EOSC433/536:

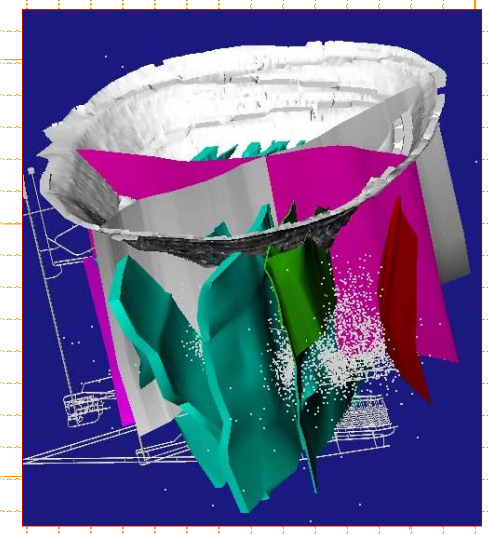
Geological Engineering Practice I – Rock Engineering

Lecture 2a: Data Collection & Confidence

Site Investigation & Monitoring

Geotechnical site investigation and monitoring are fundamental to rock engineering projects. Their use extends from prefeasibility through to operations and decommissioning.

Their purpose is multifold, serving both investigative and monitoring functions that are in part a necessity to ensure the economic feasibility of the project and part due diligence to ensure safe operations.



Role of Site Investigation & Monitoring

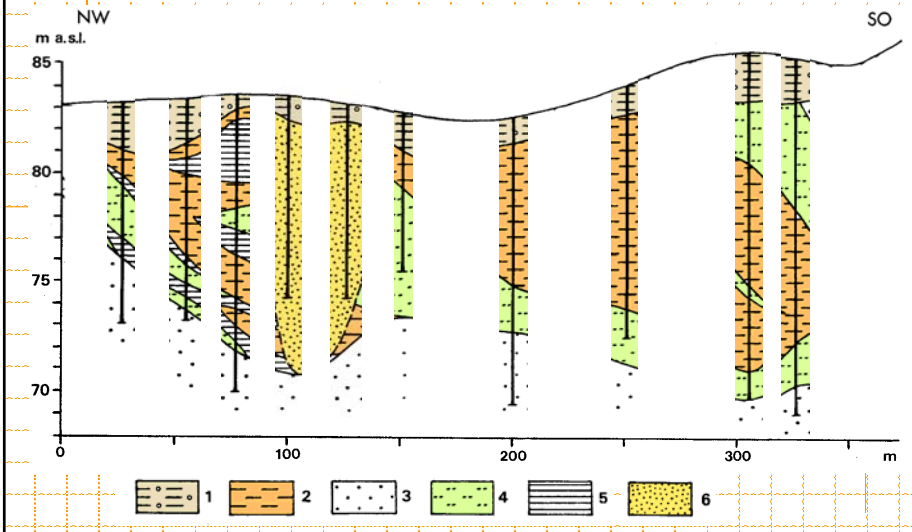
Investigation:

- To provide an understanding of the ground conditions, for prefeasibility and design purposes.
- To provide input values for design calculations.
- To check for changing ground conditions as the project develops, or advance/progress to greater depths.

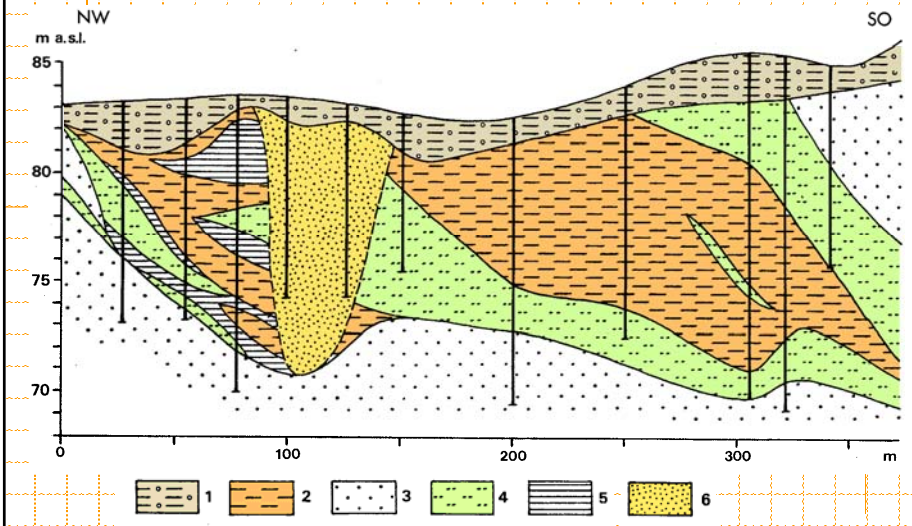
Monitoring:

- To assess and verify the performance of the design.
- To calibrate models and constrain design calculations.
- To provide a warning of a change in ground behaviour, thus enabling intervention to improve safety or to limit damage through a design change or remediation measure.

