Formation of Clay Minerals

Characterization

Clay Mineral Neoformation and Transformation in Fault Zones

FROM AEG SHORT COURSE " Tunnels Through Fault Rocks and Tectonic Melanges: A Short Course for Engineering Geologists and Geotechnical Engineers", Oakland, California; June 1, 2002; Instructors: Prof. Gunter Riedmueller and Prof. Wulf Schubert, Technical University of Graz, Austria and Gruppe Geotechnik Graz

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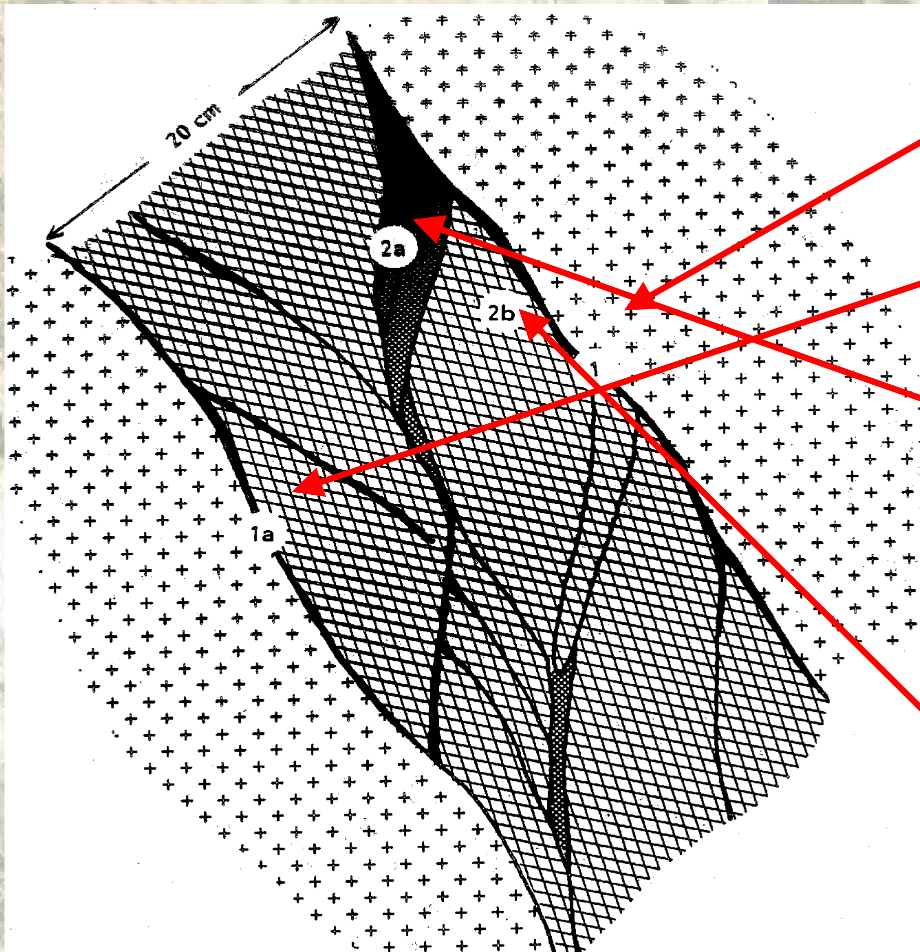
Formation of Clay Minerals



Sample 1: Smectite 92%
Illite 8%

Sample 1a: Smectite 87%
Illite 13%

Sample 2a: Smectite 77%
Mixed Layer
3%
Kaolinite 17%
Illite 3%

Sample 2b: Sample 40%
Kaolinite 50%
Illite 10%

Fault Zone in Gneiss („Zentralgneis“)
HPP MALTA – Gößß Tunnel, Km 4,615

Characterization

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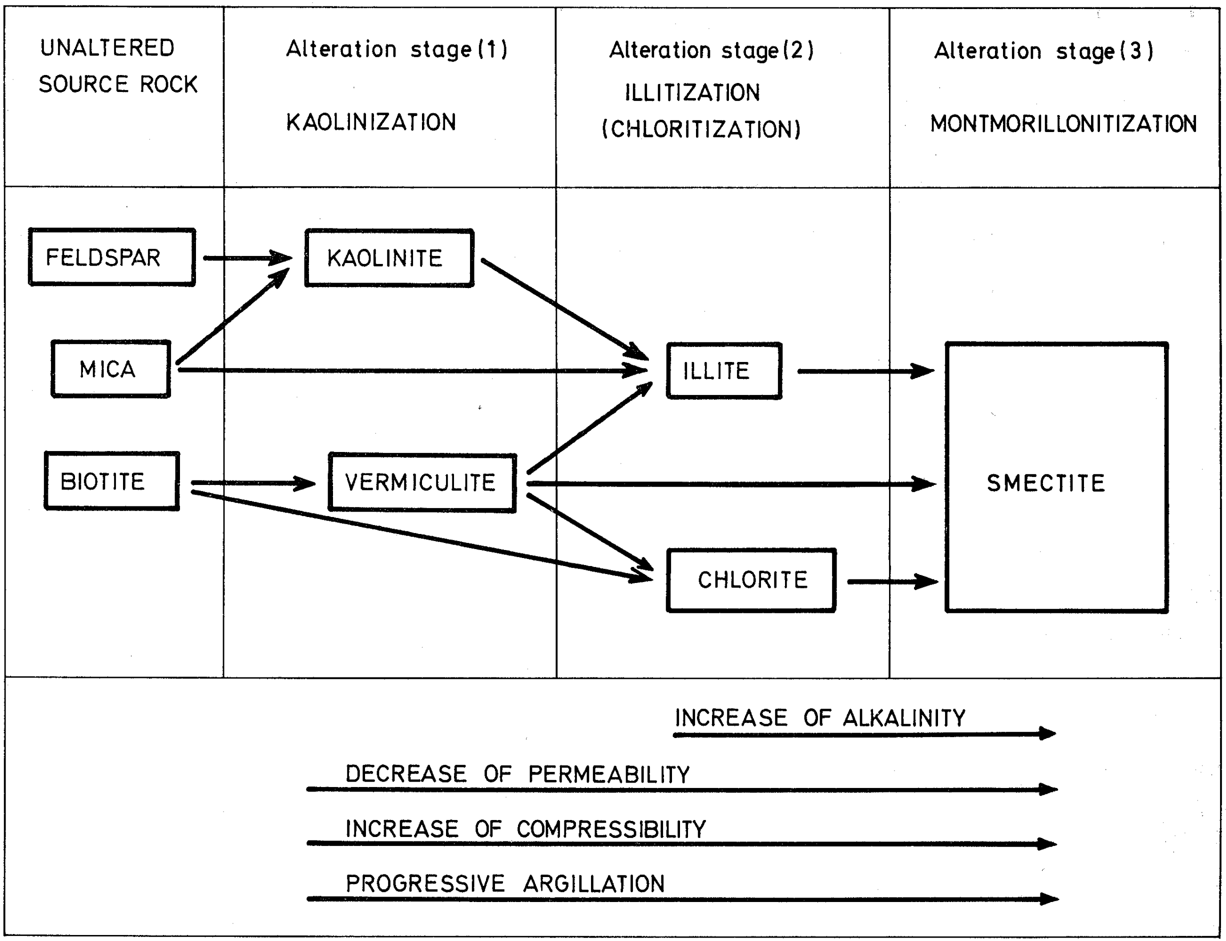
Formation of Clay Minerals

