Three-dimensional Modeling and Stress Calibration for a Complex Mining Geometry

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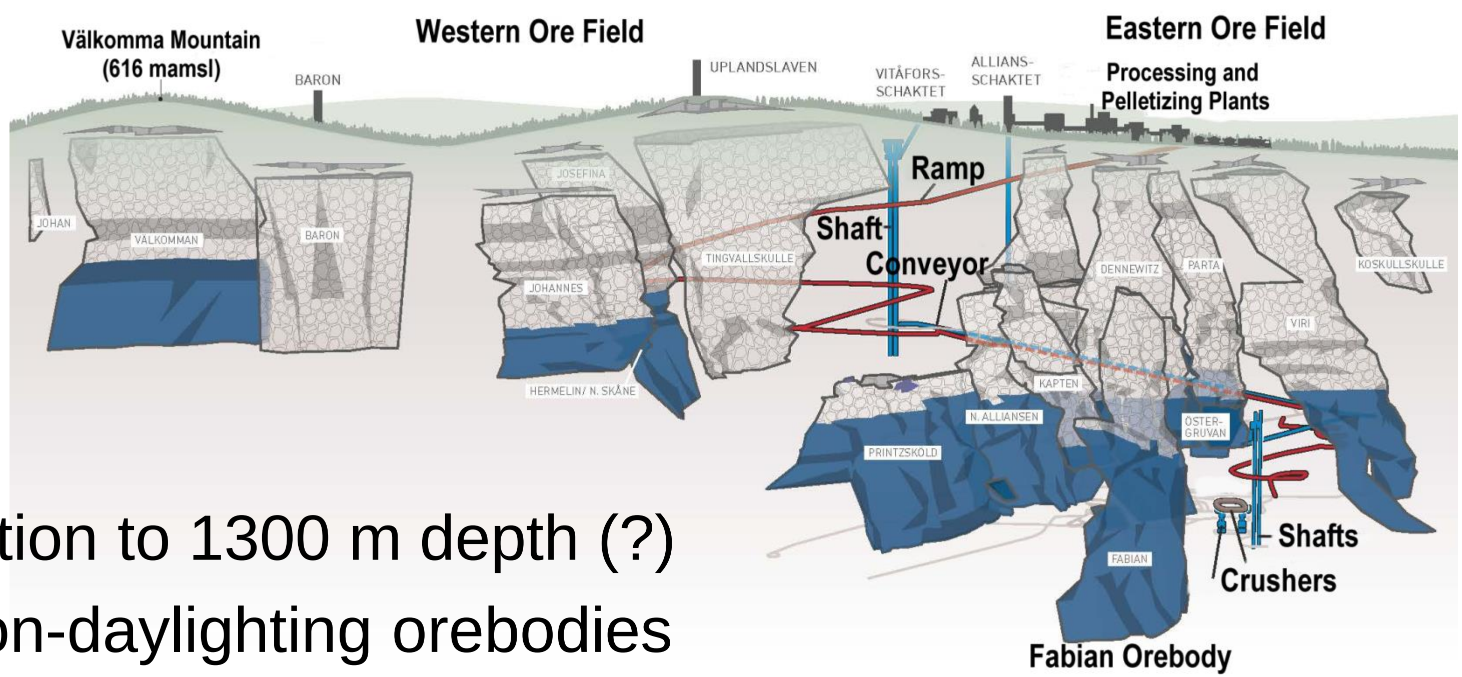
The LKAB Mining Company

- Iron ore producer
- Two underground mines in operation
  - Kiruna
    - 1 orebody (Kiirunavaara)
    - Annual production ≈ 29 Mton
  - Malmberget
    - 10 actively mined orebodies
    - Annual production ≈ 15 Mton
- Mining only with sublevel caving method

The LKAB Malmberget Mine

- Many orebodies of varying size and shape (8 km^2 area)
- Hard, strong rock mixed with weak, soft rock + some large-scale structures
- Mining currently at 400-900 m depth

