A Strategic Rock Mechanics Study for The Kevitsa Open Pit Mine

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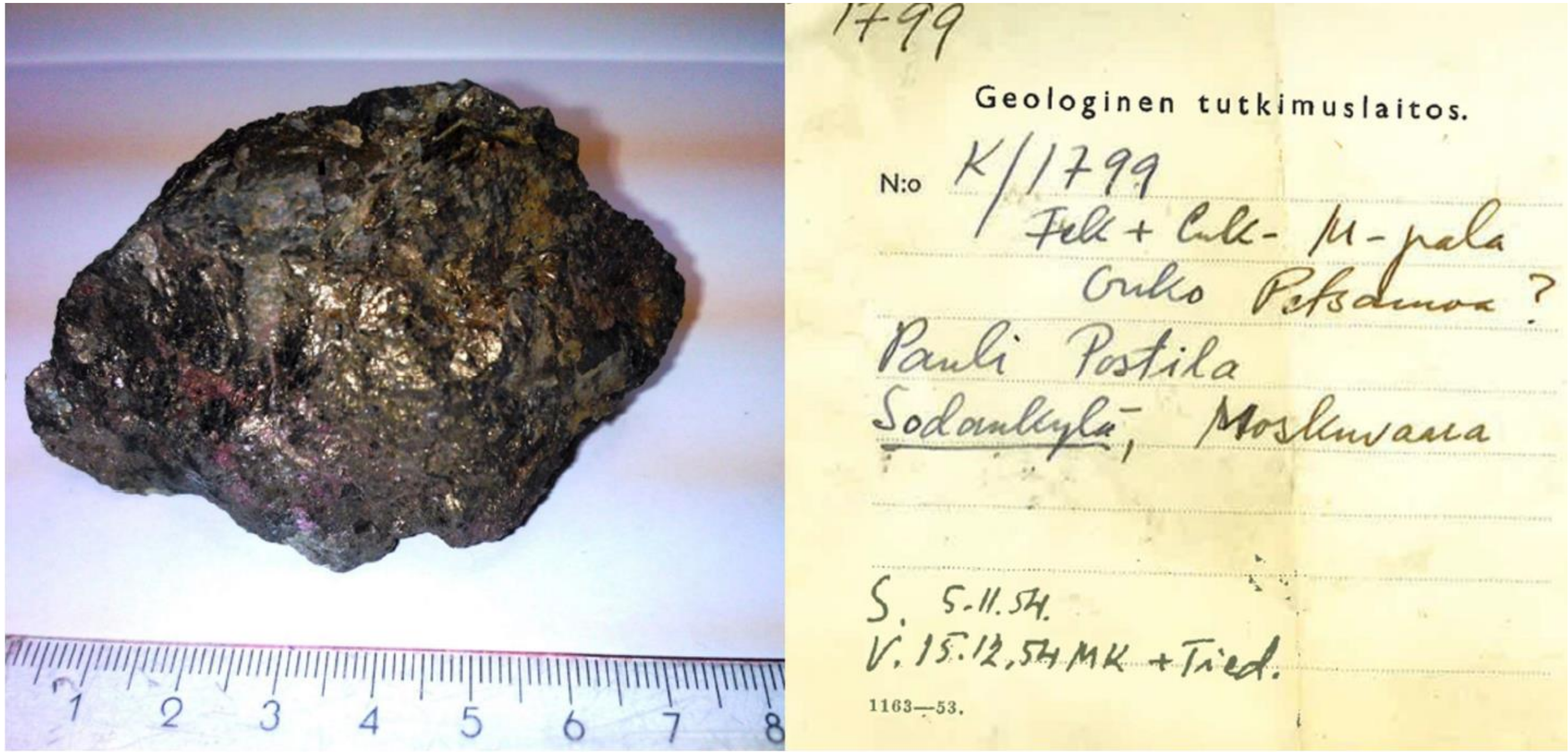
Background

- The Boliden Kevitsa open pit mine is revising its strategic plan
- New pit optimization project undertaken to investigate an increase in production
- Getechnical slope design parameters for the final pit depth (and possibly deeper pit), also need to be analyzed (bench, interramp, overall slopes)

A bit of history…

- Deposit first discovered in 1987
- First Quantum Minerals Ltd acquired the deposit in 2008, and made the decision on development of Kevitsa in 2009.

