Investigation strategies on the example of the Semmering Base Tunnel

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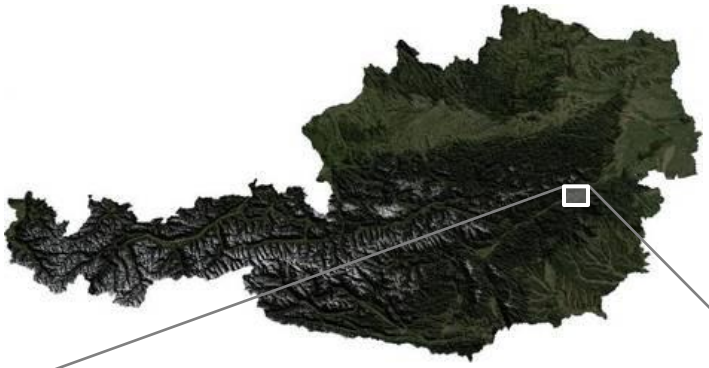
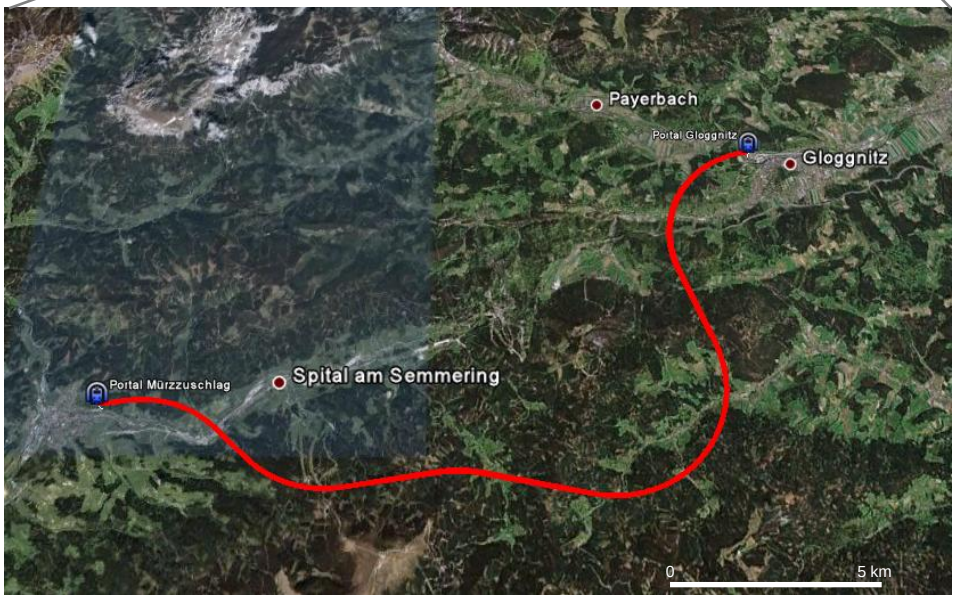
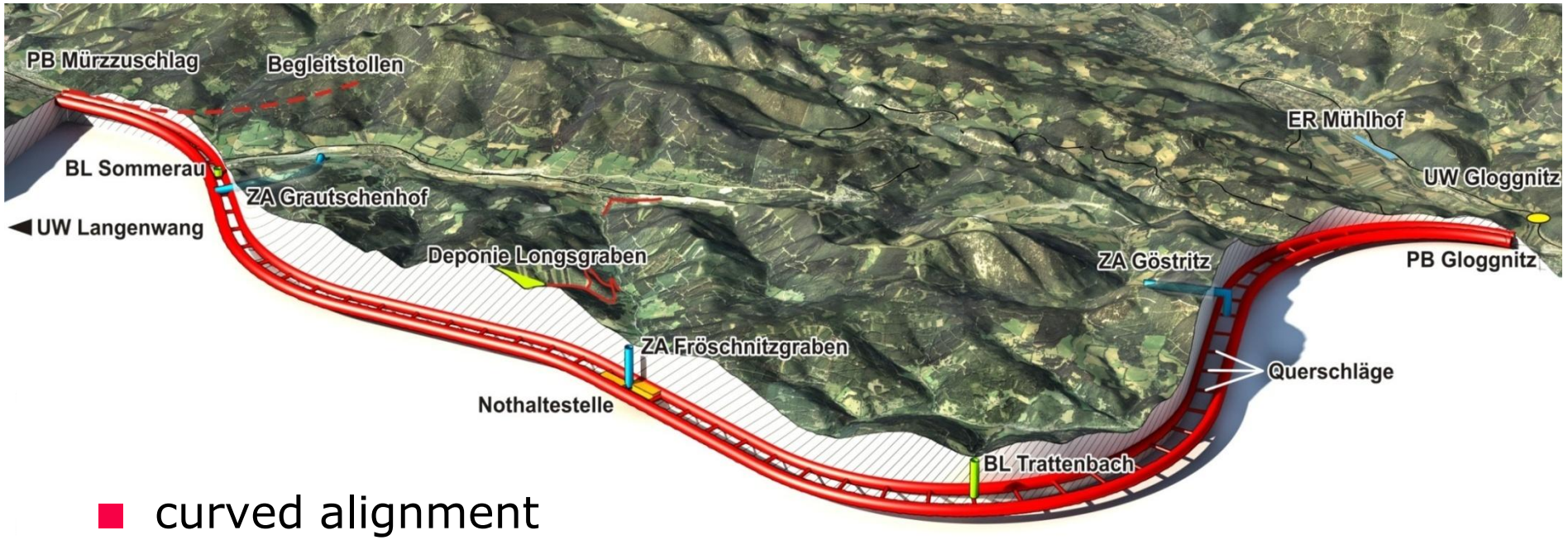
Project overview Semmering Base Tunnel