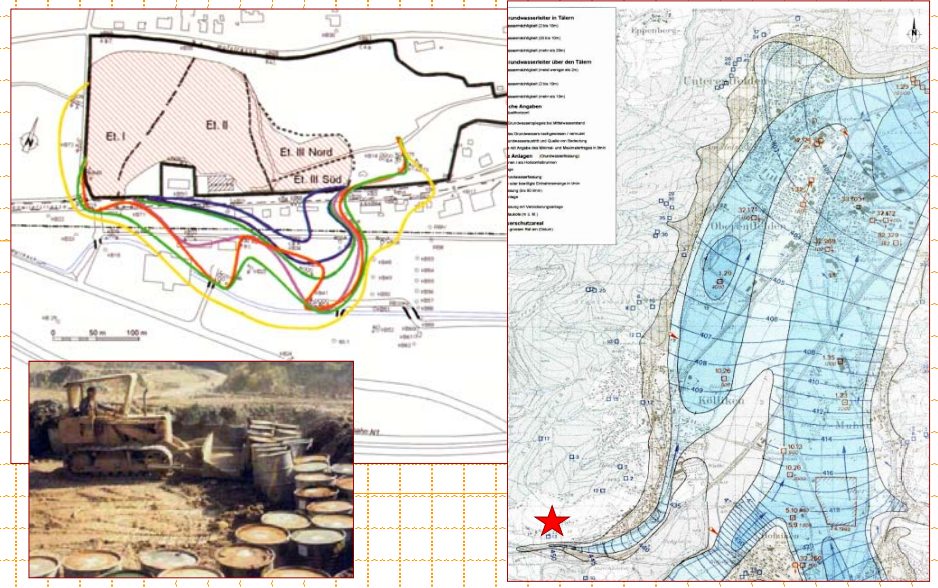
Site Investigation - Boreholes



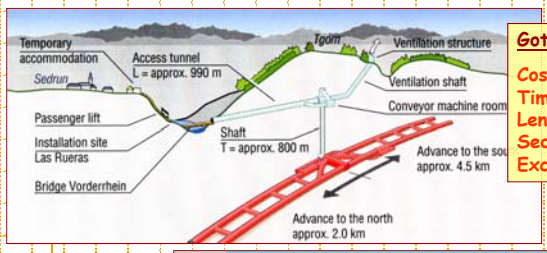
Site Investigation - Boreholes



Site Investigation - Boreholes

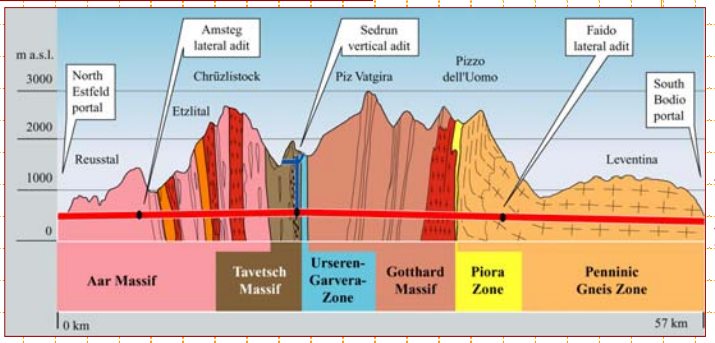


Deep Tunnels - Geological Uncertainty



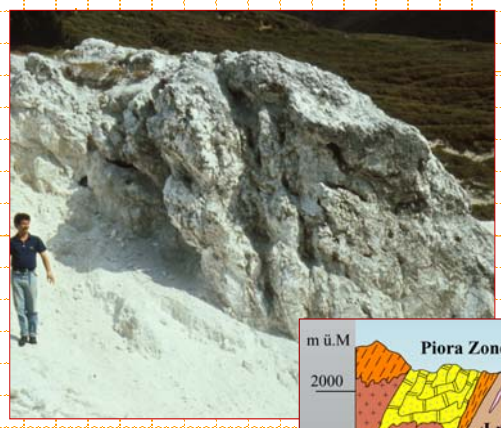
Gotthard Base-Tunnel (Switzerland)

Cost = $15+ billion
Time to build = 17 years
Length = 57.5 km
Sedrun shaft = 800 m
Excavated material = 24 million tonnes

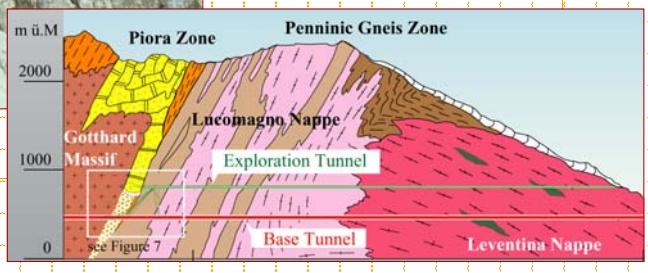


Loew et al. (2000)

Deep Tunnels - Geological Uncertainty



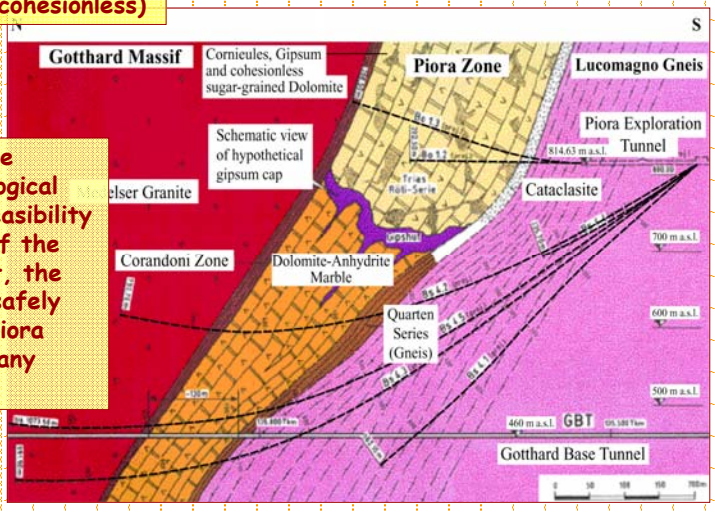
Sugar-grained dolomites (granular & cohesionless)



Deep Tunnels - Geological Uncertainty

Sugar-grained dolomites (granular & cohesionless)

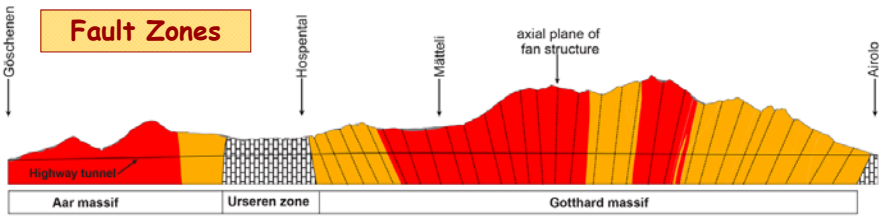
Considered the greatest geological risk to the feasibility and success of the tunnel project, the TBM passed safely through the Piora zone without any problems.

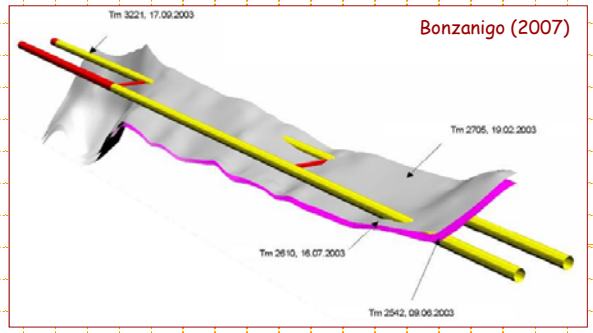


Loew et al. (2000)

Deep Tunnels - Geological Uncertainty

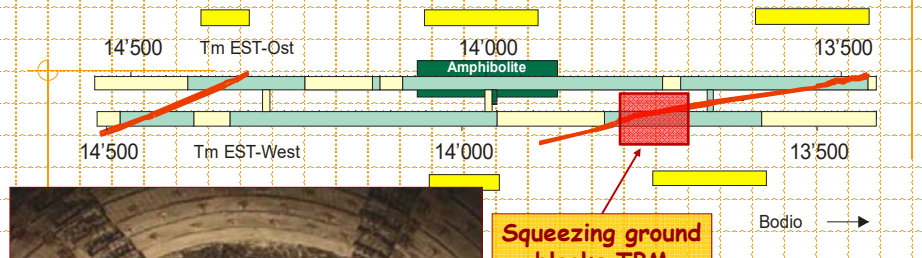
Fault Zones





Bonzanigo (2007)