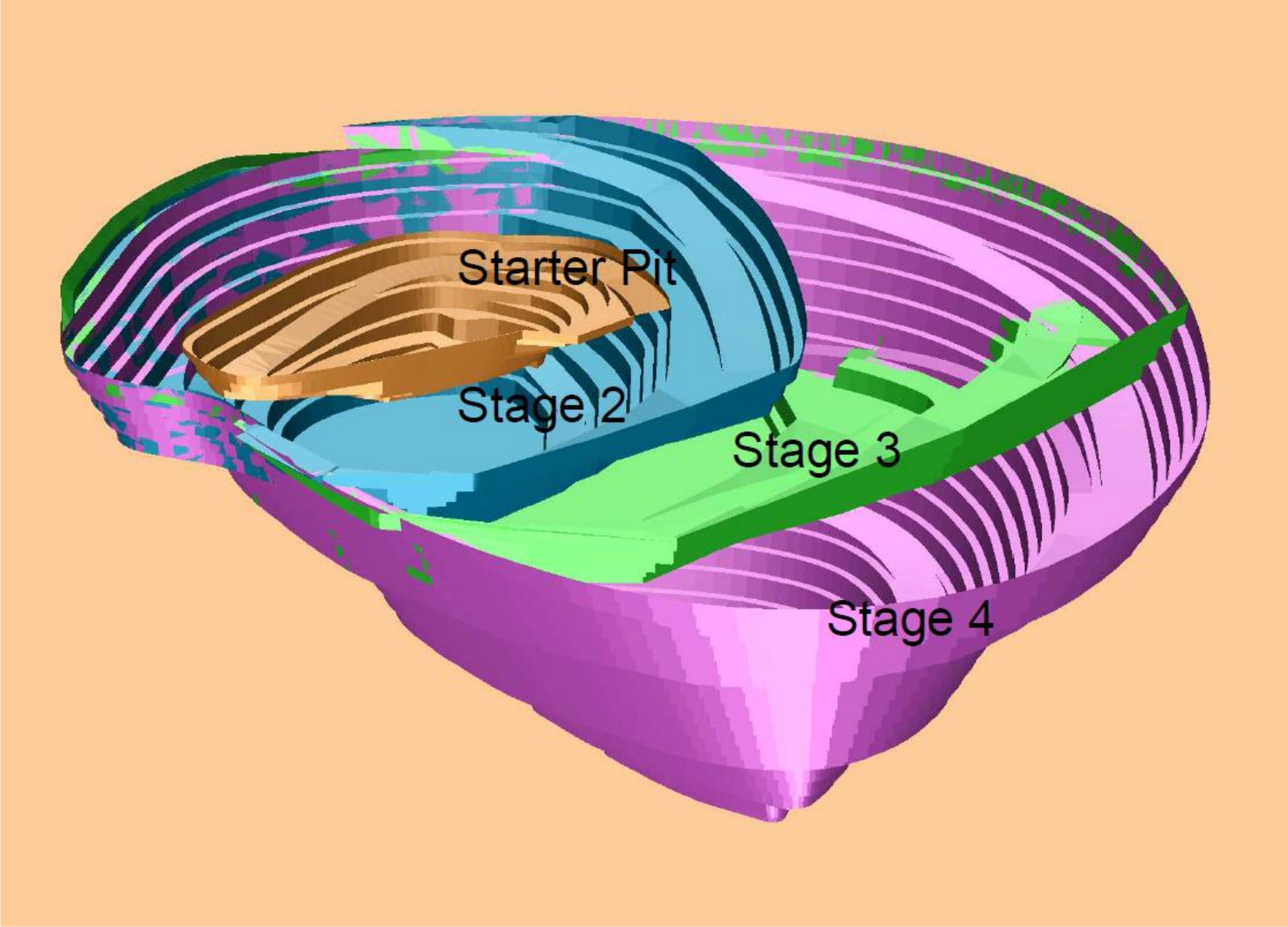


A bit of history…

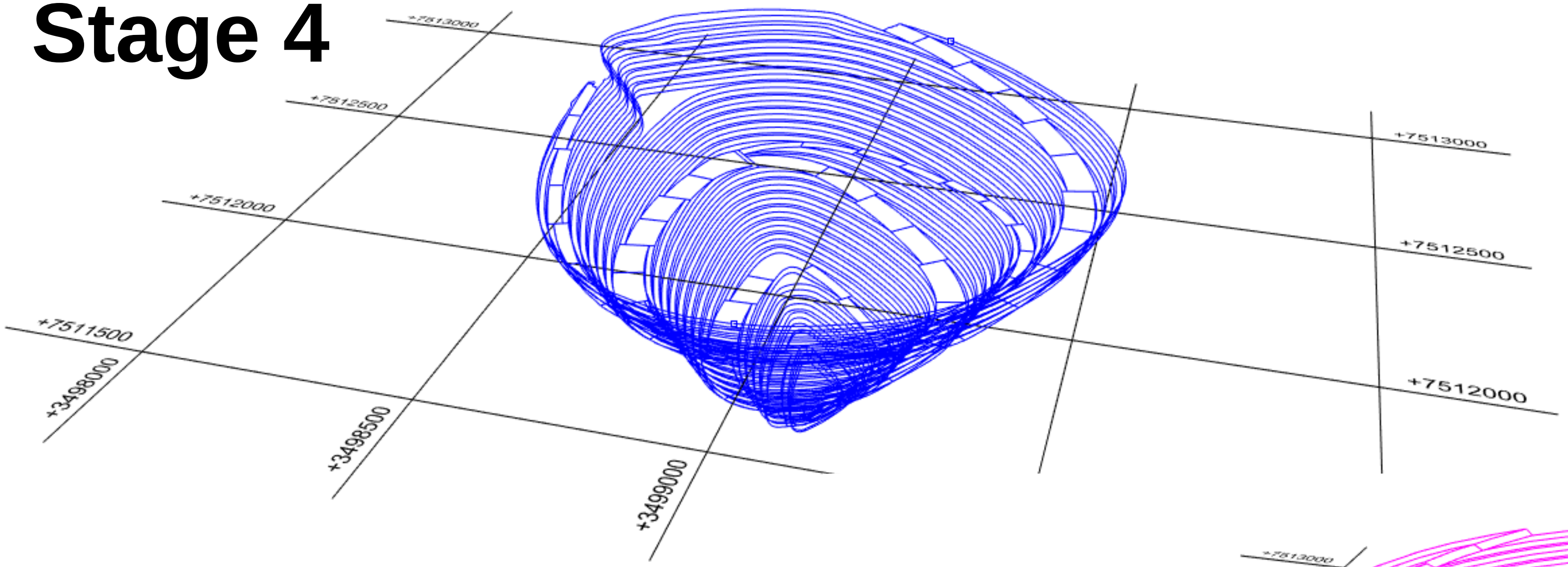
- Construction started 2010; commercial production in 2012
- Boliden purchased the mine in 2016

- Ore production 7 – 9 Mtpa; total mining rate 40–50 Mtpa.
- Nickel-PGE concentrate (120 000 tpa) and copper-gold concentrate (80 000 tpa)
- Around 400 employees on site

