

# PIT SLOPE MANUAL

## chapter 2

### STRUCTURAL GEOLOGY

This chapter has been prepared as part of the

PIT SLOPE PROJECT

of the

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## THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

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## FOREWORD

Open pit mining accounts for some 70% of Canada's ore production. With the expansion of coal and tar sands operations, open pit mining will continue to increase in importance to the mineral industry. Recognizing this, CANMET embarked on a major project to produce the Pit Slope Manual, which is expected to bring substantial benefits in mining efficiency through improved slope design.

Strong interest in the project has been shown throughout its progress both in Canada and in other countries. Indeed, many of the results of the project are already being used in mine design. However, it is recognized that publication of the manual alone is not enough. Help is needed to assist engineers and planners to adopt the procedures described in the manual. This need for technology transfer will be met by a series of workshops for mine staff. These workshops will be held in various mining centres during the period 1977-81 following publication of the manual.

A noteworthy feature of the project has been its cooperative nature. Most organizations and individuals concerned with open pit planning in the country have made a contribution to the manual. It has been financed jointly by industry and the federal government.

Credit must be given to the core of staff who pursued with considerable personal devotion throughout the five-year period the objectives of the work from beginning to end. Their reward lies in knowing that they have completed a difficult job and, perhaps, in being named here: M. Gyenge, G. Herget, G. Larocque, R. Sage and M. Service.

D.F. Coates  
Director-General  
Canada Centre for Mineral and  
Energy Technology



## SUMMARY

The chapter on structural geology provides guidance for site investigations of open pits, and for analyzing and presenting structural information for pit slope design.

Methods of gathering and evaluating geological data are given first, followed by a description of work requirements during mine operations. Time requirements and costs are given to assist planning of the various activities during mine development.

The objective of an engineering geological site investigation is to delineate design sectors for which orientations of slope faces, rock types and discontinuities are similar. This judgement is made on the basis of a semiquantitative rock strength description, and properties of geological discontinuities.

All observations are presented by their averages and dispersions to enable a stability analysis to be made on the basis of probability.

### DATA GATHERING

The first step in site investigations is the development of a geological map based on a review of regional geological information, aerial photographs, mine records, and data from geological mapping. From this a first catalogue of possible

slope stability problems can be compiled, and the necessary intensity of the geological investigation assessed. Even the location of the pit site can suggest problems typical for pits of a particular region, such as climatic conditions, typical zones of weathering, peculiar rock types, or regional zones of shearing and faulting.

The next step defines the geotechnical requirements for geological observations concerning rock types and discontinuities. A special reconnaissance survey would be valuable in this respect.

In the chapter the terminology and properties of various types of discontinuities and rock types are described first. This is followed by an account of the various methods of geological mapping, including detailed line mapping, fracture-set mapping, area mapping, and core logging.

Indirect methods of geological data acquisition, such as airphoto interpretation, plane table photography, terrestrial photogrammetry, and geophysical exploration are also presented so that the optimum approach can be chosen.

### STORAGE

During reconnaissance and detailed geological mapping, large amounts of data are collected

and must be recorded and analyzed appropriately for slope stability analysis.

Observations of major discontinuities and rock types are generally plotted on plans and sections, and statistical features are analyzed separately by graphical or numerical methods. This approach is only suitable if experienced personnel is available at every phase. With the availability of computers, the job can be organized into such simple steps that relatively inexperienced personnel can be employed for most of the data gathering and storage.

This requires a standardized approach for geological mapping, and a field guide and a computer program package, DISCODAT, have been developed for that purpose. Geological observations are noted on special field forms, and information from these is punched on computer cards for file storage. Simple retrieval requests can then make available special categories of information for analysis.

The field forms can also be used independently of computer availability, with mechanical sorting of double-row edge-punched cards with sorting rods. Retrieved information can then be analyzed graphically or numerically.

## EVALUATION

Geological observations provide three kinds of information:

- (1) rock type distribution
- (2) major discontinuities
- (3) minor discontinuities

To make this information useful for slope stability analysis, in addition the rock strength has to be estimated, and major and minor discontinuities have to be assessed in regard to their geotechnical properties.

Rock strength can be judged from crude knife and hammer tests in the field to identify potential problem areas.

Major discontinuities, eg, those affecting the whole slope, are described individually, whereas for the minor discontinuities, eg, joint sets, mean properties and their dispersions are obtained. Both major and minor discontinuities

have to be characterized as to their geotechnical properties such as: location, orientation, length, spacing, waviness, strength of fillings, and strength of fracture walls. Groundwater occurrences are described in classes from dry to free flow.

After the geological data reduction has been completed, design sectors are selected in which the types of discontinuities and their orientations are similar as far as the proposed pit layout is concerned. This can be done by superimposing an assumed slope angle, eg, 50°, on the existing topography, and placing this pit boundary on the maps showing major structures, rock types and minor discontinuities. Discontinuities of the same orientation will have different effects on the stability of opposite walls of the pit.

For the design sectors, representative sections are drawn and the kinematically possible modes of instability assessed. The three basic instability modes include rotational shear, plane shear, and block flow.

With the preliminary identification of potential slope problems, the objective of the geological investigation for pit slope design is achieved, and a basis provided for more quantitative assessments in other chapters.

## APPENDICES

The structural chapter covers many aspects of structural geology but frequently insufficient detail is provided for the reader to carry out his own investigations or to make his own evaluations. To remedy this, appendices are provided for the following topics:

- a. DISCODAT field guide
- b. core and borehole logging
- c. records of site investigations
- d. sources of aerial photographs in Canada

## SUPPLEMENTS

Comprehensive supplements, issued separately, present details on special techniques used in structural geological investigations. The following supplements are available:

Supplement 2-1 provides DISCODAT computer program description for storage, retrieval and analysis of structural data. Subroutines and their functions are presented and a card deck of programs in machine-independent Fortran can be obtained on request to complete the system documentation.

Supplement 2-2 presents program documentation on structural domain analysis. The objective of this program is to determine whether the structural geological domain boundaries selected during reconnaissance mapping need be changed after more information has become available.

Supplement 2-3, Geophysics for Open Pit Sites, describes surface and borehole geophysical methods useful in evaluating the distribution of rock types, soils and discontinuities. For surface work, emphasis is placed on methods which

operate with low-cost commercial equipment, and require little technical background for interpretation.

Borehole geophysics, except for some simple devices, requires considerable investment in logging equipment. In general, borehole geophysics is feasible only if contracted out to companies providing specialist service and interpretation. Possible benefits and costs are assessed.

Supplement 2-4, Joint Mapping by Terrestrial Photogrammetry, presents procedures, results and costs of that method.

Supplement 2-5, Case Histories presents results from field mapping which show examples of structural mapping, data presentation and evaluation.

A glossary of terms, references and a bibliography complete the structural chapter.

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## INTRODUCTION

### PURPOSE AND SCOPE

1. This chapter describes the geological information required for slope stability analysis and presents procedures and costs to obtain the necessary data.

2. Instability occurs in hard rock slopes as a result of failure along structural discontinuities which developed during geological history (Fig 1). Along these discontinuities, shear resistance of the rock material has been reduced considerably and their orientation, spacing, length and frictional properties determine the stability and the possible mode of instability of slopes. Without geological information evaluated in a suitable way, understanding of any stability problem cannot be obtained in a hard-rock pit. This also holds for testing, monitoring and designing, because all design assumptions and interpretations of monitoring results have to be related to a model of geological discontinuities in the rock mass at the pit site. Geological structure is not only fundamental to stability analysis, but is also of prime importance to groundwater flow and to production blasting.

3. The analysis and design of slopes in open pits applies to very large rock masses. This requires subdivision into smaller parts, eg,



Fig 1 - Plane shear sliding in an operating pit.



structural domains and design sectors, in which rock mass properties can be assumed to be similar in a statistical sense. Usually the sampling is limited due to the lack of rock exposure. Estimates of mean or representative values, therefore contain uncertainties.

4. This can be overcome in many cases by selecting a conservative safety factor for the slopes based on experience and judgement. This procedure has shortcomings. First, the reliability level or risk associated with the available data is unknown and secondly, additional information which can be obtained from extensive exploration work, testing techniques or experience from previous analysis, cannot be incorporated systematically enough for a subsequent reduction of the required factor of safety.

5. The application of probability analysis provides an objective tool for the modelling of uncertainties. It allows their updating for additional sources of information, and the expression of safety in terms of risk allows optimum decision-making (1). To satisfy this requirement from the point of view of structural information, an attempt has to be made to analyse data so that not only average values are reported, but also their dispersions.

#### POTENTIAL SLOPE PROBLEMS

6. The regional location of the pit site, even if geological details are lacking, can suggest problems typical for pits in that particular area. This can include particular climatic conditions, typical zones of weathering, peculiar rock types, major zones of shearing and faulting, or regional trends of formations. A review of regional geological patterns is therefore helpful when the first catalogue of possible problems is being compiled for assessing the necessary intensity of the geological investigation.

#### DATA GATHERING, PROCESSING AND ANALYSIS

7. To define the geological structure for the pit site, descriptions of the lithology and details of geological discontinuities are required. For slope stability analysis, the lithology has to



Fig 2 - Orientation measurement of discontinuities with a compass.

be described by some form of strength estimate, eg, hardness, to indicate whether or not failure is likely through the rock substance. If the likelihood exists, more specific testing is necessary. Geological fractures and weakness planes are characterized by properties such as orientation, Fig 2, length or size, spacing, waviness, and types of infillings. Initially, the information will be limited, but improvements of the data base will occur over the years, as information from surface outcrops and drill holes is supplemented by continuous mapping.

8. A considerable amount of structural data will be accumulated over a period of time, and to provide objective communication between geological and engineering staff, a system of data gathering has been developed which defines exactly what is collected and how it is analyzed. DISCODAT is a computer based system and consists of a data collection phase, a storage phase and a retrieval phase, directly connected with analytical routines described later.

9. Computer storage has the advantage that retrieval and analysis can be carried out with relatively little effort and most of the powerful statistical procedures can be applied very quickly. The engineering geologist has to decide for himself whether a computer-based system allows him to do his job more effectively, and which fracture characteristics are relevant for a particular pit site.

#### MINE OPERATING STAGES

10. Open pit wall design is the determination of the geometry of the mine boundaries, ie, the locations and slope angles of the walls. The process requires input from exploration, from experience, from stability investigations, and from financial analyses.

11. A wall design is required on many occasions in the life of a mine. The main stages have been defined in the design chapter and are called the feasibility, mine design, and operating stages. Clearly, the amount of geological information available or required at the various stages differs considerably.

12. At the feasibility stage, the results from exploration are being analyzed, and the geometry of the prospective mine is being determined for input to the financial analyses. In many cases, slope angles can make the difference between an attractive and an unattractive prospective rate of return.

13. In regard to geological information, only a reasonable grasp of the effect of geological structure on the stability of slopes is necessary to arrive at a conceptual pit design. In nearly all cases it will be necessary to assess rock type distributions, major fault locations, and orientations of joint sets. Often assumptions have to be made on the basis of reconnaissance mapping, regional geology, and drill hole data.

14. When an orebody has been established, and financing arranged to go into production, the mine design stage is entered. At this point, wall geometry must be determined on a more detailed basis and with a higher confidence level. Structural geological investigations should now aim at a) determining fault positions and major

shears, b) zoning rock types and their relative strengths, and c) obtaining mean and standard deviations of joint or bedding plane orientations.

15. Finally, during the operating stage of the pit, the assumptions contained in the original mine design may become superseded. Commodity prices change, grade information is amplified, and reserve volumes become governed by new criteria. Redesign of the mine becomes imperative at some point. By this time, experience with slopes in some of the wall formations will have been obtained. Walls may have to be cut in new formations which provides additional reason for redesign of the slopes. At this point, a large amount of structural information should be available from geological mapping, core logging, structural analysis, stability analysis, performance of previous slopes, and monitoring. On the basis of this information, a more optimal design becomes possible.

16. In addition, requirements for geological information will vary with the type of open pit being planned. Obviously, a small or shallow orebody will not justify the intensive investigation that a large, and particularly a deep pit, would warrant. At the same time, the magnitude of the waste/ore ratio and whether the orebody has geological or assay boundaries will influence the intensity of the slope investigations. Production rate, particularly the sinking rate, can also be pertinent. Complex geology and variable mechanical properties of wall rocks will clearly require more investigation than a simple geological environment. Finally, the differences between mines in bedded deposits and those in igneous/metamorphic formations can influence the program requirements.

17. Paragraphs 31-52 present a check list of design parameters which are obtained during geological site investigations. Data reduction and analysis of geological observations are given in paragraphs 132 to 190, with details in appendices and supplements. Paragraphs 191 to 235 provide guidance on the structural information that has to be collected at the various development stages of an open pit and how much it will cost.



## REPORT SPECIFICATIONS

18. Substantial time may elapse between the feasibility and mine design stages. This makes it imperative that all available geological data be collected and recorded during the active part of the exploration phase in such a way that it does not have to be redone years after the actual drilling and investigation when personnel concerned may have left or details have been forgotten. The report should therefore include the following:

- a. Title page with report title, authors, date and name of organization.
- b. Summary presenting a condensation of the information contained in the report.
- c. Contents page.
- d. Terms of reference or purpose and scope.
- e. General site description, eg, topography, rivers, creeks, groundwater flow, springs, overburden, time spent in the field, time of year, site location, access.
- f. Regional geology relating to folds, faults, lithological characteristics and a brief structural history of the area.
- g. Rock type distribution and description including weathering and alteration.
- h. Major discontinuities giving actual exposures and inferred trends, eg, bedding orientation, faults, rock type boundaries. Aerial photographs are most illustrative.
- i. Structural domains of the pit site with equal-area nets giving mean orientation and dispersion of discontinuities, with comments to aid testing. Data under g) to i) are best given in a basic geological map with various overlays.
- j. Description of design sectors and possible problem areas of the pit site with photographs.
- k. Conclusions and recommendations.
- l. List of sources of information including aerial photographs, locations of trench mapping, locations of detailed line mapping and boreholes, references of published data, core logs, geophysical surveys.
- m. Acknowledgements, definitions of terms, and a distribution list.

## GEOLOGICAL DATA GATHERING

### GENERAL SITE GEOLOGY

19. Geological information serves not only to define the orientation and location of discontinuities but will also provide the basis for analyzing groundwater occurrences, possible modes of instability, and monitoring. The flow of information is given in Fig 3.

20. First objective is a general geological map for the pit site which describes the rock type distribution, faults and tectonic structure. The general geological map can be obtained by using existing regional geological information, and photogeology, by searching relevant files, and by geological mapping.

21. Topographical control of geological observations can be obtained from topographical maps, aerial photographs, or with the aid of a plane table. Approaches to geological mapping vary according to the amount of natural outcrops, complexity of geological structure, and time constraints.

### TRAVERSE MAPPING

22. Sites with considerable rock exposure require systematic mapping to obtain a representative coverage within a given time period. This is achieved by laying out a system

of parallel traverses across the area, about 100 (30 m) to 1000 ft (300 m) apart. The traverses are located on the base map and marked in the field as in Fig 4. The geologist will make the required observations along these traverses, and the locations are either paced out or measured by more accurate means. Connections between traverses are made by interpolation and are clearly shown as such on the final map. In areas of complex geology, rock type boundaries and faults have to be actually traced out.

### AREA MAPPING

23. Area mapping is employed if the site possesses less than about 10% of natural outcrop. In this case every available outcrop has to be delineated on the base map, and all geological observations have to be plotted within these outlines. The end product is a drawing on which the geology is plotted on a series of outcrop islands. Geological features between outcrops must be interpolated. It is necessary that upon completion of the map, interpolated information can be separated from the factual evidence. The "Manual of Field Geology" by R.R. Compton should be consulted for further advice on general geological mapping (2).

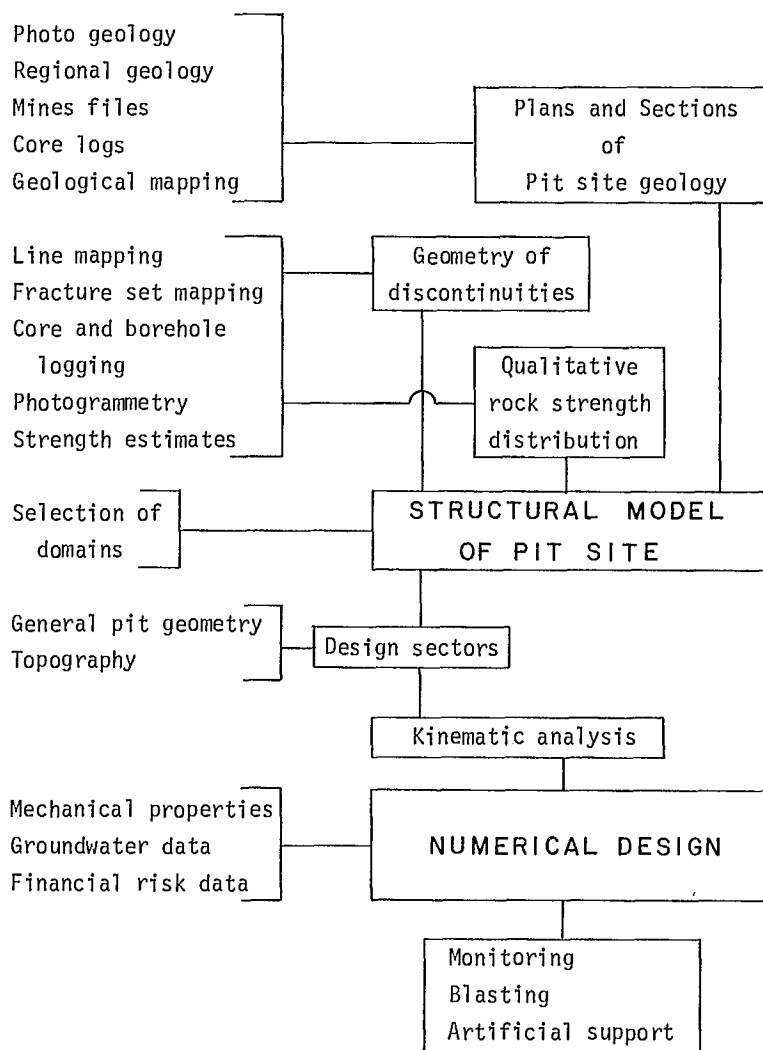


Fig 3 - Flow of geological data for the design of pit slopes.

#### REGIONAL AND MINE SCALES

24. As indicated above, the site location alone might allow anticipation of potential slope problems if open pit mining experience or data on natural slopes are available for the area. To develop a good understanding of the geology at the pit site, an integration of the local geology into the regional geological pattern is vital. Regional geological data are available from maps by the Geological Survey of Canada and provincial Departments of Mines. Other relevant sources of information are quoted in paragraph 196.

#### DETAILED MAPPING FOR PIT DESIGN

25. The general geological map of the pit site provides essential background information but is insufficient for geotechnical assessments. Rock types should not only be known by geological names, but an estimate of strength with simple hardness tests is the minimum required to identify areas where instability could occur due to a weak rock substance. The same applies for the discontinuities which have to be described in more detail than is the case in general geological mapping.





Fig 4 - Aerial photograph showing major faults, areas of overburden, dikes and a reconnaissance traverse.

26. To obtain the more specific geological data necessary for open pit design, either detailed line mapping or fracture-set mapping is carried out.

#### Detailed Line Mapping

27. This method is suitable for mapping open pit benches or the logging of diamond drill core.

Basically, a 100-ft (30-m) tape is stretched along a pit bench and all discontinuities and rock types are recorded as in Appendix A. Detailed line mapping is a form of traverse mapping but special field forms have been developed to record the information concisely, to avoid omissions, and to have observations in a format suitable for keypunching.

### Fracture-Set Mapping

28. With the rock type boundaries and major discontinuities documented on a general geological map, fracture-set mapping can provide faster coverage of a pit site than detailed line mapping. At preselected locations the prevailing fracture sets are recorded, showing orientation, spacing, extent, and other details. The number of observations which can be made with this approach is about double per man-day that which can be obtained by detailed line mapping.

### TERMINOLOGY

29. In the multidisciplinary area of slope design, terminology for rock types and discontinuities has to be uniform to allow effective communication. Most of the geological terms have genetic implications and thus relate to the formation history. This is important for the mapping geologist, because the identification of a particular geological feature enables the relating of typical occurrences and variations. Even geotechnical properties can be predicted, such as expected size and spacing, eg, bedding planes are repetitive and continuous; joints are usually discontinuous but systematic.

30. For the engineer, the identification of the type of discontinuity or the rock type is often of little use. He requires additional geotechnical properties such as rock strength or discontinuity orientation as given below.

### Discontinuity Types

31. A list of typical geological discontinuities comprises:

- bedding
- boundary
- cleavage
- contact
- fault
- gneissosity
- joint
- schistosity
- shear
- unconformity
- vein

Definitions are given in the glossary.

32. Some difficulties can arise in applying this terminology. A discontinuity might possess characteristics of two types, eg, a fault following a bedding plane. In this case, the highest term should be used in the following hierarchy of generally major discontinuities:

- 1 - fault
- 2 - shear
- 3 - unconformity
- 4 - boundary
- 5 - contact
- 6 - vein

The combination 'bedding plane fault' would be permissible in a report, but in the recording sheets of the DISCODAT system only the mnemonic for 'fault' would appear.

Generally minor but repetitive and systematic discontinuities are:

- 7 - joint
- 8 - bedding )
- 9 - cleavage ) mutually exclusive
- 10 - gneissosity ) terms
- 11 - schistosity )

33. Generally minor discontinuities with a trace length less than six ft (2 m) are not recorded. This will vary, however, according to local conditions and experience. At some mining properties experience has shown that discontinuities below a length of 12 to 45 ft (4-15 m) were not of any real consequence.

### Unique and Statistical Discontinuities

34. A distinction has been made between major and minor discontinuities. The terms major and minor are related to the size of a pit slope. Major discontinuities are those which continue across at least three benches. These discontinuities are mapped during the detailed line mapping phase, and correlations over various benches have to be attempted. This applies to faults, boundaries of rock types, and zones of weathering. Minor discontinuities usually extend from 6 to 60 ft (2-20 m).

35. Single minor discontinuities have but limited influence on general slope stability. Due



to their repeated appearance and systematic orientation, they can, however, influence slope stability as a group. The usual scales of geological maps and the effort required for documentation does not permit locating individual minor discontinuities. Before detailed line mapping is commenced, a reconnaissance survey is therefore carried out and areas or structural domains are delineated where minor discontinuities are statistically homogeneous. Statistical homogeneity exists in an area if a few joints can be "taken" from a subarea and "exchanged" for those of another subarea without resulting in a significant change. This implies that within an area of statistical homogeneity the discontinuities are repeated at intervals that are small compared with the total size of the domain. Discontinuities in an area for which statistical homogeneity can be

established are also called penetrative for that area.

36. For slope stability, the most important characteristic of discontinuities is their orientation. Domains are therefore predominantly defined on the basis of orientation. In the strict sense, however, domains or areas of statistical homogeneity can be defined for any characteristic, eg, length or spacing. An example of different domains of fracture spacing is given in Fig 5.

#### Major Discontinuities

37. For major discontinuities the properties given below are considered essential. The DISCODAT field guide shows how to observe and record the properties.

38. Location: A traverse line system has been

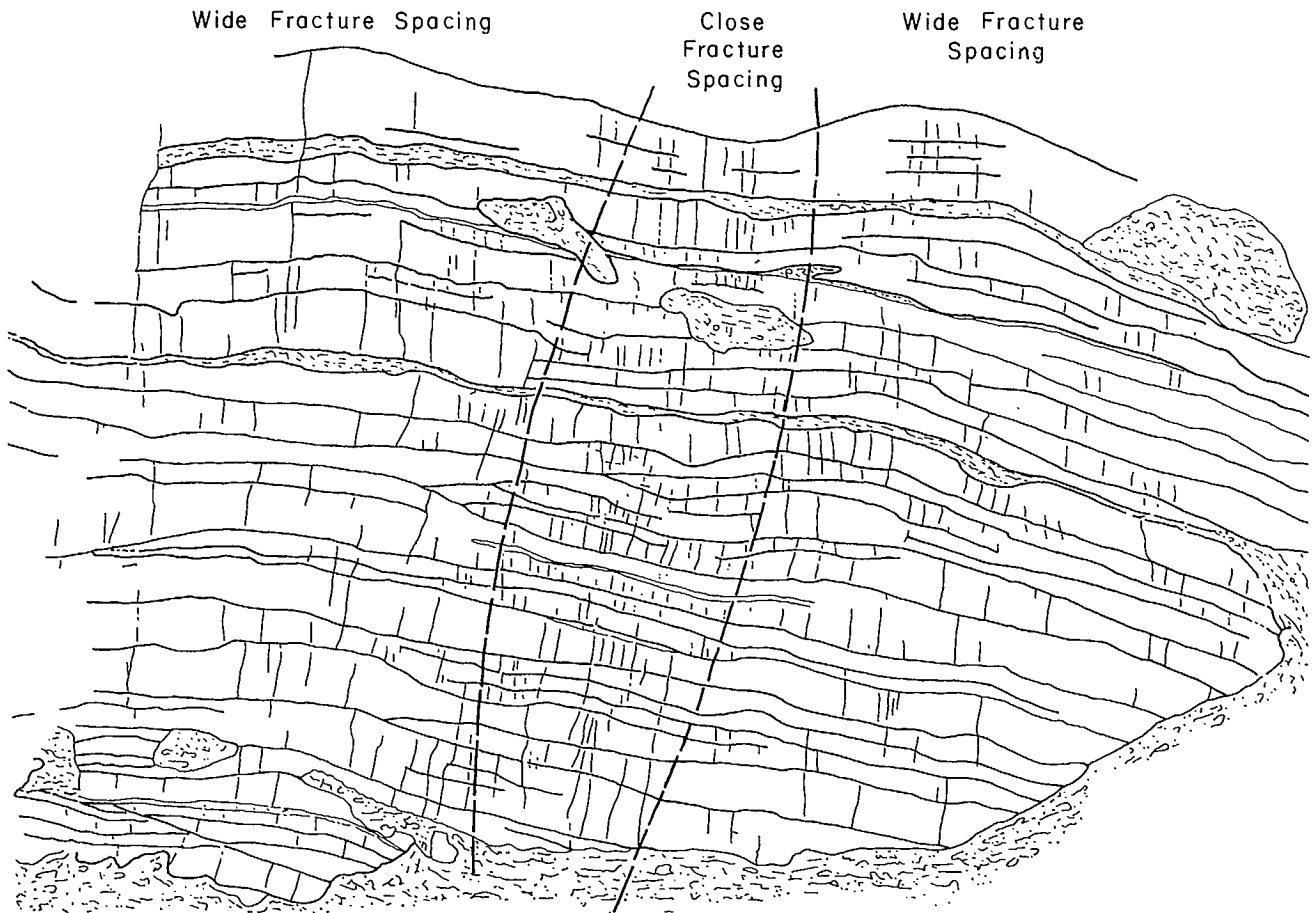


Fig 5 - Rock wall with three areas of statistical homogeneity (domains) with regard to spacing of minor discontinuities.

adopted for mapping, and the position of a discontinuity is specified by the distance from the origin of the traverse line. Major discontinuities are plotted directly on maps and interpolation between outcrops is necessary.

39. Orientation: Orientation of discontinuities to the slope face defines their effectiveness as potential failure planes. Discontinuities are idealized as planes and their orientations are described by strike and dip or by their dip vectors. Measurements can be made with a Brunton, Clar or Freiberg compass, or a clino-rule. Orientation can also be inferred from location and pit contours.

40. Waviness: All geological discontinuities possess an inherent surface roughness and undulations about a mean planar surface. Both roughness and waviness contribute to shear resistance but only waviness with amplitudes above one inch is recorded in the field. Measurements of waviness should indicate the undulations which are likely to survive shearing along the fracture surface (Fig 6). Roughness effects are studied by direct shear testing in the laboratory. Analysis of waviness measurements and their influence on the peak friction angle is given in Paragraph 175.

41. Strength of Fillings and Fracture Surfaces: Shear resistance is controlled by the strength of fillings and by the hardness of fracture surfaces. Fillings may be unconsolidated materials such as clay, sand, silt, altered wall rock, or soluble substances such as calcite, rock salt, and gypsum. Graphite, talc, and chlorite in fillings or as fracture coatings, can result in a very low shear resistance. Montmorillonite can cause detrimental swelling pressures. During field mapping, fillings are characterized by name and thickness, and if conditions appear to be critical, special sampling and testing is necessary.

42. Groundwater: Geological discontinuities, if open, permit groundwater flow, or may form important barriers to flow if filled with impermeable gouge. Fundamental changes in stability can occur if open water-bearing fractures freeze, or if water barriers are punctured. Build

up of pore water pressures in gouge filled fractures can be critical. For mapping purposes a six-point scale of flow from a discontinuity, ranging from apparently tight to free-flowing, is given in Appendix A, paragraph 43.

#### Minor Discontinuities

43. The following properties are considered essential, though there are cases where some of these properties are not relevant or have limited value for the particular site. The list below is more comprehensive than that for major discontinuities. Omissions from the listed properties should however be made only after careful consideration of the consequences.

44. Location: With the traverse line system the position of a minor discontinuity is specified by the distance from the origin of the traverse line. The origin and direction of the traverse line is given in the mine coordinate system.

45. Orientation: Discontinuity orientation is described by dip vector, eg, 210 (dip direction) /70 (dip angle) = 210/70, or by strike and dip. Analytical results are presented as mean and standard deviation of orientation. This is fully discussed in para 134.

46. Length: The length or size of a minor discontinuity indicates the portion of a rock mass where material continuity is interrupted. Limited exposures make the determination of the exact length difficult. In many cases it can be judged from geological experience, eg, bedding joints which are 100% continuous for a pit slope, or by estimating the length from observed trace exposures. If no measurements or estimates of length are available, fractures have to be assumed as being 100% continuous as discussed in paragraph 170, and Appendix A - paragraph 37.

47. Spacing: Spacing is the distance between discontinuities perpendicular to their orientation. Spacing is used in slope design for calculating the probability of occurrence of the critical geometry for the various plane shear modes analysis, eg, stepped failure. The output from measurements of spacing is a frequency diagram (paragraph 164).



Fig 6 - Measurement of waviness of a geological discontinuity.

48. Waviness is described as in paragraph 40.

49. Strength of Fillings and Fracture Surfaces: During field mapping, fillings are characterized by name and thickness, and if a critical condition is recognized, special sampling and testing is necessary, eg, grain size distribution, and Atterberg limits; see chapter on Mechanical Properties.

50. Groundwater is described as in paragraph 42. and in Appendix A - paragraph 43.

51. Aperture is the perpendicular distance between walls of an open discontinuity and might be important to record in connection with permeability and deformation parameters but is not called for on a routine basis.

### Rock Types

52. Rock types are classified according to geological origin into three major groups:

sedimentary	eg,	sandstone
metamorphic	eg,	gneiss
igneous	eg,	granite

Weakness planes such as bedding and schistosity on the scale of a hand specimen can be suggested by the rock type name. Further classification into rock types is based mainly on mineral composition, grain size and texture. Details on definitions, strength anisotropy and lists of symbols are provided in Appendix A, paragraph 51, and Appendix C.

53. The above classification is genetic and brings with it from mapping experience definite expectations of distribution and fabric. For geotechnical characterization, the rock types are not specific enough and determination of hardness, point load, or compressive strength must be used for further quantification of rock substance strength. An estimate of the rock substance strength serves to locate potential problem areas, eg, weathered, altered rock. Criteria for this area of discussion are found in para 53 of Appendix A, and in Chapter 3.

### DIRECT OBSERVATIONS

54. Direct mapping of pit benches, outcrops, and drill core provides the most reliable and immediate information and is preferred for detailed investigations. Indirect observations by photography, borehole viewing and geophysical exploration provide important complements and help to map areas with difficult access, or to allow fast routine surveys.

### Natural Outcrops

55. Natural rock outcrops and roadcuts provide the cheapest source of information and have to be documented first on maps and field forms in the vicinity of the pit site (Appendix A). In addition, the topography, creeks and springs must be sketched because later excavations, building activities and dumps at the mine site will cover

the original ground surface. Knowledge of preconstruction topography is essential because undermined water courses, even when surface flow has been diverted, can still cause water seepage and potential slope instability due to faulting or severe weathering.

#### Trenches

56. There are pit sites where natural outcrops are practically nonexistent and artificial exposures have to be developed. Trenches might be available from mineral exploration activities and should have been mapped in detail.

57. Trenches can be dug by bulldozers with a ripper blade or by a backhoe. Light blasting is sometimes necessary. Trenches can be practicable to a depth of 25 ft (8 m). Depth of overburden should be known from previous drilling or geophysical work. To obtain the maximum benefits from trenches, they should be perpendicular to the strike of lithological sequences, alteration zones, or major structural discontinuities.

#### Benches

58. Excavations developed at the beginning of the pit operation provide the largest possible exposure surface. Bench mapping is important throughout the life of a pit and can be done by detailed line mapping, or by fracture-set mapping.

59. The detailed line survey gives objective results and is described as a routine procedure in Appendix A. Interpolation between benches is often a problem due to limited visibility. Plane table work by viewing across the pit can be an efficient measure for correlating geological information between benches. Some benches are dangerous because of rock falls. In this case photos taken across the pit with a 200-500 mm focal length camera can be used to advantage to mark position and apparent orientation of structural discontinuities (Fig 8). Terrestrial photogrammetry can be used if accurate measurements are necessary.

#### Exploration Drifts

60. Underground excavations are expensive and are generally not driven unless there is

reasonable confidence that an economic orebody exists. They provide good access into the rock mass from which valuable information can be obtained on structures, groundwater flow, and other geotechnical factors. To make use of the two-dimensional plan geometry of underground openings, geological mapping should concentrate on drift intersections, as they provide a unique opportunity to obtain the extent of geological fractures in three dimensions. Mapping procedures are similar to those used in bench mapping.

#### Drill Core

61. Diamond drilling provides the cheapest and most efficient way of obtaining direct structural information with depth. At any potential pit site, some diamond drilling will have been carried out for ore evaluation, and can provide valuable information (Fig 7). In many cases the core has been split for assay purposes, and the core logs with their emphasis on mineralization rarely provide structural information beyond some indication of rock types and major faults. If the original core or core photographs are still available, they should be logged according to standards described in Appendix B.

62. Exploration drilling will be carried out throughout the lifetime of a mine because original drilling is usually carried out only to a depth at which a profitable orebody can be established. Whenever additional drilling is planned, ore assay and geotechnical drilling requirements should be coordinated so that optimum use is made of money spent on drilling and availability of drilling rigs.

