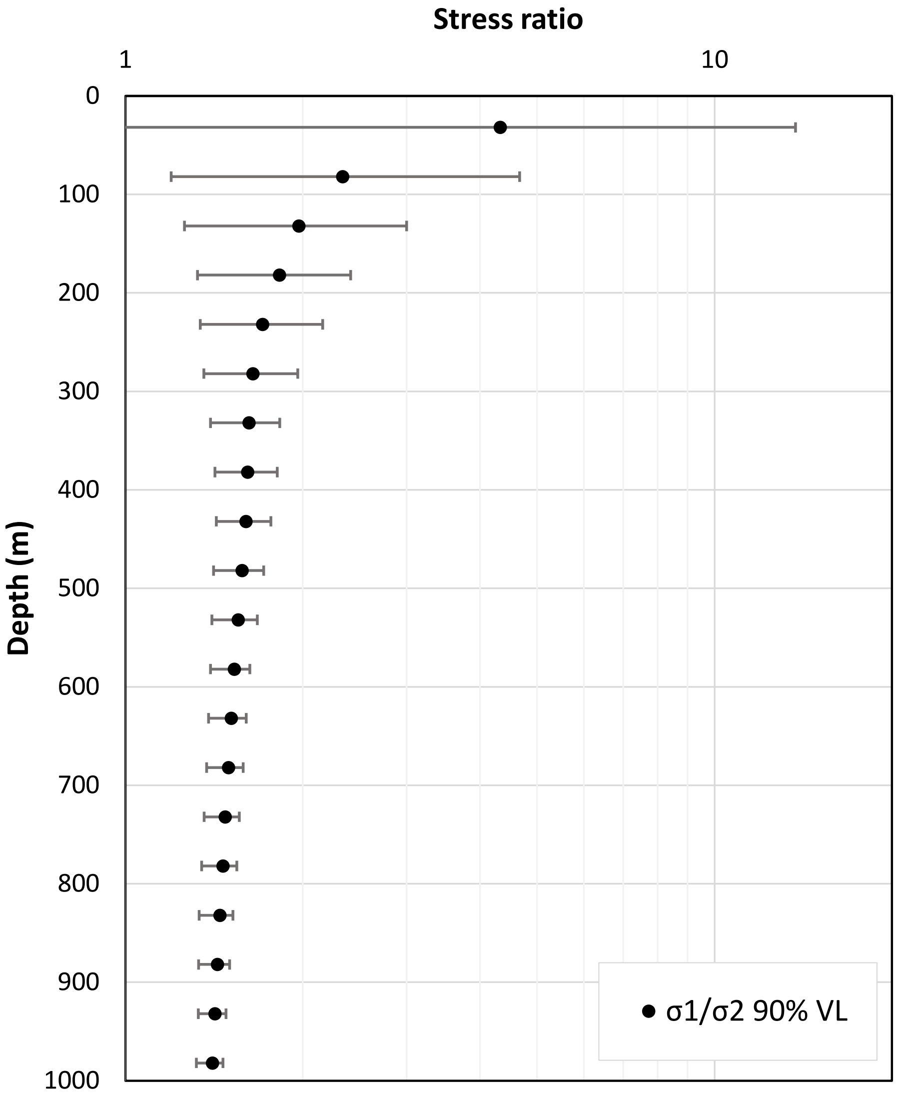
RESULTS: PHASE 2





RESULTS: PHASE 2





CONCLUSIONS

- The measured stress state can be considered reliable:
  - Best match with observed variation using thrust
  - Glaciation disturbances required as well
  - Undulating fault geometry recommended
- Resulting mean stresses insensitive to parameters
- Lower yet realistic parameters mainly increase variation
- Fairly good correlation with stress measurements
- Low magnitudes near the surface possible → low stress measurements not to be discarded
- High magnitudes possible, but not to the level observed → some measurements affected by heat → reliability ranking for all stress measurements in progress