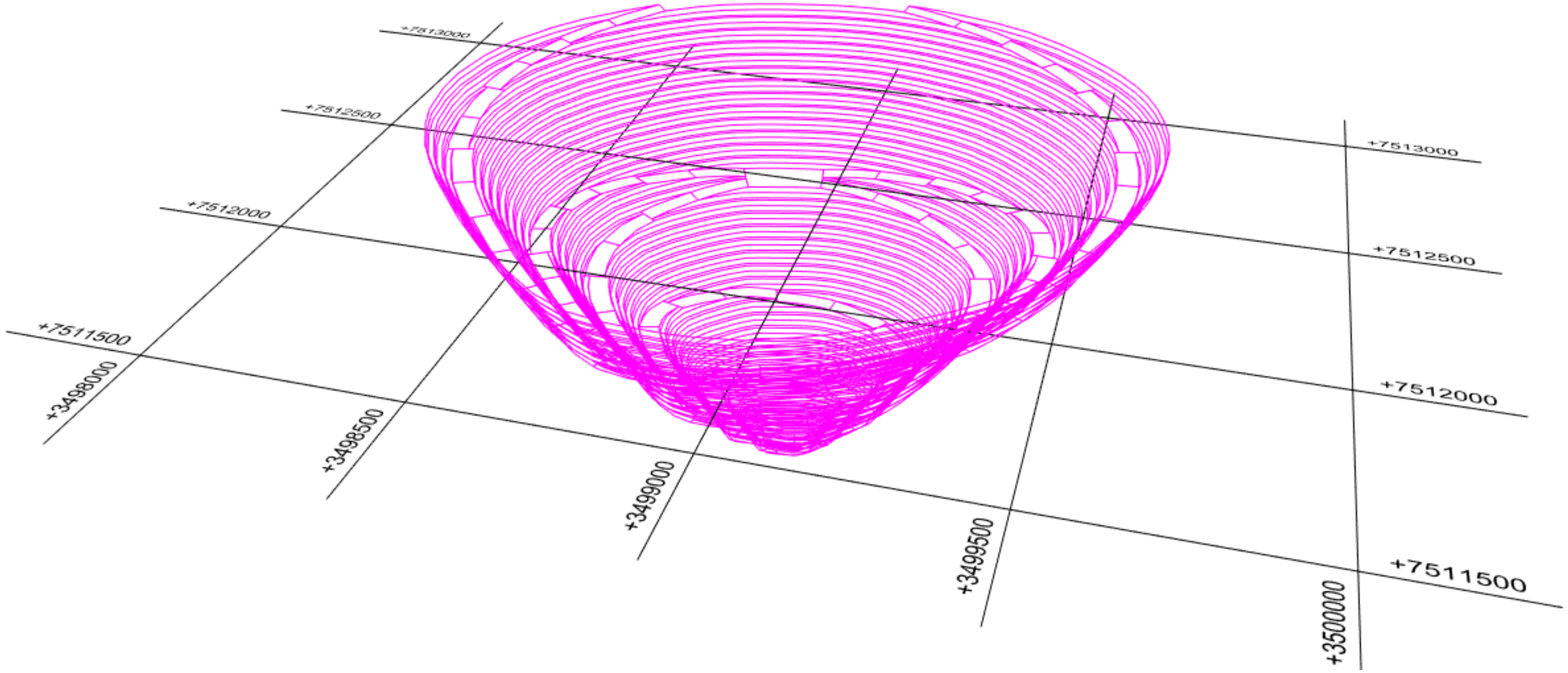
Pit expansion



Stage 4



Stage 5



October 2014

April 2016

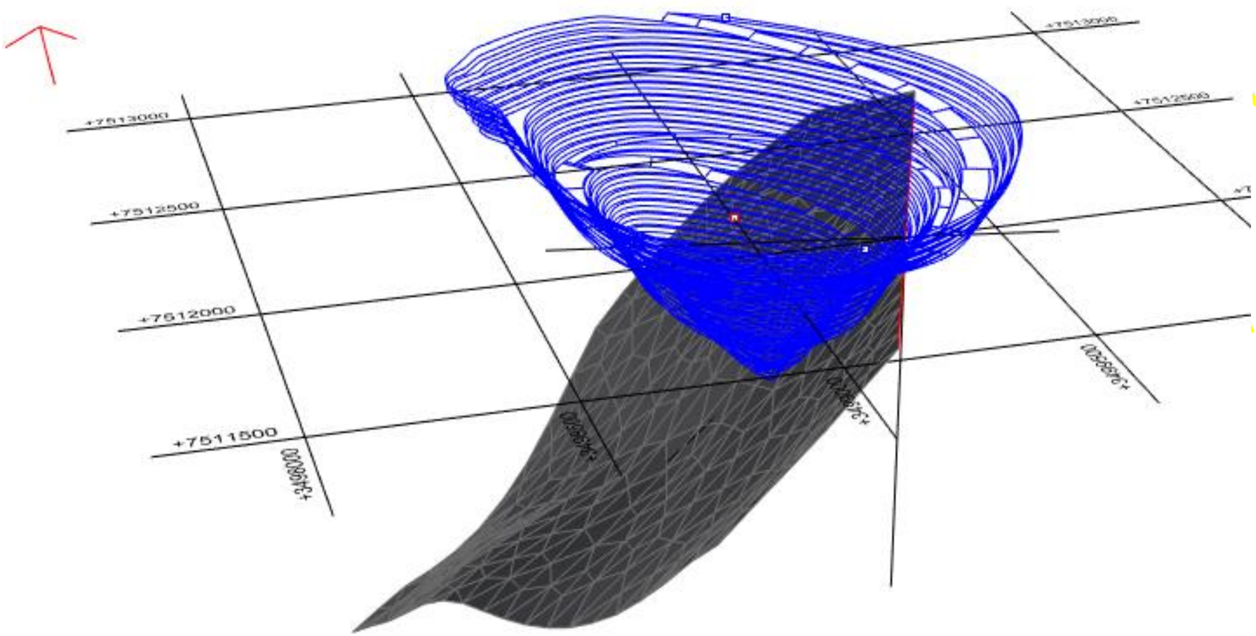

June 2017

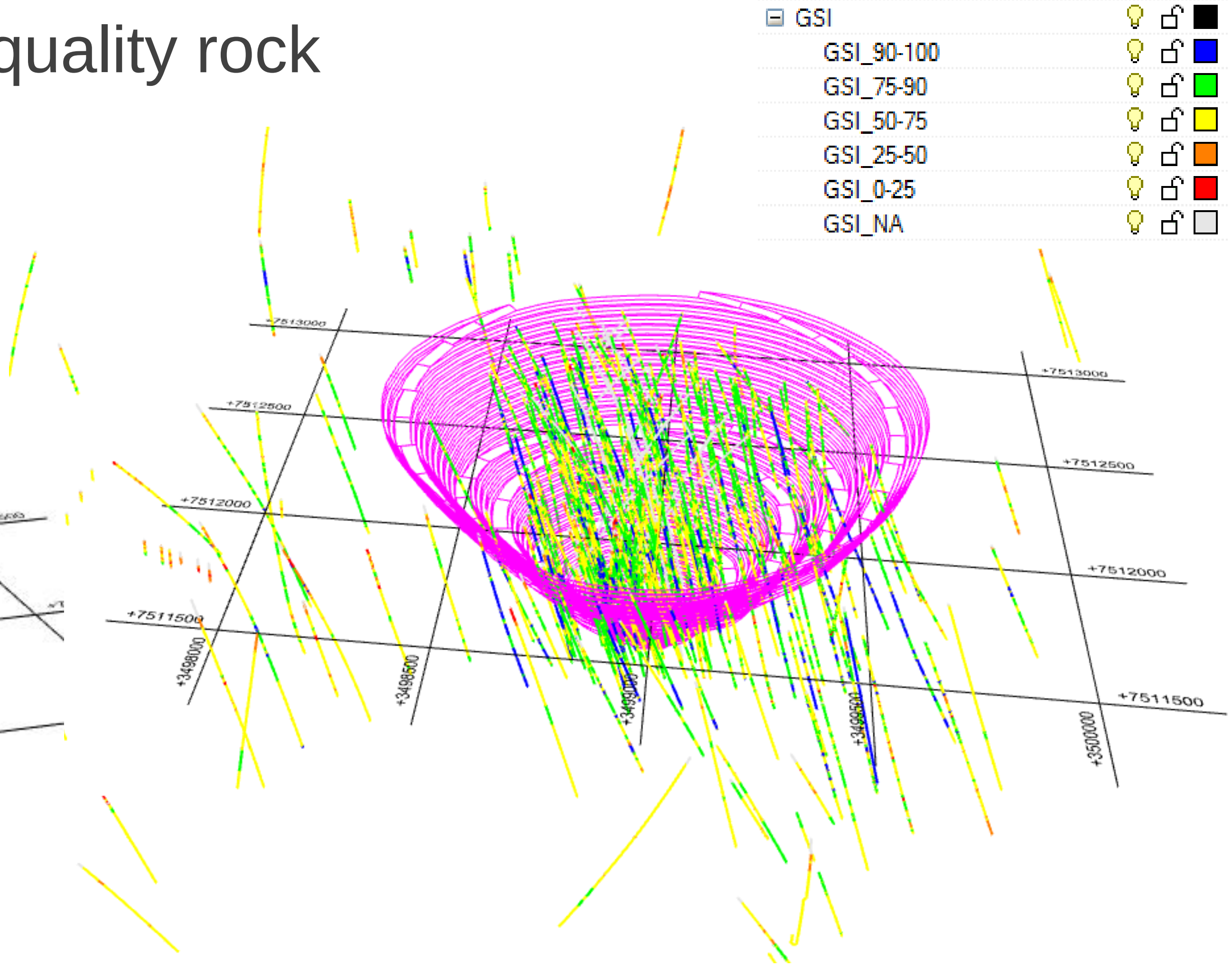
Rock mechanics for the Kevitsa Strategy Project