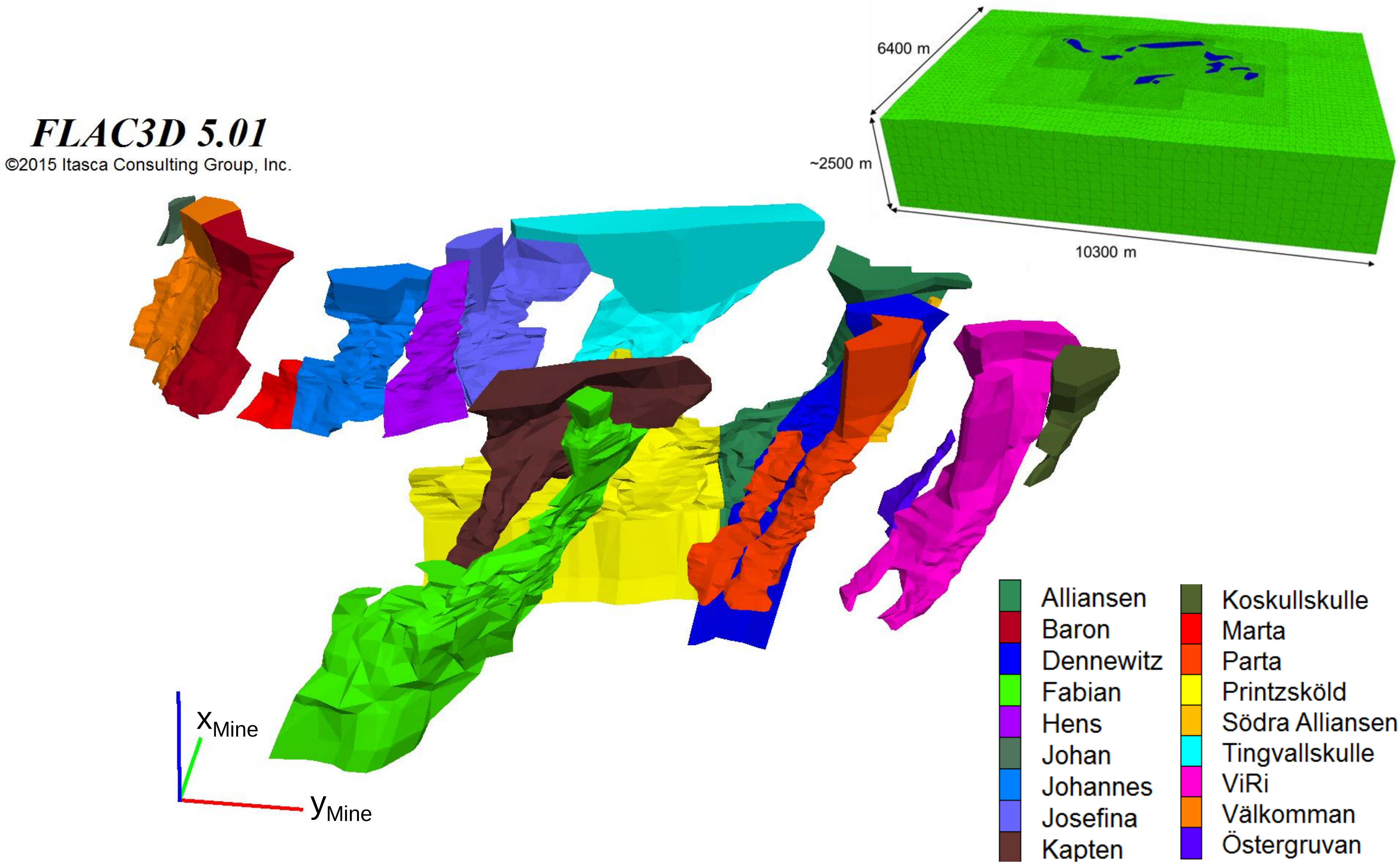


- Mineralization to 1300 m depth (?)
- Several non-daylighting orebodies

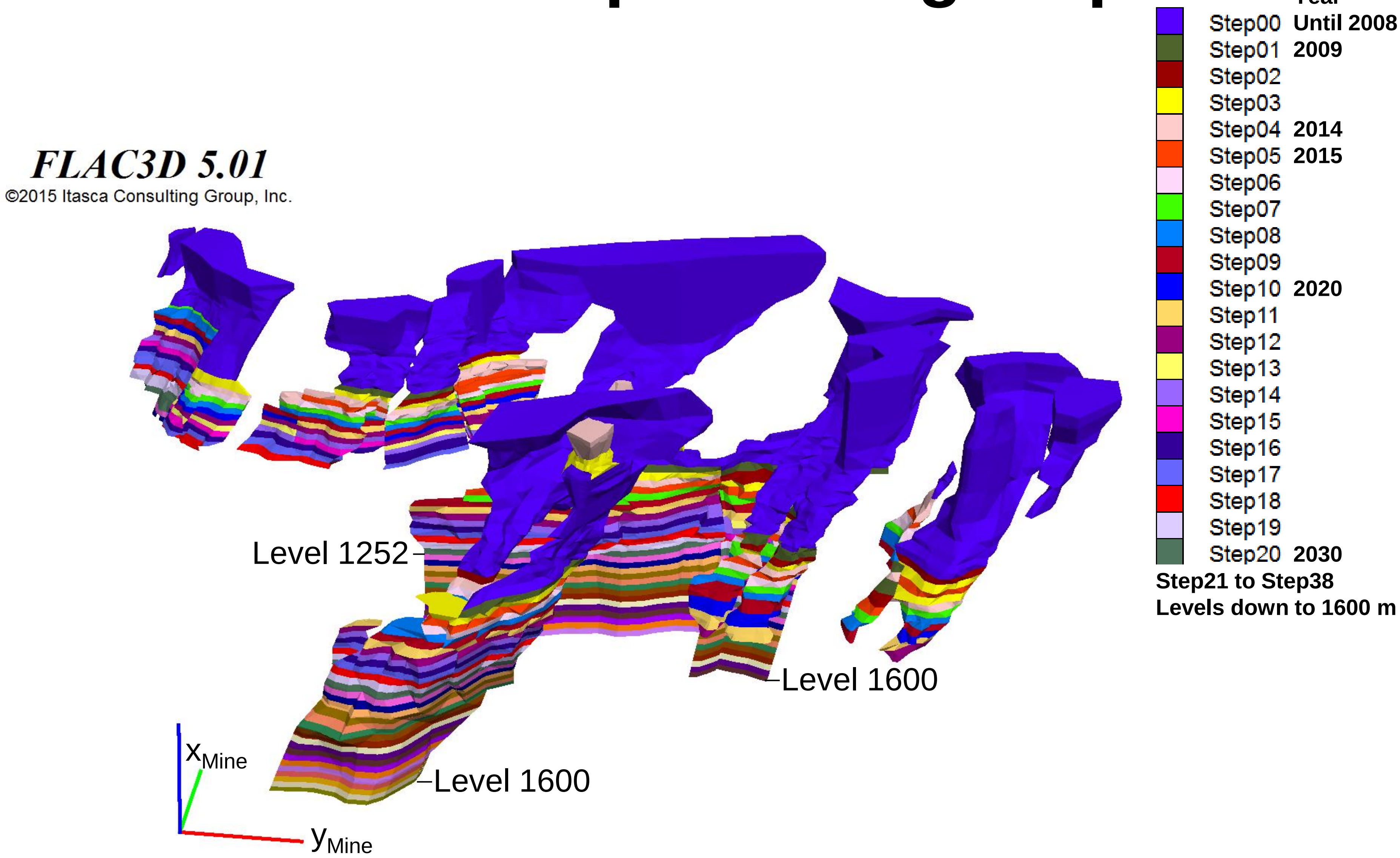
Objective & Scope

- Study stress situation for potential continued mining towards greater depths
- Stress calibration against stress measurements using numerical modeling
- Use of calibrated model:
  - Study stresses at existing infrastructure
  - Study stresses at potential future haulage level locations
  - Input to local models