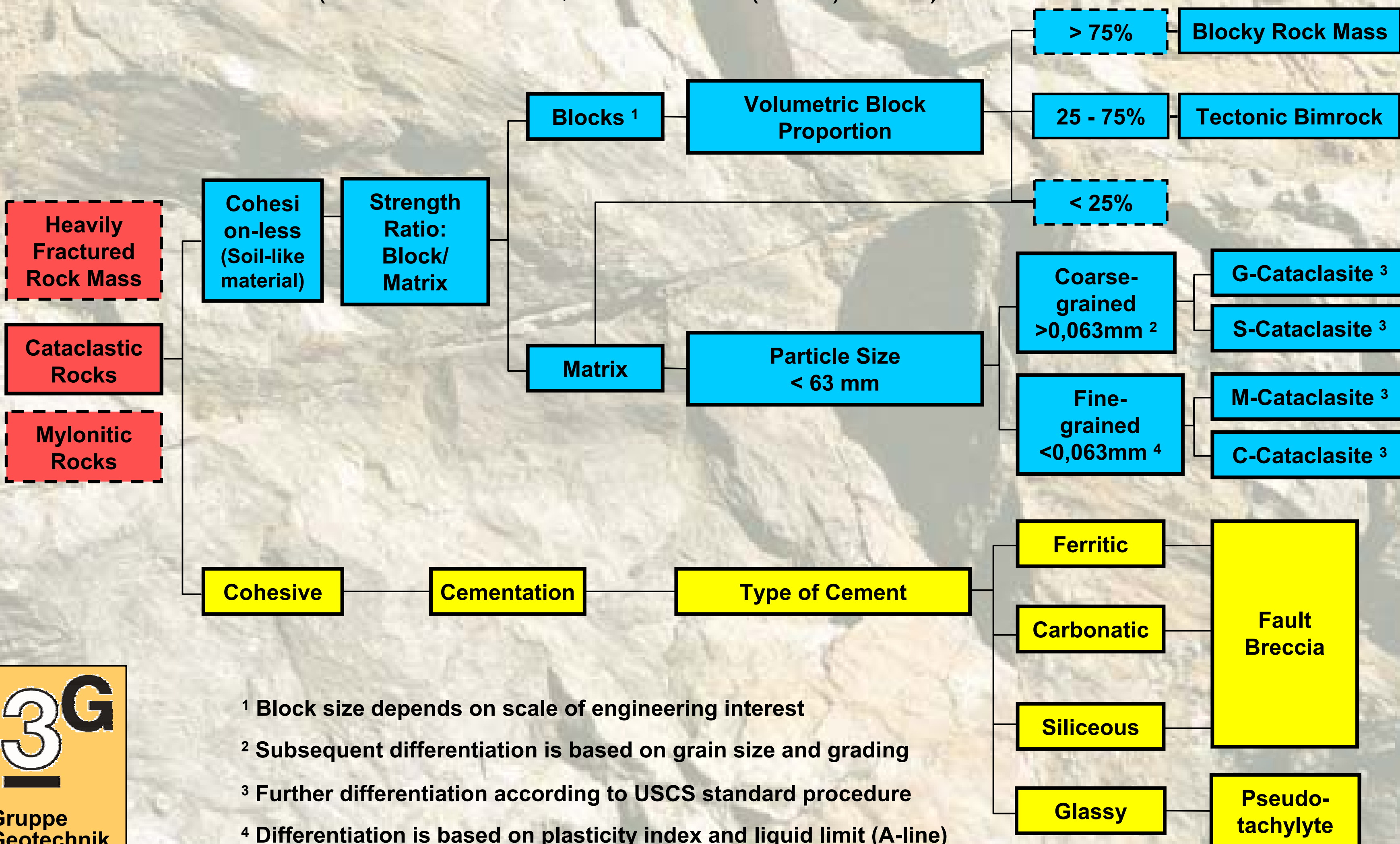


Systematic Transformations of Clay Minerals in Fault Zones
(G. Riedmüller 1976)

Classification

Engineering Geological Classification of Fault Rocks

(Riedmüller et al., Felsbau 19 (2001) No. 4)



[1] Block size depends on scale of engineering interest

[2] Subsequent differentiation is based on grain size and grading

[3] Further differentiation according to USCS standard procedure

[4] Differentiation is based on plasticity index and liquid limit (A-line)

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General Procedure

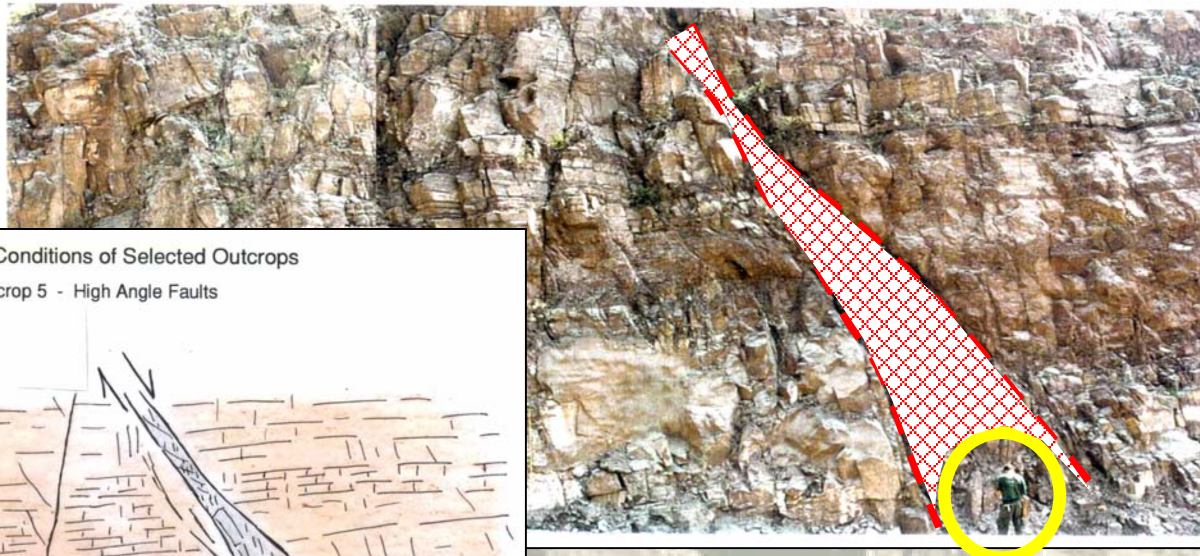
- **Desk Studies**
  - Satellite Images, Aerial Photographs, Maps etc.
- **Geological Field Survey**
  - Morphological Features
  - Outcrop Studies
    - Rock Mass Characterization
    - Paleostress Analysis
- **Subsurface Investigation**
  - Trenches, Trial Pits
  - Core Drilling
  - Borehole in-situ tests
  - Geophysical Survey
- **Laboratory Analyses**
  - Mineralogical Analyses
  - Mechanical Analyses

