SLOPESTABILITY 2018

The Spanish **Mining Council** is organising the 2018 International Symposium in Slope Stability in Open Pit Mining and Civil Engineering at the XIV International Congress for Energy and Resource Mining in Seville.

Analysis of Large-Scale Pit Slope Stability — The Aitik Mine Revisited

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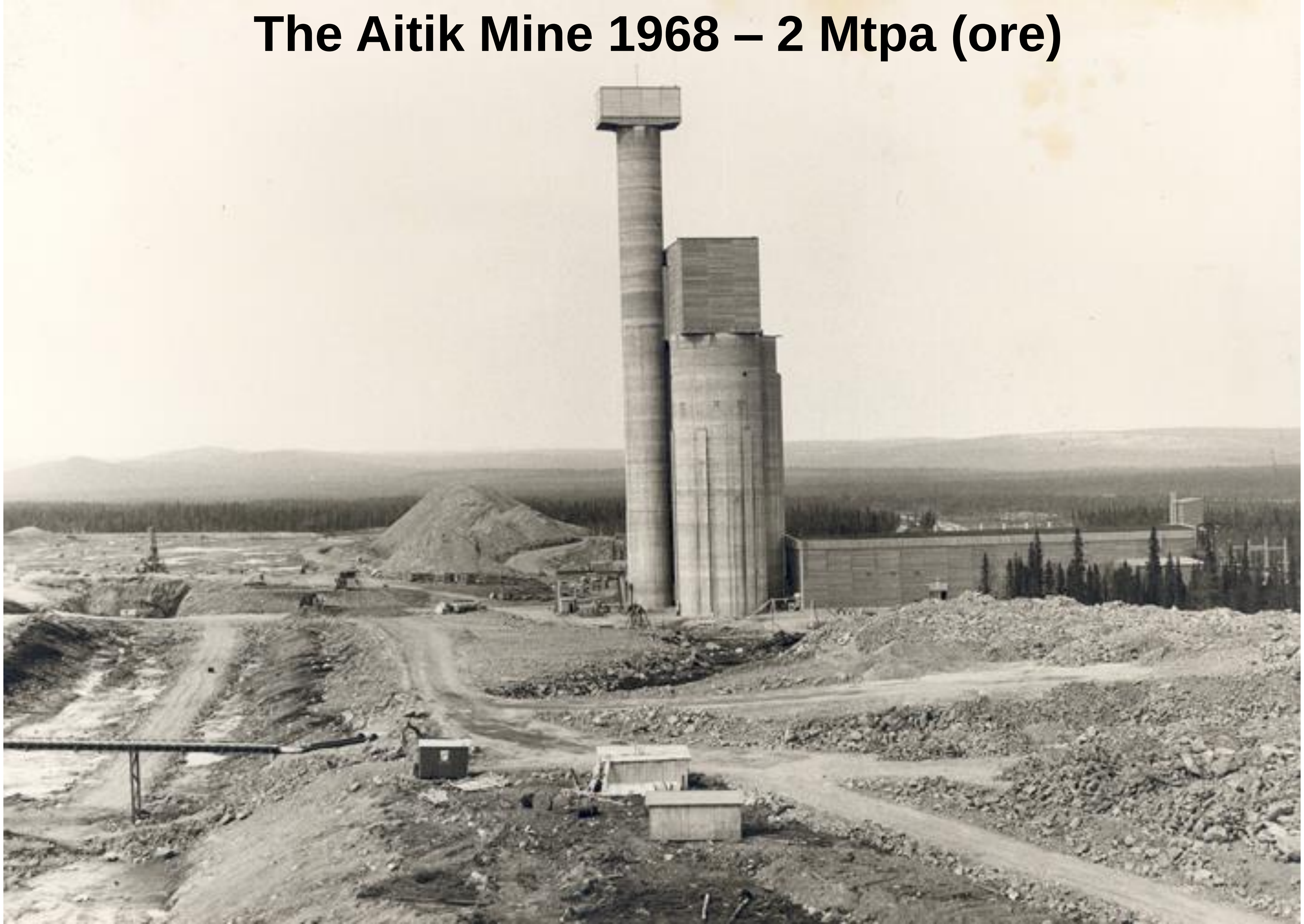
Things we all know…

- Design of overall slopes is important – for open pits of all scales – and further underlined by the push towards larger, and deeper pits
- Evolution of design tools:
  - From simple empirical and limit equilibrium methods to sophisticated numerical computer modelling
  - Rapid increase in computer capacity, but also an increased understanding of the behaviour of large-scale slopes
  - Still severely data- and knowledge constrained…
- Illustration of design development and current state-of-the-art using the Aitik open pit mine as a case in point.

The Aitik Mine

- Owned and operated by Boliden (from the start)
- Mineralization discovered in the 1930s
- Mining commenced 1968 – Boliden's first open pit
- Currently the largest metal open pit mine in Europe

The Aitik Mine 1968 – 2 Mtpa (ore)