- Data compilation and analysis of pit slope stability for Stage 5 at a pre-feasibility level
- Assessment of large-scale slope stability & depressurization requirements
  - ❖ Overall slope angles; interramp slope angles; maximum interramp height
  - ❖ Required drained zone / phreatic surface level
- Review of bench design
  - ❖ Bench slope geometries
- Recommendations for future feasibility level study
  - ❖ Further data collection
  - ❖ Recommendations for slope monitoring for operational purposes

Geomechanical model

- Generally high strength, good quality rock
- One lithological unit (pyroxenite-peridotite)
- Potential fault in the east wall



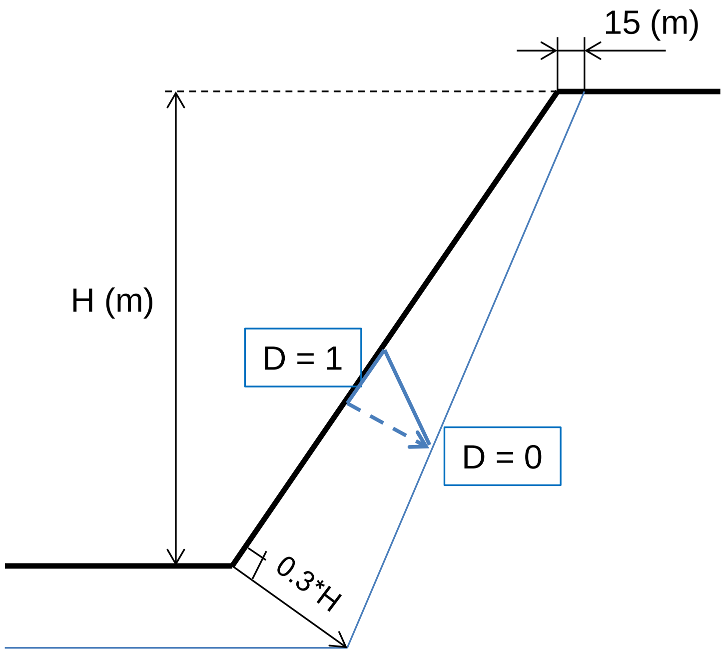


Large-scale stability assessment – approach

- Numerical modeling, Factor-of-Safety calculations (2D & 3D)
- Perfectly-plastic material model (no softening; peak strength = residual strength); Hoek-Brown material model
- Rock mass strength values estimated empirically using characterization (*GSI*) and Hoek-Brown failure criterion
- Experiences and practices from Itasca analysis of large pit slope used to supplement and refine estimates
- Acceptance criteria:
  - ❖Factor-Of-Safety for the Overall Slope Angle > 1.3
  - ❖Factor-Of-Safety for the Interramp Slope Angle > 1.2

Rock mass strength

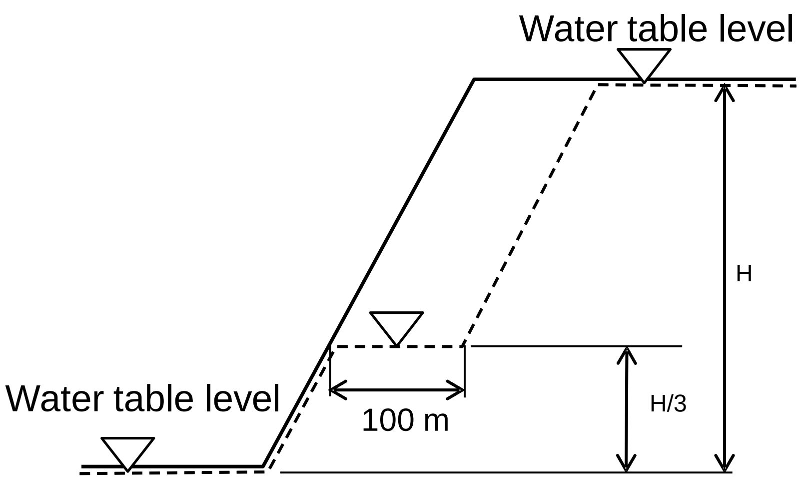
- Design values for *GSI* and *UCS*:
  - *mean – 0.5 std.dev*
  - Corresponds to 30-35 percentile
  - Accounts for heterogeneity in large-scale rock masses, and the ability for the rock to fail through the weaker components (based on experience and empirical evidence)
- Variation of *D* (disturbance factor) with depth
  - *D*=1.0 everywhere proven too conservative
  - Blast damage highest close to slope face
  - Stress relief close to slope face
  - Possible stress damage at depth