- 27.3 km railway tunnel
- part of „Südbahn" railway line
- Baltic-Adriatic Axis (BAA)





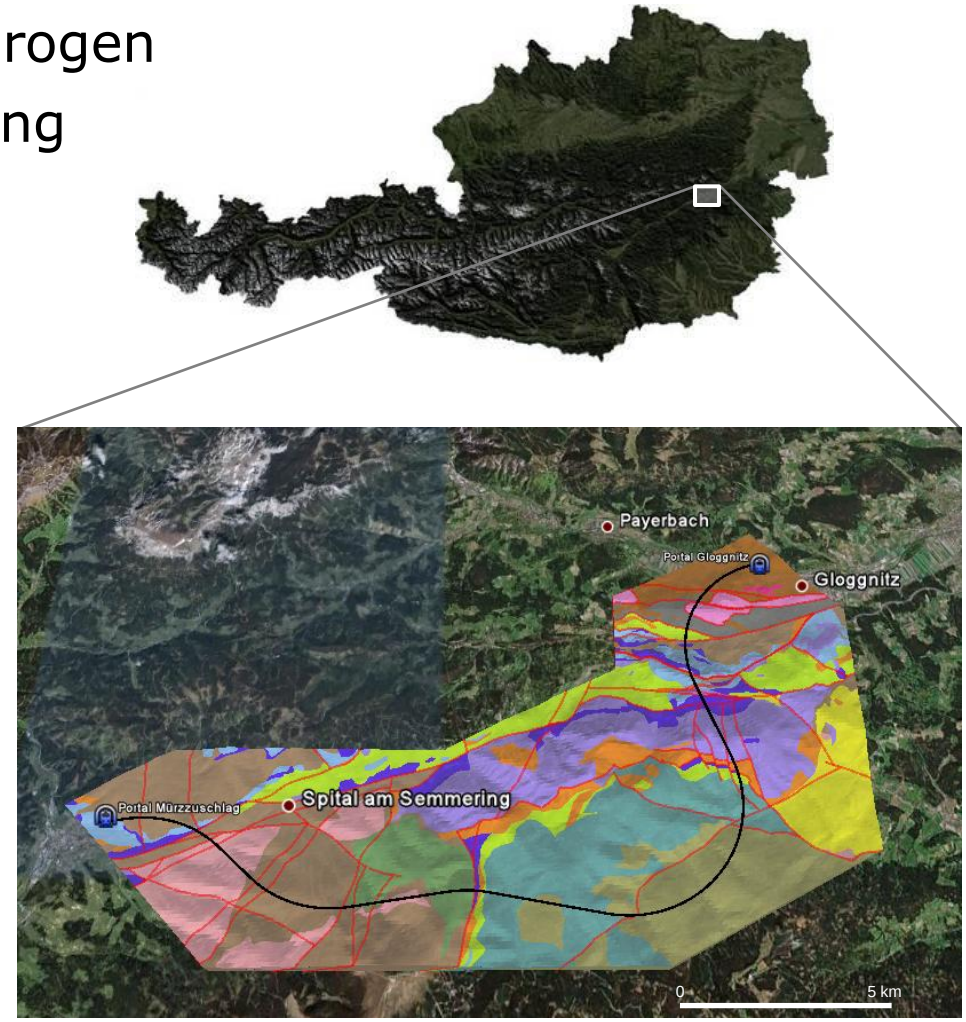
Project overview Semmering Base Tunnel



- curved alignment
- double tube tunnel system
- cross passages (500 m distance)
- emergency stop
- 3 temporary access structures for construction purposes (shafts and access tunnels)

Project overview – geological setting

- eastern margin of alpine orogen
- intense thrusting and folding
- 4 major tectonic nappes (crystalline basement and sedimentary cover
- large-scale fault systems
- complexe and heterogeneous ground conditions!!



