From Palmström A.: RMi – a rock mass characterization system for rock engineering purposes.
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Chapter 3

COLLECTION OF GEO-DATA - LIMITATIONS AND UNCERTAINTIES

> *"The geotechnical engineer should apply theory and experimentation but temper them by putting them into the context of the uncertainty of nature. Judgement enters through engineering geology."*
> Karl Terzaghi, 1961

The purpose of this chapter is to outline briefly how rock mass properties are determined and to show the special problems related to the uncertainties connected to acquisition and application of geological data.

In contrast to most other materials used for construction purposes, judgement of the quality of the rock mass is based on observations rather than test results. The large volume of the material involved, and the 'given properties' of the material, in addition to the lack of access to "see" the actual material involved, cause great challenges in the execution of investigations, interpretation of the results as well as characterization of the complex material called rock mass. Thus, there are no clearly established guidelines when attempting to define the extent or scope of methods to be applied in collection of relevant geo-data for a project (Merritt and Baecher, 1981). The investigations and procedures may vary according to the nature of the project, the complexity of the geology, the background of the engineering company, and the experience of the individual geologists or rock mechanics engineers involved. A general approach to collection of data on ground conditions in different stages of a project is shown in Fig. 3-4 where also the methods applicable to finding parameters applied in the RMi system are indicated.

The fact that geological formations are spatially variable, and that only a limited number of measurements or observations can be made, has important consequences. The principal one is that the subsurface must be described and characterized by a limited number of parameters, and that the values of these parameters are imprecisely known. It is important to accept the fact that a geotechnical parameter is expressed by a range and also that the actual range may be greater than that observed. Thus, in most cases it is recommended not to make too large an effort to obtain accurate values of the various parameters. Often it is better to obtain a wider statistical material (Einstein and Baecher, 1982).

Although the types of structures that may be encountered in different parts of a proposed tunnel can be assessed, Terzaghi (1946) points out that it is not possible to make in advance of construction a quantitative evaluation of the difficulties. Hence the first estimate of the material and equipment required for constructing a tunnel inevitably involves a certain amount of guesswork.

3.1 GEO-DATA FOUND BEFORE, DURING AND AFTER EXCAVATION

There are two main stages in the collection of geological data:

1. From observation and investigation on surface from which interpretations and extrapolations have to be made. These data are mainly used for planning of a project and are collected *before* construction (see Fig. 3-1).
2. From characterization of 'known' ground conditions; either in surfaces of excavations or in outcrops belonging to the excavation to be made. This more straight forward characterization is further dealt with later in this chapter.

Rock mass characterization *before* construction requires an understanding of the rock mass expected to be encountered, and the influence of the geologic variables inherent in any rock mass. Later, *during and after* construction, the characterization is carried out in the surfaces of the excavation on known conditions. The same parameters of the rock mass may be used in the characterization in all phases of the project.

Almost all types of geo-data collection require some degree of extrapolation, with projection from the known to the unknown (Piteau, 1973). How well this extrapolation is performed has obvious practical implications, since the method(s) used often can influence the amount of necessary subsurface exploration. Some principles of extrapolation are shown in Figs. 3-1 and 3-2.