Outcrop Studies

Investigation

Photographic Substantiation of Selected Outcrops

Outcrop 5 - High Angle Faults



Geological Conditions of Selected Outcrops

Outcrop 5 - High Angle Faults

① FAULT ZONE WITH FAULT BRECCIA AND GOUGE

② PARENT ROCK HEAVILY FRACTURED

Hydro Power Project Xiaolangdi

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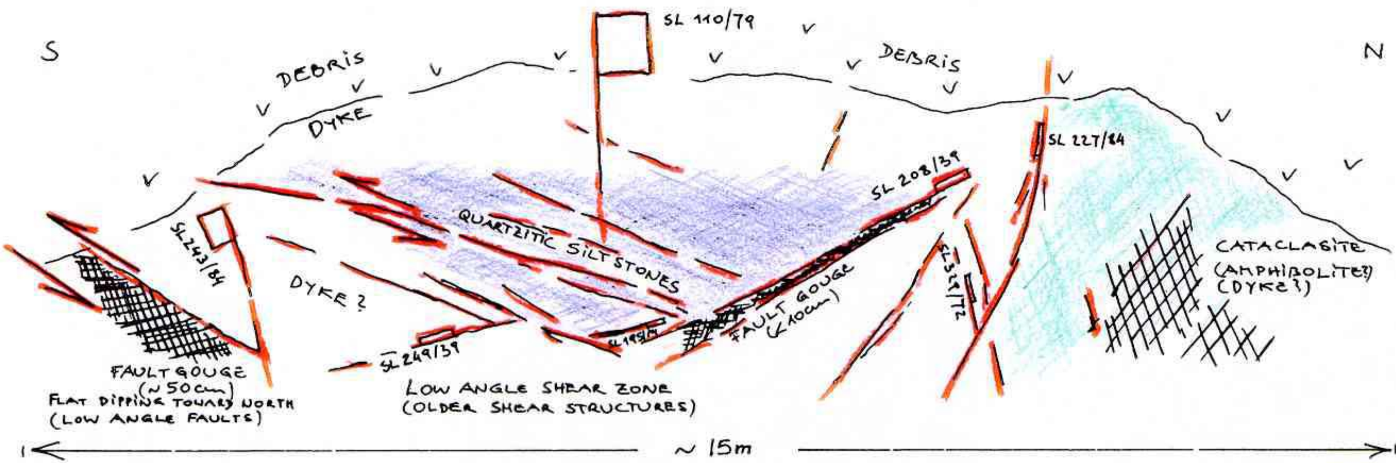
Outcrop Studies

Paleostress Analysis

- **Fault Slip Data**
  - P/T Method
  - Method of Right Dihedra
- **Extension Joints**
  - Plumose Structure

Outcrop Studies

Thrust Displaced by Strike – Slip Faults



Low angle faults (SL 293/34, 290/42, 302/37, 331/42, 208/39, 249/39) displaced by conjugated faults (SL 227/84, 329/72, 91/87, 243/84, 226/86)

Bolu Tunnel, Turkey

Investigation

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Strategies

Objective of Investigation

OWNER‘S INTEREST:

- **Construction schedule**
- **Construction costs**

- **Definition of uncertainties**
- **Geotechnical risk assessment**
- **Identification of environmental problems**

Strategies

Common understanding

High standards and quality for a site investigation lead to an economical and technical successful construction

Strategies

Quality

QUALITY *is a relative attribute and depends upon the specific circumstance. In the sense of a technical sound and economic investigation quality is determined to be either adequate or inadequate.*

What is an acceptable quality investigation in one situation can be an inadequate and unacceptable investigation in another.

Strategies

Design Requirements

Project Phases

Quality Data
Quality Analyses
Quality Investigation

Complexity of Rock Mass

Complexity of Geology

Strategies

Quality Data Collection
Quality Data Analysis

- geotechnically relevant
- statistically representative
- legally defensible

Strategies

Quality Data Collection
(with adequate quality control and quality assessment)

- Office Data Collection
- Field Survey
- Subsurface Exploration
- In Situ Testing
- Laboratory Testing

Strategies

Quality Data Analysis
(with adequate quality control and quality assessment)

- Statistical Evaluation
- Assessment of Probabilistic Confidence
- Geologic Modelling
- Kinematic Modelling
- Mechanical Modelling

Strategies

Quality Site Investigation

A QUALITY INVESTIGATION needs more than just QUALITY DATA and QUALITY ANALYSES.

It requires:

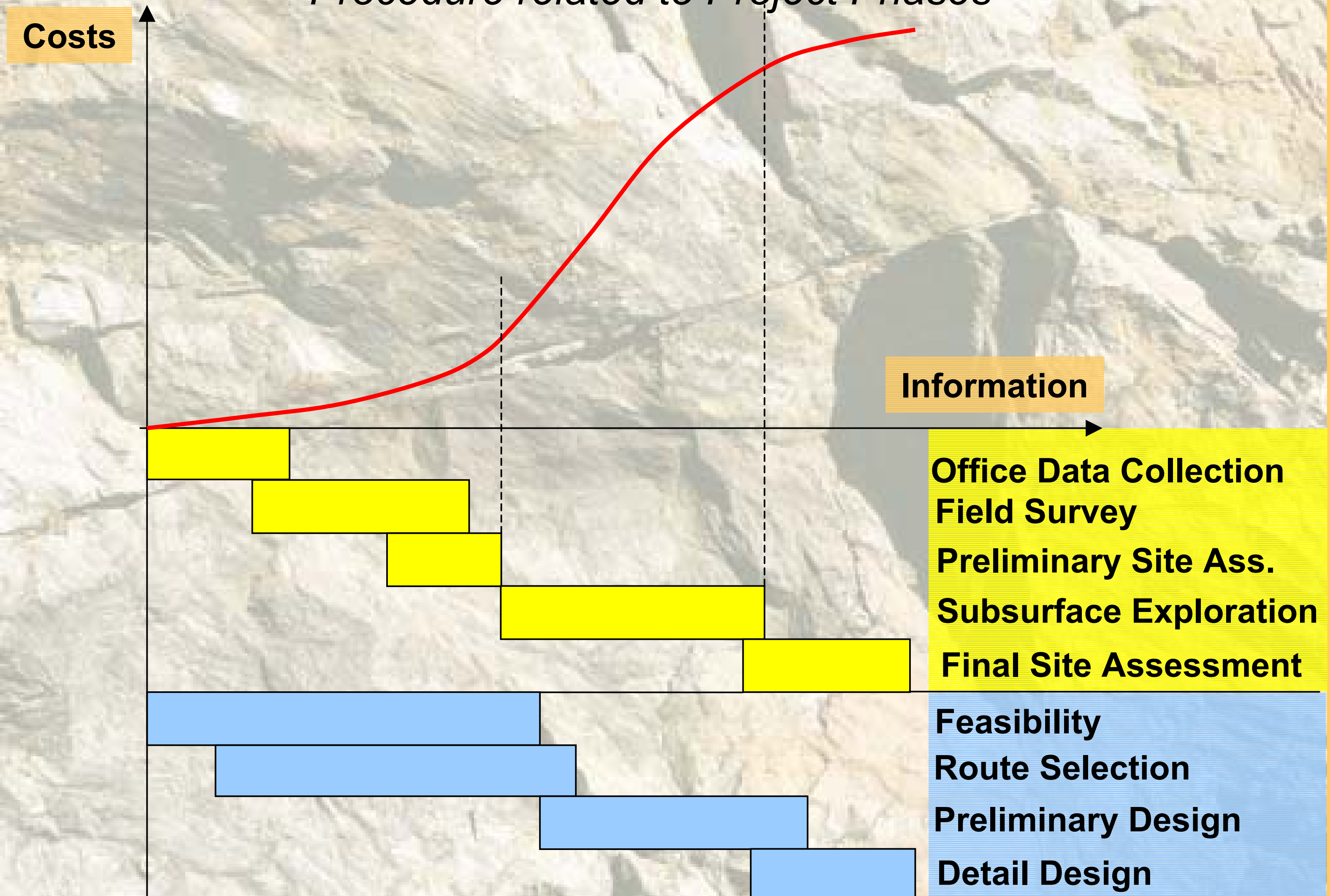
1. Specific sequence of investigative procedures

2. Design phase and rock mass specific investigations

3. Input from experienced professionals

Strategies

Cost - Benefit Relation of Investigation Procedure related to Project Phases



Investigation

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Strategies

Project Phases - Geotechnical Objectives

Pre-Feasibility Feasibility	Conceptual Design Route Selection	Preliminary Design	Detail Design Tender	Final Design Construction
Corridor Assessment ■ Comparison of Routes ■ First Cost Estimate	Basic Assessment of Rock Mass Behaviour, Support Systems and Construction Methods ■ Assessment of Routes ■ Cost Estimate	Assessment of Rock Mass Behaviour, Support Systems and Construction Methods ■ Environmental Impact Assessment ■ Cost Estimate	Detail Construction Design ■ Bill of Quantities ■ Contractual Set-Up ■ Final Cost Estimate	Final Determination of Support and Construction Methods ■ Update of Construction Schedule and Costs

