Investigation

"You pay for site investigation whether you have one or not."

Waltham, A.C. in "Foundations of Engineering Geology", 1994

STEP BY STEP: Data Collection

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

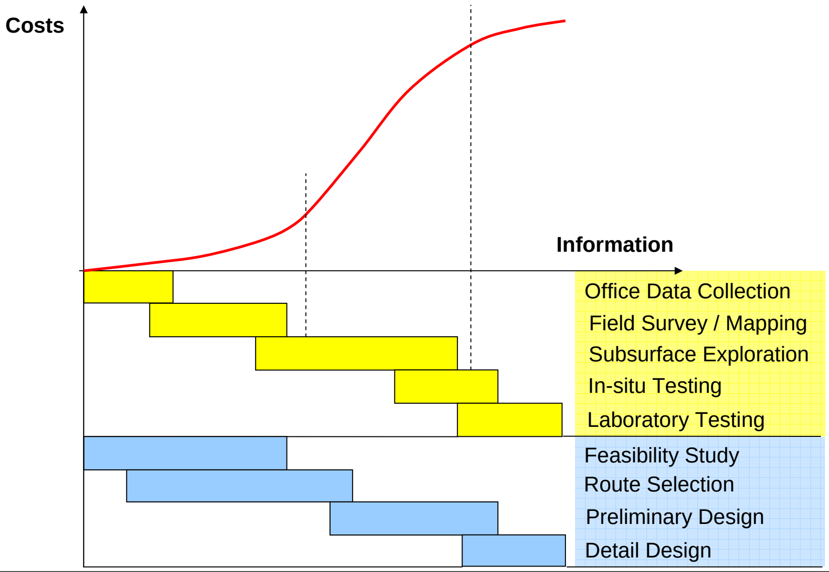
STEP BY STEP: Data Analysis

- Statistical Evaluation
- Assessment of Probabilistic Confidence
- Geological Modeling
- Kinematical Modeling
- Mechanical Modeling

STEP BY STEP: Project phases and objectives of project phases

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

Cost - Benefit Relation of Investigation



Level of quality of investigation

- Any of the steps of investigation can be done at individual levels of quality
- Level of quality applied may depend on:
- Project requirements
- Project phase
- Available time
- Available resources
- Climate conditions
- Accessibility of project area
- Complexity of geology

Methods of engineering geological investigation

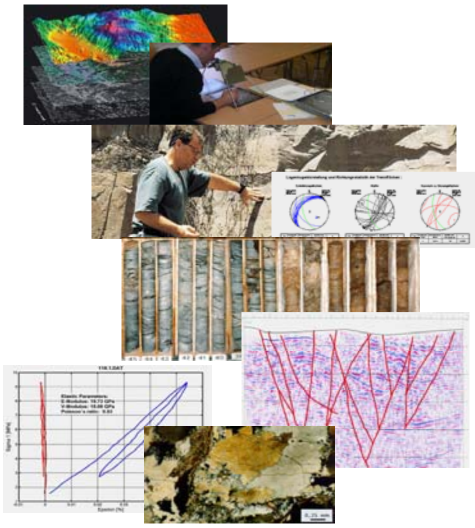
Desk Studies, Remote sensing, aerial photo interpretation

Engineering geological field mapping

Core-drilling

Geophysical survey

In-situ and laboratory testing



Site Investigation

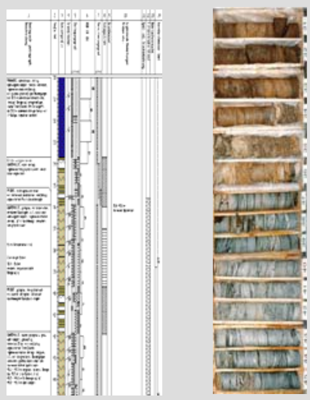
Subsurface Investigations

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

Laboratory testing

- Mechanical analyses
- Mineralogical analyses

DRILL CORE LOGGING



Concepts and Guidelines

- **Dumbleton, M. J. & G. West 1976**. A guide to site investigation procedure for tunnels. *Transport and Road Research Laboratory Report LR* 740: 24 pp.
- **Clayton, C.R.I., N.E. Simons & M.C. Matthews 1982**. *Site investigation - a handbook for engineers*: 423 pp. Granada Publishing.
- **Head, J. M. 1986**. Planning and design of site investigations:1-5. In Hawkins, A. B.: *Site investigation practice: assessing BS 5930*: 423 pp. Geological Society of London.
- **Anon 1987**. Guide to site investigation, Geoguide 2: 365 pp. Geotechnical Control Office, Civil Engineering services Department. Hong Kong.
- **BS 5930:1999.** Code of practice for site investigation.
- **A.F.T.E.S 2003**. Guidline for characterization of rock mass useful for the design and the construction of underground structures. Association Française des Tunnels et de l'Espace Souterrain. Paris, France.
- **Austrian Society for Geomechanics 2008**. Guideline for the Geomechanical Design of Underground Structures with Conventional Excavation (2. edition)

Desk studies

Objectives of Desk Studies:

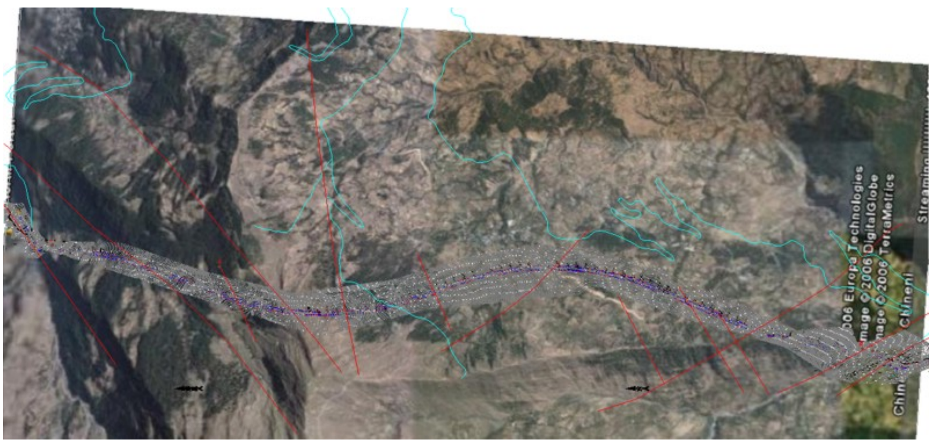
- Collecting of any available information on the project area
- Establishing a tentative geological model as a basis for further steps of investigation

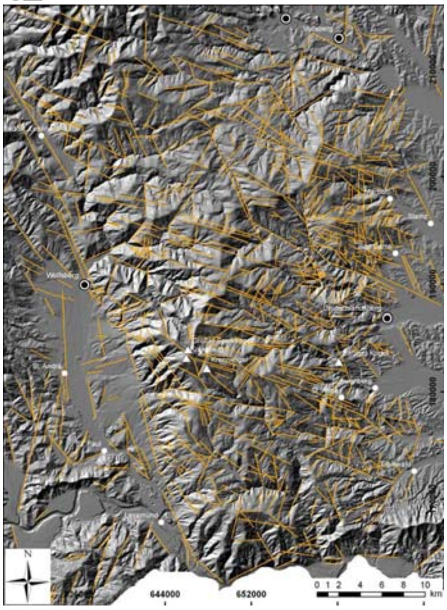
Assessment of Geological Models

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

Remote sensing

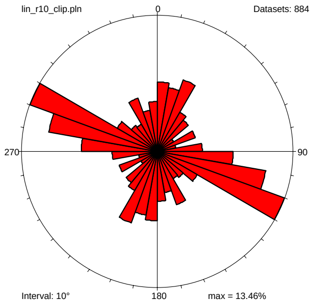
Low level of quality: Interpretation of structures from image from Google-Earth
Example: Patnitop tunnel (9 km long freeway tunnel) Kashmir, India