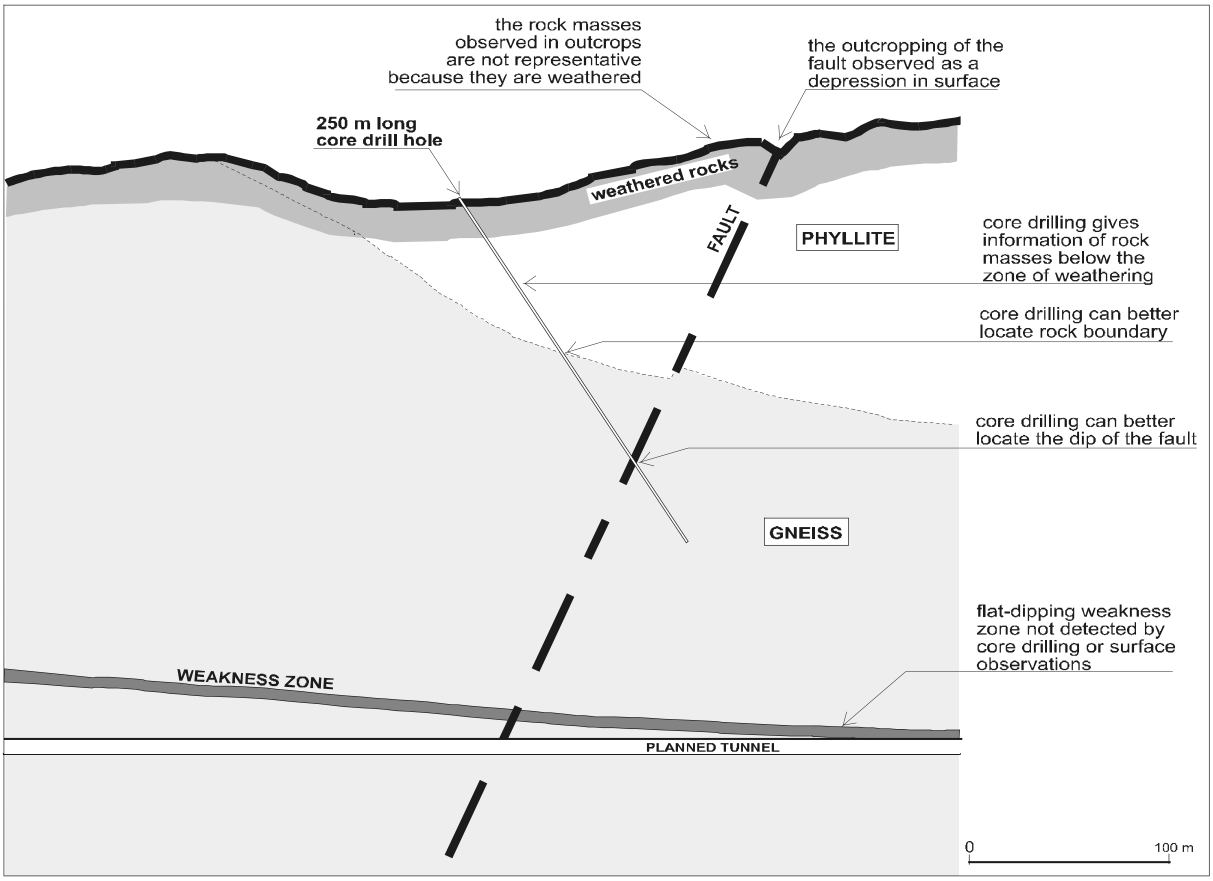

Fig. 3-1 For deep tunnels the main source of geological information before construction is from surface observations in outcrops. Core drillings combined with the surface information can improve the accuracy of the geological interpretation and yield additional information of the rock mass condition. But as no information is available of the conditions where the tunnel is planned, unexpected rock mass conditions may be encountered.

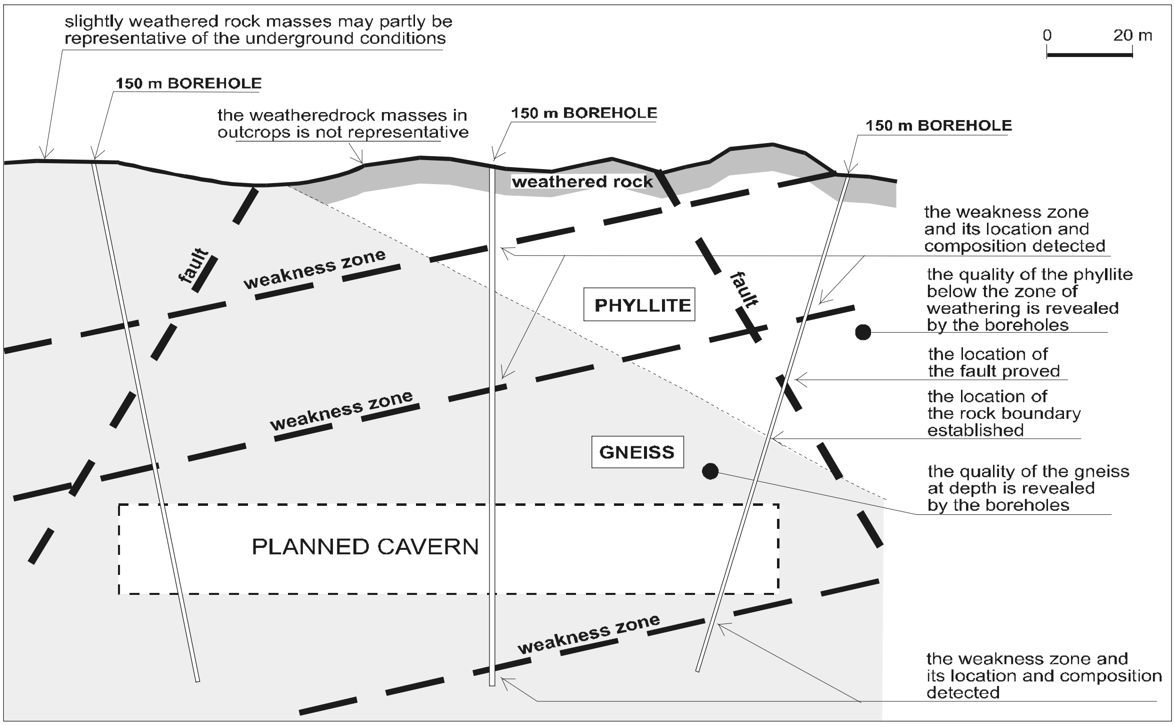

Fig. 3-2 For shallow caverns and tunnels the rock mass conditions can be found from core drillings penetrating the planned location. Surface mapping and geophysical measurements (refraction seismic) may further improve the quality of geo-data.