Model setup – orebodies

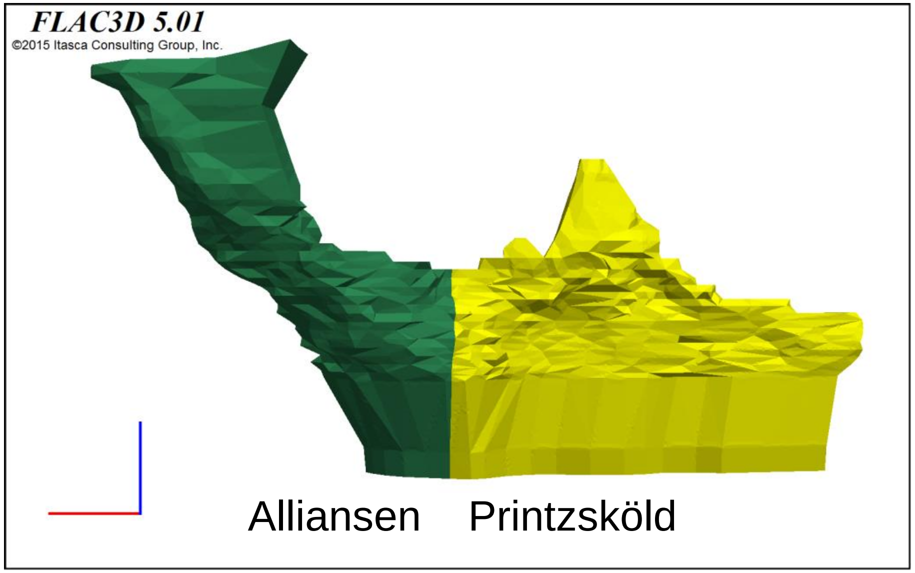


Model setup – Mining steps

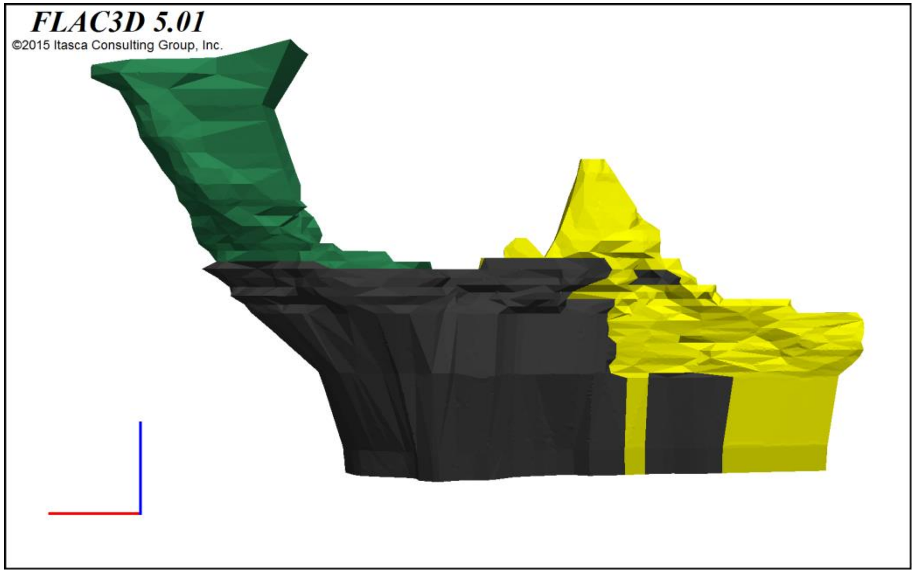


Rock materials

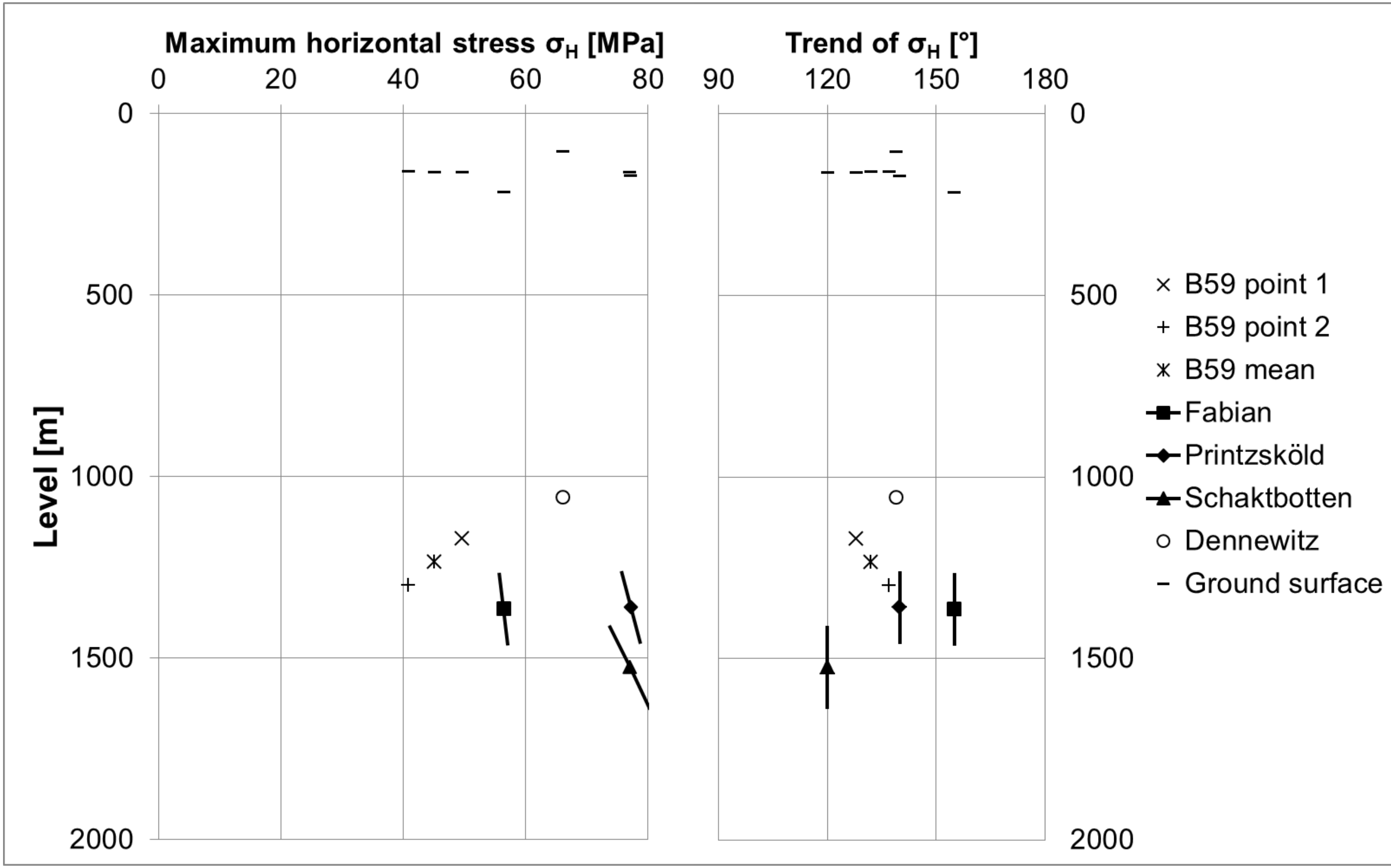
orebodies



orebodies + biotite-zone



Rock stress data



Stress calibration

- Assumptions:
  - Primary stress (before mining) is horizontally and vertically oriented, thus: $\tau_{xz} = 0$
    $\tau_{yz} = 0$
  - Linear-elastic
  - Vertical stress is primarily gravitational
- Each stress component can be described by:

$$\sigma_{ij}^{total} = \sigma_{ij}^{constant} + \sigma_{ij}^{gradient} \cdot z + \sigma_{ij}^{gravitation}$$

- Unit stresses + superposition, two solving methods:
  - Excel Solver
  - Genetic Algorithms

