Case Studies

Investigation

Preliminary Design

Project Data

Part of the Egnatia Motorway which will connect the towns Igoumenitsa at the Adriatic Sea and Thessaloniki at the Agean Sea. Double tube two lane tunnel. Length 2100 m, maximum overburden 230 m

Tasks

Geological alignment mapping. Assessment of rock mass behaviour and support for the preliminary and detail design. Consulting service during construction

Geology

Complex fold-thrust belt in Tertiary flysch sequences. Development of thick tectonic melanges with clayey gouges

Egnatia Motorway, Anilio Tunnel (Greece)

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Case Studies

Location

Egnatia Motorway, Anilio Tunnel (Greece)

Investigation

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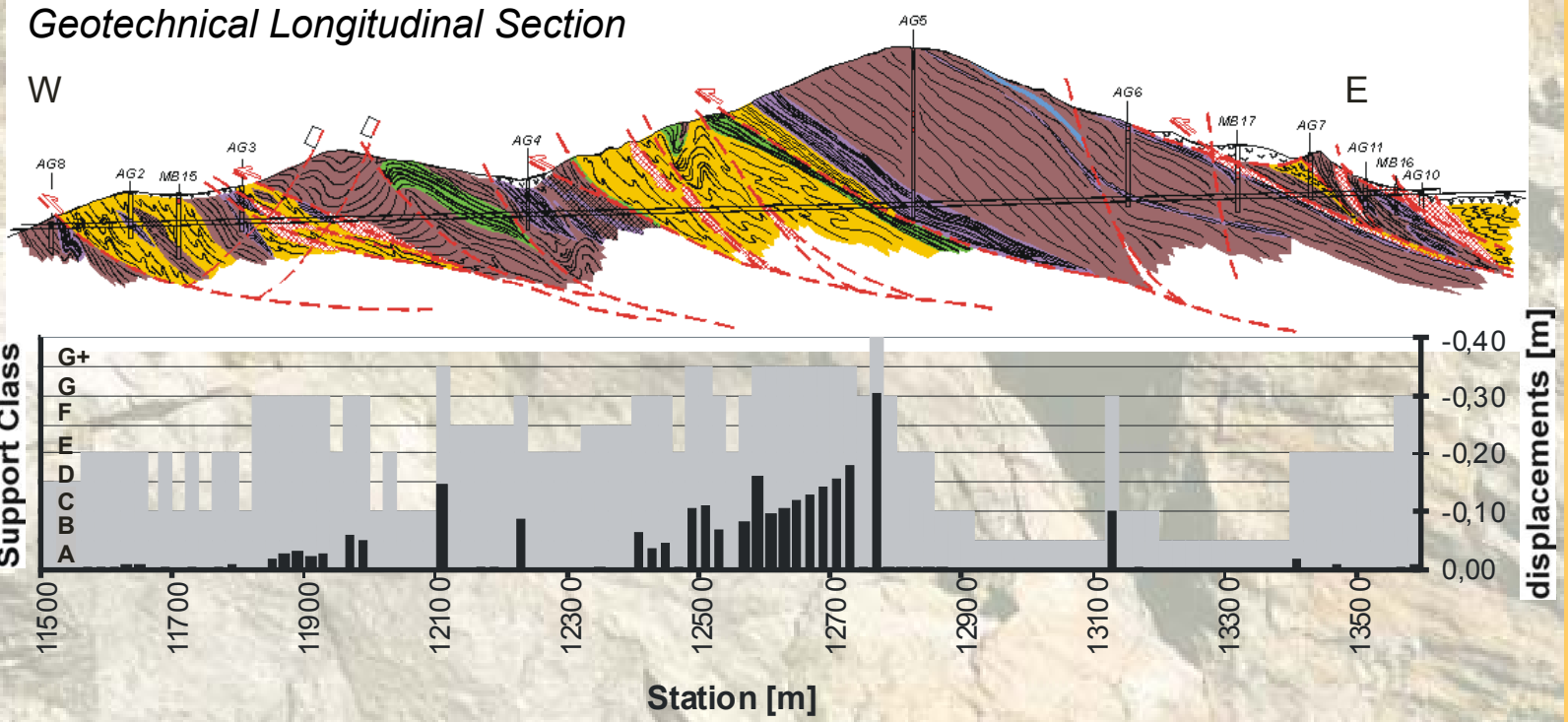
Case Studies

Preliminary Design

Geotechnical Longitudinal Section



Egnatia Motorway, Anilio Tunnel (Greece)

Investigation

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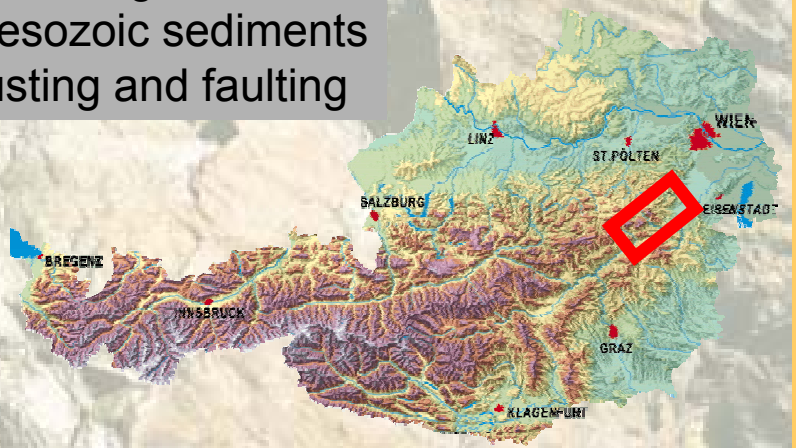
Case Studies

Detail Design

Project Data
Core piece of Austrian‘s high speed railway project.
Length 22 km, maximum overburden 900 m

Tasks
Geological-geotechnical site investigations from the feasibility study to the detail design. Geotechnical risk assessment for TBM excavation.
Investigation of alternative systems (double track tube with emergency tunnel versus two single track tubes).

Geology
Polymetamorphic basement rocks and low-grade metamorphic Paleozoic as well as Mesozoic sediments were subjected to intense Alpine thrusting and faulting



Semmering Base Tunnel, Austria

Investigation

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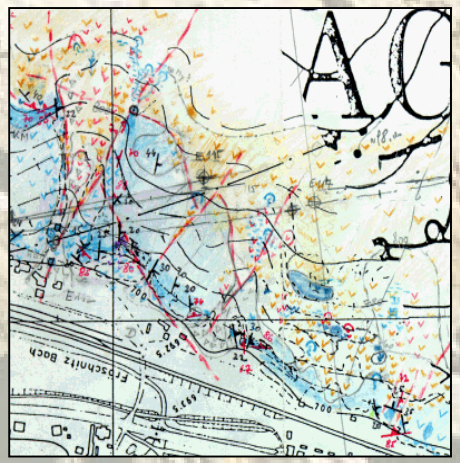
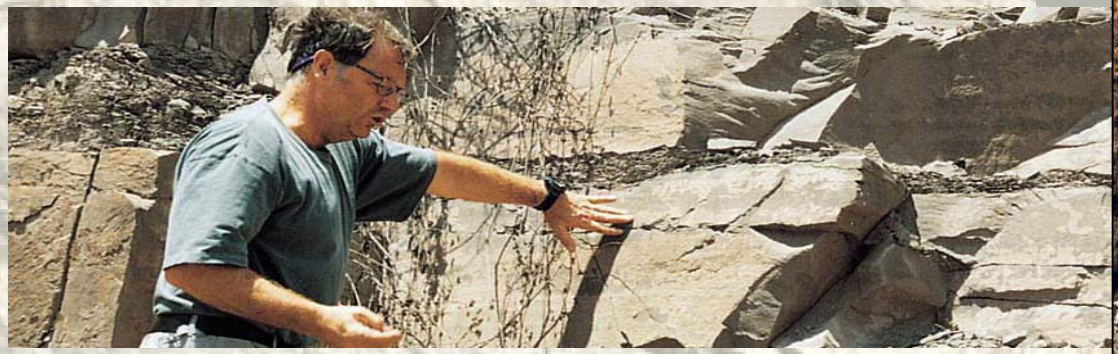
Case Studies

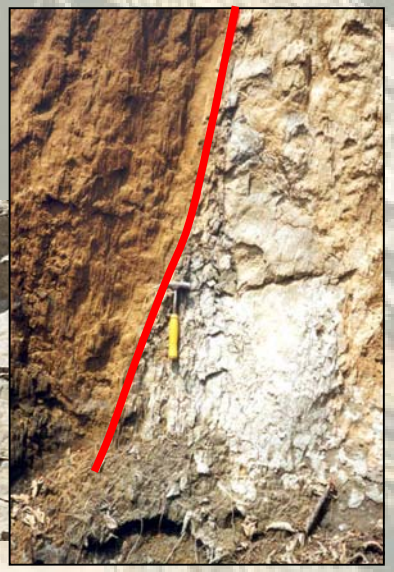
Site Investigation



Engineering geological mapping

- Identification of relevant morphological features
- Outcrop Studies
- Identification and characterisation of fault zones
- Assessment of seeps and springs





Semmering Base Tunnel, Austria

Investigation

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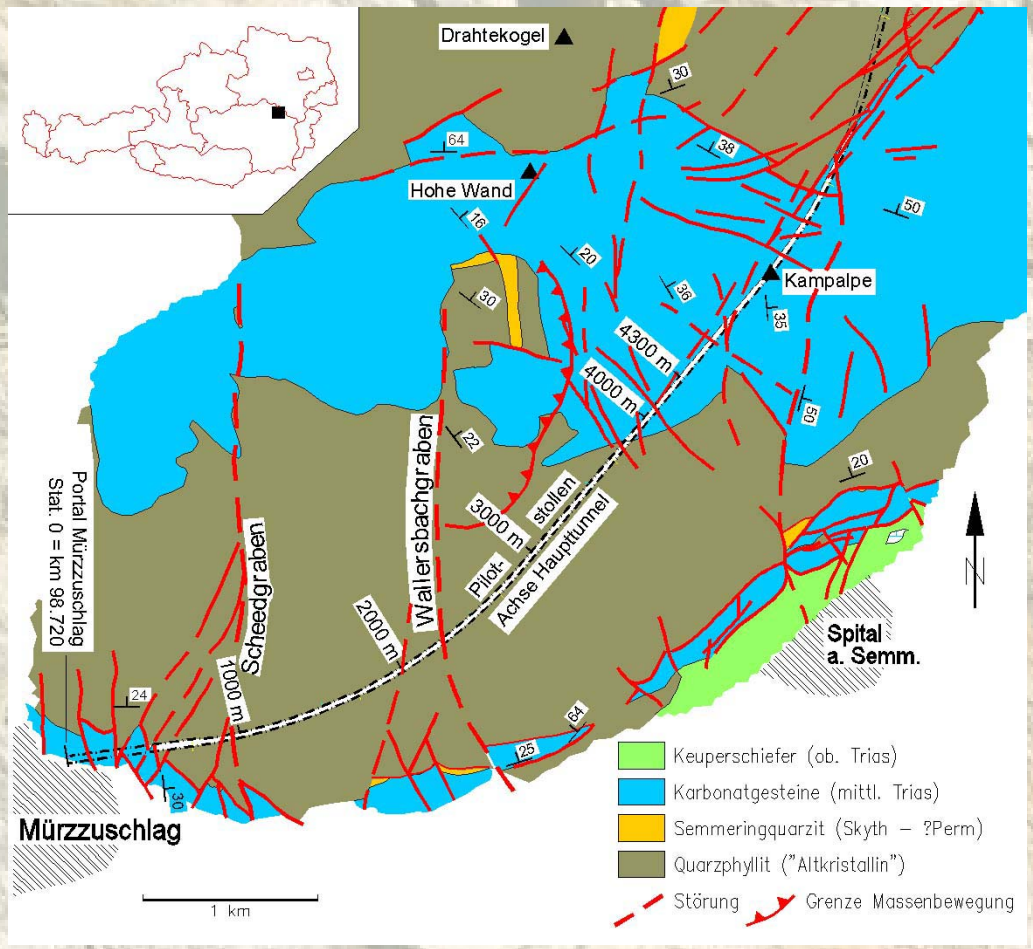
Site Investigation