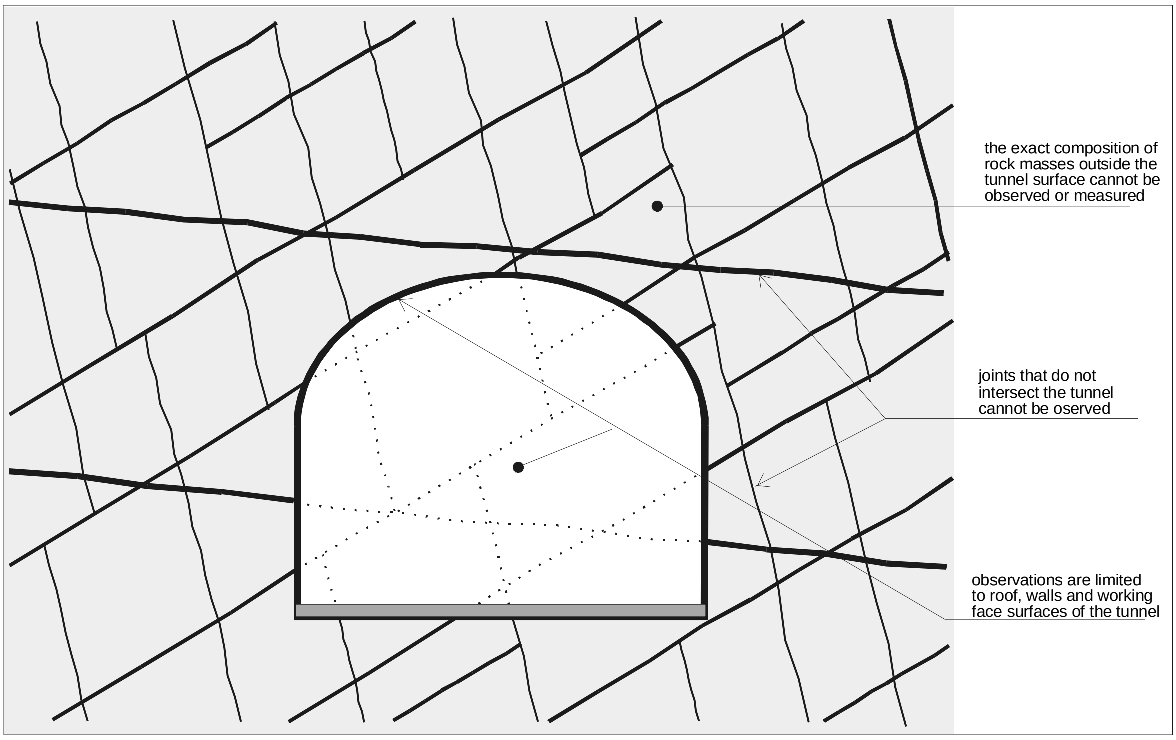

Fig. 3-3 In tunnels and in man made cuttings the 'real' rock masses can be observed in the excavated surfaces. The rock mass behaviour is often governed by the conditions in the volumes surrounding the tunnel. It is not possible to observe or measure the properties of the rock mass exactly.

The actual rock mass conditions are not known until they are encountered in the tunnel. But still it is not possible to determine the exact nature of the rock mass involved as parts of these are located outside the tunnel surface, as indicated in Fig. 3-3.

The following features can influence determination of the quality of the rock mass in an excavation:
- The possible development of new discontinuities from the excavation process.
- The limited observation of the actual rock mass conditions where the surface is covered by mud, shotcrete, lining etc.
- The development of cracks from overloading of the ground surrounding the tunnel.

3.2 SOME METHODS USED IN GEO-DATA COLLECTION

The methods for the collection of geological data have not changed very much over the past 20 years and there is still no acceptable substitute for the field mapping and core logging carried out by an experienced engineering geologist (Hoek, 1986). On certain projects it may be justified to set out a complete rock investigation program and generate a full suite of tests. In general, however, only a limited amount of testing is likely, and the main investigation is restricted to field observations. The reason is often the high cost of sub-surface exploration by core drilling or by the excavation of trial shafts and adits. The site of a proposed underground excavation is therefore seldom investigated as fully as a design engineer would wish.

The field observations are mainly carried out in the following types of locations:
- outcrops or cuttings;
- pilot tunnels, adits or shafts made before construction; and
- excavated tunnels/shafts/caverns.

And in addition: in bore holes made from these locations; or on drill cores. Also tests are made or samples for tests taken from these locations. More specifically, the various kinds of observations and tests used in description, characterization, tests and measurements of rock mass features are:
- In outcrop and surface observations, in the form of:
  - geological mapping;
  - engineering geological mapping; and
  - joint surveying.
- In bore holes, performed as:
  - core drilling; or
  - percussion boring.
- Geophysical methods, the main types being:
  - seismic reflection measurements;
  - seismic refraction measurements;
  - cross hole tomography measurements;
  - resistivity measurements; as well as
  - radar, electromagnetic and
  - gravity measurements.
- Laboratory tests of geological and mechanical properties of rock samples and limited volumes of rock masses, some of the tests are:
  - mineral composition and texture;
  - compressive strength;
  - tensile strength;
  - shear strength;
  - elastic constants; as well as
  - density, porosity, anisotropy, and
  - durability.
- Various field investigations and tests, such as:

- shear strength measurements of joints:
- deformation measurements in excavations;
- modulus measurements of rock masses;
- in situ stress measurements;
- hydraulic fracturing; and
- permeability tests.

For various reasons the simple observations made on the surface provide the most reliable data of rock mass parameters (Bieniawski, 1984). If the observation of outcrops yields insufficient knowledge for forecasting the ground conditions for a planned site, or if unfavourable rock conditions are anticipated, various other investigations may furnish more specific information on the rock conditions. The following sections briefly outline the principles in applying these for geo-data collection and how rock mass features influence the results and procedures. Methods for numerical characterizations from various types of measurements are described in Appendix 3.

3.2.1 Geological observations and mapping

Conventional geological mapping is conducted before construction to determine rock types, delineate major geological structures, such as faults, dykes, lithological contacts, and any other features that present major weakness zones in the mass. Large features like faults can be individually mapped in outcrops, trenches, or exploratory openings. Their course can be significantly better projected through intersections with borings. Regional or local geology may be of use in projecting faults or large shears to unexplored parts of the rock mass, but poor correlation between predicted and encountered geology in tunnelling casts doubt on the accuracy with which structural features at the surface can be projected into a rock mass (Wahlstrom, 1969; Dowding and Miller, 1975).

The knowledge of the underground from surface mapping is usually limited to information found in sporadic point observations, core drilling and occasionally in extensive outcrops or cuttings. The engineering geologist's task is from this information, combined with geo-logical information, to interpolate and to estimate the properties of the rock masses and the constituent rock types at the site. The quality of this depends upon the simplicity of the geology, the experience of the geologist and rock engineer, and in addition the possibility of observing representative rock masses in outcrops. Table 3-1 shows the influence, which the geological setting may have on the confidence of the rock mass characteristics observed.

TABLE 3-1 CLASSIFICATION OF OUTCROP CONFIDENCE (from Kirkaldie, 1988)

TERM	**DESCRIPTION**
High level	Massive homogeneous rock units with large vertical and lateral extent. History of low tectonic stress levels.
Intermediate level	Rock characteristics are generally predictable but with expected lateral and vertical variability. Systematic tectonic stress features.
Low level	Extremely variable rock conditions due to depositional processes, structural complexity, mass movement or buried topography. Frequent lateral and vertical changes can be expected. Frequent and variable tectonic stress features.