Strategies

Analytical Procedure in Each Design Phase

Assessment of Geological Models

↓

Rock Mass Characterisation
Rock Mass Types

↓

Stresses, Groundwater, Orientation
Size & Shape of Tunnel

↓

Mechanical Modelling
Rock Mass Behaviour

↓

Geotechnical Design Assumptions

Strategies

Assessment of Geological Models

Conceptual **Geological Models** include
three-dimensional interpretations of the distribution and orientation of structures and rock types.
The models are presented as geological maps, vertical and horizontal sections and, most recently, as 3D-models

Strategies

Rock Mass Characterisation
Rock Mass Types

Rock Type

Mineralogical Parameter
Mechanical Properties

Discontinuities

Geometrical Properties
Mechanical Properties
Hydraulic Properties

ROCK MASS TYPE

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Strategies

Definition of Rock Mass Types

Rock Mass Types are defined by

“KEY PARAMETERS“

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Strategies

Key Parameters

Key Parameters depend on

- Rock Type
- Project Phase
- Design Requirements

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Strategies

Rock Type → Key Parameters

Phyllite

- Anisotropy
- Shear parameters and stiffness of foliation planes
- Content of sheet silicates and clay minerals

Investigation

Strategies

Rock Type → Key Parameters

Granite

- → Grain size
- → Texture
- → UCS
- → Joint sets (orientation,number)
- → Persistence, spacing

Strategies

Basic Rock Types	Key Parameters																				
	Intact Rock Properties														Discontinuities						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Volcanic Rocks				o	x	x						x	x		x	x		o	x	o	
Plutonic Rocks		x	x	x		o						x			x	x		o	x	o	
Fine-Grained Clastic Rocks (massive)			x				x	x	x		x	o			o	o					
Fine-Grained Clastic Rocks (bedded)	x		x				x	x	x		x			x			x			o	x
Coarse-Grained Clastic Rocks (massive)		o	x	o	o			o			x	x	x		o	o		o	o		
Coarse-Grained Clastic Rocks (bedded)	x	o	x		o			o			x	x	x	x			x				x
Carbon. Rocks		x								x		x			x	x		o	x	o	
Sulfatic Rocks		x							x	x		o									
Metam. Rocks (massive)		x	x	x		o						x			x	x		o	x		
Metam. Rocks (foliated)	x	x	x	x		o						x		x						x	x
Brittle Fault Rocks		o				o	x	x	x		x	x	x								

LEGEND

x Significant Parameter

o Less Important Parameter

(1) Anisotropy
(2) Mineral Composition
(3) Grain Size
(4) Texture
(5) Porosity
(6) Secondary Alteration
(7) Clay Mineral Composition
(8) Clay Content
(9) Swelling Properties
(10) Solution Phenomena
(11) Cementation
(12) Strength Properties
(13) Ratio Matrix/Components
(14) Orientation of Dominant Set
(15) No. and Orientation of Sets
(16) Fracture Frequency
(17) Roughness
(18) Persistence
(19) Aperture
(20) Infilling
(21) Shear Strength

Rock Type Specific Key Parameters

Faulted Rock Mass

- **Block / Matrix Ratio**

- **Matrix Properties**
  - Particle Size Distribution
  - Clay Mineral Composition
  - Swelling Properties
  - Shear Strength

- **Block Properties**
  - Lithology
  - Size
  - Shape
  - Strength

- **Discontinuities**
  - Type (shear, extension fractures etc.)
  - Orientation
  - Fracture Degree
  - Relative Movements on Slickensides

Key Parameters

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AUSTRIAN GUIDELINE FOR THE GEOTECHNICAL DESIGN OF UNDERGROUND OPENINGS

Published by the Austrian Society for Geomechanics

Guideline

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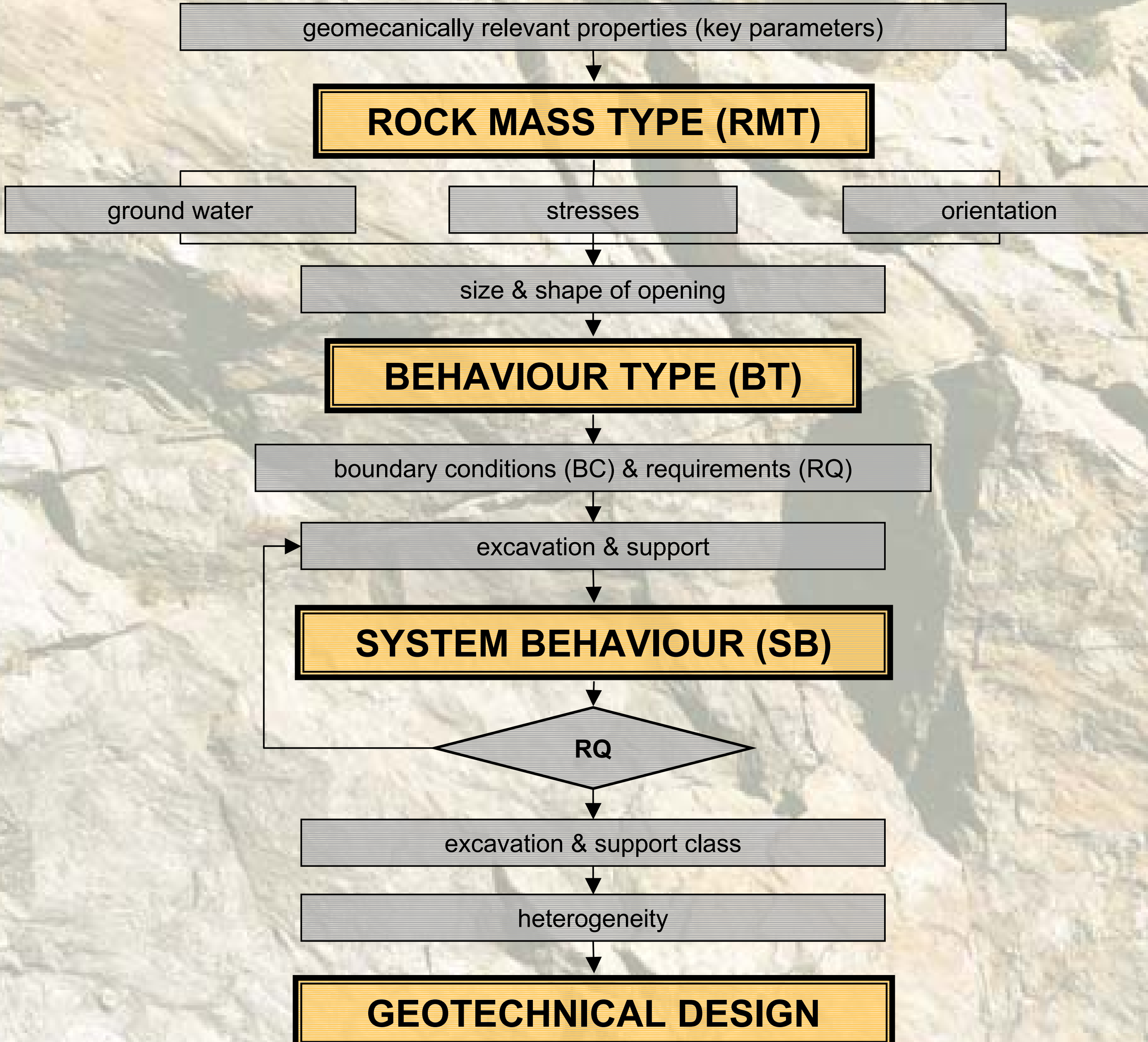
OBJECTIVE

