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16. Abstract

This reference manual was prepared by Dr. D. R. Piteau & Associates, British Columbia, in conjunction with a series of Rock Slope Engineering Workshops sponsored by the Implementation Division of the Federal Highway Administration.

The manual consists of eight main parts as follows:

Part A: Engineering geology considerations and basic approach to rock slope stability analysis.

Part B: Methods of obtaining geologic structural, strength and related engineering geology data.

Part C: Approach and techniques in geologic structural analysis.

Part D: Slope stability analysis methods.

Part E: Rock slope stabilization, protection and warning - instrumentation measures and related construction considerations.

Part F: Blasting for rock slopes and related excavation considerations.

Part G: (Field Manual) Desicription of Detail Line Engineering Geology Mapping Method

Part H: (Appendix) Chapter 9 of Landslides; Analysis and Control (TRB Report 176)

A precise Table of Contents is given in each part of the manual.

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This report does not constitute a standard, specification or regulation.

FIELD MANUAL

DESCRIPTION

OF

DETAIL LINE ENGINEERING GEOLOGY

MAPPING METHOD

by

Douglas R. Piteau and Dennis C. Martin

D. R. Piteau and Associates Limited

West Vancouver, B. C.

July, 1977

PREFACE

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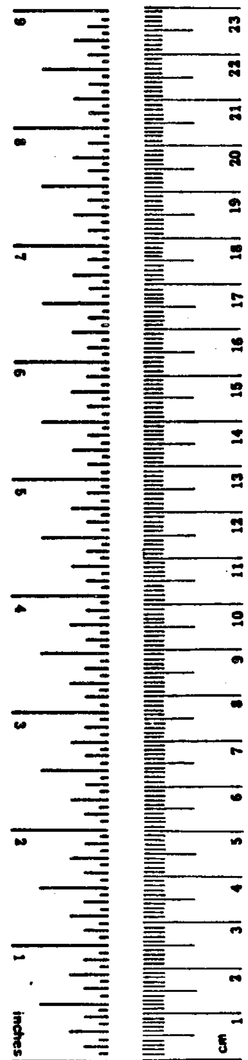
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

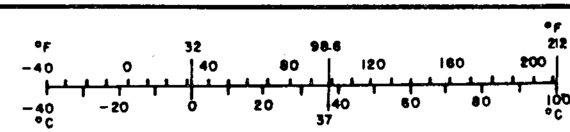


TABLE OF CONTENTS

DESCRIPTION OF DETAIL LINE ENGINEERING GEOLOGY MAPPING METHOD

1. INTRODUCTION

The detail line mapping method consists of stretching a measuring tape at waist height, or some other appropriate height depending on the nature of the rock face and toe conditions, along the exposed rock face or tunnel wall and recording the measurements and features of interest of the geological discontinuities that intersect the tape. The basic format and approach is a variation of the method described by Piteau (1971)* which was used in open pit stability analysis work in Africa.

The basic approach taken is easily adapted to computer based systems which can be used to great advantage to aid with the processing, synthesis and manipulation of the survey data. It aims to relieve the geologist of much of the tedious clerical work involved in transforming his observations into a model for the rock mechanics engineer but makes no attempt to supplant his judgement.

The details of the various procedures for setting up a traverse line and recording features of interest in terms of the slope stability analysis requirements are explained in the following. The basic format of the detail line survey sheet is shown in the Fig. 1. Genetic descriptions and terms of geological discontinuities which should be used in general mapping are given in Appendix A.

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* Piteau, D. R. (1971). Geological factors significant to the stability of slopes cut in rock, Planning Open Pit Mines, Published by A. A. Balkema, Amsterdam, pp 33-53.

2. BASIC EQUIPMENT REQUIRED

The basic equipment required for this mapping method is:

(a) clino rule and/or brunton compass for measuring structural attitudes

(b) 100-foot tape for locating structures between traverse stations

(c) notebook and field recording data sheets

(d) nails, flagging tape and spray paint for establishing and identifying traverse stations

(e) brunton compass for measuring traverse trend and plunge

(f) rock hammer for lithologic and hardness (strength) classifications

(g) large scale plan map of survey area for mapping basic structures in conjunction with the detailed mapping

(h) basic geological survey equipment such as hand lens, magnet, pocket knife, acid, etc.