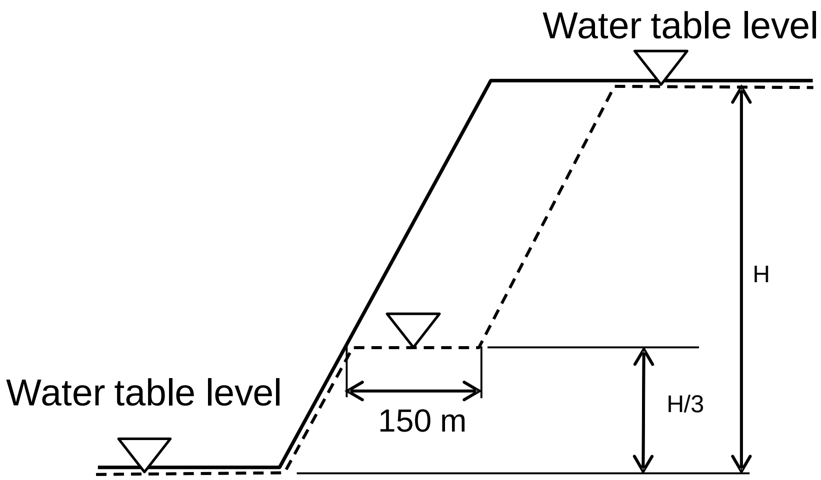
Groundwater conditions

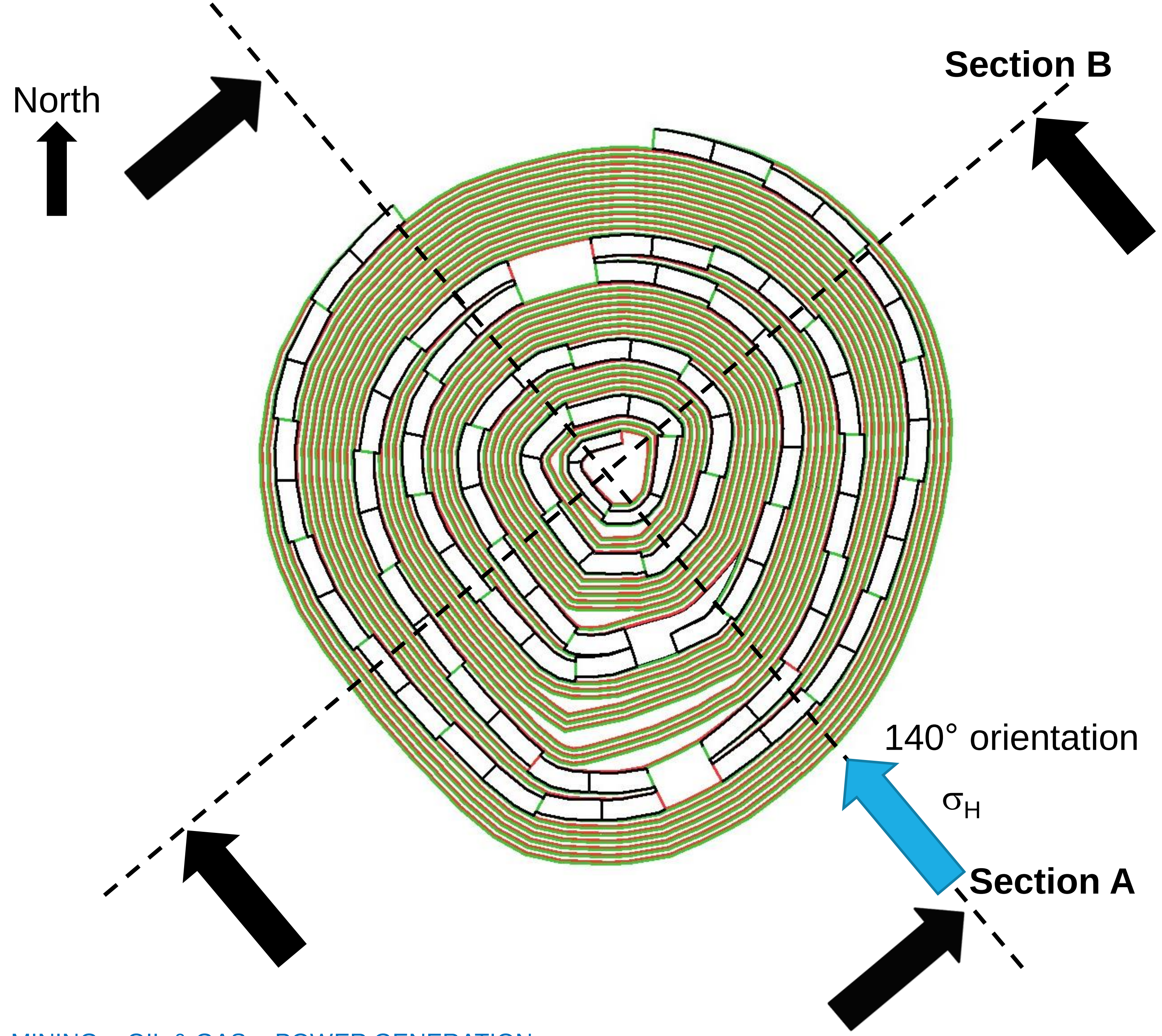
- Groundwater level currently at surface
- Future mining – groundwater conditions for Stage 5:
  - ❖ Not depressurized,
  - ❖ Depressurized 100 m horizontal distance (upper 2/3 of slope height),
  - ❖ Depressurized 150 m horizontal distance (upper 2/3 of slope height).

Partially depressurized slopes (100 m)

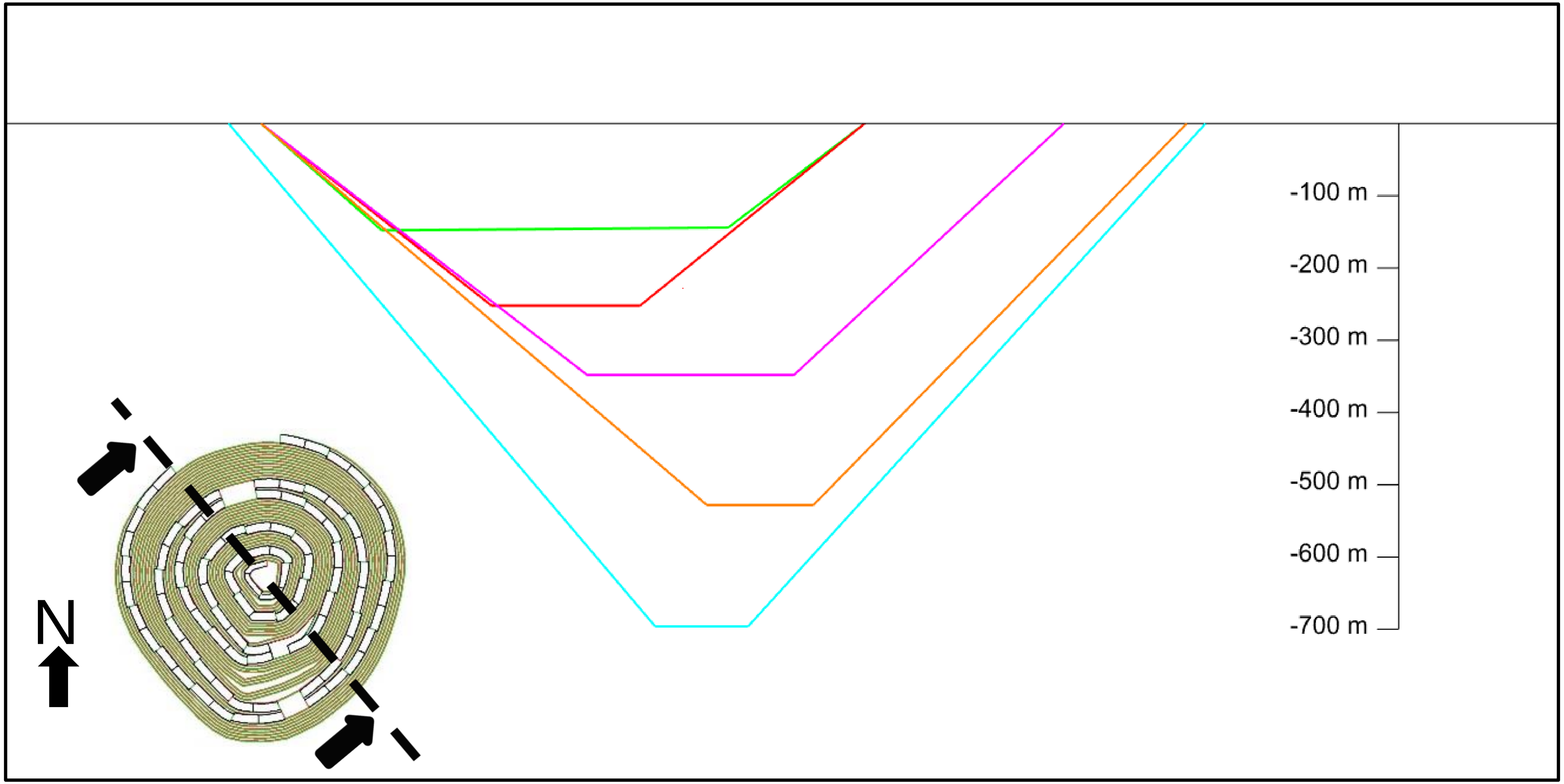


Partially depressurized slopes (150 m)