Deep Tunnels - Geological Uncertainty



Ehrbar (2008)

Squeezing ground blocks TBM

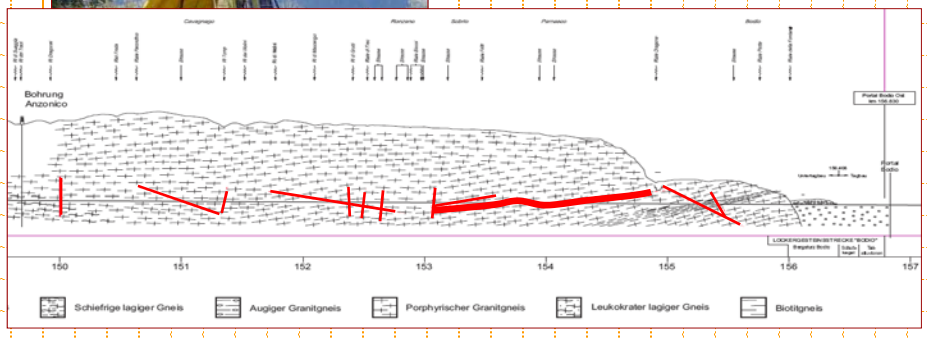
The total delay for passing through these faults along this section ... two years.

Budget overrun... more than 200%.

Deep Tunnels - Geological Uncertainty

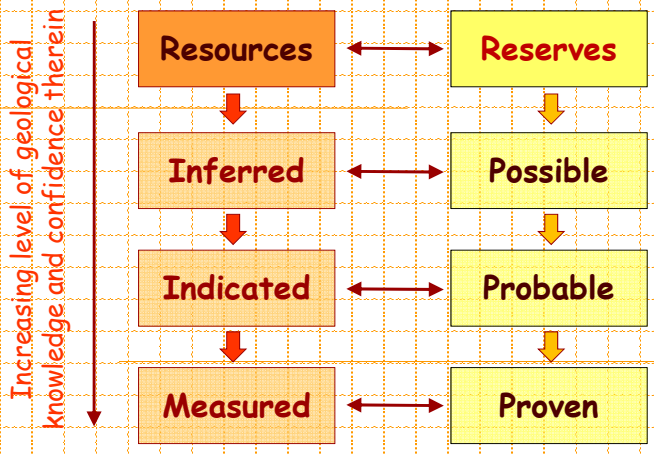
Bonzanigo (2007)

You pay now, or you pay later!

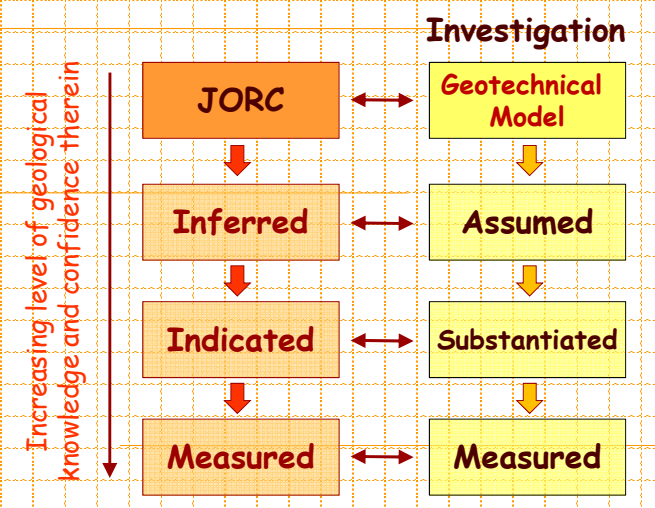


Uncertainty in Ground Characterization

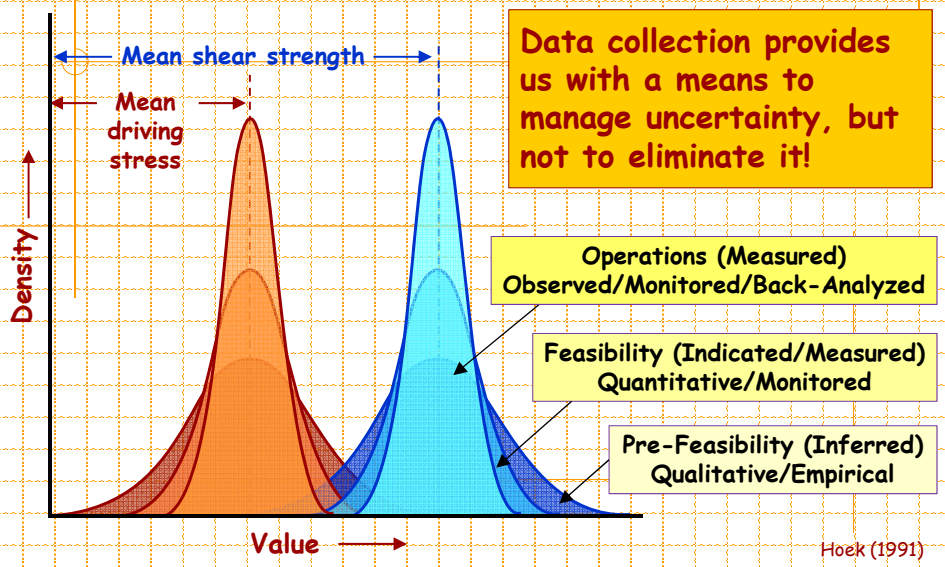
As a mining project moves from prefeasibility through to detailed mine design, the amount of data collected will increase as efforts are made to minimize uncertainty and reduce risk.



Uncertainty in Ground Characterization



Managing Geotechnical Uncertainty

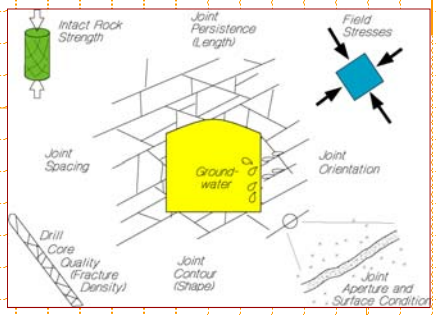


Hoek (1991)

Influence of Geological Factors

In the context of the mechanics problem, we should consider the material and the forces involved. As such, five primary geological factors can be viewed as influencing a rock mass.

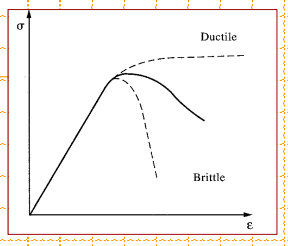
- We have the intact rock which is itself divided by discontinuities to form the rock mass structure.
- We find then the rock is already subjected to an *in situ* stress.
- Superimposed on this are the influence of pore fluid/water flow and time.