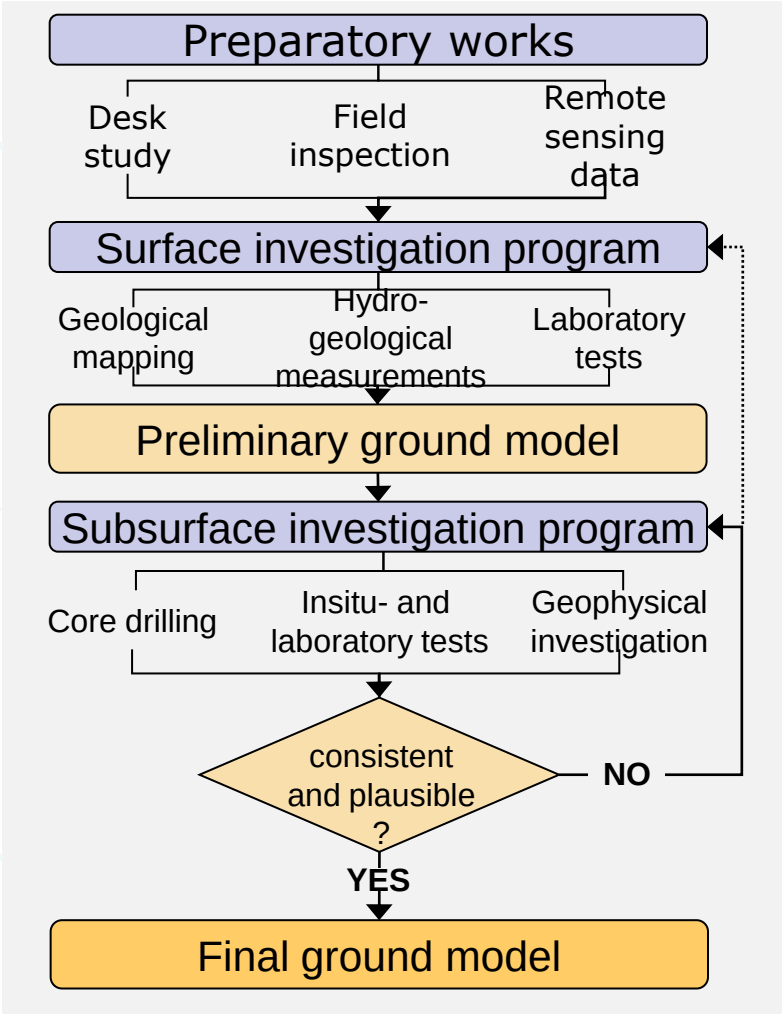
simplified geological map of the projekt area (tectonostratigraphic units)

Geological and geotechnical investigation

Feasibility, route selection

Approval procedure, design phase

Construction



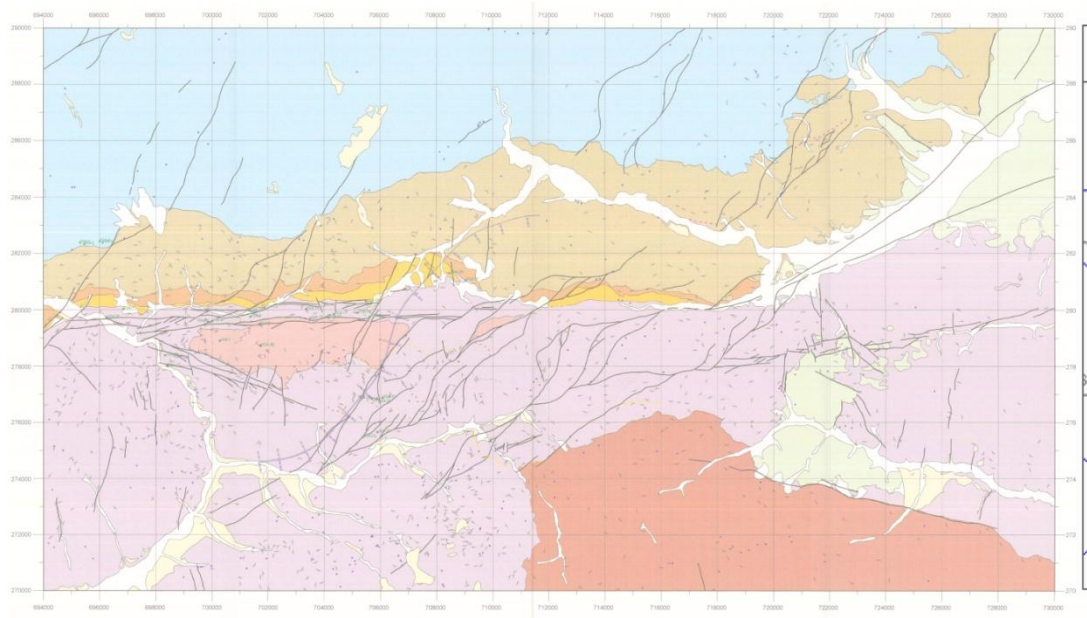
- Type of project
- Size of project
- Complexity
- Who is the Client?
- Where is the project?
- Availability of investigation methods
- Acceptance of the project
- Contract model (BOT, DBOT, etc.)

Geological and geotechnical investigation

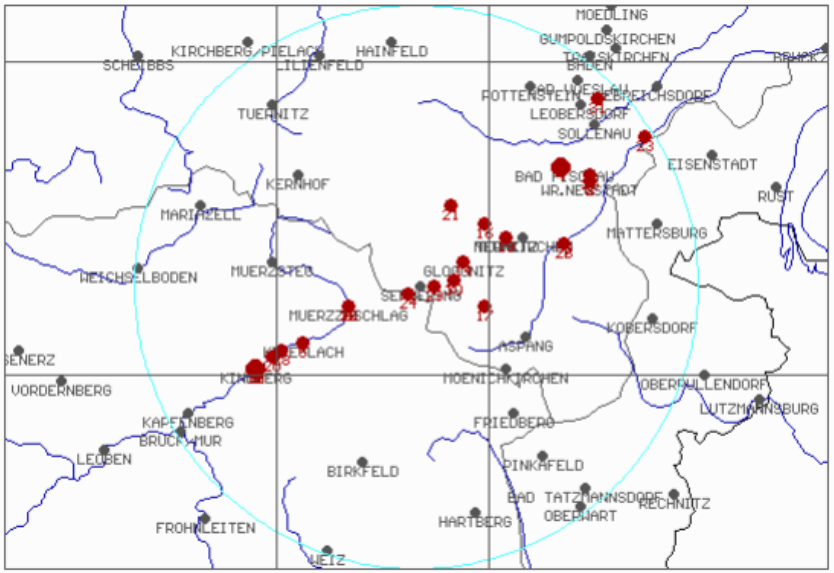
- investigation campaigns:
  - phase I: investigation for route selection design (2005-2007), area of 300 km²
  - phase II: investigation for preliminary design (2008 - 2009), corridor along selected alignment
  - phase III: investigation for detailed and tender design (2010 – 2014), selected alignment, 3 construction lots
- methods applied:
  - field mapping
  - core drillings
  - borehole measurements and in-situ testing
  - surface geophysical investigations
  - laboratory testing
  - evaluation of data from tunnel projects in the project area