63. Exploration drilling is aimed at defining the orebody and will mainly provide information about the ore material and, probably, about the hanging wall formations. Drilling for assessing slope wall stability in most cases requires additional drill holes in waste rock, eg, the foot-wall. For structural drilling, holes should be inclined at 30° to 60° to the structures to be intersected. Boreholes less than 30° to the strike of a joint set will not penetrate a sufficient number of structures for a good statistical sample. This is particularly true if the borehole





Fig 7 - Logging of exploration drill core (courtesy Inco Triangle).

is short relative to the spacing of joints.

#### Core Sizes

64. Larger diameter core will in general give better core recovery and thus a better representation of in situ geological conditions. Many structural investigations are therefore carried out currently with coring equipment providing core with at least NX size with a diameter of 2-1/8 in. (54 mm). Most exploration drilling is carried out with EX and AX bits which provide core with diameters of 7/8 in. (22 mm) and 1-1/8 in. (29 mm). Typical sizes are given in Appendix B, Table B-2. Larger diameter core requires heavier drilling equipment and extra time for coring, but

the increased reliability for assay and structural information obtained from larger sizes very often justifies the higher costs. Multi-purpose holes, which provide assay samples, structural data, and a site for monitoring equipment, should not be drilled below NX size.

#### Orientation

65. Diamond drilling can be used to determine the orientation of major discontinuities, with at least three drill holes. This method is only suitable to detect major, planar, continuous faults.

66. To determine the orientation of discontinuities in a single borehole, the core

has to be oriented in some manner. This is not easily done but the following means are available:

- a. by the use of naturally occurring structural features or markers such as bedding or schistosity which are of known orientation for the site.
- b. by the use of marking devices in the core barrel such as Christensen-Huegel or BHP Systems, or underwater paint.
- c. by devices obtaining imprints of the bottom or sides of the borehole, as in the Craelius method, clay pot impression, impression packers.
- d. by downhole viewing with cameras, periscopes or seismometers.
- e. by the integral sampling method, where the recovered core has been reinforced with a bar of known orientation.

67. The Craelius core orientor works satisfactorily if adjacent pieces of core can be matched, and if no fractures occur perpendicular to the core axis. Other methods, somewhat similar to the Craelius technique, use ink marking or acid etching on the core stub after orienting the core barrel.

68. The Christensen-Huegel orienting barrel (3) or the multiple-shot corex method by Eastman employ a conventional diamond core barrel with three triangular hardened knives or scribes mounted in the shoe at the bottom of the inner core barrel. In addition, a compass-angle device, a multi-shot camera, and a clock mechanism are used. The orientation is obtained from the compass photo and the groove cut in the core by the knives.

69. The clay pot impression is obtained by a pot filled with a stiff clay-oil mix, which can be lowered into a drill hole. An imprint of the hole bottom is obtained before the next core run.

70. If stratigraphic horizons cannot be correlated, the Craelius method is possibly the most efficient technique presently available for core orientation. The Christensen-Huegel barrel is probably more accurate, but is more time-consuming. In areas with poor recovery, integral sampling can be tried in critical

locations.

71. The cost of core orientation ranges from about 1-1/2 to 2 times the cost of conventional diamond drilling, depending on the nature of the technique and geology. Core orientation has been used primarily in NX size and larger, and the accuracy of the core orientation is probably better than 3° (4). If core recovery is not 100%, the data may be erroneous as it is not always possible to tell from what section the core is lost.

#### Recovery

72. An experienced driller can tell by the sound and action of drill rods the speeds and penetration rates he should use to obtain optimum core recovery. This cannot be achieved if progress is assessed only on the basis of the footage drilled.

73. Rough handling of the core will render it useless for structural logging. By controlling the drilling rate and water pressure, core recoveries are improved. Well maintained drilling equipment is necessary for structural drilling. Development of double- and triple-tube core barrels, in association with wireline drilling techniques and hydraulic feed machines, has greatly increased core recovery. Split inner tube core barrels, for example, prevent the core from rotating and breaking. Core recovery can also be improved by reducing bit speed, rate of water circulation in weak formations, and by using high density barite-bentonite drilling muds.

#### RECORDS

74. The basic information must provide the location of the borehole and information about the client, contractor, driller and drill inspector (5).

75. Details of the drilling method should be noted, such as the flush system, the make and model of drill, feed type and the types of core barrel and bits. Records must show the drilling performances, drill hole characteristics, sampling locations, water loss, water level, water inflow, and routine permeability tests. A standard form is given in Appendix B.



## MAINTENANCE

76. After the drill casing is pulled, the borehole should be collared, capped, marked, located, and plotted for later use. To maintain drill holes for later monitoring, it is desirable to insert a plastic casing.

## LOGGING

77. In all cases of good core recovery, pieces of core should be fitted together in the trays and colour transparencies obtained. A scale should be added for obtaining dimensions from the photographs. If core orientation is available, a reference line should be marked so that discontinuity orientation can easily be obtained by reorienting the core in space. A core log for geotechnical purposes has to provide information on the rock substance and on the existence of geological discontinuities. Rock types and discontinuities are described by the geological name, and are characterized by geotechnical properties. For best readability, core logs are composed of a descriptive and graphical part. Standard forms are given in Appendix B. This information is coded for storage in computer files.

78. An approach which distinguishes between lithology, major faults and minor fractures may be too elaborate for core evaluation. In this case, classification of the core by using Rock Quality Designation (RQD) or a fracture spacing index is sufficient, Appendix B. RQD values should not be regarded, however, as fully satisfactory, because adopting a routine approach can lead to the neglect of important fault intersections.

## STORAGE

79. The cost of logging and storing core is only a small portion of the total cost of exploratory drilling, and the extra expense is usually amply justified by future possible savings. Core should not be split until it is completely logged and photographed. In many deposits, as in many of the porphyry or sedimentary rocks, the structural patterns in ore and waste are often identical. Temporary and final walls may be in ore for a

large part. Core should be catalogued and stored so that specified sections can be easily extracted and relogged. Well maintained files of colour transparencies give easy access to original core information. Further details are given in Appendix B.

## TIME AND COSTS

### Field Mapping

80. From detailed line mapping of open pit benches, experience has been obtained on qualifications necessary for mapping personnel, and the footage of face and number of discontinuities which can be mapped per day. Using the detailed line mapping approach of Appendix A, the results of Table 1 were obtained.

81. The range of discontinuities measured per man-day is small, in spite of the differences in traverse lengths, pit dimensions and complexity of geology.

- a. Pit 1 was a compact site and its geology relatively simple.
- b. Pit 2 had very complex geology, and covered a large area.
- c. Pit 3 had simple geology.
- d. The geology at Pit 4 was poorly known and complex. Time was lost defining geological units. Only discontinuities over 12 ft (4 m) in trace length were mapped.

82. The personnel employed for the routine detailed line mapping were a recent graduate and a third year geology student, neither with previous training in the DISCODAT system (Supplement 2-1).

83. Assuming the employee costs \$100.00 per day, unit cost is \$2.00 per discontinuity. Table 1 allows costs to be estimated by the length of exposed wall to be mapped. More accurate estimates of the cost of a survey can be given after making a preliminary survey of the various domains throughout the property. The use of preliminary surveys will also allow concentration of effort in the more critical areas of the pit.

84. An example of the total cost of a detailed structural survey in a large pit is shown in Tables 2 and 3.

Table 1: Number of discontinuities mapped per man-day

Open pit	Total no. discontinuities	Length of traverse	Man-days	Discontinuities mapped/man-day	Traverse length mapped/man-day
1	1216	5300 ft (1616 m)	24	50	220 ft (67 m)
2	733	4200 ft (1280 m)	18	40	233 ft (71 m)
3	860	5100 ft (1555 m)	19.5	49	261 ft (80 m)
4	3244	24752 ft (7546 m)	92	35.2	269 ft (82 m)

Table 2: Cost for structural field survey (excluding structural analysis)  
Pit 4 (25000 feet of line traverse)

Item	Man-days	Costs (\$)
Field work (including draft of summary report)		
Engineering fees		
Senior engineering geologist	30	9000
Junior engineering geologist	110	11000
Student assistant	90	7200
Expenses		
Materials and supplies		100
Living expenses, for 2 field mappers		1800
Travel expenses, supervisory visits		3000
Summary report on geological conditions		
Engineering fees		
Senior engineering geologist	10	3000
Junior engineering geologist	3	300
Draftsman	2	150
Secretarial	3	200
Reproduction, photographs		600
TOTAL COST		<u>36350</u>

NOTE: Cost of services provided by mine are not included. These services included transport of mappers and surveying. Manpower costs are based on fees recommended by Assoc. of Prof. Engineers of Ontario (1975), Executive Engineers: \$300 per day; staff assistants: payroll costs multiplied by two.

Table 3: Cost for structural and related slope stability analysis (1974)

Item	Man-days	Costs (\$)
Engineering fees		
Senior engineering geologist	15	4500
Engineering geologist	50	4700
Direct costs		
Photographs, printing, typing, etc		1000
Visit to mine to present findings		650
Computer processing of structural data		700
TOTAL COST		<u>11550</u>

#### Drilling and Core Logging

85. Drilling costs vary considerably depending on remoteness of location, hole size and recovery requirements. General guidance is difficult to give, but Tables 4 and 5 are an indication of price ranges for different jobs in Western Canada.

86. Core logging costs are less than mapping of field traverses due to lower travel time. As no survey controls have to be set up, it is estimated that about 400 ft (120 m) of core can be logged per day.

#### INDIRECT OBSERVATIONS

87. Photography, borehole viewing, and geophysical methods provide essential complements to the direct documentation of geological structures in the field, and make possible the mapping of inaccessible areas.

88. Indirect observations have the disadvantage that geological information is available only following an analytical procedure. Time is saved in the field, but the possibility of making larger errors and incurring waiting periods subsequently have to be taken into account.

#### Photography

89. Photographs of rock exposure can often replace pages of text. Airphoto interpretation, plane table photography, and terrestrial photogrammetry provide permanent records of pit sites

and convenient means for the mapping of inaccessible areas.

#### Airphoto Interpretation

90. Virtually all of Canada has been photographed and aerial photographs are available through government agencies listed in Appendix D. Aerial photographs, either singly or as a mosaic, permit planning for reconnaissance surveys and geological field mapping.

91. Photography at suitable scales will locate faults and joints, regional structural patterns, unstable ground conditions, rock outcrops, borrow material, water level, and drainage patterns, Fig 4. Different rock types develop different residual soils which can often be identified by their unique vegetation cover. Some clues to groundwater conditions may be indicated by growth of vegetation along faults and basic dykes.

92. In mountainous terrain where access is difficult, access routes, campsites, drill sites and exploration programs can be planned with the help of airphotos. This also holds for areas with limited outcrops, or for cases where immediate subsurface conditions may present severe foundation problems, ie, permafrost, muskeg, sensitive clay, etc.

93. Typical tools for airphoto interpretation are a mirror stereoscope and a parallax bar for measuring strike and dip. For extensive work,

Table 4: Variation of drilling, sampling and testing tenders for an open pit mine  
in central British Columbia (1974)

Item	Quantity	Company A		Company B		Company C		Company D		Company E	
		Unit	Total	Unit	Total	Unit	Total	Unit	Total	Unit	Total
		price \$		price \$		price \$		price \$		price \$	
Mobilization and demobilization		-	1200	-	1800	-	3290	-	2000	-	6800
Set-up at drill holes	9 holes	60	540	300	2700	210	1890	135	1215	304	2736
Drilling in tailings sand	310 ft	3	930	4	1240	6	1860	7	2170	17	5270
Drilling in glacial till	300 ft	9	4500	8	4000	8	2400	12	6000	24	12000
Drilling in rock	50 ft	6	300	6	300	9	450	7	350	35	1750
Split spoon sampling in tailings sand	-	15		6		16		12		30	
Split spoon sampling in glacial till	50	15	750	8	400	20	1000	12	600	35	1750
Core recovery in rock	50 ft	8	400	12	600	-	-	2	100	10	500
Undisturbed sampling in tailings sand	62	15	930	12	744	25	1550	18	1116	38	2356
Permeability testing	50 tests	25	1250	48	2400	35	1750	20	1000	40	2000
Installation of 3/4-in. PVC pipe	200 ft	2	400	2	400	1	200	2	200	4	800
TOTAL			11200		14584		14390		14751		36162
Number of rigs		1		2		1		2		2	
Type of rig(s)		Becker		1 rotary 1 washbore		LY-38		1 BBS2		1 cable tool	
Notice to commence		5 to 10 days		7 days		10 days		10 days		10 days	
Completion time		21 days		42 days		25 days		30 days		60 days	
Shifts per day		1		1		3		2		1	
Hours per shift		10		8		8		10		8	
Days per week		6		6		7		7		6	

Table 5: Drilling costs for several open pit projects in Western Canada (1974)  
for hard rock drilling

Location	Access	Time and length of program	Footage in ft (m)	Core size	Rigs	Mobilization (\$)	Demobilization (\$)	Costs/ft (costs/m)	Cost (\$) / ft (m) (incl mobil. and demobil.)
1 South central B.C.	good road	spring, 1973	23600 (7193)	NQ	2	incl	incl	-	6.93 (23.10)
2 Northwestern B.C.	aircraft & barge	June/Sept 73	49000 (14935)	NQ BQ	4	35K	20K	14.56 (48.53)	15.68 (52.00)
3 Chilcotin area, B.C.	good road	April/July 73	10300 (3139)	NQ	1	incl	incl	-	14.53 (48.43)
4 Northwestern B.C.	aircraft & barge	summer, 1974	8600 (2621)	NQ	-	incl	incl	11.70 (39.00)	16.59 (55.30)
5 Central Yukon	good road	July/Sept 74	6600 (2011)	PQ	1	15K	10K	14.25 (47.50)	18.04 (60.13)
6 West Central B.C.	good road	summer, 1974	6000 (1828)	BQ	1	incl	incl	-	32.90 (109.66)
7 Southeastern B.C.	good road	June/Nov 74	17000 (5181)	HQ	2	incl	incl	-	18.20 (60.66)
8 West of Prince George, B.C.	good road	summer, 1974	17500 (5334)	NQ	2	3K	2K	13.16 (43.86)	13.46 (48.86)

NOTE: Engineering services such as drill inspection, logging, etc are not included in contracts. The costs for Examples 5 and 6 were based on providing drilling services only. Costs for 1975 drilling contracts were ca 25% higher than 1974 cost. Example 6 required 100% core recovery. (K = 1000).

more expensive but work-saving instruments are recommended.

94. Most observations from airphotos should be verified by field mapping. Where there are no topographical maps, airphotos can be used as base maps. Distortion in scale can be removed by photogrammetric processes and the information transferred to a final map. A useful scale for

detailed mapping is about 1:10000. Constant reference to airphotos during surface mapping gives a better appreciation of structure at the site, and thus assists in extrapolating observations.

95. The largest cost in acquiring aerial photographs is represented by aircraft operation. Detailed cost estimates require a knowledge of the

size and location of the job. The cost of moving the aircraft to the job site in remote areas could exceed the aerial survey itself. The maintenance of the flight crew on a standby basis in the event of poor weather may have to be budgeted in addition.

96. The minimum number of photographs required for a given mine area can be calculated from the total area to be flown, divided by the area covered by each photograph. With a forward and side overlap of 60% and 30% respectively, the net gain per photograph is  $0.4 \times 0.7 \times \text{total area}$  represented by an individual photograph. For a

9 in. x 9 in. ( $0.05 \text{ m}^2$ ) photo at a scale of 1:12000, the net area gained per photograph is 0.81 square miles ( $2.1 \text{ km}^2$ ). The number of flight lines equals the width divided by the width gained per flight line rounded to the next whole number plus one additional photo at each end. For an area of 10 miles x 10 miles ( $259 \text{ km}^2$ ), about 92 line miles (148 km) are required. Additional costs arise if topographic maps are to be obtained from aerial photography. This service is available from companies which are members of the Canadian Association of Aerial Surveyors, CAAS. Table 6 provides minimum service fees per acre for

Table 6: Minimum service fees per acre for photogrammetric topographical mapping (1974)  
(Courtesy, Northwest Survey Corporation (Yukon) Ltd.)

Map scale	C.L.	A			B			C			Minimum area acres (sq km)	Percentage increase if area below minimum and more than figures in column		
		1	2	3	1	2	3	1	2	3		10%	15%	20%
1 in. = 40 ft (1:480)	1 ft*	50.00	40.00	33.00	36.00	33.00	29.00	24.00	20.00	16.50	100	80	60	40
	2 ft*	42.00	36.00	30.00	32.00	28.00	24.00	21.00	18.00	15.00	(0.4)			
1 in. = 50 ft (1:600)	1 ft*	45.00	37.50	30.00	33.00	30.00	26.25	22.50	18.75	15.00	100	80	60	40
	2 ft*	38.00	32.00	26.00	28.00	25.00	21.00	19.00	16.00	14.00	(0.4)			
1 in. = 100 ft (1:1200)	2 ft	9.00	8.00	7.25	6.50	6.00	5.75	5.50	4.00	3.50	1,000	800	600	400
	5 ft	5.00	4.50	3.75	3.25	3.00	2.90	3.00	2.25	1.80	(4)			
	10 ft	4.50	4.00	3.25	2.75	2.50	2.40	2.50	1.75	1.30				
1 in. = 200 ft (1:2400)	2.5 ft	3.70	3.20	2.75	2.10	1.75	1.50	1.45	1.25	1.10	3,000	2,500	2,000	1,500
	5 ft	3.25	2.75	2.25	1.75	1.50	1.15	1.10	1.02	.95	(12)			
	10 ft	2.30	2.00	1.75	1.50	1.25	1.10	.95	.80	.70				
1 in. = 400 ft (1:4800)	5 ft	1.75	1.50	1.30	1.00	.80	.70	.65	.55	.50	5,000	4,000	2,000	1,000
	10 ft	1.40	1.25	1.10	.85	.62	.50	.45	.39	.35	(20)			
	20 ft	1.30	1.15	1.00	.60	.50	.40	.35	.25	.20				
Planimetric only -		20%	15%	10%	20%	15%	10%	20%	15%	10%				
Reduce by														
A = Urban		1 = Heavy Relief												
B = Suburban		2 = Moderate Relief												
C = Rural		3 = Minimal Relief												
*Prices for 1 in. = 40 ft and 1 in. = 50 ft														
(1:480 and 1:600) include field edit.														

Note: The tariff (C.L. = Contour lines) refers to work done in accordance with the appropriate specifications presently issued by the Canadian Association of Aerial Surveyors. Inasmuch as these specifications pertain to the photogrammetric compilation and the production of fair drawings. The taking of aerial photographs, the establishment of ground control, and field checking are not included in this tariff.

For areas less than indicated in final column - add 25%

If fair drawing not required - above fees may be reduced by 30%

photogrammetric mapping by members of the CAAS. These costs do not include the establishment of ground control and field checking.

97. A variety of photographic materials and techniques are available and can be used to advantage. The following types of photography and film represent only a small selection but probably cover the most useful.

98. Panchromatic film, a black-and-white negative film with approximately the same range of sensitivity as the human eye, is the most common and the cheapest film for aerial photography. This film provides reasonable contrast in grey tones and satisfactory resolving power. Excluding aircraft operation, photography at the scale of 1000 ft to the inch (1:12000) with panchromatic photography costs roughly \$12-15 per linear mile.

99. Colour photography with Aerofilm gives transparencies with fairly natural colour grades. Colour photography provides considerably more information than black-and-white film, particularly for identifying rock, soil, and vegetation types. Colour photography costs about \$25 per linear mile. The value of photos is generally enhanced if taken at low sun angles, though in areas of high relief they should be taken at high angles to avoid shadows in valleys.

100. Helicopter photography is used to take aerial photographs at low altitudes for very large-scale stereophotos. The costs are high, but these photos can provide detailed structural analysis of an area adjacent to a pit site. At present this method is used mainly in narrow railway or highway cuts.

101. Infrared black-and-white film and colour infrared photography are suitable for the identification of different vegetation types, as they appear on the film as various shades of red. Slight differences in soil moisture, which cause minor changes in vegetation, are readily detectable by infrared colour photography. Colour infrared has haze penetration superior to other types of films, but does not provide sufficient detail in grey tones for areas of exposed rock. The same holds for thermal infrared photography. Its greatest potential in connection with mining activities is to locate areas of groundwater

discharge or effluent leakage from tailings dams.

102. Orthophotography is a process whereby the geometry of ordinary aerial photos is modified so that the prints have the geometry of an orthographic projection. Normal aerial photos present a perspective view with objects displaced toward, or away from, the centre of the photo, depending on their distances from the camera. This is removed in orthophotography but the process is not successful in areas of great topographic relief. The cost of producing orthophotos is high, and therefore unlikely to be used for slope stability purposes.

103. Side-looking airborne radar or SLAR produces a continuous strip image of the terrain on photographic film by a radar beam reflected off the terrain. It cannot be recommended for pit site investigations because of the low resolution and relatively high cost.

104. The earth resources technology satellite, ERTS, provides repeated image coverage of Canada every eighteen days on a scale of 1:1000000 by black and white and colour photography. Enlargements up to 4.5X are possible. ERTS imagery is ideal for mapping regional geologic structures, particularly large faults; the photographs are of limited value, however, for detailed investigations.

#### Plane Table Photography

105. The plane table principle can be used to advantage for mapping major faults and rock type boundaries on bench faces. Photographs are taken across the pit by a camera of long focal length, eg, 500 mm. Camera position and camera axis are surveyed, and pictures are taken to include survey or position information such as hydro towers or survey pegs. Pictures are enlarged to give sufficient detail to allow mapping of vertical faces. Mapping is done on a transparent overlay and the information is transferred to base maps, using the plane table principle. Base maps are revised every six months and, in general, geological features less than 10 ft (3 m) in extent are not documented, Fig 8 and 9. This particular adaptation of plane table photography was developed at the Bingham Copper pit and has been used for



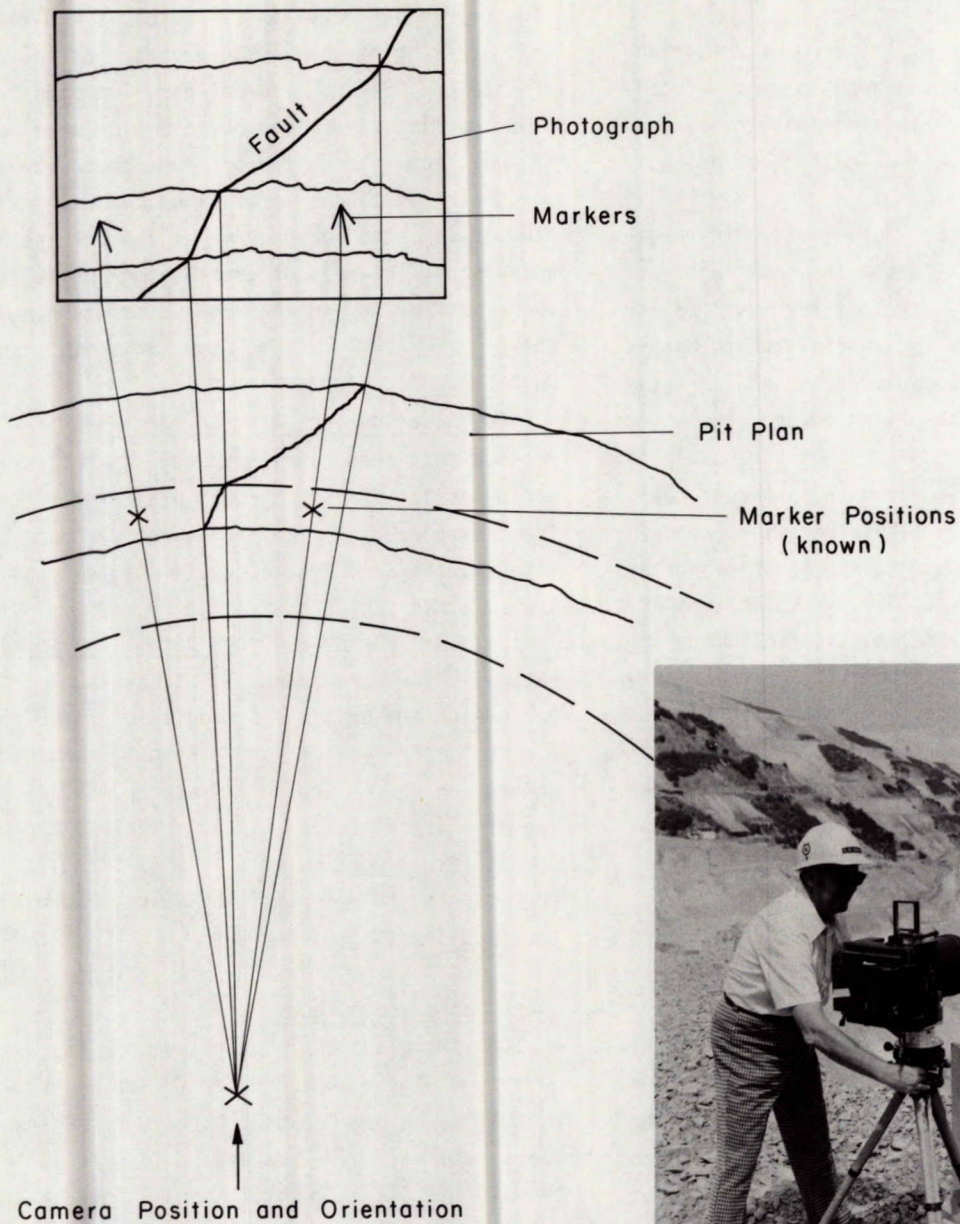


Fig 8 - Plane table photography for mapping of pit faces with the aid of a long focal length camera and a pit survey plan (courtesy Kennecott Copper Corporation).





Fig 9 - Enlarged photograph for field mapping and office procedure for plane table photography (courtesy Kennecott Copper Corporation).

many years for routine mapping of fast-moving pit faces.

### Terrestrial Photogrammetry

106. For inaccessible areas, terrestrial photogrammetry can provide orientation and extent of discontinuities, excavated rock volumes, rock surface profiles, and bulk movements of pit walls. For the mapping of cliffs or deep canyon areas, terrestrial photogrammetry frequently offers the only solution. At pit sites, long shots across the pit are generally required, and to achieve the desired resolution long base lines are necessary and are sometimes difficult to find in the confines of a pit.

107. Principles employed are similar to those of aerial photogrammetry, except that tighter survey control is maintained. Photographs are taken normal to the base line and as nearly horizontal as possible. Targets are placed on the object within the area of stereoscopic viewing so that photographs can be oriented and discontinuities measured. Accuracies can be similar to field mapping if suitable camera stations can be found.

108. For quick results if access is available, field work by direct observation at selected locations is more efficient and cheaper. For evaluating long slopes extending for several kilometers, photogrammetry is very competitive.

109. Equipment required for taking terrestrial photographs comprises a camera, film material, and a theodolite. Black-and-white photo material either as glass plates or film is available commercially. Combinations of camera and theodolite known as phototheodolites cost about \$10,000, with prices increasing with more versatile equipment. A camera attachment for a T2 theodolite can be obtained for about \$5000.

110. The cost of analytical equipment, ranges from \$2000 for a stereoscope and parallax bar to \$100,000 for automated stereoplotters and stereocomparators. There is little point in considering large equipment outlays for taking and analyzing terrestrial photographs for small jobs, as service companies can do this work at far lower costs.

111. An analysis of costs for terrestrial photogrammetry at a pit site with field personnel at \$100 per day, resulted in about \$2.00 per discontinuity. This included photographing 1600 ft (480 m) of face, providing survey control, plotting 1500 discontinuities, program conversion and printout. Four weeks were required before the results were available and an additional field visit was necessary to establish geotechnical properties not clearly defined on the photographs.

112. With surveyors available at a mine site to set up the base line, camera stations, targets, and obtain the survey readings and photographs, service costs can be limited to analytical services. Detailed instructions for terrestrial photogrammetry are given in Supplement 2-4.

### Borehole Viewing

113. In cases where drill holes are available with poor recovery of core, borehole viewing is helpful. Existing borehole viewing devices are generally adapted for holes with diameters of about 3 in. (7.6 cm). By viewing or photographing borehole walls, the thickness of fault gouge, joint orientation, bedding, and level of waterflow may be determined. Depths and dimensions of structures can be determined to an accuracy of  $\pm 0.02$  ft (0.6 cm) compared with depth determination during drilling which is generally considered accurate to about  $\pm 0.1 - 0.5$  ft (3 - 15 cm), depending on depth.

114. The principal types of borehole viewing devices are photographic and television cameras, and periscopes. The cost of borehole viewing devices, listed in Table 7, generally makes mine personnel reluctant to risk the cameras in soft caving formations. A dummy camera or clearing device is usually lowered into the hole to ensure that the hole is open and safe. Cameras have been used in boreholes to depths greater than 1300 ft (400 m), but generally do not exceed 500 ft (150 m) due to water pressure problems. Periscopes, on the other hand, are limited to about 110 ft (30 m) of depth; beyond this depth images are distorted by imperfections in the optical systems.

115. The NX borehole camera photographs the wall of the hole continuously with flashlights.

Table 7: Estimated costs for borehole viewing equipment and services (1975)

Instrument	Maximum range in ft (m)	Direction of view	Transmission of image	Maximum diameter of instrument	Approximate borehole size	Cost (\$)		Remarks
						purchase	lease	
Borescope	10 (3)	at right angles to borescope	2 telescoping tubes	1.25 in. (3.2 cm)	-	360	-	
Borescope	25 (8)	at right angles to borescope	series of coupled extension tubes	1.31 in. (3.3 cm)	-	480	-	
Periscope	110 (33)	at right angles to periscope	coupled extension tubes	2.20 in. (5.6 cm)	2.5 in. (6.4 cm)	27000	250/wk	
Camera	1000 (300)	parallel to probe axis	record image on film	2.75 in. (7.0 cm)	3.0 in. (7.6 cm)	30000	-	cost includes camera + 1000 ft (300 m) cable and winch
Television	1000 (300)	parallel to probe axis	power and transmission cable	3.0 in. (7.6 cm)	4.0 in. (10.2 cm)	-	300/day	cost includes probe with 1000 ft of cable, monitoring unit, truck technician and all facilities except mobilization and interpretation
Television	1000 (300)	at right angles to probe axis	power and transmission cable	2.48 in. (6.3 cm)	3.0 in. (7.6 cm)	46000	-	cost includes all equipment with 1000 ft (300 m) of cable, monitoring unit etc

Note: Costs given are those for new units; used equipment is considerably cheaper.  
 Delivery time for periscope, camera or television is approximately 5 months.  
 Range is limited by the amount of cable with unit and by the water pressure on the probe: the probes given here are only rated to withstand 750 psi (5MPa).

It includes compass orientation and depth on the 16 mm film. Analysis involves projecting the doughnut-like picture onto a 360° groundglass screen, using a conical mirror. A special transparent overlay sheet is used to make the necessary structural interpretations (6).

116. The borehole television camera (7) uses a closed-circuit television system and consists of a probe containing the television camera, a lowering device, drum of coaxial cable, control console, and monitoring unit as shown in Fig 10. Dirty water is a drawback and must be removed. Minimum



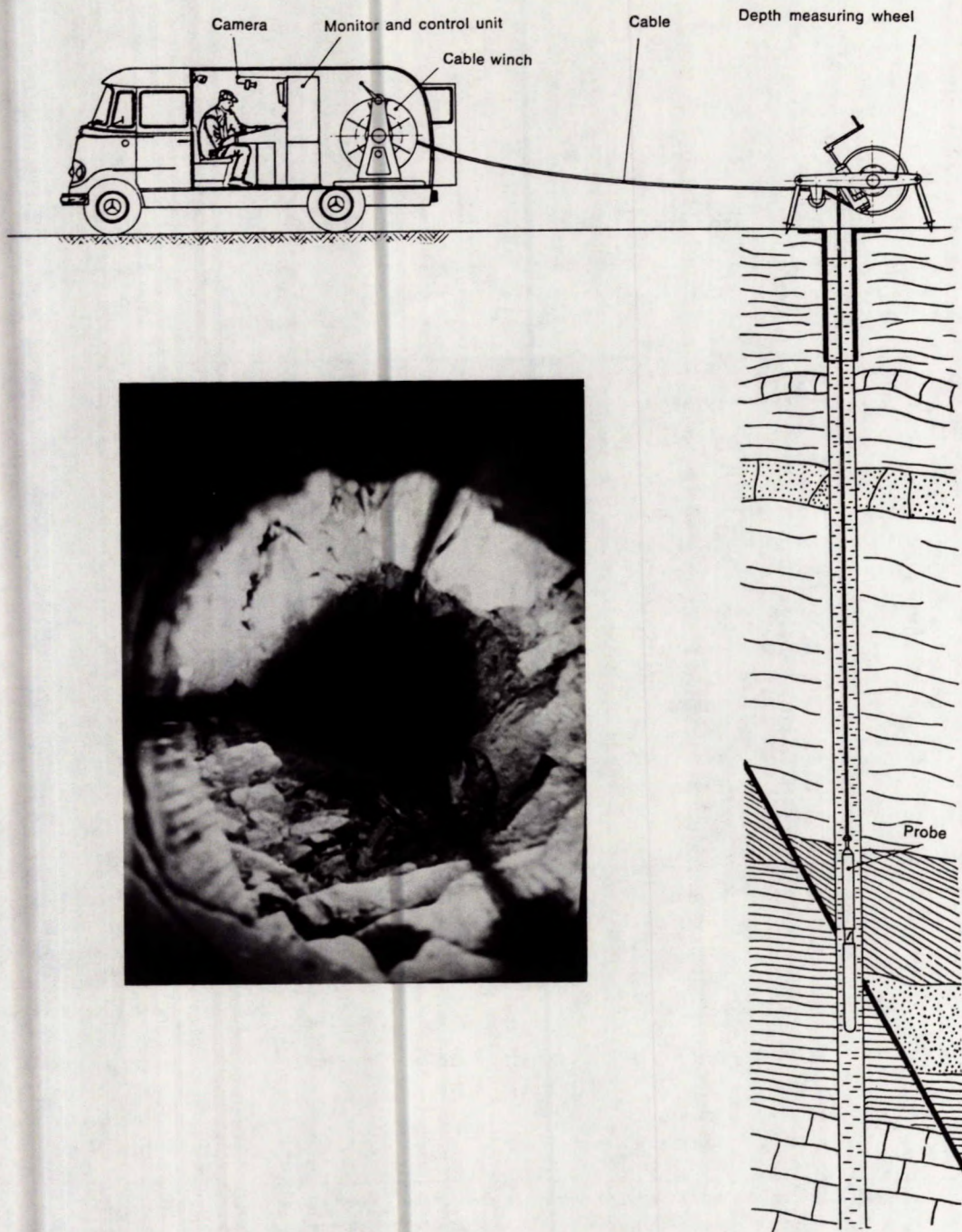


Fig 10 - Borehole viewing with a television probe (7).

hole size required is about 2.0 in. (5 cm).