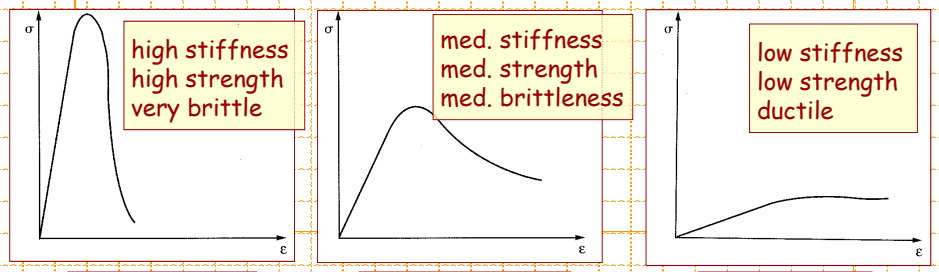
With all these factors, the geological history has played its part, altering the rock and the applied forces.

Laboratory Testing of Rock/Soil Behaviour

Uniaxial Compressive Strength (UCS), or peak strength, is the maximum stress that the rock can sustain. After it is exceeded, the rock may still have some load-carrying capacity, or residual strength.

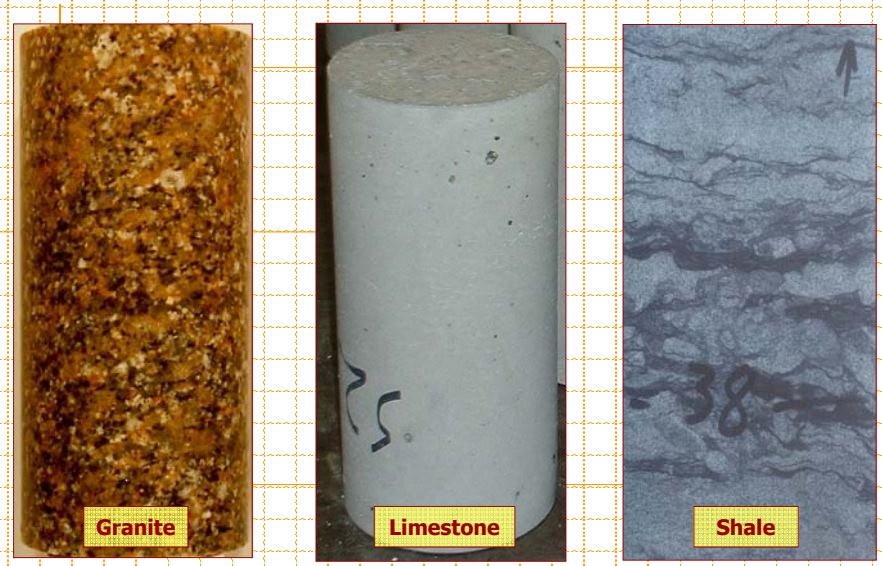


Hudson & Harrison (1997)



e.g. Granite | e.g. Limestone | e.g. Shale

Laboratory Testing of Rock/Soil Behaviour



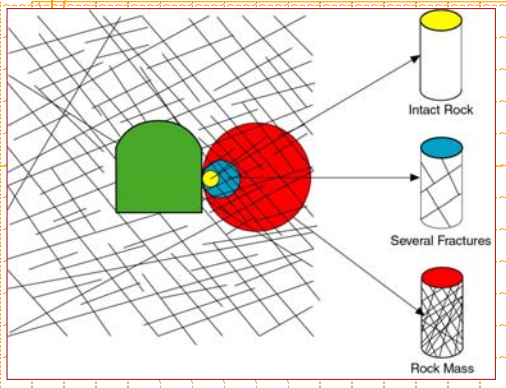
Understanding Rock Behaviour

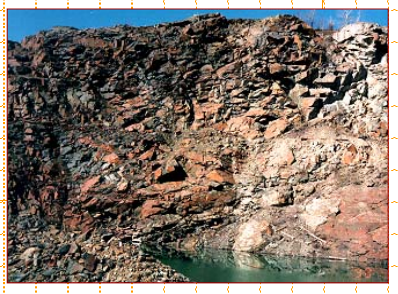
Parameter	Value (MPa)
Number of Tests	20
Min. Peak Strength, σ_{UCS}	183.0
Max. Peak Strength, σ_{UCS}	231.1
Avg. Peak Strength, σ_{UCS}	206.9 (± 13.5)

Location	Sample No.	Geology	Schmid Hammer Test		Uniaxial Conpression	Triaxial Shear Strength		Direct Shear strength		Young's modulus	Poission's Ratio
			Mean Hardness No.	Equilant strength MPa	σ ci MPa	C MPa	ϕ °	C MPa	ϕ °	E 10^4MPa	μ
Count			59	59	26	12	12	12	12	22	22
Maximum			56	72	201	39.64	45.20	0.60	40.00	15.30	0.676
Minmum			24	17	11	2.10	28.60	0.25	27.00	1.17	0.023
Mean			44	53	76	19.48	38.50	0.39	35.08	5.37	0.284
Standard Deviation			7	13	46	12.39	4.42	0.12	3.73	3.35	0.159
Standard Error			0.89	2.75	82.99	12.79	1.63	0.00	1.16	0.51	0.001
Standard Error					28	0.00		0.98	0.48	0.00	