Geological and geotechnical investigation

- methods applied:
  - external experts for satellite image analysis, seismicity and stratigraphy



map of tectonic lineaments from satellite image analysis

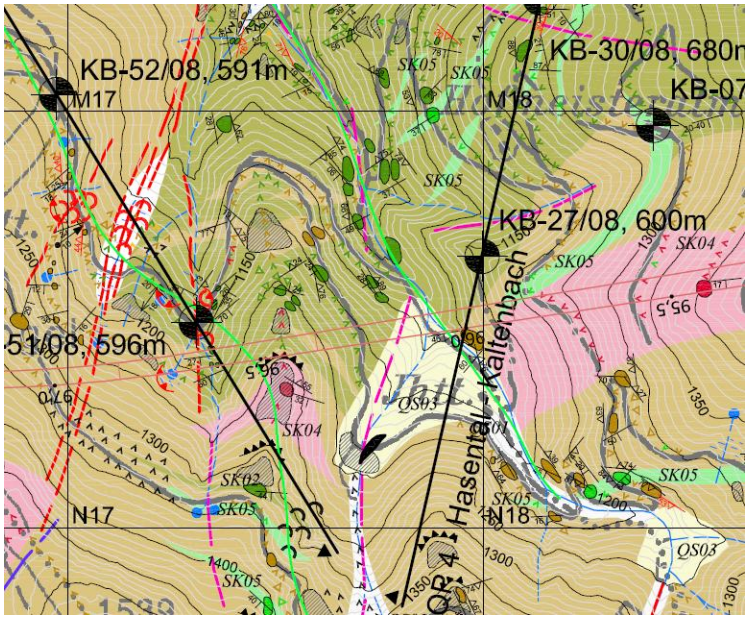


location of earthquaces causing damages in a distance of 50 km to the Semmering area

Geological and geotechnical investigation

- Field mapping
  - scale 1:10000, approx. 300 km^2 for route selection
  - scale 1:5000, along selected alignment corridor
  - detailed-scale mapping of portal areas

field mapping - outcrop



geological map

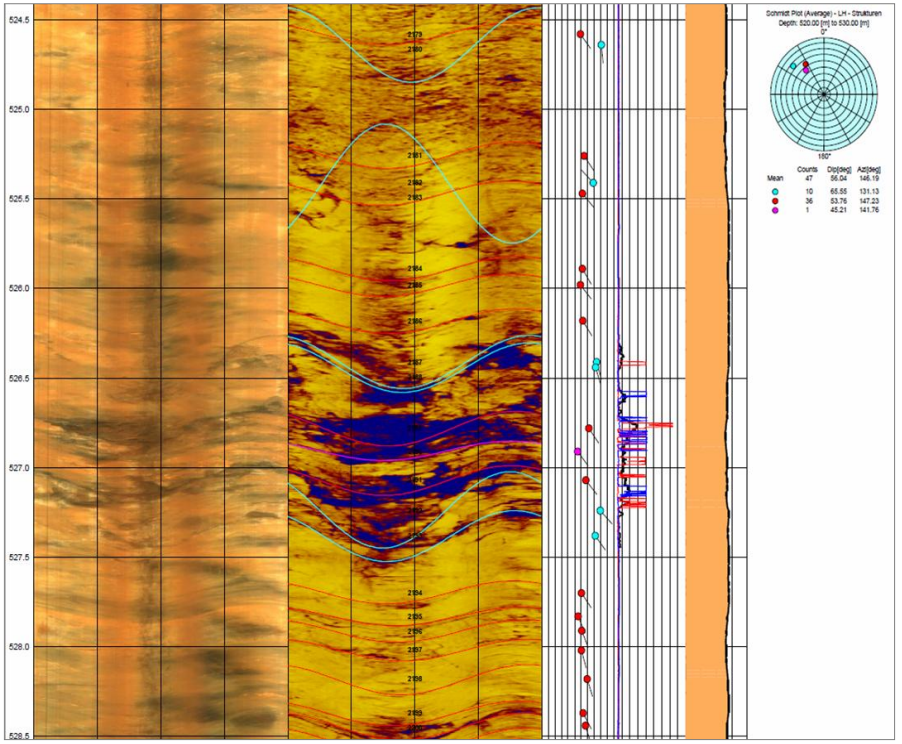
Geological and geotechnical investigation