- Transparent, consistent procedure for the design and construction of tunnels
- Design phases, rock mass types and influencing factors have to be considered
- Decisions during construction have to be based on objective and systematic collection, evaluation and interpretation of quality data



Guideline

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KEY PARAMETERS

Basic Rock Types	Key Parameters																				
	Intact Rock Properties														Discontinuities						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Volcanic Rocks				o	x	x						x	x		x	x		o	x	o	
Plutonic Rocks		x	x	x		o						x			x	x		o	x	o	
Fine-Grained Clastic Rocks (massive)			x				x	x	x		x	o			o	o					
Fine-Grained Clastic Rocks (bedded)	x		x				x	x	x		x			x			x			o	x
Coarse-Grained Clastic Rocks (massive)		o	x	o	o			o			x	x	x		o	o		o	o		
Coarse-Grained Clastic Rocks (bedded)	x	o	x		o			o			x	x	x	x			x				x
Carbon. Rocks		x								x		x			x	x		o	x	o	
Sulfatic Rocks		x							x	x		o									
Metam. Rocks (massive)		x	x	x		o						x			x	x		o	x		
Metam. Rocks (foliated)	x	x	x	x		o						x		x						x	x
Brittle Fault Rocks		o				o	x	x	x		x	x	x								

LEGEND

x Significant Parameter

o Less Important Parameter

(1) Anisotropy
(2) Mineral Composition
(3) Grain Size
(4) Texture
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(18) Persistence
(19) Aperture
(20) Infilling
(21) Shear Strength

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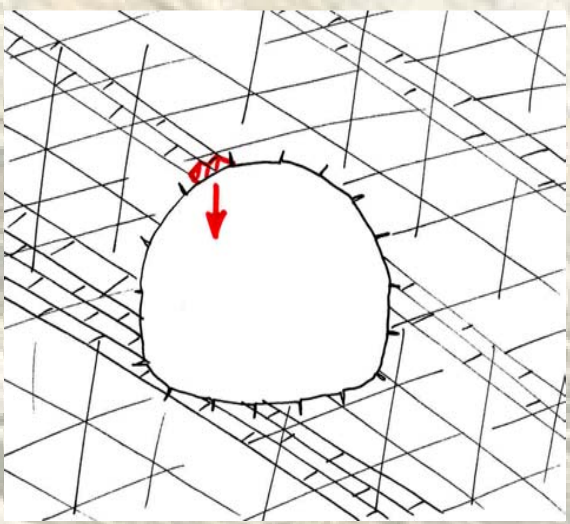
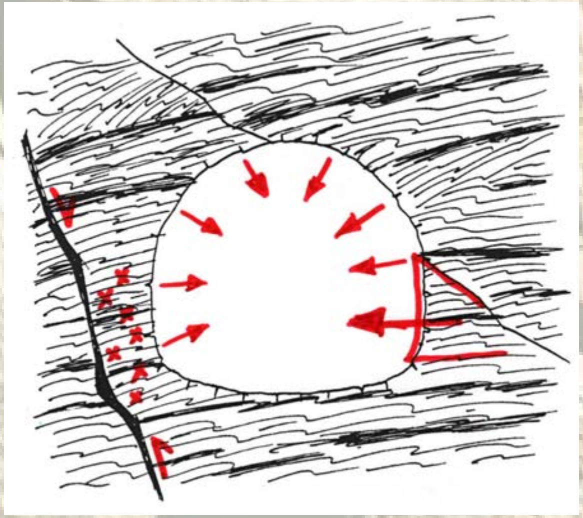
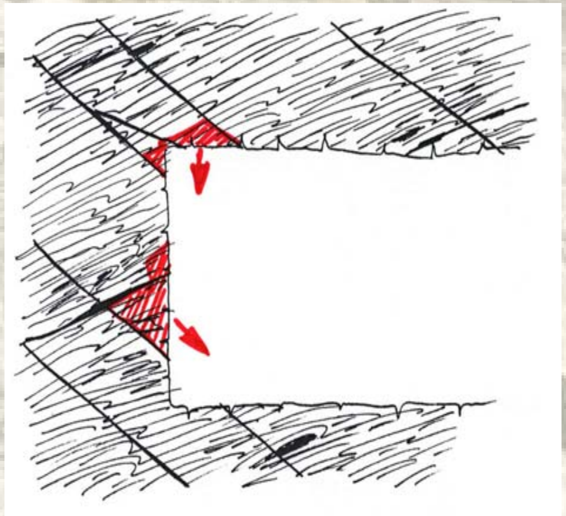
BASIC BEHAVIOUR TYPES

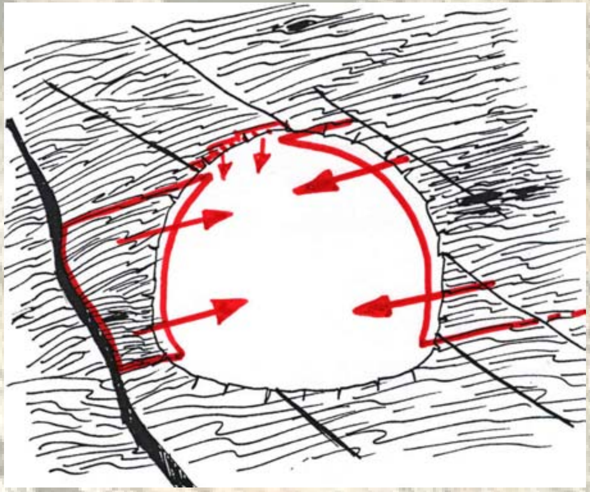
Basic Behavior Type		Description
1	Stable	Stable rock mass with small local gravity induced falling or sliding of blocks
2	Stable with the potential of discontinuity controlled block fall	Deep reaching discontinuity controlled, gravity induced falling and sliding of blocks, occasional local shear failure
3	Shallow shear failure	Shallow stress controlled shear failures in combination with discontinuity and gravity controlled failure of the rock mass
4	Deep seated shear failure	Deep seated, stress induced shear failures and large deformations
5	Rock burst	Sudden and violent failure of the rock mass, caused by highly stressed rock and the rapid release of accumulated strain energy
6	Buckling failure	Buckling of rocks with a narrowly spaced discontinuity set, frequently associated with shear failure
7	Shear failure under low confining pressure	Potential for excessive overbreak and progressive shear failure with the development of dead loads, caused mainly by a deficiency of side pressure
8	Raveling ground	Flow of cohesionless dry or moist material
9	Flowing ground	Flow of material with high water content
10	Swelling	Time dependent volume increase of the rock mass, caused by physical- chemical reactions of rock and water in combination with stress relief, leading to inward movement of the tunnel perimeter
11	Rock mass with frequently changing deformation characteristics	Rapid variations of stresses and deformations, caused by block-in matrix situation of a tectonic melange (brittle fault)

BEHAVIOUR TYPES (examples)









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TRANSFER OF GEOLOGICAL MODELS INTO GEOTECHNICAL DESIGN

GEOLOGICAL LONGITUDINAL SECTION

↓

ROCK MASS TYPES

stepwise assigned (e.g. 20 m intervals)

↓

ANALYTICAL CALCULATIONS

for each 20 m step

Input: influencing factors, geotechnical properties

Output: displacements, depths of broken zones, etc.