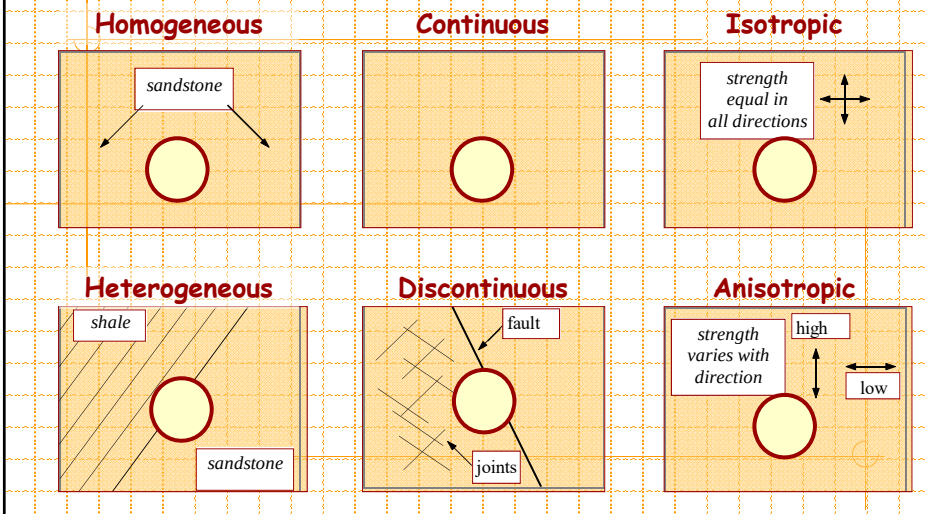
Rock Mass Properties - Scale

Rock/Soil Behaviour – Scale Effects

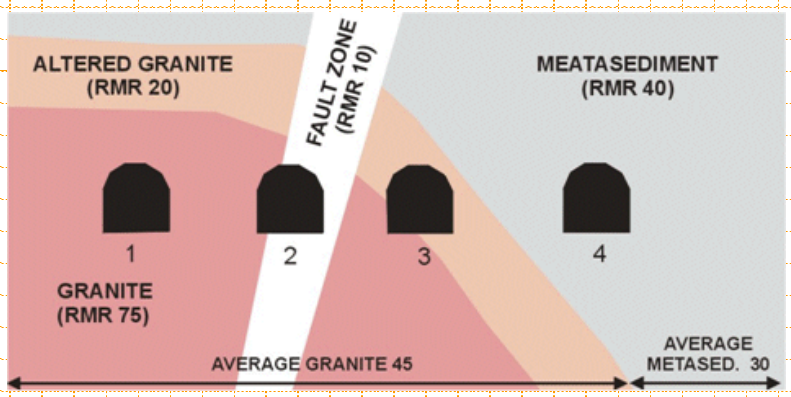




Rock as an Engineering Material

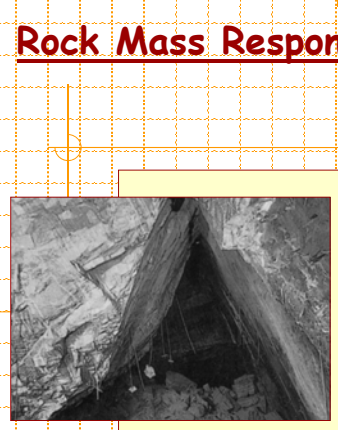


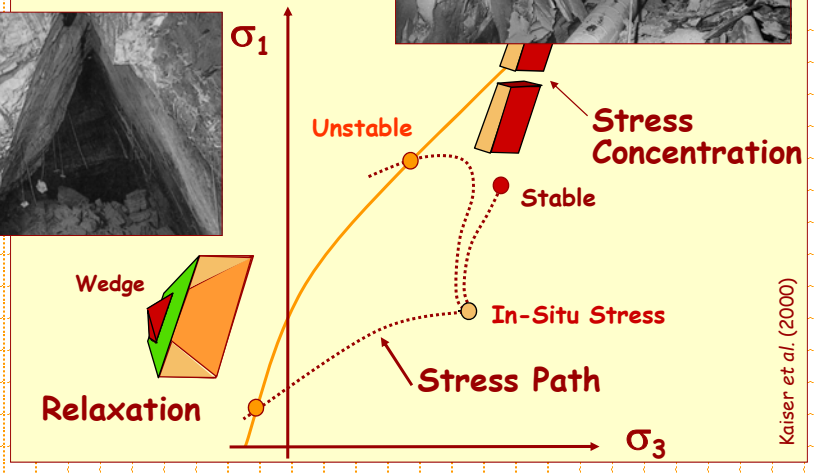
Reporting – Distribution and Variability



'Averaging' of data that can lead to a misrepresentation of important geological features, particularly major structures.

Rock Mass Response

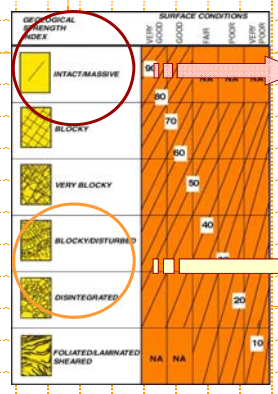




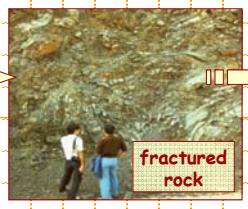
Rock Mass Behaviour

The key factor that distinguishes rock engineering from other engineering-based disciplines is the application of mechanics on a large scale to a pre-stressed, naturally occurring material.

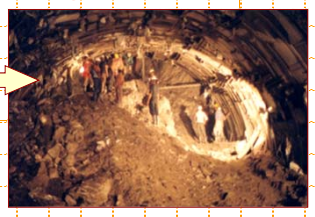
Hoek's GSI Classification



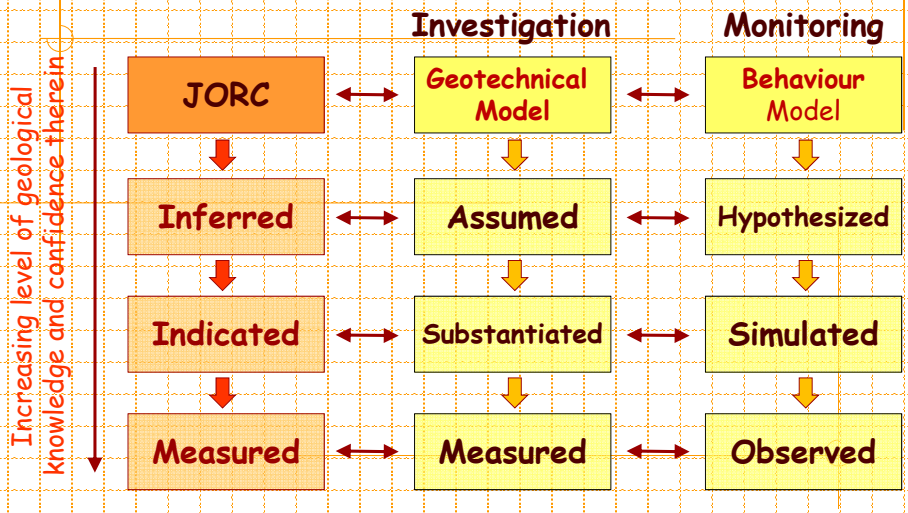
rock mass



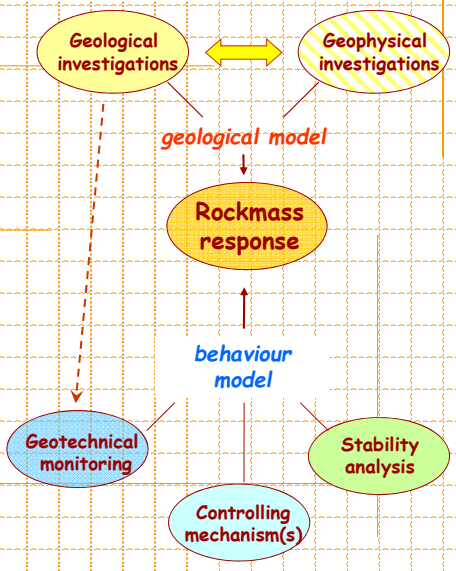
ground response



Uncertainty in Ground Characterization



Site Investigation & Data Collection



Geotechnical Data Collection

- **Main Objectives**
  - Provide input parameters for geotechnical design calculations
  - Optimize existing operations/construction
  - Limit/manage uncertainty
- **Compatibility with the stage of the project**
  - Inferred, Probable, Proven
- **Practicality**
  - Data collection in the context of the engineering design
  - Underground design often has to be completed prior to underground exposure (based on core only)
  - Degree of certainty has to be considered
  - Sensitivities of parameters and consequences must be tested
  - Integral part of the geological investigation
  - Communication between disciplines (geology, engineering, miners)