Semmering Base Tunnel, Austria

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Case Studies

Site Investigation

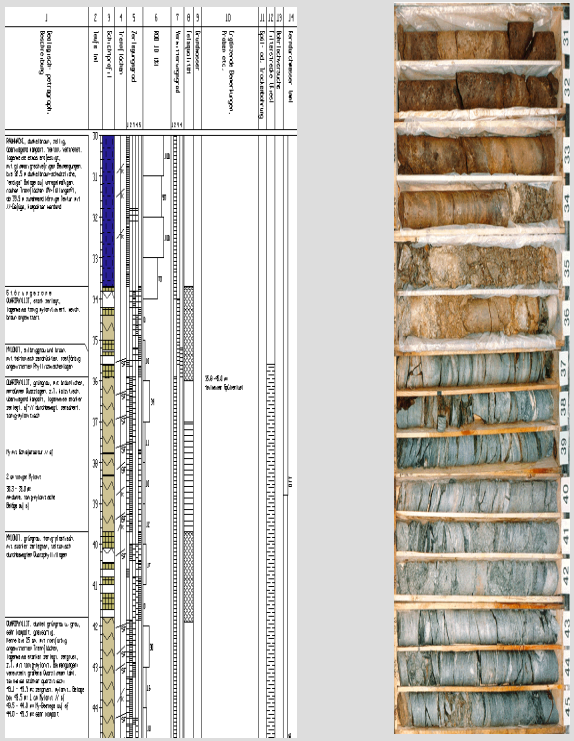
Subsurface Investigations

- Exploratory drilling
- Geophysical surveys
- Borehole in situ testing
- Pilot tunnel

Laboratory testing

- Mineralogical analyses
- Mechanical analyses

DRILL CORE LOGGING



Semmering Base Tunnel, Austria

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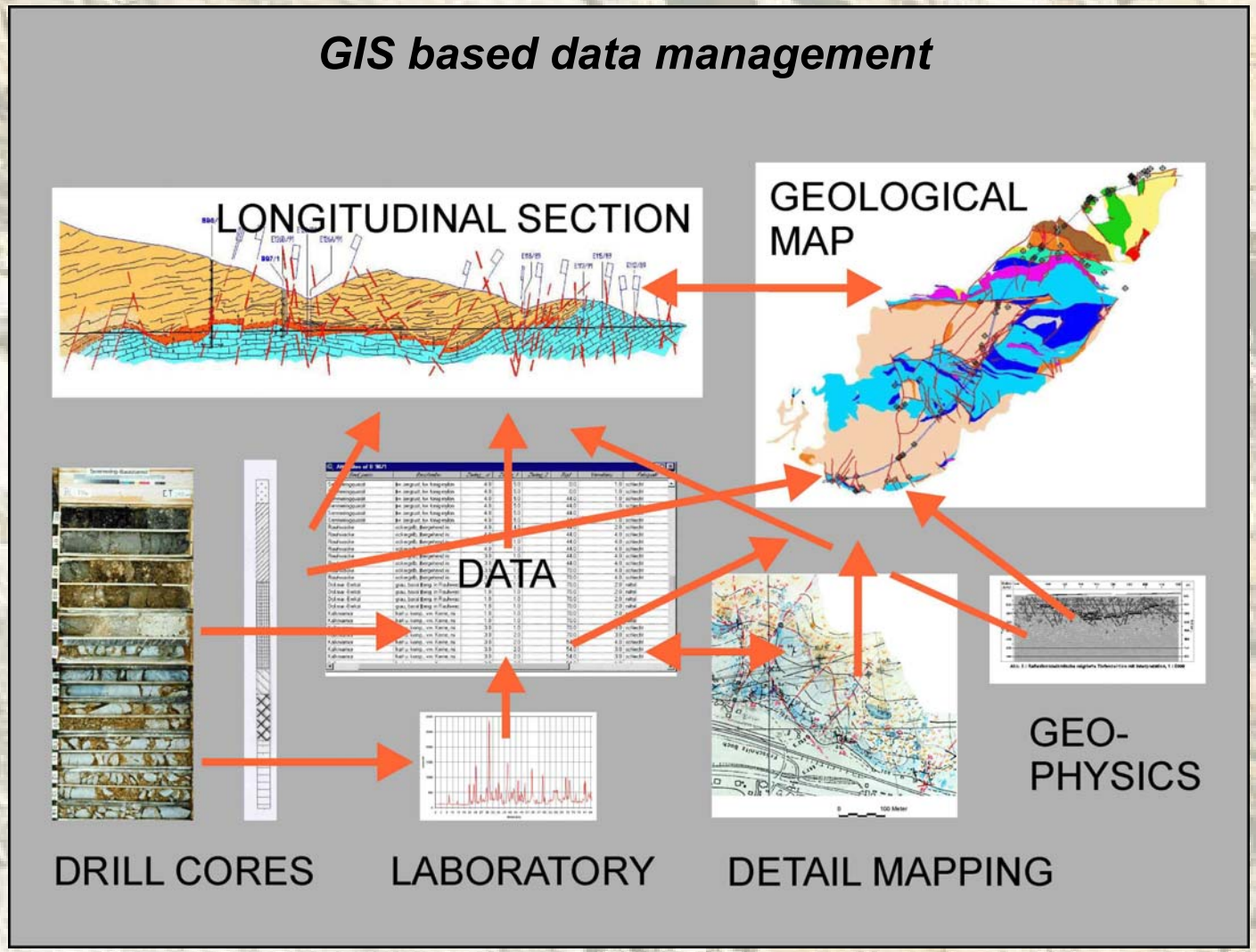
Site Investigation



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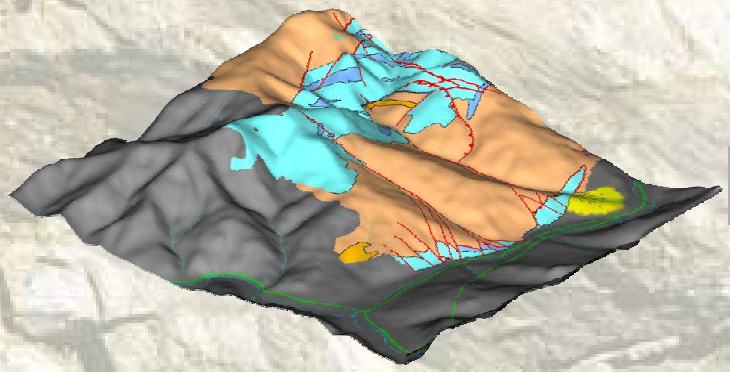
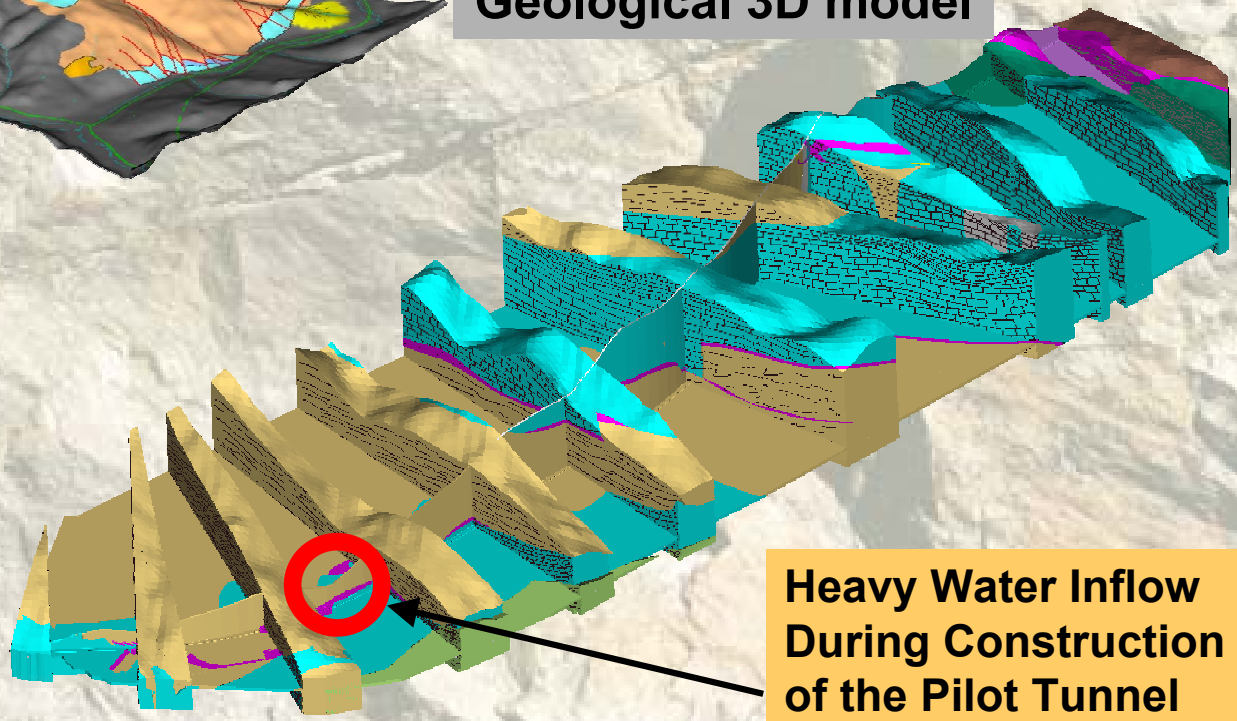
Site Investigation