McKinnon, S. D. 2001. Analysis of stress measurements using a numerical model methodology. *Int. J. Rock Mech. Min. Sci.*, ***38***, pp. 699-709.

Stress calibration

Unit stresses (7 different cases)

$\sigma_x^{constant} = 1.0\,\text{MPa}$

$\sigma_y^{constant} = 1.0\,\text{MPa}$

$\tau_{xy}^{constant} = 1.0\,\text{MPa}$

$\sigma_x^{gradient} = [0,1]\,\text{MPa}$

$\sigma_y^{gradient} = [0,1]\,\text{MPa}$

$\tau_{xy}^{gradient} = [0,1]\,\text{MPa}$

0.0 MPa at z=0 m
1.0 MPa at z=-2500 m (bottom)
=> 0.0004 MPa/m)

gravitation (g = 9.81 m/s^2)

Stress relation for each component exemplified for σ_x

$$\sigma_x^{calc} = A\sigma_x^{\sigma_x^{constant}} + B\sigma_x^{\sigma_y^{constant}} + C\sigma_x^{\tau_{xy}^{constant}} + D\sigma_x^{\sigma_x^{gradient}} + E\sigma_x^{\sigma_y^{gradient}} + F\sigma_x^{\tau_{xy}^{gradient}} + G\sigma_x^{gravitation}$$