- Core drillings
  - phase I: 82 drillings (< 450 m)
    total 11354 m
  - phase II: 60 drillings (< 720 m)
    total 18034 m
  - phase III: 55 drillings (< 850 m)
    total 9219 m

    grand total: 38607 m

Geological and geotechnical investigation

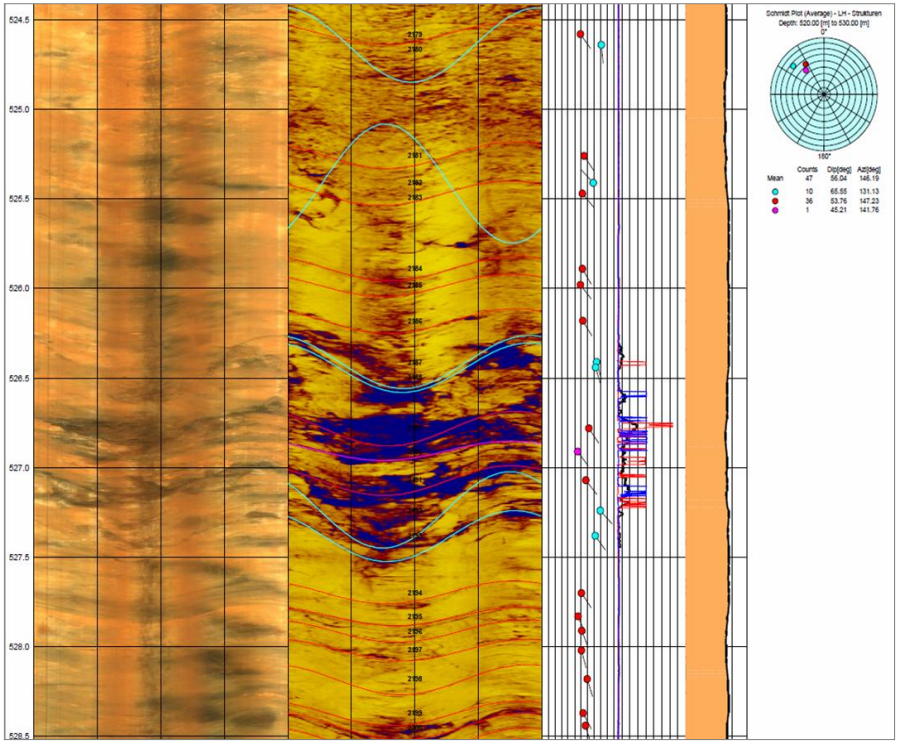
- Borehole testing and measurements
  - geophysical/geotechnical methods
    - deviation log
    - calliper log
    - acoustic and optical borehole imaging
    - density log
    - natural gamma log
    - vertical seismic profiling
    - dilatometer test
    - in-situ stress measurements



borehole logging: ABI, CAL, DENS, incl. interpretation of discontinuities

Geological and geotechnical investigation

- Borehole testing and measurements
  - hydrogeological methods
    - fluid conductivity and temperature log
    - flowmeter measurements
    - tracer fluid logging
    - hydraulic packer tests

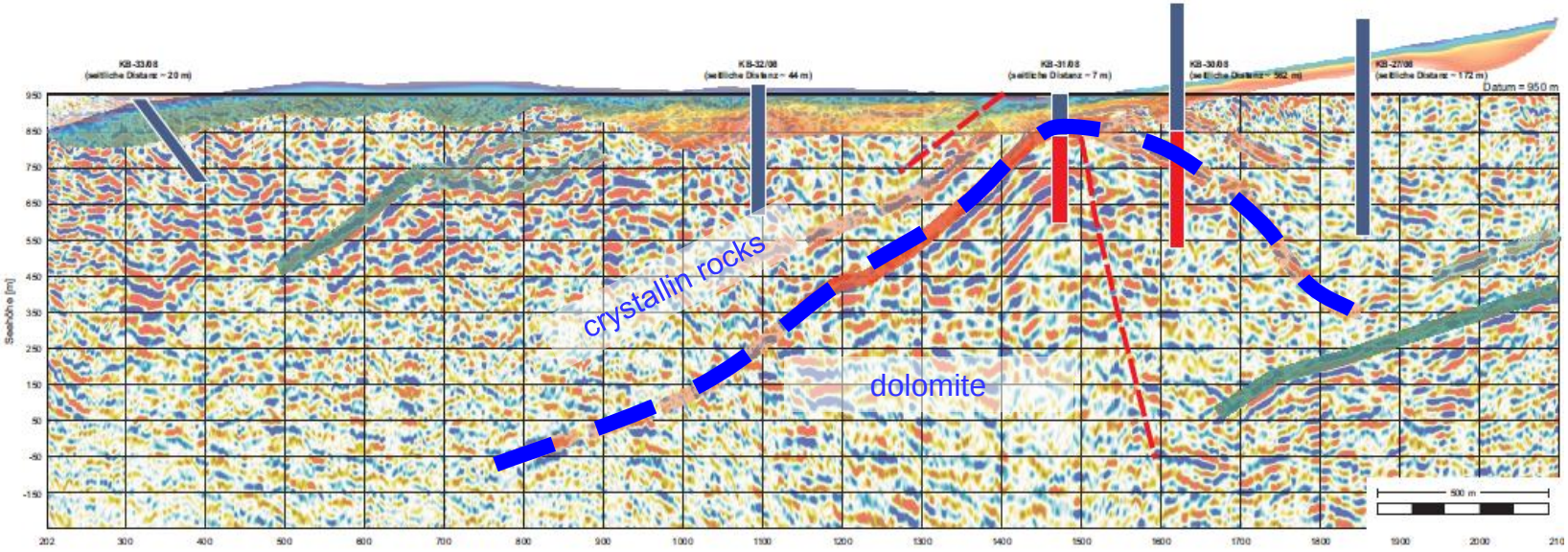


borehole logging: ABI, CAL, DENS, incl. interpretation of discontinuities

Geological and geotechnical investigation

- surface geophysical investigations
  - seismic reflection
  - seismic refraction tomography
  - electrical resistivity tomography