Geological 3D model



Heavy Water Inflow During Construction of the Pilot Tunnel

Semmering Base Tunnel, Austria

Investigation

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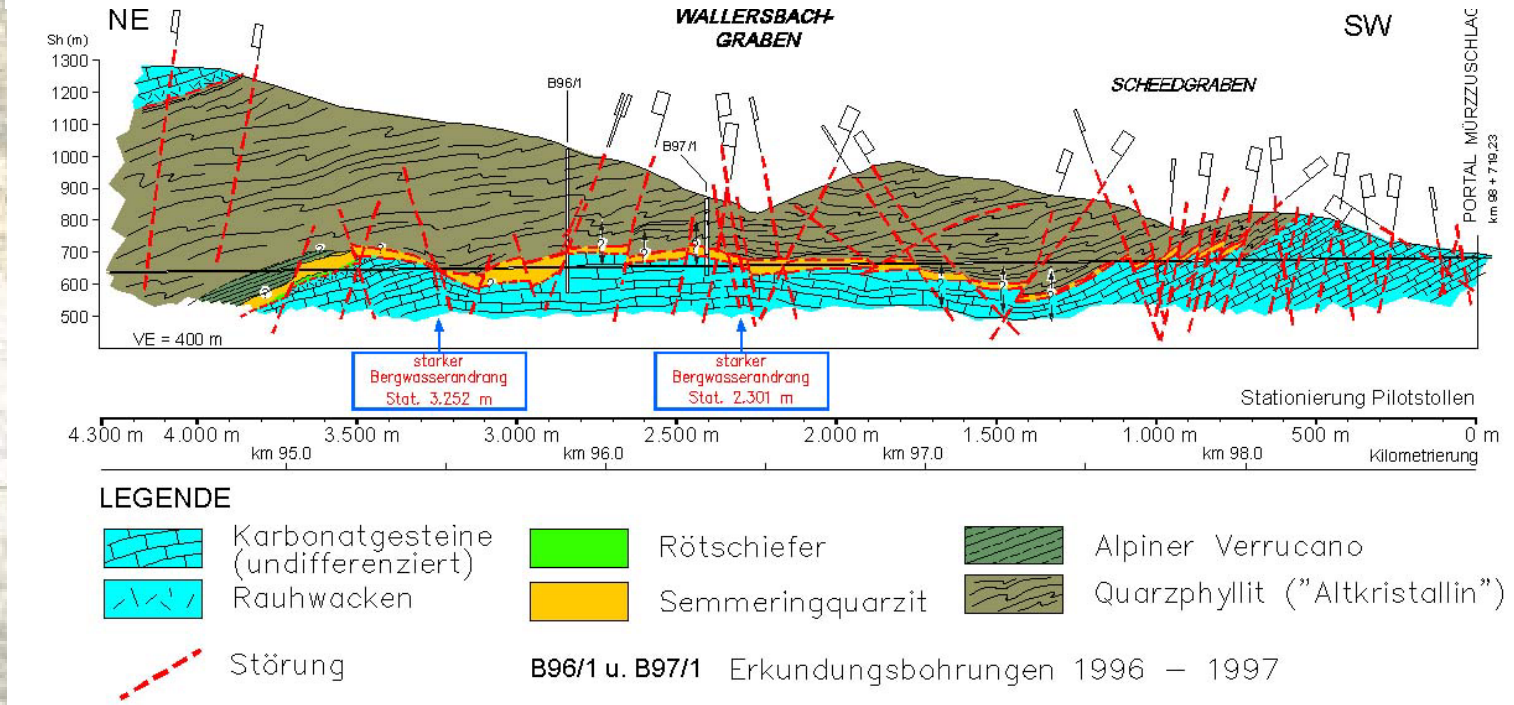
Case Studies

Site Investigation

Pilot tunnel, water inflow (350 l/s) at station 2301 m



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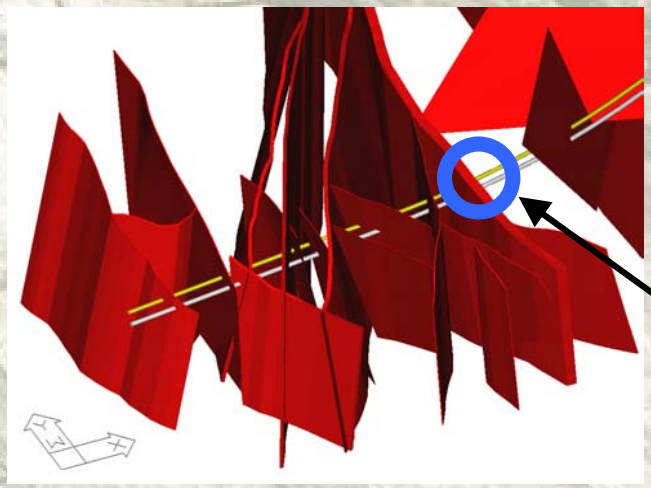
Site Investigation



Water Inflow
STATION 2.301 m

Semmering Base Tunnel, Austria

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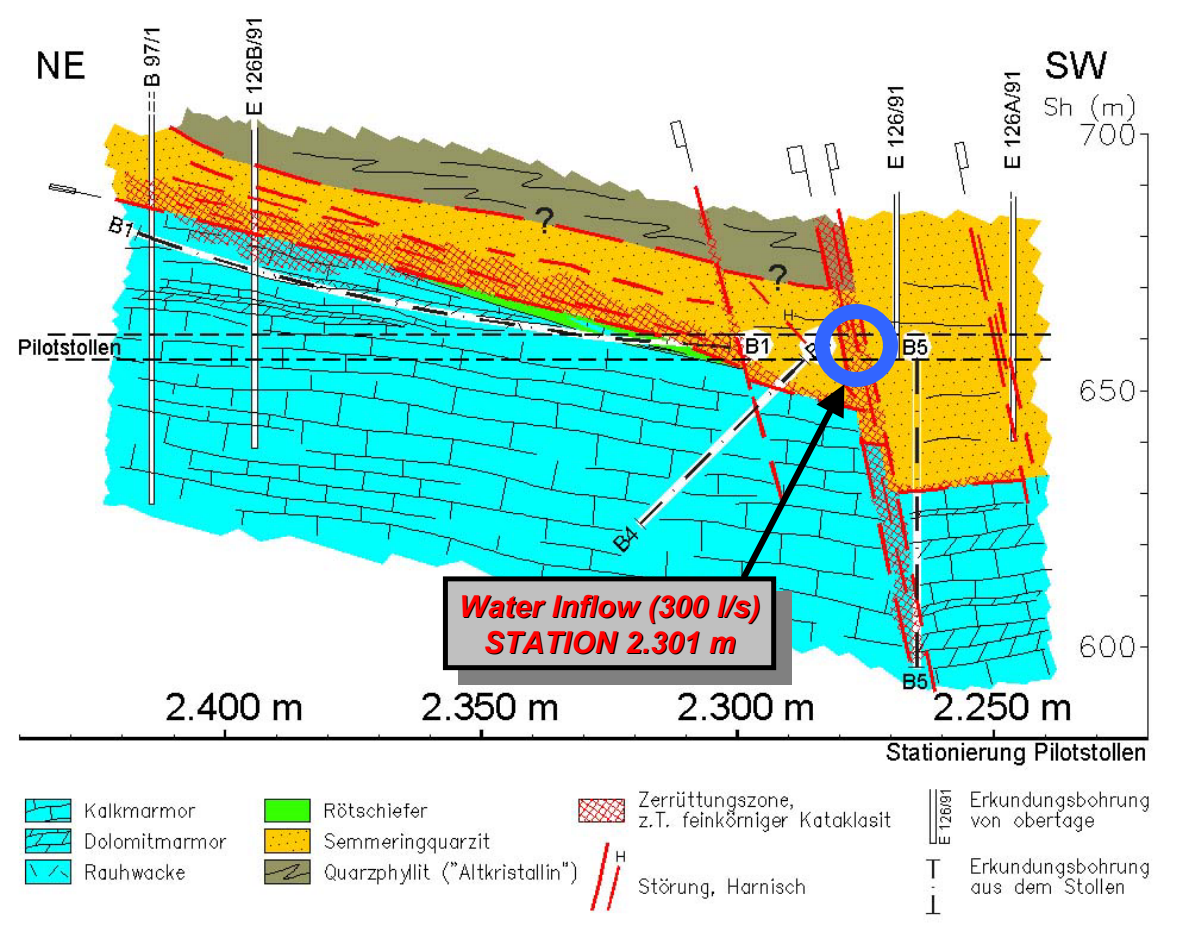
Site Investigation



Semmering Base Tunnel, Austria

Investigation

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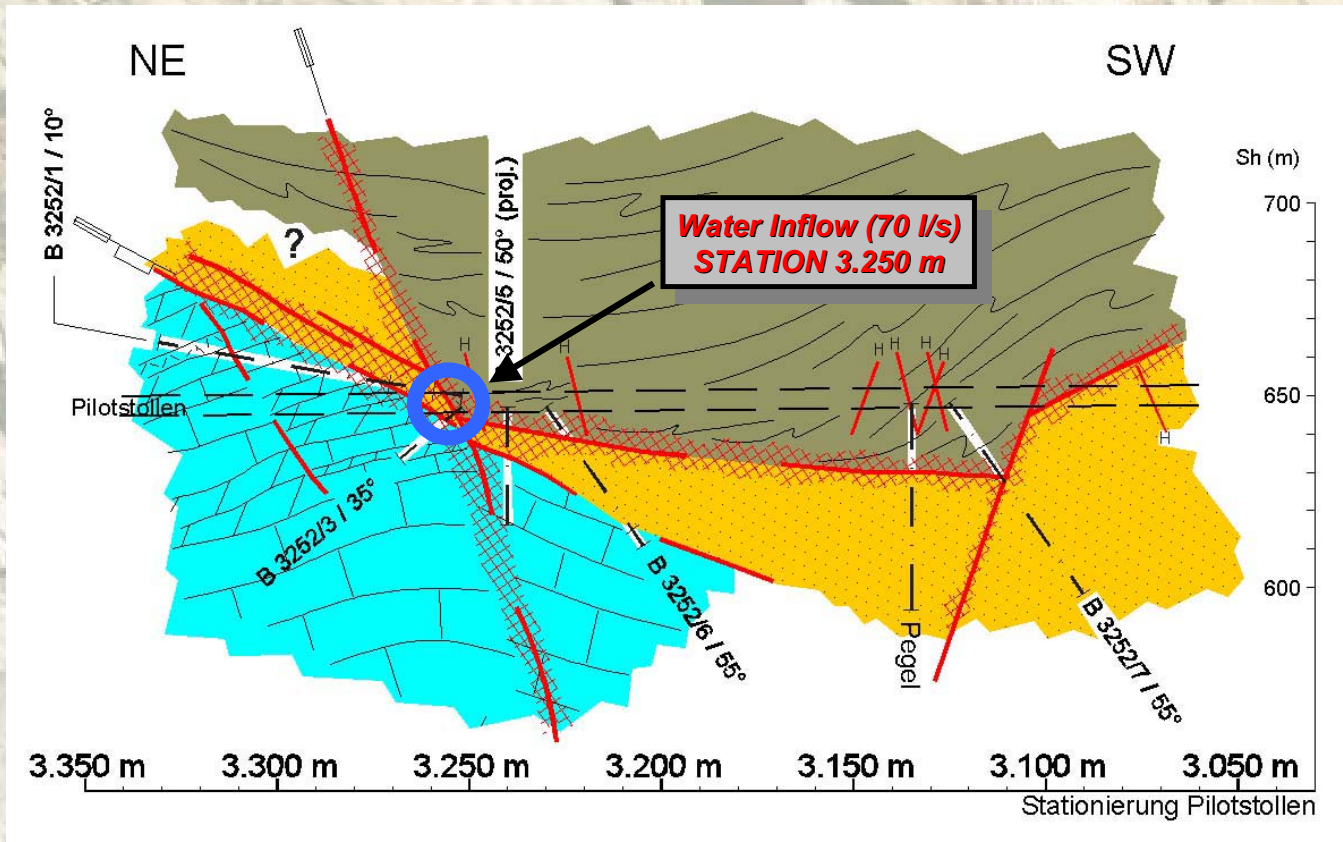
Site Investigation