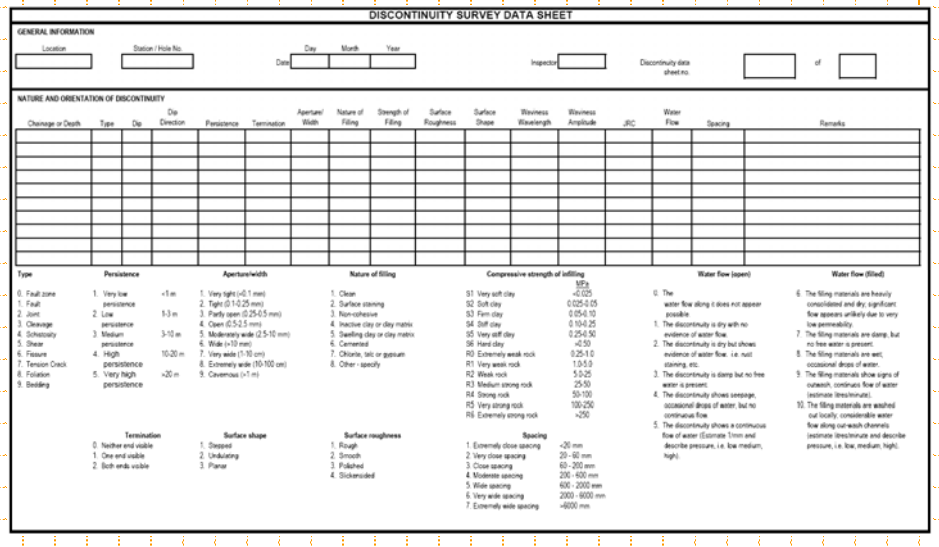
General Data Requirements

Data should be measured and recorded in systematic ways using standardized procedures. Much time and effort can be wasted by collecting data which may be irrelevant or inadequate. The nature of the data will also become more specialized as measurements transition from surface boreholes to excavation/construction.

The quality of the data is critical to the reliability of the interpretation...

... POOR QUALITY OR INACCURATE DATA CAN BE MISLEADING AND IS WORSE THAN NO DATA

General Data Requirements - Standardization



DISCONTINUITY SURVEY DATA SHEET

GENERAL INFORMATION

Location | Station / Hole No. | Date: Day Month Year | Inspector | Discontinuity data sheet no. | of

NATURE AND ORIENTATION OF DISCONTINUITY

Chainage or Depth	Type	Dip	Dip Direction	Persistence	Termination	Aperture/ Width	Nature of Filling	Strength of Filling	Surface Roughness	Surface Shape	Waviness Wavelength	Waviness Amplitude	JRC	Water Flow	Spacing	Remarks

Type
0. Fault zone
1. Fault
2. Joint
3. Cleavage
4. Schistosity
5. Shear
6. Fissure
7. Tension Crack
8. Foliation
9. Bedding

Persistence
1. Very low persistence <1 m
2. Low persistence 1-3 m
3. Medium persistence 3-10 m
4. High persistence 10-20 m
5. Very high persistence >20 m

Aperture/width
1. Very tight (<0.1 mm)
2. Tight (0.1-0.25 mm)
3. Partly open (0.25-0.5 mm)
4. Open (0.5-2.5 mm)
5. Moderately wide (2.5-10 mm)
6. Wide (>10 mm)
7. Very wide (1-10 cm)
8. Extremely wide (10-100 cm)
9. Cavernous (>1 m)

Nature of filling
1. Clean
2. Surface staining
3. Non-cohesive
4. Inactive clay or clay matrix
5. Swelling clay or clay matrix
6. Cemented
7. Chlorite, talc or gypsum
8. Other - specify

Compressive strength of infilling

	MPa
S1 Very soft clay	<0.025
S2 Soft clay	0.025-0.05
S3 Firm clay	0.05-0.10
S4 Stiff clay	0.10-0.25
S5 Very stiff clay	0.25-0.50
S6 Hard clay	>0.50
R0 Extremely weak rock	0.25-1.0
R1 Very weak rock	1.0-5.0
R2 Weak rock	5.0-25
R3 Medium strong rock	25-50
R4 Strong rock	50-100
R5 Very strong rock	100-250
R6 Extremely strong rock	>250

Water flow (open)
0. The water flow along it does not appear possible
1. The discontinuity is dry with no evidence of water flow.
2. The discontinuity is dry but shows evidence of water flow. i.e. rust staining, etc.
3. The discontinuity is damp but no free water is present.
4. The discontinuity shows seepage, occasional drops of water, but no continuous flow.
5. The discontinuity shows a continuous flow of water (Estimate l/min and describe pressure, i.e. low, medium, high).

Water flow (filled)
6. The filling materials are heavily consolidated and dry, significant flow appears unlikely due to very low permeability.
7. The filling materials are damp, but no free water is present.
8. The filling materials are wet, occasional drops of water.
9. The filling materials show signs of outwash, continuous flow of water (estimate litres/minute).
10. The filling materials are washed out locally; considerable water flow along out-wash channels (estimate litres/minute and describe pressure, i.e. low, medium, high).

Termination
0. Neither end visible
1. One end visible
2. Both ends visible

Surface shape
1. Stepped
2. Undulating
3. Planar

Surface roughness
1. Rough
2. Smooth
3. Polished
4. Slickensided

Spacing

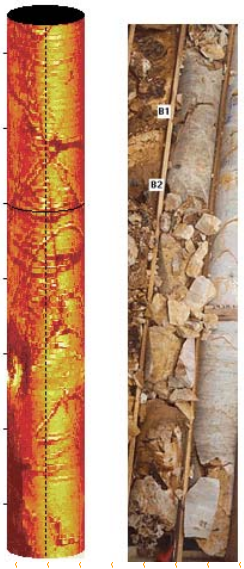
1. Extremely close spacing	<20 mm
2. Very close spacing	20 - 60 mm
3. Close spacing	60 - 200 mm
4. Moderate spacing	200 - 600 mm
5. Wide spacing	600 - 2000 mm
6. Very wide spacing	2000 - 6000 mm
7. Extremely wide spacing	>6000 mm

Oriented Core

Borehole Imaging and Characterisation

Type	Advantages	Disadvantages
Acoustic Televiewer	Provides a continuous record of borehole wall (3-D virtual core); provides high accuracy and confidence in data; can be used in highly fractured rock.	Requires a stable borehole; requires water or mud in borehole to operate.
Optical Televiewer	Provides a continuous record of borehole wall (3-D virtual core); provides high accuracy and confidence in data; can be used in highly fractured rock.	Requires a stable borehole; requires air or clear water to operate.