3. ESTABLISHING THE TRAVERSE

After a preliminary survey of the area (Photo 1) the traverse station is established at waist height by driving a nail into the rock as shown in Photo 2. The traverse is then identified using flagging tape and spray paint (Photo 3). A 100-foot cloth tape is attached to the nail, stretched along the rock face as shown in Photo 4 and a second traverse station is estabilished at the end of the traverse. By convention, traverses should be set out in a clockwise sense around the area so that the traverse line is on the operators left when looking down the traverse. Traverses should be well marked at each end with spray paint and flagging tape so that they can be readily recognized from some distance (i.e. across a valley) for purposes of correlation of structures between elevations, and for field recognition by the survey crew who may pick up and locate the traverse stations on a plan drawing. Where possible the traverses should be joined end to end to reduce the number of points surveyed. If two operators are mapping, they should generally attempt to alternate traverses along the rock faces so that any differences of bias in mapping procedures would, in part be minimized.

4. THE TRAVERSE LINE DATA

The traverse line data located at the top of Fig. 1 concerns information which is common to the whole traverse line. This includes the location (i.e. highway chainage or grid coordinates) of the start of the traverse line and its elevation, the trend and plunge of the traverse line, and the operators personal location code. If a mountain side is being mapped, the elevation and general location may also be recorded. The date, weather and other general comments on the traverse are also recorded.

4.1 STATION NUMBER (col. 1 to 4)

The traverse station refers to the starting point of each individual traverse line; this is recorded as a number and ideally should be in the form of consecutively increasing numbers from one station to the next.

4.2 TRAVERSE TREND (col. 5 to 7)

The traverse trend and plunge are measured with a brunton compass as shown in Photos 5 and 6. The trend of the traverse line is measured in degrees clockwise from true north. Trends directed to true north should be recorded as 360. To facilitate the incorporation of line bias corrections, the trend may be recorded in columns for each individual discontinuity measured.

In a magnetically disturbed area the required value of the trend cannot be entered immedately. 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. The traverse trend may also be obtained from the plotted traverse station for the start and end of the traverse as picked up by the location survey. The traverse line data is recorded on the field sheet in Fig. 1.

5. THE DISCONTINUITY DATA

The discontinuity data (Fig. 1) concerns information which describes discontinuities along the traverse line by type, location, orientation, in filling, folding, size, spacing, water content and irregularities. Orientation and type of any linear structures on the discontinuities, the rock type and hardness are also recorded. F r these and other methods see ISRM (1977).**

5.1 DISTANCE (col. 8 to 11)

Distance recorded is the distance between the traverse station and the point where the observed structure intersects the tape.

5.2 ROCK TYPE (col. 12 to 14)

The rock type is determined by conventional geological techniques. In all cases, the type of rock up traverse from the last geological feature observed is recorded using a three letter mnemonic. Exposed rock further along the traverse is recorded with the next surface observation.

5.3 HARDNESS (col. 15 to 16)

The rock hardness or consistency is determined by a series of simple mechanical tests using a rock hammer and pocket knife (see Photo 7). The rock hardness can be related to unconfined compressive strength as in Table I (after Jennings, 1968)*. The various methods that hardness categories are determined are also explained in Table I and illustrated in Fig. 2(a) and 2(b).

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* Jennings, J. E. (1968). A preliminary theory for the stability of rock slopes based on wedge theory and using results of joint surveys. Univ. of the Witwatersrand, Internal Report, Unpublished.

** "Suggested Methods for the Quantitative Description of Rock Masses and Discontinuities". by ISRM (1977)

TABLE I

DESCRIPTION FOR DETERMINING CONSISTENCY OR HARDNESS OF SOIL AND ROCK USING FIELD MAPPING METHODS.

Hardness	Consistency	Field Identification	Approximate Range of Unconfined compressive strength Kg/cm² (Approx Tons/ft²)	p.s.i.
S1	very soft	Easily penetrated several inches by fist	<0.25	<3.5
S2	soft	Easily penetrated several inches by thumb	0.25-0.5	3.5-7
S3	firm	Can be penetrated several inches by thumb with moderate effort	0.5 -1.0	7-14
S4	stiff	Readily indented by thumb but penetrated only with great effort	1.0-2.0	14-28
S5	very stiff	Readily indented by thumbnail	2.0-4.0	28-56
S6	hard	Indented with difficulty by thumbnail	>4.0	>56
R0	extremely soft rock	Indented by thumbnail	2.0-7.0	28-100
R1	very soft rock	Crumbles under firm blows with point of geological pick, can be peeled by a pocket knife	7.0-70	100-1000
R2	soft rock	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow of geological pick.	70-280	1000-4000
R3	average rock	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of hammer end of geological pick	280-560	4000-8000
R4	hard rock	Specimen required more than one blow with hammer end of geological pick to fracture it	560-1,120	8000-16,000
R5	very hard rock	Specimen required many blows of hammer end of geological pick to fracture it	1,120-2240	16,000-32,000
R6	extremely hard rock	Specimen can only be chipped with geologic pick	> 2,240	> 32,000