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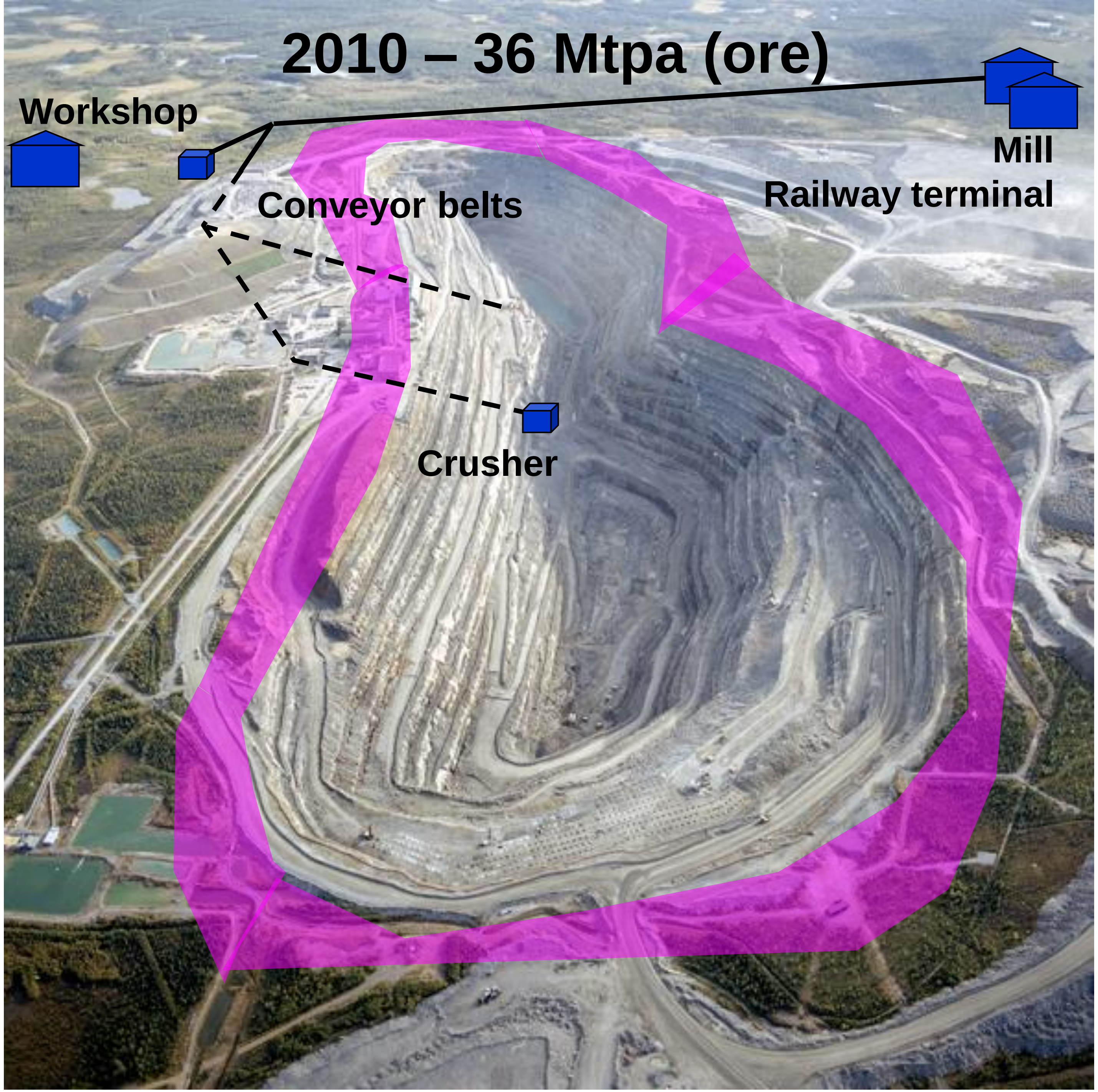
Early 70’s – 6 Mtpa (ore)

2000 – 18 Mtpa (ore)



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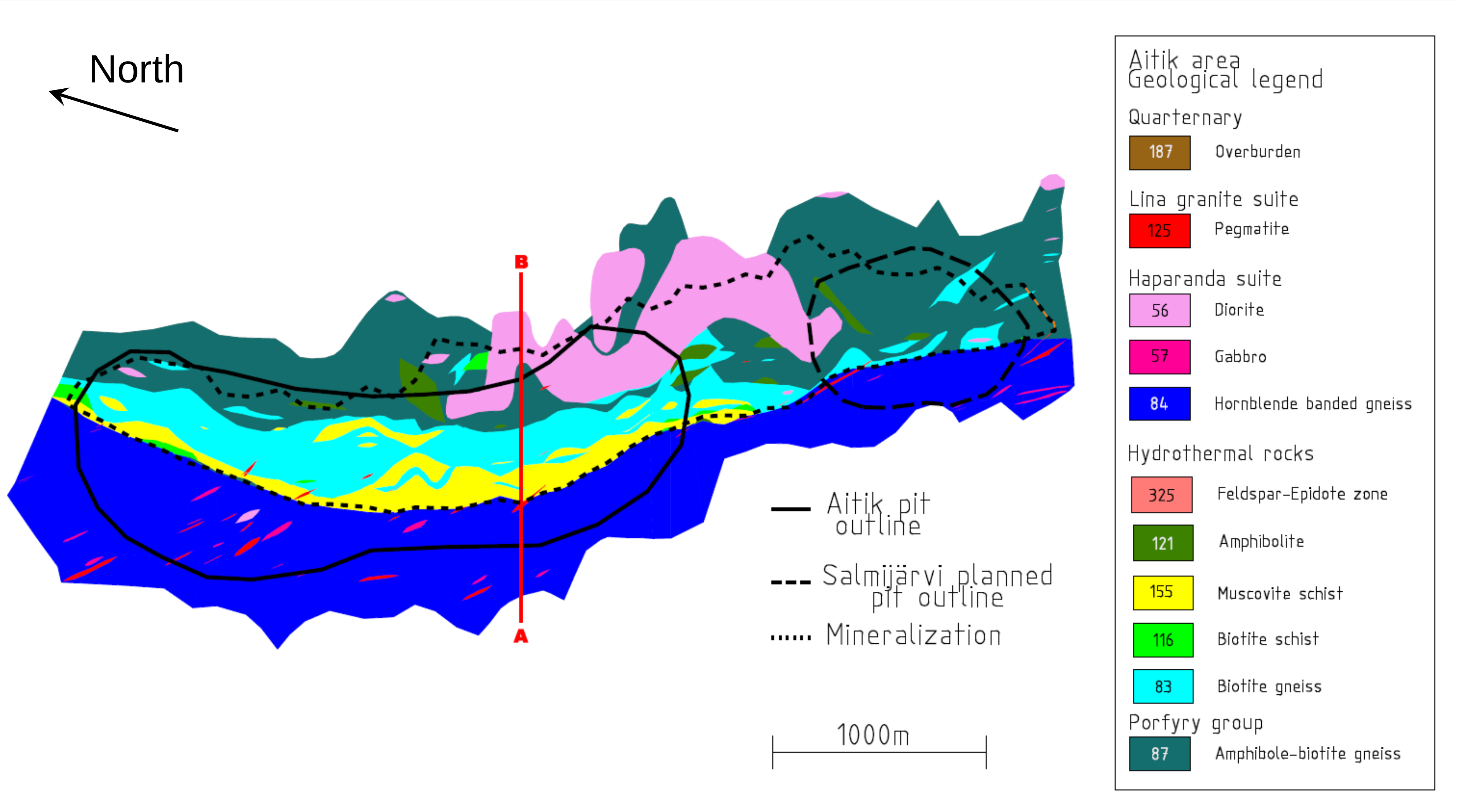
Today – 40 Mtpa (ore)
3000 x 1000 m, 420 m depth, main pit + satellite pit