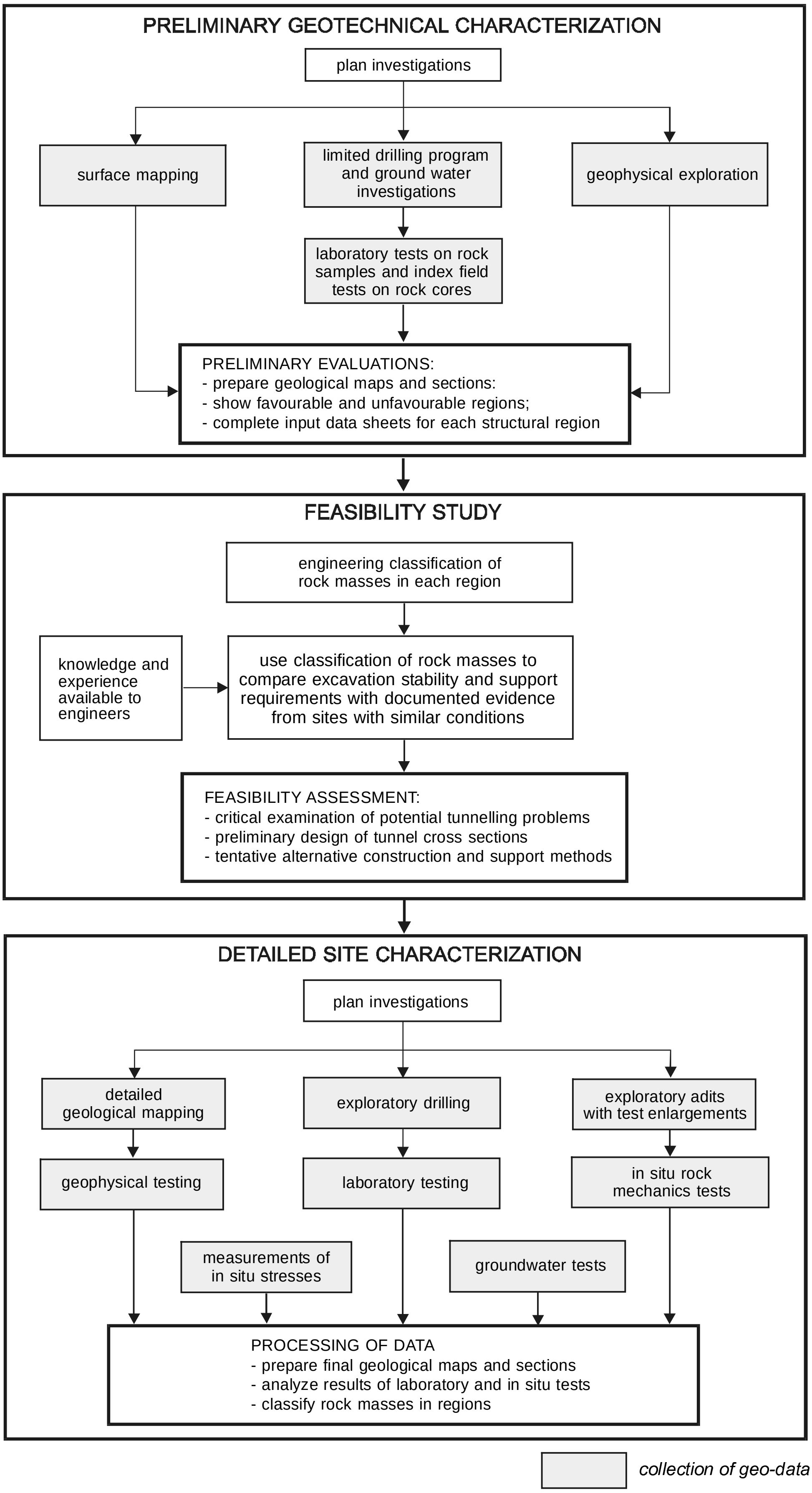

Fig. 3-4 The main principles in acquisition of data on geological and ground conditions before construction of a project (modified from Bieniawski, 1984). Methods useful in collection of input data to RMi are shown

Geological and engineering geological mapping provide three types of information:
1. Rock type and distribution with estimate of strength. At this stage of the planning Herget (1982) recommends that rock strength can be judged from simple hardness tests in the field with geological pick or rebound hammer.
2. Location of major weakness zones or larger faults, which are described individually.
3. Description of jointing including data on spacings and frictional properties. Detailed joint measurements can be carried out in specially designed joint surveys.

<u>During and after</u> excavation the observations are made on 'known' surfaces. From this it follows that the descriptions can be much more detailed for use in various analyses and methods of design.

3.2.2 Joint surveys

Joint surveys are mainly made during the planning stage of a rock construction to provide more detailed information on the jointing. They can also be conducted for special engineering purposes, such as for slope stability analyses in opencast mines, rock slopes, cuttings or valley sides.

Some form of *statistical* approach can be beneficial in such surveys because of the inherent stochastic nature of joints and because complete information concerning their geometry can never be obtained. Hudson and Priest (1979) find that the ability to express block lengths, areas and volumes by statistical distribution functions will be of great assistance in the characterization of rock mass geometry.

The objective of statistical sampling is to infer characteristics of a large population without measuring all its members. The joints measured or *sampled* are only a portion of those exposed, and these in turn are only a small part of all the joints in the rock mass. Various survey methods may be used to sample the jointing, but in all instances the sample will have a bias dependent upon nature of the exposed face and the method of sampling (Einstein and Baecher, 1983)

In common joint surveys, Einstein and Baecher (1983) use three geometric properties which can be described statistically. These, which might be recorded in a number of equivalent measures, involve:
- Density of joints (joint spacings, numbers per rock volume or per outcrop area).
- Size (trace lengths, joint surface areas or radii).
- Planar orientation (strike or dip direction and dip).