5.4 TYPE OF STRUCTURE (col. 17 to 18)

The genetic type of geological structure observed is in Photo 8 and recorded as a two letter code. These features are shown in Fig. 3 (after Cruden, 1974)* . Common geologic structures are as follows:

Axial Plane (AP) - The surface joining the lines of maximum curvature on successive layers of a fold. Axial planes are imaginary planes which define the shape of folds and do not represent any physical discontinuity in the rock mass.

Bedding (BG) - Regular layering in sedimentary rocks marking lithological contacts.

Cleavage (CV) - closely spaced parallel surfaces of fissility in rock not parallel to lithologic contracts.

Contact (CN) - Surface between two rock types, one or both of which is not sedimentary.

Dyke (DK) - A sheet-like body of igneous rock that cuts across the structure in adjacent older rocks which it entered while in a molten condition.

Fault (FL) - Surface of shear recognizable either by the displacement of another surface that crosses it or by striated slickensides on the surface. Faults thus include all "shears". Faults can be classified by the direction of slip of the fault block which rests on the fault plane (the hanging wall block). Refer to slip and separation under type of lineation. For descriptive terms use *fault breccia* (FB), *slickensides* (SK), *striae* (ST), *gouge* (GO), *mylonite* (MO), *fault zone* (FZ), etc.

---

* Cruden, D. (1974). Discodat Manual. Pit Slope Project, Energy Mines and Resources, Ottawa, Internal Report (unpublished).

Folation (FN) - Surface parallel to compositional contacts in a metamorphic rock.

Gneissosity (GS) - Surface parallel to lithological layering in metamorphic rocks.

Joint (JN) - Fracture in rock mass along which there has been no identifiable displacement. For descriptive and/or analysis purposes it may prove advantageous to record the genetic type if known. Some of these of which could be considered are *tectonic joint* (TJ), *bedding joint* (BJ), *columnar joint* (CJ), and *sheet joint* (SJ).

Joint Sets (JS) - recognized set of joints, which have the same attitude and length. The spacing and frequency of these joints is recorded. For descriptive purposes if these joint sets are tending to be uniformily related they could be referred to as a *joint system* (JY) and when they persist over great areas we designate this jointing as the *regional joint pattern* (RJ).

Schistosity (SC) - surface of easy splitting in a metamorphic rock defined by the preferred orientation of metamorphic minerals.

Shear (SR) - surface of shear without recognizable displacement. It can be recognized by slickensides, polishing or slickness of the surface or striations on the surface.

Sill (SL) - A tabular body of igneous rock that has been injected while molten between layers of sedimentary rocks or along the foliation planes of metamorphic rocks.

Tension Crack (TC) - an unnaturally developed tension feature which is open and planar in form; such features could be tension cracks at slope crests or naturally occurring discontinuities which have opened.

Unconformity (UC) - Eroded surface covered by sedimentary rock.

Vein (VN) - Fracture in rock with a filling apparently injected at the time the fracture formed.

5.5 SPACING AND FREQUENCY OF JOINT SETS (col. 19 to 22)

In cases where several joints of one set and of the same size are identified, the spacing in feet and the number of joints are recorded in the appropriate columns to facilitate the mapping. The orientation of the set is recorded as the best average orientation of the joints observed.

5.6 STRIKE (col. 23 to 25)

The direction of a line formed by the intersection of the structural plane with a horizontal plane. Because of magnetic deflections due to metal pipes and train tracks, this being particularly prevalent in tunnels, it may be advisable to take this measurement with an ordinary carpenters angle rule or clino-rule, placing one leg parallel to the stretched tape, and measuring the strike as illustrated in the case of tunnel mapping, in Fig. 4 and Photo 9.

A Brunton compass may also be used to measure strike in nonmagnetic areas or in magnetic areas if appropriate corrections can be made for regional and local declination. If the Brunton is used, proper checks must be made to insure it is accurate.