High level of quality:

Lineament analysis



Lineaments from 10m DEM

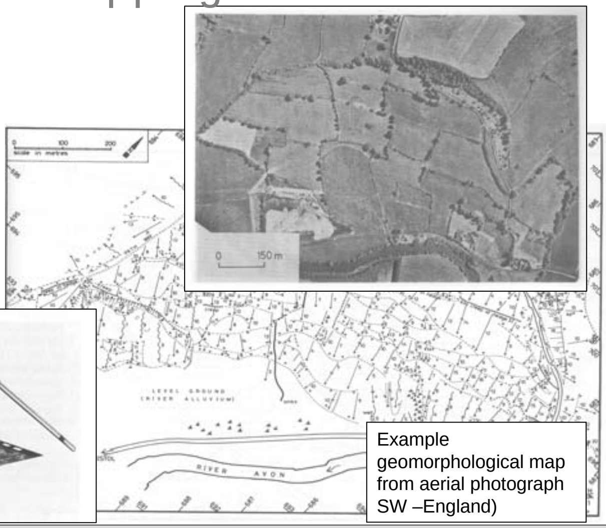
mapping scale: 1:50.000

Aerial photo interpretation

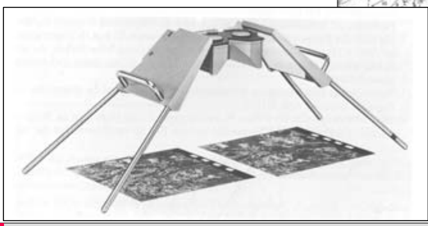
Photo-geological investigations and mapping

Visual variables:

- Size
- Brightness
- Shape
- Pattern
- Orientation
- (Color)



Example geomorphological map from aerial photograph SW –England)



Geological maps

Carta Geoloica de Bolivia

(GEOBOL & Swedish Geological AB)

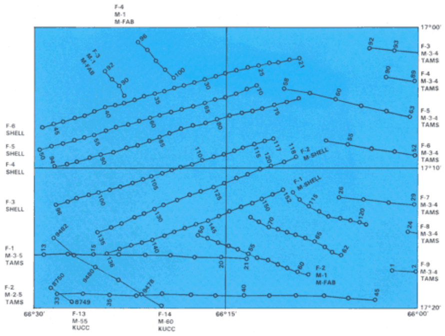
Scale 1 : 100.000

Prepared from aerial photos, only a few field checks

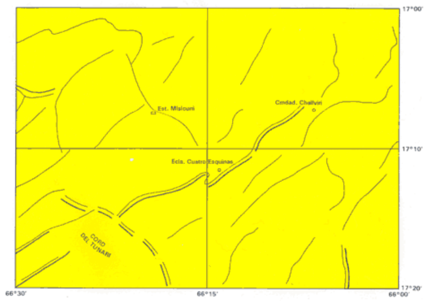
Geological maps

Carta Geoloica de Bolivia (GEOBOL & Swedish Geological AB) Scale 1 : 100.000
Prepared from aerial photos, only a few field checks

INDICE DE VUELOS
INDEX OF AERIAL PHOTOGRAPHS



RELEVAMIENTO GEOLOGICO Y TRAVESIAS
LOCATION OF GEOLOGICAL FIELD SURVEYS



FUENTE DE INFORMACION/*SOURCE OF INFORMATION*
— Revisión y actualización geológica 1991-1992, Proyecto 1
— Departamento de Geología Regional: Mapa Geológico e Informe inédito 1983
Información Geológica anterior a 1990

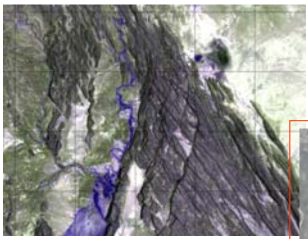
Terrain Survey Intensity Level

TERRAIN SURVEY INTENSITY LEVELS	SCALE	% OF POLYGONS FIELD CHECKED	FIELD CHECKS ** PER 100 ha (1km²)	METHOD OF FIELD CHECKING	TYPICAL OBJECTIVES
A	> 1 : 20,000	75 - 100	> 1.5	foot traverses	Slope stability in sensitive areas: residential land planning; hazard zonation
B	1 : 10,000 to 1 : 50,000	50 - 75	1.0 to 3	foot and vehicle traverses	Slope stability assessment
C	1 : 20,000 to 1 : 100,000	25 - 50	0.5 to > 1.0	foot, vehicle, some flying	Inventory mapping; biophysical mapping
D	1 : 20,000 to 1 : 250,000	0 - 25	0 – 0.1	Vehicle and flying	Regional planning; preliminary mapping
E	any scale	0	none	no field work (air photo inter-predation only)	General reconnaissance

** Data in column 4 are based on the following estimates of mean polygon size: 1 : 10.000 – 25 ha (estimated); 1: 20,000 – 50 ha; 1 : 50,000 – 250 ha; 1 : 100,000 – 400 ha; 1 : 250,000 – 2500 ha

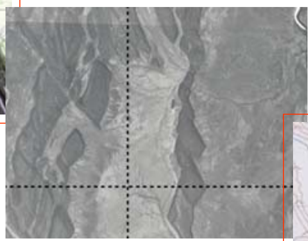
Geological Survey of Canada (BC)

Digital terrain analysis (DTA) procedure using aerial photographs and DEM´s



ETM+ - 2001
ETM - 1986
TM - 1972

…. data Input



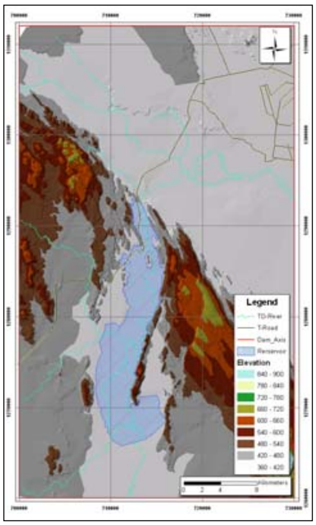
Aerial Photo (37) – 1994 (1:50000)

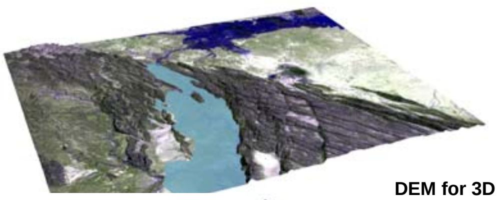
Topo Map (7) – 1997 (1:50000)

Nehemia Solomon

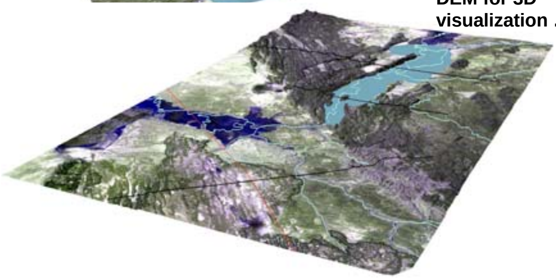
Tendaho Dam; Geological Modeling

Digital terrain analysis (DTA) procedure using aerial photographs and DEM´s





DEM for 3D visualization …



Nehemia Solomon
Tendaho Dam; Geological Modeling

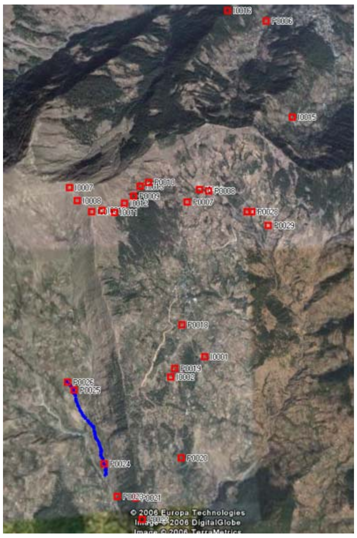
Engineering geological field mapping

- Field checks
- Mapping of rock exposures
- Field mapping

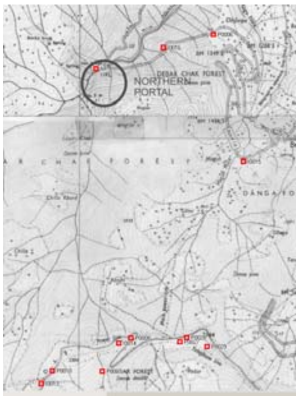
Objectives of engineering geological field mapping