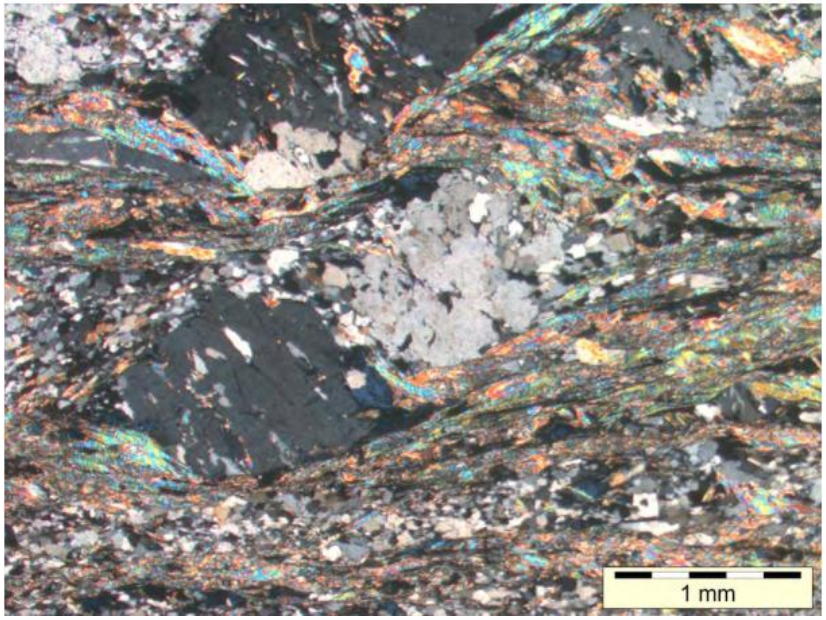
  in total 21 profiles



geophysical investigation of the Kaltenbach anticline

Geological and geotechnical investigation

- laboratory analyses and testing
  - geology/mineralogy (>700 samples)
    - mineralogical composition (x-ray, point-counting)
    - clay mineral content
    - microscopic analyses (thin sections)
    - abrasivity tests (Cerchar Abrasivity Index)



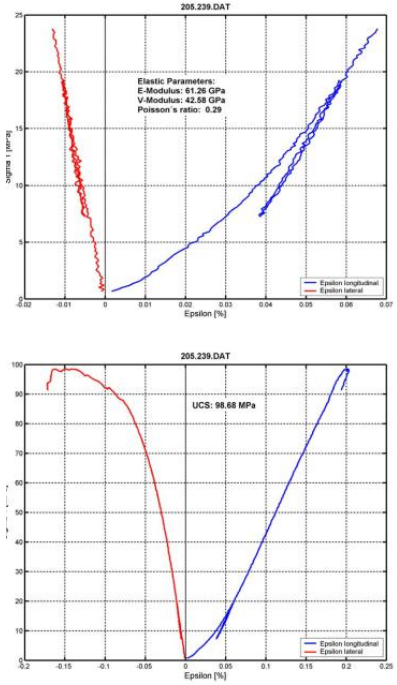
thin section, nicols crossed;
chlorite-muscovite-quartz-feldspar-gneiss

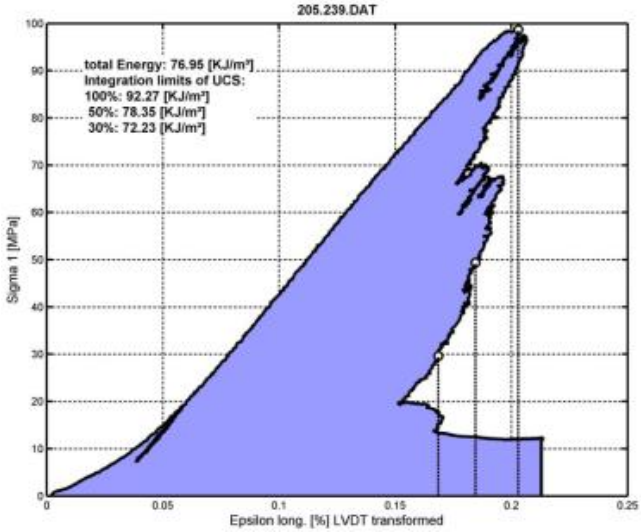
Cerchar abrasivity index test,
sericitic phyllite

Geological and geotechnical investigation

- laboratory analyses and testing
  - rock mechanics testing (>1100 samples)
    - uniaxial compression tests
    - triaxial compression tests
    - Brazilian tests
    - shear tests (discontinuities, intact samples)