Sampling is conducted on limited exposed rock surfaces in the form of outcrops, trenches, and tunnels in addition to bore hole walls and drill cores. If the surface is large, the number of joints exposed may also be large and some form of selection may have to be applied to reduce the sample size. Techniques which rely on the geologist's judgement for recognising the joint sets of importance can greatly reduce the volume, but there is always the risk of missing or discounting sets which are nevertheless of considerable importance (Robertson, 1970). This risk is greatly reduced when using some standard sampling plan, for instance:
- the unit area method (Krumbein and Graybill, 1965),
- the detail line survey, or
- the cluster sampling plan.

Piteau (1970, 1973) and Robertson (1970) have made important contributions to joint surveys from practical experiences in South African mines. Joint surveys are also described by Baecher and Lanney (1978) and Einstein and Baecher (1982, 1983).

No joint survey can furnish complete information about all joints present in a body of rock, but a properly conducted survey can furnish data which have a high probability of approximating the orientation, spacing and condition of these joints (Terzaghi, 1965).

3.2.3 Core drilling

The recovery of core by diamond drilling is used to obtain geo-information from volumes of rock masses that cannot be observed. The drilling technique or the problems of obtaining high core recovery of good quality is not outlined here, but rather the value of the information gained from this type of field investigation is described. It is one of the most important methods of sub-surface exploration. The information from drill cores can greatly improve the results from outcrop mapping, and can also preferably be used to improve knowledge of the underground when combined with geophysical measurements (Hoek and Brown, 1980; Hoek, 1981). Drilling from the surface or probing ahead of an advancing heading is the most effective means of collecting information of the rock mass condition.

The purpose of a core drilling investigation can be to:

- Confirm the geological interpretation.
- Obtain information on the rock types and their boundaries in the rock mass.
- Obtain more information of the rock mass structure.
- Study ground water conditions.
- Provide material (samples) for rock mechanics testing and petrographic analyses.

In "hard rocks" dominated by discontinuities core drillings are often carried out to study certain larger faults or weakness zones which are assumed to determine the stability and ground water conditions of the opening. The bore holes will, however, also give additional information where they penetrate the adjacent rock masses.
Considering the very high cost of good quality core recovery, Hoek and Brown (1980) comment that it is invariably worth spending a little more to provide for good routine core examination and carefully prepared reports with high quality photographs of the cores before they are placed in storage. A method for improved core description is presented in Appendix 3.

Kikuchi et al. (1985) have described the use of a bore hole television camera to observe joint location and orientation, joint aperture, and presence of joint filling, i.e. information from bore holes can be gained without obtaining cores.

3.2.3.1 Limitations and deficiencies in core logging

Core drilling results are not necessarily typical of the overall rock mass (Terzaghi, 1965). The jointing density measured along a bore hole through a rock mass is often quoted as a single figure, yet the value can depend significantly on the orientation of the line through the rock mass (Hudson and Priest, 1983). The amount of variation that could be expected along bore holes or scan lines in different directions is a function of the jointing geometry, particularly the degree to which the joints tend to be orientated in certain preferred directions. In general, rock masses with a few joint sets will exhibit much greater jointing variation than those with many sets. Also Deere et al. (1969) described that it is usually difficult to obtain an accurate estimate of the joint spacing or the fracture spacing on the basis of exploratory borings.

Lugeon or water pressure tests in bore holes can yield information of ground water conditions. The measurements can, however, be markedly influenced by single joints, and the results can therefore be misleading. There are also often uncertainties connected with the execution of the test, for instance leakage through the packer. This is especially true for double packers.

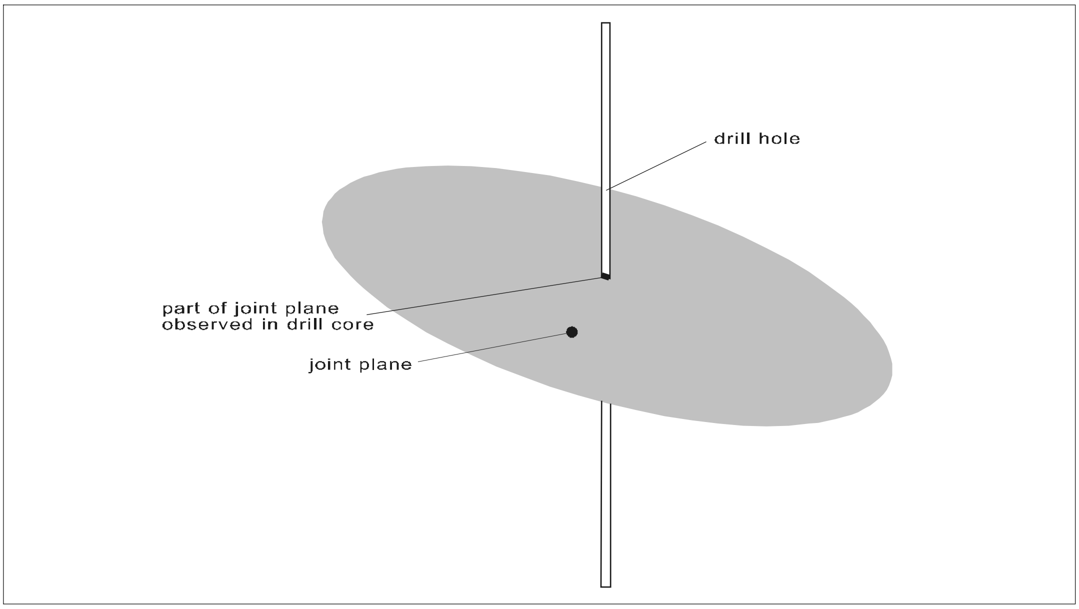

Fig. 3-5 Only a very small part of the joint plane can be observed in a drill core.

It has long been desirable to use bore hole data alone as the basis for rock mass classification without the need for additional tests in adits or pilot tunnels. As a result of the availability of more advanced coring techniques, such as directional drilling and oriented core sampling as well as both bore hole and core logging procedures, bore hole data are of increasingly better standard. Knowing the deficiencies associated with bore holes mentioned above, such data - except where several differently orientated bore holes are drilled - can seldom provide enough relevant data; a combination of data from bore hole and observation of exposed rock surfaces form the best input for rock mass classification, rock design and rock engineering.