Care must be taken to note for each traverse whether the clino-rule or Brunton is used for structural mapping.

5.7 DIP (col 26 to 30)

The dip angle, being the angle between the horizontal plane and the structure taken in a direction normal to the strike, is measured with a clino-rule or Brunton as shown in Photo 10. Dip direction may be related to the compass points if the Brunton is being used. If a clino-rule (or even the Brunton) is being used, the dip direction may be recorded relative to the traverse as:

positive (+) if it dips in a clockwise direction from strike
negative (-) if it dips in a counterclockwise direction from strike

5.8 LENGTH OF DISCONTINUITY (col. 31 to 34)

The length or size of a discontinuity is determined by estimating or measuring the actual dip trace length of the joint in feet which is visible on either the surface outcrop or cut face (columns 31 to 33).

Additional information on continuity of the joints may be recorded as described in the following. If one end of the structure is continuous upwards or downwards out of the rock face being considered, either along the dip of the joint trace, a figure 1 is shown behind the recorded trace length. Similarly, if both ends are continuous out of the face a figure 2 is shown following the trace length. If both ends of the joint can be seen the space is left blank, or a figure 0 is used (column 34).

5.9 INFILLINGS (col 35 to 40)

Infilling is meant to include any materials that occur between the planes of any structural feature regardless of the type. Infilling is thus taken to include materials derived from breakage of the country rock due to movements (i.e. alteration products) and foreign infilling materials deposited between the structural planes such as calcite.

(i) *Type* (col 35 to 37)

The type of joint infilling material is recorded using single letter mnemonics. The more abundant type of infilling should be recorded in the right hand column. Some typical infillings are given in the following:

Air (A) - total void exists between the walls of the plane.

Soil - Clay (C), sand (S)

Calcite (Z)

Detritus (D) -debris washed into an open fracture.

Evaporites (E) - gypsum, halite, anhydrite.

Feldspar (F) - hard, often pink, insoluble, good cleavages, easily weathered.

Gouge (G) - wall rock is often ground up by movements along a fault zone. Gouge is the result of the accelerated weathering of the resulting fine grained materials; it is generally a green clay.

Breccia (B) - consolidated angular rock fragments larger than sand grains resulting from fault movement.

Ore (Ø) - valuable.

Quartz (Q) - hard, white and insoluble.

(ii) *Thickness* (38)

Thickness of the joint or gouge infilling is taken as the width of that material between sound intact rock. Thickness is generally recorded on catagorized scale as follows:

Category	*Thickness*
1	0.00"
2	0.00" - 0.25"
3	0.25" - 1.00"
4	1.00" - 2.00"
5	2.00" - 4.00"
6	4.00"

(iii) *Hardness* (col. 39 to 40)

The hardness of the infilling may be recorded using the scale described for rock hardness (see Table 1 and Fig. 2).

5.10 WATER (col. 41)

The presence or absence of water in either joint infilling materials or in the structural plane in general may be recorded in a miscellaneous collumn based on the following six categorizations:

Category	*Degree of Water*
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 water flow, rust staining of discontinuity surface, etc.
4	The discontinuity is damp but no free water is present.
5	The discontinuity shows seepage, occasional drops of water, no continuous flow.
6.	The discontinuity shows a continuous flow of water.

5.11 ROUGHNESS (col. 42)

Roughness asperities are illustrated in Fig. 5. Roughness of the joint surface may be recorded on a five-finger scale. The five categories of roughness are illustrated in Fig. 6 and as follows:

Category	*Description*
1	Slickensided or polished
2	Smooth
3	Defined ridges
4	Small steps
5	Very rough

5.12 WAVINESS (col 43 to 45)

Waviness of the structural plane may measure if required by placing a clino-rule in the hollow of the wave and recording the interlimb angle (ILA) that occurs between the legs of the clino-rule in columns 43 to 45 (see Fig. 7 and Photo 11). The legs of the clino-rule should be opened to the full 12 inches when this is measured. In addition to the interlimb angle the wavelength may be recorded to the nearest 1/10 of a foot in columns 46 and 47 to obtain a feeling for the physical size of the waves. In doing this both the amplitude and length of the wave can be measured as illustrated in Fig. 8. If this is done the waviness columns would have bo be adjusted accordingly. The pitch of wave or fold oxes can be measured as shown in Photo 12.