Semmering Base Tunnel, Austria

Investigation

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Case Studies

Rock Mass Characterisation

Key Parameters

Rock Mass Type 1	
Lithology	Limestone / Dolomite
Foliation / Anisotropy	massive
Block size	> 20 cm
Joint properties	mainly rough
Persistence	low
Aperture	closed
Intact Rock	
Parameter	average / standard deviation / number of samples
UCS [MPa]	102,6 / 29,0 / 26
m_i Hoek Constant [ ]	13,4 / 6,2 / 20
c [MPa]	24,2 / 8,2 / 20
φ [°]	40,7 / 4,9 / 20
E [GPa]	68,3 / 17,6 / 23
ν [ ]	0,19 / 0,05 / 23
Cerchar Abrasivity Index	1,4 / 0,4 / 18
Rock Mass	
Parameter	average / standard deviation
GSI	70 / 10
UCS [MPa]	33,2 / 12,1
c [MPa]	8,0 / 2,8
φ [°]	37,7 / 4,7
E [GPa]	35,0 / 19,4
Joint properties	
Parameter	estimated values
Friction angle [°]	35-45
Residual friction angle [°]	30-40

Semmering Base Tunnel, Austria

Investigation

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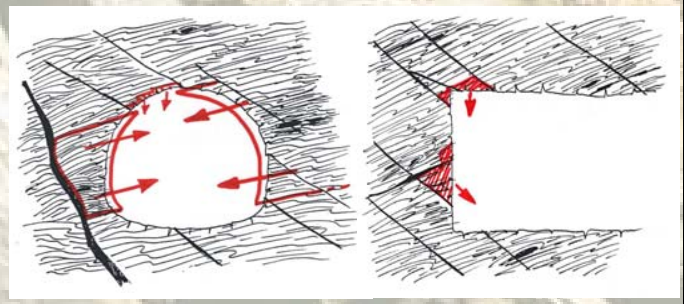
Case Studies

Definition of Rock Mass Behaviour Types

Rock Mass Type 15			
Rock type	Phyllite		
Foliation	< 6 cm		
Block Size	< 20 cm		
Joint condition	coated with clay		
Persistence	dominating low		
Aperture	Dominating closed		
Intact Rock Properties	μ	σ	No. of tests
UCS [MPa]	28,2	13,6	19
m_i [-]	14,5	6,0	6
c [MPa]	10,8	3,1	6
φ [°]	31,7	1,5	6
E [GPa]	26,7	19,1	18
ν [-]	0,43	0,18	5
CAI [-]	2,5 bis 3		
Joint Properties	μ	σ	Anz.Vers.
Friction angle [°]	33,7	6,3	15
Res. Friction angle [°]	28,5	5,6	23
Rock Mass Properties	μ		σ
GSI [-]	40		5
UCS [MPa]	3,9		2,0
c [MPa]	1,1		0,5
φ [°]	31,3		3,6
E [GPa]	3,0		1,0

... shaded => estimated values

Type of Rock Mass Behaviour 4/1



Symbolische Darstellung für Phyllit

Rock Mass Type	RMT15
Orientation of main discontinuity set	Foliation, dipping moderately to flatly towards direction of drive
Stress Conditions	stress level equals rock mass strength
Groundwater	Dry, occasionally dripping
Rock Mass Behaviour (excavatability, failure mechanism)	Potential for overbreak. Highly anisotropic rock mass. Block failures controlled by shearing along foliation planes. Favourable face stability for foliation dipping into the face. Potential of small, local block sliding caused by unfavourably oriented discontinuities. Slickensides with high persistence may generate deep reaching shear failures.
Radial Deformation	Several centimetres, controlled by discontinuities.

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Investigation

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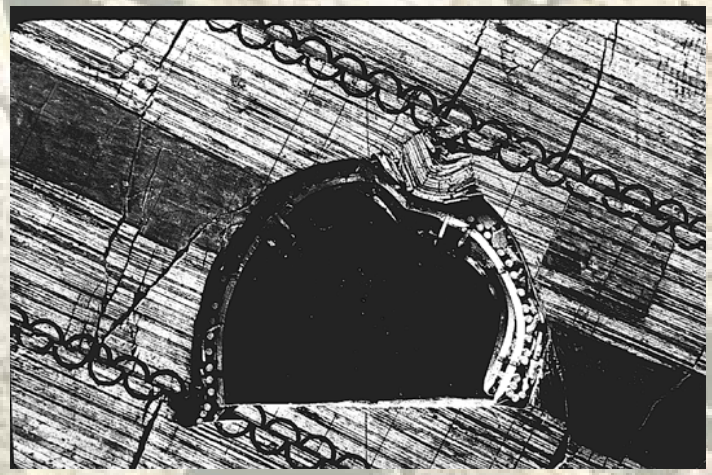
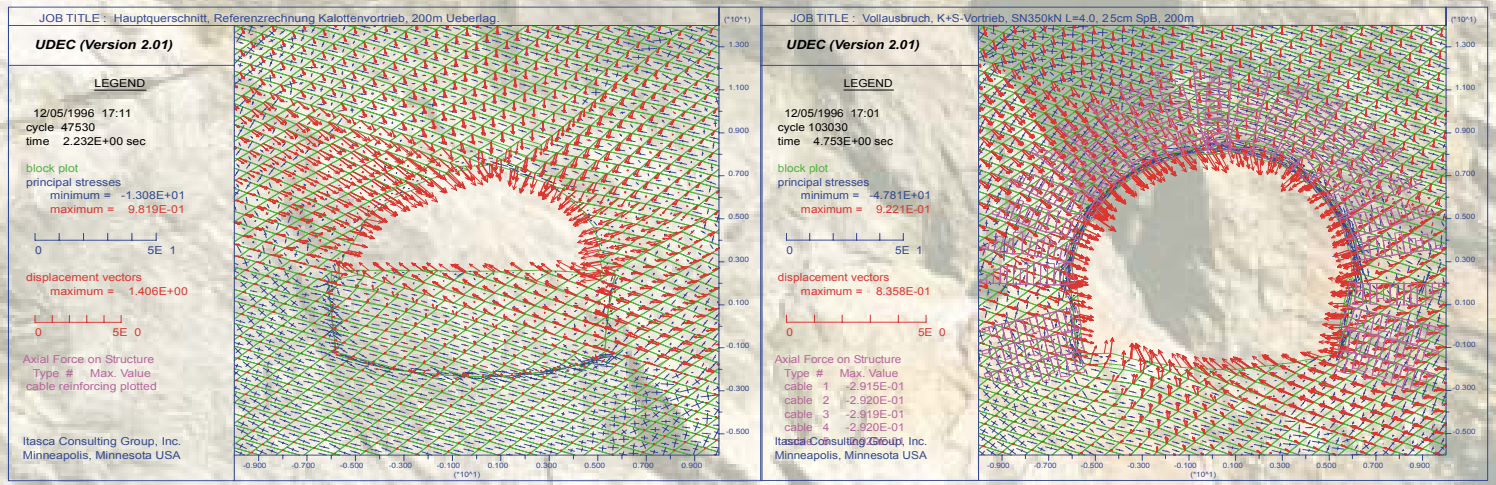
Calculation of Failure Mechanisms (Phyllite)

Failure mechanisms





Semmering Base Tunnel, Austria

Investigation

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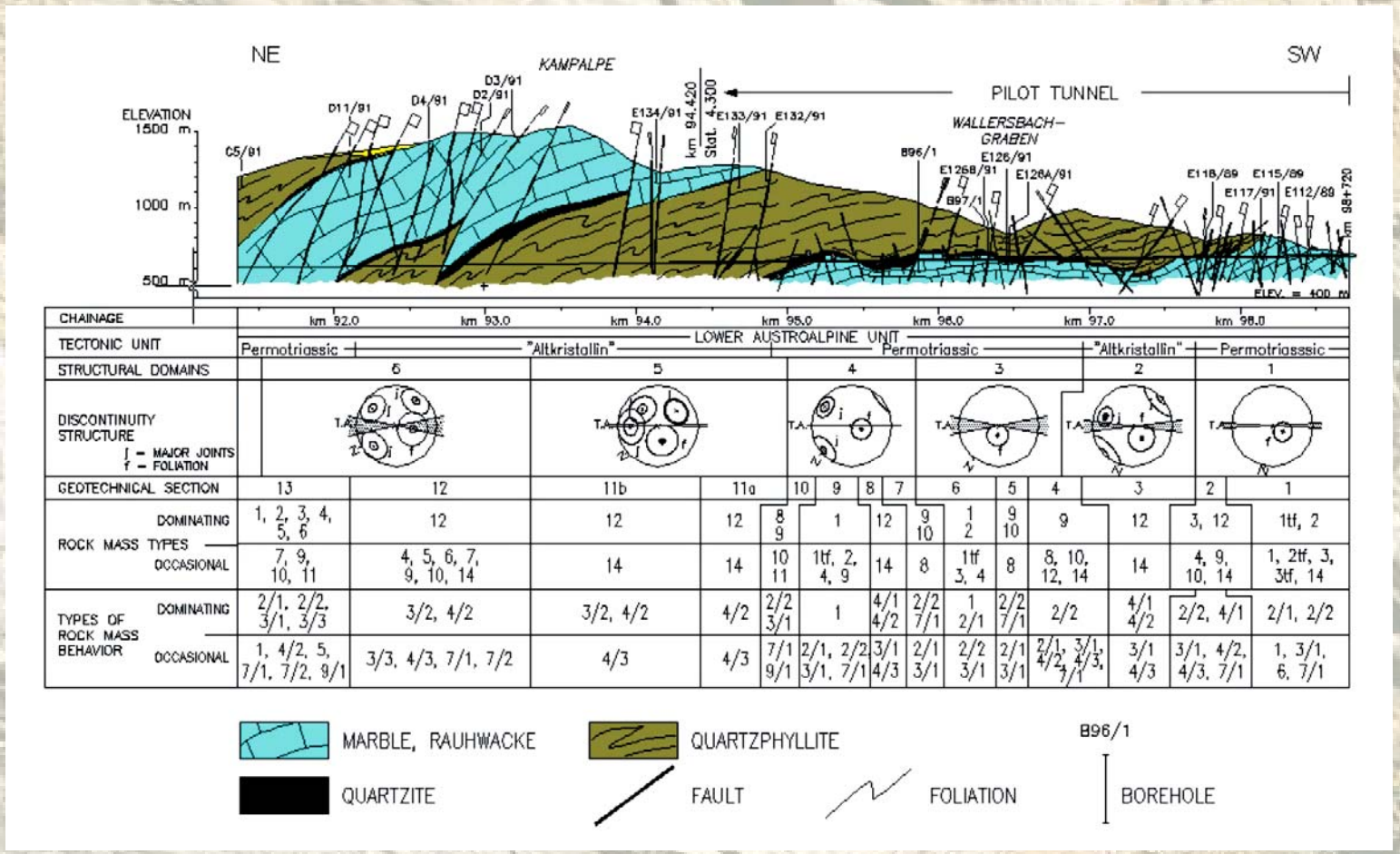
Geotechnical Longitudinal Section