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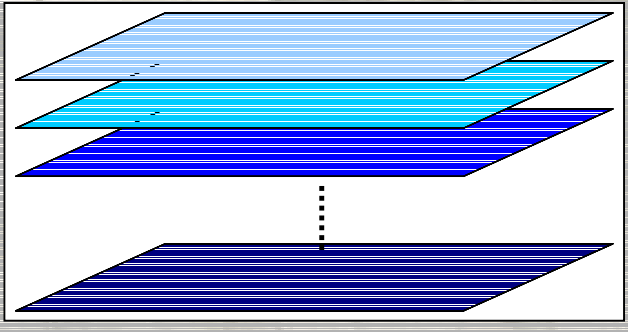
DETERMINATION OF BEHAVIOUR TYPES

OUTPUT OF ANALYTICAL CALCULATIONS

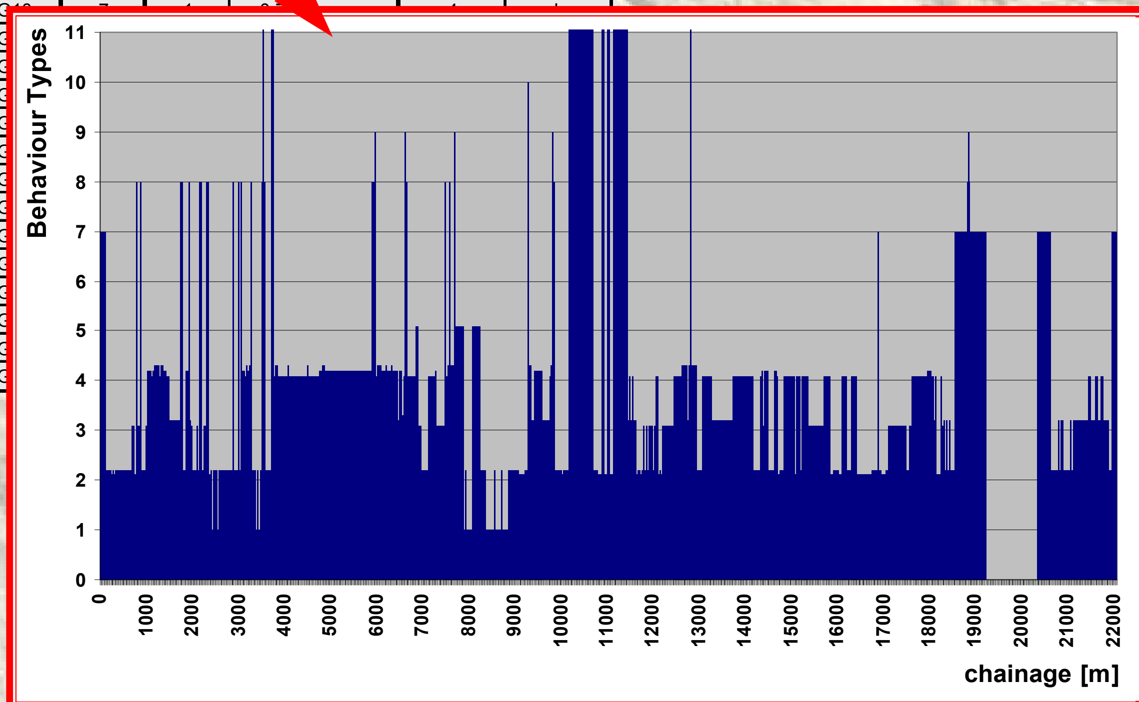


eleven parameter groups for the determination of the basic **BEHAVIOUR TYPES**

BEHAVIOUR TYPE
determined for each 20 m step

DETERMINATION OF BEHAVIOUR TYPES

chainage from	to	Rock Mass Type	Behaviour Type	Displacement Category	Support Pressure	System Behaviour	Excavation Category	Support Class
0	20	G10	7	1	0,7	c	4	b
20	40	G10	7	1	0,	c	4	b
40	60							
60	80	G						
80	100	G						
100	120	G						
120	140	G						
140	160	G						
160	180	G						
180	200	G						
200	220	G						
220	240	G						
240	260	G						
260	280	G						
280	300	G						
300	320	G						



Distribution of **BEHAVIOUR TYPES** along the tunnel alignment

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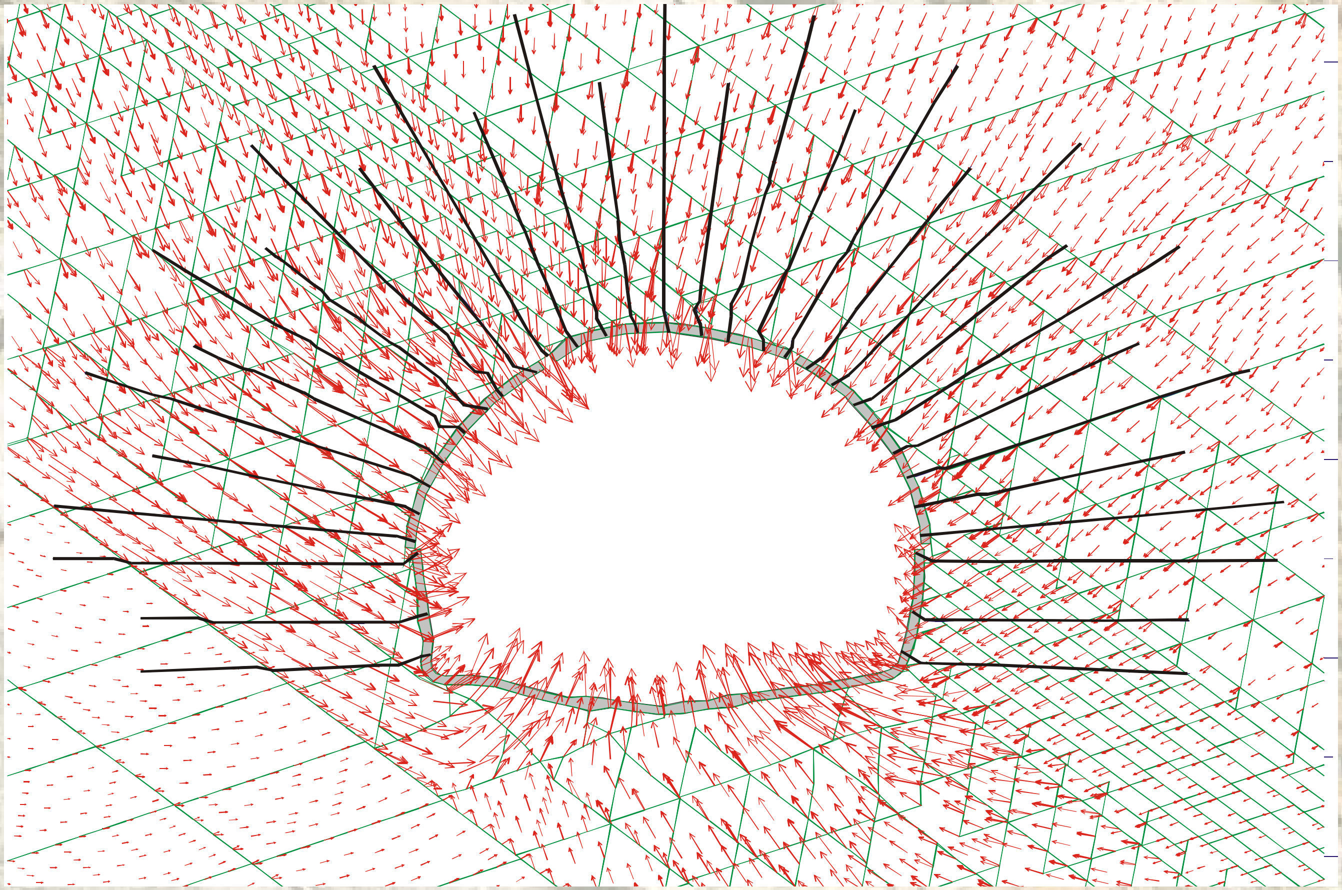
DETERMINATION SYSTEM BEHAVIOUR