Results

$$\sigma_x^{calc} = D\sigma_x^{\sigma_x^{gradient}} + E\sigma_x^{\sigma_y^{gradient}} + F\sigma_x^{\tau_{xy}^{gradient}} + G\sigma_x^{gravitation}$$

Case	Description	D	E	F	G	Mean error
Solver case 1	5 points	0.02909	0.02665	-0.01169	-1.0	20.9 %
Solver case 2	5 points Biotite	0.02995	0.02733	-0.01217	-1.0	33.5 %
GA case 1	5 points Constraints	0.02204	0.01984	-0.01132	-1.0	21.7 %
GA case 2	5 points Biotite Constraints	0.02300	0.02020	-0.01212	-1.0	23.1 %

$\sigma_H = 0.0396$ z

$\sigma_h = 0.0161$ z

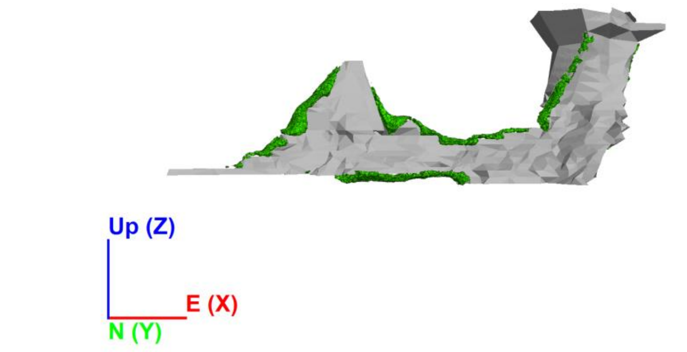
$\sigma_v = \rho gh / 10^6$ (~0.0265 z)

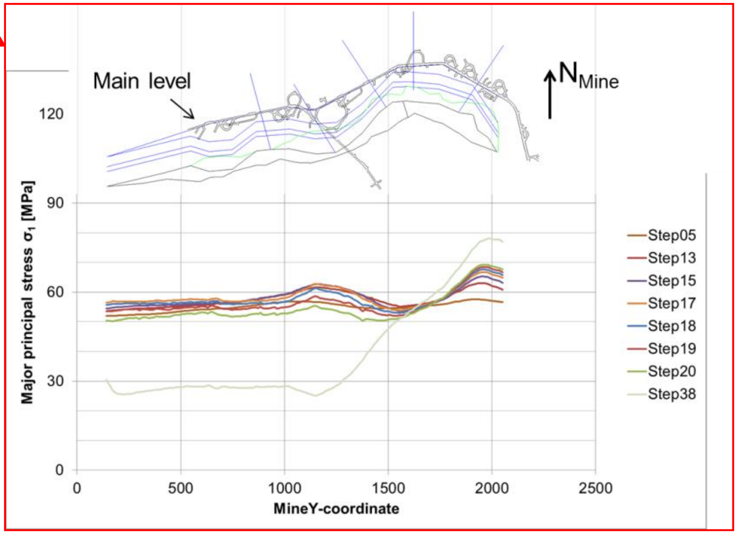
Orientation of $\sigma_H = 132°$

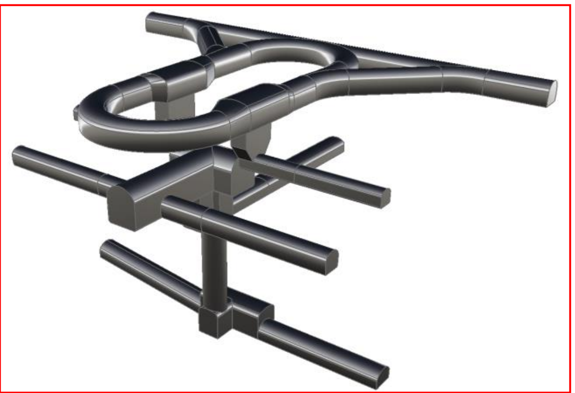
Applications

- Overall stress evaluation
- Main haulage level
  - 1250 m
  - 1500 m
- Haulage levels
  - at Fabian 1250 m
  - at Fabian 1500 m
  - at Västra fältet 1000 m
- Input to local 3D model of Crusher