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Case Studies

Geotechnical Hazard Assessment

Project Data
Upgrading of the Seyhan river for energy production. Located in the Toros mountains north of Adana.
- Weir at the confluence of Yenice and Göksu river
- Headrace tunnel (length 9km, diameter 9,0m
- Power house

Tasks
Geotechnical hazard assessment and optimization of design prior to construction

Hepp Kavsak, Turkey

Investigation

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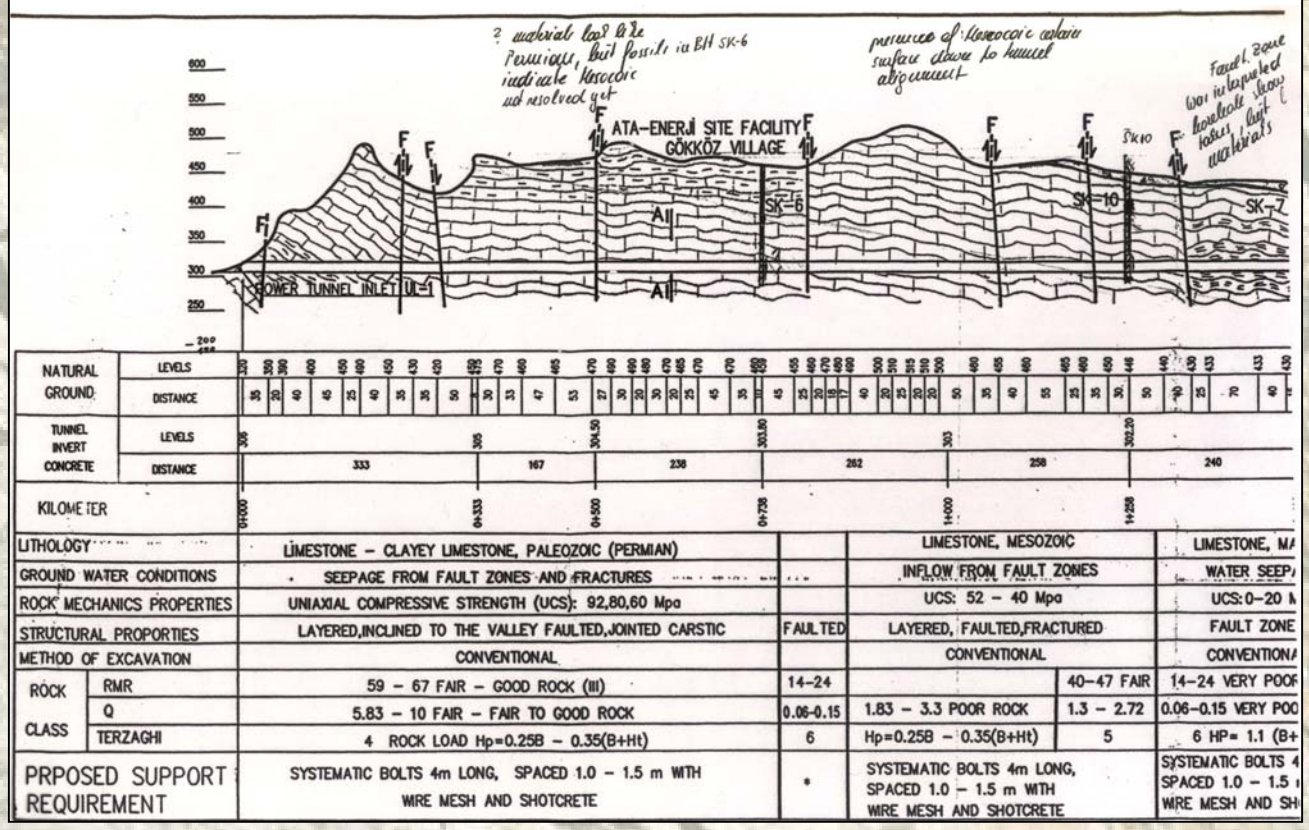
Case Studies

Geotechnical Hazard Assessment

Geotechnical Longitudinal Section of the Tender Design



Hepp Kavsak, Turkey

Investigation

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Case Studies

Geotechnical Hazard Assessment

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Case Studies

Geotechnical Hazard Assessment

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Geotechnical Hazard Assessment

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Geotechnical Hazard Assessment

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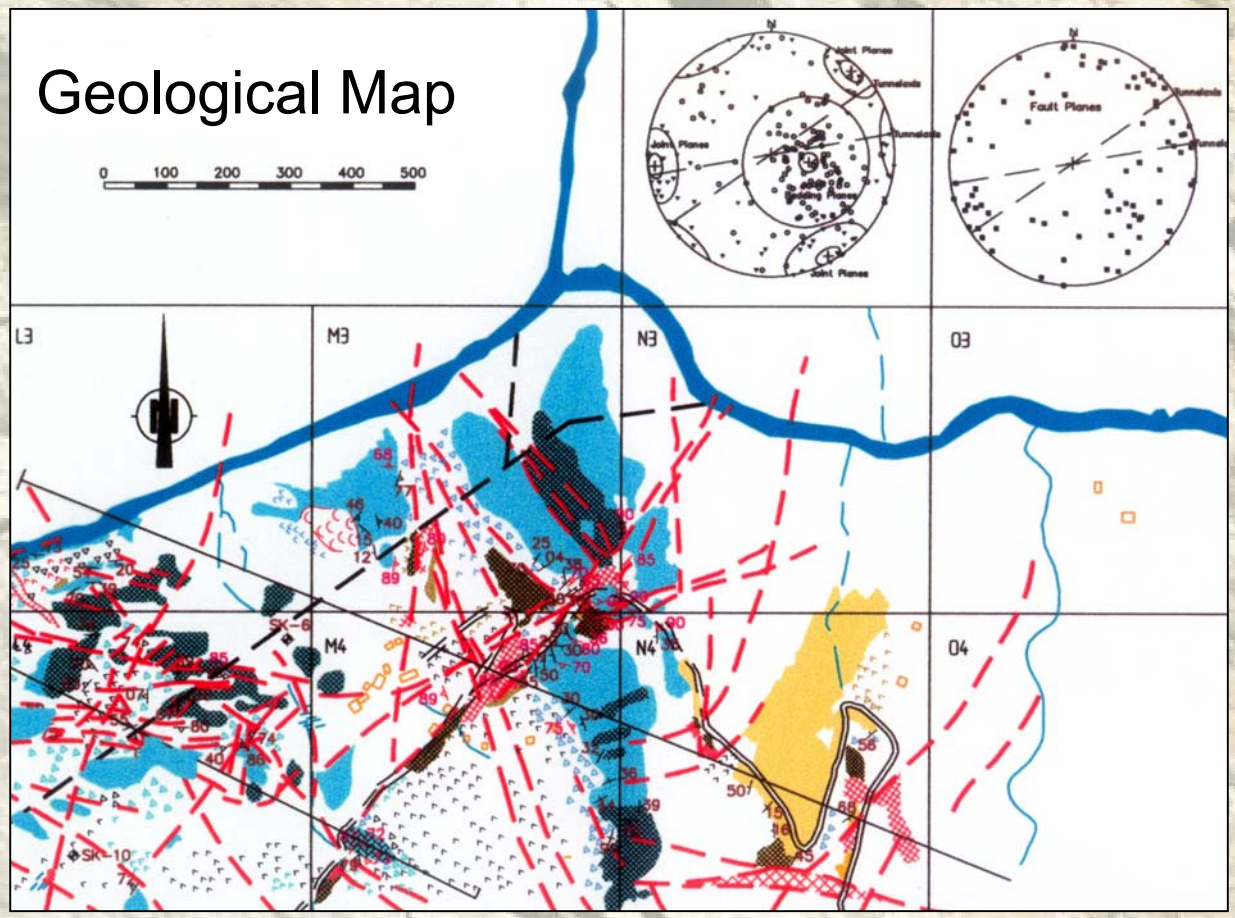
Geotechnical Hazard Assessment



Hepp Kavsak, Turkey

Investigation

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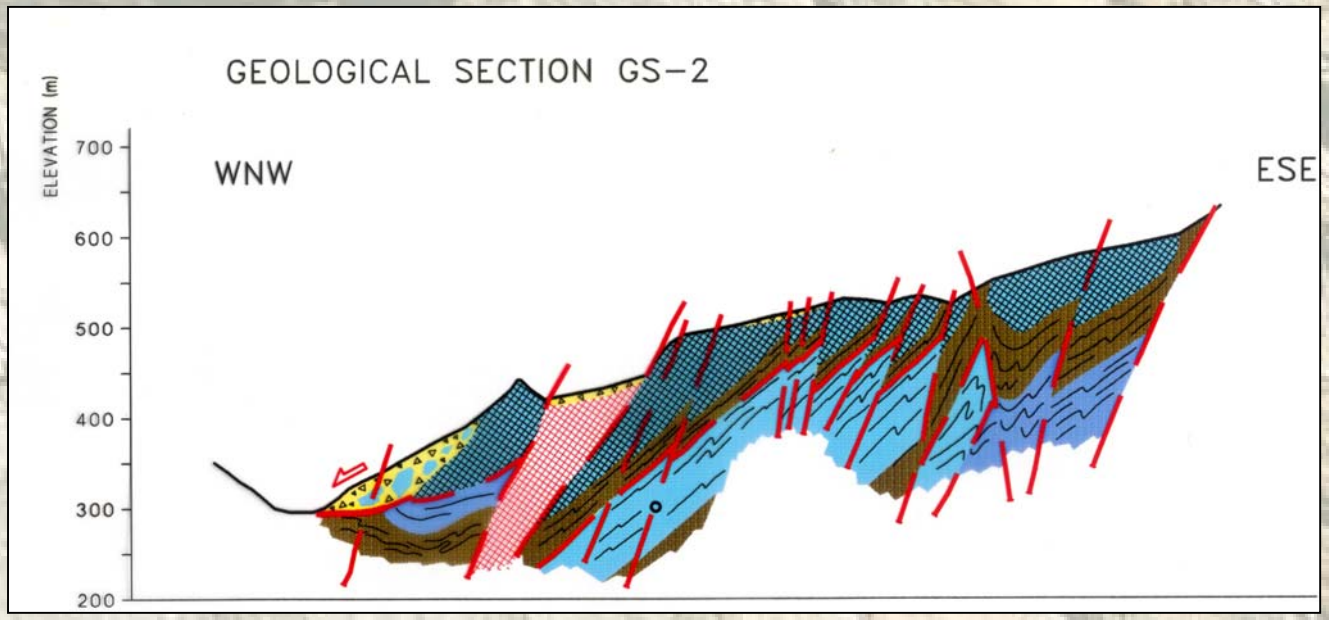
Case Studies