117. The borehole television camera delivers a direct view of the drillhole and allows observation of interesting detail. It can be oriented such that a fracture plane shows as a straight line on the screen, and the angle of dip

and strike can readily be determined. Photographing the television picture is possible, but lacks the clarity of direct photographs of the borehole wall.

118. The borehole periscope is the least expensive tool for borehole viewing and combines the



advantages of the borehole and television cameras. It is of relatively simple construction and allows immediate observation of the borehole wall to a depth of 110 ft (30 m). The hole size required is 2.5 in. (6.3 cm). The image of the borehole can be photographed in colour, and the orientation of discontinuities is obtained by measuring the dip and its direction on the elliptical trace of the discontinuity on the borehole walls. The location of the discontinuity is recorded from precise markings on the extension tubes. The general layout is given in Fig 11 (8).

119. Borehole viewing methods are essential when no core is available or when boreholes have

to be inspected for particular reasons. In general, borehole viewing is only used on a standby basis.

#### Geophysical Exploration

120. Geophysical methods are used for ore prospecting on a regional scale but the results are rarely detailed enough to assist in pit site investigations. Geophysical tools with better resolution are, however, available and can be used at the pit site, in adits and drifts, and in boreholes.

121. Geophysical tools supplement core logging and surface mapping by evaluating the rock between

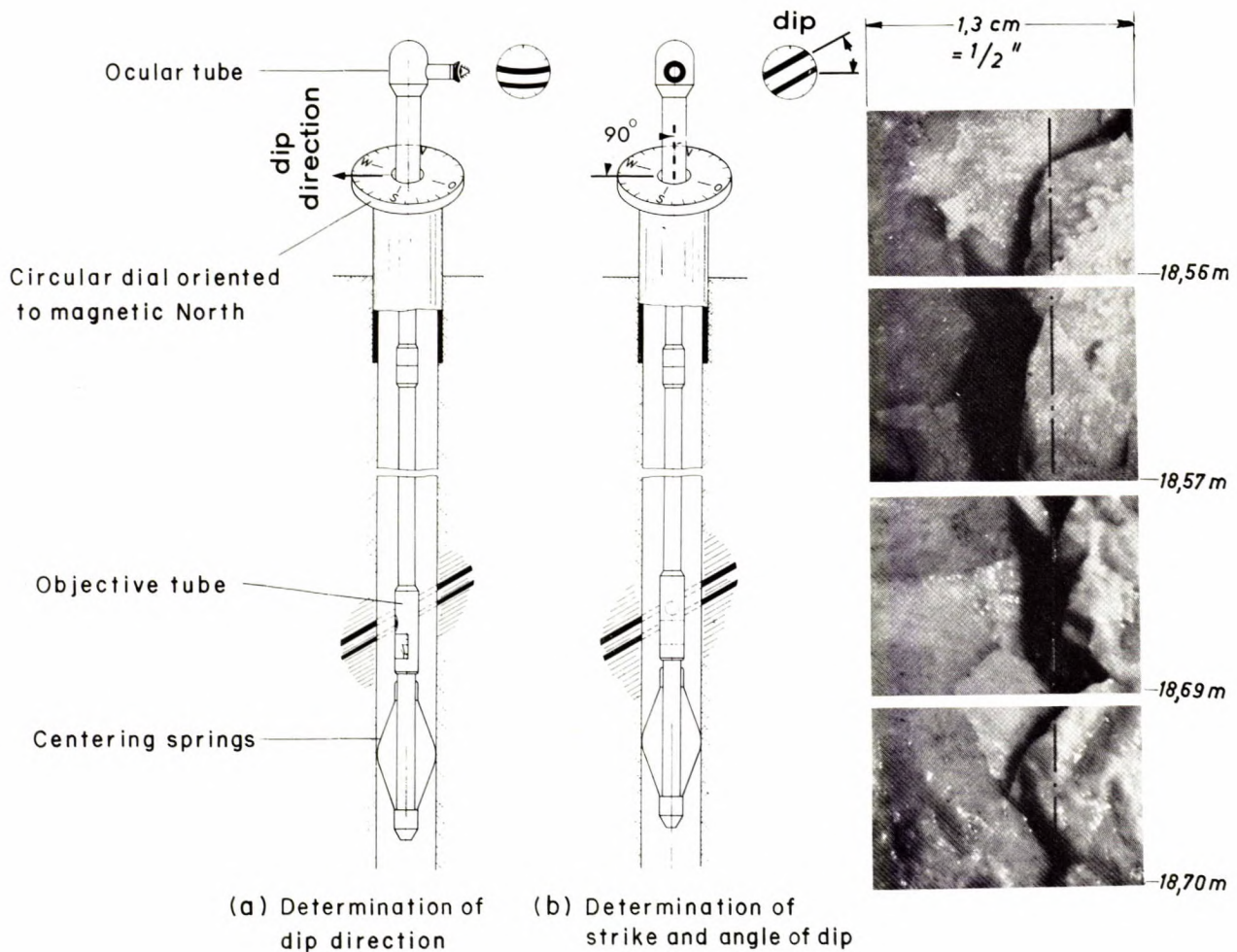


Fig 11 - Borehole periscope and view of borehole wall (courtesy Eastman International Company).



boreholes, and provide general background information. Equipment is available which allows rapid determination of overburden thickness. As for locating discontinuities, geophysical techniques are only useful for those which are major, well-defined and through-going.

122. Only those techniques are mentioned in the following which can be carried out with commercially available equipment and which allow a successful do-it-yourself job. Supplement 2-3 provides details of these survey methods and the costs charged by service companies for more sophisticated work.

#### Surface Geophysics

123. Best results are obtained with geophysical equipment if two complementary approaches are used, and if the results can be verified in a few locations with boreholes, adits, or trenches. To delineate horizontal stratification and overburden depth, the seismic refraction method is the most desirable. In many cases electrical resistivity provides a complement to the seismic refraction method. Both methods require very little analytical effort.

124. Seismic refraction surveys are based on travel times of ground vibrations through rock or soil. They are well suited to delineate soils or deeply weathered or fractured rock overlying solid rock, and if the area is generally flat. If shock generation is by hammer impact (hammerseismic), subsurface exploration is possible to a depth of about 50 ft (15 m) (Fig 12(a)). Recently marked signal enhancement seismographs allow further depth penetration and provide a quick analysis of the subsurface (9). Substantially better depth penetration is possible with shock generation by explosives (Fig 12(b)).

125. Electrical resistivity of soil and rock varies in wide ranges and can be determined with the aid of electrodes placed in the ground. Electrical resistivity surveying is used in rock and overburden evaluation, and depending on conditions and equipment, a depth from 100 to 500 ft (30-150 m) can be reached. This survey complements seismic refraction surveys in determining depth of soil cover, water table, and thickness of gravel beds. Analysis becomes difficult if more than three layers are involved. Further details can be found in Supplement 2-3.



(a)



(b)

Fig 12 - Seismic refraction survey (a) shock generation by hammer impact (courtesy Soiltest, Inc.), (b) with the aid of explosives.

### Borehole Geophysics

126. In most cases, drill core or borehole viewing with a periscope or similar method provides a more direct answer than geophysical borehole logging. Borehole geophysics is expensive due to the sophisticated probes used and the chances of losing them in the hole. Advantages are that up-hole and cross-hole investigations can be carried out. Logging is generally left to service companies which will have a selection of tools for holes down to a diameter of 2 in. (5 cm) diameter. Price schedules are set up mainly for deep, large-diameter drill holes, as the market is still limited for short, small-diameter drill holes, eg, 1000 ft (300 m) depth, 2 in. (5 cm) diameter, typically found at pit sites. Many service companies will not provide interpretation of the borehole logs. If companies are employed to provide a good interpretation service, the costs of logging and interpretation per hole can approach the cost of drilling a new hole. Further details are given in Supplement 2-3.

127. Geophysical techniques appear to be useful for detecting overburden depth and gravel beds. Borehole logging requires special services which can be expensive, but has the advantage that logs can be made immediately available at the site.

### DATA STORAGE AND DISPLAY

128. Up to 5000 observations with as many as

ten characteristics of discontinuities might be necessary for a site investigation. This will require the handling of approximately 50,000 items of information.

129. Major discontinuities and rock types are generally plotted on plans and sections, and statistical features are usually analyzed by graphical methods. This approach is suitable if experienced personnel undertake the complete process. With the availability of computers, jobs can, however, be broken down into such simple segments that relatively inexperienced personnel can do the mapping and perform analyses without losing essential information.

130. This requires a standard approach for detailed geological mapping, for which two field forms have been developed to serve as guides, as shown in Appendix A. Information from these sheets can be punched directly on computer cards as in Supplement 2-1. Simple retrieval requests can then extract special categories of information such as the orientation of joints for analysis by appropriate computer programs.

131. The field forms can also be used independently of computer availability. They can be sorted by using double-row edge-punched cards in an instant data system, and sorting rods. Retrieved information can then be analyzed graphically or numerically, as presented in the next section.

## EVALUATION OF GEOLOGICAL INFORMATION FOR SLOPE STABILITY ANALYSIS

### ORIENTATION OF DISCONTINUITIES

132. Results of general geological data gathering are commonly displayed on maps and sections covering such aspects as:

- a. rock type boundaries, age relationships, and bedding plane orientation
- b. major faults and shears
- c. orientation of joints
- d. groundwater occurrences

133. Compilations of this kind provide essential information to develop a geological model for a site. Such a model is valuable when considering the extrapolation of a geological data base, but additional analytical efforts are necessary to obtain from information collected with the aid of the DISCODAT field guide, the properties required for a slope stability analysis on the basis of probability. This requires the following refinements:

- a. Rock type distributions have to be supplemented by strength estimates (Fig 13).
- b. Structural geological maps have to show in addition to major structures the orientation of minor discontinuities on equal area nets (Fig 14).
- c. Separate listings have to be supplied on:
  1. mean and dispersion of discontinuity orien-

tation

2. mean and dispersion of discontinuity spacing
  3. mean and dispersion of discontinuity length
  4. analysis of waviness.
- d. Finally, domain boundaries are to be checked, preliminary design sectors selected, and a preliminary kinematic analysis carried out.

Point a.) can be evaluated from plotting field estimates or results from rock strength tests on rock type distribution maps. Points b.) and c.) require special plotting procedures or analytical efforts which form part of the DISCODAT program package and are explained below, with graphical or numerical examples. In some cases, alternatives are suggested which provide quick and often sufficiently accurate estimates. Point d.) is carried out in the final phase of the geological data analysis and should provide the qualitative mode of instability for the different design sectors of the pit.

### Mean Orientation and Dispersion of Discontinuity Sets

134. The orientations of discontinuities relative to the slope face are usually among the most significant properties. At most sites, joints



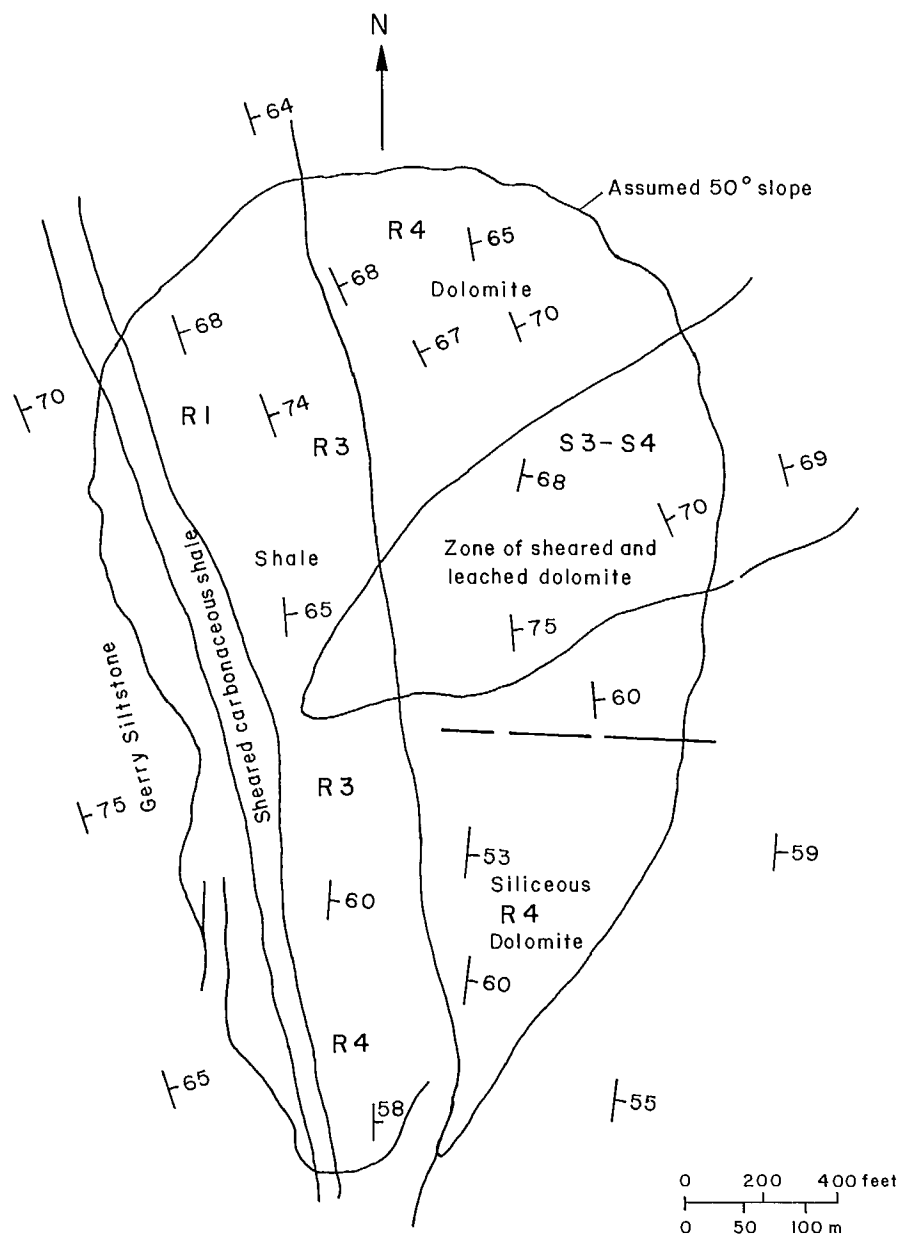


Fig 13 - Sketch map showing rock type distribution, strength estimates and bedding plane orientation for a pit site.

will occur in systematic orientations. Joints parallel to each other are called a joint set and various joint sets form a joint system. Joint sets are defined by the mean orientation and a value of dispersion about this mean. To obtain mean and a measure of dispersion for joint sets, measurements of joint orientations are treated as

follows:

- plotting of observations on equal-area nets
- determination of joint sets (clusters of joint poles) from contouring
- determination of mean orientations in each cluster
- determination of dispersion from the mean.

### Projections

135. An important tool for statistical analysis of orientation measurements is the equal-area net. This represents the projection of coordinates of a hemisphere onto a plane so that the relationship of relative areas is maintained (Fig 15). This projection is available as an equatorial (Fig 16) and as a polar equal-area net (Fig 17). Forms are provided at the end of the chapter with 15 cm diameter. For plotting strike and dip measure-

ments all discontinuities are considered to pass through the centre of the hemisphere (Fig 15). By convention, only the lower hemisphere is used.

136. The orientation of a plane can be represented by a great circle or trace which is the intersection of the plane with the hemisphere (Fig 15). This requires counting the strike clockwise from north on the periphery. The dip is plotted at right angles to the strike, counting the angles of dip from the periphery to the centre

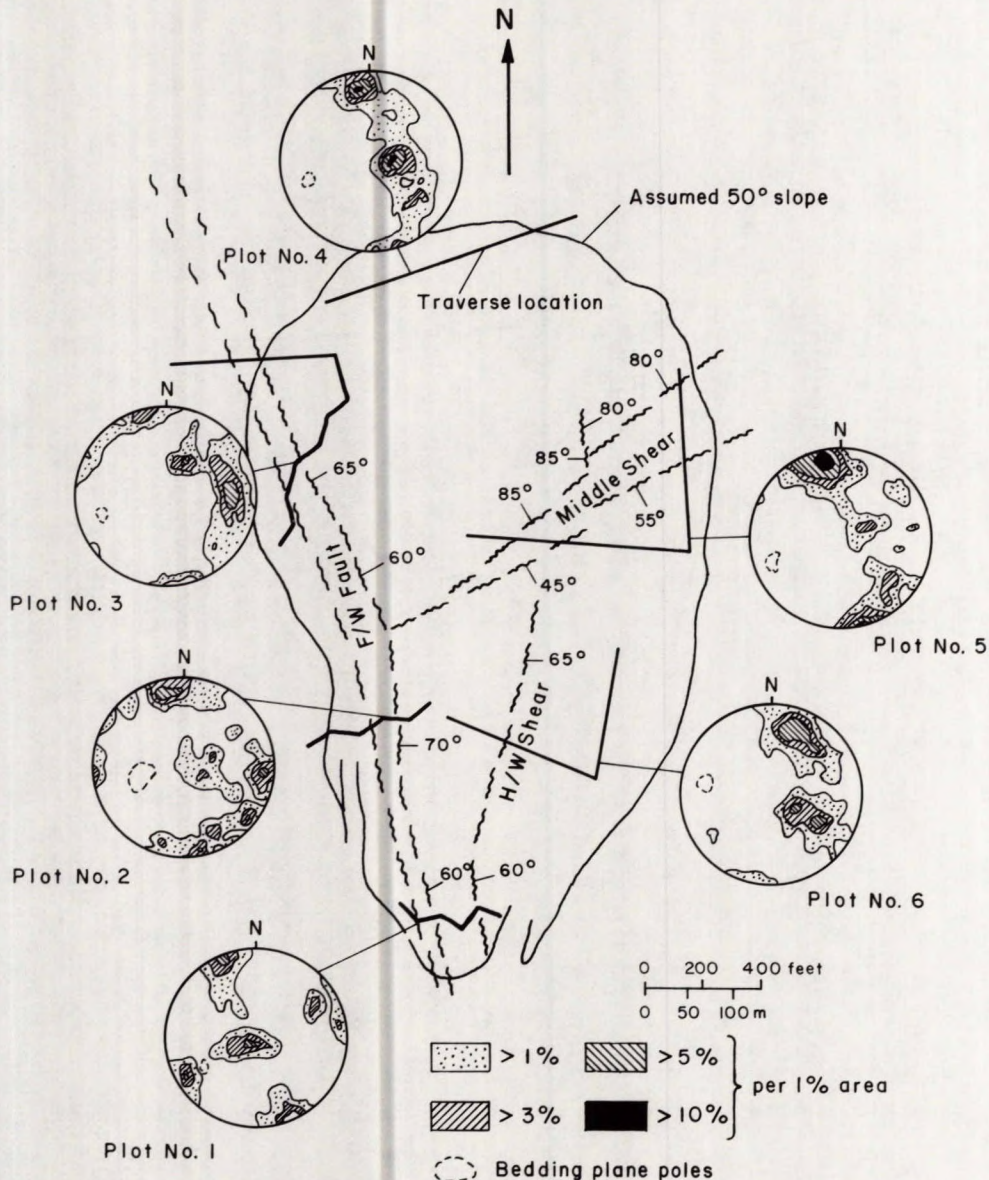


Fig 14 - Sketch map showing major discontinuities and orientation of minor discontinuities.



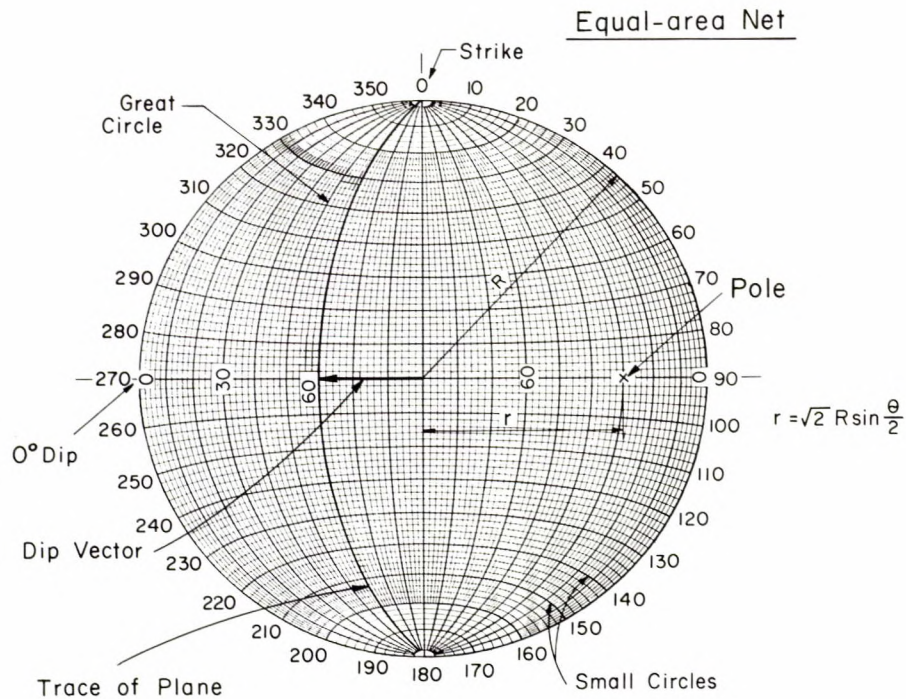
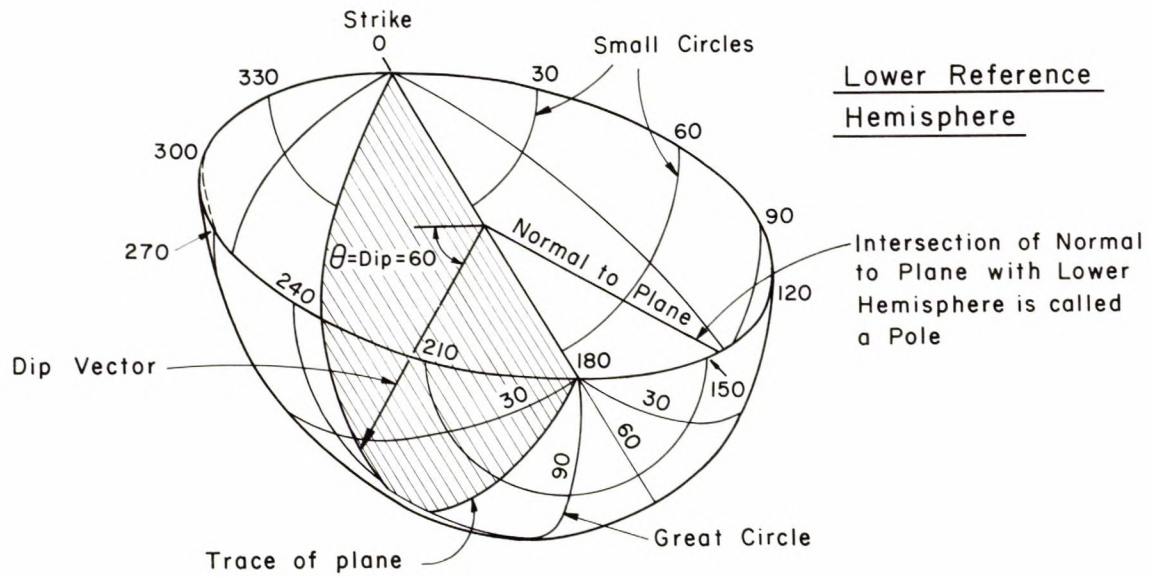
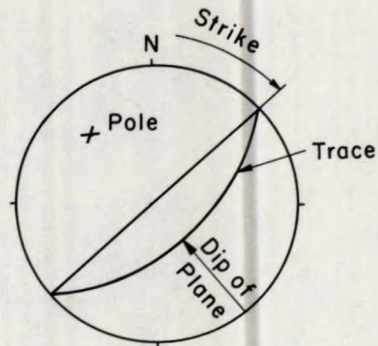


Fig 15 - Representation of a plane and pole in an equal area net.



Strike and Dip  
of a Plane  
 $N50^{\circ}E / 60^{\circ}SE$   
  
Pole of Plane  
above  
 $N320^{\circ}E / 30^{\circ}$



Dip Direction  
and Dip  
for Plane above  
 $140 / 60$

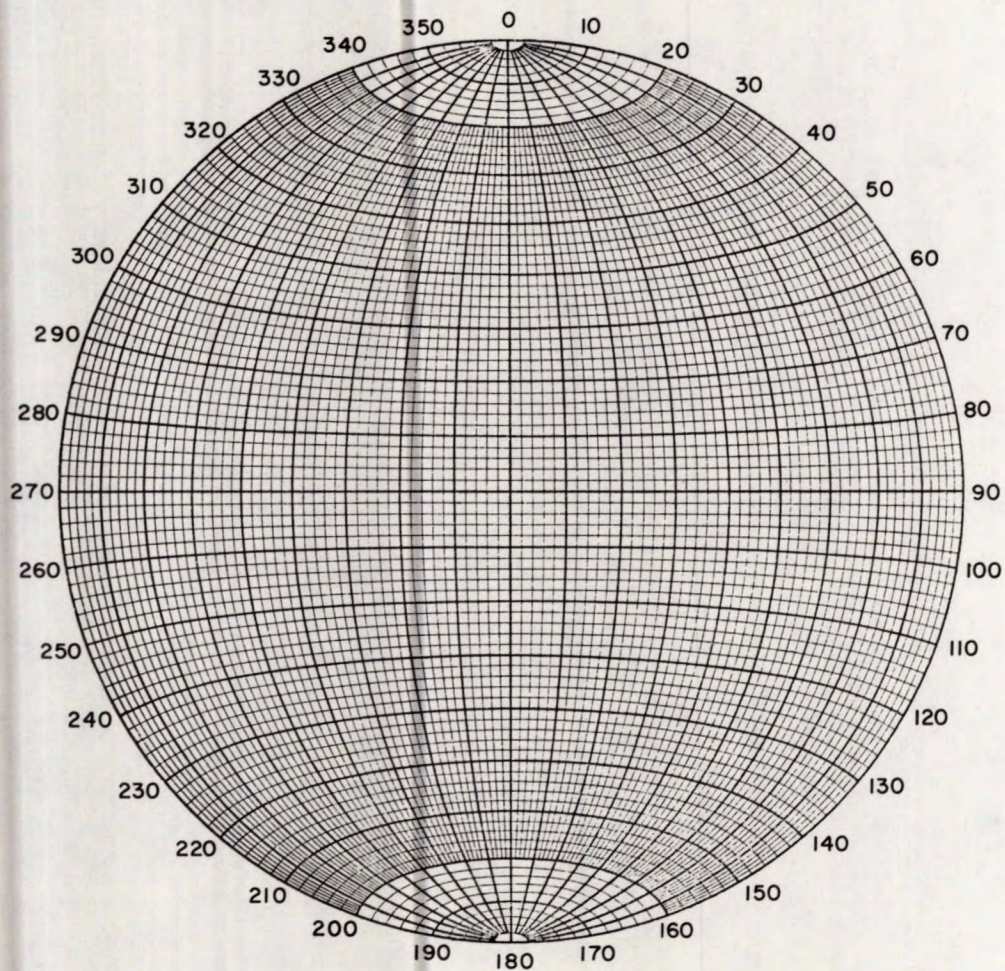
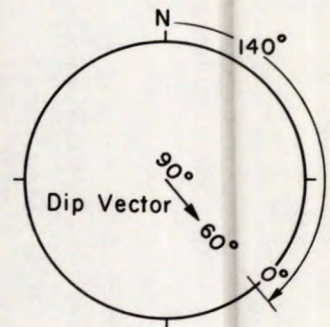
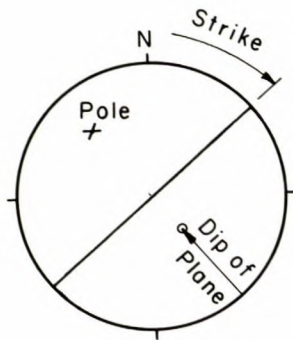


Fig 16 - Equatorial equal area net in  $2^{\circ}$  intervals and three ways of representing the orientation of a plane.



Strike and Dip  
of a Plane  
 $N 50^{\circ} E / 60^{\circ} SE$

Pole of Plane  
above  
 $N 320^{\circ} E / 30^{\circ}$



Dip Direction  
and Dip  
for plane above  
 $140 / 60$

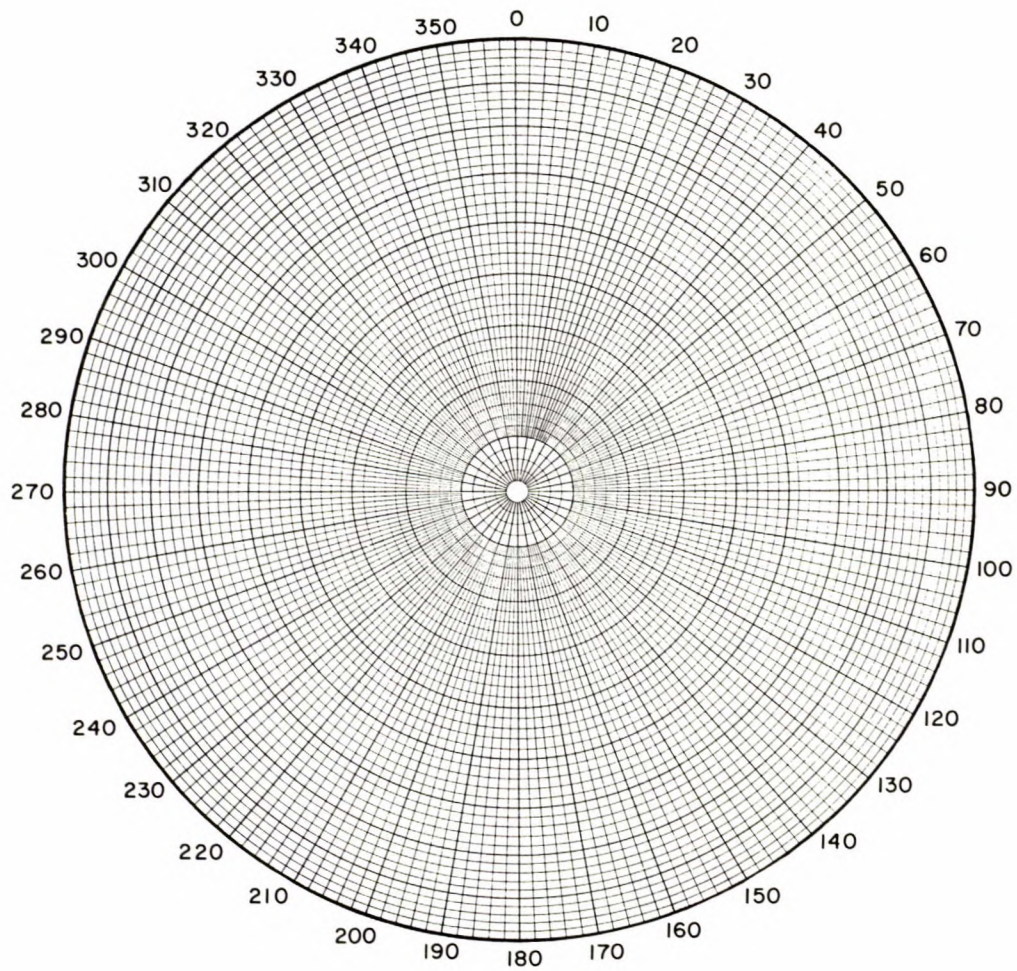
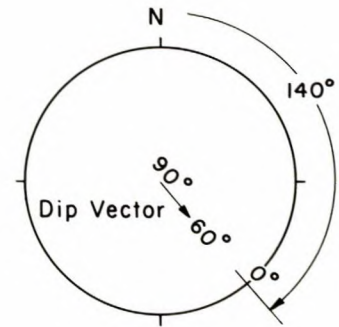


Fig 17 - Polar equal area net in  $2^{\circ}$  intervals and three ways of representing the orientation of a plane.

(Fig 16).

137. A more space saving representation is the plotting of the pole of the plane. This is obtained at the intersection of the normal to the plane with the lower hemisphere. To plot the pole, the dip angle is counted from the centre of the net at right angles to the strike towards the periphery (Fig 15, 16, 17).

138. The plotting of poles is usually done on an overlay of the polar equal-area net to avoid rotation of the overlay. Both nets will yield the same geometric distribution of poles but if graphical manipulations are necessary, such as rotation of clusters or construction of great circles, the equatorial net has to be used. Figure 18 represents 156 measurements of joints and shears as an example. For routine plotting, computer processing saves time.

#### Cluster Delineation and Shape

139. The first step in obtaining mean orientations of joint sets requires that clusters of joints can be visually delineated on the equal-area net (Fig 18). In cases where too many poles are plotted, the clusters might not be clearly recognizable, and the Schmidt contouring method, Fig 19, can be used to clarify and enhance the pattern as shown for the data of Fig 18 in Fig 20.

140. The contouring involves superimposing a square grid on the equal-area net (10). A circle, which represents 1% of the total area of the net, is placed with its centre at the grid intersections and the number of poles in the circle is counted and noted on the grid intersection. For contouring of the pole density close to the periphery of the net, two point counters, 1% area, mounted on a bar which can rotate about the centre of the net are used. With the centres of both point counters placed on the periphery at opposite ends, the number of points in each half of the point counter is added and marked on the periphery (Fig 19). Pole densities can then be contoured, and six contour intervals are usually sufficient to display density variations.

141. The shape of pole concentrations can vary between point maxima and girdles extending over

the whole net. Contoured equal-area nets can show spurious detail which can be neglected in further analysis provided the data base is large enough (>200 observations) to make this judgement.

142. Statistical tests are available for assessing the significance of preferred orientations, but if clusters of joints or fractures are not clearly recognizable on the contoured plots, the orientation data should be assumed to be random or uniform.

#### Mean Orientations

143. For clusters of orientation measurements, a mean value can be estimated. Ideally, a distinct preferred orientation has a central value of high concentration that falls away continuously to zero, or to the random or uniform background in all directions. The point of highest concentration can be chosen as the sample mean. If only a few measurements are contained in a cluster, eg, 5 to 8, the middle of the range of the cluster can be selected as the mean value. In the DISCODAT program package numerical determination of the mean orientation treats each pole of an orientation measurement as a vector. The orientation of the sum of the vectors in a cluster represents the mean orientation as described in paragraph 155.