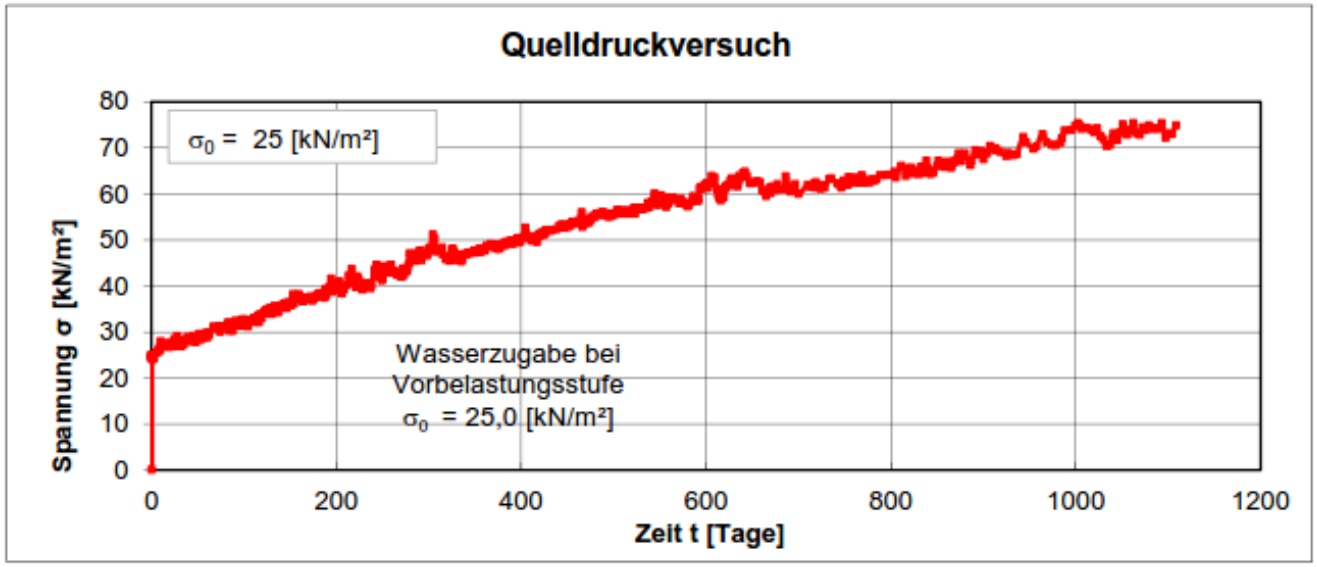
uniaxial compression test
limestone





Geological and geotechnical investigation

- laboratory analyses and testing
  - swelling tests (48 samples)
    - free swelling strain
    - axial swelling stress
    - swelling strain/stress (Huder/Amberg)



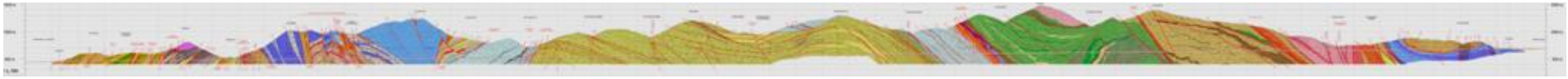
  - chemical analysis for classification of muck for recycling and waste disposal planning

Evaluation and results

- highly complex and heterogeneous ground conditions

- 18 large-scale geological units
- > 60 rock types

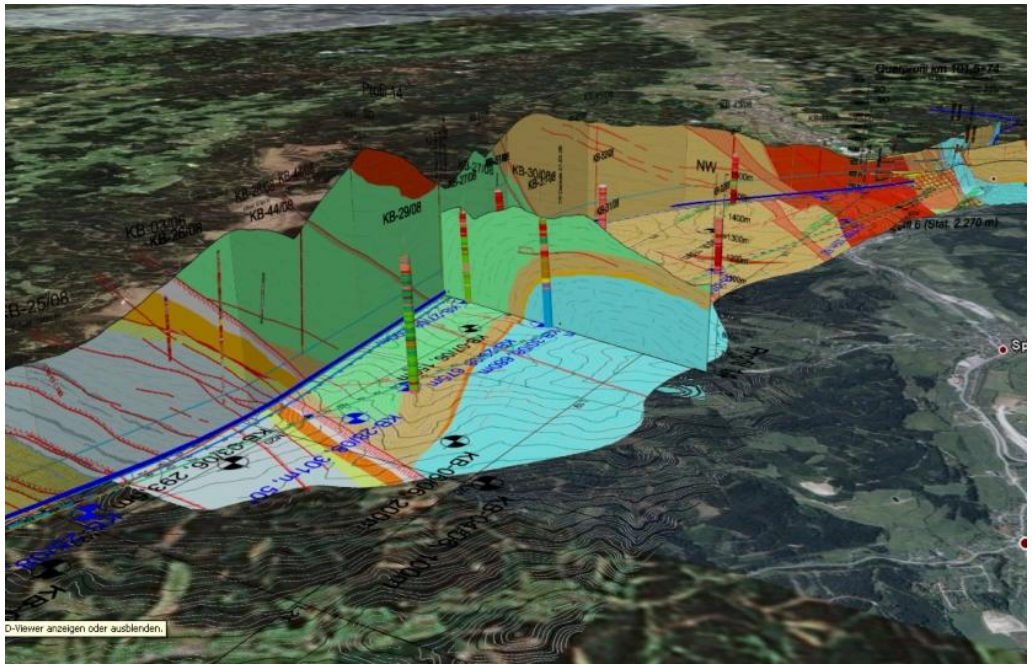
- poor ground conditions: 12 - 15 % fault zone material, overburden up to 870 m
- water inflow ≤300 l/s: in sections with limestone, dolomite (~2000 m) , hydraulic pressure ≤28 bar
- swelling rocks: anhydrite
  fault gouge material rich in clay minerals