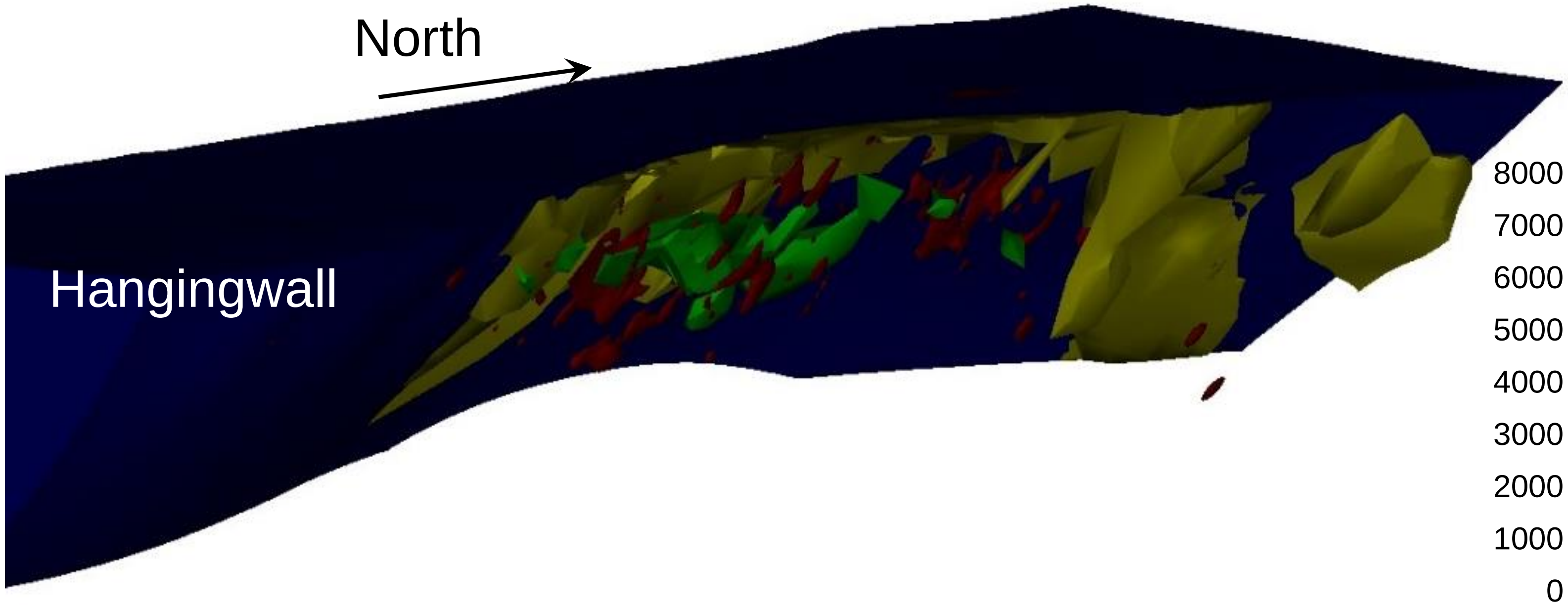
Main pit hangingwall

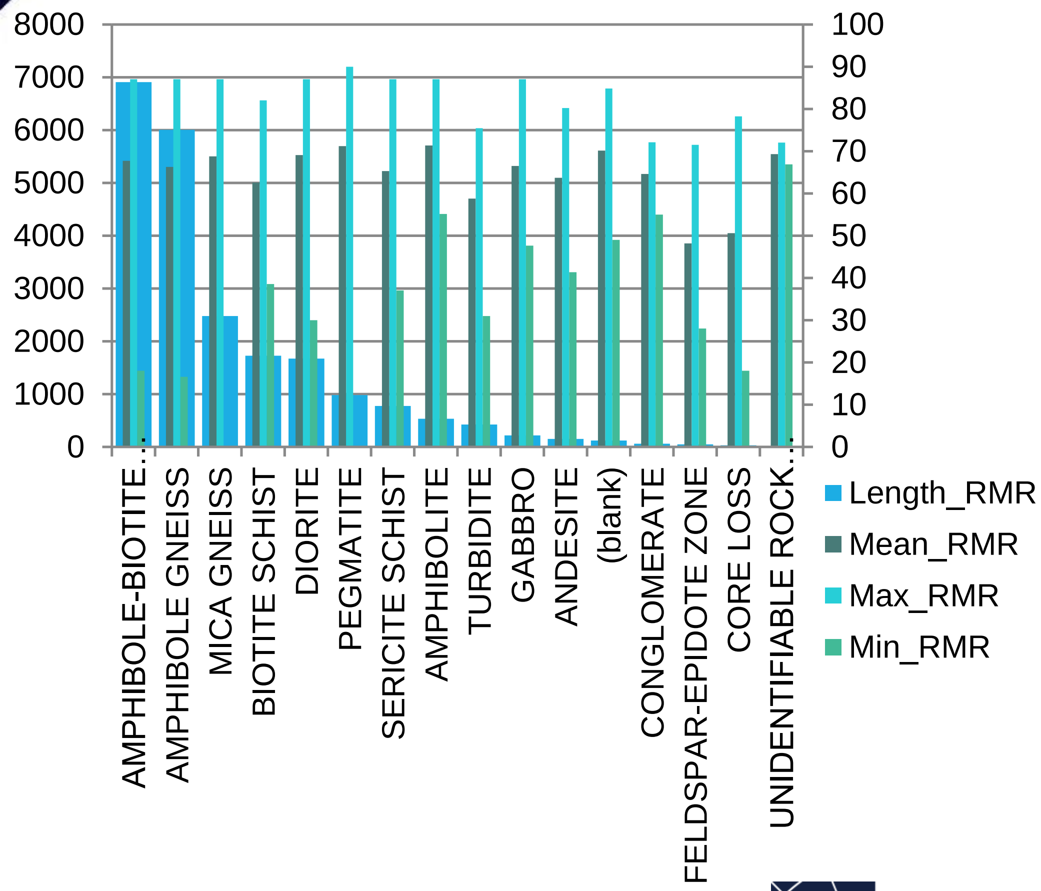
Main pit footwall

Geological setting



Geology & Geomechanics