#### Fitting a Distribution

144. To assess the confidence range about a mean orientation or to determine the probability of finding a discontinuity orientation or dip other than the mean, we have to obtain an estimate of the true frequency distribution of the discontinuity orientations in that cluster. If a large sample of measurements is available, the sample frequency distribution can be used for direct input into a Monte Carlo simulation. However in most cases the data base is insufficient and considerable advantages exist if a distribution function for which the statistics are known can be fitted to a sample of measurements.

145. Selection of a suitable distribution function depends mainly on the shape of the cluster which can vary from a point maximum over an elongated (elliptical) distribution to a girdle. Due to the properties of the equal-area net,

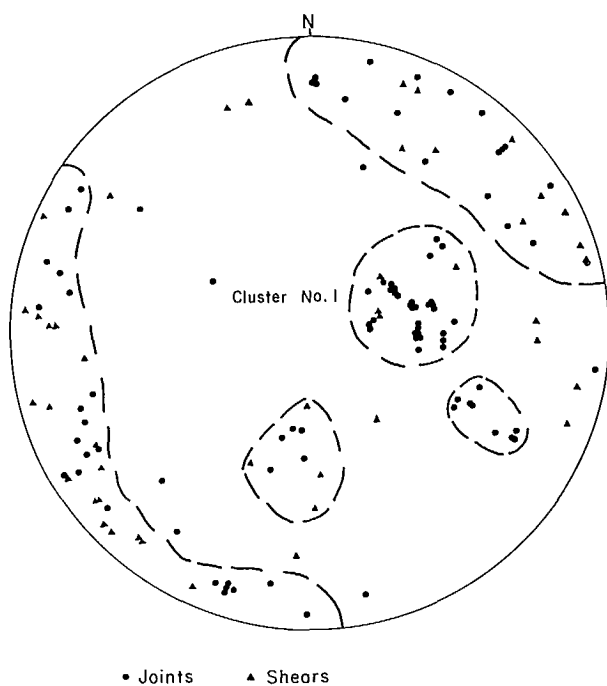


Fig 18 - 156 measurements of joints and shears plotted as poles in lower equal area net.

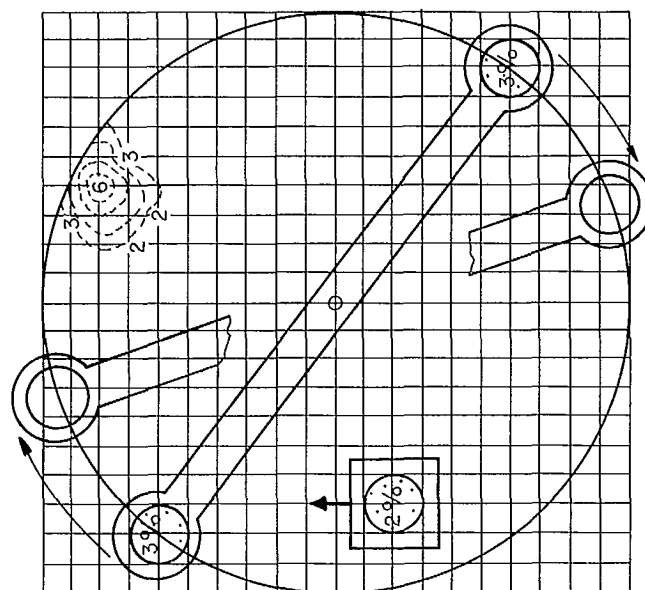


Fig 19 - Contouring a pole with a point counter. In case 300 points have been plotted, 6 points observed in a 1% point counter represents 2% of total (10).

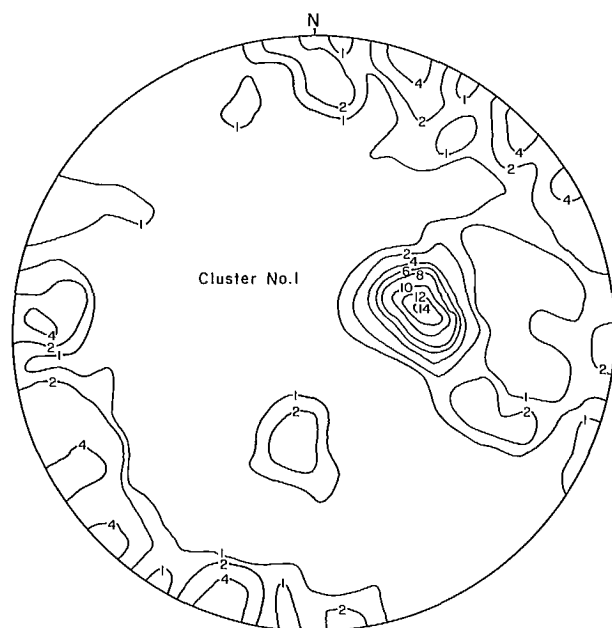


Fig 20 - Frequency contours in per cent per 1% area for 156 observations.

shapes of clusters are distorted if not plotted close to the centre. Rotation of the cluster mean to the centre of the equal area net can, therefore, be an asset as shown in Supplement 2-1. Statistics are available for point maxima on a sphere (Fisher distribution) and are best dealt with by computer calculation. For clarity a graphical solution is provided in paragraphs 155-160.

146. The spherical normal distribution is not suitable if the cluster is elongated. The mean pole can be calculated as before but the formula for the cone of confidence is not applicable. An approximation is possible with the two dimensional normal distribution. The error is negligible if the range in the cluster is  $< 30^\circ$  (15). The two dimensional normal distribution has two axes (X and Y) with standard deviations  $S_1$  and  $S_2$  in case of anisotropy. If  $S_1$  is much larger than  $S_2$  or independent of  $S_2$ , the one dimensional normal distribution can be used. If X is taken parallel to the mean strike and the dip angles are normally distributed along Y by approximation, statistical formulae for range and optimum sample size may be used.

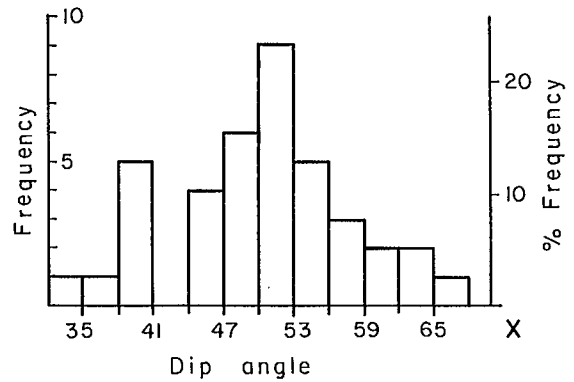
#### One Dimensional Normal Distribution

147. The one dimensional normal distribution is widely used in applied statistics and its properties have been thoroughly investigated (11, 12). When the probability is to be assessed for the occurrence of joints in a joint set with a dip angle less than the slope angle, the one dimensional normal distribution can be of value. As an example, measurements of dip angles for a joint set with a strike parallel to the pit wall are shown in Fig 21.

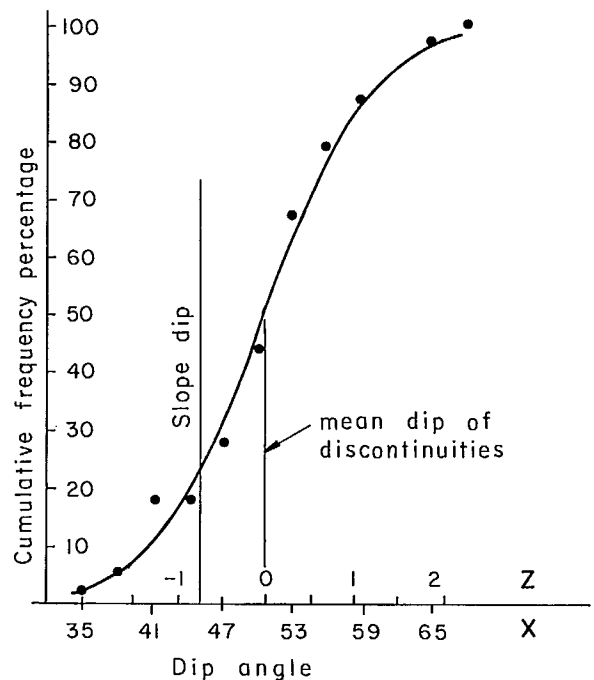
148. By plotting dip angles against frequency, a sample frequency distribution is obtained (Fig 21-a) which shows similarities to the normal distribution. A sample cumulative frequency percentage diagram is shown in Fig 21-b. Both plots are the analog of the probability density function (PDF) and the cumulative distribution function (CDF) for the population. With the assumption that the dip angles are normally distributed, a CDF can be obtained from the mean ( $m$ ) and standard

Dip observations: 33, 38, 40, 40, 40, 40, 41, 45, 45, 47, 47, 48, 48, 48, 50, 50, 50, 51, 51, 51, 51, 51, 51, 52, 52, 54, 55, 55, 55, 56, 58, 58, 58, 60, 60, 65, 65, 66 ( $n = 39$ )

mean = 50.67  
std. dev. = 7.64



(a) Frequency distribution



(b) Cumulative frequency distribution

Fig 21 - Statistical analysis of dip angles.



deviation (s) of the sample with the aid of tables (11, p. 229) for the standardized variable  $z = (x - M)/S$ , where  $z$  is normal with zero mean and unit standard deviation. For the example above, the probability of dip angles being shallower than the slope dip is 0.23.

149. Given a normal distribution the standard deviation of a mean dip angle can be estimated from the range (R) of a small sample of measurements (12, table G1).

$$s = \frac{R}{d_n} \quad \text{eq 1}$$

n	2	3	4	5	6
$d_n$	1.13	1.69	2.06	2.33	2.53

150. In many cases it is valuable to know the optimum number of measurements which gives the required information with sufficient precision at a minimum cost. This requires that the relationship is known between the number of observations in a sample and the precision of a characteristic which can be obtained for that size. Knowing the costs of an individual observation, costs can be estimated for obtaining a sample of sufficient observations which will yield an acceptable level of precision. From the properties of the one dimensional normal distribution it is known that

$$M - a = \frac{t \cdot S}{\sqrt{n}} \quad \text{eq 2}$$

where  $t$  is the appropriate value of Students'  $t$  (11, 12) and  $s$  is an estimate of the standard deviation.  $M - a$  describes the maximum allowable difference between the estimate made from the sample and the actual universe of available samples (precision). For  $> 25$  observations  $t$  is approximately 2 and the precision thus varies with  $1/\sqrt{n}$ .

151. For example, if dip angles for a set of 25 joints have an estimated standard deviation of  $5^\circ$  and the mean should be determined with a precision of  $1^\circ$ , the following number of observations is required.

$$n = \left( \frac{2 \cdot x \cdot s}{M-a} \right)^2 = \left( \frac{2 \cdot x \cdot 5}{1} \right)^2 = 100 \text{ observations}$$

If about 50 discontinuities of this set can be recorded per man day and only 1 day of field work can be allocated (= 50 observations), the precision of the sample would be from eq 2:

$$E = M-a = \frac{2 \cdot x \cdot s}{\sqrt{n}} = \frac{2 \cdot x \cdot 5}{\sqrt{50}} = 1.4^\circ$$

152. At this point the accuracy of structural field measurements might be of interest. An analysis (13) has shown that estimated standard deviations of dips over most of the dip range are about  $2^\circ$ , whereas strike errors are approximately  $2/\sin d^\circ$  where  $d$  is the dip angle.

#### Two Dimensional Normal Distribution

153. As mentioned before, this distribution is appropriate if the discontinuity cluster is strongly elongated. Two great circles can be drawn along the planes of symmetry (X, Y) of the elliptical cluster and the assumption is made that angular deviations along both great circles have independent normal distribution (Fig 22-a). The standard deviations along each great circle can be calculated and a chart technique (11, p 269) is available to determine, eg, the probability of finding discontinuity orientations within a particular (critical) area of a cluster, eg, those which are undercutting a slope but have angles steeper than the angle of friction (11, 14, 15). The procedure is to determine the critical area of pole locations first (Fig 22-b), rotate it towards the centre (Fig 22-c) and then redraft the target area in the scale of the standard deviations for  $x$  and  $y$ . If standard deviations differ, a circular target area would appear as an ellipse. In Fig 22-d the rectangular normal probability chart is shown with the superimposed target area. To obtain the probability of orientation measurements falling into the target area, the number of covered squares is counted, which represent  $P = 0.001$  per rectangle.

154. If orientation measurements are tightly clustered, the mean can be obtained from mid range



and also the dispersion can be estimated for small samples from the range.

$$s = \frac{R}{d_n}$$

n	2	3	4	5	6	7	8
$d_n$	0.90	1.35	1.65	1.86	2.02	2.16	2.28

### Spherical Normal Distribution

155. This distribution is a three dimensional distribution and is applied to clusters with a distinct preferred orientation (point maximum) with a central value of high concentration which falls away continuously to zero or to the random or uniform background. The number of observations per cluster should not be below thirty if it is desired to test the fit of data. The description below provides the calculation of the mean vector of a cluster and the confidence cone about the mean. Calculation of the mean orientation treats each pole of an orientation measurement as a vector. The orientation of the resultant of the vectors represents the mean orientation. The spherical normal distribution,

$$P(\theta) = \left( \frac{K}{4\pi \sinh K} \right) e^{K \cos \theta} d\theta \quad \text{eq 3}$$

is rotationally symmetrical about the true mean direction.  $P(\theta)$  is the probability of finding a pole at angles between  $\theta$  and  $\theta + d\theta$  from the mean (16, 17).

156.  $K$  describes the scatter of observations. If there is no preferred orientation, then  $K = 0$ , and if all fractures are parallel, ie,  $N = R$ , then  $K = \infty$ . High  $K$  values thus indicate a small scatter. For  $K \geq 3$  and for large samples (18) with

$$k = \frac{N - 2}{N - R} \quad \text{eq 4}$$

( $N$  = number of observations,  $R$  = resultant vector), the equation of the spherical normal distribution reduces to

$$P(\theta) = \frac{K}{2\pi} e^{-K(1-\cos \theta)} \quad \text{eq 5}$$

Integration gives

$$\cos \theta = 1 + (1/K) \ln (1 - P) \quad \text{eq 6}$$

Figure 23 shows the percentage of observations contained in the range  $\pm \theta$  of the sample mean for different  $K$ -values. This graph is useful for assessing the angle for any confidence interval. For example, given  $K = 50$  and desired confidence interval 95%, then  $\theta = \pm 19^\circ$ .

157. Numerical solutions for  $R$  and  $K$  are available in Supplement 2-1, where a computer program handles the tedious vector calculation for each observation and their summation. A quick graphical solution is possible with the Braitsch overlay, Fig 24 (19, 20). In the Braitsch overlay, an equal-area net is subdivided into 220 cells for which the mean vector components are given in Table 8. The overlay is superimposed on an equal-area net and the number of observations per cell are counted and multiplied with the component values of the mean cell vector. For example, to determine the mean vector for cluster 1 of Fig 18

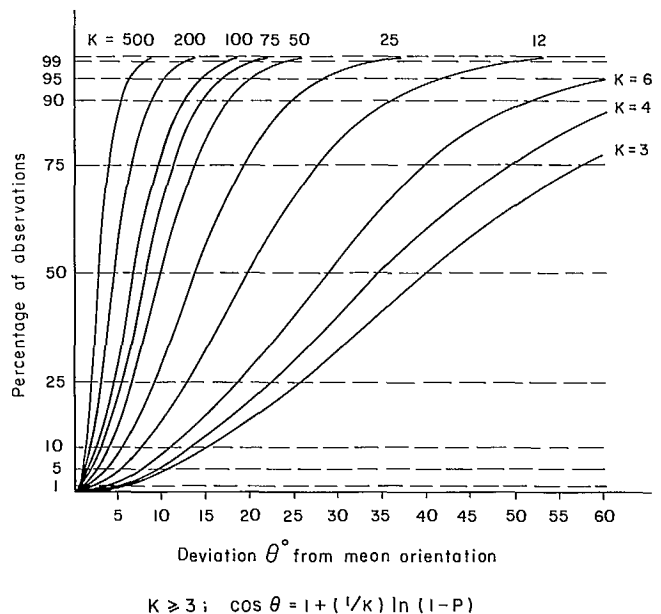
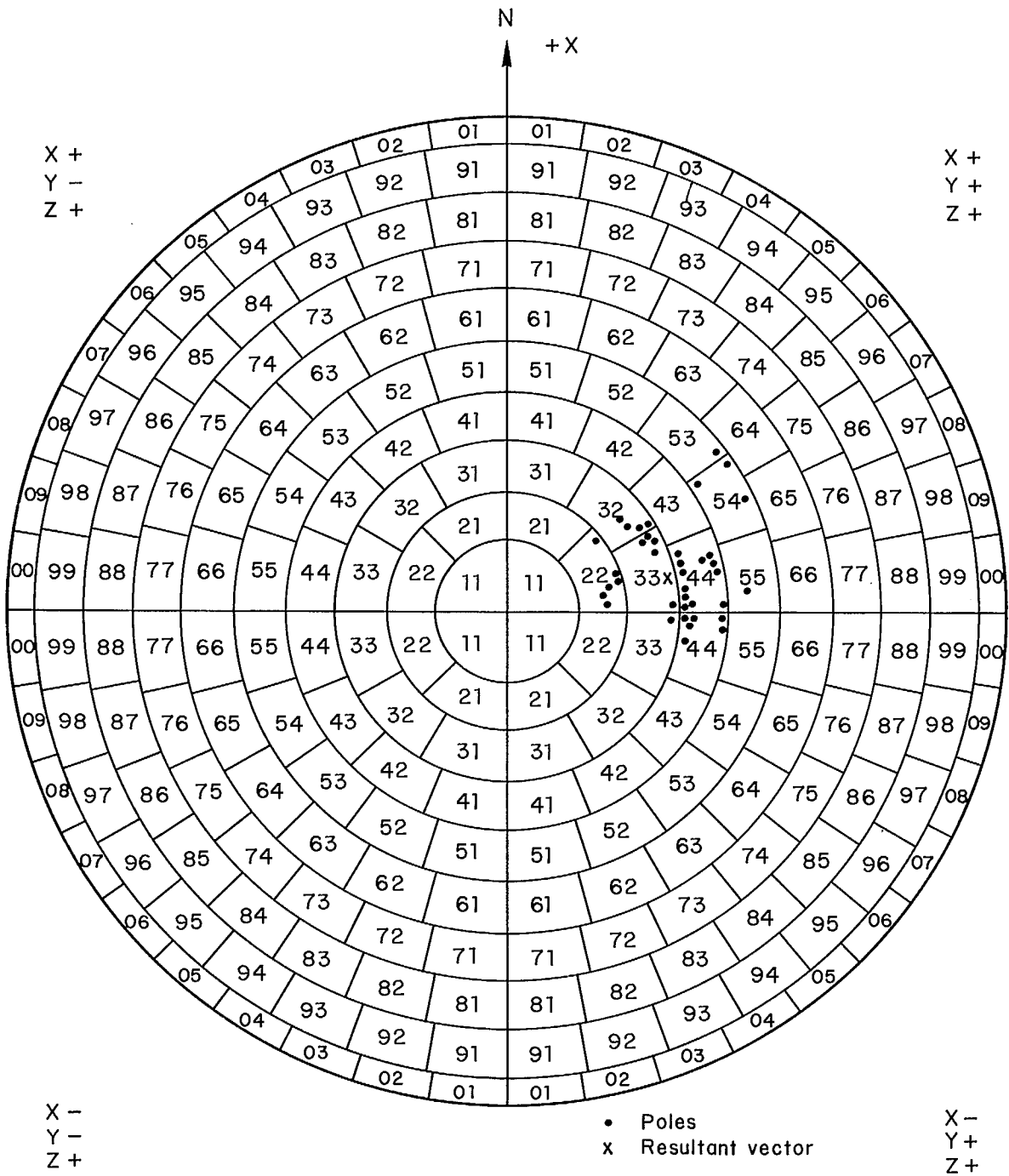


Fig 23 - Cumulative frequency of  $\theta$  from mean orientation with different  $K$  values.



Braitsch overlay

Fig 24 - Overlay to define mean and dispersion of a discontinuity cluster.

and the concentration factor K, the following procedure is necessary:

- list mean vector components for cells which contain poles
- count no of poles per cell, Fig 24
- multiply mean vector components of cell, Table 8, by number of poles ( $X^+ = N$ ,  $Y^+ = E$ ,  $Z^+ = \text{down}$ )
- summarize component values separately for X, Y, Z

				Mean vector			
Mean vector components of cell				No of poles	components multiplied by number of poles		
Cell	x	y	z	(n)	nx	ny	nz
22	1048	2531	9618	6	6288	15186	57708
32	2906	2906	9117	4	11624	11624	36468
33	1064	3970	9117	5	5320	19850	45585
33	-1064	3970	9117	1	-1064	3970	9117
44	1054	5298	8415	12	12648	63576	100980
44	-1054	5298	8415	6	-6324	31788	50490
53	4665	4665	7514	1	4665	4665	7514
54	2995	5879	7514	3	8985	17637	22542
55	1032	6517	7514	1	1032	6517	7514
TOTAL				39	43174	174813	337918
					= X	= Y	= Z

- multiply X, Y, Z by 0.0001

- calculate resultant vector

$$R = \sqrt{(\sum X)^2 + (\sum Y)^2 + (\sum Z)^2} \quad \text{eq 7}$$

$$R = 38.29$$

- Calculate concentration parameter k from eq 2

$$k = \frac{39 - 2}{0.71} = 52.11$$

- Define trend and plunge of resultant vector

158. If the trend of the resultant vector, or pole, is defined by azimuth A ( $0 - 360^\circ$ ) from north, and the plunge by angle H which is counted from the horizontal, ie, from periphery of equal-area net towards the centre, we can show that

$$X = \cos H \cos A \quad \text{eq 8}$$

$$Y = \cos H \sin A \quad \text{eq 9}$$

$$Z = \sin H \quad \text{eq 10}$$

Table 8: Vector components for fitting of spherical normal distribution to measurements of orientation with Braitsch overlay

Cell	x	y	z
11	816	816	9933
21	2531	1048	9618
22	1048	2531	9618
31	3970	1064	9117
32	2906	2906	9117
33	1064	3970	9117
41	5298	1054	8415
42	4492	3001	8415
43	3001	4492	8415
44	1054	5298	8415
51	6517	1032	7514
52	5879	2995	7514
53	4665	4665	7514
54	2995	5879	7514
55	1032	6517	7514
61	7607	1002	6413
62	7089	2936	6413
63	6087	4671	6413
64	4671	6087	6413
65	2936	7089	6413
66	1002	7607	6413
71	8541	962	5111
72	8113	2839	5111
73	7278	4573	5111
74	6078	6078	5111
75	4573	7278	5111
76	2839	8113	5111
77	962	8541	5111
81	9281	914	3609
82	8924	2707	3609
83	8225	4396	3609
84	7209	5916	3609
85	5916	7209	3609
86	4396	8225	3609
87	2707	8924	3609
88	914	9281	3609
91	9779	856	1905
92	9482	2541	1905
93	8897	4149	1905
94	8041	5631	1905
95	6942	6942	1905
96	5631	8041	1905
97	4149	8897	1905
98	2541	9482	1905
99	856	9779	1905
01	9969	785	0
02	9724	2334	0
03	9239	3827	0
04	8526	5225	0
05	7604	6494	0
06	6494	7604	0
07	5225	8526	0
08	3827	9239	0
09	2334	9724	0
00	785	9969	0

The components of the resultant vector are

$$X_R = \frac{\sum X}{R}, \quad \text{eq 11}$$

$$Y_R = \frac{\sum Y}{R}, \quad \text{eq 12}$$

$$Z_R = \frac{\sum Z}{R} \quad \text{eq 13}$$

159. This allows calculation of the resultant vector orientation for cluster 1:

Plunge (H)

$$H = \arcsin Z_R$$

$$H = \arcsin \left( \frac{33.75}{38.29} \right) = 61.94^\circ$$

Plunge of resultant vector or pole =  $62^\circ$

Trend (A)

$$A = \arcsin \left( \frac{Y_R}{\cos H} \right)$$

$$A = \arcsin \left( \frac{17.48}{38.29 \times 0.4704} \right) = 76.04$$

Trend of resultant vector or pole =  $N76^\circ E$

Orientation of the mean plane is therefore  $N 166^\circ E / 28^\circ W$ , or by dip direction and dip =  $256/28$ .

160. From the estimate of  $K$  we can determine the confidence cone (accuracy) of the mean by

$$\cos \theta = 1 - \frac{N - R}{R} [(1/P)^{1/(N-1)} - 1] \quad \text{eq 14}$$

or by approximation (21)

$$\cos \theta = 1 - \frac{\log_e P}{KN} \quad \text{eq 15}$$

which gives for a probability of  $P = 0.05$ , a  $k$  of 52.1 and  $N = 39$  an angle  $\theta$  of  $3.1^\circ$ . In other words only a probability of  $P = 0.05$  exists that the true mean deviates more than  $3.1^\circ$  from the calculated mean.

#### Errors in Frequency Contours of Orientation Data

161. The Schmidt contouring process is still widely used and is adequate to enhance joint clusters. Due to the distortion of angles on an

equal area net towards the periphery which results from maintaining number/area, or density relationships of a sphere, the 1 per cent counting circle should be replaced by an elliptical shape, close to the periphery of the net. This is not generally done and results in the distortion of the density contour lines and a displacement of the mode of the cluster. The computer program in the DISCODAT package (Supplement 2-1) counts poles on the hemisphere rather than on its projection and calculates a correct representation of pole densities. If one does not use this numerical calculation, the Braitsch overlay is better than a contoured diagram.

162. It is often taken for granted that the contoured equal-area net not only describes the existence of pole concentrations, but also shows the relative importance of individual joint sets by the number of observations shown. If many measurements have been taken over a large area and across different elevations, this is generally true. If measurements are taken only along a limited length of drill hole or line traverse in one particular direction, however, some joint maxima can be severely underrepresented because the number of observations changes with direction; eg, a strong bias can develop about horizontal fractures if sampling is done only along a horizontal line traverse. In pits, wall irregularity will often provide sufficient three-dimensional exposure so that the mistake of overlooking a joint set is rarely made, but for drill core data sampling bias can be severe. If a comparison of relative frequency is required, then each observation is weighted by a factor  $C$ .

$$C = \frac{1}{\cos \phi} \quad \text{eq 16}$$

where  $\theta$  = angle between normal of a plane and direction of sampling (Fig 25).  $\cos \phi$  varies between 0 to 1 and  $C$  thus varies between  $\infty$  and 1. It is usual however to truncate  $\phi$  at  $85^\circ$ , which then reduces the maximum weight of a measurement to a value of 11.5. The weighting is provided as a routine in the DISCODAT program package of Supplement 2-1.

163. Routine application of the trigonometric

correction can overcompensate and before applying it, it is desirable to compare results from different mapping directions within the same domain. If frequency patterns are similar, a directional bias correction may not be warranted.

#### SPACING OF DISCONTINUITIES

164. Spacing is used as a qualitative measure to indicate the importance of discontinuities occurring in a set and provides direct input into slope stability design. The spacing of fractures of the same orientation is described by the distance perpendicular to adjacent fractures. From the length of traverse,  $L$ , and the number of fractures,  $N$ , the spacing is:

$$D = \frac{L}{N} \quad \text{eq 17}$$

165. If the fractures are not intersected at right angles by the line traverse or drill hole direction, a correction has to be applied to obtain the true spacing:

$$D = D' \cos \phi \quad \text{eq 18}$$

$D$  = true spacing

$D'$  = apparent spacing

$\phi$  = angle between traverse direction and pole to fracture plane (Fig 25)

166. Frequency distributions of discontinuity spacings follow a negative exponential distribution as shown in Fig 26 (22). The negative exponential distribution is

$$f(x) = \lambda e^{-\lambda x} \quad \text{eq 19}$$

where

$f(x)$  = frequency of a discontinuity spacing  $x$

$\lambda$  = average number of discontinuities per meter

The mean fracture spacing and the standard deviation are both equal to  $1/\lambda$ . The probability density function of sample data in Fig 26 are plotted on a logarithmic scale in Fig 27. This plot shows a good agreement between the theoretical and meas-

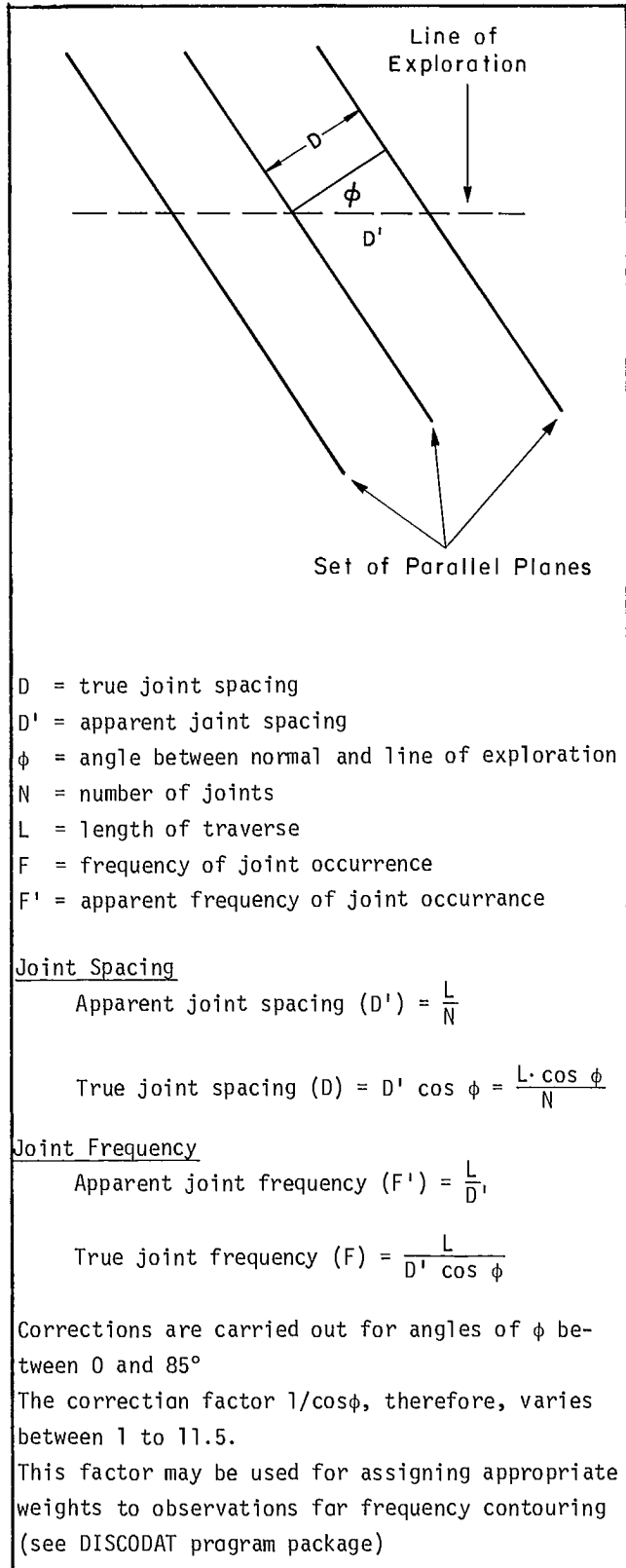


Fig 25 - Correction of directional bias.

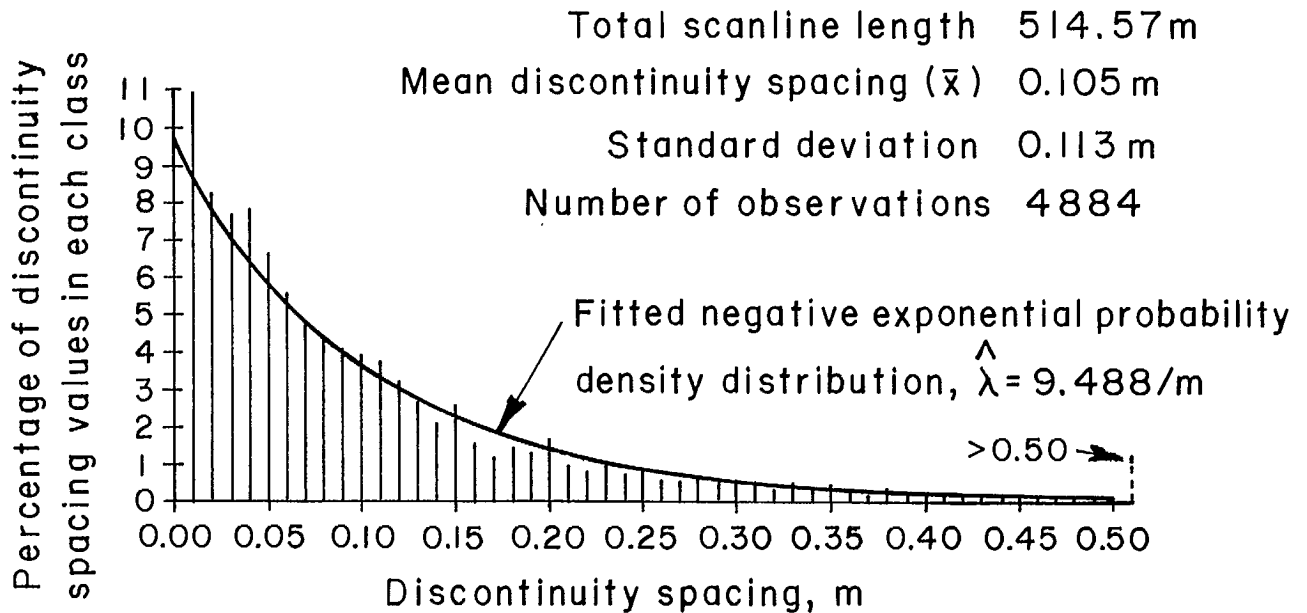


Fig 26 - Negative exponential distribution and observations of discontinuity spacing.

ured distribution.

167. From the negative exponential distribution a relationship can be developed between Rock Quality Designation, RQD, and mean discontinuity spacing as shown in Fig 28 (22):

$$RQD = 100 e^{-0.1\lambda} (0.1\lambda + 1) \quad \text{eq 20}$$

This allows integrating borehole and site investigation data.