Section B
North
140° orientation
σH
Section A

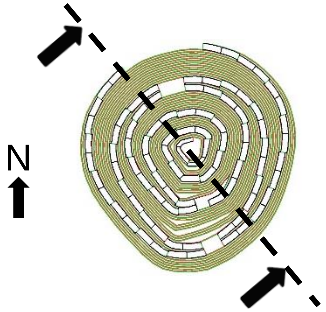
Section A



Analyzed cases

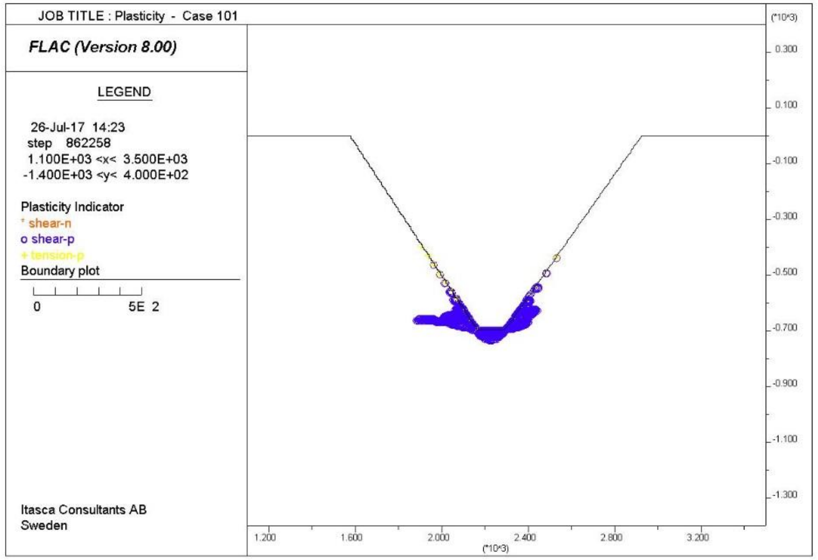
- Base Case
  - ❖ Stage 5; 50°/48° overall slope angle; no depressurization
- Depressurization
  - ❖ Stage 5; 50°/48° overall slope angle; 100-150 m depressurized zone
  - ❖ Stage 5; 54°/52° overall slope angle; 100-150 m depressurized zone
  - ❖ Stage 5; 56°/54° overall slope angle; 100-150 m depressurized zone
- Reduced strength
  - ❖ *GSI* -15%; Stage 5; 50°/48° overall slope angle; no drainage
  - ❖ *GSI* -15%; Stage 5; 50°/48° overall slope angle, 100-150 m drainage
  - ❖ *GSI* -15%; Stage 5; 54°/52° overall slope angle, 100-150 m drainage
  - ❖ *GSI* -15%; Stage 5; 56°/54° overall slope angle, 100-150 m drainage

Selected results

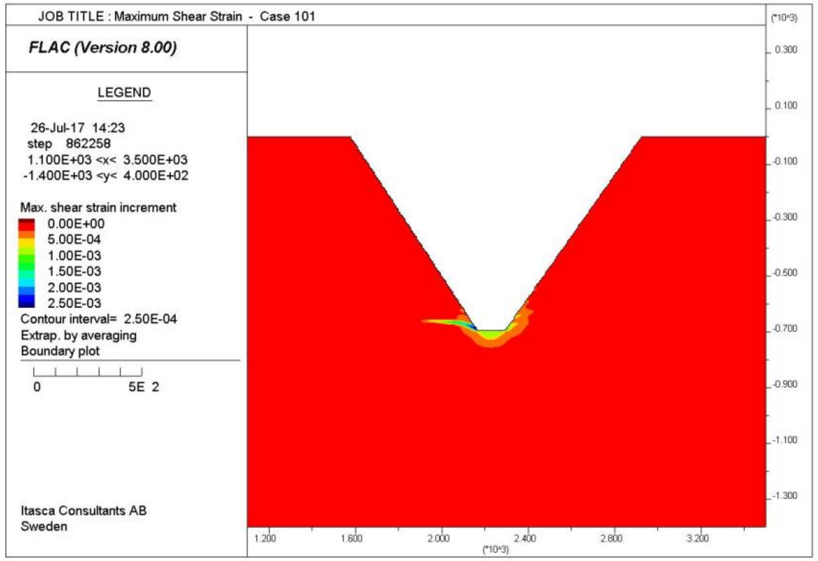


Section A – Stage 5
Base Case

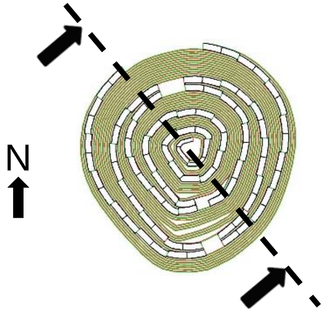
Yielding



Shear Strain Inc.