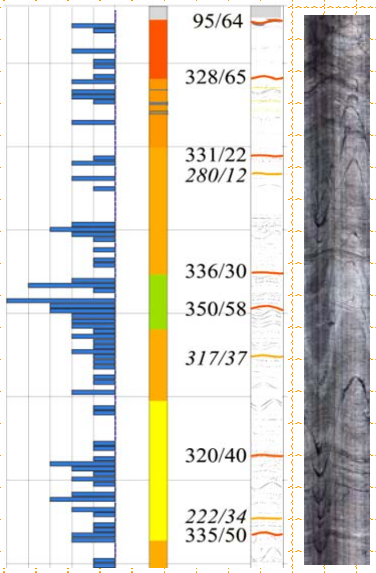
Eberhardt & Stead (2011)



Borehole Imaging and Characterisation

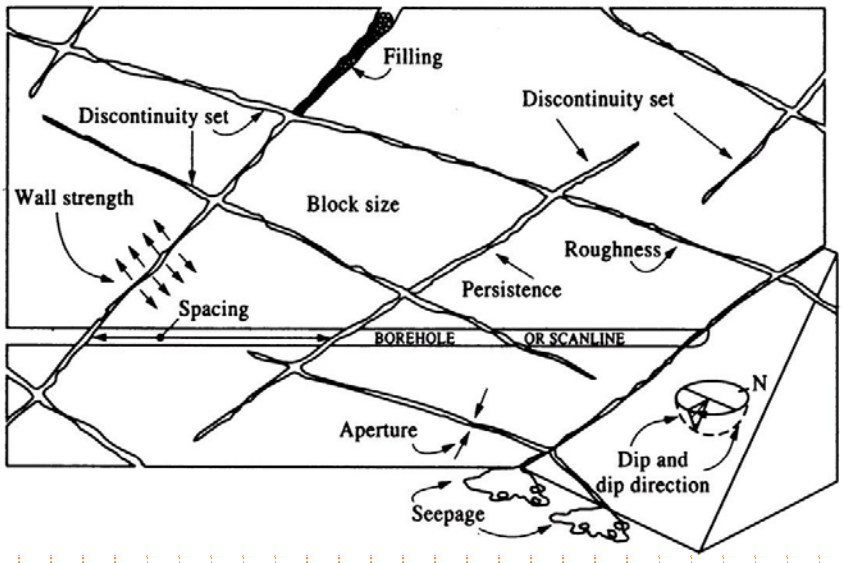
Televiewers are chosen for:

- Defining dip, dip-direction and aperture of fractures, bedding and contacts
- Obtaining critical information from areas with missing core or low core recovery (low RQD)
- Detailing fracture and fault zones regarding depth, size, frequency and attitude
- Depicting the in-situ stress field orientation



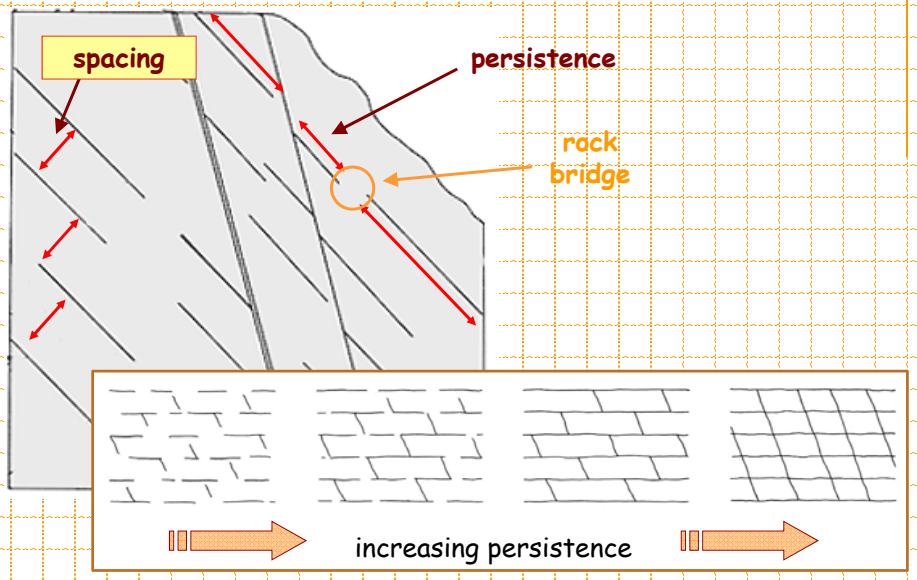
Willenberg *et al.* (2008)

Discontinuity Data Collection



Hudson & Harrison (1997)