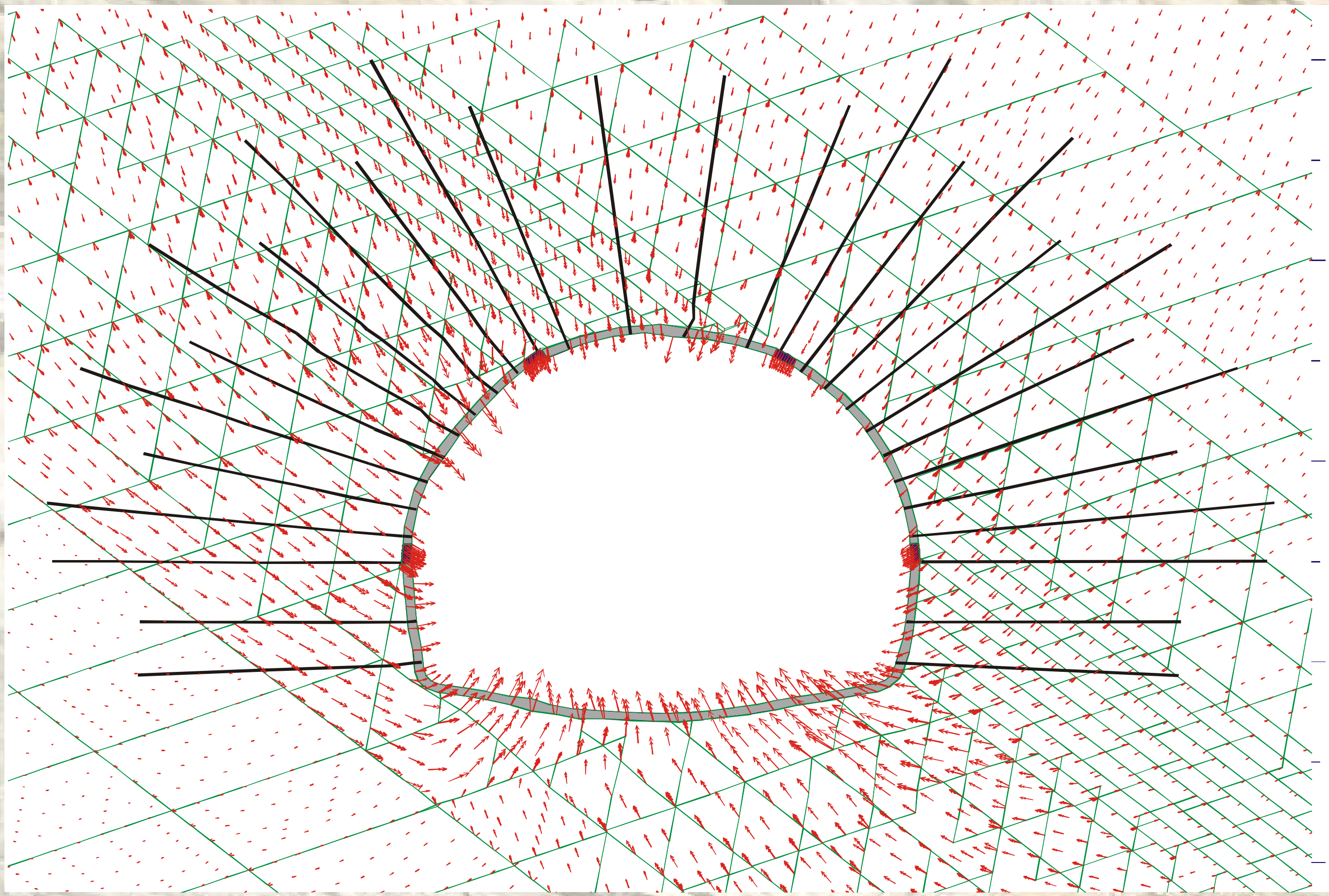
Heavily broken primary lining



Galgenberg Tunnel, Austria

DETERMINATION SYSTEM BEHAVIOUR

Substantial improvement by installing LSC elements



Galgenberg Tunnel, Austria

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PROCEDURE DURING CONSTRUCTION

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Definition/monitoring of relevant rock mass type specific parameters

ROCK MASS TYPE (RMT)

stresses, kinematics, water quantity & pressure

Update model, failure mechanisms
short term prediction

BEHAVIOUR TYPE (BT)

Selection of excavation and support

Prediction of system behaviour (SB)

Final design of excavation and support

Monitoring results

$SB_o = SB_d$

Reevaluate & modify criteria

Additional support

Reevaluate & modify criteria

EXCAVATION & SUPPORT ✓

Verification of System Behaviour

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EXAMPLE CONSTRUCTION

area	lithology	bedding thickn. a	b	c	deg. of fract. low	med.	high	apert. +/-	R. M. Type
A	MS		X			X		+	9
B	LD	X				X		+	2
C	LD	X				X		+	2
D	LD		X			X		+	3

area	interlocked yes	no	water inflow no	< 5	> 5	Behav. Type local
A		X	X			4
B	X		X			2
C		X	X			3
D		X	X			4

dominating regions
A,C

Displacement category (cm)

<5 5-10 >10

Behavior Type 2
rock mass with potential for systematical and voluminous overbreak, no stress induced failures

Support & Excavation Concept
round length: 1.3 m
support type: ST 3

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Case Studies

Conceptual (Route Selection)and Feasibility Study

Mae Kuang Inflow Augmentation Project

Investigation

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Case Studies

Conceptual (Route Selection)and Feasibility Study

Project Data and Tasks

Chiang Mai flood protection project. Deviation of water from the Mae Ngut reservoir through TBM tunnels

- No.1 Tunnel (length: 32.6 km, diameter 4.60 m)
- No.3 Tunnel (length: 25.0 km, diameter 4.60 m)
- No.6 Tunnel (length: 28.8 km, diameter 4.60 m)
- Main Tunnel (length: 21.7 km, diameter 5.0 m)

Geological-geotechnical field studies and consulting services, supervision of site investigation, cost estimate and comparison

Geology

Paleozoic and Mesozoic shale,sandstone,limestone and Triassic granitic intrusions were subjected to intense thrusting. Tertiary tectonic events generated pull-apart-basins filled with gravels and sands