168. For rock mass classification the number of joints per volume, eg, a 10 ft (3m) cube, can be calculated if the joints are continuous and the spacing is known for the joint sets. For example, with a spacing of joint sets  $S_1 = 2$  ft (0.6 m),  $S_2 = 3.3$  ft (1 m) and  $S_3 = 5$  ft (1.5 m), the total number,  $N$ , of joints per volume,  $V$ , in a cube with length,  $L_1 = 10$  ft, is:

$$\begin{aligned} \frac{N}{V} &= \frac{L_1/S_1 + L_1/S_2 + L_1/S_3}{L_1^3} \quad \text{eq 21} \\ &= 0.01 \text{ joint/ft}^3 = 0.3 \text{ joint/m}^3 \end{aligned}$$

This number can be of use when comparing joint densities. Fundamental difficulties exist, however, when evaluating densities of discontinuous joints because shapes and continuities are difficult to assess.

#### LENGTH OF DISCONTINUITIES

169. The length of fractures defines the distance over which the tensile and cohesive strength of the rock substance has been reduced or lost. In cases of partial exposure and repetitive, but short fractures it is difficult to determine the true fracture length, but an estimate of the length of fractures can be obtained.

170. In the field forms of the DISCODAT system the largest trace length of a discontinuity in any direction is recorded according to size classes. This information is analyzed to obtain an estimate of the mean fracture length and standard deviation.



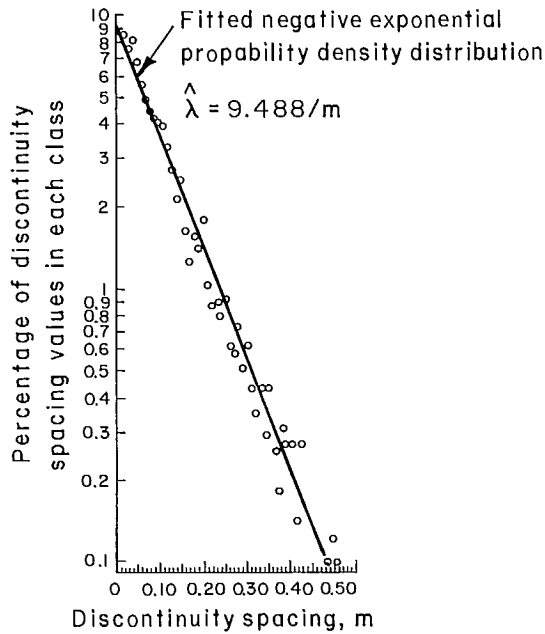


Fig 27 - Sample probability density distribution of discontinuity spacing values, plotted on a logarithmic scale. 4884 observations (22).

#### Mean Length

171. Within the computer package of the DISCODAT system, a routine is provided which calculates the mean fracture size on the basis of a negative exponential distribution (Fig 29).

172. This printout shows a plot of frequency  $\ln [\ln(1/P > x)]$  on the Y-axis and spacing as  $\log x$  on the X-axis. The advantage of this plot is that a perfect fit to a negative exponential distribution would show a straight line with a 45° slope and an intercept on the Y-axis at  $\ln \lambda$ . A horizontal line is given where  $\ln [\ln(1/P > x)] = 0$ .

173. Discontinuities less than 6 ft (2 m) in length are often ignored in surveys. This leads to an underestimation of the frequency of discontinuities and an overestimation of their mean size.

174. A modification of the observation procedure can provide better data for the analysis of trace length of fractures:

- a. observing the actual trace length of the discontinuity exposed above the tape, and

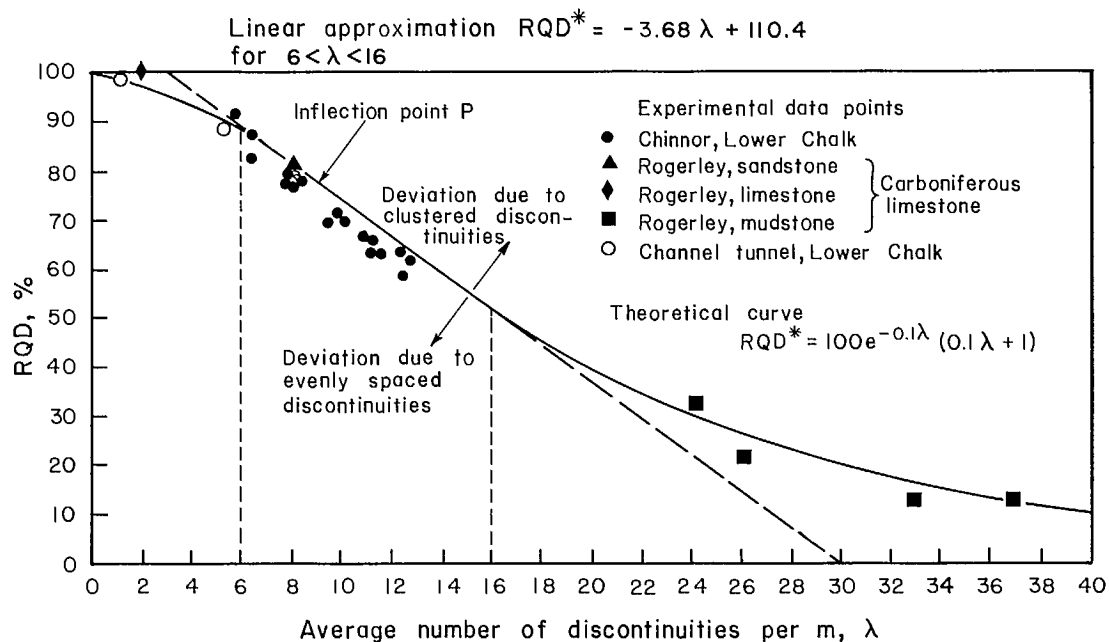


Fig 28 - Relationship of fracture spacing and RQD (22).

TESTDATA  
SIZE

```
1.5260 *****
```

\*  
\*  
\*  
\*

Total no. of discontinuities = 30

L	1.0734	*
N		*

\*  
\*  
\*  
\*

```

1  1212.0  1
2  SIZE                                83  1  6
3    20  35  60  110  200  350
4  J    K    L    M    N    O

```

0.6200 \*

\*  
\*  
\*  
\*

Testdata

P 0.1682 \*

Frequency table for variable size  
Total no. of observations = 36

G \*  
B \*

\*  
 \*  
 \*  
 \*  
 \*

X	No. less than X	% less than X
---	--------------------	------------------

E	*
D	*

\*  
\*  
\*  
\*

J	20.0	20.	55.56
K	35.0	30.	83.33
L	60.0	30.	83.33
M	110.0	30.	83.33
N	200.0	30.	83.33
O	350.0	30.	83.33

A \*

N \*

\*  
\*  
\*  
\*

Mean size                       $(1/\text{LAMBDA}) = 20.83$

) \*

\*  
\*  
\*  
\*

Testdata

\*

\*  
\*  
\*  
\*

Chisquared table for Z  
 $\text{Log}(Z) = \text{LAMBDA} * X$ , where  
 $\text{LAMBDA} = 1/\text{mean size}$   
 $X = \text{SIZE}$

\*

\*  
\*  
\*  
\*

Class limits	FE	F0	(FE-F0)**2/FE
--------------	----	----	---------------

\*

\*  
\*\*

0.0 - 1.33	9.	20.	13.4
1.33- 2.00	9.	0.	9.0
2.00- 4.00	9.	10.	0.1
4.00 over	9.	6.	1.0

```
-3.0000 *****0*****0*****0*****0*****0*****0*****
```

J	K	L	M	N	O
20.0	35.0	60.0	110.0	200.0	350.0

Chisquared = 23.56  
.245 RC = 0

Fig 29 - Analysis of discontinuity size with DISCODAT program package.

- b. stating whether or not the trace extends to the top of the slope

In addition, distance from the tape to the top of the slope must be recorded. This approach is similar to that used by Epstein (23) for testing the life expectancy of tubes. The observation can be handled by the HIST2V routine; it is suggested, however, that the collection of observations for a censored negative exponential distribution is made part of a special survey for selected sets of discontinuities after a routine DISCODAT survey.

#### WAVINESS

175. Waviness is measured to estimate peak shear resistance, because design on the basis of residual shear resistance can be unnecessarily conservative and wasteful. Roughness refers to the small irregularities existing on rock surfaces, and waviness refers to the larger undulations in the order of feet or metres which are not represented in the size of a typical test specimen subjected to direct shear. Material bridges can provide an additional source of shear resistance.

176. Both waviness and roughness contribute to peak shear resistance when a block of rock is moved from an initially seated position (Fig 30). Conceptually, waviness refers to undulations on a shear surface that are not destroyed during shearing, whereas most of the roughness is crushed even under moderate normal stresses. Measurements of waviness can therefore be used to estimate the geometric component ( $d$ ) of shear resistance (dilatancy) as expressed in:

$$\tau = \sigma_n \tan(\phi + d) \quad \text{eq 22}$$

177. A measurement of waviness can be made by placing a 24 in. (60 cm) clinorule on a rock surface in the direction of potential movement and measuring the interlimb angle (Fig 31). For plane shear instability the interlimb angle would be measured in the down dip direction of the discontinuities and for a wedge instability in the direction of their intersection. Subtracting the interlimb angle from 180 and dividing by two gives the waviness angle, which describes the expected dilatancy ( $d_0$ ) for that particular surface.

Testing is necessary to evaluate whether under the given conditions this expected dilatancy will be effective.

178. From back analysis, we know that the effective dilatancy will rarely exceed 10°. For this purpose, it is worth plotting a histogram of the measured waviness angles against frequency (Fig 31). The apparent angle of friction expressed by:

$$\tan(\phi + d)$$

can in no case exceed the internal angle of friction of the wall rock material and is generally lower than the peak shear resistance from a laboratory direct shear test. For more detailed descriptions, the chapter on Mechanical Properties should be consulted.

#### STRENGTH OF INFILLINGS AND FRACTURE SURFACES

179. Descriptions of fillings or wall characteristics of discontinuities (Appendix A-40) can be plotted on equal-area nets with the relevant orientations, and a check for systematic trends can be carried out (Fig 32). If structural features with critical orientations possess soft or low-friction fillings, samples should be taken and the Mechanical Properties chapter should be consulted.

#### GROUNDWATER

180. Mapped groundwater occurrences as discussed in Appendix A, paragraph 43 should be plotted on the geological map, and a preliminary assessment of the water level and the groundwater flow carried out. An assessment of whether discontinuities will act as groundwater barriers, or as ground water channels, will be of great value. The Groundwater chapter should be consulted for details.

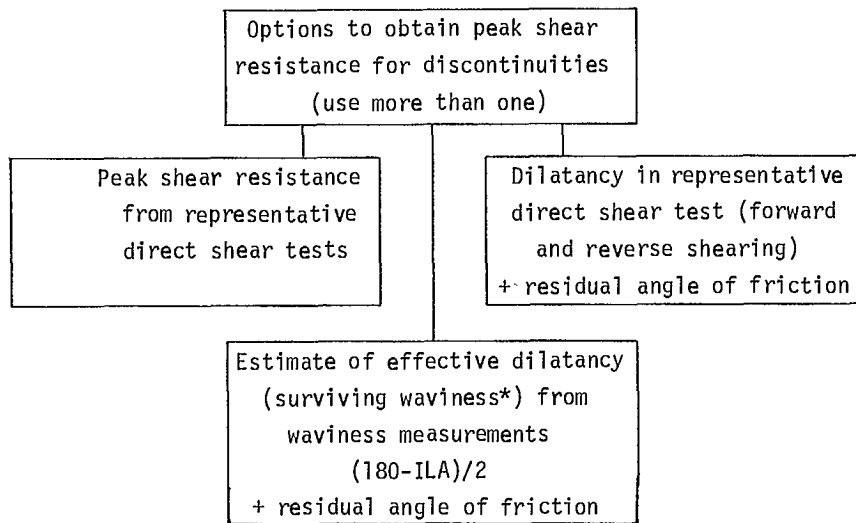
#### STRUCTURAL DOMAINS AND DESIGN SECTORS

181. After the results of the geological investigation have been plotted and analyzed, it is necessary to carry out a check on the adequacy of the structural domain boundaries chosen during reconnaissance mapping. This can be done

For sliding to occur, roughness has to be gouged and material resting on discontinuity has to be lifted over surviving waviness. This uplift can be measured and forms the geometric component (Dilatancy  $d$ ) of shear resistance of discontinuities.

Minimum: Residual or basic friction  $\tau = \sigma_n \tan \phi$

Maximum: Peak shear resistance  $\tau = \sigma_n \tan(\phi + d)$   
 (not exceeding intact rock strength of discontinuity walls) ↑  
dilatancy



\* rarely exceeds  $10^\circ$

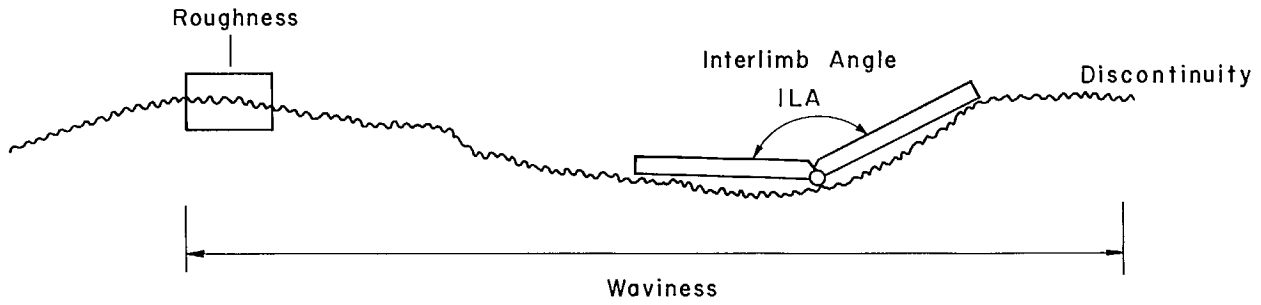
Fig 30 - Peak shear resistance of discontinuities.

graphically or numerically beginning with the orientation of discontinuities.

182. In most cases plotting mean discontinuity orientations on a survey plan will show whether the orientations of discontinuity sets stay the same, vary continuously, or whether there are abrupt changes which require further division of a structural domain. For a numerical assessment, Supplement 2-2 provides further details. Slight changes of mean orientation are generally of little consequence on overall design; they may become important, however, if the orientations of discontinuities have to be extrapolated into

unknown sections of pit walls.

183. The next step after defining structural domains is to define design sectors (Fig 33) in which the types of discontinuities and their orientations with respect to the pit wall are similar. At this point it has to be considered that structures of the same orientation will have different effects on opposite walls of the pit. Straight or curved sectors of the pit have to be considered separately. By superimposing the anticipated pit outline on the map showing major structures, rock types and minor discontinuity orientation, slope sectors of similar conditions



TALLJA

HISTOGRAM 3 -  $(180-ILA)/2$ 

Frequency	19	0	2	3	4	4	6	3	8	11	12	6	4	4	11	11	5	4	4	1
Each * equals	1	points																		
19	*																			
18	*																			
17	*																			
16	*																			
15	*																			
14	*																			
13	*																			
12	*										*									
11	*									*	*				*	*				
10	*									*	*				*	*				
9	*									*	*				*	*				
8	*								*	*	*				*	*				
7	*								*	*	*				*	*				
6	*						*		*	*	*	*			*	*				
5	*						*		*	*	*	*			*	*	*			
4	*				*	*	*		*	*	*	*	*	*	*	*	*	*	*	*
3	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Interval	.0	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
Class																				
Mean = 6.4																				
St. Dev. = 4.22																				
No. of observations = 162																				
No. of discontinuities = 682																				
↑																				
field dilatancy ( $d_0$ )																				

Fig 31 - Principle of and output from waviness measurements.

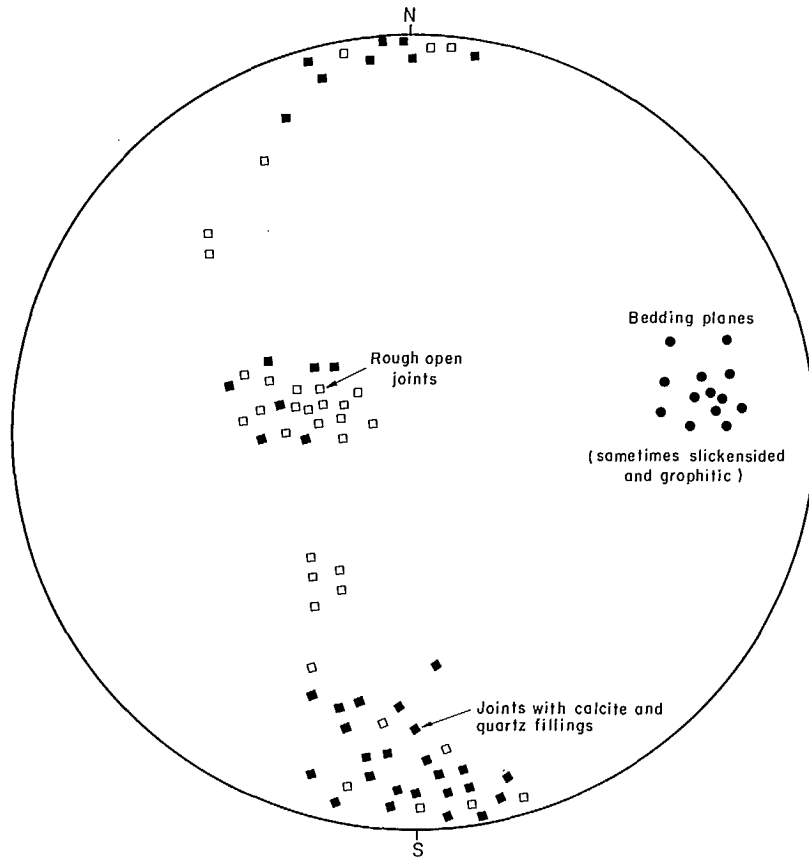


Fig 32 - Fracture sets showing different wall characteristics and in-fillings.

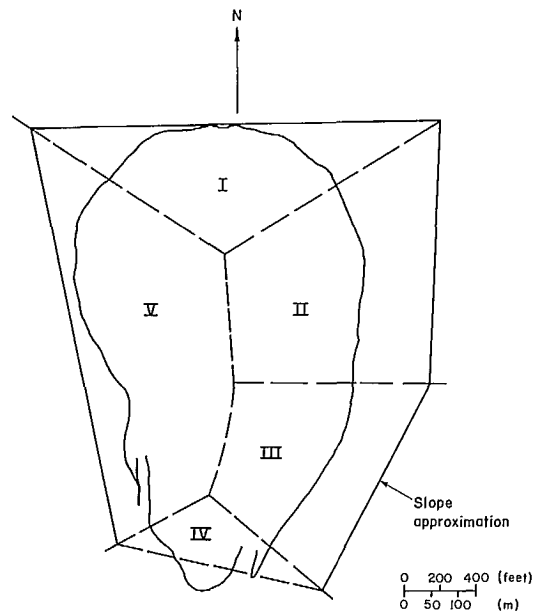


Fig 33 - Pit plan with design sectors.



can be delineated.

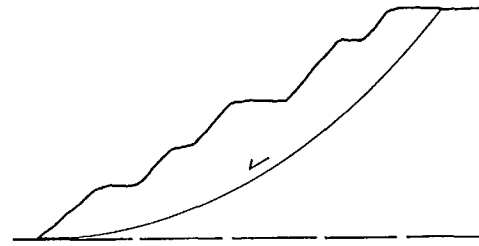
#### KINEMATIC ANALYSIS

184. Kinematic analysis defines the various modes of rock transport during the development of instability in slopes. From observations and analysis of slope deformations three basic types or modes can be distinguished (Fig 34). These are:

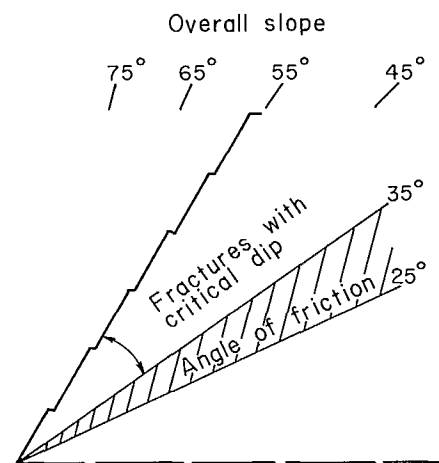
- a. Rotational Shear. This occurs in soil-like materials (see Class S - Appendix A, para 53). Typical is the development of a curved shear surface which passes through or below the toe and intersects the crest with a steep angle, or joins a tension crack. Extremely fractured hard rock can show an instability mode as in Fig 34-a.
- b. Plane Shear Along Discontinuities. This occurs in hard rock which contains discontinuities with a dip component into the pit larger than the expected friction angle, eg,  $25^\circ$ , but shallower than the planned slope face, eg,  $45^\circ$ - $70^\circ$ , (Fig 34-b). A number of very complex deformation patterns can develop such as wedges, stepped shear, etc.
- c. Block Flow. Block flow can occur in areas of deep weathering (eg, slope creep) or in hard rock where high stress concentrations occur in the toe area, eg, appearance of toppling as in Fig 34-c. Critical stress concentrations can occur if hard rock contains closely spaced parallel discontinuities dipping steeply into the slope.

185. If rotational shear failure is suspected, testing with the aid of the chapter on Mechanical Properties is necessary. The potential of block flow, or toppling failure, is difficult to assess unless natural slopes in the vicinity provide guidance. Further details can be obtained from the Design chapter.

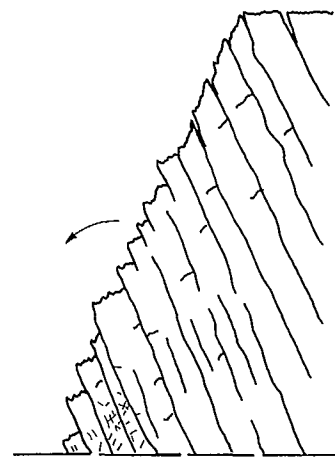
186. Regarding the various plane shear instability modes, purely geometric considerations connected with some field experience can evaluate the probability of sliding. Here the equal-area net is of considerable assistance. In Fig 35, a few typical examples of different instability modes are given. These include: simple plane



(a) Rotational shear



(b) Plane shear



(c) Blockflow

Fig 34 - Typical cases of slope instability.

shear, stepped plane shear and 3-d wedge. Some basic points are graphically displayed in Fig 36 and 37.

187. Figure 36 shows the graphical treatment of simple plane shear in an equal-area net. Cross section 36-a gives a typical section with 36-b showing the stable dips of discontinuities due to friction. Figure 36-c represents Fig 36-a and b in an equal-area net. Figure 36-d shows the range of discontinuity dips which might be obtained from a pole cluster. Figure 36-e shows how to obtain the probability of sliding,  $P_s$ , from the cumulative frequency percentage of dip angles.

If the strikes of the slope face and those of the discontinuities do not agree, a graphical solution of the two dimensional normal distribution can be used (11, 14). Following assessment of the probability of sliding, the probability of instability,  $P_I$ , from trace-length, spacing data and slope volume can be calculated by means explained in the Design chapter.

188. In the case of stepped shear instability, two discontinuity sets form the failure surface. In this failure mode the two sets have different functions. Set I is the active set on which sliding takes place, whereas set II provides the

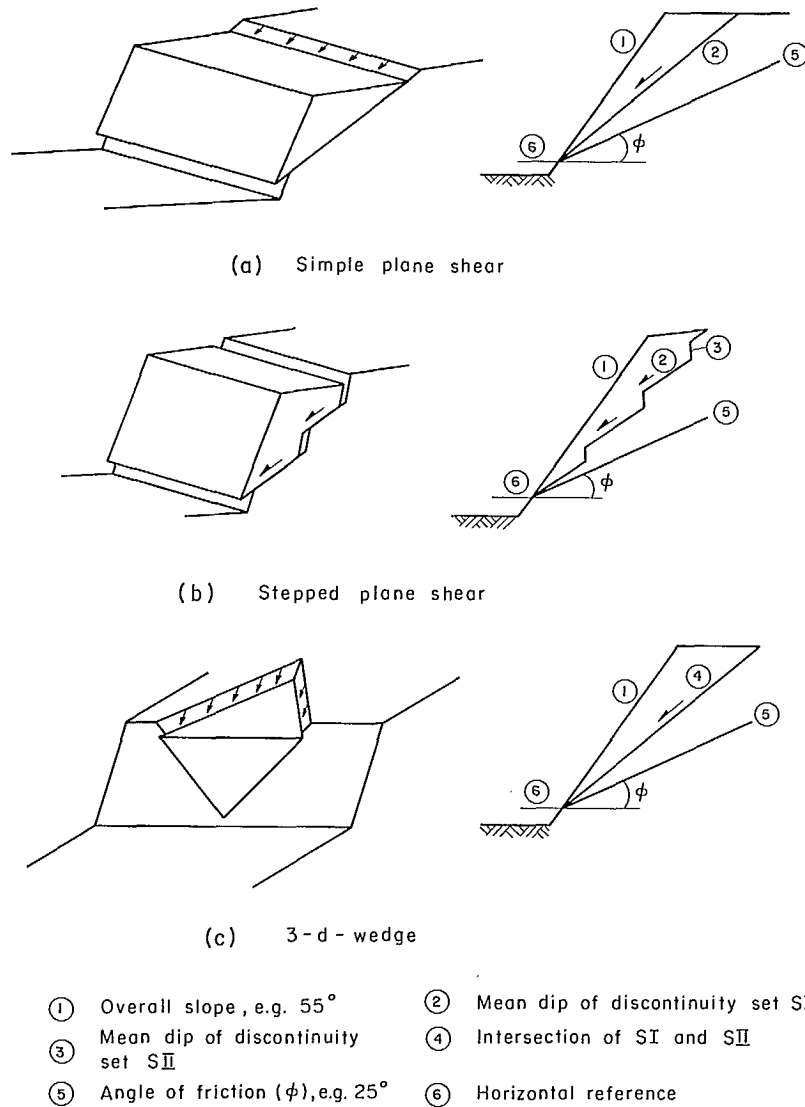
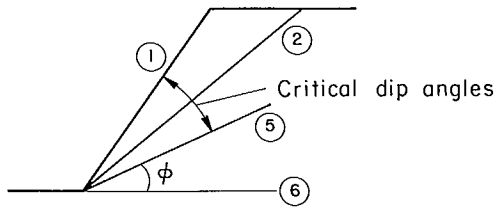
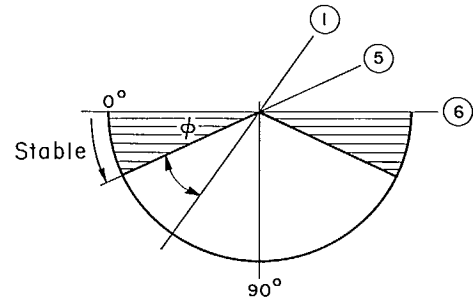


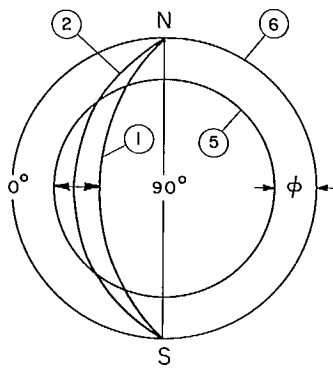
Fig 35 - Typical cases of plane shear instability.



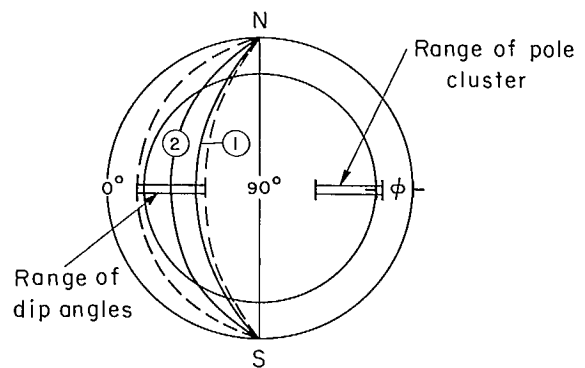
(a) Cross section of simple plane shear



(b) Cross section of lower hemisphere of equal area net with stable dip angles due to friction ( $\phi$ )

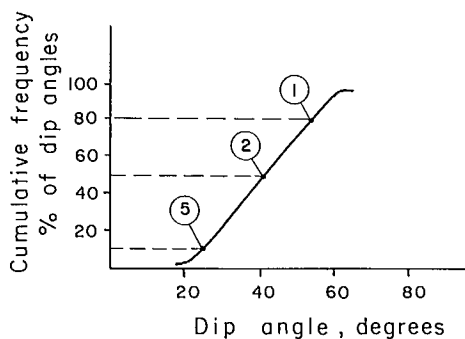


(c) Equal area net presentation of (a) showing range for critical dip angles



(d) Range of discontinuity dips from pole cluster

All discontinuities with dip angles  $< \phi$  are stable  
All discontinuities with dip angles  $> \phi$  are unstable



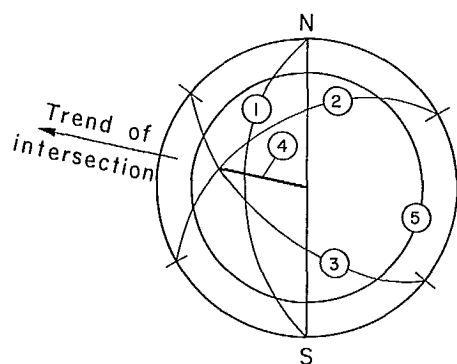
(e) Cumulative frequency percentage of dip angles

Cumulative frequency % dip  $> 5 = 90\%$

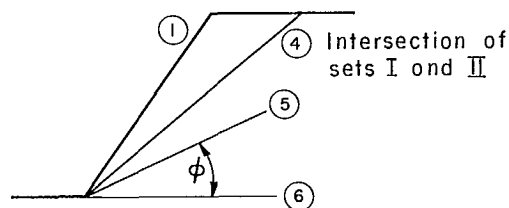
Cumulative frequency % dip  $> 1 = 20\%$

$$P_s \approx 0.9 - 0.2 = 0.7$$

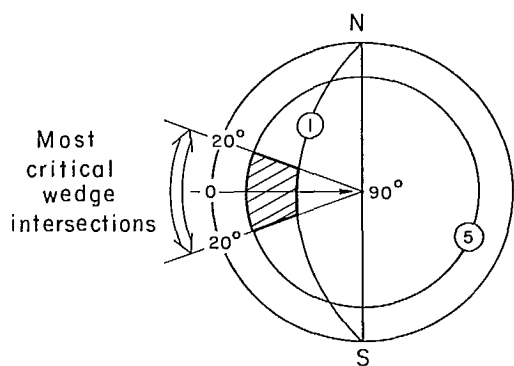
Fig 36 - Steps to analyse probability of sliding for plane shear instability (for explanation see fig 35).



(a) Determination of intersection from mean orientation of sets I and II



(b) Section of wedge instability



(c) Area of critical plunge and trend

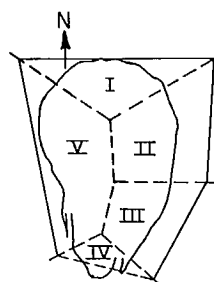
Fig 37 - Determination of critical plunge and trend of intersection for wedge forming discontinuity sets (for explanation see fig 35).

necessary separation surface (Fig 35). As the separation is effective whether the apparent dip of set II is steep or shallow the probability of sliding is dependent only on the distribution of dip angles of set I. Set II however influences the probability of occurrence as discussed in the Design chapter.

189. Wedges are formed by two or more discontinuity sets. Critical wedges require that the line of intersection between the two discontinuity sets forming the wedge plunges at an angle steeper than the angle of friction, and shallower than the slope face. Figure 37 shows the steps to assess the most critical wedge intersections. In cases

where the potential instability modes are not clear, base friction models can help.

190. In calculating the probability of sliding, one enters the area of numerical design. The geological data collection and analysis are complete at the point where a description of preliminary design sectors can be given and the instability modes have been identified. An example of a summary sheet providing the analyzed geological information for a typical case is given in Fig 38 to 41. On the basis of this information testing programs and numerical design can be developed.



Design sector	I	II	III	IV	V	
Slope						
Dip direction	180	273	299	014	079	
Dip	50	50	50	50	50	
Rock strength						
	R3-R4	S3-S4	R4	R4	R3-R4	
Major faults						
	-	middle shear	H/W shear	-	F/W fault	
Dip direction and dip		145/45-55	085/60	-	085/60	
		325/85	015/65		265/65	
Infilling						
crushed rock	-	✓	-	-	✓	
gouge	-	-	✓	-	-	
width	-	30m	1m	-	20m	
Extent	-	450m	400m	-	1000m	
Waviness	-	14°	8°	-	10°	
Minor discontinuities						
Plot no.	P <sub>4</sub>	P <sub>5</sub>	P <sub>6</sub>	P <sub>1</sub>	P <sub>2</sub>	P <sub>3</sub>
Sets	S <sub>1</sub> , 2, 4	S <sub>1</sub> , 2, 4	S <sub>1</sub> , 2, 3	S <sub>1</sub> , 2, 3, 4	S <sub>1</sub> , 2, 3, 4	
Mean dip vector (range, N*)						
S <sub>1</sub> (bedding)	070/65 (12, 15)	068/70 (14, 6)	102/63 (20, 5)	075/60 (10, 12)	072/40 (35, 20)	072/65 (10, 8)
S <sub>2</sub>	170/70 (35, 7)	160/80 (80, 4)	200/70 (50, 7)	160/85 (80, 5)	165/75 (32, 8)	165/85 (30, 9)
S <sub>3</sub>	275/20 (60, 20)	237/25 (44, 9)	297/40 (65, 5)	240/70 (35, 9)	270/85 (41, 7)	268/70 (40, 3)
S <sub>4</sub>	-	-	-	075/08 (50, 8)	285/20 (62, 2)	212/35 (40, 5)

Fig 38 - Compilation of geological data for design sectors I to V from figures 13 to 14 (\*N = number of observations).