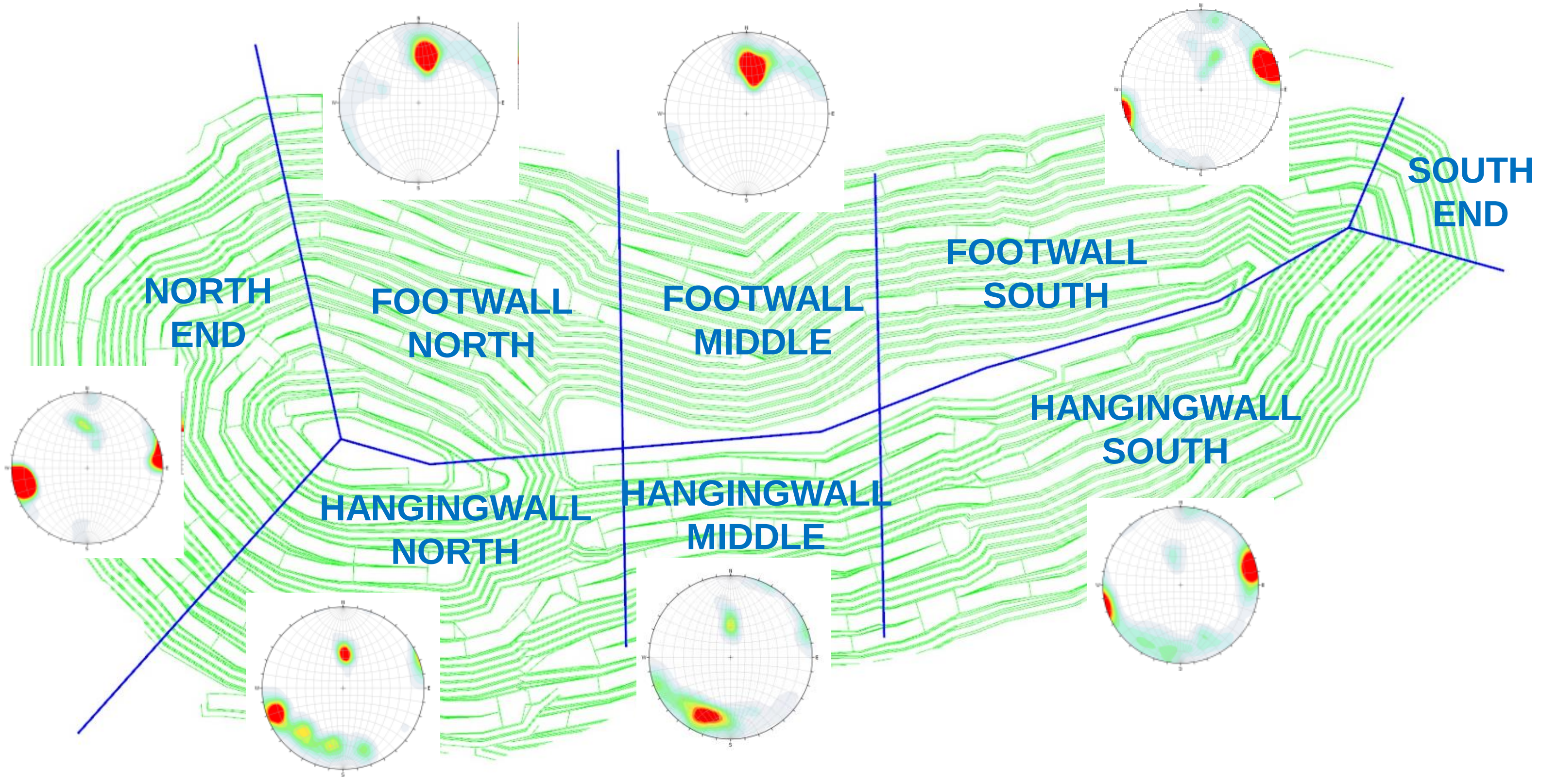




- Generally strong, metamorphic rock, with some weaker units (biotite/muscovite schist)
- Medium to good rock quality; poor quality in schist units