Case Studies

Mae Kuang Inflow Augmentation Project

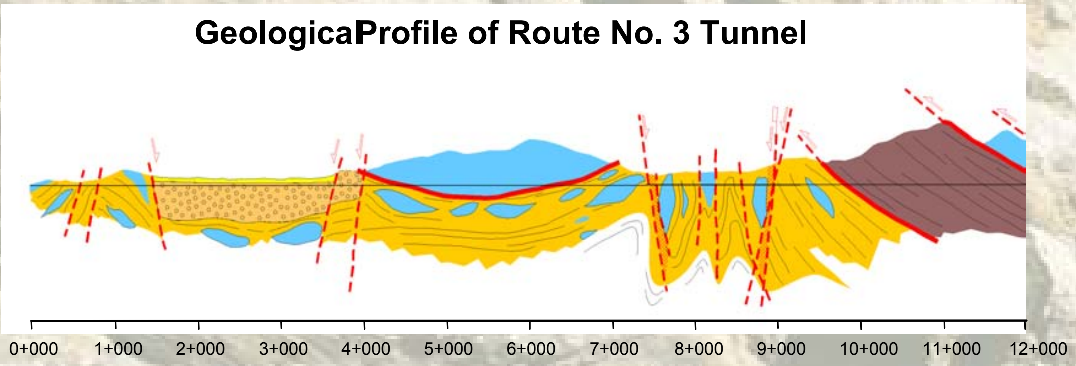
Rock Mass Type

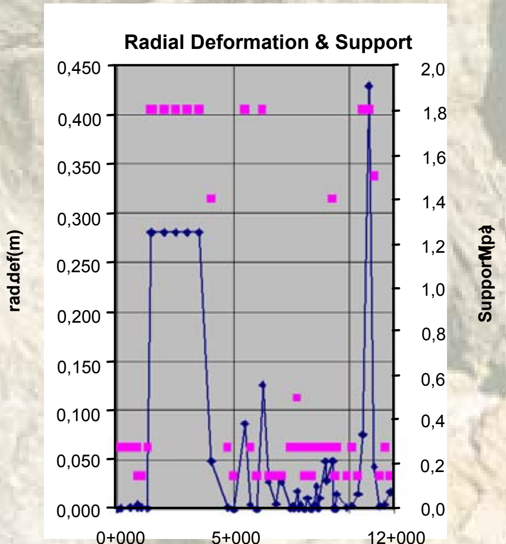
- Rock Type
- UCS
- mi
- GSI

Parameters for Analytical Calculation

Case Studies

Mae Kuang Inflow Augmentation Project





Results of Analytical Calculation

Investigation

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Case Studies

Investigation

Mae Kuang Inflow Augmentation Project

coh	s	mb	a	E	my	pcr	Dpz(m);R=2,5	dR(m);R=2,5	dR(m);R=2,5
4,64	0,0039	2,52	0,50	10000	0,30	-2,42	0,00	0,0010	0,0010
29,12	0,1889	17,56	0,50	118569	0,10	-17,22	0,00	0,0002	0,0002
29,12	0,1889	17,56	0,50	118569	0,10	-17,51	0,00	0,0001	0,0001
0,35	0,0000	0,17	0,63	1257	0,40	4,71	7,28	0,0809	0,0809
15,01	0,1084	4,90	0,50	56234	0,10	-8,98	0,00	0,0004	0,0004
15,01	0,1084	4,90	0,50	56234	0,10	-8,93	0,00	0,0004	0,0004
15,01	0,1084	4,90	0,50	56234	0,10	-9,14	0,00	0,0003	0,0003
15,01	0,1084	4,90	0,50	56234	0,10	-9,14	0,00	0,0003	0,0003
1,29	0,0004	1,15	0,50	2000	0,25	2,21	0,45	0,0096	0,0096
5,25	0,0013	1,17	0,50	6887	0,10	-1,31	0,00	0,0025	0,0025
5,25	0,0013	1,17	0,50	6887	0,10	-1,52	0,00	0,0023	0,0023
29,12	0,1889	17,56	0,50	118569	0,10	-17,64	0,00	0,0001	0,0001
0,35	0,0000	0,17	0,63	1257	0,40	3,53	4,06	0,0288	0,0288
1,29	0,0004	1,15	0,50	2000	0,25	1,37	0,15	0,0061	0,0061
15,01	0,1084	4,90	0,50	56234	0,10	-9,14	0,00	0,0003	0,0003
5,25	0,0013	1,17	0,50	6887	0,10	-0,12	0,00	0,0034	0,0034
5,25	0,0013	1,17	0,50	6887	0,10	0,30	0,01	0,0037	0,0037
4,64	0,0039	2,52	0,50	10000	0,30	1,37	0,15	0,0040	0,0040
4,64	0,0039	2,52	0,50	10000	0,30	2,70	0,31	0,0052	0,0052
10,16	0,0007	2,36	0,50	6668	0,10	-1,64	0,00	0,0063	0,0063
1,52	0,0013	1,64	0,50	3557	0,25	5,43	1,45	0,0227	0,0227
2,03	0,0013	2,11	0,50	3976	0,25	4,52	1,00	0,0166	0,0166
0,62	0,0004	0,99	0,50	1414	0,35	5,96	3,47	0,1009	0,1009
1,29	0,0004	1,15	0,50	2000	0,25	4,44	1,15	0,0240	0,0240
0,35	0,0000	0,17	0,63	1257	0,40	8,47	21,62	0,8037	0,8037
0,35	0,0000	0,17	0,63	1257	0,40	8,25	20,63	0,7233	0,7233
10,16	0,0007	2,36	0,50	6668	0,10	-3,95	0,00	0,0041	0,0041
5,25	0,0013	1,17	0,50	6887	0,10	1,21	0,14	0,0045	0,0045
15,01	0,1084	4,90	0,50	56234	0,10	-6,59	0,00	0,0007	0,0007
15,01	0,1084	4,90	0,50	56234	0,10	-6,59	0,00	0,0007	0,0007
15,01	0,1084	4,90	0,50	56234	0,10	-6,12	0,00	0,0007	0,0007
15,01	0,1084	4,90	0,50	56234	0,10	-6,12	0,00	0,0007	0,0007
15,01	0,1084	4,90	0,50	56234	0,10	-6,95	0,00	0,0006	0,0006
5,25	0,0013	1,17	0,50	6887	0,10	1,84	0,22	0,0051	0,0051
1,29	0,0004	1,15	0,50	2000	0,25	5,41	1,42	0,0327	0,0327
1,52	0,0013	1,64	0,50	3557	0,25	4,21	1,16	0,0160	0,0160
0,35	0,0000	0,17	0,63	1257	0,40	8,90	23,65	0,9857	0,9857
0,35	0,0000	0,17	0,63	1257	0,40	9,33	25,76	1,1990	1,1990
0,62	0,0004	0,99	0,50	1414	0,35	5,96	3,47	0,1009	0,1009
10,16	0,0007	2,36	0,50	6668	0,10	-5,38	0,00	0,0027	0,0027
0,62	0,0004	0,99	0,50	1414	0,35	2,99	1,88	0,0300	0,0300
1,52	0,0013	1,64	0,50	3557	0,25	0,24	0,00	0,0025	0,0025
1,29	0,0004	1,15	0,50	2000	0,25	-1,13	0,00	-0,0016	0,0000
0,35	0,0000	0,17	0,63	1257	0,40	-0,34	0,00	-0,0006	0,0000
0,35	0,0000	0,17	0,63	1257	0,40	-0,34	0,00	-0,0042	0,0000
0,35	0,0000	0,17	0,63	1257	0,40	-0,34	0,00	-0,0042	0,0000
0,35	0,0000	0,17	0,63	1257	0,40	-0,34	0,00	-0,0042	0,0000
0,35	0,0000	0,17	0,63	1257	0,40	-0,34	0,00	-0,0042	0,0000
10,16	0,0007	2,36	0,50	6668	0,10	-7,28	0,00	0,0008	0,0008
2,03	0,0013	2,11	0,50	3976	0,25	0,46	0,08	0,0037	0,0037
0,62	0,0004	0,99	0,50	1414	0,35	2,20	1,38	0,0185	0,0185
1,52	0,0013	1,64	0,50	3557	0,25	1,39	0,36	0,0051	0,0051
0,62	0,0004	0,99	0,50	1414	0,35	2,71	1,70	0,0254	0,0254

577,6	0,988928
2750	0,919888
2750	0,919888
2750	0,919888
1149,5	0,919888
919,6	1,016886
334,4	1,076473
917,4	1,446551
919,6	1,106425
919,6	1,663293
906,4	1,050262
680	1,181781
1316	1,081596
2000	1,028203
1044	1,028203
2299	1,029657
2020	1,028203
1738	1,021948
504	1,041299
1227,6	1,13905
1738	1,190815
1529	1,350347
671	1,072473
1100	1,14007
1100	1,14007
605	1,239269
360	1,160934
800	1,104293
800	1,062382
1243	1,037425
438,4	1,009634
800	1,001101
66585,50	

66585,50

Geotechnical Rating for No.3 Tunnel

3G
Gruppe
Geotechnik
Graz ZT GMBH

Case Studies

Mae Kuang Inflow Augmentation Project

Mae Kuang Project, 2nd Mission Report

Geotechnical Ratings:

Tunnel No.1:	**51,757**
Tunnel No.3:	**66,585**
Tunnel No.6:	**59,926**
Main Tunnel:	**32,866**

Construction costs of No. 1 Tunnel are
10% less than No.3 Tunnel