Design sector	Rock type	Discontinuity type	Characteristics, mean (number of observations)			
			Length [feet]	Spacing [feet]	Haviness (180-ILA)/2	Fillings, roughness
I	Shale	S <sub>1</sub> , bedding	∞	0.05 (30)	3.5 (12)	tight, smooth
	Dolomite	S <sub>1</sub> , bedding	∞	0.5 (15)	10.1 (16)	tight, smooth
		S <sub>2</sub> , E-W joints	18 (12)	4.1 (4)	8.4 (16)	qtz-calcite filling, rough
		S <sub>4</sub> , shears	15 (8)	2.1 (12)	2.5 (13)	tight, smooth
II	Leached and sheared	S <sub>1</sub> , bedding	∞	0.1 (35)	3.9 (6)	open, deeply weathered
		S <sub>2</sub> , E-W joints	17.5 (8)	3.9 (7)	9.1 (4)	open, rough
	Dolomite	S <sub>4</sub> , shears	35 (9)	2.5 (3)	4.9 (5)	tight, smooth
III	Siliceous	S <sub>1</sub> , bedding	∞	2.1 (26)	5.8 (11)	closed, rough
	Dolomite	S <sub>2</sub> , E-W joints	12.8 (12)	8.0 (6)	11.4 (13)	qtz filled, rough
		S <sub>3</sub> , shears	19 (14)	3.1 (5)	5.5 (12)	tight, smooth
IV	Shale	S <sub>1</sub> , bedding	∞	0.02 (19)	4.6 (6)	closed, graphitic
		S <sub>2</sub> , E-W joints	35 (3)	3.5 (10)	8.7 (7)	calcite filled rough
		S <sub>3</sub> , shears	22 (5)	6.6 (11)	3.0 (8)	tight, smooth
		S <sub>4</sub> , joints	8 (12)	8.1 (5)	8.5 (4)	open, smooth
V	Sheared	S <sub>1</sub> , bedding	∞	0.01 (14)	3.4 (3)	closed, slickensided
	Carbonaceous	S <sub>2</sub> , E-W joints	20 (15)	2 (31)	7.6 (4)	calcite filled, rough
	Shale and	S <sub>3</sub> , shears	18 (8)	1.1 (16)	3.9 (7)	tight, minor graphite
	Shale	S <sub>4</sub> , joints	15 (21)	10 (12)	7.0 (2)	open, smooth

Fig 39 - Compilation of characteristics of minor discontinuities for design sectors I to V by mean and number of observations.

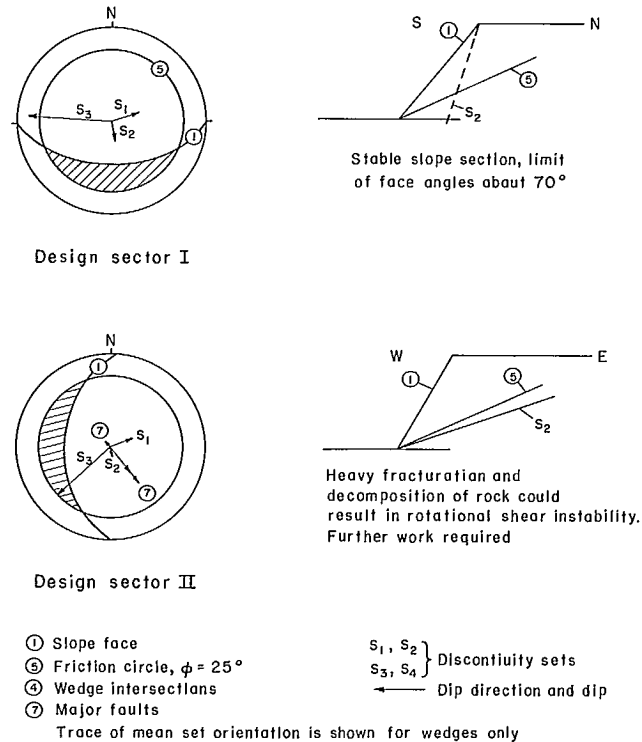
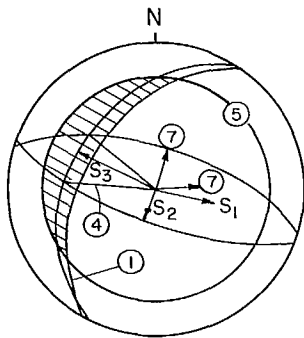
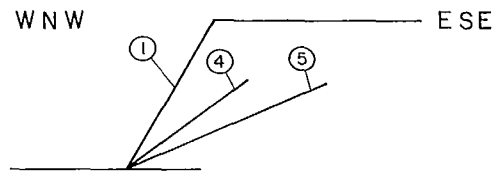


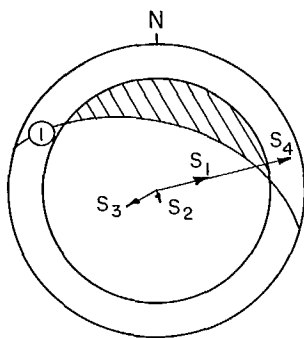
Fig 40 - Kinematic analysis to identify potential slope problems for design sectors I and II.



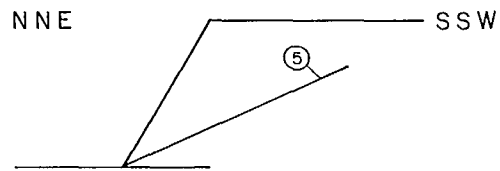
Design sector III

④ Wedges at  $35^\circ$  from sets  $S_2$  and  $S_3$ 

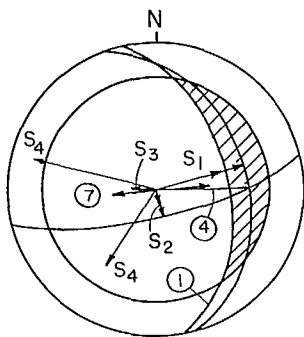
⑦ Hanging wall shear



Design sector IV



Stable slope section



Design sector V

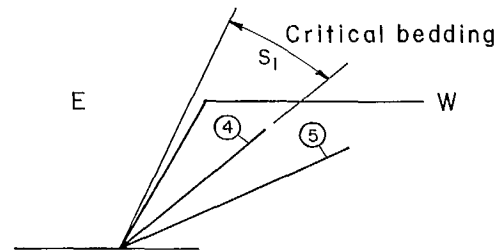
④ Critical wedges at  $40^\circ$ , check shear resistance for bedding direction in case of undercut

Fig 41 - Kinematic analysis to identify potential slope problems for design sectors III to V.



## REQUIREMENTS DURING THE FEASIBILITY STAGE

### OBJECTIVES

191. The feasibility stage of mine development defines the economic potential of an orebody which requires, among other factors, determination of the mining costs on the basis of existing ground conditions. Often feasibility studies are based on excavation experience and the mining equipment to be used. As the excavation effort is directly related to slope stability, geotechnical assessments will be more critical in marginal situations of ore grade. The effect of geological conditions on mine slopes is fundamental and will influence working conditions throughout the life of the mine. To avoid unnecessary risks and to allow educated decisions, three kinds of engineering geological information should be obtained during the feasibility stage.

### Rock Types

192. Rock types have to be delineated and the rock substance has to be classified according to strength. Areas of alteration, weathering, leaching and intensive fracturing have to be delineated to establish whether failure is likely to occur through the rock substance (Fig 13).

### Major Discontinuities

193. Faults can have the most profound influence on rock slope stability. They can form seepage zones or act as barriers to water flow. They must be accurately located and their characters carefully defined. Notes have to be made about the likely shear resistance by describing fillings, water content, and waviness. The major discontinuities must be integrated with the regional geological setting. Many orebodies are structurally controlled; hence an adequate understanding of structural discontinuities will assist not only with geotechnical assessments, but will also provide guidance for locating and controlling ore (Fig 14).

### Minor Discontinuities

194. The minimum requirement during the feasibility stage is to document the joint sets with regard to mean orientation (Fig 14). A choice has to be made at some point as to the minimum length of discontinuity to be recorded. As the investigation is aimed at both bench and overall slope design, neglecting features of less than 6 ft (2 m) in extent is usually of little

consequence. Spacing and length of fractures are difficult to assess, and at this stage of mine development only estimates of their effect on slope stability and water permeability are possible.

195. Further details can rarely be obtained during the feasibility stage as time restraints, lack of exposure, and lack of funds may pose restrictions. Emphasis, therefore, has to be placed on reconnaissance and judgement with the aim of reducing assessments to an acceptable risk. Full documentation by reports is necessary during this stage of development.

#### SOURCES OF INFORMATION

196. A complete review should be made of relevant mine files as well as of published geological information on the area. The following sources should be consulted:

##### a. Mine Files

Any exploration effort at the potential mine site will have included geophysical exploration, geological mapping of outcrops, trenches, adits and logging of boreholes. Either old records have to be used, or if core material is still available, it has to be logged for geo-technical purposes.

##### b. Regional Geology, Geological Maps, Publications

Geological Survey of Canada,  
601 Booth Street,  
Ottawa, Ontario K1A 0E8

##### c. Previous Exploration Work, Drilling and Reports on Particular Properties

Provincial Mines' Offices

##### d. Topographic Maps

Map Distribution Office,  
Surveys and Mapping Branch,  
615 Booth Street,  
Ottawa, Ontario K1A 0E4

##### e. Aerial Photographs

To supplement field mapping and to provide a mapping base from low and high level photographs, consult,

National Airphoto Library,  
Surveys and Mapping Branch,  
615 Booth Street,  
Ottawa, Ontario K1A 0E4.

More limited collections of aerial photographs are available from provincial governments and private sources (Appendix D). Photographs are useful in planning field work, detecting naturally unstable slopes, locating prominent linear features, and providing a general overview of the regional geology of the area.

197. Previously recorded information will assist in formulating an engineering opinion of the site but will require follow-up in the field. This will include field mapping of natural exposures and drilling in the prospective pit area as outlined below.

#### FIELD WORK

198. Conventional geological reconnaissance mapping is conducted to assess basic rock types, delineate major geological structures, eg, faults, dykes, lithological contacts and areas of heavy fracturing and weathering. Plane table, airphoto and other techniques listed in this text will assist with this mapping.

199. Having acquired an appreciation of the general geology in the field, the next step is to estimate particular areas of the rock mass which appear to be similar in a structural sense. This leads to the definition of structural domains which are often controlled by major structures. After structural domains are defined, a detailed mapping program can be established. The geological investigation is concentrated in areas where stability problems are most likely to occur.

200. At this point the severe lack of natural exposures might be of considerable hindrance in obtaining information. Overburden thickness can be determined by geophysical means, and shallow overburden by trenching. Overburden removal to expose bedrock is not very productive unless it can be incorporated into a program of initial mine overburden stripping.

201. It is more productive to call for specific drill holes in potentially critical sites. Coordination with ore exploration might allow drilling of multipurpose holes, which may be used later for groundwater or for slope movement monitoring.

202. As previously indicated, exploration drill

holes for inclined orebodies may not have penetrated footwall strata; hence there may be a need to obtain information about the footwall strata. Logging and storage of core should comply with the system described in Appendix B. After the drill casing is pulled, the borehole should be capped, marked and located on survey plans. To maintain holes for monitoring or testing, a plastic casing can be inserted into the borehole.

203. Magnetic and seismic methods can sometimes be used at this stage to determine the orientation of major geologic structures. These methods are particularly useful for locating shallow dipping contacts or thrust faults, or for tracing out the course of dykes or other intrusions which may cross the area.

#### TIME AND COSTS

204. Mobilization of personnel and equipment will represent the most expensive item during the feasibility stage. The quickest assessment can probably be obtained from a geologist who knows the area and is familiar with slope stability evaluations. A lead time of two weeks is generally necessary to obtain previous

information.

205. Diamond drilling at about \$10-15 per ft is fairly expensive but provides essential information about the geology at depth. A program has therefore to be planned with care. Apart from drilling expenses, costs have to include supervision, core logging, core sampling, core storage, survey of drill hole coordinates, and costs of demobilization. Drilling contracts require development of cost estimates, development of binding contracts and mobilization. Lead times vary considerably with remoteness and climatic conditions, but a lead time of two months is probably a minimum. Costs are provided in the section on drill core.

206. Geophysical ground exploration with portable equipment can be obtained in many cases on four weeks' notice and relatively large areas can be covered quickly to determine overburden thickness. All geophysical results have to be checked against a few locations where reliable information of ground conditions is available. Geophysical borehole logging can be costly but may be desirable; Supplement 2-3 should be consulted for details of this work.

## REQUIREMENTS DURING THE MINE DESIGN STAGE

### OBJECTIVES

207. When the decision has been made to commence mining, the engineering staff has the responsibility to improve and complement inadequate information, and to verify assumptions made in the feasibility assessment. The basic objective of obtaining rock type distribution, major and minor discontinuities for the pit site remains the same, but with the commencement of stripping and additional drilling, better and more exposures are available to establish a more reliable data input for optimum slope design. Refinements of the basic information are as follows.

### Rock Types

208. There should be improved delineation of rock type boundaries, and a strong emphasis on description of mechanical properties. With the aid of the chapter on Mechanical Properties the assessment has to be made whether failure is likely to occur through the rock substance. An example of a rock type distribution map is given in Fig 13.

### Major Discontinuities

209. Whereas the initial versions of the mine

geological map and mine sections contained only the bare essentials, this has to be supplemented by tracing individual major discontinuities from boundary mapping (2). As the data base and analysis advance, it will become obvious which of the major discontinuities are significant, either as potential sources of instability or as controls on groundwater flow and ore distribution. Significant major discontinuities should be subject to individual stability analyses. Specific drilling and testing programs may be required to obtain sufficient information for more elaborate analyses.

### Minor Discontinuities

210. With better exposures available, more detailed information can be obtained about structural properties in each structural domain, such as dispersion of orientation, length, spacing, waviness and type of infilling. Representative joints can now be selected for testing, and minor discontinuities can be checked for common shear strength characteristics.

211. For inclined tabular deposits the footwall side of the ore zone often forms the final wall. In these cases an extensive investigation should

be performed on the boreholes drilled in the foot-wall, as the wall exposed by mining in this area will often be a final wall with no chance for redesign.

#### SOURCES OF INFORMATION

212. With the information already incorporated in the feasibility stage, new information can be obtained from geophysical investigations, from the stripping operation and drilling programs. If new exposures are mapped as soon as possible, access problems are minimized, and the work can proceed as part of the mine routine.

213. With considerable amounts of data collected during the mine design stage, data storage becomes important and reports have to be prepared. Most of the geological correlations will be carried out on plans and sections, and thus rock type boundaries and major structures will be documented on maps. The symbols and principles of Appendices A to C should be incorporated.

#### FIELD WORK

##### Core and Drill Hole Evaluation

214. All orientation, logging, photography, and testing of core must be carried out before it is split. In poor quality ground, core orientation may be impossible due to poor recovery. In these conditions, down-the-hole logging such as borehole photography or television cameras, periscopes and geophysical tools, might be helpful.

215. When planning structural drilling programs, the need for boreholes to accept instrumentation such as inclinometers, piezometers, thermistors, extensometers, etc, should be considered. Ideally, boreholes near the proposed pit perimeter should contain monitoring devices to provide long term stability information for final wall design.

216. Seismic and acoustical surveys can be used to advantage to log boreholes for additional structural data, such as in borehole sections where core recovery has been poor. Measurement of seismic velocities of the rock mass by either surface or borehole surveys could also be used to give some indication of rock quality.

#### Field Mapping

217. A detailed surface geologic map should be made of the stripped surface areas at a scale which the mine intends to use for its geological mapping during development and production.

218. It is advisable to compile geology on both a large and small scale. For a large pit an outcrop map such as 1 in. = 100 ft, or 1 in. = 200 ft (1:1000 to 1:2000, will give a drawing of convenient size, whereas a large scale map at 1 in. = 50 ft or 1 in. = 40 ft (1:500 to 1:400) is best suited to present more detailed information. Where considerable detail is required, a scale of 1 in. = 20 ft (1:200) can be used.

219. It is important that the outcrop maps are developed and constructed with accurate survey control. This involves plane table or transit mapping methods or an accurately surveyed grid within which the geologist can map with compass and tape. The mine survey team will assist in picking up the reference points as the geological mapping progresses.

220. With heavy excavation equipment available, trenches can be developed at lower costs than during the exploration phase. Trenches should be accurately located and mapped to scales compatible with those of the pit maps so that the two can be readily combined. The results of the outcrop and trench mapping should be combined with those from core logs, bench, and underground mapping. This information should be transferred to a set of level plans and cross-sections for showing the geology in the pit. These drawings must be updated as the pit develops.

221. Underground openings can be used to advantage for subsurface geotechnical assessment in the design stage. Adits, crosscuts, and inclines may be available from bulk sampling of ore material for both grade and grindability assessments. Extensive subsurface work may be initiated during this stage to install an underground dewatering system, or to evaluate other parts of the ore zone.

#### PHOTOGRAPHY

222. During the mine design stage, a detailed analysis of aerial photographs should be conducted

to obtain the maximum amount of geological information before the surface area is too highly disturbed by stripping, or becomes covered by waste dumps, tailings ponds and plant buildings. High level aerial photos are usually available that show the mine site in the undisturbed state.

223. Aerial photographs are a useful aid in planning the location of the mine and mill facilities, access roads, waste dumps, and ponding areas. Airphotos may also prove useful for assessing the local groundwater regime, as well as for delineating major faults, shear zones, and rock type boundaries.

224. It is generally advisable to examine both high level and low level airphotos to evaluate the regional as well as the local geology. High level photos will probably already have been analyzed during the exploration stage. Low level photos, on the other hand, may not be available and the area may have to be flown specifically by a private company. Low level airphotos can also be used to construct an accurate base map of the proposed mine area and are useful for establishing a general ground survey grid on the property.

### COSTS

225. Information on costs for mapping and analysis during the mine design stage can be obtained from Tables 1, 2, and 3.

### REQUIREMENTS DURING THE OPERATING STAGE

#### Objectives

226. At this point the overburden stripping is complete and scheduled production is under way. As a redesign can occur at any stage of mine development, it is imperative that exposures be documented with regard to structural information. Mapping should be carried out every 200-300 ft (100 m) of advance. If this is done immediately after exposure, later problems of access are eliminated. If structural information is collected for several pit face advances, it may be feasible to present the data on a series of level plans so that structures can be correlated.

227. With some benches already developed, a map showing major structures is prepared and updated

by plane tabling, entering observations at the same scale as that used for production records. The plane tabling crew could consist of the geologist acting as rod man and a surveying assistant at the plane table. Two-way radios aid communication between crew members. A telescopic alidade might be necessary in large mines. If bench crests and toes are accurately located on the base map, it may not be necessary for the geologist to carry a rod. A useful alternative is the mapping on photo enlargements, taken with a long focal length camera (paragraph 105).

228. Minor structures can be mapped using the detailed line system as presented in Appendix A.

229. For routine mapping during the operating stage, the DISCODAT system can be very helpful as it allows a quick update of previous evaluations. Several stages of complete redesign might occur, eg, change in commodity prices, and in each case the structural analyses can become more realistic as the data base becomes more reliable.

230. With the concern during redesign directed towards selected parts of the pit, special drilling might be required. At this point core orientation will be warranted. Boreholes can be drilled now from the pit crest and from benches, making possible a variety of hole orientations.

231. Seismic refraction surveys on benches may possibly be correlated with actual geologic bench mapping to obtain a qualitative evaluation of the general ground condition or degree of fracturing. Seismic refraction surveys can be used to locate geological structures and to evaluate damage due to blasting.

232. Problems arise with drilling or mine haulage equipment operating during a geophysical survey. This can produce high background "noise" levels which can distort results and make interpretations difficult.

233. The digging of benches to examine broken rock or failures along the pit crest will be in many cases an alternative for shallow seismic work. If adits, inclines, or raises have been developed, they should be mapped as they become available.

234. Terrestrial photogrammetry is particularly useful for structural mapping of hazardous or in-

accessible pit walls. Stereophotographs can be taken and analyzed within a relatively short time.

times and costs can be estimated for routine mapping and evaluation. Some guidance is given in Tables 1, 2, and 3 and a summary is given below:

#### Costs

235. From previous activities at the pit site,

Table 9: Cost estimates for structural geological investigations  
excluding drilling costs (1974 \$)

Development stages:	Feasibility		Design		Operating	
Depth of Pit	Man Days	Cost	Man Days	Cost	Man Days	Cost
100 ft (30 m)	5	1500	15	4500	35	10500
100-1000 ft (30-300 m)	15	4500	40	12000	120	36000
1000 ft (300 m)	20	6000	50	15000	160	48000



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## APPENDIX A

### THE DISCODAT FIELD GUIDE



## INTRODUCTION

1. DISCODAT is a computer-based system to aid the collection, retrieval and manipulation of data on discontinuities in rock masses. It aims to relieve the geologist of much of the tedious clerical work involved in transforming his observations into a model for the designer, but makes no attempt to supplant his judgement.

2. The components of the system are two forms for recording field observations, and computer software for retrieving, manipulating and displaying the data. This guide describes only the use of the coding forms. Though it offers some reasons for the rules it lays down, full appreciation of the logic of DISCODAT requires study of the analytical procedures. While the system has considerable flexibility, restrictions on the use of the coding forms should not be violated without considering the problems this may cause in the computer programs.

3. Use of the system requires that the site has been mapped beforehand by conventional reconnaissance mapping and that preliminary domain boundaries have been delineated. This requires an elementary knowledge of geology, and a text such as "Manual of Field Geology" (1) will supplement the information presented here. Following the reconnaissance, detailed line traverses are

laid out and the observations along a line are recorded.

### RECORDING SHEETS

4. The recording sheets are reproduced in Fig A-1 and are called 'Traverse line' and 'Discontinuity data' sheets respectively. Both sheets can be used as separate cards in the field or together on an 8-1/2 x 11 in. sheet as shown.

5. The traverse line sheet records information which is common to the whole traverse line. This includes the grid coordinates of the start of the traverse line and its elevation, the direction of the line, the structural domain, the rock formation covered, the reference direction of the observations, and the geologist's personal identification code. If an open pit mine is being mapped, the pit bench and its location can also be recorded.

6. Discontinuities along the traverse line are described under the appropriate headings by number, distance from origin of traverse, type, orientation, length, spacing, filling, water content and waviness. Type and orientation of any linear structures on the discontinuities can be recorded, including rock type and its hardness.

7. DISCODAT is suited to both detailed

## LINE MAPPING SHEET

### TRAVERSE LINE

Card Type	Identification	Elevation	Dmn.	Formatn.	Pit Bench		
					Level	Location	
0 1 0 1							
Local Grid		Traverse				Nos.	Reference
Northing	Easting	Trend	Plunge	Length	Sc.	Obs.	Direction
Remarks:							

## DISCONTINUITY DATA

[illegible]

Fig A-1 - Line mapping sheet.

mapping of adits and along benches in mines, and to the logging of drill core.

#### RECORDING RULES

8. The following rules for recording aim at making the completed forms as legible and unambiguous as possible:

- a. all letters should be capitals
- b. all numbers should be right-hand justified
- c. no decimal points should be inserted
- d. the letter "O" should be written Ø to distinguish it from the number zero
- e. one is indicated by a simple vertical line and distinguished from the letter "I" by the horizontal bars on the top and bottom of the "I"
- f. care is necessary to keep the letter "Q" distinct from the letter "O".

#### MNEMONICS

9. Tests show that data recording is slowed and errors occur if much numerical coding of non-quantitative information is used. These errors could have serious consequences for the entire analysis. Using mnemonically coded abbreviations reduces the likelihood of recorder error and simplifies checking the forms. Mnemonics are generated as follows:

- a. preserve the first letter of all words

b. delete in order a, e, i, o, u, w, h, y

c. delete one of each double

d. delete in order t, n, s, r, l, d

e. truncate from right to required number of letters.

10. A mnemonic should have only one meaning in a data bank. As mnemonics are defined, they should be recorded on the traverse line sheet under "remarks". Transcribing definitions and further remarks from these sheets to a set of file cards may help keep records consistent within the bank.

#### UNITS

11. The manual has been written in Imperial Units, with Systeme Internationale (SI) in brackets. A choice of the system of units to be used should be made and maintained for each data bank constructed. Grid coordinates and elevations should be measured in the same unit. For example, elevations should not be given in tenths of a foot and grid coordinates in metres. The same holds for the traverse length and the discontinuity distance. The units of traverse length may be varied, however, by powers of ten from traverse to traverse by altering the traverse scale (paragraph 24).

## TRAVERSE LINE

### IDENTIFICATION

12. First, traverses are selected and marked with flagging tape. Short concrete nails (1-1/2 x 1/8) have been found very useful to hold the tape (Fig A-2). The identification of the traverse line is marked on both recording sheets. This is essential for sorting data.

13. The identification number is formed by placing the year in the first column, ie, 1971 = 1, 1972 = 2, etc., the observer's initials in the next two columns, and the station number in the final columns; maximum station number is 9999.

### ELEVATION

14. The elevation of the start of the traverse line is given above some datum. Elevations below the datum are indicated by a leading negative sign. No blank spaces should be left between the negative sign and the number representing the elevation. Details of the datum level should be carefully recorded. Only one datum can be used in each data bank.

### DOMAIN

15. A preliminary analysis of the geology of the area should allow its division into areas in which the fabric of the rock mass is statistically

homogeneous. These areas are termed domains.

### FORMATION

16. The geological formation or unit to which the lithology belongs is recorded by a 3-letter mnemonic formed by the rules of paragraph 9.

### PIT BENCH

#### Level

17. Bench levels, as defined by the system at the mine, are recorded in four columns. Popular systems include numbering consecutively from the top of the pit downwards, or recording the height from bench to surface.

#### Location

18. This accepts a four letter code for the location of the bench face.

### LOCAL GRID

19. Space is provided for any local numerical rectangular grid coordinates of the start of the traverse line. Numbers should be positive, decimal points omitted. The easting is marked in the first six columns and the northing in the next six columns. Details of the origin of the grid





Fig A-2 - Preparation of traverse station.

should be carefully recorded. Again only one grid system can be used in each data bank.

## TRAVERSE

### Trend

20. Trend of the traverse line is measured in degrees clockwise from true north (Fig A-3a). Trends directed to true north should be recorded as 360. No record indicates that no observation was made.

21. In a magnetically disturbed area the required value of the trend cannot be entered immediately. The minimum information necessary is an accurate location of the start of the traverse, a bearing onto some distant object whose position is known, and the bearing of the traverse. These two bearings can be made with a Brunton compass and entered under "remarks" on this sheet.

### Plunge

22. Plunge is the inclination of the line of traverse to the horizontal. Zeros indicate a horizontal traverse line; uphill traverses are indicated by a leading negative sign (Fig A-3b).

### Length

23. The total length of the traverse line is recorded in the same unit as distance as discussed in paragraph 29. The option exists to increase the basic unit of measurement by powers of 10 using the traverse scale (Fig A-3c).

## Traverse Scale

24. For reconnaissance mapping, topographic control may be less precise and distances perhaps determined only by pacing. The traverse scale allows the basic unit of distance measurement, whether it is 0.1 ft or 0.1 m, to be increased by powers of 10. To increase the unit to 1 ft or a metre, write 1 in the traverse scale field; to 10 ft, write 2, etc. The same scale factor will also apply to distance measurements on the discontinuity data sheet.

## REFERENCE DIRECTION

25. The reference direction is the angle that should be added to the recorded strike of a discontinuity observed on the traverse, to convert it to the dip direction of the discontinuity.

26. Generally the strike of discontinuities will be measured with a Brunton compass adjusted to read true north. Then the reference direction is 90°. If the regional magnetic field is locally distorted, a clino-rule may be used, and the reference direction is then the trend of the traverse minus 90°. If this quantity is less than or equal to 0°, add 360° and enter the result. If a Freiberg or Clar geological compass has been used and adjusted to read true north, the space should be filled with zeros.

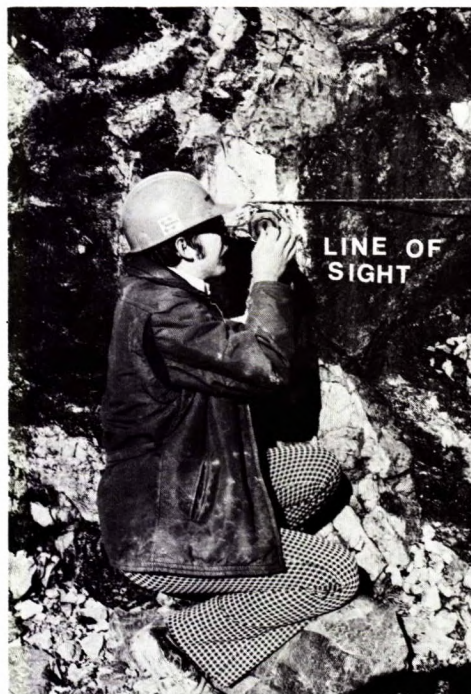
## REMARKS

27. This space accepts information on date of mapping, duration of exposure of rock face, more detailed descriptions of rocks, reliability of exposure, etc.





(a) Measuring the traverse trend with a Brunton compass.



(b) Measuring the traverse plunge with a Brunton compass.

Card Type	Identification	Elevation	Dmn.	Format	Pit Bench
* 0101	0700103				Level Locn.
Local Grid					
Easting	Northing	Traverse		Nos. Ref.	
		Trend	Plunge	Length	Dirctn.
		111E-02	446		
Remarks - July 15, 1973 - weather sunny					

(c) Recording information on the traverse line sheet (card type 01) for the detailed line mapping system (DISCODAT).

Fig A-3 - Measurement and recordings of trend and plunge for traverse line.

## DISCONTINUITY DATA

28. Whether a particular discontinuity is described on this sheet will depend on the scale of mapping. If the discontinuity does not appear to be sufficiently extensive, it can be ignored. When a discontinuity is penetrative, ie, when individual surfaces are very close together and are parallel, not all surfaces need be described; it is sufficient to sample the surfaces and to estimate the spacing between them. Discontinuities with an average spacing over 6 ft (2 m) should be mapped individually. Ten separate surfaces should form a sample of the discontinuity that is adequate for most purposes.

### DISTANCE

29. Record the distance along the line of traverse from the start. Units are tenths of a ft (m), decimal points are omitted, and measurement is to the point where the projected discontinuity surface would cut the tape stretched along the face. Most common length of a traverse is 100 ft (30 m).

### TYPE

30. The type of discontinuity is recorded as a two-letter mnemonic formed by the rules specified

in paragraph 9. Mnemonics follow the definition of each discontinuity type (Fig A-4).

#### Bedding (BG)

- regular layering in sedimentary rocks marking the boundaries of lithological units or beds.

#### Boundary (BD)

- surface delineating rock types of different composition or strength resulting from processes of rock formation or alteration.

#### Cleavage (CV)

- closely-spaced, parallel surfaces of fissility.

#### Contact (CN)

- surface between two rock types, one or both of which is not sedimentary.

#### Fault (FL)

- surface of shear recognizable by the displacement of another surface that crosses it. Faults can be classified by the direction of slip of the fault block which rests on the fault plane, ie, the hanging wall block. Refer to slip and separation under type of lineation.



- Gneissosity (GS) - surface parallel to lithological layering in metamorphic rocks.
- Joint (JN) - fracture in rock mass along which there has been no identifiable displacement.
- Schistosity (SC) - surface of easy splitting in a metamorphic rock defined by the preferred orientation of minerals.
- Shear (SR) - surface of shear without recognizable magnitude of displacement. A shear can be recognized by slickensides, polishing, or striations on the surface.
- Unconformity (UC) - eroded surface overlain by sedimentary or igneous rock.
- Vein (VN) - fracture in rock with a filling less than 1/10 ft (3 cm) thick.



Fig A-4 - Measurement of location of a major discontinuity which intersects the traverse line.

31. Some discontinuities might be described by two or more terms; some faults follow bedding planes, for instance. Use the first applicable term in the following list: fault; shear; unconformity; boundary; contact; vein; joint; bedding; cleavage; gneissosity; schistosity.

## ORIENTATION

### Strike

32. Strike is the azimuth of a horizontal line on the discontinuity. If a Brunton compass is used, look up the direction of dip of the discontinuity and measure the orientation of the right hand end of the strike line. The compass should be adjusted so that directions are read in degrees from true north.

33. If a geological compass is used, record the dip direction of the discontinuity in the column headed "strike". Again, the compass should be adjusted to read in degrees from true north.

34. The regional magnetic field may be locally distorted by some orebodies, by equipment and metal pipes within five paces of the outcrop. In such cases, traverse directions should be arranged so that the rock face lies to the observer's left when facing in the traverse direction, that is, looking down the traverse. Then, looking down the traverse, measure in a clockwise sense the angle from the trend of the traverse, or zero degrees, to the strike line using a clino-rule (Fig A-5). One end of the rule should be horizontal on the discontinuity and the other parallel with the traverse tape. Refer to the discussion under reference direction.

### Dip

35. The maximum acute angle the discontinuity makes with the horizontal can be measured with a clino-rule or clinometer, Fig A-6.

36. If a clino-rule has been used to measure the strike, record the dip as negative if the dip direction is 90° anticlockwise from the measured strike direction.





Fig A-5 - Measuring the strike of a discontinuity with a clino rule.

#### SIZE OR LENGTH

37. The size of discontinuities is recorded in a coded format by estimating the largest extent in any direction and recording the appropriate size class as given below.

38. Grain sizes and the size of discontinuities are classified according to the modified Wentworth scale below.

<u>Name</u>	<u>Size Limits</u>	<u>Code</u>
	>200 ft (60 m)	N
	60 - 200 ft (20 - 60 m)	M
	20 - 60 ft (6 - 20 m)	L
	6 - 20 ft (2 - 6 m)	K
	2 - 6 ft (0.6 - 2 m)	J
Boulders	8 in. - 2 ft (0.2 - 0.6 m)	I
Cobbles	3 - 8 in. (60 mm - 0.2 m)	H
Coarse gravel	20 - 60 mm	G
Medium gravel	6 - 20 mm	F
Fine gravel	2 - 6 mm	E
Coarse sand	.6 - 2 mm	D
Medium sand	0.2 - 0.6 mm	C
Fine sand	0.06 - 0.2 mm	B
Silt, clay	<0.06 mm	A

#### SPACING

39. The average spacing between penetrative

discontinuities can be recorded using the size scale of paragraph 38. If the discontinuity is not penetrative, this field should be left blank. Spacing can also be calculated from the traverse position of discontinuities.

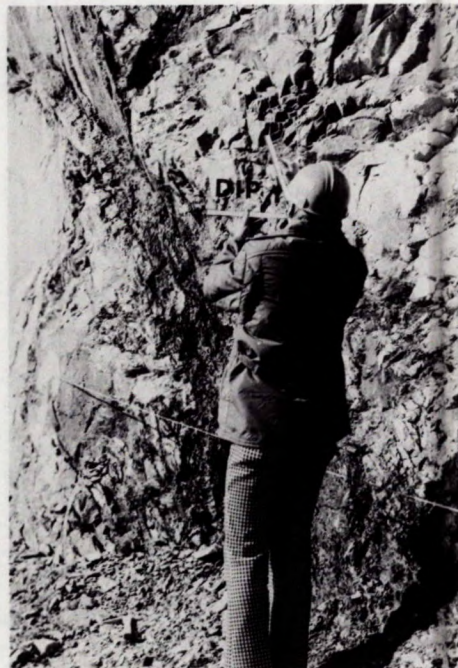


Fig A-6 - Measuring the dip of a discontinuity.