- Project-related assessment of underground condition
- Field-characterization of rocks with respect to their geotechnical properties
- Acquisition of statistically representative data (rocks, discontinuities…….)
- Identification of singularities (Karst, faults…)
- Basis for or updating of geological model
- Evaluation of uncertainty of the geological model
- Basis for further underground investigation (drilling, geophysical investigation

Field checks



Location of field checks as fixed by using GPS (Patnitop tunnel, Kashmir, India)

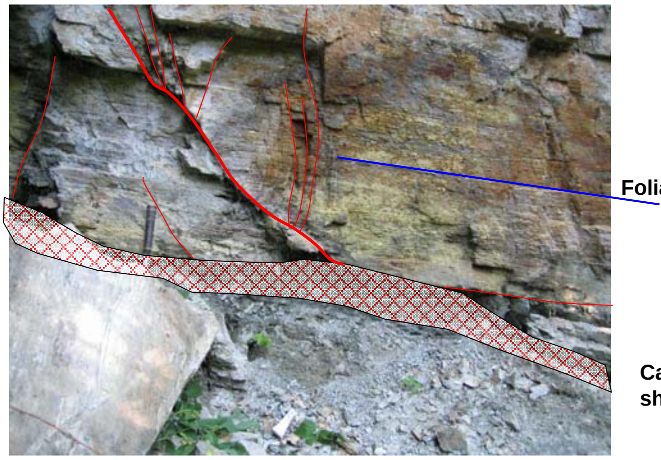


Field checks

Faults recognized by Google Earth image interpretation verified by field checking (Patnitop tunnel, Kashmir, India)

Investigation Methods

Mapping of rock exposures: Data from outcrop of mylonitic gneiss in the Eastern Alps

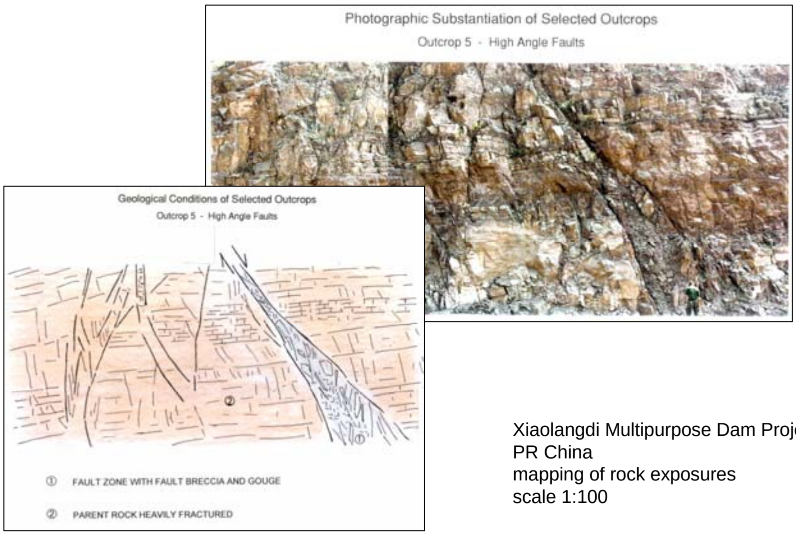


Foliation

Cataclastic shear zone

Investigation Methods

Mapping of rock exposures

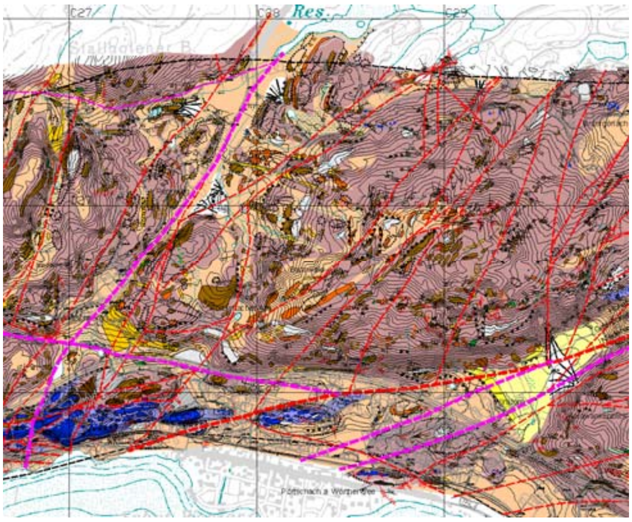


Xiaolangdi Multipurpose Dam Project – PR China
mapping of rock exposures
scale 1:100

Engineering geological field mapping

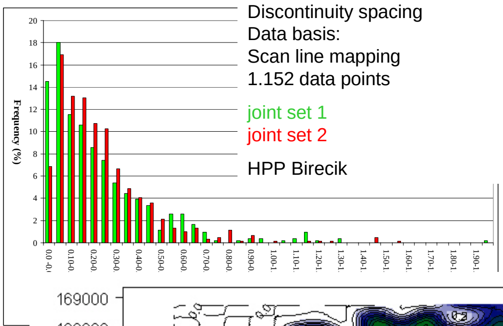
Manuscript map, Carinthia, Austria scale 1:10.000

Engineering geological field mapping



Final map, Carinthia, Austria scale 1:10.000

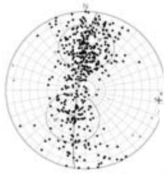
Engineering geological field mapping



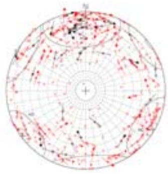
Discontinuity spacing
Data basis:
Scan line mapping
1.152 data points

joint set 1
joint set 2

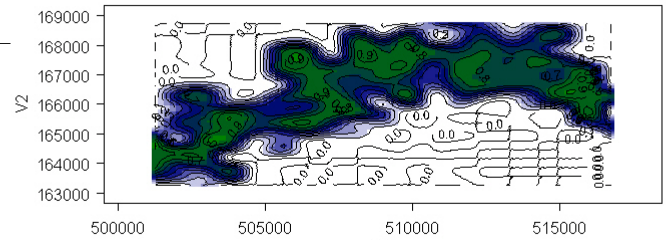
HPP Birecik



ZRK - HB2
shistosity

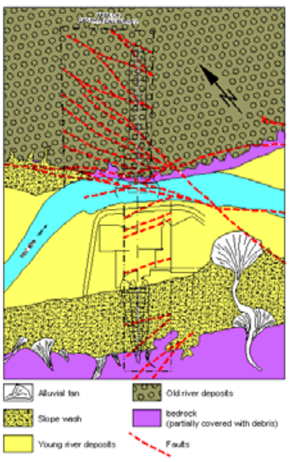


ZRK - HB2
slickensides
linears



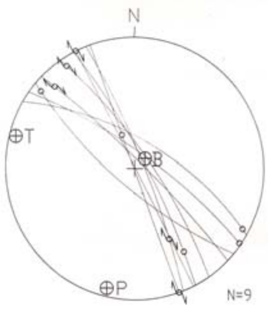
Carinthia, Austria scale 1:10.000

Engineering geological field mapping



Northeastern Abutment Area
Statistical Parameters of Discontinuities

Kinematic Analysis of Dextral Strike-Slip Faulting
by the method of H.Peresson (1992)