Geotechnical Hazard Assessment



Hepp Kavsak, Turkey

Investigation

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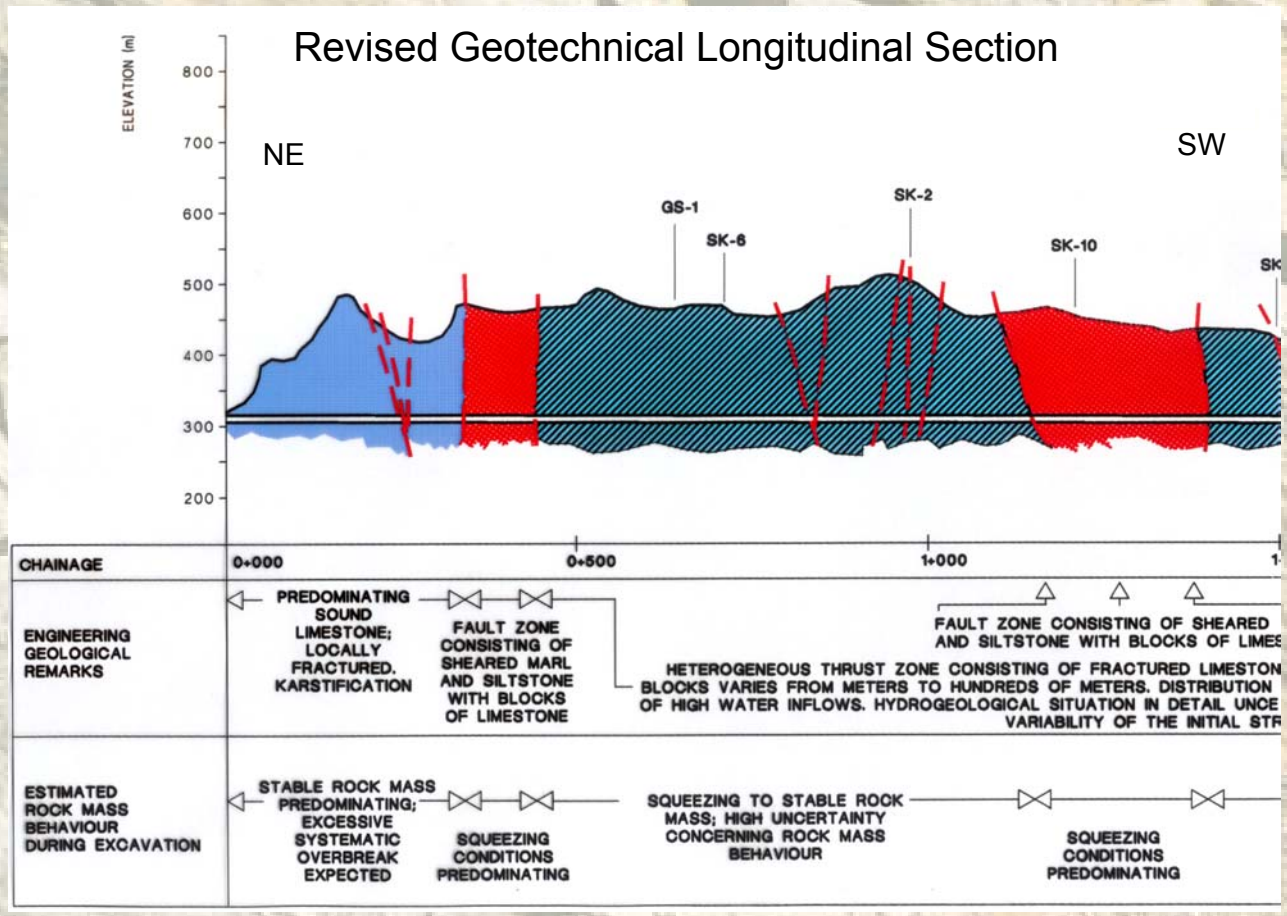
Case Studies

Geotechnical Hazard Assessment



Hepp Kavsak, Turkey

Investigation

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Final Design / Construction

■

Final Determination of Support and Excavation (Type and Sequence)

■

Update of Construction Schedule and Costs

Geological Face Mapping and Geotechnical Monitoring

■

Specific Laboratory and in situ Testing

■

Probing ahead of the Face

- **Statistical and Probabilistic Evaluation of Data from Rock Mass Characteristics, Excavation, Support and Displacements**
- **Short - term Prediction**
- **Mechanical Analyses and Numerical Simulations**
  stress redistribution, displacements
- **Refinement of Mechanical and Hydraulic Models** by extrapolating data from face mapping, monitoring and short-term prediction

Investigation

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Final Design / Construction

Tunnel Construction

Geotechnical Tasks

- Geological Face Mapping
- Geotechnical Monitoring

Face Mapping /Monitoring

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Objective of Geological Face Mapping

- Updating of predicted geological models
- Assessment of rock mass types
- Continuous short-term prediction
- Support with the interpretation of geotechnical measurements
- Documentation

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Final Design / Construction

Tasks

- **Mapping of tunnel faces and tunnel walls**
  - Continuous collection of relevant data
- **Continuous evaluation and interpretation of data**
  - Statistical Analyses
  - Continuous updating of predicted models
  - Continuous short-term prediction ahead of the face

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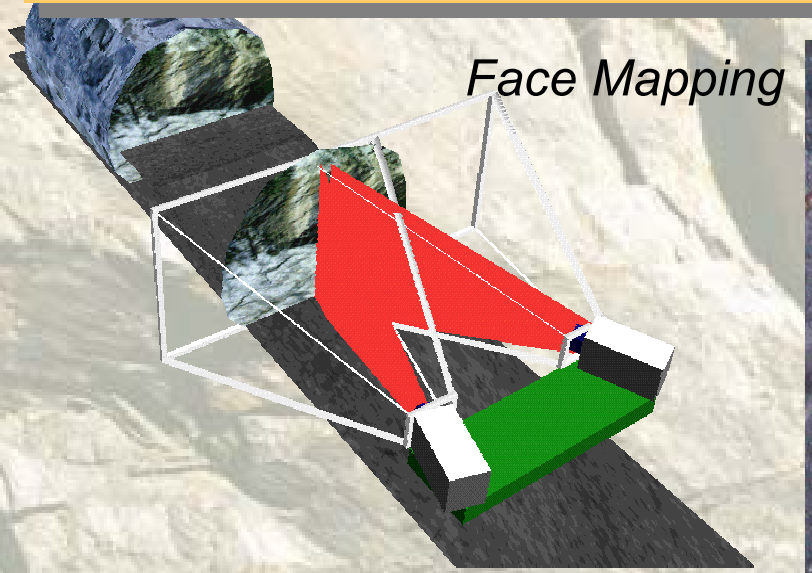
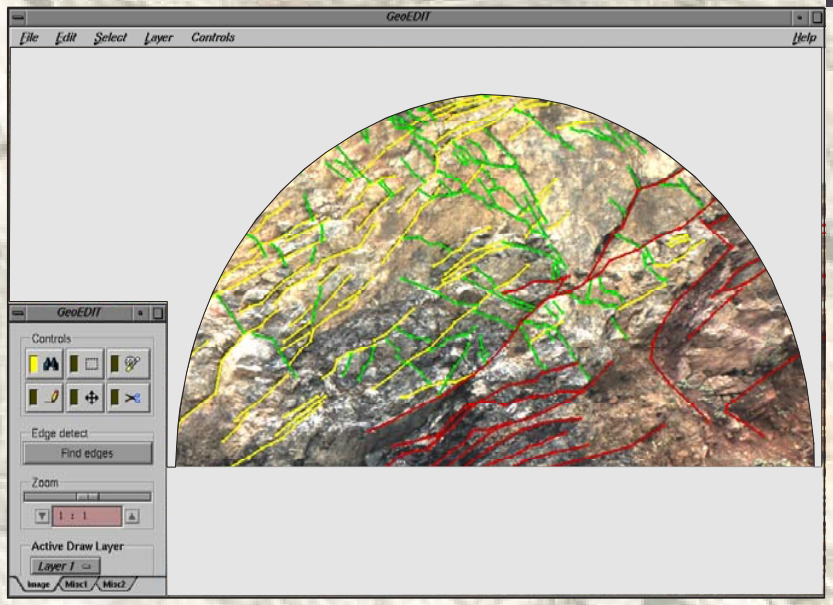
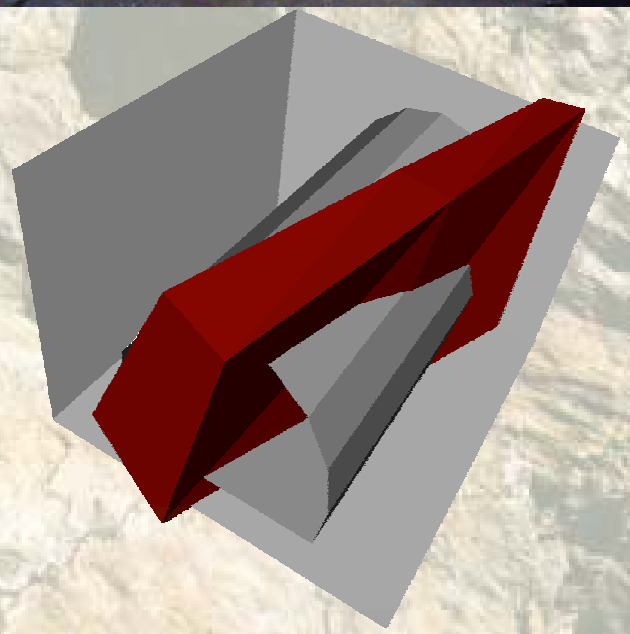
Final Design / Construction



Face Mapping





Face Mapping /Monitoring

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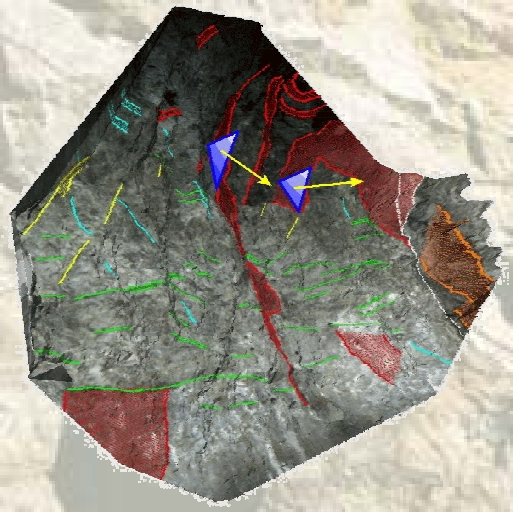
Photo – Image Analyses