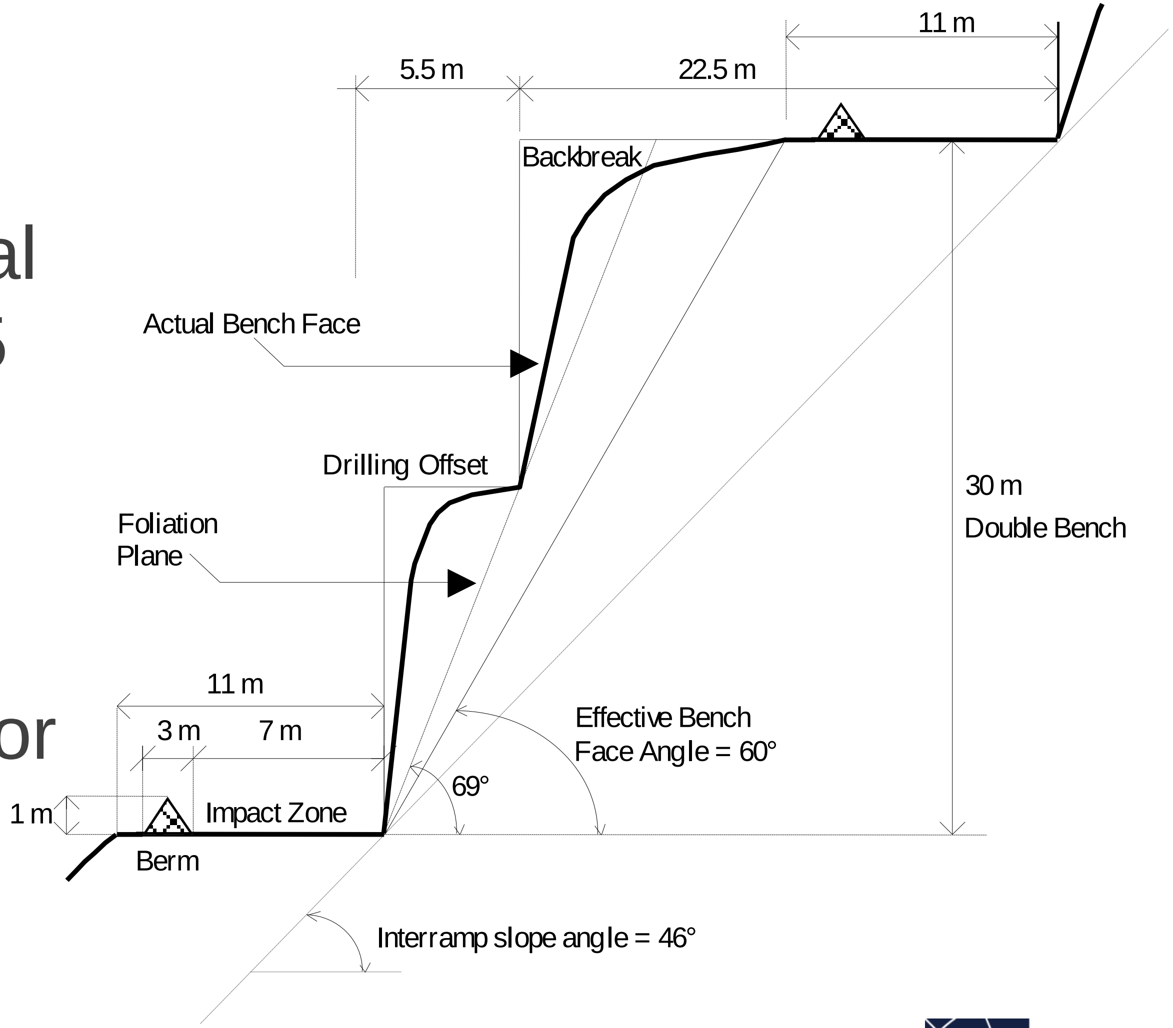
Structural Characteristics

- Well-developed foliation + cross-joints and vertical jointing
- Hangingwall contact = old thrust fault with clay
- No other large-scale structures identified



The early stages…

- First major design study in 1976 with follow-up in 1985
- Bench design based on structural control; Double-benching (2 x 15 m) with offset chosen to match foliation dip
- Catch bench width based on original Ritchie criterion – 11 m for 90% of the cases
- Overall slopes not assessed



Blasting can make things better…

- Problems:
  - ❖Vertical blast damage
  - ❖Quality control / hole deviation
  - ❖Local crest failures & bench widths not attained

- Solutions:
  - ❖Blast damage model (PPV)
  - ❖More buffer rows
  - ❖Pre-split with decoupled charges

Large-scale slope stability at Aitik…

- Issues for hard rock slopes:
  - ❖ No failure observations = no calibration of properties possible (except that failure should not develop for current mining geometries)
  - ❖ Failure may be rapid and uncontrollable (brittle rock)
- Remedies:
  - ❖ Develop methodology for modeling and parameter assessment and apply to other slopes ***with*** failure
  - ❖ Design methodology must be conservative => use residual strength parameters

Large-scale and 2D – at Aitik…

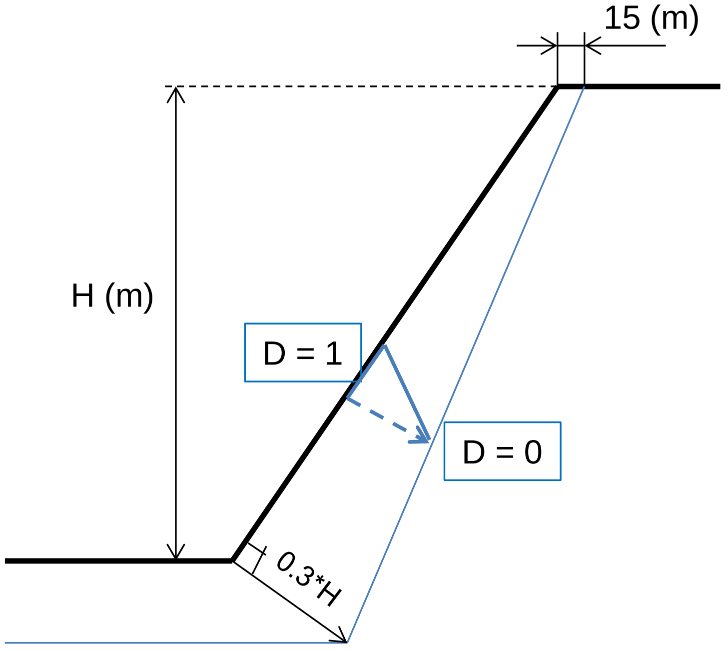
- Project on large-scale slope stability in hard rocks (1990s) & revision of overall slope angles:
  - Empirical case study database
  - Updated geomechanical model
  - 2D numerical modeling – continuum models, rock mass strength + residual strength parameters + ubiquituos joints (foliation)
- Results
  - Stability assessment to 500 m depth
  - Increase of interrramp and overall angles (+5°) with drainage program
  - Additional modeling for deeper (750 m) pit => additional drainage