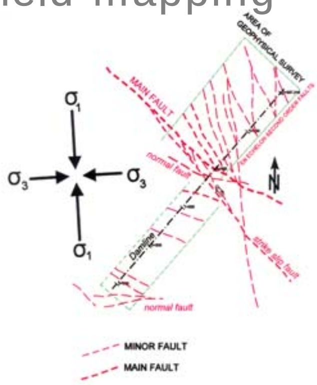


Abb.3: Störungssystem mit Hauptdruckspannungsrichtungen

Axis	Center of Gravity	Distribution Factor
P-Axis (Shortening)	196/06°	93%
T-Axis (Extension)	284/01°	94%
B-Axis (Intermediate)	026/83°	92%

Birecik Dam & HPP, Türkei
Paleostress analysis

Core Drilling

Objectives of core-drilling

- Verification or falsification or upgrading of the geological model
- Characterization of rocks with respect to their geotechnical properties
- Characterization of discontinuities with respect to their geotechnical properties
- Localization of faults and changes in lithology
- Characterization and quantification of rocks mass properties
- Sampling of specimens for laboratory testing
- Evaluation of underground water conditions
- Execution of geophysical borehole tests or of geotechnical in-situ tests

Advantages of core drilling

- Investigation to great depth
- Continuous rock sampling and logging
- Direct access to the rock mass
- The rock mass can be investigated in different directions, a 3d insight into the rock mass is possible
- Groundwater does not interfere with investigation
- Calibration of geophysical sounding outputs
- Drill-hole can be used for in-situ testing and geophysical surveying

Precautions in core drilling

- Pin hole information only
- Risks of misinterpretation
- Cost – benefit relation frequently inadequate (especially in deep bore-holes)
- Optimal interpretation requires experience and continuous supervision of drilling works
- Layout of drilling pattern is decisive for the quality, amount and value of information obtained

Optimization of core drilling investigation results requires:

- A layout design of drilling pattern according to geological requirements in order to establish a reliable conceptual geological model in accordance with other investigation
- Clearly formulated tasks of the borings with respect to weak and decisive points in information quality / quantity or to strengthen geologic assumptions
- The evaluation of all logable (and continuously logged) parameters of geotechnical concern (key parameters) so as to refine the geological model
- Inclusion, consideration and explanation of all findings, wether they assert previous assumption or contradict them

Requests to the contractor

- Suitable equipment
- Experienced foreman
- Optimal core recovery
- Flexible adoption of equipment due to changes in rock conditions
- Continuous monitoring of performance

Requests to the client

- Sufficient preparatory time
- Appropriate season for performance
- Contractual rights of the experts to have a suitable working place for the investigation of
- Flexible contract to modify the drilling program according to preliminary investigation

Drilling and Coring Bits

- Diamond bits are the best and hardest, producing high quality core. Fastest cutting rates. Expensive
- Synthetic bits. Less expensive. Generally good quality cores.
- Tungsten carbide. Least expensive. Slower coring rates.

Types of Coring Bits

Diamond, Carbide
Tungsten, Sawtooth

Carbide Type Bits

Diamond Core Bits

- Core Size: Larger better but more $
- Diamond setting: hardest vector set against the work
- Bit Profiles: Full-round, semi-round, flat crown, semi-flat
- Diamond size: relates to hardness and fineness of rock minerals
- Waterways: flushing cuttings & rock flour; Number of ports, slots, discharge direction.
- Matrix: secure diamonds & dissipate heat

Core barrels

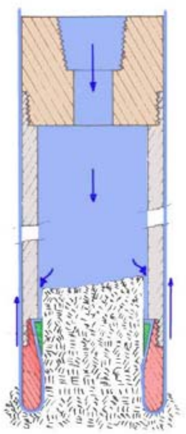
Single tube core barrel

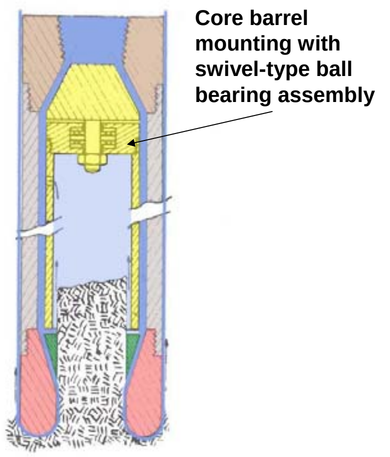
- Simple, rugged & cheap;
- Disadvantage: High mechanical stresses on core, washout due to full contact with high pressure flushing medium

Double tube core barrel

- Double tube core barrel is the standard.
- Outer barrel rotates with cutting bit
- Inner barrel is either fixed or swivel type (with bearings) that retains core sample.
- Core diameters generally range from 42 to 123 mm
- NX core: U.S. standard diameter = 54 mm (2.15 inches)

Core Barrels





Single tube core barrel   Double tube core barrels

Core drilling: quality

- Insufficient equipment
- Unskilled personnel
- Low quality of cores
- Low core recovery

Core drilling: quality

Worn out core barrel and drilling bits

Diamond Drill Bits

Core drilling: quality

Core drilling: quality

High quality drilling rig
Using wireline core barrel
drilling to depth of several 100 of meters

Core drilling: quality

Core drilling: quality

Core sampling according to quality of equipment ??

Core drilling: quality

Core diameter 10 cm
100% core recovery, even in faulted rock!

Storing of cores

- Cores are valuable specimens
- Cores should be stored in either wooden boxes or corrugated cardboard boxes or sheet steel boxes.
- Box marked with boring number, depth of core run, type core, bit type, core recovery (core loss marked by replacement material, e. g. wooden log pieces), rock type, removed samples and other notes.
- Cores should be stored on a save place that guarantees easy access at any time

Storing of cores

Storing of cores

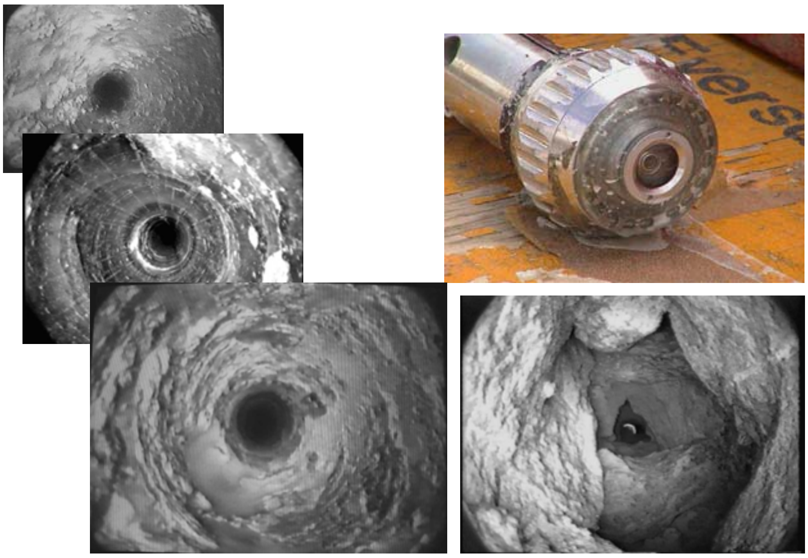
Storing of cores
Core logging at the storage

Drill-hole in-situ testing Standard In-hole Tests and Measurements

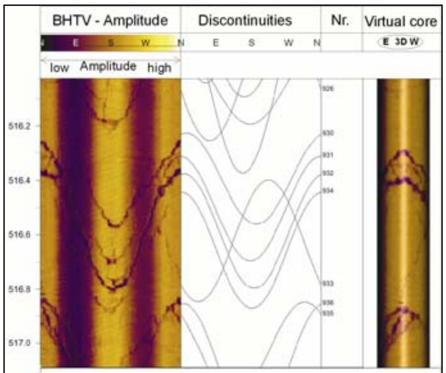
- Dilatometer (pressuremeter) tests
- Water pressure tests (Pumping t.)
- Geophysical measurements:
  - Caliper-log
  - Gamma (-Gamma)-log
  - Neutron - log
  - Resistivity-log
  - Acoustic bore hole televiewer (BHTV)
  - Formation micro scanning (FMS)