geological longitudinal section

Evaluation and results

- Flexibility during execution of investigation program
  - investigation phase I – geol. Model:
    Semmering Crystalline Complex with gneiss, micaschist, and amphibolite
  - investigation phase II:
    unexpected:
    dolomite at tunnel alignment – highly water permeable
    additional investigation:
    5 core drillings (500 to 700 m each)
    surface geophysical seismic survey (3 lines)

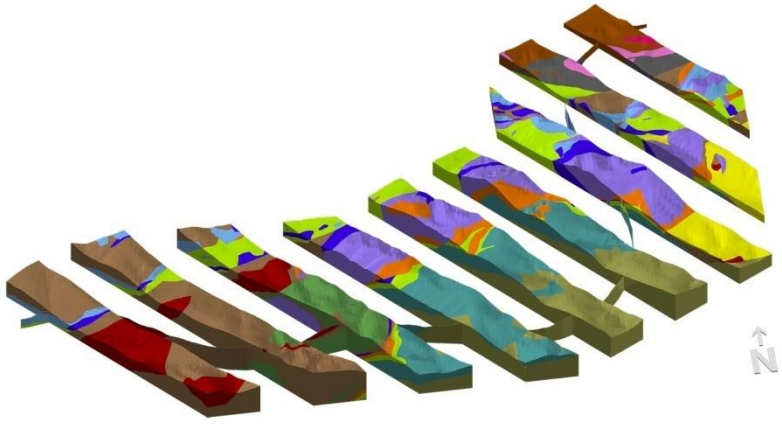


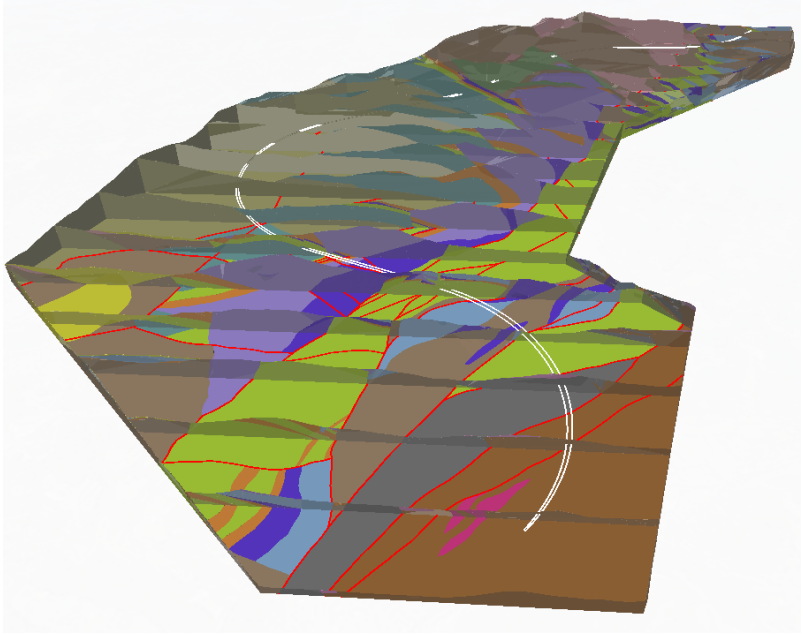
  - consequence: realignment of tunnel axis

Evaluation and results

- 3D Geological Model
  - to check and ensure the plausibility and consistency of the geological and structural model
  - easy information transfer of the geological architecture
  - presentation purposes

  - whole tunnel length of 27.3 km
  - model width of up to 10 km
  - simplifications required!





Conclusion

- The investigation methods applied represent a state of the art ground investigation program for large infrastructure tunnel projects
- Each ground investigation program has to be individually designed for each project and for each design phase
- The design of an investigation program requires a sound knowledge about the investigation aims, the requirements as well as the capabilities and limitations of each investigation method

Conclusion

- The designer and geological consultant of an investigation program needs to have a ground model in the sense of a forecast model
- This model has constantly to be compared with the actual investigation results and updated during the investigation process
- As soon as substantial divergences between expected and factual conditions are detected adjustments of the investigation program are required

Conclusion

- In case of the Semmering Base Tunnel project the originally designed investigation program had to be modified during the execution
- The adjustment of the investigation program allowed for an identification, assessment and characterisation of geotechnical key structures
- Therefore short term decision processes are essential as well as a profound technical understanding by the client for the reasons of the adjustments required and consequences in case of omitting them

- A 3D geological model is an effective tool for checking the consistency and plausibility of a geological and structural model and it provides an understandable access to complex information for all parties involved

Semmering Base Tunnel, construction lot SBT2.1 Tunnel Fröschnitzgraben site installation area (ÖBB Webcam, 2015-03-22)