2D and deeper – and the importance of "disturbance"…

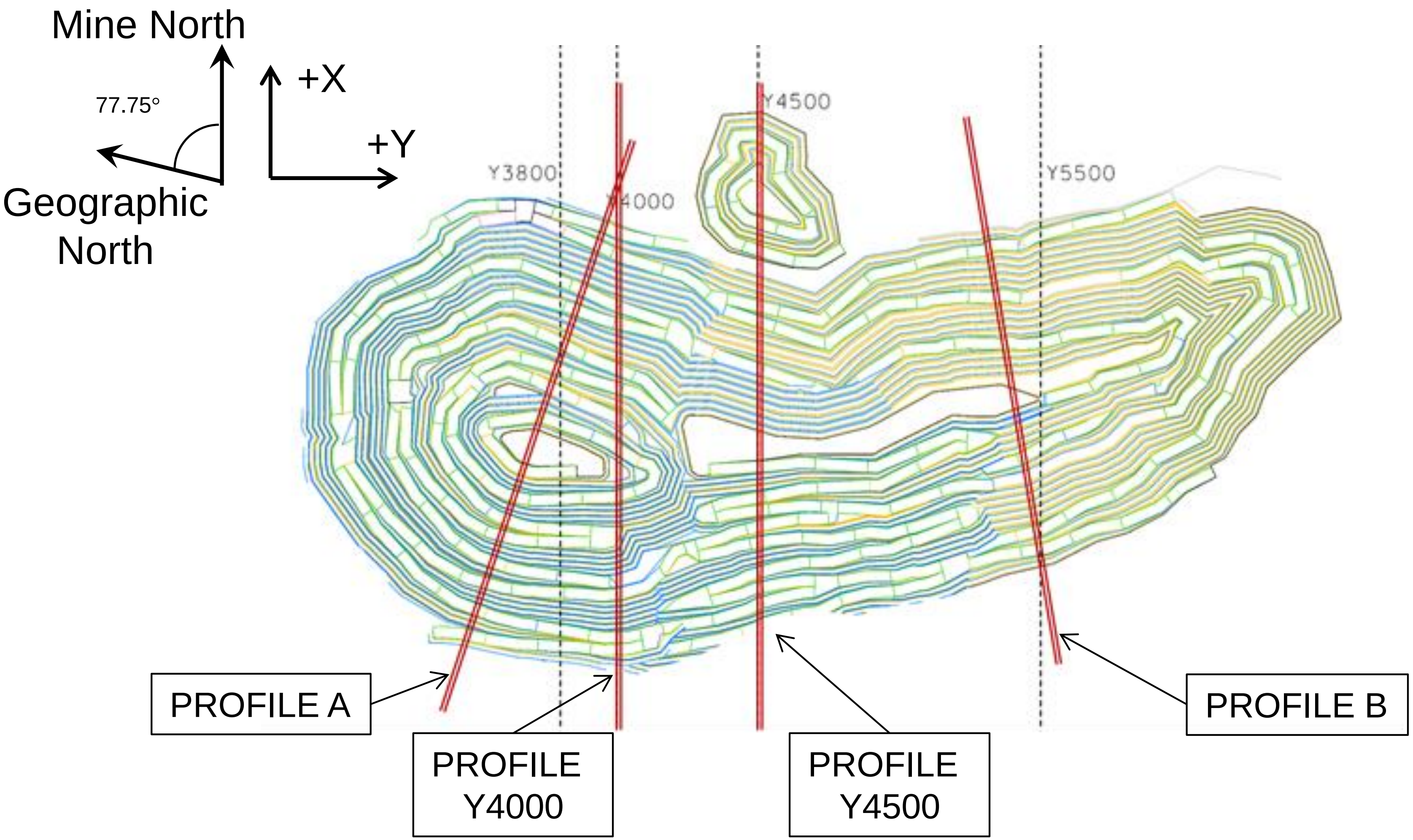
- New strategic plan – and deeper mining (2015-2016)!
- New analyses:
  - ❖Numerical modeling, Factor-of-Safety calculations, 2D (& 3D)
  - ❖Perfectly-plastic material model (no softening; peak strength = residual strength); Hoek-Brown material model
  - ❖Rock mass strength values estimated empirically 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 criterion: FoS for the Overall Slope Angle > 1.2

2D and deeper – and the importance of "disturbance"…

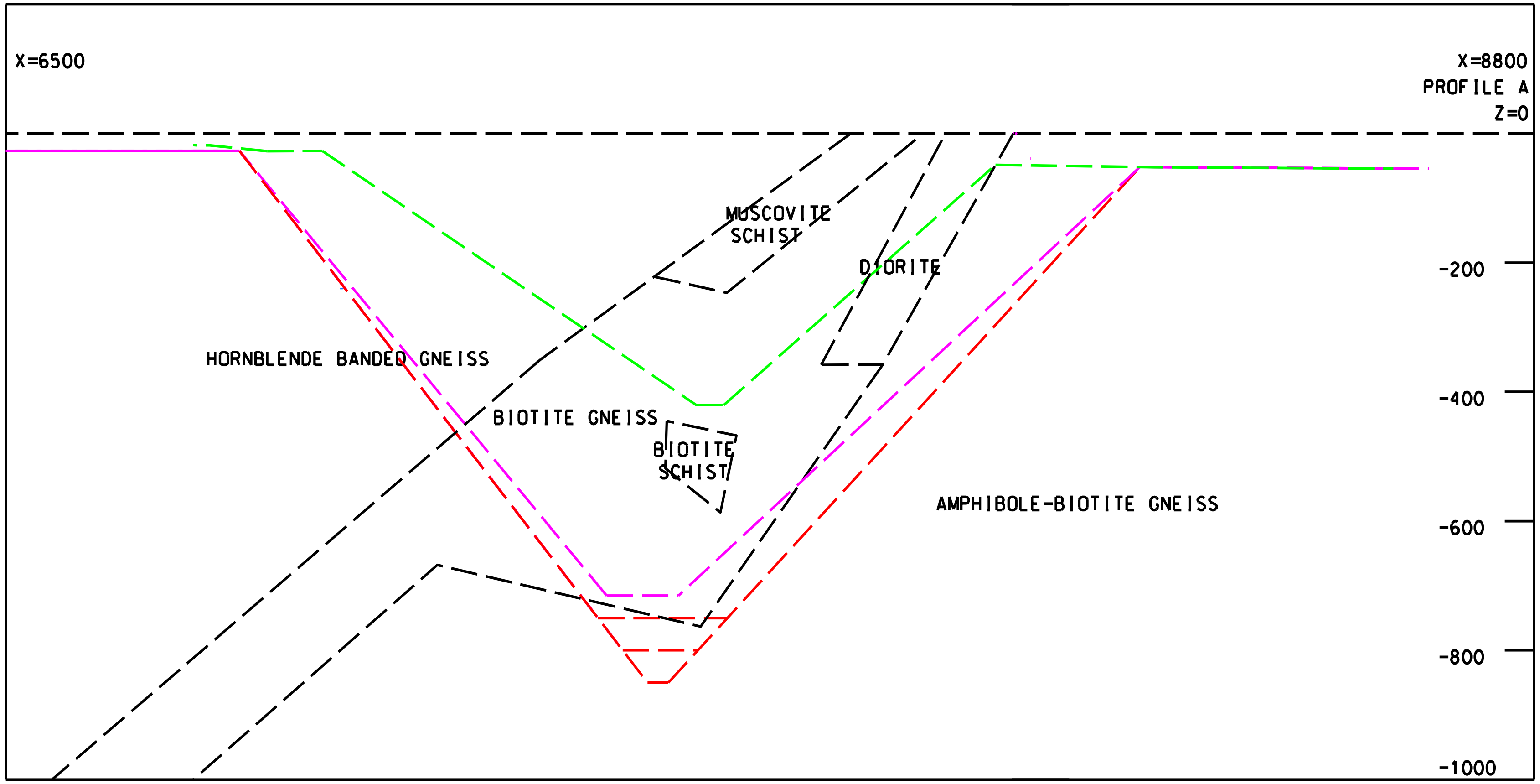
- Design values for *GSI* and *UCS*:
  - *mean – 0.5 std.dev*
  - Corresponds to 30-35 percentile
  - Accounts for heterogeneity in large-scale rock masses, and the ability for the rock to fail through the weaker components (based on experience and empirical evidence)
- Variation of *D* (disturbance 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