Merritt and Baecher (1981) point out another limitation with core drilling: the problem of reliably identifying faulting or shear zones in drill cores. *"Post construction analyses of boring logs at power plant sites indicate that the likelihood of recognizing even many inch wide faults in boring logs is extremely small."*

Section 3.8 in Appendix 3 and Section 4 in Appendix 4 outline how information obtained from drill cores can be improved by better quality core logging, but still the quality of the data found is limited due to spatial variability of rock masses and the fact that a bore hole only represents one dimension, see Fig. 3-5.

3.2.4 Geophysical measurements

The high cost of sub-surface exploration by core drilling or by excavation of exploratory adits or shafts, results in that the use of these investigations is generally limited. Geophysical methods can often be used to supplement the information from such explorations.

Of the different geophysical methods for rock mass investigation the seismic methods and crosshole tomography seem most promising in delivering useful information of rock mass features. Seismic methods will not give satisfactory results in all geological environments (Hoek and Brown, 1980). When geological conditions are suitable, seismic methods can give valuable information on the structural orientation and configuration of rock layers and on the location of major geological discontinuities such as weakness zones and faults.

In addition to structural settings the data provided by refraction seismic measurements may also be used to estimate the jointing density. This is further described in Appendices 3 and 5. McFeat-Smith et al. (1986) mention an example where a seismic refraction survey provided the most cost-effective solution for locating zones of adverse tunnelling ground in Hong Kong's igneous rock and densely populated terrain.

3.2.5 Exploratory adits and shafts

The unreliability of projecting geological information obtained from surface mapping and core drillings can be such that excavation of an adit or a shaft to provide access to the rock mass for more detailed information at the site may be required. Such investigations are used for detailed information of the rock mass conditions in the actual area. The characterization is carried out from observations of the excavated surfaces. Special characteristics or properties may be measured by large-scale field tests.

When surface exposure is limited, or when it is considered that those outcrops - which are available - have been severely altered by weathering, the excavation of a trench or a shaft is sometimes advisable (Hoek and Brown, 1980).

3.2.6 Laboratory and field tests

These tests are generally carried out for more specific measurements of individual properties of a rock or a rock mass. Some of the test are made for investigation of inherent properties, other are for stress or deformation measurements. A special part of such tests is connected to control of deformations in excavations or slopes.

Many of the large field tests are very expensive. They can be performed in exploratory adits or shafts before project construction or in tunnels or caverns during construction. As a consequence, the value of results found from such tests should be carefully weighted against the costs (Franklin, 1970).

Laboratory testing methods for rock material are generally well established and testing techniques have been recommended by the International Society for Rock Mechanics (ISRM) and the American Society for Testing and Materials (ASTM).

There are sometimes doubts about the reliability of many of the tests and how their results can be applied. Nieto (1983) mentions, for example, that *"a surprising number of in situ testing programmes in intrusive igneous rock and high-grade metamorphics give values of static modulus ranging between 7 and 14 GPa using bearing plates, and between 41 and 55 GPa using flat jacks"*.

3.3 UNCERTAINTIES AND ERRORS IN GEO-DATA COLLECTION

"In thinking about sources of uncertainty in engineering geology, one is left with the fact that uncertainty is inevitable. One attempts to reduce it as much as possible, but it must ultimately be faced. It is a well recognized part of life for the engineer. The question is not whether to deal with uncertainty, but how?"
Herbert H. Einstein and Gregory B. Baecher (1982)

In connection with this section the following expressions need an explanation:

Uncertainty or lack of absolute sureness, in geology means that observations, measurements, calculations and evaluations made are not reliable. The consequences are that the use of geological data often may involve some kind of guesswork.

Error is defined as the difference between computed or estimated result and the actual value.

A *bias* is the difference between the estimated value and the true value of a statistic obtained by random sampling. For example, R. Terzaghi (1965) pointed out that joints sub-parallel to an outcrop have less chance of being sampled than joints perpendicular to an outcrop. This is a bias in sampling for orientation.

Einstein and Baecher (1982) have defined three main sources for uncertainties and errors in engineering geology and rock mechanics:

1. Innate, spatial variability of geological formations, where wrongly made interpretations of geological setting may be a significant consequence. This has been outlined in the beginning of this chapter.
2. Errors introduced in measuring and estimating engineering properties, often related to sampling and measurements.
3. Inaccuracies caused by modelling physical behaviour, including incorrect type of calculations or models.

In any engineering study, one can never know what has been left out of an analysis. Thus, in addition to the three major uncertainties above, there is also uncertainty due to *omissions*. The real world has variations and properties that can never entirely be included in a characterization or an analysis. According to Einstein and Baecher (1982) most of the major failures of constructed facilities have been attributed to omissions.

Some of the features in rock masses, which determine the quality of geo-data, are mentioned earlier in this chapter. Consequently, they contribute to uncertainty. In this section, additional basic factors causing uncertainties and errors are outlined.

3.3.1 Uncertainties caused by spatial variability of rock masses

The geological subsurface is spatially variable in that it is composed of different materials which are stratified, truncated, and in other ways separated into more or less discrete zones. It is also spatially variable in that within an apparently homogeneous body, material properties vary from point to point. While with sufficiently many observations this variability can be precisely characterized, the number of observations is usually limited. Thus, uncertainty remains concerning material properties or classification at points not observed.

The variability can be such that a construction in rock, within short distances, may encounter the most diverse conditions. It is nearly impossible to uncover all the important variations by presentday exploration techniques. A large number of case histories attest to the frequency with which unexpected conditions occur, often with disastrous results. A larger part of these unexpected events have been caused by wrong geological interpretation, i.e. how the main geological structures are distributed below the surface (Merritt and Baecher, 1981). From this it is clear that the quality of the geological interpretation is vital for characterization of the rock masses at the construction site before construction. Where the geological interpretation is wrong or incorrect, it follows that the assumed rock mass characterization is equally wrong - however good the description of the observed rock masses is.