Dilatometer

Bore-hole video camera

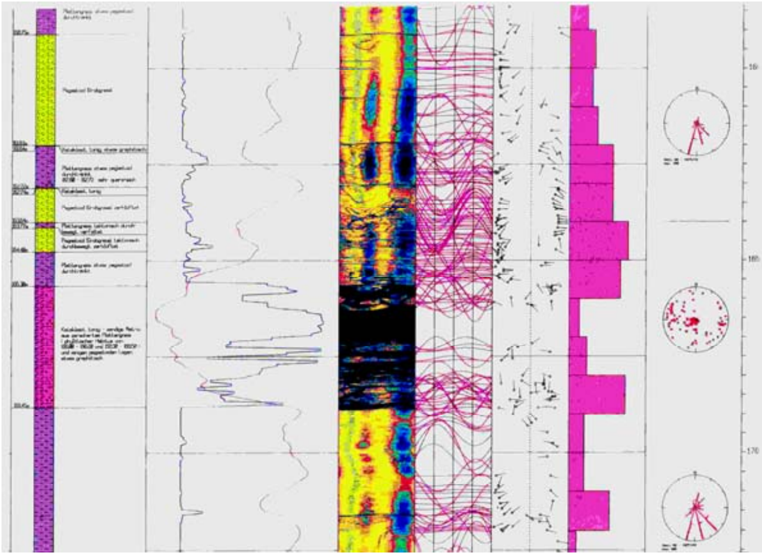


Acustic bore-hole televiewer

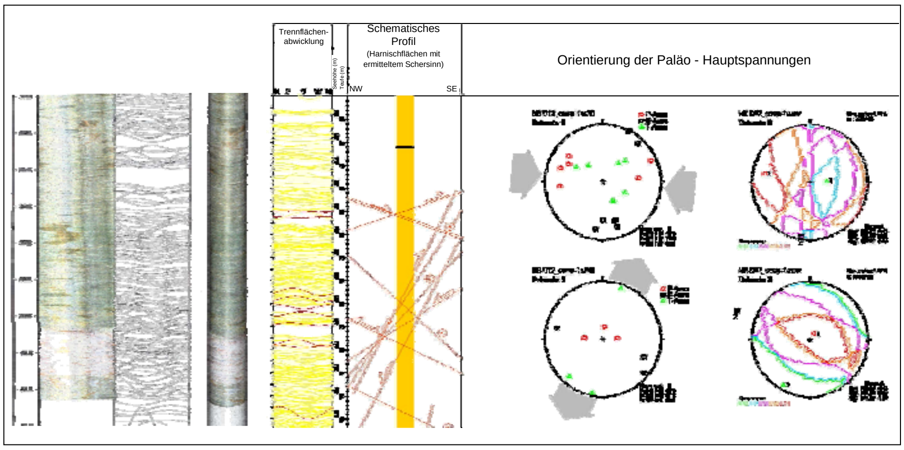


Nr.	Depth [m]	Dip direction/dip [°]		Discontinuity type
		uncorrected	corrected	
930	516,393	194/66	194/54	extensional joint, 2 mm calcite
931	516,504	179/69	177/57	extensional joint, 1 mm calcite
932	516,586	188/71	188/58	extensional joint, 2 mm calcite
933	516,623	045/72	043/83	extensional joint, partly open
934	516,658	182/71	181/59	extensional joint, 2 mm calcite
936	517,087	187/73	186/60	extensional joint, 3 mm calcite

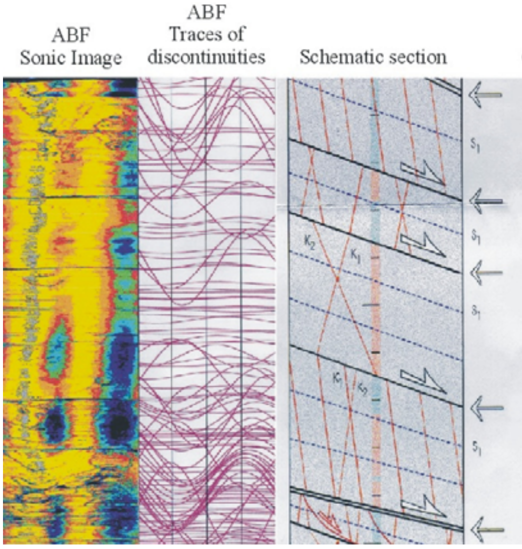
Acustic bore-hole televiewer



Geological drill core logging and kinematic discontinuity analysis

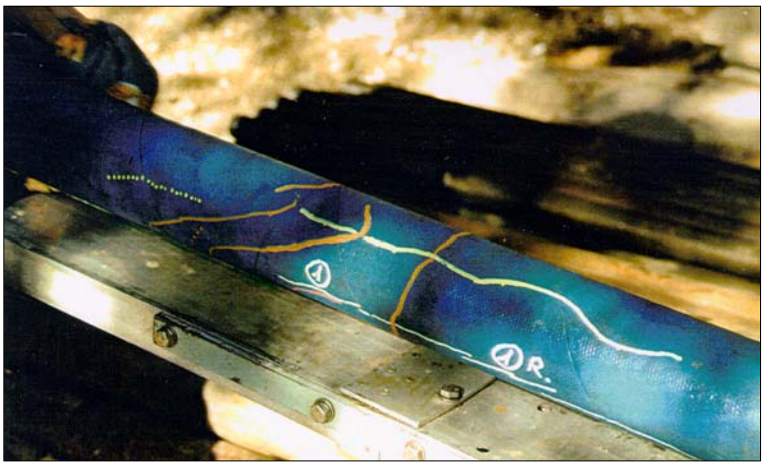


Kinematic Discontinuity Analyses on Drill Cores

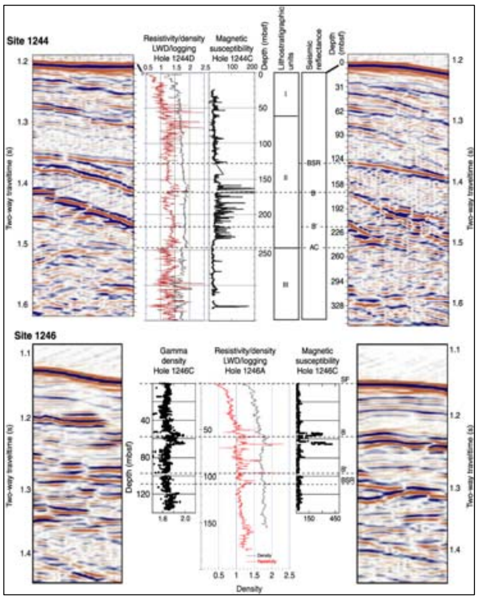


Detachment along foliation, development of clayey gouge

Impression-Packer

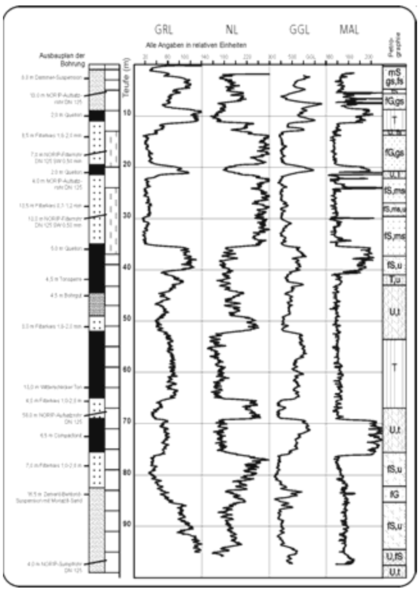


fracture investigation result (traces highlighted), Koralm example, ISMES photo



Geophysical bore-hole logging

Geophysical (seismic cross-hole and others) investigation example including electric resistivity, density, magnetic susceptibility bore-hole logging