### INFILLING

40. Any rock type or mineral that is evenly distributed over the surface of the discontinuity can be recorded as a filling. Space is provided to record two types of infilling using a single letter mnemonic. The more abundant type should be recorded in the first column.

41. If the bond between the filling and the discontinuity has some tensile strength, the filling should be described mineralogically. One can easily distinguish by mnemonics: calcite (C), feldspar (F), quartz (Q), and so on.

42. If the filling is an aggregate, its grain size becomes important. We can distinguish mud (M), sand (S), breccia (B), and so on.

### WATER

43. We can distinguish:

#### Code

- 1 The discontinuity is tight; water flow along it does not appear possible.
- 2 The discontinuity is dry with no evidence of water flow.
- 3 The discontinuity is dry with evidence of past water flow, eg, rust staining of discontinuity surface.
- 4 The discontinuity is damp but no free water is present.
- 5 The discontinuity shows seepage, occasional drops of water, but no continuous flow.
- 6 The discontinuity shows a continuous flow of water (estimate litres/minute and describe pressure, ie, low, medium, high).

### WAVINESS

44. Waviness is measured by placing a clino-rule on the discontinuity surface in a direction parallel to the anticipated direction of sliding. Then open the rule until the opening arm touches the surface. Move the position of the hinge on the surface until the angle between the arms of the rule is at a minimum. Record the angle in degrees between the arms, which should be open to the full foot length when making this measurement (Fig A-7). Planes will be recorded as 180; no record indicates irregular or inaccessible

waviness.

45. The pitch of the axis of waves should be recorded under line pitch, and a fold axis should be recorded under line type (Fig A-8).

### LINE TYPE

46. The type of linear structure is recorded



Fig A-7 - Measuring the interlimb angle (ILA) of waves of a discontinuity.



Fig A-8 - Measuring the pitch of a fold axis of waves of a discontinuity.



as a two-letter mnemonic formed by the rules of paragraph 9. The mnemonics follow each definition. No record in this space indicates that no observation was made.

47. We can distinguish the following types of line:

#### Fold Axis (FA)

- the generatrix of the fold. The line which moved parallel to itself would generate the folded surface.

#### Slip (SP)

- the direction the hanging wall block has moved with respect to the footwall block. The slip direction can be measured when a point on the hanging wall can be identified with a point on the footwall or when striae can be seen.

#### Separation (SR)

- amount of displacement of a bed of rock due to faulting measured at right angles to the intersection (line) formed by the fault plane and the orientation of the bed; the component of a slip along the line of intersection remains often unknown. Most geological observations are of apparent slips or separations.

48. If more than one lineation is present, slips or separations should be recorded in preference to fold axes. If more than one lineation of the same type is present, the most obvious lineation should be recorded.

#### LINE PITCH

49. Looking up the dip direction of the plane, measure the clockwise angle on the plane from the right-hand end of the strike line of the plane to the line which is to be recorded. Use the 360° scale; an upward slip direction making an angle of 45° with the right-hand end of the strike line would be recorded as 315°. Record the downward pointing ends of axes.

50. The measurement is simply made with a clino-rule by placing one arm horizontally on the surface and opening the other until parallel with the line.

### LITHOLOGY

51. The lithology up traverse from the discontinuity being described is recorded using a three-letter mnemonic. Rock exposed down traverse, that is, in the direction of the trend of the traverse, is recorded with the next surface observation, Fig A-9.

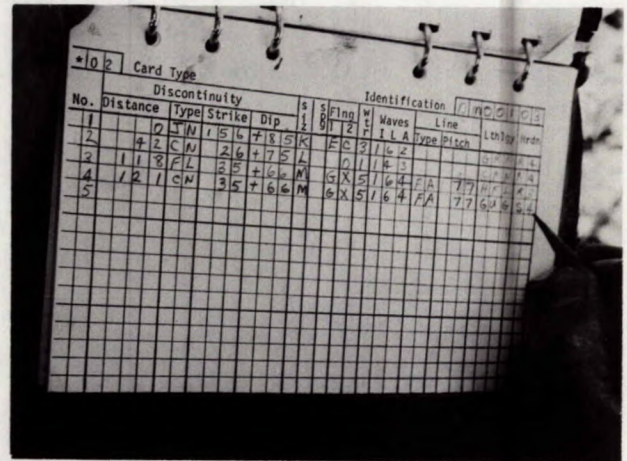


Fig A-9 - Recording discontinuity data information.

52. A list with mnemonics is given below:

### SEDIMENTARY ROCKS

#### Detrital

Unconsolidated detrital materials are classified according to grain size into

clay	< 0.002 mm
silt	0.002 - 0.06 mm
sand	0.06 - 2.00 mm
conglomerate	> 2.00 mm

The same grain size boundaries are used to classify consolidated materials.

#### Shale (SHL)

a fissile 'clay' stone composed of extremely fine-grained minerals (<0.002 mm)

Siltstone (SLN)  
indurated silt.

Ironstone (INS)  
mixture of iron, clay silica, and carbonate.

Mudstone (MDS)  
consolidated mud, sometimes also for an indefinite mixture of clay, silt and sand particles.

Pyroclastic

Agglomerate (AGM)  
consolidated angular clastic particles larger than 2 mm.

Sandstone (SDS)  
dominantly quartz and feldspar with a prevailing grain size less than 2 mm, and above 0.06 mm.

Tuff (TFF)  
consolidated ash

#### MAGMATIC ROCKS

Arkose (ARK)  
sandstone with more than 25% feldspar.

#### Plutonic

#### Volcanic

Greywacke (GRK)  
dark coloured sandstone with large angular quartz, and rock fragments, feldspar in a fine-grained 'clay' matrix. Sometimes graded bedding.

Anorthosite	ARS	Andesite	ADS
Diorite	DRT	Basalt	BSL
Gabbro	GBR	Dacite	DCT
Granite	GRN	Latite	LTT
Granodiorite	GDR	Pegmatite	PGM
Monzonite	MZN	Rhyolite	RLT
Peridotite	PRD	Trachyte	TRC
Syenite	SNT		

Conglomerate (CGM)  
consolidated and rounded clastic particles larger than 2 mm.

#### Biogenic

Chert (CHR)  
composed of silica with grain sizes less than 0.004mm; can be bedded, nodular or massive.

The nomenclature of magmatic rocks is explained in Table A-1.

#### METAMORPHIC ROCKS

#### Regional Metamorphism

Coal (COL)  
rock developed from peat beds with high carbon content.

Amphibolite (AMP)  
medium to coarse-grained, dominantly amphibole and plagioclase, commonly massive but possibly foliated and layered.

Dolomite (DLM)  
rock with the approximate composition of the mineral dolomite, massive.

Augen Gneiss (AG)  
gneiss with lenses of, eg, K - Feldspar, in fine-grained groundmass.

Evaporite (EVP)  
deposited from aqueous solution as a result of evaporation, eg, halite, anhydrite, gypsum

Mylonite (MLN)  
fine-grained material completely pulverized by extreme differential movement.

Limestone (LMS)  
more than 50% calcite, massive

Granulite (GRL)  
fine-grained, pyroxene, garnet and quartz in

flattened lenticles oriented parallel to the foliation, minor hornblende or mica.

#### Gneiss (GSS)

bands of dominantly quartz and feldspar alternating with dark coloured bands composed of mica and hornblende.

#### Phyllite (PHL)

fine-grained, abundant chlorite and mica define fine foliation surfaces. Grain size intermediate between slate and schist.

#### Slate (SLT)

very fine-grained rock possessing very good cleavage.

#### Schist (SCS)

rich in lamellar or platy minerals (micas) in sub-parallel orientation, quartz or feldspar may occur.

#### Quartzite (QRZ)

more than 75% quartz, uniform grain size.

#### Contact Metamorphism

#### Hornfels (HFL)

fine to medium-grained, without preferred orientation, cleavage absent; large crystals of garnet, or staurolite may be present.

#### Marble (MBL)

mainly calcite or dolomite, foliation weak.

#### Skarn (SKR)

hornfels with pyroxene, garnet and carbonate.

#### Cataclastic

#### Mylonite (MLN)

fine-grained material completely pulverized by extreme differential movement.

#### COMPRESSIVE STRENGTH ESTIMATES

53. Uniaxial compressive strength is a good indicator whether slope failure through the rock substance is likely. A set of simple mechanical tests with hammer (Fig A-10) and pen knife for description of hardness can be used to obtain a quick estimate (2, 3).

- S1 - easily molded by hand, shows distinct heel marks - 5 psi (0.03 MPa)
- S2 - molded by strong hand pressure, shows faint heel marks - 10 psi (0.07 MPa)
- S3 - molded with difficulty, difficult to cut with hand spade - 25 psi (0.15 MPa)
- S4 - cannot be molded by hand, cannot be cut with a hand spade and requires hand picking for excavation - 100 psi (0.7 MPa)
- S5 - difficult to move with handpick, requires pneumatic shovel for excavation - 250 psi (1.5 MPa)
- R1 - crumbles under firm blows with point of geological pick, can be peeled by a pocket knife - 500 psi (3 MPa)
- R2 - can be peeled by a pocket knife with difficulty, shallow indentation made by firm blow of geological pick - 1500 psi (10 MPa)
- R3 - cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of hammer or end of geological pick - 4000 psi (25 MPa)
- R4 - specimen requires more than one blow with hammer end of geological pick to fracture - 12000 psi (80 MPa)
- R5 - specimen requires many blows of hammer end of geological pick to fracture it - 30000 psi (200 MPa)

More precise estimates can be obtained with the rebound hammer, point load tester and in soils with a standard soil mechanics penetrometer as described in the chapter on Mechanical Properties.



Table A-1: Nomenclature of magmatic rocks

Plagioclase content as fractions of total feldspar	Quartz < 10%	Quartz > 10%
Less than 1/3	SYENITE Trachyte	GRANITE Rhyolite
1/3 to 2/3	MONZONITE Latite	QUARTZ MONZONITE Quartz latite
More than 2/3	DIORITE Andesite	GRANODIORITE Rhyodacite
	GABBRO Basalt (pyroxene present)	
	ANORTHOSITE (plagioclase only)	QUARTZ DIORITE Dacite
Less than 1/10 feldspar	PERIDOTITE (more than 5% olivine)	
Special types	PEGMATITE - Silicic, dyke rock having conspicuously coarser texture than parent	
	NOTE: UPPER CASE = coarse grained rocks Lower case = fine grained equivalents	



Fig A-10 - Estimation of rock hardness in the field.

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2. Robertson, A.M. "The interpretation of geological factors for use in slope theory"; Proc. Open Pit Mining Symposium, Johannesburg; pp 55-71; 1970.
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## APPENDIX B

### CORE AND BOREHOLE LOGGING



## INTRODUCTION

1. Drilling records and core logs should provide a complete description of the conditions encountered during drilling or borehole testing, as well as a full documentation of the drill core. This is important because core drilling is expensive but can provide the most reliable information with depth. Two standard logs are suggested, one of which comprises drilling information and borehole data, and one which is used for recording structural information from core logging.

### DAILY DRILLING RECORD

2. A sample data sheet is given in Fig B-1 and covers general drilling and site information, drilling progress, core recovery, water flow, flush type, and borehole testing.

### General Drilling and Site Information

- a. drilling company
- b. job and site description
- c. borehole number, sheet number, job number
- d. drilling method and machine
- e. name of driller and drill inspector
- f. grid and collar elevation
- g. borehole orientation and depth

### Drilling and Casing Progress

3. This information is gathered during the drilling operation and presents start and finish of drilling, depth of casing, end of core run and depth of borehole at end of shift as in Table B-1; depth from collar can be shown on scale.

### Flush Type

4. The type of drilling fluid should be noted using a one letter symbol such as water (W), bentonite (B), revert mud (R) etc. Symbols for other flush types should be noted under 'miscellaneous'.

### Bit Size

5. Both bit and casing size should be indicated in the appropriate columns using conventional symbols ie, AX, BX, NX, etc as given in Table B-2.

### Recovery

6. Core recovery should be expressed as percentage of core obtained per unit length of core:

$$\text{Recovery (\%)} = \frac{\text{core length} \times 100}{\text{length of run}}$$

## DAILY DRILLING RECORD

Page 1

Drilling Company:		Job and Site Description:				Bore hole No: Sheet No: Job No:	
Drilling Method and Machine:						Driller: Inspector:	
Collar Elevation		Northing		Easting		Azimuth	
Drilling and Casing Progress	Depth:	Flush Type	Bit Size	Recovery (%)	Water Level	Water Flow	Penetration Rate
	Scale:						
							Miscellaneous: Type of Cuttings, Colour of Return Water, Packer Tests, Location of Core Loss

## DAILY DRILLING RECORD

Page 2

Job No:		Borehole No:				Sheet No:	
Drilling and Casing Progress	Depth:	Flush Type	Bit Size	Recovery (%)	Water Level	Water Flow	Penetration Rate
	Scale:						
							Miscellaneous: Type of Cuttings, Colour of Return Water, Packer Tests, Location of Core Loss

Fig B-1 - Daily drilling record.

Table B-1: Suggested symbols for daily drilling record

Description	Symbol
<b>1. Drilling</b>	
Casing depth	=====
End of core run	=====
Borehole depth at end of shift	<u>3-5-75</u> am
Water table depth	▽
Standing water level at start of drilling	▼
Flush type	
water	W
bentonite mud	B
revert mud	R
Water return	
grey	g
black	bl
brown	br
red	rd
Water flow	
location of gain in gal/min	■ 10
location of loss in gal/min	□ 5
<b>2. Sampling</b>	
sludge	[M]
core	[C]
shelby	[S]
chip	[CH]
<b>3. Testing</b>	
penetration	[P]
vane shear	[S]
permeability	[K]
core orientation	[CO]
<b>4. Instrumentation</b>	
piezometer	◇ P
extensometer	◇ E
slope indicator	◇ I

### Water Level

7. Standing water levels are recorded directly on the log using an inverted triangular symbol as suggested in Table B-1.

8. Standing water levels should be recorded after they have become adequately stabilized. Whether the levels are rising or falling, can be recorded under column 'miscellaneous'.

### Water Flow

9. The location and volume of any loss or gain of water should be noted, ie:

Gain of 10 gpm = ■ 10

Loss of 5 gpm = □ 5

Measurements can easily be done with a stop watch and a container which takes a known volume. Both the loss and gain of drilling fluid during drilling are useful indicators of subsurface conditions.

### Penetration Rate

10. The penetration rate is recorded in ft/min or m/min for each core run by dividing the length of hole gained by the time required for drilling.

### Miscellaneous

11. In the column 'miscellaneous' all other observations or activities connected with drilling are described. This includes type of cuttings, colour of return water, test descriptions and observations, the location of core loss, blockage or rough running of drill, sampling and any other remarks deemed important.

### STRUCTURAL CORE LOG

12. The structural core log is used to record information regarding structural discontinuities and rock strength. Core should be washed before logging if the material is not sensitive to wetting and drying. To facilitate computer processing of the structural data, especially from oriented core, the specific structural information required for pit site investigations is coded and delineated on the log by heavy lines (Fig B-2). The other particular feature is a symbolic log for

Table B-2: Regular bit and core barrel sizes

SPECIFICATIONS (after compilation by J.K. Smit &amp; Sons)

Bit size	Core barrel size	Approximate weight		O.D. of set bit		I.D. of set bit	
		lb	kg	in.	mm	in.	mm
XRP	XRP	.27	.12	1.275	32.39	.885	22.48
XRT *+	XRT	.25	.11	1.160	29.46	.735	18.67
EX ++	EX, EWX	.44	.20	1.470	37.34	.845	21.46
EXT *	EXT, EWT	.42	.19	1.470	37.34	.905	22.99
AX ++	AX, AWX	.69	.31	1.875	47.63	1.185	30.09
AXT *	AXT, AWT	.69	.31	1.875	47.63	1.281	32.54
BX *++	BX, BWX	1.00	.45	2.345	59.56	1.655	42.04
NX *++	NX, NWX	1.56	.71	2.965	75.31	2.155	54.74
HWX **	HWX	3.10	1.41	3.890	98.81	3.000	76.20
H *	H	3.12	1.41	3.890	98.81	2.875	73.04
EXK *	EXK, EWK	.44	.20	1.470	37.34	.905	22.99
AXK *	AXK, AWK	.69	.31	1.875	47.63	1.281	32.54

\*Conforms to Canadian Diamond Drilling Association Standards (C.D.D.A.)

+Conforms to U.S.A. Standards (D.C.D.M.A.)

+Conforms to British Standards Institute (B.S.I.)

All sizes shown are mean dimensions with a tolerance of  $\pm 0.005$  in. (0.13 mm)

easy visual evaluation, and a large 'miscellaneous' column which allows universal use of the form.

GENERAL DRILLING AND SITE INFORMATION

13. The top portion of the structural core log is a brief repeat of the daily drilling record and is self explanatory.

SURVEY DATA

14. This information is entered in coded format identical to that for the traverse line sheet of the DISCODAT system. It covers

Identification 16 | G H 1 2 3 4  
 1976 |  
 Initials Borehole  
 of No.  
 observer

Collar elevation last five digits, with values below datum by a leading negative sign

Easting last 6 digits, numbers positive, no decimal point

Northing last 6 digits, numbers positive, no decimal point

Azimuth degrees clockwise from true north

Inclination 0 indicates a horizontal drill hole  
 90 indicates a vertical down hole  
 -90 indicates a vertical up hole

Length total length of drill hole with no decimal point (see scale)

Scale scale gives power of basic unit of distance measurement (0.1 ft and 0.1 m) used for measuring



	length or distance. If unit of measurement is 0.1 ft or 0.1 m write 0, if unit of length is 1 ft or 1 m write 1 etc.
Obs	number of observations
Reference	
Direction	Angle that should be added to azimuth when northing is other than true north, eg, magnetic north.

#### Borehole Diameter and Recovery

15. The above information is transferred from the daily drilling record and is not coded.

#### Coded Discontinuity Data and Lithology

16. This comprises ten columns of information which is recorded in coded format similar to the discontinuity data sheet. This includes:

Number	consecutive number of observations from 1 to 99
Distance from collar	Distance from collar is recorded in 0.1 ft or 0.1 m without decimal point.
Discontinuity type	Mnemonics are used to describe discontinuity types as given in Appendix A, paragraphs 9 and 30. Omit breaks which clearly occurred during drilling.
Dip direction	Dip direction is recorded if core orientation is possible. If only angles to core direction are given, enter 000 at this point.
Dip	This column contains the true dip angle or, if no core orientation was achieved, the angle of the discontinuity to the long axis of the core.
Spacing	The average spacing is recorded by using the size scale of paragraph 38 of Appendix A.
Infilling	Space is provided to record two types of infilling. The more abundant type is recorded in

#### Lithology

the first column. Only the best quality drilling equipment (double or triple tube core barrels, split inner tube, and controlled flushing) will provide a good sample of the softer fillings. Traces of soft fillings on discontinuities have to be recorded and any interpretation should be noted under miscellaneous.

The rock type along the hole is recorded by using a three-letter mnemonic, see paragraphs 9 and 52 of Appendix A.

#### Strength

The compressive strength estimates based on hardness description are recorded at this point as in paragraph 53, Appendix A in the classes S1 to R5.

#### Symbolic Log

17. The symbolic log is intended to give the reader a quick overview and can be used to allow quick visual display of rock types, dip of major discontinuities and sampling locations (1). The column 'miscellaneous' is placed beside it so that explanations can be recorded that are of interest, but not represented in the coded columns. Rock type symbols are those given in Appendix C "Records of Site Investigations".

18. For better visual presentation, symbols for lithological units and discontinuities should be slanted if strata or discontinuities are other than flat-lying.

#### Miscellaneous Parameters

19. This column allows for the recording of notes, detailed strata descriptions, rock alteration, weathering, penetrometer and point load results, mineralization, core orientation, and information representative for long sections of the drill core such as core diameter, RQD, drill core quality and fracture spacing index.

20. A classification of drill core quality is desirable in case detailed structural information

[illegible][illegible]

Fig B-2 - Structural core log.

is not going to be analyzed because of the limited data base.

#### Rock Quality Designation

21. Rock quality designation (RQD), after Deere, is the percentage length of pieces of sound hard core larger than 4.0 in. (10 cm) in each core run for NX core, 2.13 in. (54.1 mm) diameter (2). Measurements are made along the core centre line and fractures which occurred clearly during drilling are ignored.

$$RQD = \frac{100[\text{Total core length} - \text{core length} < 4 \text{ in.}]}{\text{length of core run}}$$

The length of the core run should be variable rather than fixed to suit rock formations, domains, etc. A relative classification has been given as:

<u>RQD</u>	<u>Classification</u>	<u>Rock Fracturing</u>
90-100	excellent	massive
75-90	good	lightly fractured
50-75	fair	moderately fractured
25-50	poor	highly fractured
0 -25	very poor	sheared

For core sizes other than NX, the lengths of core pieces which are discounted should be smaller than twice the core diameter.

22. A comparison with measured fracture spacing and RQD has been given in para 168 on 'evaluation of geological information for slope stability' under the heading 'spacing of discontinuities'.

#### Fracture Spacing Index

23. The fracture spacing index (3) is recorded as the total length of a homogeneously fractured zone in the core, divided by the number of core pieces in that zone. This index, denoted  $I_f$ , is a measure of the average diameter of typical rock blocks in the zone. If the core is badly broken, the index may best be observed directly by selecting a typical piece, and recording its diameter. It may also be helpful to record on the core log the sizes of the largest

and smallest pieces in the zone, for example, 15 (3-30) cm would denote a zone with typical block size of 15 cm, with a range typically from 3 to 30 cm. An RQD index may, if required, be derived from the fracture spacing index using the equation:

$$RQD \% = 1.1 [100 - 20/I_f(\text{ft})]$$

24. It may be noted from this equation that RQD is approximately zero for  $I_f$  less than 2.4 in. (6.1 cm), and is 100% for  $I_f$  greater than 2.2 ft (0.66 m). It has been found best to count all core fractures except those that are without doubt artificially created when estimating  $I_f$ , since any attempt at distinguishing between natural and artificial fractures leads to considerable lack of reproducibility of results. If drilling is to the standard recommended in this chapter, and is of adequate diameter, the error of including all core breaks in the count will be small.

#### CORE PHOTOGRAPHY

25. All core that has been received and labelled in core boxes should be photographed on a routine basis. Best results are obtained if a photographic stand is set up in a dark corner of the core shack where standard lighting can be obtained with flash units. Self-winding cameras are an asset (Fig B-3). Film material should in general be 35 mm to obtain framed colour transparencies. These colour transparencies should carry borehole number and footage, a suitable scale and the downhole direction of the core.

26. To improve the quality of the core pictures all core should be washed, the grease removed, and photographed when dry. Photographing the core when wet can bring out additional details, but introduces undesirable reflections of the flash, unless flash units are aimed at low angles. If the core is not kept wet during adjustment of camera, dry spots create an undesirable mottled appearance of the core; also, weak core should not be subjected to unnecessary water. If the true colour is critical, a standard colour strip should be photographed to provide a calibration for the colour reproduction in the

transparency.

27. Colour photography of drill core also

provides an essential check on core logs and computer storage of drillhole data.



Fig B-3 - Rig for routine core photography (courtesy Falconbridge Nickel Mines Limited).

## REFERENCES

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2. Deere, D.U. "Geological consideration"; Rock mechanics in engineering practice; Ed. Stagg, K.G. and Zienkiewicz, O.C.; John Wiley and Sons; pp 1-20; 1968.
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## APPENDIX C

### RECORDS OF SITE INVESTIGATIONS





## INTRODUCTION

1. The purpose of this appendix is to provide guidance on the efficient storage and presentation of geological data in plans and sections for engineering design. Full standardization is difficult to achieve, but reasonable uniformity is desirable to accommodate the various methods of data gather-

ing, and to allow effective communication.

2. The following presentation is based on a consolidation of existing information as published by various Canadian and international working groups.

## PERMANENT PLANS AND SECTIONS

3. For ease of communication and transfer of information, it is necessary to standardize the plotting and storage of results on plans and sections from geological mapping. In general, no geological data are entered on any master survey record but only on copies of surveyed plans and sections, eg, on sepia plates from original survey plans. Plans and sections that have a major recording function should not be a mixture of all types of information.

4. Separate overlay sheets should be kept for general geological information. If detail warrants, separate overlays should be obtained to document:

a. Lithology: plans and sections for rock types,

locations of traverses, drill holes, sample locations, and trenches.

b. Major Discontinuities: plans and sections for outcrops of major structures, interpretations and groundwater levels.

c. Minor Discontinuities: plans and sections for domains, and statistical information of joints and shears.

5. Geological sections normal to structural trends, or normal to the pit slope are desirable. It should be left to the geologist as to how far a section should be extended by projection, but the amount should be stated. Composite plans or sections should only be used for reports or submissions.

### SCALE

6. Mine maps can be subdivided into the following categories:

	Scale	
	Metric	Imperial equivalent
<u>Detail map</u>		
e.g., geological mapping, blast hole maps, surveys.	1:250	1 in. = 20 ft
	1:500	1 in. = 40 ft
	1:600	1 in. = 50 ft
<u>Pit map</u>		
e.g. basic major structures, pit planning	1:1000	1 in. = 100 ft
	1:2000	1 in. = 200 ft
<u>Mine site map</u>		
e.g., pit and adjacent area, planning of slopes, location of roads and dumps.	1:5000	1 in. = 500 ft
	1:10000	1 in. = 1000 ft
	1:20000	1 in. = 2000 ft
<u>District or regional map</u>		
e.g., regional geological structure and hydrology	1:25000	1 in. = 1/2 mile
	1:50000	1 in. = 1 mile
	or standard government map scale.	

The planning department should have a base map of each type.

7. The scales used for slope design should, as far as possible, coincide with the scales used for mine planning to reduce the time spent transferring data, enlarging or reducing.

### LAYOUT

8. Permanent geological records should be drawn on transparent polyester film or copies of survey plans, eg, on sepia plates. Sizes should be 36 in. x 48 in. for plans, and 36 in. x 24 in. for sections. Sub-multiples of these two standard sizes may be employed for specialized design or report drawings that do not serve a major long-term central recording purpose. With metrication, paper sizes equivalent to the 36 in. x 48 in. and 36 in. x 24 in. sheets are 90 x 126 cm and 90 x 63 cm, respectively.

9. Every drawing should include:

- a well defined border and margin, one inch or three cm wide,
- a title box in the lower right-hand corner, with dimensions one tenth of the overall drawing size and containing all necessary information to clearly identify the company, the property and area portrayed,
- a graphic scale, and
- a north arrow.

10. At least one set of survey grid lines, or grid and elevation lines in the case of a section, should be shown and usually oriented to be approximately parallel to the sides of the paper. Grid north is to be shown at the top of the sheet whenever possible. Where a second survey grid is to be included, it should be indicated by orthogonal intersecting lines 4 cm in length. Grid lines will normally be shown at intervals of 10-15 cm. All grid lines are to be explicitly named on the drawing and adjacent plans and sections should not overlap.

### SYMBOLS

11. Engineering geological maps draw information from surveying, geological mapping, and geo-technical testing. For efficient communication some standardization is desirable. Complete standardization is difficult because local requirements for differentiation of rock types and geological structure would demand a complex catalogue of symbols that would require elaborate drafting.

12. Three different groups of symbols are required to cover descriptions of topography, structural symbols, rock and soil types. A list of ten important survey symbols required for pit sites is given in Fig C-1. Figure C-2 describes the principal symbols for geological structures and surface features as used by the Geological Survey of Canada (1).

13. No similar standard exists for rock types. For completeness four proposals are mentioned here. These are Dearman et al (2), International Organization for Standardization (3), the Norwegian National Group of the International

Society of Rock Mechanics (4) and the IAEG guide for engineering geological maps (5). The first two result in rather elaborate drafting requirements and as example Fig C-3 is shown. The third proposal restricts the symbols to a few principal rock types based on composition, grain size, and

texture. This allows use of patterns readily available in LETRASET or MECANORMA as shown in Fig C-4. For geotechnical descriptions, symbols of the International Society for Rock Mechanics (6) should be used.







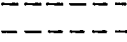

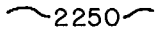
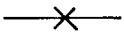
①		The crest of a slope
②		The toe of a slope
③	2197 	Spot elevation
④		Dewatering well (no pump)
⑤	150 	Dewatering well (150 g.p.m. pump installed)
⑥		Haulage road (maintained)
⑦		Access road, or haulage road (unmaintained)
⑧		Hydro pole (with guys)
⑨		Topographic contour
⑩		Pipeline valve

Fig C-1 - Conventional signs for open pit mine plans.

GEOLOGICAL FEATURES	SYMBOL
Drift-covered area	
Rock outcrop, area of outcrop, probable outcrop, float, frost heaved rock	
Geological boundary (defined, approximate, assumed) (shown in legend for final map)	
Geological boundary (defined, approximate, assumed) (preliminary map)	
Geological boundary (gradational inferred or metamorphic) (final map)	
Geological boundary (gradational inferred or metamorphic) (preliminary map)	
Limit of geological mapping	
Limit of area surveyed with aircraft	
Flow contact	
Bedding, tops known (horizontal, inclined, vertical, overturned, dip unknown)	
Bedding, tops unknown (inclined, vertical, dip unknown)	
Bedding, general trend (dip unknown, top unknown; dip and top known; dip known, top unknown)	
Bedding, estimated dip (gentle, moderate, steep)	
Primary flow structures in igneous rock (horizontal, inclined, vertical, dip unknown) If a supplementary symbol is needed use	
Schistosity, gneissosity, cleavage, foliation (horizontal, inclined, vertical, dip unknown) Second generation (horizontal, inclined, vertical) . . .	
<ul style="list-style-type: none"> <li>The minimum distance between two boundaries should be .020"</li> <li>Number of ticks indicates generation</li> </ul>	
Schistosity, gneissosity, cleavage, foliation, general trend	
Banding (inclined, vertical, dip unknown)	
Axial plane of minor fold (horizontal, inclined, vertical, dip unknown)	
Lineation (horizontal, inclined, inclined but plunge unknown, vertical)	

Lineation, axes of minor folds (horizontal, inclined, vertical)	
Layering (in intrusive rocks)	
Drag-fold (arrow indicates plunge) Drag-fold in gneissosity	
Minor fold (arrow indicates plunge)	
Multiple fold (arrow indicates plunge, inclination of axial plane known, unknown) Multiple fold (plunge unknown)	
Structural trend (from air photographs)	
Lineament (from air photographs)	
Fault (defined, approximate, assumed)	
Fault (inclined, vertical)	
Fault (solid circle indicates downthrow side, arrows indicate relative movement)	
Thrust fault (teeth in direction of dip; defined) (teeth indicate upthrust side)	
Thrust fault (approximate, assumed)	
Fault zone, shear zone; schist zone (width indicated)	
Shearing and dip	
Vein fault (defined, assumed)	
Mineralized bed or seam (hematite)	
Dyke, vein, or stockwork (defined, approximate, assumed)	
Joint (horizontal, inclined, vertical, dip unknown)	
Anticline (defined, approximate) Antiform	
Syncline (defined, approximate) Synform	

Fig C-2 - Principal symbols for geological maps and figures (1).



## IGNEOUS ROCKS

## Plutonic



GRANITE



DIORITE, SYENITE



GABBRO



PERIDOTITE

## Volcanic



RHYOLITE



ANDESITE, TRACHYTE



BASALT

## Pyroclastic



AGGLOMERATE



VOLCANIC BRECCIA



TUFF

\* Use in combination with symbols for volcanic rocks for example:

Rhyolitic  
AGGLOMERATE

Andesitic TUFF

## METAMORPHIC ROCKS

METAMORPHIC ROCKS -  
REGIONAL

SLATE, PHYLLITE



SCHIST



GNEISS



MIGMATITE



QUARTZITE



Metamorphosed LIMESTONE



AMPHIBOLITE, ECGLOGITE



SERPENTINITE

METAMORPHIC ROCKS -  
CONTACT

## SEDIMENTARY ROCKS

## Detrital



CONGLOMERATE



BRECCIA



SANDSTONE



SILTSTONE



MUDSTONE



SHALE



Gravelly SANDSTONE



Silty SANDSTONE



Clayey SANDSTONE



Sandy SILTSTONE



Clayey SILTSTONE



Silty MUDSTONE



Sandy MUDSTONE

## Biogenetic



LIMESTONE



CHALK



DOLOMITE



CHERT, FLINT



HALITE



GYPSUM



ANHYDRITE



COAL, LIGNITE



Oolitic LIMESTONE



Dolomitic, LIMESTONE



Argillaceous LIMESTONE



Cherty, LIMESTONE

F Ferruginous

P Phosphatic

B Bituminous

Si Siliceous

## SOILS

## Chief constituent



GRAVEL



SAND



SILT



CLAY



Boulders, Cobbles



Shells



Peat

## Secondary constituent



Gravelly



Sandy



Silty



Clayey



Bouldery



Shelly



Peaty

## Symbols may be combined:



Shelly SILT



Bouldery CLAY



Sandy GRAVEL



Silty CLAY







































Silty PEAT

Fig C-3 - Symbols for rock and soil types (2).

## Symbols

## Rock and Soil types

		Shale, Clay
LT 67 1) MN 241 2)	LT 69 1) MN 233 2)	
		Conglomerate
LT 129 1) MN 275 2)	LT 130 1) MN 275 2)	
		Sandstone, Quartzite, Sand
LT 90 1) MN 258 2)	LT 89 1) MN 253 2)	
		Gneiss, Granitic Gneiss, Granulite, Augengneiss, Siltstone, Mudstone, Silt
LT 120 1) MN 353 2)	LT 121 1) MN 272 2)	
		Arkose
LT 912 1) MN 204 2)	LT 914 1) MN 206 2)	
		Dolomite
LT 166 1)		
		Greywacke
LT 164 1)		
		Limestone
LT 123 1) MN 461 2)	LT 116 1) MN 465 2)	
		Amphibolite, Greenstone, Norite, Gabbro, Diabase, Basalt, Anorthosite
MN 299 2)	LT 957 1)	
		Eclogite, Serpentine, Peridotite
LT 91 1) MN 434 2)	LT 92 1) MN 433 2)	
		Hornfels
LT 80 1) MN 917 2)	LT 83 1) MN 247 2)	
		Marble
LT 165 1)		
		Phyllite
LT 125 1) MN 447 2)	LT 126 1)	
		Schist
LT 94 1)	LT 188 1)	
		Slate
LT 127 1) MN 229 2)	LT 128 1) MN 228 2)	
		Andesite, Diorite
LT 157 1)	LT 158 1)	
		Dacite, Granodiorite, Monzonite, Syenite
LT 131 1) MN 276 2)	LT 132 1)	
		Granite, Rhyolite
LT 958 1)	LT 959 1) MN 298 2)	

1) Letraset

2) Mecanorma

Fig C-4 - Symbols for a few principal rock and soil types (4).