Face Mapping /Monitoring

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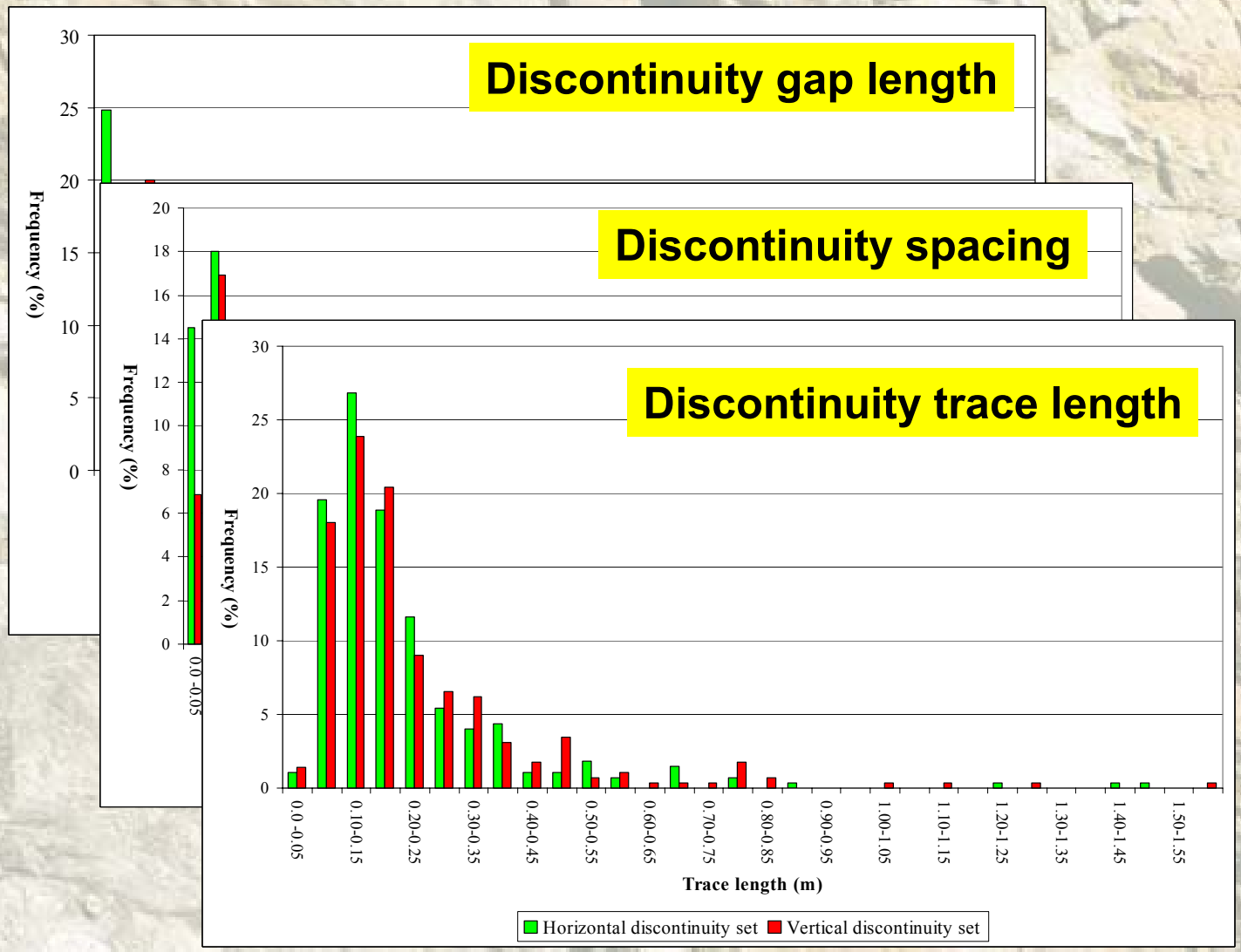
Final Design / Construction

Parameters of Discontinuities



Face Mapping /Monitoring

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Final Design / Construction

DEST

Data Evaluation System for Tunnelling

Face Mapping /Monitoring

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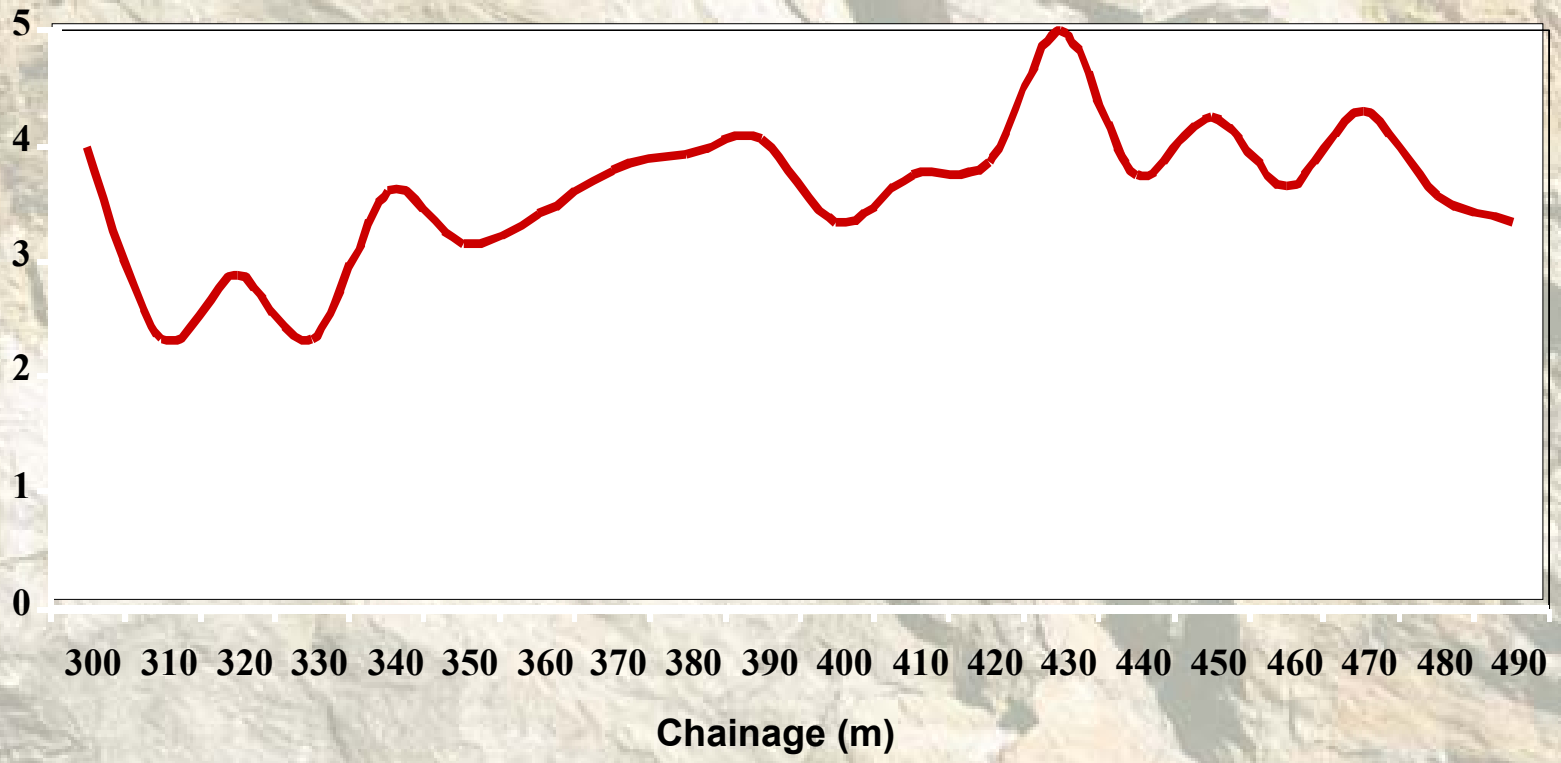
DEST

- **Geology**
  - **Face Mapping**
    - **rock:** lithology, colour, strength, general description
    - **rock mass:** joint block shape, joint block interlocking, weathering, loosening
    - **ground water:** amount / time, position of inflow, type of inflow
  - **Joints**
    - type, position, orientation, spacing, opening, infilling, trace length, termination, surface conditions
  - **Laboratory**
    - particle size distribution, clay minerals, mineralogical composition
- **Support**
  - **Support Timing**
    - shotcrete, welded mesh, ribs, rock bolts, total
  - **Rock Bolt Pattern**
  - **Temporary Rock Bolts**
  - **Additional Rock Bolts**
    - type, position, length, number
  - **Ribs / Welded Mesh / Shotcrete**
    - rib type, rib spacing, lattice type, shotcrete thickness, shotcrete consumption
  - **Face Support**
    - thickness of shotcrete / reinforced shotcrete, rock bolts
  - **Invert**
    - type, thickness, reinforcement, rock bolts
  - **Injection / Drainage**
    - type, position, pressure, type of grout
  - **Forepoling**
    - type, length, number
- **Monitoring**
  - **Convergence**
  - **Geodesic Measurement**
  - **Extensometer**
  - **Strain Gauge**
    - overburden, date, value, position
- **Excavation**
  - **Site of Excavation**
    - main excavation, cavern, shaft, niche, cross cut, etc.
  - **Part of Excavation**
    - top heading, bench, etc., date, type of excavation, round length, overbreak, shape of section, consumption of explosives / detonators, excavation class

Final Design / Construction

DEST

Trend Curve of
Discontinuity Orientation Ratings



very favourable (=1), favourable (=2), fair (=3), unfavourable (=4), very unfavourable (=5)

Pilot Tunnel, Semmering Base Tunnel Project, Austria

Face Mapping /Monitoring

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Final Design / Construction

DEST

Matrix of Zonation Based on Rock Mass Type and Normalized Support Quantity Value

Zonierungsmatrix nach Gebirgstyp und Stützmittelzahl (ÖNORM)

Anzahl der Zonen	2	3	4	5	6	7	8	9	10	11
Reduktion der Variation (%)	*46.31*	*63.94*	*72.02*	*75.82*	*78.22*	*81.72*	*83.92*	*86.97*	*88.16*	*89.12*
Zonengrenzen (m)	560	330	330	330	330	330	330	330	290	290
	990	560	560	560	530	490	490	490	320	320
		990	950	950	570	520	520	520	490	490
			990	970	950	570	570	560	520	520
				990	970	950	830	660	560	560
					990	970	950	830	660	660
						990	970	950	830	830
							990	970	950	950
								990	970	960
									990	970
										990