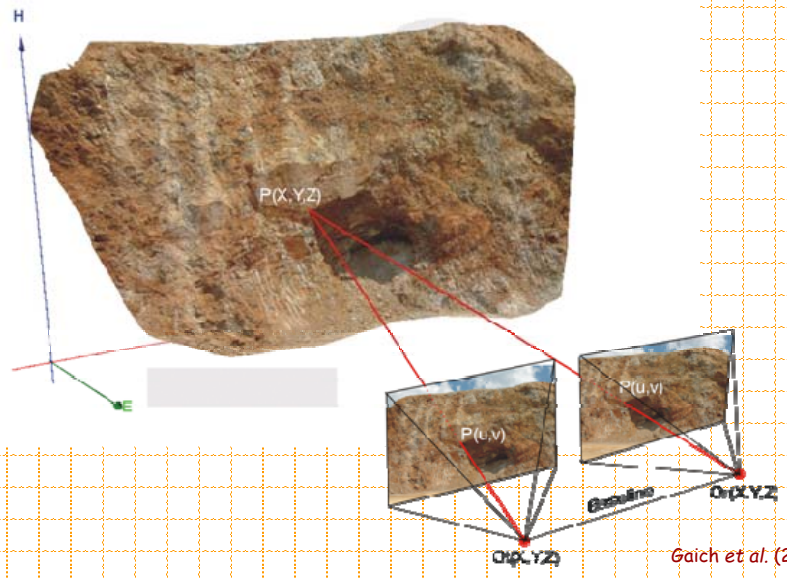
Spacing & Persistence



Remote Sensing - Photogrammetry & LiDAR

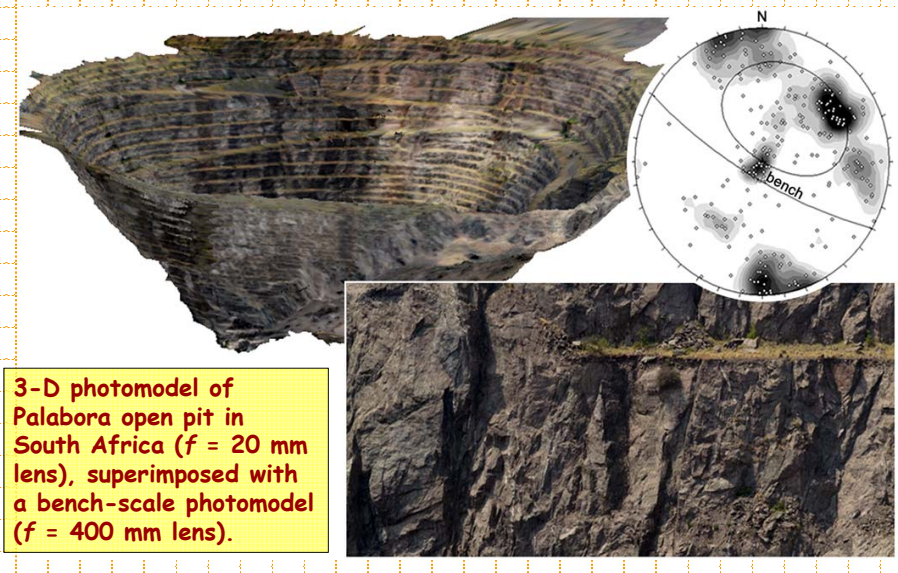
- **Advantage**: able to provide data for remote and inaccessible areas where safety concerns often preclude conventional mapping.
- **Disadvantage**: suffer measurement bias (e.g., orientation, truncation, censoring), which must be fully considered during processing, analysis, and interpretation of the data.

Remote Sensing - Photogrammetry



Gaich et al. (2006)

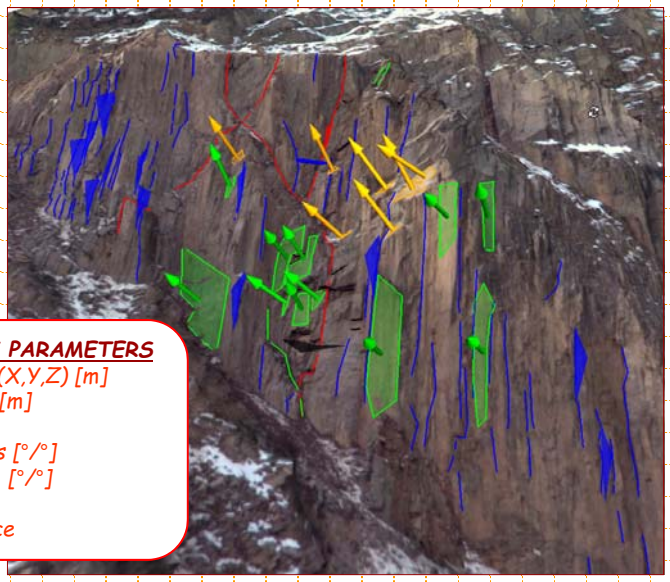
Remote Sensing - Photogrammetry



3-D photomodel of Palabora open pit in South Africa (f = 20 mm lens), superimposed with a bench-scale photomodel (f = 400 mm lens).

Stead et al. (2009)

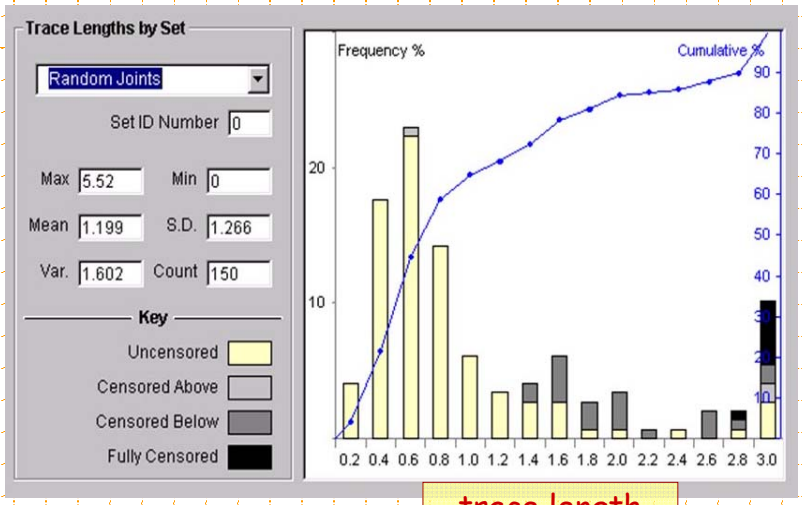
Remote Sensing – Measured Parameters



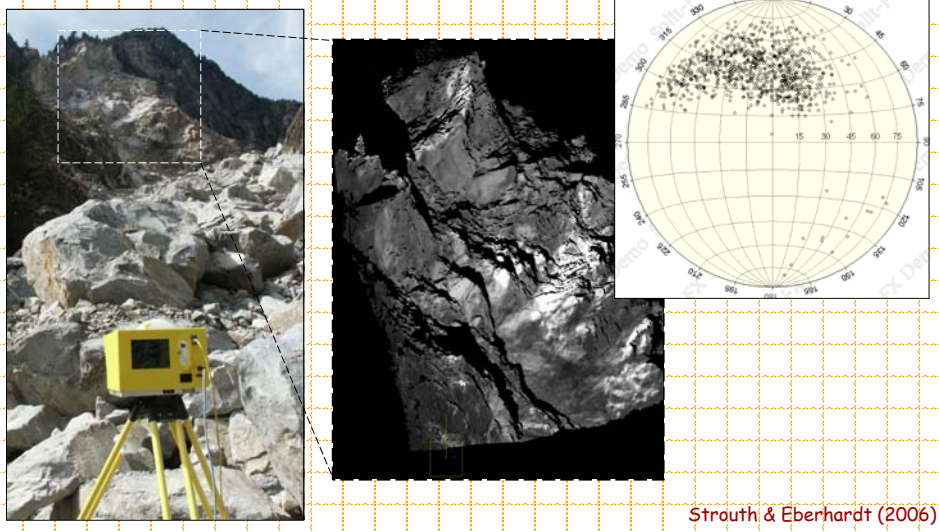
DISCONTINUITY PARAMETERS
Discrete positions (X,Y,Z) [m]
Distances, lengths [m]
Areas [m^2]
Dip / Dip directions [°/°]
Trace orientations [°/°]
Rock bridges
Spacing, persistence

Gaich et al. (2006)

Remote Sensing – Data (Added Value)



Remote Sensing - LiDAR



Strouth & Eberhardt (2006)

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