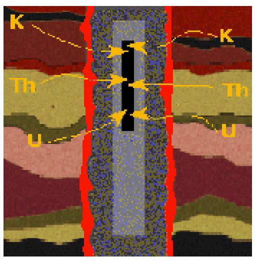
Example geophysical log in geotechnical soil sequence:

GRL Gamma Ray Log (Clay contents)

NL Neutron log, (Saturation, Permeability)

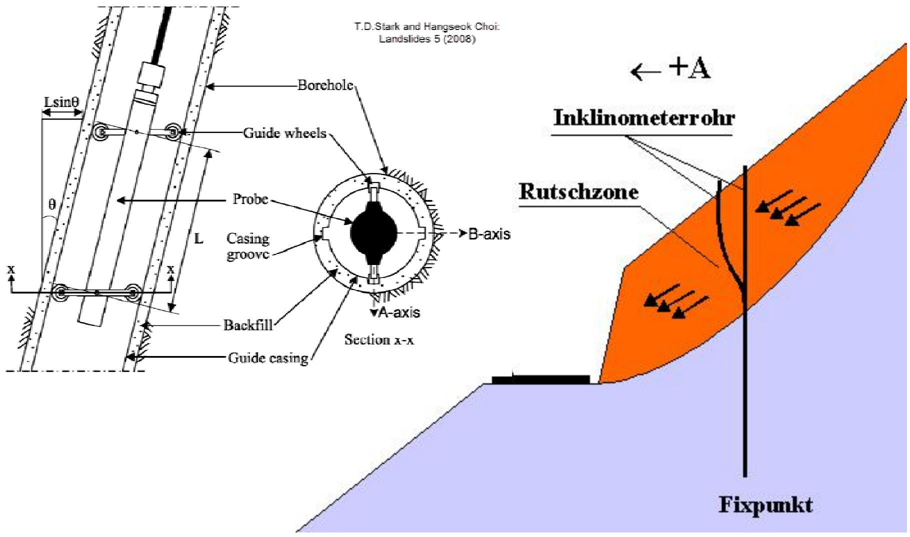
GGL Gamma-Gamma-Log (Density)

MAL Magnetic log (Silt, Fine Sand)



Investigation Methods

Inclinometer



Investigation Methods

Inclinometer

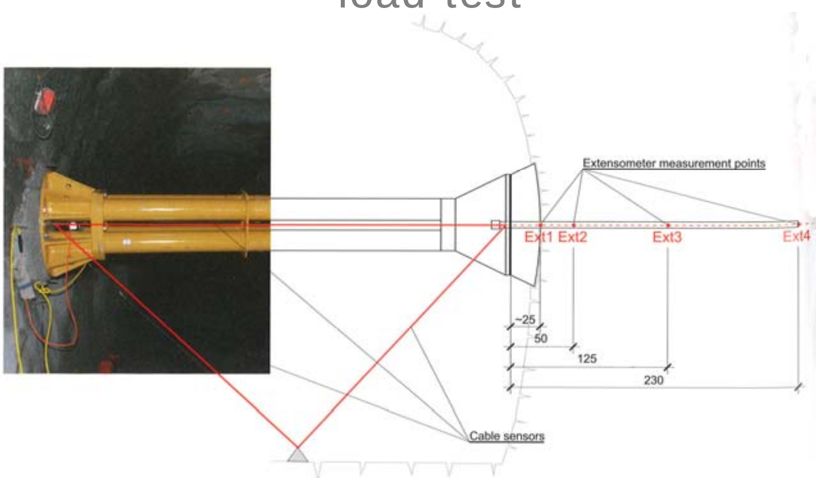
Large scale in-situ testing: plate load test

HPP Feldsee, Austria

Pressure tunnel

2007

Large scale in-situ testing: plate load test



HPP Feldsee, Austria, Pressure tunnel 2007: Test geometry and sensor setup

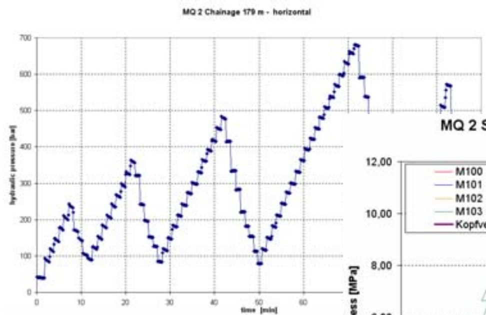
Large scale in-situ testing: plate load test

HPP Feldsee, Austria

Pressure tunnel

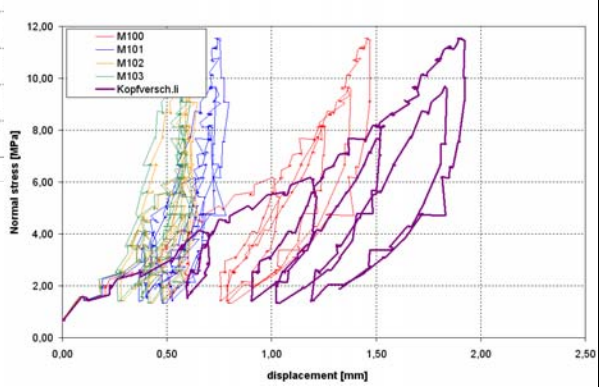
2007

Large scale in-situ testing: plate load test



Hydraulic pressure vs time

Horizontal displacement vs normal stress



Geophysical survey

Geophysical survey methods

- Mechanical Wave Measurements
  - Crosshole Tests (CHT)
  - Downhole Tests (DHT)
  - Spectral Analysis of Surface Waves
  - Seismic Refraction/Reflexion
  - Suspension Logging
  - Echo sounding (bathymetry)
- Electromagnetic Wave Techniques
  - Ground Penetrating Radar (GPR)
  - Electromagnetic Conductivity (EM)/Resistivity (SR)
  - Magnetometer Surveys (MT)
  - Others
  - Gravymetry
  - . . .

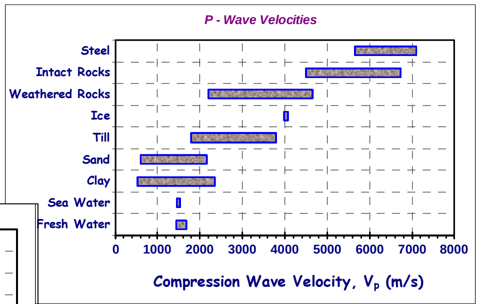
Investigation Methods

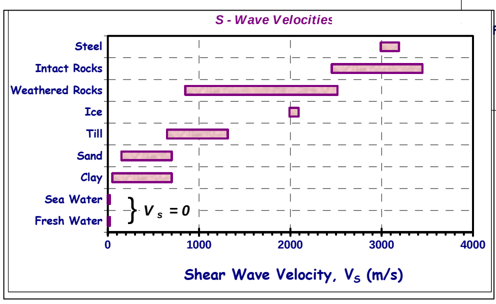
Objective of geophysical survey

- Filling gaps in information after geological field-mapping and core-drilling
- Updating and verifying geological model
- Optimum interpretation of geophysical data needs for a reliable geological model
- Drill-hole results necessary for calibration of geophysical data
- Therefore geophysical survey should be done after field-mapping and core-drilling