Stations 230 m – 1000 m

Pilot Tunnel, Semmering Base Tunnel Project, Austria

Face Mapping /Monitoring

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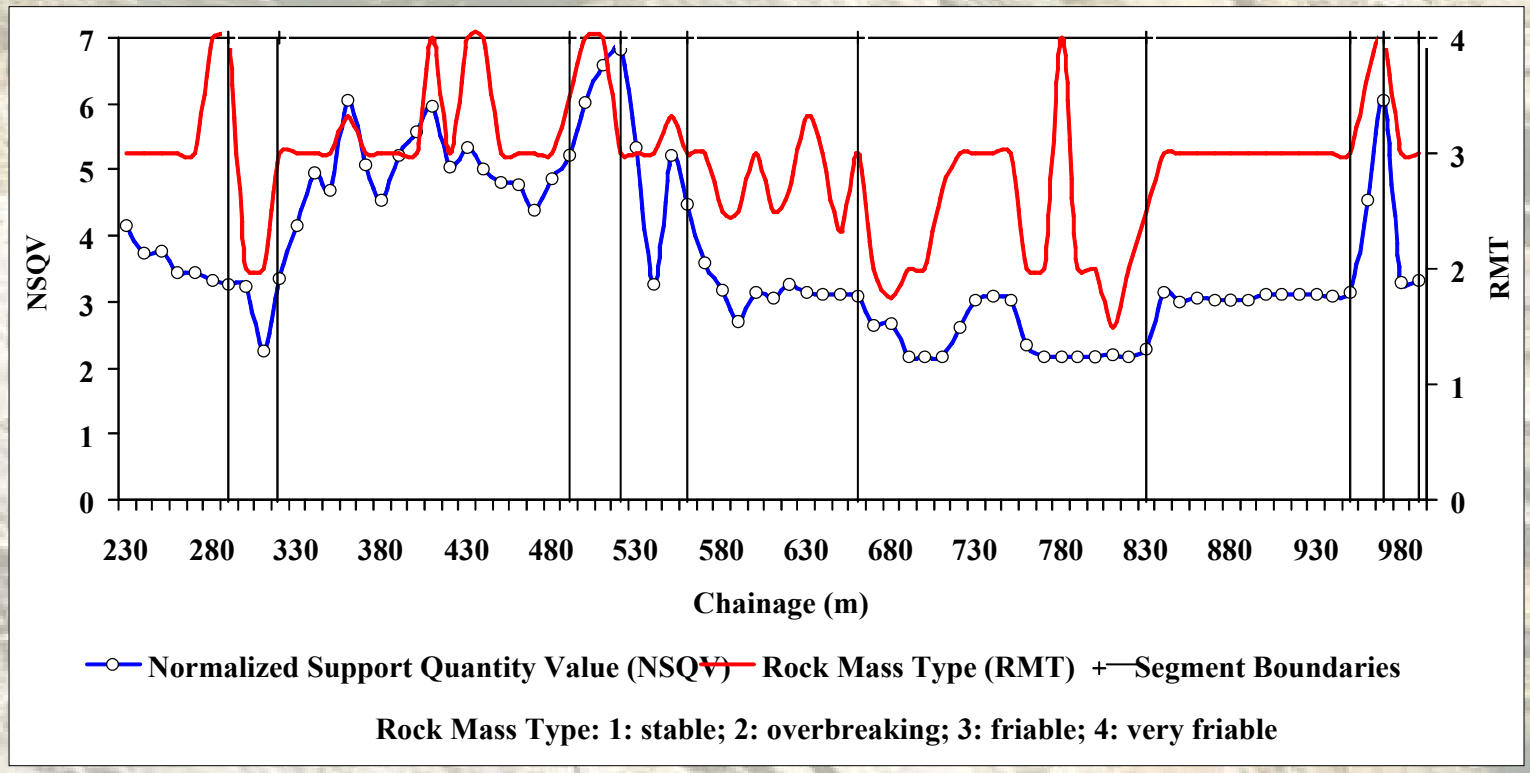
Final Design / Construction

Zonation based on Rock Mass Type (RMT) and Normalized Support Quantity Value (NSQV)

Zonierungsmatrix nach Gebirgstyp und Stützmittelzahl (ÖNORM)



Pilot Tunnel, Semmering Base Tunnel Project, Austria

Face Mapping /Monitoring

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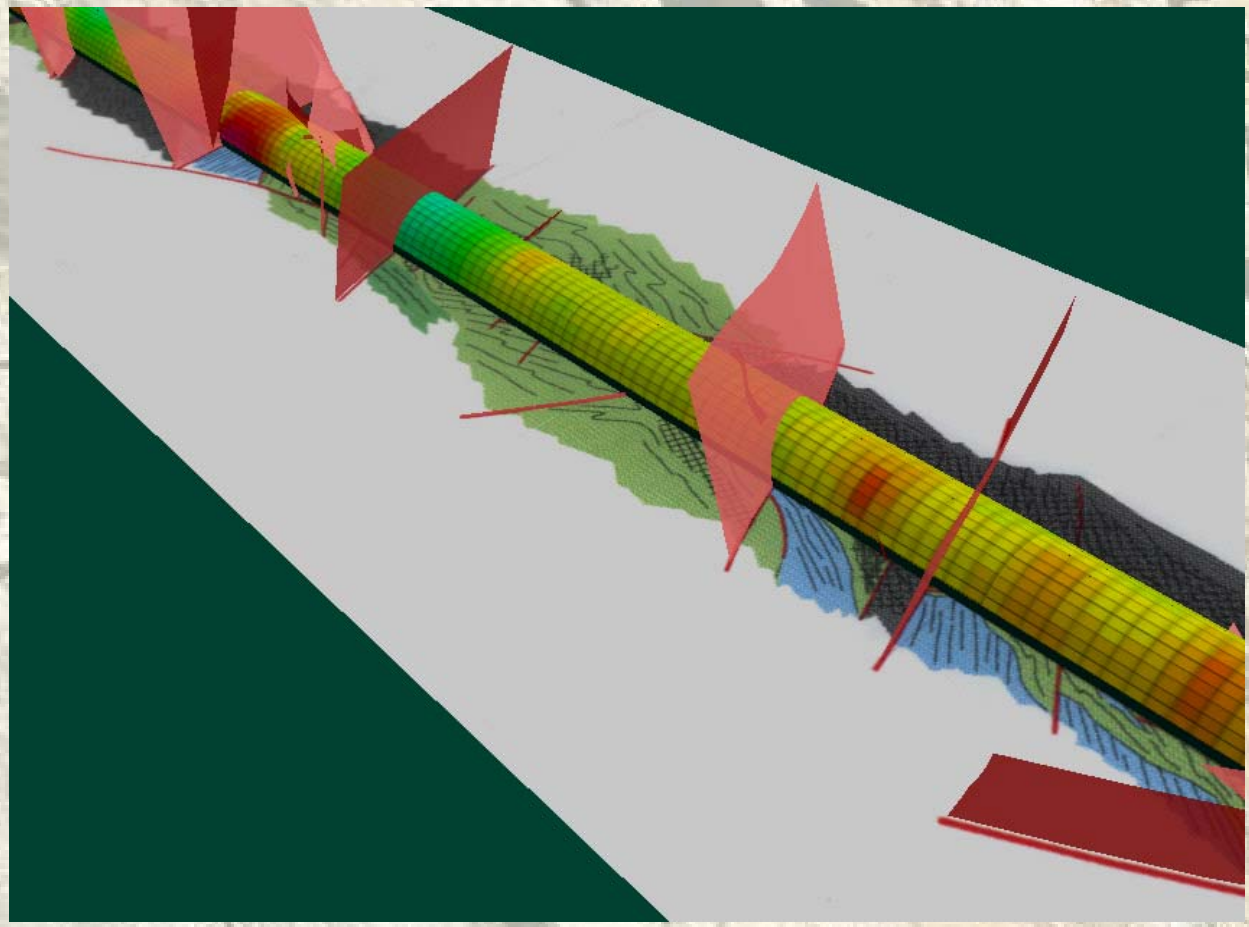
Final Design / Construction

Geotechnical Model



Galgenberg Tunnel, Austria

Face Mapping /Monitoring

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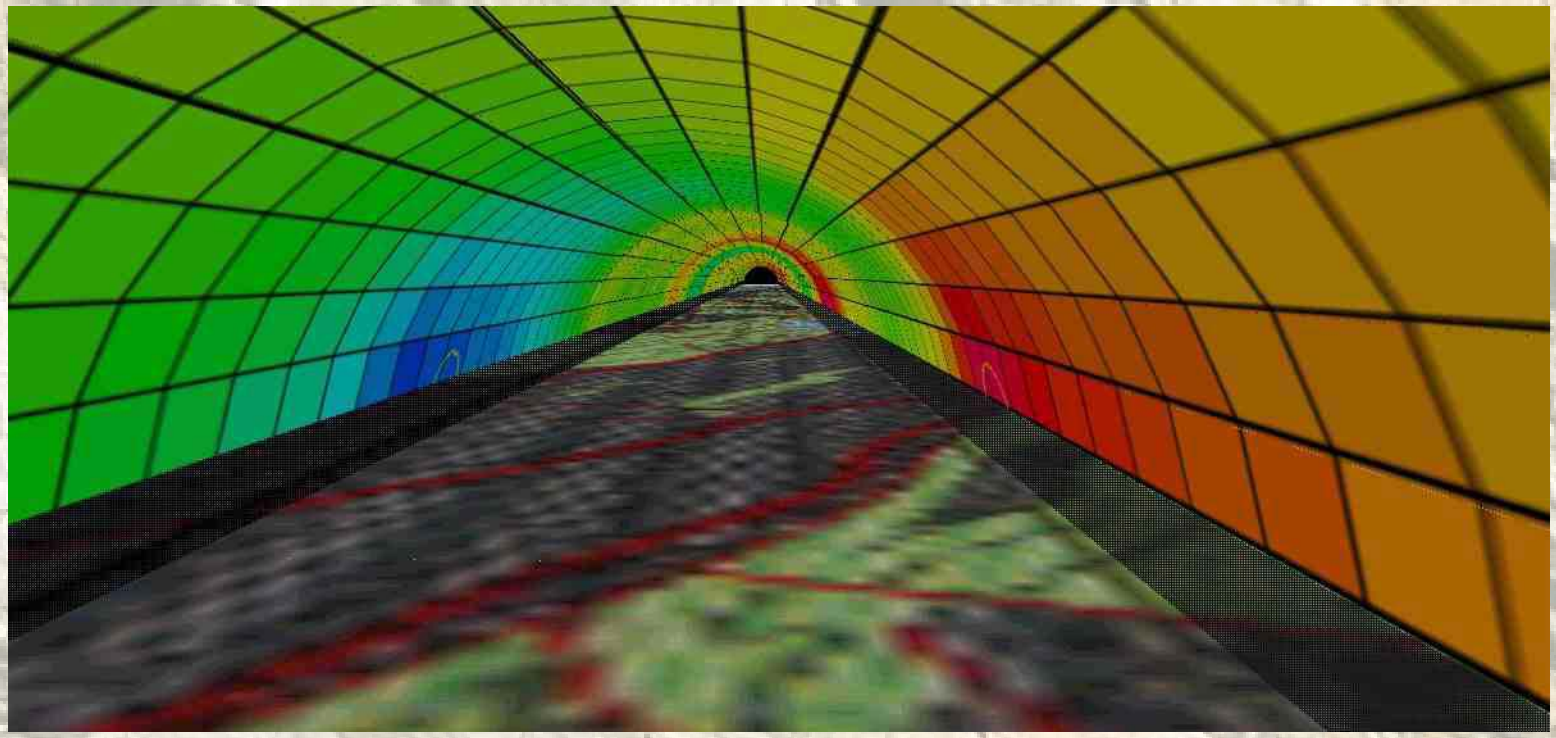
Final Design / Construction

Geotechnical Model



Galgenberg Tunnel, Austria

Face Mapping /Monitoring

3G
Gruppe
Geotechnik
Graz ZT GMBH