6. ADDITIONAL INFORMATION AND REMARKS

All additional information or comments on major structures should be included in the columns provided in Fig. 1 or in a separate set of field notes which are recorded in conjunction with the geological mapping.

At the completion of each traverse, lithology and information concerning major structures obtained from the detail line mapping should be plotted on a large scale field plan to construct a detailed geological map of the area examined. This map will be particularly useful for correlation of both major geological structural features and lithological contacts and completion of the final lithology and structural geology map of the rock cut involved.

SITE: ____________

COORDS. OR CHAINAGE

NORTH [ ] ELEV. [ ] TREND [ ] OBS. [ ] NAME: ____________

TRAVERSE STATION [ ]

EAST [ ] LOCAT. [ ] PLUNGE [ ] LENGTH [ ] DATE: ____________

STATION (FROM)	TRAV. TREND	DISTANCE (FEET)	ROCK		STR. TYPE	NO. of JNS	JN SPCG. (FT)	STRIKE	DIP			SIZE		INFILLINGS			W T R	R G S	WAVINESS		REMARKS
			TYPE	HDNS					±	ANG	DIR.	LENGTH (FT)	ENDS	TYPE	TH	HDNS			ILA	WAVE LTH.	
1	5	8	12	15	17	19	21	23	26	27	29	31	34	35	38	39	41	42	43	46	

FIG. 1

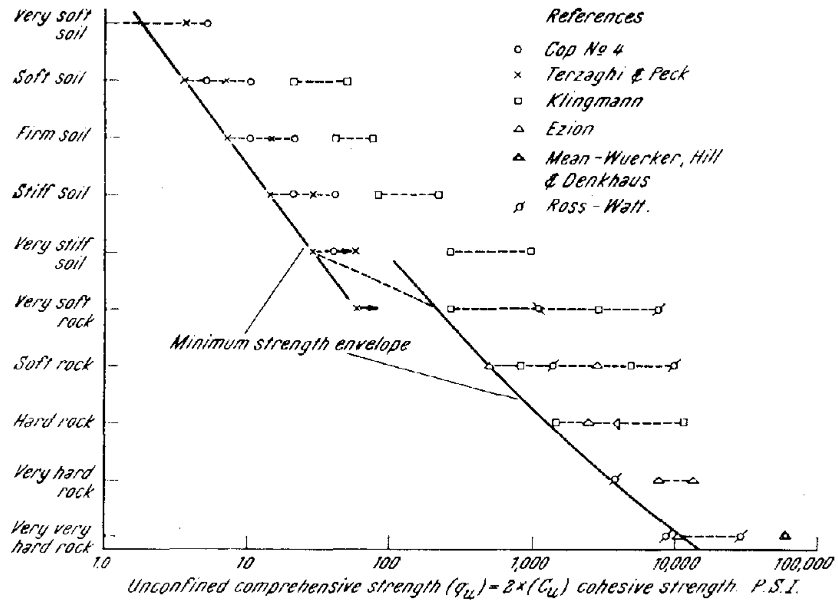


Fig. 2(a) Relationship between consistency of hardness as classified in the joint survey and in confined compressive strength of the material (after Jennings, 1968).

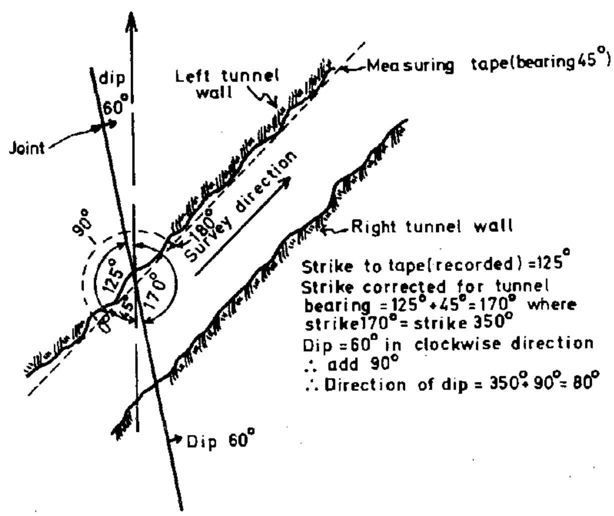


Fig. 4. Determination of joint attitude from the survey (after Piteau, 1971).