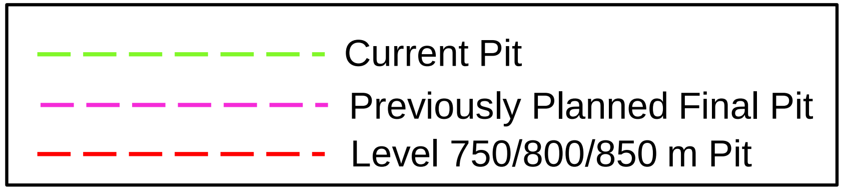
2D and deeper – and the importance of "disturbance"…



2D and deeper – and the importance of "disturbance"…



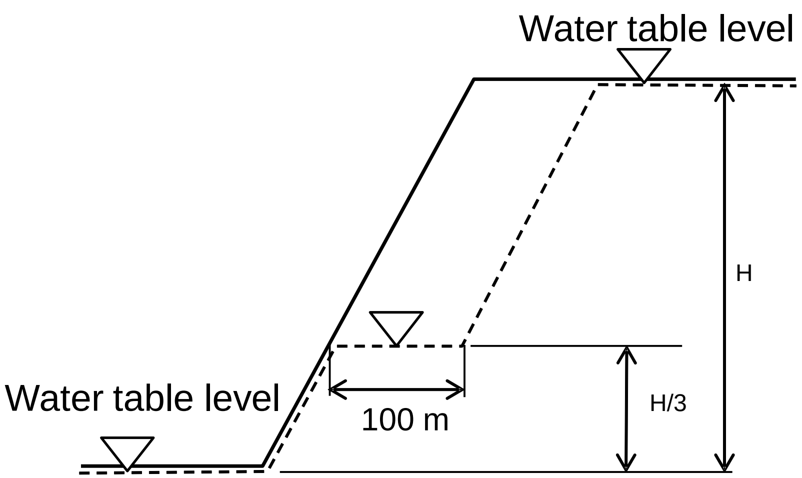
DESIGN PROFILE A



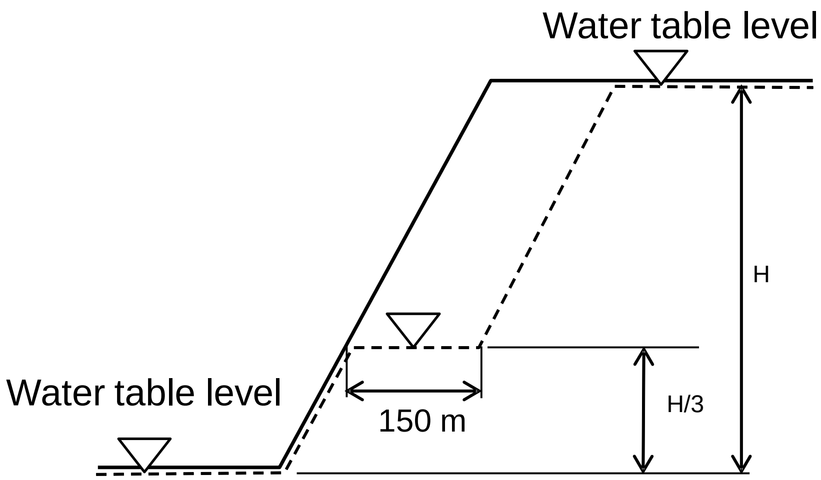
2D and deeper – and the importance of "disturbance"…

- Groundwater conditions:
  - Partly depressurized in upper portion; face seepage in lower portion
  - Scenario 1: Depressurized 100 m horizontal distance (upper 2/3 of slope height)
  - Scenario 2: Depressurized 150 m horizontal distance (upper 2/3 of slope height).

Partially depressurized slopes (100 m)



Partially depressurized slopes (150 m)



Results & design recommendations

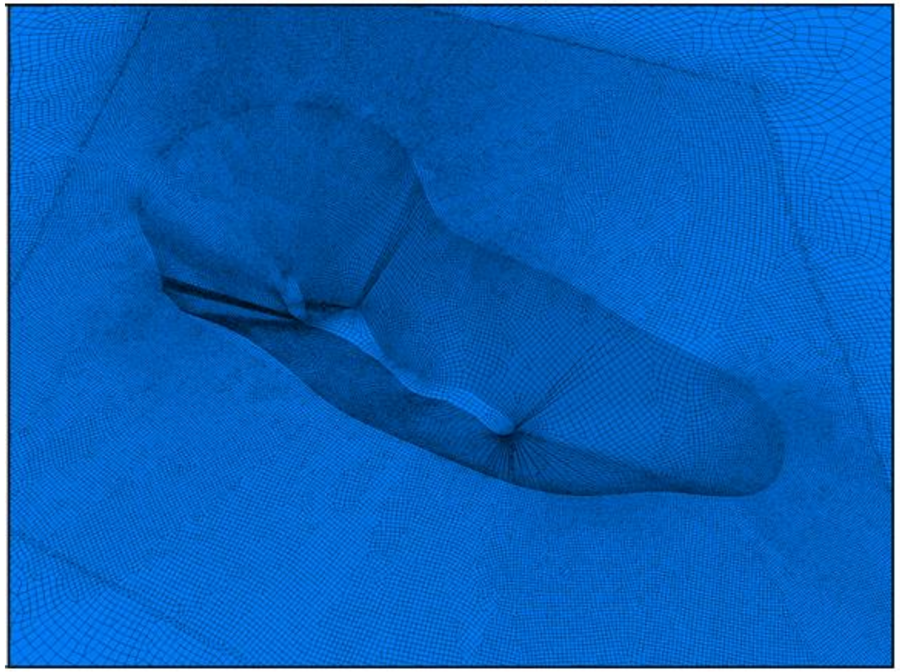
HW overall slope angle [°]	Pit bottom [level]	Depressurization [m]
48	800 m	100 (2/3 H)
52	800 m	150 (2/3 H)
50	850 m	150 (2/3 H)
54	850 m	150 (H)
54 *	600 m	100 (2/3 H)
54 *	600 m	100 (2/3 H)