Investigation Methods

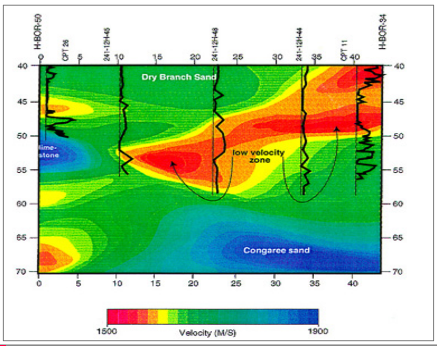
Seismical wave propagation investigation methods

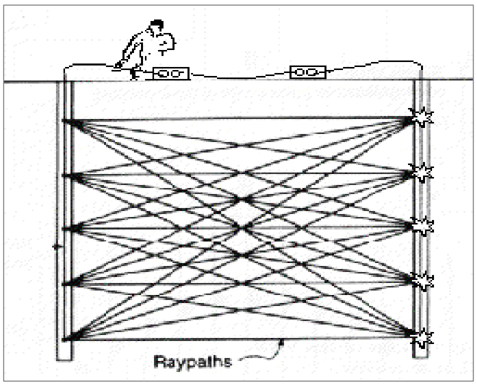




Investigation Methods

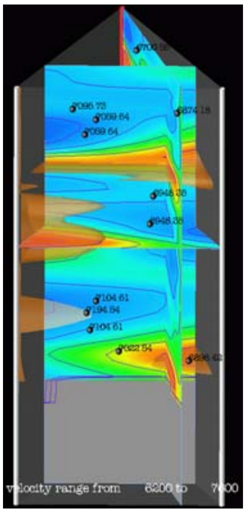
Crosshole seismic tomography: scheme and example analysis output