Error from the geological variability can never be avoided; it can, however, be reduced by the use of well experienced geologists with extensive knowledge of the geology in the actual region, and also by directing specific, appropriate investigations towards possible key geologic structures that may occur.

3.3.2 Measurement errors

The division of errors described by Krumbein and Greybill (1965) is used to explain inconsistencies in repeated measurements of the same quantity. They have outlined four kinds of measurement error commonly recognized or associated with the observer, the instrument, the operational definition, and the measurement process itself, namely:

Gross errors, attributable mainly to blunders on the part of the observer, are usually large in magnitude and irregular in occurrence. They may result from momentary inattention, and when subsequently noted, the observation may be discarded by the observer.

Systematic errors arise when measurements tend to be consistently either too large or too small. They may be produced by a miscalibrated instrument, but they also occur from such external conditions as atmospheric moisture (in air-drying a sediment, for instance)

Errors of method occur when there is a discrepancy between the conceptual definition of the quality to be measured and the operational definition used to make the measurement. The quantification process in geology gives rise to many situations in which errors of method may occur.

When measurement processes are free of the errors listed above, there still remain fluctuations in the numerical values obtained by repeated measurement of the same object. These are *unpredictable deviations* or *random errors*, which in the long run may be compensating, in that positive and negative deviations tend to balance each other, so that the average value of the numbers tend to approach the 'true value'.

Farmer and Kemeny (1992) show that, apart from a few simple physical property tests, virtually none of the methods used in rock testing give reliable data. The main reason for inadequacy in test results - which is accepted in most engineering design in rock - can be explained by the complex and variable composition and structure of rocks and rock masses.

Another significant measurement error is associated with the angular measurement of dip and strike. This error varies with the inclination of the joint, increasing as the joint tends to be horizontal. For flat-lying structures of the order of 5 - 10^o, where the horizontal line of projection is extremely limited, such as for joint in a tunnel wall, Robertson (1970) has experienced that the measured strike may vary as much as ± 20^o. For attitude measurements of planar features, Friedman (1964) estimates accuracy of ± 1^o for dips greater than 70^o and ± 3^o for inclinations of 30 - 70^o. The latter estimates may apply to mapping of large surface outcrops, but not to observations of limited dimensions such as in tunnels.

Ewan et al. (1983) reports from an interesting investigation carried out in the Kielder aqueduct tunnels, UK, to see the reproducibility of joint spacing and orientation measurements:

> Three 10 m long scanlines were set up in each of the three rock types: sandstone, mudstone and limestone. On each scanline 6 experienced observers recorded the position and the orientation of each joint (less than 15 m long), see Fig. 3-6.

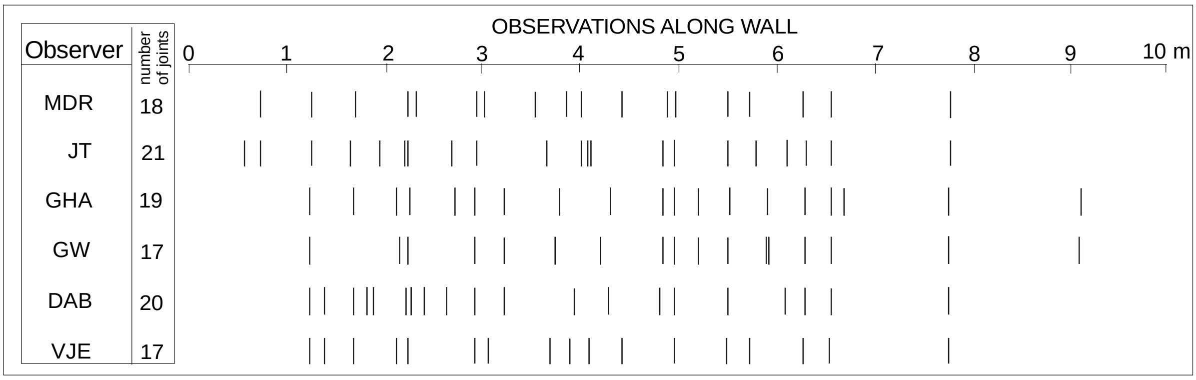

Fig. 3-6 Position of joints recorded by different observers on one of the scanlines (modified from Ewan et al.)

By comparing the results of the measurements carried out by the 6 persons it was found that:

- The variation in the number of joints recorded by different observers along any one scanline varied considerably. The ratio between the highest and lowest number of joints recorded was as high as 3.8 , but with a mean of about 2. (The maximum number of joints along a scanline was 37.)
- The average maximum error in measurement of joint orientation was $\pm 10^{o}$ for dip direction and $\pm 5^{o}$ for dip angle.

The fact that different observers did not identify joints at the same position underlines the difficulty of interpretation of joints and jointing.

Piteau (1973) mentions that since many joints are highly undulating and the scale of the tunnel or observation area often is much smaller than that of the joint, measurements of both strike and dip may be extremely erroneous, depending where the joint is measured. Piteau has further observed that man-made cracks from blasting in open pit mines probably involve less than one per cent of the joints recorded. Löset (1992) has, however, experienced a significant impact from blasting on the amount of rock support in a partly blasted, partly full face bored tunnel. The influence from blasting may lead to higher values of the degree of jointing, joint length and joint continuity being recorded.

A more serious error may come in outcrops from joints developed by the effect of weathering. Extrapolating data from weathered outcrops should, as mentioned earlier in Section 3.1, be done carefully.

In addition to the errors mentioned above significant errors may be introduced by the characterizations caused by poor definitions and/or personal interpretations.