Printzsköld / Alliansen
σ_D = 70 MPa – Year 2015

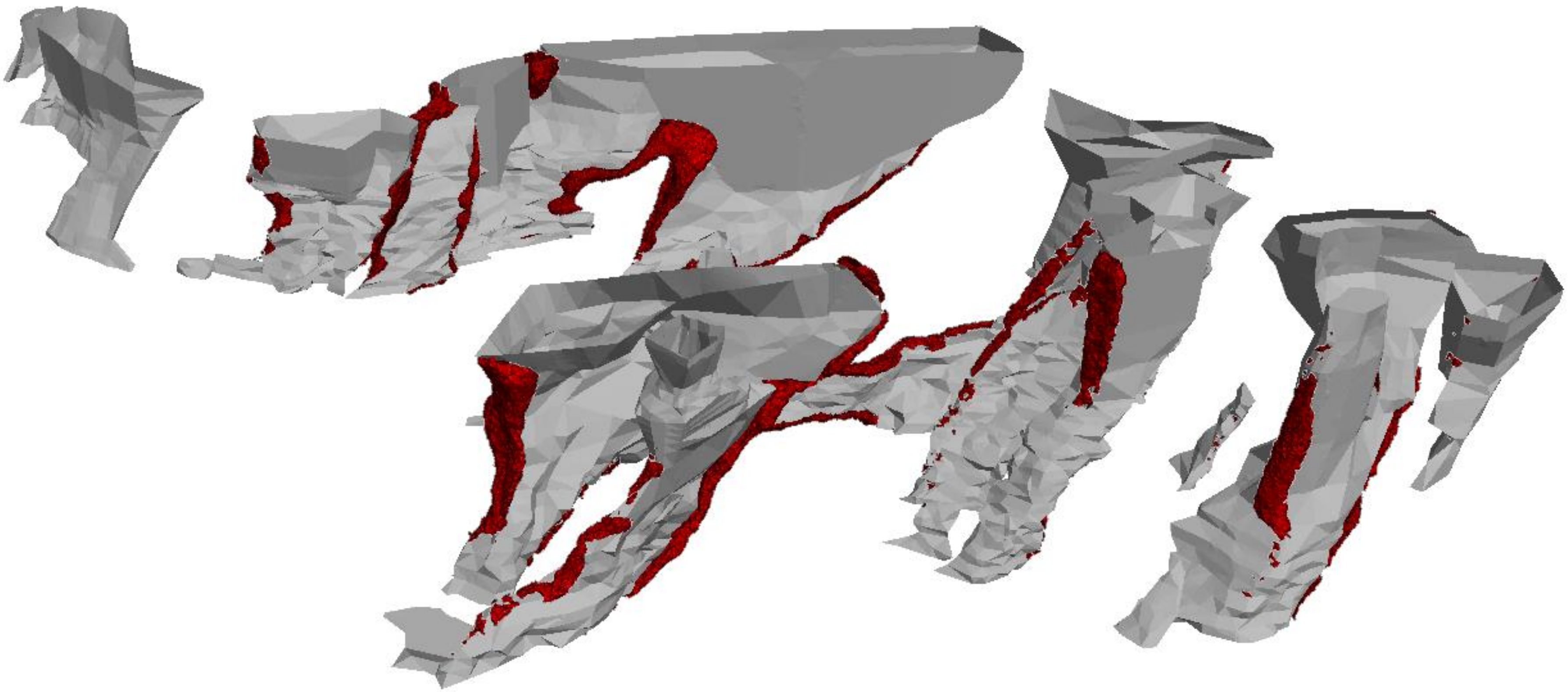






Conclusions

- Boundary stresses were successfully determined:
  - Two alternative methods were used
  - The Genetic Algorithms method is more general and can find the global error minimum
  - The Solver method resulted in a lower mean error (additional constraints only with GA method)
- The resulting stress state is in fair agreement with previous calibration and earlier assumptions of the stress field
- The derived stress equations represent an average stress state for the entire model; local variations in the rock mass are likely
- Calibrated model successfully used for assessment of infrastructure location, overall stress evaluation, input to local models



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