Selected results

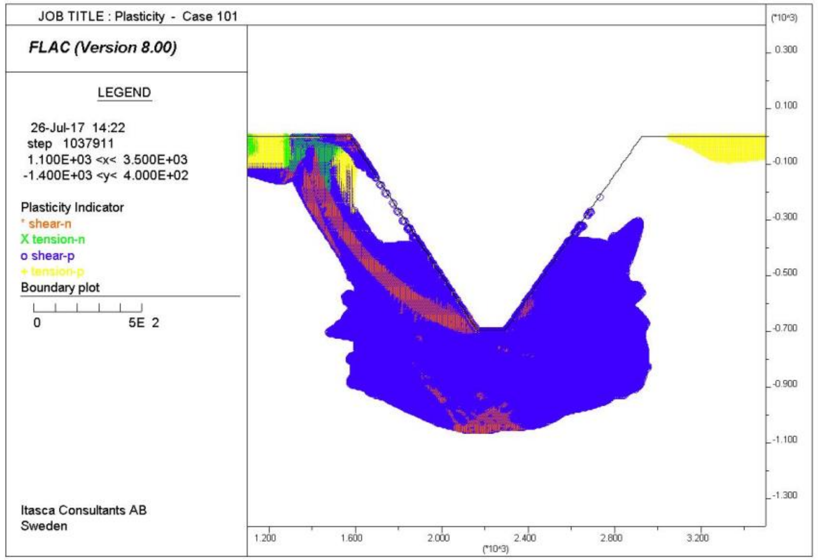


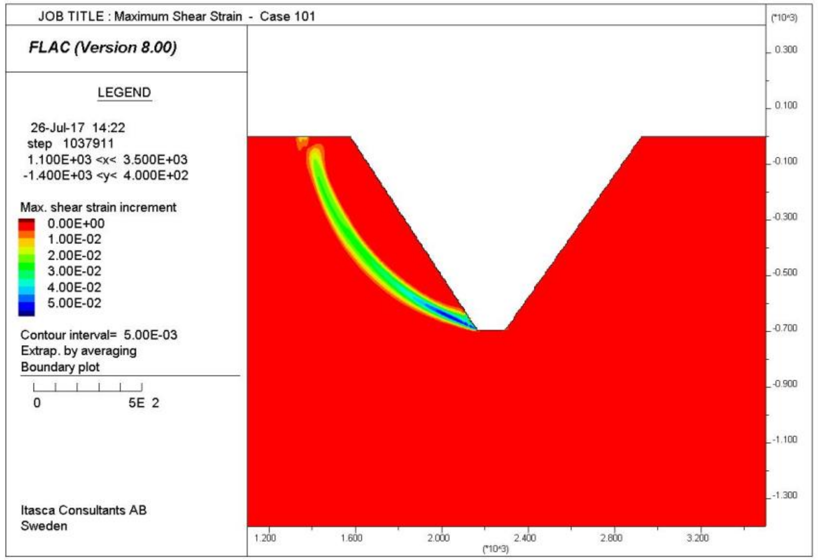
Section A – Stage 5
Base Case

Yielding

FoS = 2.37

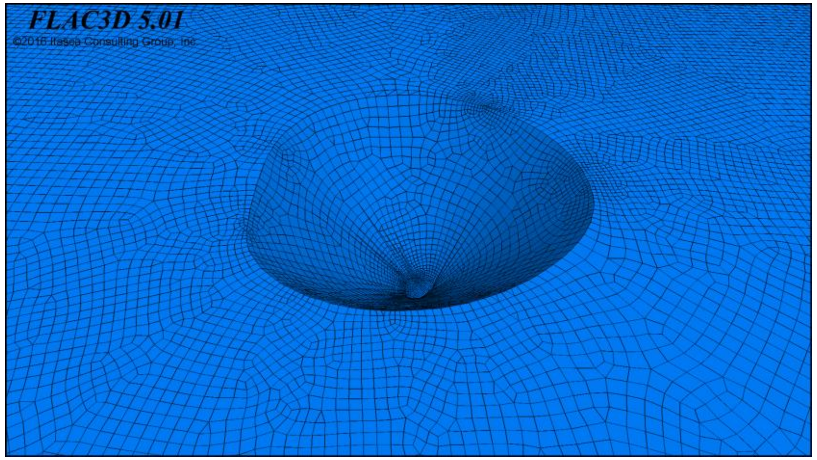
Shear Strain Inc.





Results & Design

- FoS ranging from 1.4 to 2.9 for all cases
- Results confirmed with 3D-analysis (increased FoS due to confinement effects)
- Assumed fault does not jeopardize the large-scale stability



- Drainage may be optional for the assumed rock mass quality
- Additional data collection required to meet criteria for PFS/FS level design to focus on: (i) structural-geological model, (ii) discontinuity mapping for certain portions, and (iii) core logging and strength data for certain areas.