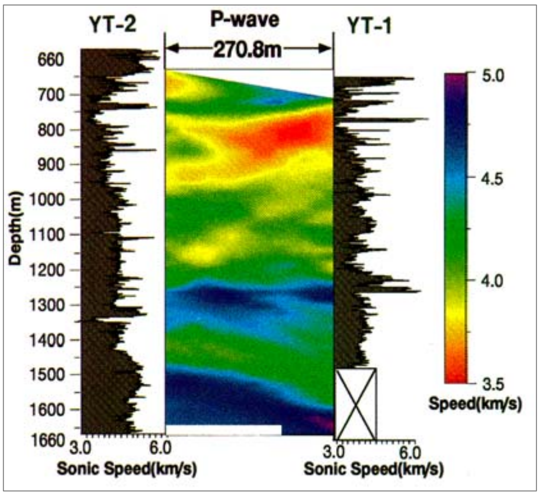




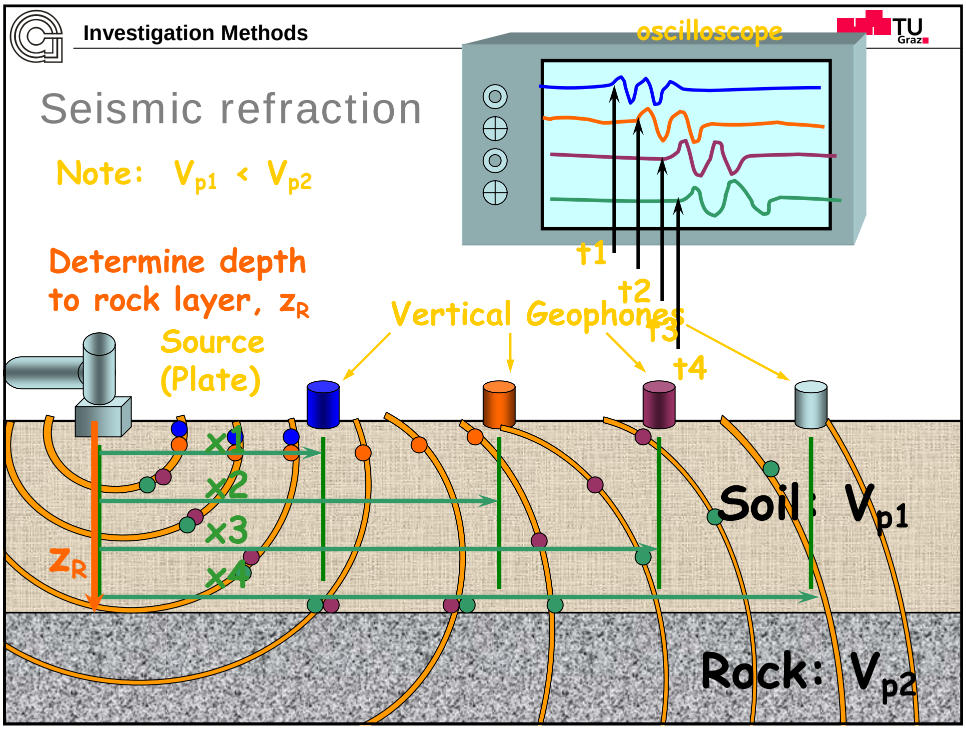
Investigation Methods

Crosshole seismic tomography: example analysis outputs

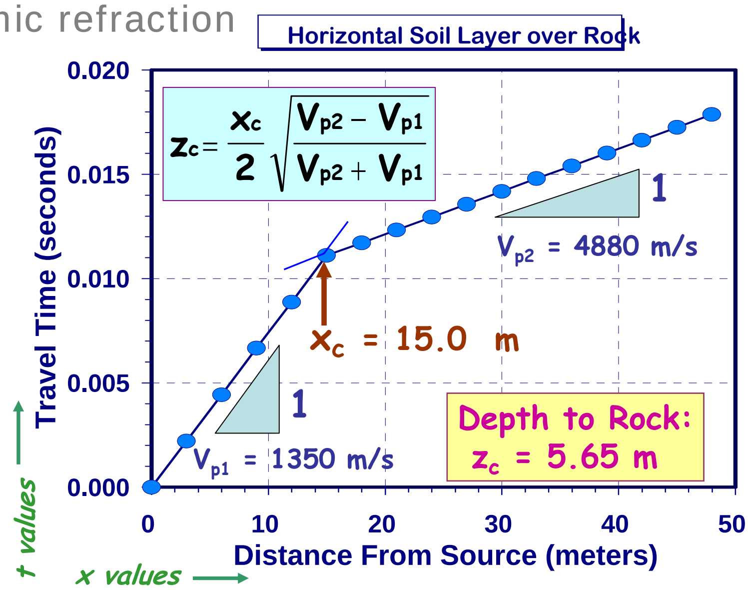




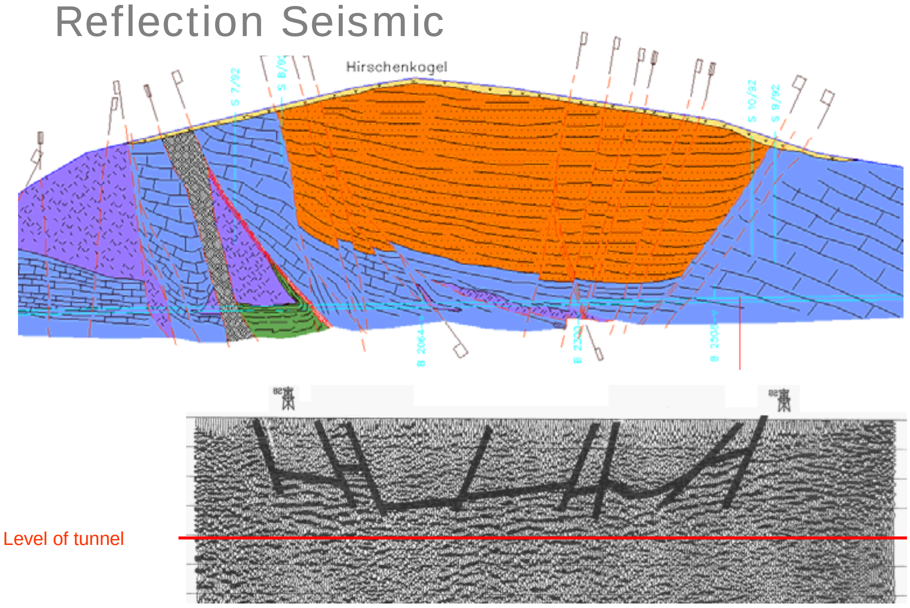
Seismic refraction



Seismic refraction



Reflection Seismic



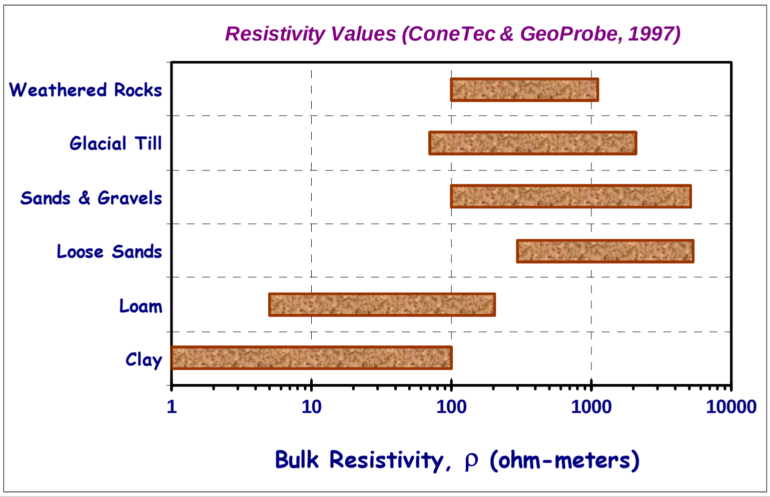
Electromagnetic Wave Geophysics

- Surface Mapping Techniques:
  - Ground Penetrating Radar (GPR)
  - Electrical Resistivity (ER) Surveys
  - Electromagnetic Conductivity (EM)
  - Magnetometer Surveys (MS)
- Downhole Techniques
  - Resistivity probes,
  - 2-d and 3-d Tomography

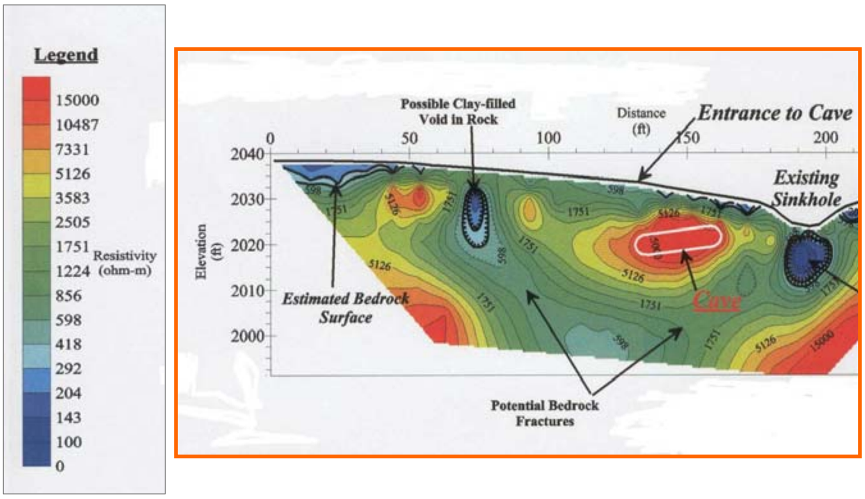
Electrical Resistivity (ER)

- Resisitivity R (ohm-m) is an electrical property. It is the reciprocal of conductivity
- Arrays of electrodes used to measure changes in potential.
- Evaluate changes in soil types and variations in pore fluids
- Used to map faults, karst features (caves, sinkholes), stratigraphy, contaminant plumes.

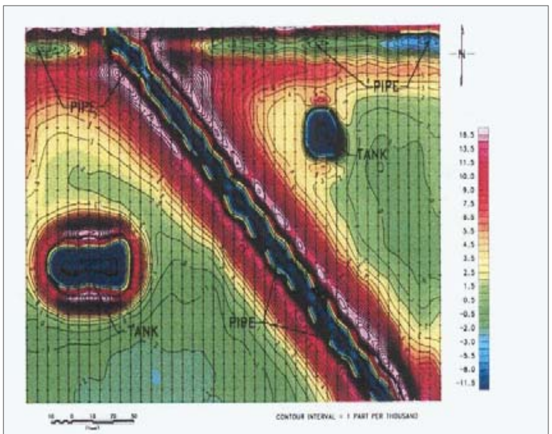
Electrical Resisitivity Measurements



Example resistivity profiling output

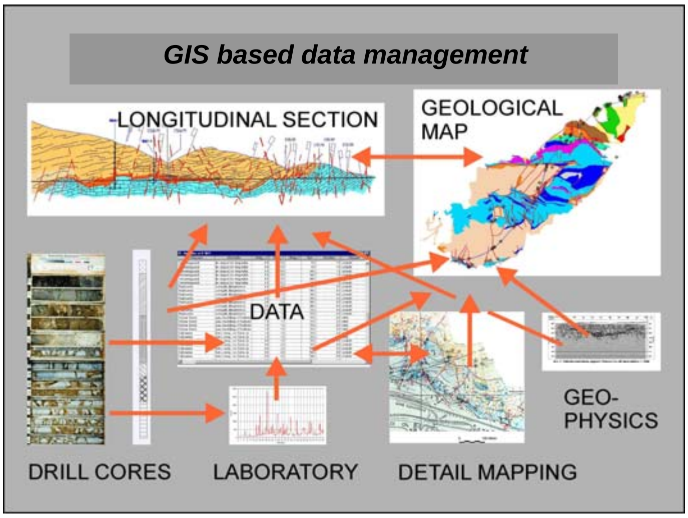


Electric conductivity mapping, example

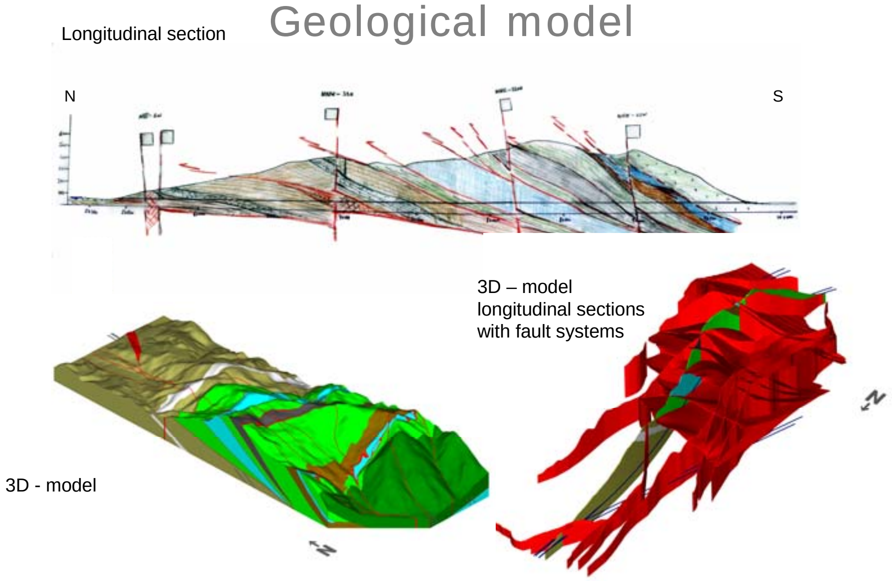


Geonics EM-31 Survey to Locate Underground Storage Tanks

Investigation data management



Geological model



Eastern Expressway Project, Taiwan