## REPORT DRAWINGS

14. Report drawings are of comparatively short term use and are often of a composite nature. The format of plans and sections should be selected so that drawings can be bound directly into a standard size report, or will fit easily into a pocket at the back of the report, when folded.

15. Written information should occur at the right-hand side of the drawing for easy reference, even when folded. All symbols or abbreviations must be explained on the drawing or on a separate explanation sheet within the report.

16. Figure C-5 represents a typical layout for a drawing describing the geology of a pit. Seven features are significant besides the body of the drawing. These are:

- legend
- symbols
- notes
- scale
- title block
- north arrow
- survey coordinates

Some comments are given below for the first five items.

### LEGEND

17. The legend appears on the top right-hand side of the drawing and presents age relationships for the various rock types. Generally, this legend is only required for small-scale maps giving a regional overview of the geology surrounding the pit site. Typical map legends can be found on geological maps of the Geological

Survey of Canada (1).

### SYMBOLS

18. To present survey data, rock type boundaries, rock types and structural information, symbols are necessary, and their explanations are given either directly on the drawing, or in a separate table if too extensive. Figures C-1 to C-4 should be consulted.

### NOTES

19. Notes should be numbered, and should cover aspects such as data source, if not affiliated, and points pertinent to the information on the drawing.

### SCALE

20. A scale should be placed on the drawing below the notes. It is generally most convenient to construct a bar type scale which retains its scale if the drawing is reduced or enlarged.

### TITLE BLOCK

21. The title block should be placed in the bottom right corner of the drawing so as to remain exposed even when folded.

22. The title block should contain:

- a. project description
- b. title of drawing
- c. name of person who constructed the drawing
- d. name of supervisory engineer
- e. drawing number and date
- f. figure number.

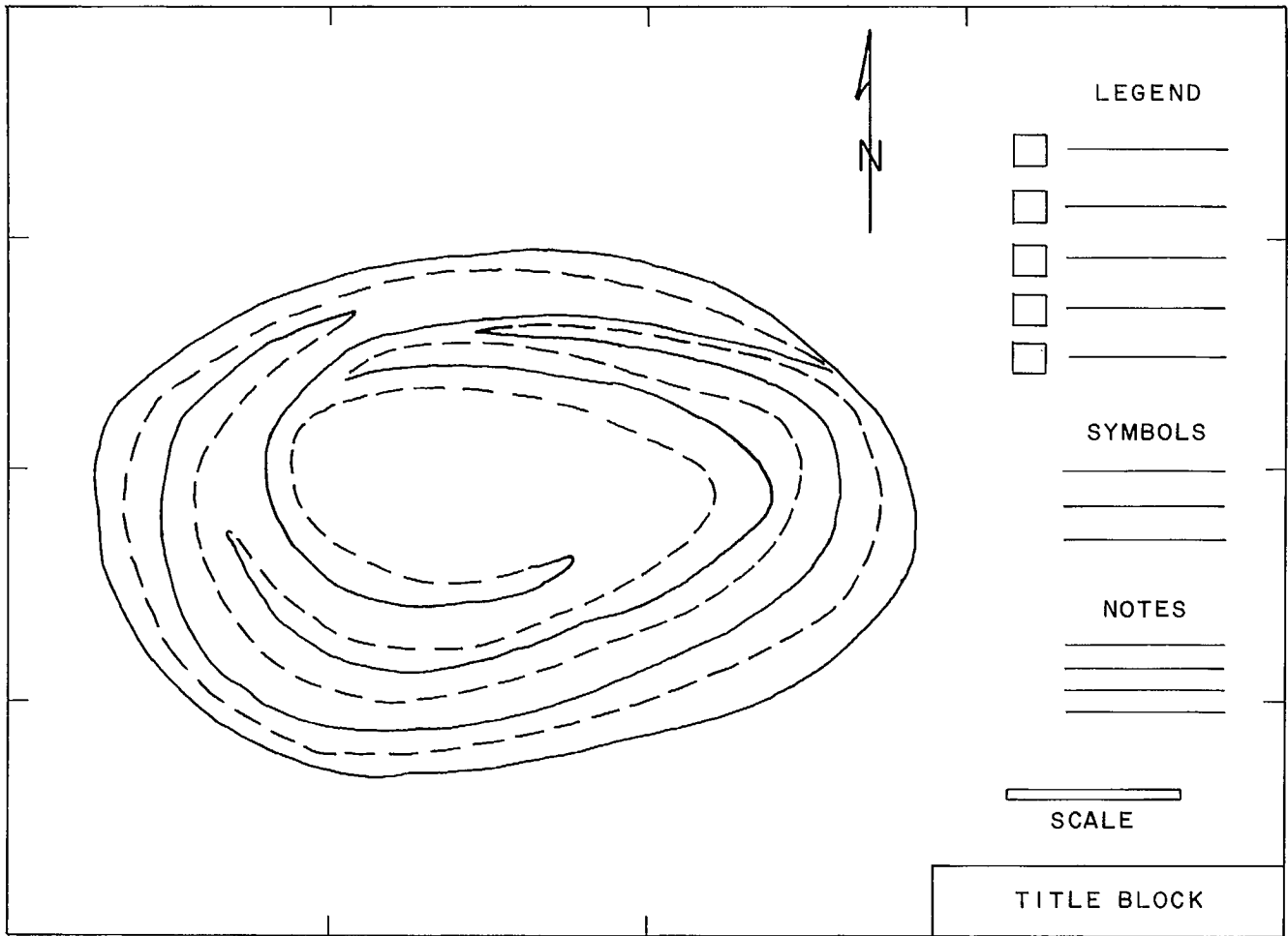


Fig C-5 - Standard format for report drawing.

## REFERENCES

1. Blackadar, R.G., Dumych, H., and Griffin, P.J. "Guide for the Preparation of Geological Maps and Reports"; Geological Survey of Canada; Miscellaneous Report 16; EMR; Ottawa; Revised edition; 1975.
2. Geological Society Engineering Group "The preparation of maps and plans in terms of engineering geology"; Quart. J. Eng. Geol., v. V, no. 4; 1972.
3. International Organization for Standardization "Graphical symbols for use on detailed maps, plans and geological cross-sections"
  - Part I General rules of representation ISO 710/I-1974(E)
  - Part II Representation of sedimentary rocks, ISO 710/II-1974(E)
  - Part III Representation of magmatic rocks, ISO 710/III-1974(E)
4. Norwegian National Group of ISRM "Terminologi, definisjoner og karttegn innen bergmekanikk og ingeniorgeologi"; Trondheim, 1974.
5. International Association of Engineering Geology "Engineering geological maps. A guide to their preparation"; Earth Science; 15; The Unesco Press, 1976.
6. International Society of Rock Mechanics "List of Symbols"; Commission on Terminology; Symbols and Graphic Representation; 1970.

## APPENDIX D

### SOURCES OF AERIAL PHOTOGRAPHS IN CANADA



## SUMMARY

Aerial photographs of Canada are available from the government agencies listed below. Photographs may also be available from photographic contractors; their coverage will usually be restricted to small areas, often near major population centres.

### Federal Agencies:

National Air Photo Library  
615 Booth Street  
Ottawa, Ontario K1A 0E9

Holdings include panchromatic photo coverage of the entire country with most photography at a scale of 1:50000 or larger.

Canada Centre for Remote Sensing  
2464 Sheffield Road  
Ottawa, Ontario K1A 0E4

The CCRS holds all types of remote sensing imagery taken of Canada. Most of this imagery is available for very restricted areas only. The Centre also provides ERTS imagery for Canadian users.

### Provincial Agencies

Province of Alberta  
Department of Lands and Forests  
Technical Division  
325 Natural Resources Building  
Edmonton, Alberta T5K 1H4

Holdings: Complete panchromatic coverage of Alberta at a scale of one inch to half a mile, or greater.

Province of British Columbia  
Department of Lands, Forests and Water Resources  
Victoria, British Columbia  
Attention: Air Division

Holdings: Coverage of much of British Columbia at a scale of one inch to a mile, or larger.

Province of Manitoba  
Department of Mines, Resources and Environmental Management  
Surveys and Mapping Branch  
1007 Century Street  
Winnipeg, Manitoba R3H 0W4

Holdings: A detailed catalogue of air photos of Manitoba is available from the agency, but photos must be ordered from the Federal Government.

Province of New Brunswick  
Land Registration Information Service  
P.O. Box 1660  
Summerside, N.B.

Holdings: Complete coverage of the entire province at a scale of 1:40000, or larger.

Province of Newfoundland and Labrador  
Department of Forestry and Agriculture  
Bldg 810 Pleasantville  
St. John's, Newfoundland

Colour and panchromatic photography is available from the Federal Government.

Province of Nova Scotia  
Department of Lands and Forests  
Halifax, Nova Scotia

Holdings: Complete panchromatic coverage, as well as colour photography of much of the province.

Province of Ontario  
Ontario Ministry of Natural Resources  
Air Photo Library  
Room 3501, Whitney Block

Queens Park, Toronto, Ontario

Holdings: Complete coverage at a scale of four inches to the mile of the province, except for non-forested areas in the far north.

Province of Prince Edward Island  
Land Titles Division  
P.O. Box 2000  
Charlottetown, P.E.I.

Holdings: One set of complete panchromatic coverage of Prince Edward Island, as well as large scale photography of townsites.

Province of Québec  
Ministère des Terres et Forêts  
Service de la Cartographie  
1995 ouest, boul. Charest  
Québec, P.Q.

Holdings: Panchromatic coverage of most of the Province of Québec at scales of 1:40000, or larger.

Province of Saskatchewan  
Department of Tourism and Renewable Resources  
Lands and Surveys Branch  
2340 Albert Street  
Regina, Saskatchewan

Holdings: Complete panchromatic coverage of the province at a scale of 1:40000, or larger.

The private sector has also limited holdings and local companies should be contacted.



## GLOSSARY

(Dimensions: L = Length, F = Force,  
D = Dimensionless)

### ALIDADE

A straight-edge ruler carrying slot sights or a telescope for recording observed directions on a plane table.

### ALTERATION

Change of the mineral composition of a rock by hydrothermal solutions, eg, kaolinization.

### ANGLE OF INTERNAL FRICTION (D)

The angle  $\phi$  between the axis of normal stress and the tangent to the Mohr envelope.

### ANGLE OF REPOSE (D)

The maximum slope angle at which loose material will be stable on a horizontal base.

### BEDROCK

The more or less continuous body of rock which underlies the overburden soils.

### BEDDING

Repetitive layering in sedimentary rocks marking the boundaries of small lithological units or beds; on the scale of open pits, bedding is generally continuous.

### BENCH

Working level.

### BENCH FACE

The vertical or nearly vertical surface of rock exposed by a production cut or when blasting a bench.

### BERM

The step in a slope resulting from the combination of two or more benches at successive levels.

### BERM FACE

The vertical or nearly vertical surface of rock exposed by successive benches that have been combined into a berm.

### BRECCIA

Rock with coarse angular fragments developed from rock-like materials during tectonic deformation in faults, or during gravity sliding.

### BOUNDARY

Surface separating rock formations or zones of alteration.

**CLINO RULE**

Carpenter's rule with angle indicator.

**CLEAVAGE**

Closely spaced parallel surfaces of fissility. This feature is often parallel to axial planes of folds in bedded formations.

**COEFFICIENT OF INTERNAL FRICTION**

The tangent of the angle of internal friction.

**COHESION ( $FL^{-2}$ )**

In rock mechanics the shear resistance at zero normal stress arising from interlock or inter-granular binding forces.

**COMPASS**

An instrument for determining azimuth or bearing, usually by the pointing of a magnetic needle which can turn freely in a horizontal plane.

**CONTACT**

Surface between two rock types, one or both of which are not sedimentary.

**CREST**

The top of an excavated slope.

**CRITICAL CIRCLE (CRITICAL SURFACE)**

The sliding surface for which the factor of safety is a minimum in an analysis of a slope in ductile ground where average stresses can be used.

**CRITICAL SLOPE ANGLE (D)**

The maximum angle with the horizontal at which a slope of given height will stand unsupported.

**DESIGN SECTOR**

Sector of slope with uniform geology and similar geometry.

**DIP (D)**

The angle in degrees of a slope, vein, rock stratum, or borehole as measured from the

horizontal plane downward along the direction of steepest declination. Angle is given as a two-digit number, eg, 05 or 65.

**DIP DIRECTION**

Azimuth of vector along the fall line of a plane expressed in three-digit numbers of degrees clockwise from north ( $360^\circ$ ), eg, 010, 090, 105, 345.

**DIP VECTOR**

The dip direction described by azimuth of dip in degrees ( $00-360^\circ$ ) and angle of dip (declination  $00-90^\circ$ ), eg, 010/15.

**DISCONTINUITY**

Surface of change of mechanical properties or composition in rock. This includes fracture surfaces, weakness planes and bedding planes and is not restricted to mechanical discontinuities.

**DISPLACEMENT (L)**

The change of position of a point.

**DOMAIN**

An area or volume in a body which possesses statistical homogeneity or uniformity with respect to one or more variables.

**EQUAL-AREA NET**

Aid to analyze three dimensional data, eg, orientation of planes in a two dimensional presentation. Ratios between individual areas of a sphere are maintained in this projection, but angles are distorted.

**FABRIC**

In structural geology the pattern of discontinuities in rock.

**FACE**

The vertical or nearly vertical surface of rock exposed by mining operations.

**FAULT**

Surface of shear recognizable by the displace-

ment of another surface that crosses it. Frequently rock on both sides of the fault is shattered, resulting in fillings like fault breccia (coarse angular fragments), gouge (fine, soft powder) or mylonite, a hard, fine-grained laminate. Walls often show striations from shear displacement known as slickensides. With regard to orientation and displacement, faults can be classified into thrust, normal and reverse faults. Numerous small faults or a zone of gouge, breccia or mylonite sometimes many kilometers wide, can be called a fault zone.

#### GOUGE

Fine, soft powder developed during tectonic deformation.

#### GNEISSOSITY

Lithological layering in metamorphic rocks.

#### HOMOGENEITY

A characteristic of a volume or area of a substance in which each element has the same property or value regardless of location.

#### HYDROTHERMAL SOLUTIONS

Hot water solutions having a high mineral or element content.

#### IGNEOUS ROCKS

Rocks formed by cooling from a molten or partially molten magma. Differentiation is made between volcanic rocks which cool at or near the surface, and plutonic rocks which cool at depth. At-depth cooling generally results in larger grain size. Individual rock types are defined with regard to the content of free silica, prominent minerals, and grain size.

#### INFILLING

Material occupying the space between fracture or discontinuity surfaces.

#### INSTABILITY

The description of the most likely mechanism

of instability.

#### INTERIM SLOPE

The slope of the wall of an interim pit before a final pushback occurs to the ultimate wall.

#### ISOTROPY

Condition of having the same property in all directions.

#### JOINT

Fracture in a rock mass along which there has been little or no displacement. Joints are surfaces of rupture or extension which can form during crustal movements (regional joint systems), shrinkage from cooling (columnar joints in basalt), or from elastic rebound of the earth's crust giving sheet joints. Joints can follow bedding planes in weakly cemented layers, and these may be called bedding joints. A group of parallel joints is called a joint set, and various joint sets form a joint system.

#### JOINT ORIENTATION

Mean planar surface representing the attitude of a joint. Plane can be described by strike and dip or preferably by the dip vector.

#### JOINT SET

Group of parallel joints.

#### JOINT SYSTEM

Consists of two or more joint sets, or any group of joints with a characteristic pattern.

#### KINEMATIC INFORMATION

Observations of material transport in rock exposures.

#### LEACHING

Removal of minerals by aqueous solutions percolating through rock.

#### LINEATION

The parallel orientation of geological features that are lines rather than planes,

such as striae on slickensides, long axes of pebbles, and cleavage/bedding plane intersections.

#### LITHOLOGY

Mineralogical composition and physical characteristics of a rock. See Appendix A paragraph 51.

#### METAMORPHIC ROCKS

Rocks which have been subjected to high pressures and temperatures so that the original composition and texture have been changed.

#### METAMORPHISM

Change of rocks in texture, mineral and chemical composition due to geological processes.

#### MOHR'S CIRCLE

Graphical presentation of the state of stress at a specific point within a stressed material.

#### MOHR'S ENVELOPE

The envelope of a sequence of Mohr's circles describing the state of stress of failure in a material.

#### MYLONITE

A fine-grained laminated rock developed during tectonic deformation between fault planes by microbrecciation and metamorphism.

#### NORMAL DISTRIBUTION, STANDARD NORMAL, NORMAL CURVE, GAUSSIAN

The distribution of numerical data,  $x$ , about an average value,  $M$ , that follows the Gaussian Equation:

$$y = \frac{1}{S\sqrt{2\pi}} e^{-0.5(x-M)^2/S^2}$$

where  $y$  is the frequency of occurrence and  $S$  is the standard deviation of the data.

#### NORMAL FAULT

A fault with the hanging wall portion positioned down dip; it is generally steeply inclined.

#### OVERALL SLOPE ANGLE (D)

The angle measured from the horizontal to the line joining the toe of a wall to the crest.

#### PIEZOMETER

A device for measuring the hydrostatic pressure at a point in the ground.

#### PITCH

The angle that a line in a plane makes with a horizontal line in that plane.

#### PLANE TABLE

Surveying instrument for mapping and locating of topographical features. It consists of a drawing board, a level, a compass, a ruler and slit sights or an alidade.

#### PLUNGE

Vertical angle between a horizontal plane and the maximum elongation of a body, or the direction of a fold axis.

#### POLAR EQUAL-AREA NET

Equal-area net in polar projection with great circles in radial direction and concentric small circles for plotting dip angles.

#### PROBABILITY

It is concerned with unpredictable individual events but events which are predictable in large numbers. It is the frequency ratio of occurrence of one event that can be expected in an infinitely large population of events. For less than an infinite population, it has the meaning of relative likelihood of occurrence.

#### PROBABILITY OF INSTABILITY

The probability that the variations in length

and spacing of discontinuities will combine with those governing the probability of sliding to permit instability.

#### PROBABILITY OF SLIDING

Chance of instability along one or two sets of discontinuities based on the orientation of discontinuity sets, shear strength and ground-water pressures.

#### PROGRESSIVE FAILURE

Failure in which the ultimate resistance is progressively, rather than simultaneously, mobilized along the ultimate failure surface.

#### RANDOM SAMPLE

A sample taken in such a way that there is an equal chance of every member of the target population being selected or observed. By contrast, a biased sample is one that is taken in a manner that results in a greater or lesser possibility of it being selected or observed than others in the target population; eg, a set of dip angles obtained from core will be biased against dips parallel to the hole.

#### REVERSE FAULT

A fault with the hanging wall portion positioned up dip, generally steeply inclined.

#### ROCK MASS

The in situ rock made up of the rock substance with all its structural discontinuities.

#### ROCK SUBSTANCE

The solid part of the rock mass, typically obtained as drill core.

#### ROCKFALL

The relatively free fall of a detached rock of any size.

#### ROUGHNESS

Asperities of a rock surface on the scale of a hand specimen.

#### SAMPLE POPULATION

The group of data representing actual samples which may or may not be equivalent to the target population, eg, the dip of the joints available for measurement on the faces of the benches may not include all representative joints.

#### SCHISTOSITY

Surface of easy splitting in metamorphic rocks defined by the preferred orientation of metamorphic minerals.

#### SCHMIDT NET (EQUAL-AREA NET)

Aid to present three dimensional information or orientation, in a plane where ratios between areas on a sphere are maintained for areas on the net, but with angles distorted. Nets are available in equatorial and polar projection.

#### SECTOR

The length of wall, or pit slice, that can be considered sufficiently homogeneous to use one slope angle resulting from a comprehensive stability analysis.

#### SEDIMENTARY ROCKS

Rocks formed by accumulation of sediments in water or from air. They can be made up of rock fragments of various sizes as in conglomerates, sandstones and shales; of organic matter, eg, certain limestones and coal; or they can be the result of chemical precipitation, eg, salt, gypsum. Characteristic is a layered structure known as bedding or stratification.

#### SEGMENT

A vertical interval in a wall of one sector.

#### SHEAR

Surface of shear recognized by slickensides, polishing or slickness of the surface, or striations on the surface.

**SHEAR FAILURE**

Failure resulting from shear stresses.

**SHEAR STRENGTH ( $FL^2$ )**

The resistance offered to shear stress.

**SLIDE**

A relatively deep-seated failure of a slope.

**SLICKENSIDES**

Scratched surface, sometimes polished, resulting from shear movement.

**STADIA**

Surveying transit or theodolite equipped with two fine parallel horizontal wires which allow determination of distance to a point from the observed length of survey rod intersected by the two wires.

**STANDARD DEVIATION**

A measure of dispersion

$$\sigma = \left[ \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2 \right]^{0.5}$$

**STEREO NET (WULFF NET)**

Aid to present three dimensional information, eg, rock wedges, in a plane with correct angular relationships between reference sphere and net, but with distortions in regard to representation of areas.

**STRIKE (D)**

The azimuth of a horizontal line on a planar surface, eg, a joint or bedding plane, expressed in degrees clockwise from north, eg, N 110° E.

**STRIKE AND DIP**

Measure to determine orientation of a plane, eg, N110°E/65°NNE. Strike and dip are given in degrees. Dip direction is given approximately to avoid ambiguity.

**STRIKE SLIP FAULT**

A fault with the net displacement almost completely in the strike direction.

**STRUCTURAL FEATURE**

In geology, a feature representing a discontinuity of mechanical properties, such as a joint, fault, or bedding plane.

**STRUCTURAL DOMAIN**

Areas or volume of structural homogeneity.

**STRUCTURE**

(a) In civil engineering, the assemblage of structural elements designed to support and transmit loads to the subgrade of the foundations.

(b) In geology, the assemblage of structural features that together with the rock substances make up the rock mass, with emphasis on the structural features.

**TARGET POPULATION**

The entire group of data from which representative samples are to be taken, eg, the dip of the joints in a set.

**TECTONIC ANALYSIS**

Attempt to analyze the observed fabric represented in faults, joints, folds, etc. of an area in terms of deformational events. This requires assessment of fabric geometry, kinematic information and a failure model.

**TEXTURE**

Arrangement of component particles of minerals and rock fragments in rock.

**THRUST FAULT**

A reverse fault with a small angle of inclination to the horizontal.

**TOE**

The bottom of a slope.



## TRACE LENGTH

Exposure of a discontinuity surface.

0.1 ft (0.1 m). Thicker fillings are mapped as separate lithological units.

## TRAVERSE

A line surveyed across a plot of ground.

## WAVINESS

Undulations of a rock surface on a field scale.

## TREND

The azimuth of the horizontal projection of an elongated body.

## WEATHERING

Break-down of rock strength and mineral composition by chemical, organic and mechanical processes under atmospheric conditions.

## UNCONFORMITY

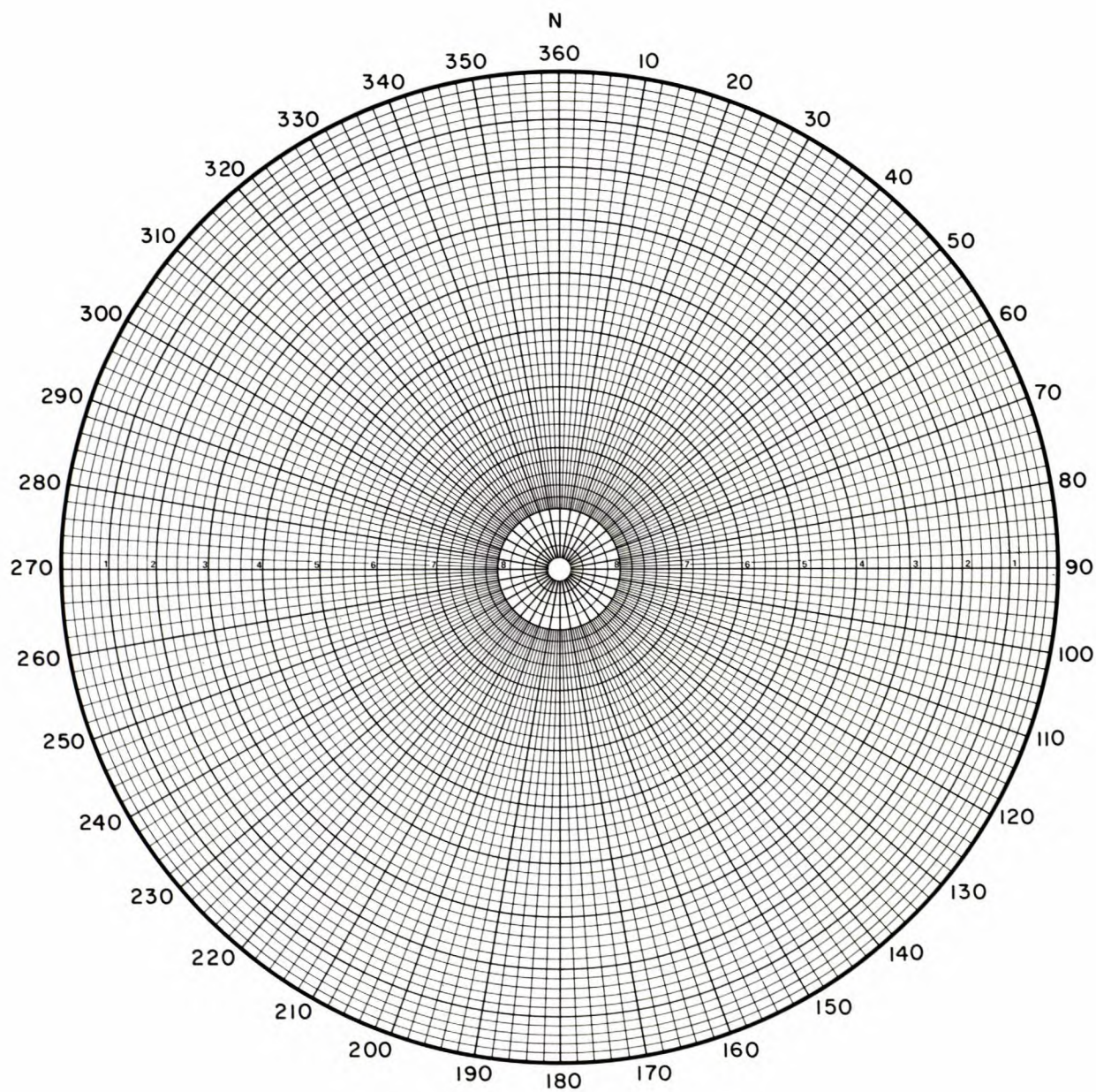
Eroded surface overlain by sedimentary rock.

## WULFF NET (STEREO NET)

See STEREO NET above.

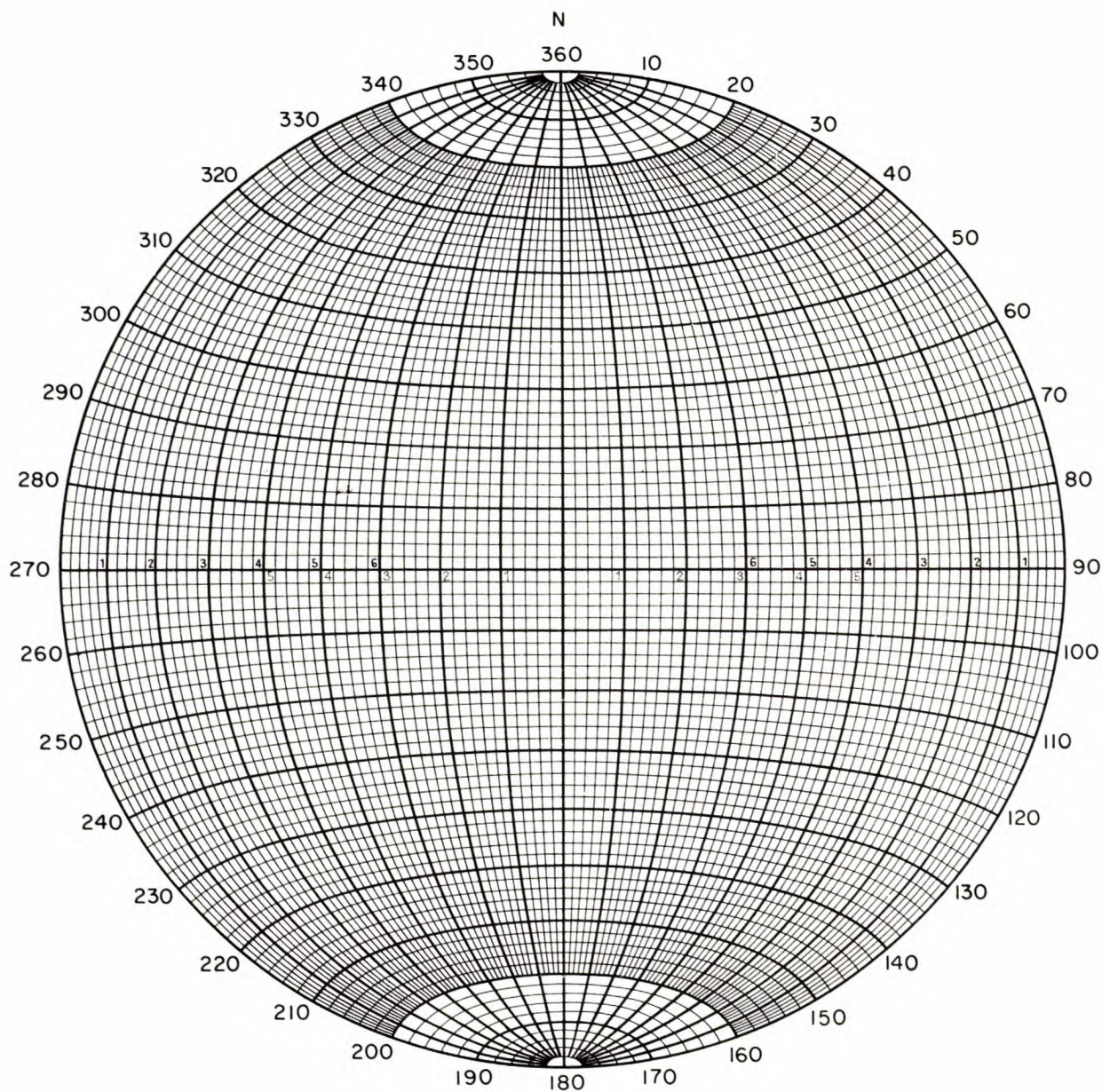
## VEIN

Fracture in rock with a filling not exceeding

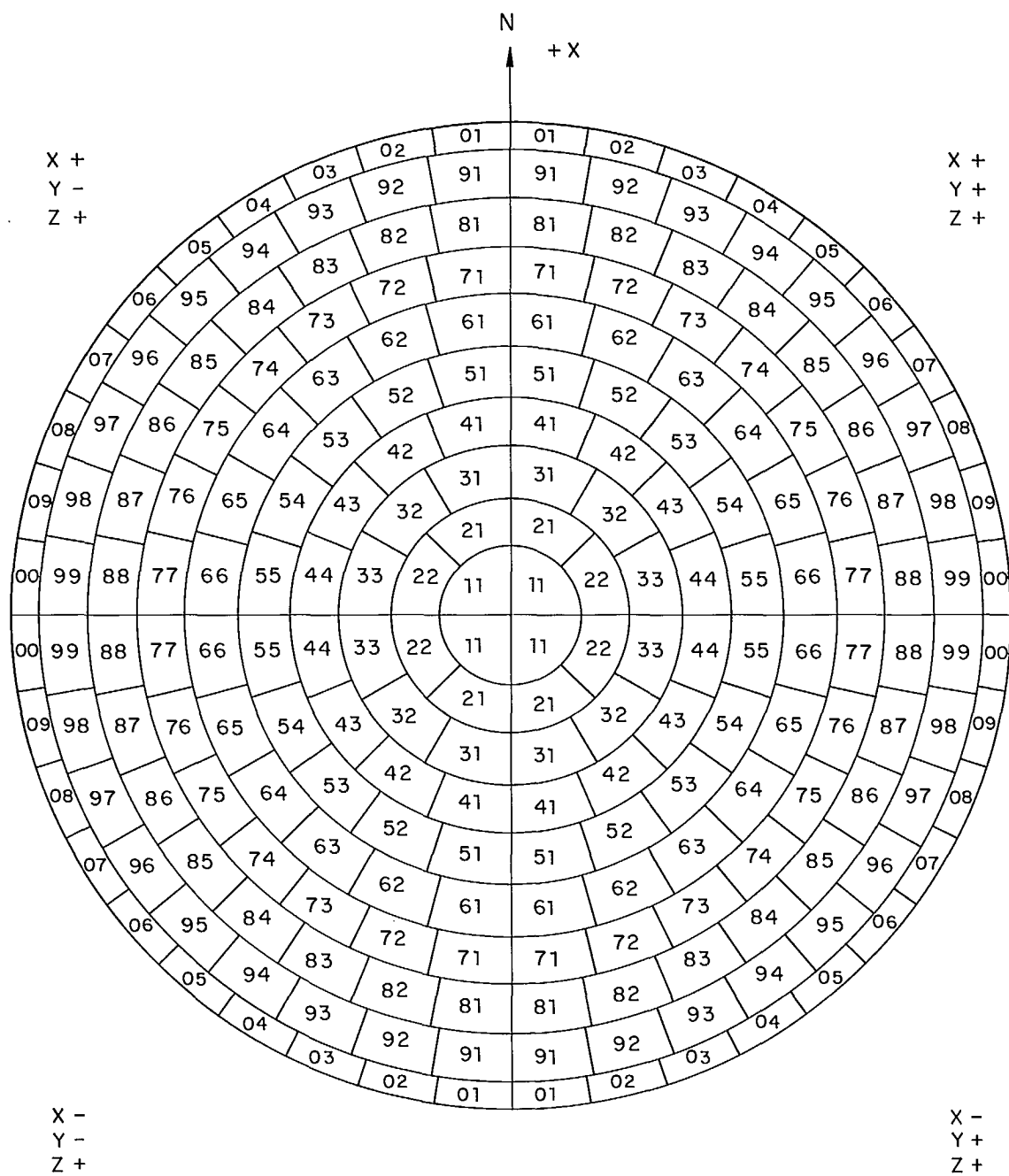


Polar Equal Area Net  
( Schmidt Net )





Equatorial Equal Area Net  
(Schmidt Net)



Braitsch overlay