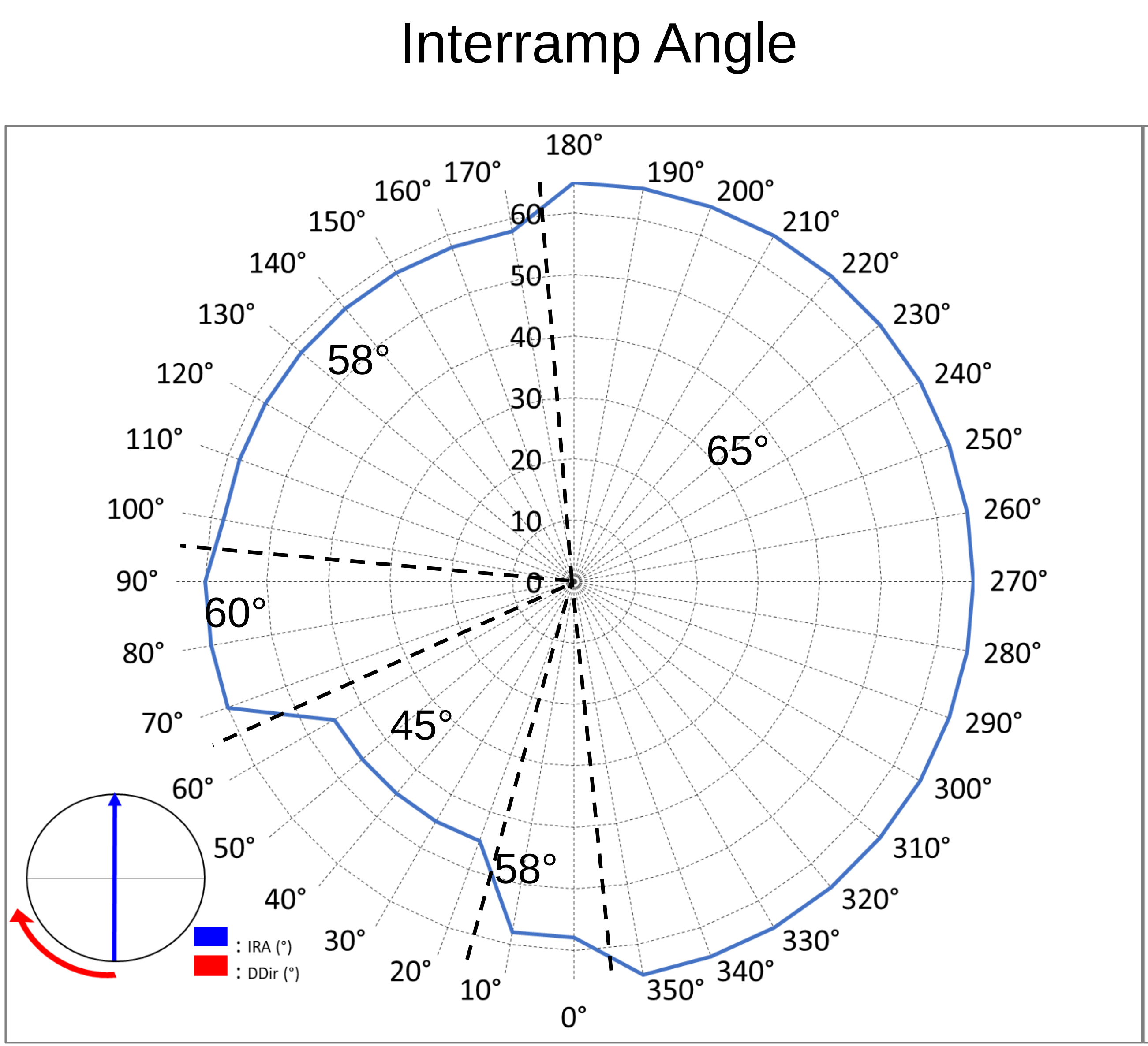
Design recommendations

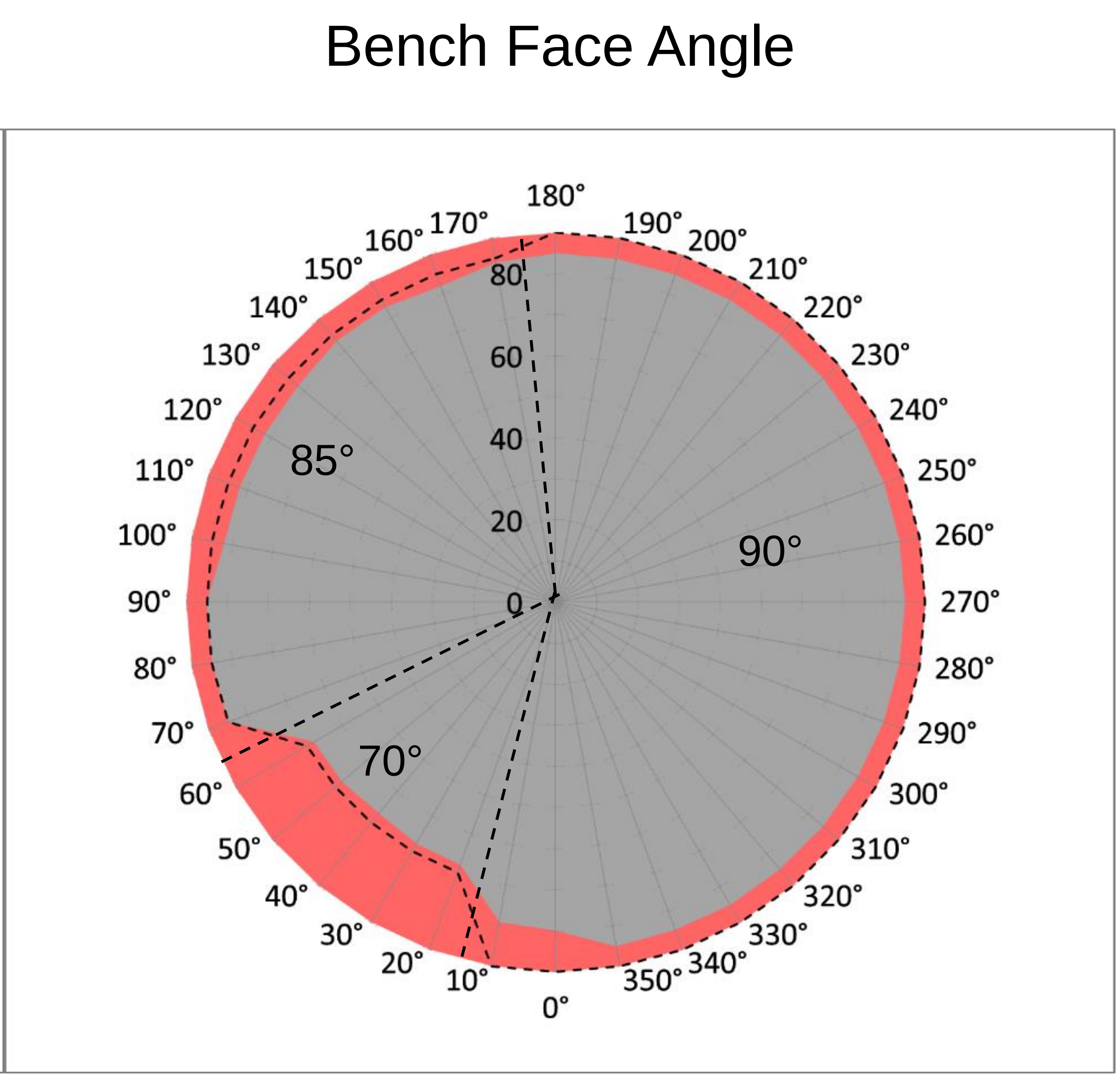
- Overall slope angles can be steep (54-56°) for an ultimate pit depth of up to 800 m
- Depressurization (drainage drilling) is ***not required*** from a stability perspective for assumed rock mass quality
- If the rock mass quality is reduced by 15%, drainage (100 m; 2/3 of the slope height) is required.

GSI [-]	Pit Depth [m]	Depressurized zone from slope face (m)	Overall Slope angle SE [°]	Overall Slope angle NE [°]	Overall Slope angle NW [°]	Overall Slope angle SW [°]
Values suggested by Boliden for Design Stage 5			48	49	50	48
Standard	800	-	54	55	56	54
↓15%	800	100 m (2/3 H)	54	55	56	54

A few words on bench design…

- Analysis of bench and interramp slopes considering:
  - ❖Spill length
  - ❖Catchment criteria
  - ❖Kinematic stability.
- Analysis sequence:
  1. Kinematic analysis of individual bench performance using joint fabric
  2. Kinematic analysis of bench stacks (interramp slopes) using minor faults fabric
  3. Compilation of the results and final kinematic design recommendations.
- Results validated against the as-built geometry of the current pit
- Maximum kinematic interramp angle & bench face angle for different slope orientations
- Each recommendation associated with an expected *median* rockfall retention performance



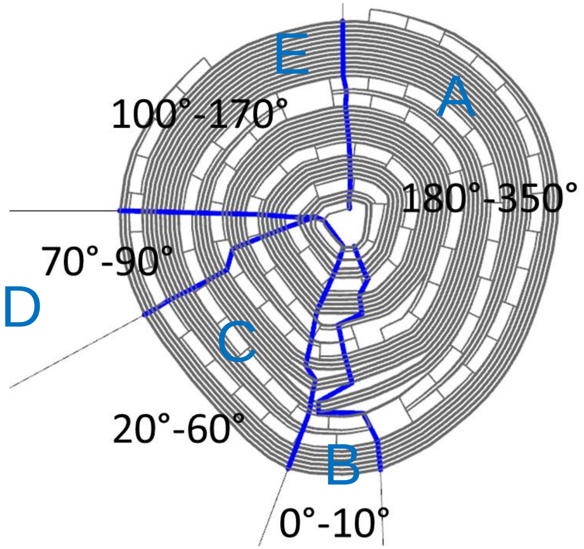


This radar plot is applicable to any future pit designs (not just the current Stage 5)

Summary – bench & interramp slopes

Slope Dip Dir.	Design Sector	Bench Face Angle [°]	Bench Width [m]	IRA [°]	Median RF Retention	Toppling Potential[1]
180°-350°	A	90°	11.2	65°	85%	≤ 11%
0°-10°	B	90°	15.0	58°	90%	≤ 5%
20°-60°	C	70°	15.3	45°	90%-95%	≤ 5%
70°-90°	D	85°	11.8	60°	90%-95%	≤ 3%
100°-170°	E	85°	12.9	58°	90%	≤ 3%

[1] Proportion of strucutral fabric with orientation prone to flexural toppling



These domain boundaries are valid for the current Stage 5-design pit shell. For any future design, please use the value in the radar plot (previous slide).

What was learnt…*for Kevitsa:*

- Steep slope angles possible for overall and interramp slopes; no obvious structural control; rock mass strength governs stability
- Drainage (depressurization) is optional if rock mass quality can be confirmed in all areas
- Opportunity to optimize bench design exists (bench face angle, bench widths)
- More structural data required to increase confidence (new structural model being developed)
- Rockfall hazard map and hazard plan (TARP) to be developed
- Document as-built bench and interramp slope geometries
- Pore pressure monitoring to verify drainage needs

What was learnt…*for the future of slope design:*

- The applied state-of-the-art approach for large-scale stability assessment seems reasonable and results appear realistic, but:
  - ***No failures observed => calibration not possible***
  - ***Validation remains a major issue***
- Experiences from from many open pit operations worldwide, in which calibration has been carried out, lends reliability to the methodology
- The approach also recognizes that failure paths can develop through the weaker parts in a heterogeneous rock mass
- Using material properties corresponding to 30–35 percentile values adds an additional margin of safety to the analyses, but:
  - ***Are properties overly conservative? and if so, by how much?***

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