A complete description of joints is difficult because of their three-dimensional nature and their limited exposure in outcrops, borings or tunnels. According to Dershowitz and Einstein (1988), the ideal characterization of jointing would involve the specific description of each joint in the rock mass, exactly defining its position and geometric and mechanical properties. This is not possible for a number of reasons, among others:

1. The visible parts of joints are limited, for instance to joint traces only, and thus prevent complete observation.
2. Joints at a distance from the exposed rock surfaces cannot be directly observed.
3. Direct (visual or contact measurements) and indirect (geophysical) observations have limited accuracy.

For these reasons joints in the rock mass are usually described as an assemblage rather than individually. The assemblage has a stochastic character in that joint characteristics vary in space.

Joints show great variation in properties and some of the most significant errors due to selection of joints to be characterized are according to Robertson (1970):

- Small joints are often disregarded.
- Very large fracture surfaces may be measured more than once.
- Joints almost parallel to the foliation or bedding may be overlooked.

Baecher and Lanney (1978) have confirmed similar trends from their studies.

3.3.3 Model uncertainties

Models used in assessments of rock mass behaviour are mainly based on theory and/or empirical relations. As they are simplifications of reality, modelling errors are introduced. Modelling errors are caused by errors in the theory assumed to apply to physical processes, boundaries and initial conditions which must be chosen, errors introduced by numerical or mathematical approximations, and important factors left out of the model. Sometimes, of course, modelling errors in predicting engineering performance and modelling errors in estimating material properties, partially compensate (Einstein and Baecher, 1982).

3.4 SUMMARY

As most of the geo-data collection is based on observations - either on outcrops, on tunnel surfaces or on drill cores - it is important to know whether the condition of the rock mass observed is representative, see Table 3-2. Some of the main parameters that determine the mechanical properties of a rock mass have been listed in Table 3-3 along with various possibilities to collect them.

As a result of possible errors, many of the measurements and tests used in rock mechanics, while useful in identifying rock behaviour characteristics and in empirical comparisons of rock behaviour, have limited use in design (Farmer and Kemeny, 1992).

The great spatial variability and great volumes involved result in that only a limited number of measurements can be made. The subsurface must, therefore, be described by a limited number of imprecisely known parameters. Interpretations and extrapolations that are made to work out the geological setting may introduce considerable uncertainties. Also, the fact that horizontal and other features, which do not outcrop, may be overlooked, adds to these errors.

TABLE 3-2 POSSIBLE FEATURES THAT REDUCE INFORMATION AND QUALITY IN SURFACE OBSERVATIONS

FEATURES THAT MAY REDUCE MEASURE-MENT OR INTERPRETATION QUALITY	CONSEQUENCES FOR THE MEASUREMENTS
Observations in outcrops: - loose material, vegetation, water, snow, or ice which cover the rock surface; - weathered rocks occur in the outcrop (but not deeper underground).	- No or limited area of exposed rocks for observations - The rock conditions observed are different from the conditions in deeper located rock masses
Observations in excavated cuttings, trenches, adits, etc: - weathered rocks occur in the surface (but not deeper)	- the rock conditions observed are different from the conditions in deeper located rock masses
Observations in deep located underground openings: - the surface has been covered by mud, shotcrete or other remedial (before geological mapping)	- the cover hides the rock conditions for observation

TABLE 3-3 INFORMATION ON CHARACTERISTIC ROCK MASS PARAMETERS OBTAINED FROM VARIOUS POSSIBILITIES OF DATA COLLECTION.

ROCK MASS PARAMETER	DATA COLLECTED FROM				
	DRILL CORES	ADITS	UNDER-GROUND OPENINGS	OUTCROPS	REFRACTION SEISMIC PROFILES
Rocks					
- distribution of rocks	x	x	x	x/(x)	-
- sample for strength tests	x	x	x	x/(x)	-
Joints and jointing					
- joint spacing	(x)	x	x	x	(x)
- joint length	-	(x)	(x)/x	x/(x)	-
- orientation	-	x	x	x	-
- waviness	-	x	x	x	-
- smoothness	(x)	x	x	x/(x)	-
- filling or coating	(x)/x	x	x	(x)/-	-
Faults and weakness zones					
- persistence	-	-	-	(x)	-
- orientation	-	(x)	x	(x)	-
- thickness of zone	-	(x)/x	x	(x)/-	(x)
- gouge material	(x)	x	x	-	-

here is: x parameter or task can be measured
(x) parameter or task may partly or sometimes be measured
- not possible to measure the parameter or task

From the foregoing it has been found that the following features may cause uncertainties, and errors and hence reduced quality of rock mass characterizations:

- The spatial occurrence, variations and large volume of the material (i.e. rock masses) involved in a rock construction.
- The geological interpretation, on which the characterizations are based.
- How the investigations are performed.
- Uncertainties connected to the joints measured, as they may only be a portion of the joints exposed which are considered to be representative of the joints within the entire rock mass.

- Outcrops or surfaces, where they occur, may not be representative due to weathering.
- In excavated surfaces and in drill cores it may be difficult to distinguish between natural and artificially induced discontinuities.
- Limitations in drill core logging: soft gouge is lost during core recovery and information relating to the waviness and the continuity of joints is minimal.
- The way the description is performed or the quality of the characterization made of the various parameters in rock masses. As most of the input parameters in rock engineering and rock mechanics are found from observations, additional errors may be introduced from poorly defined descriptions.

All these aspects have important consequences in the application of geo-data in rock mechanics, rock engineering, and construction design. The main conclusions of this chapter are therefore:

1. Although extensive field investigation and good quality descriptions will enable the engineering geologist to predict the behaviour of a tunnel more accurately, it cannot remove the risk of encountering unexpected features.
2. A good quality characterization of the rock mass will, however, in all cases, except for wrong or incorrect interpretations, improve the quality of the geological input data to be applied in evaluation, assessment or calculations and hence lead to better designs.
3. The methods, effort and costs of collecting geo-data should be balanced against the probable uncertainties and errors.

The work behind this thesis is mainly directed to improve the characterization in the second item listed above.