FW overall slope angle [°]	Pit bottom [level]	Depressurization [m]
47	800 m	100 (2/3 H)
45	850 m	100 (2/3 H)
47	850 m	150 (2/3 H)
47*	600 m	100 (2/3 H)

* Middle-southern portion (lower final slope heights)

2D or 3D? Or both?

- How conservative are 2D-analyses?
- 3D-check for Aitik geometry:
  - ❖ Simplified slope, undrained conditions
  - ❖ FoS (3D) = 2.0 ⬄ FoS (2D) = 1.2 for the same case
- Geometry matters (a lot)!



Aitik findings….

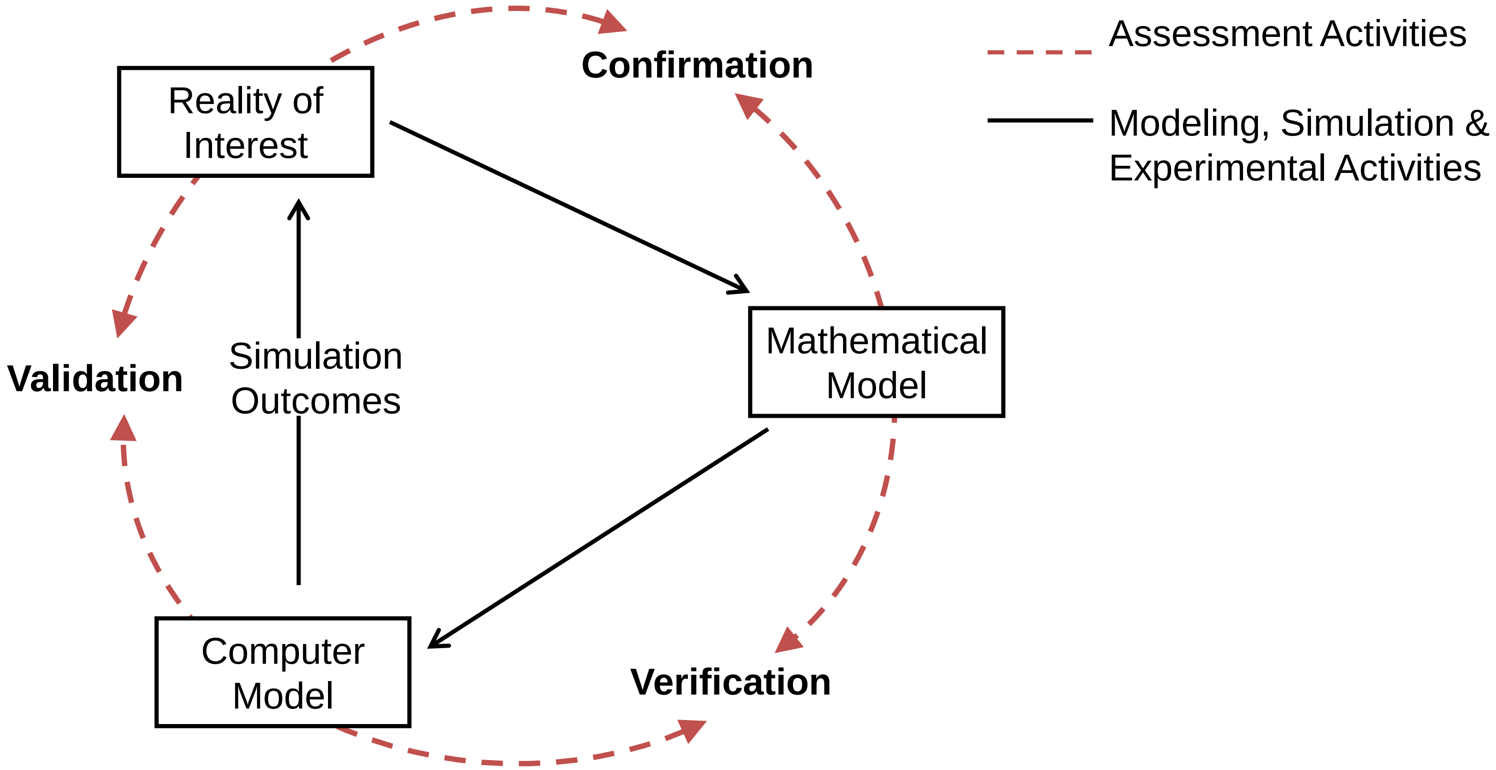
- Increased reliability in bench slope design
  - ❖ Presplit blasting on footwall (inclined, 70°) and for modified ramp design
  - ❖ Increased safety of benches; maintained catch bench design
  - ❖ Revised acceptance criteria
- Improved interramp slope design
  - ❖ Increase on footwall interramp slope angle from improved blasting
  - ❖ Implemented allowed maximum interramp height = 200 m (6–7 double benches)
  - ❖ Rock mass stability => steeper interramp angles allowed
- Overall pit slope design
  - ❖ Verified overall pit slope angles: 47° for footwall; 54° for hangingwall, for a maximum pit depth of 850 m
  - ❖ Depressurized conditions required (150 m horizontal distance)

The future…

- Analytical methods are standard for bench-scale design
- Numerical modeling remains the preferred tool for large-scale stability assessment
  - 3D models, DFN input, coupled (water-stress) modeling, etc. are all increasingly used
  - Computational speed less of an issue…cloud computing emerging!?
- Advances in data collection not on par with advances in modeling capabilities
  - Are we using the right tools? Volumetric coverage?
  - Is there "unconventional" data to be used? As "proxies" for rock mechancis parameters?

The future…

- Validation efforts required:
  - ❖Partial validation is also of value!
  - ❖Acceptance criteria for validation



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