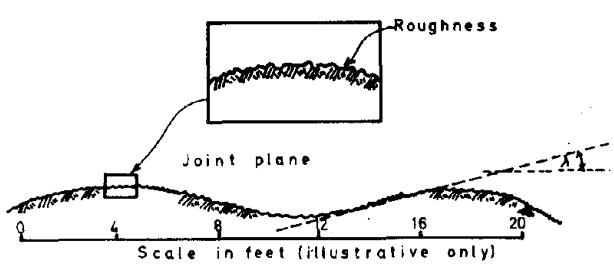
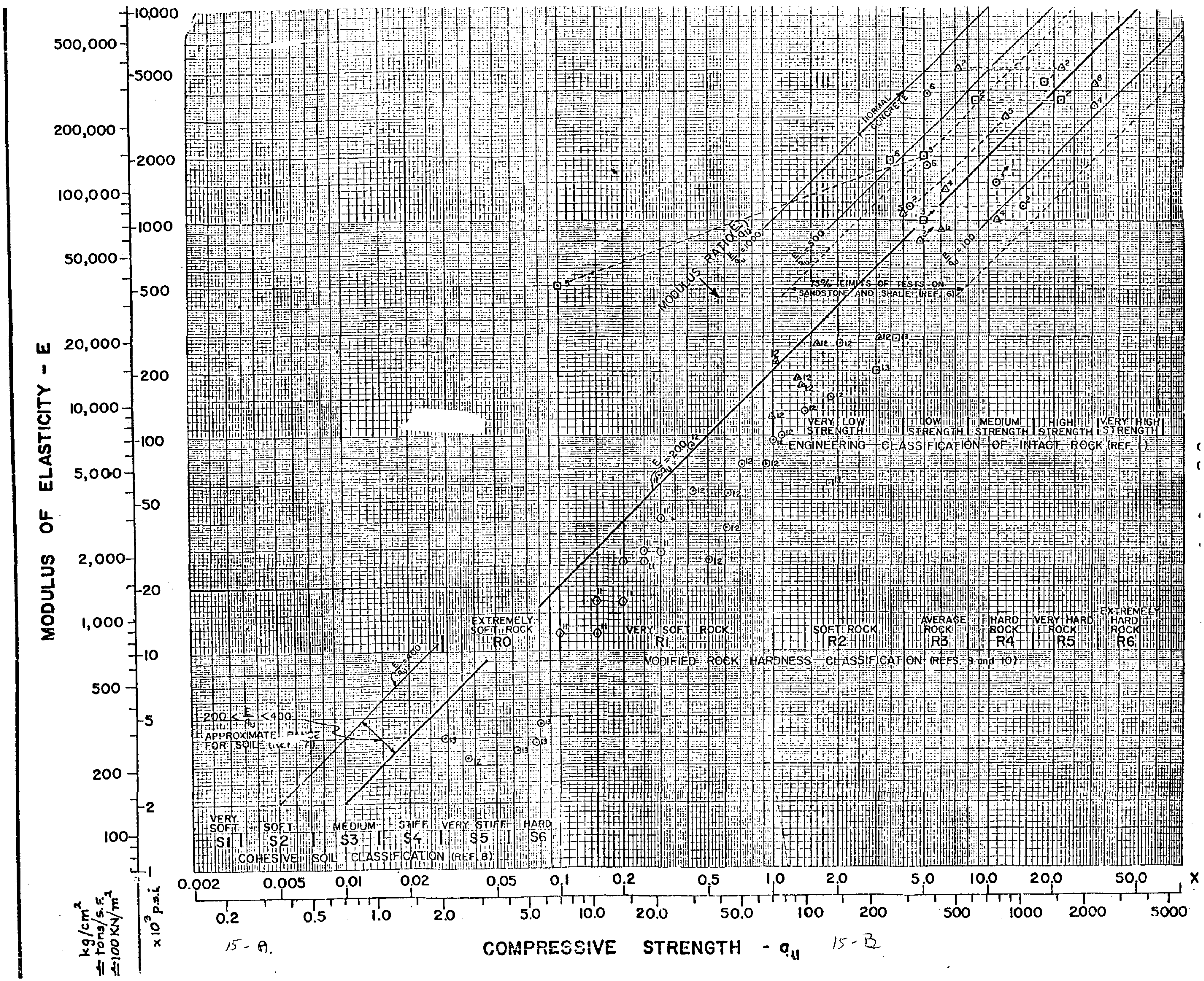
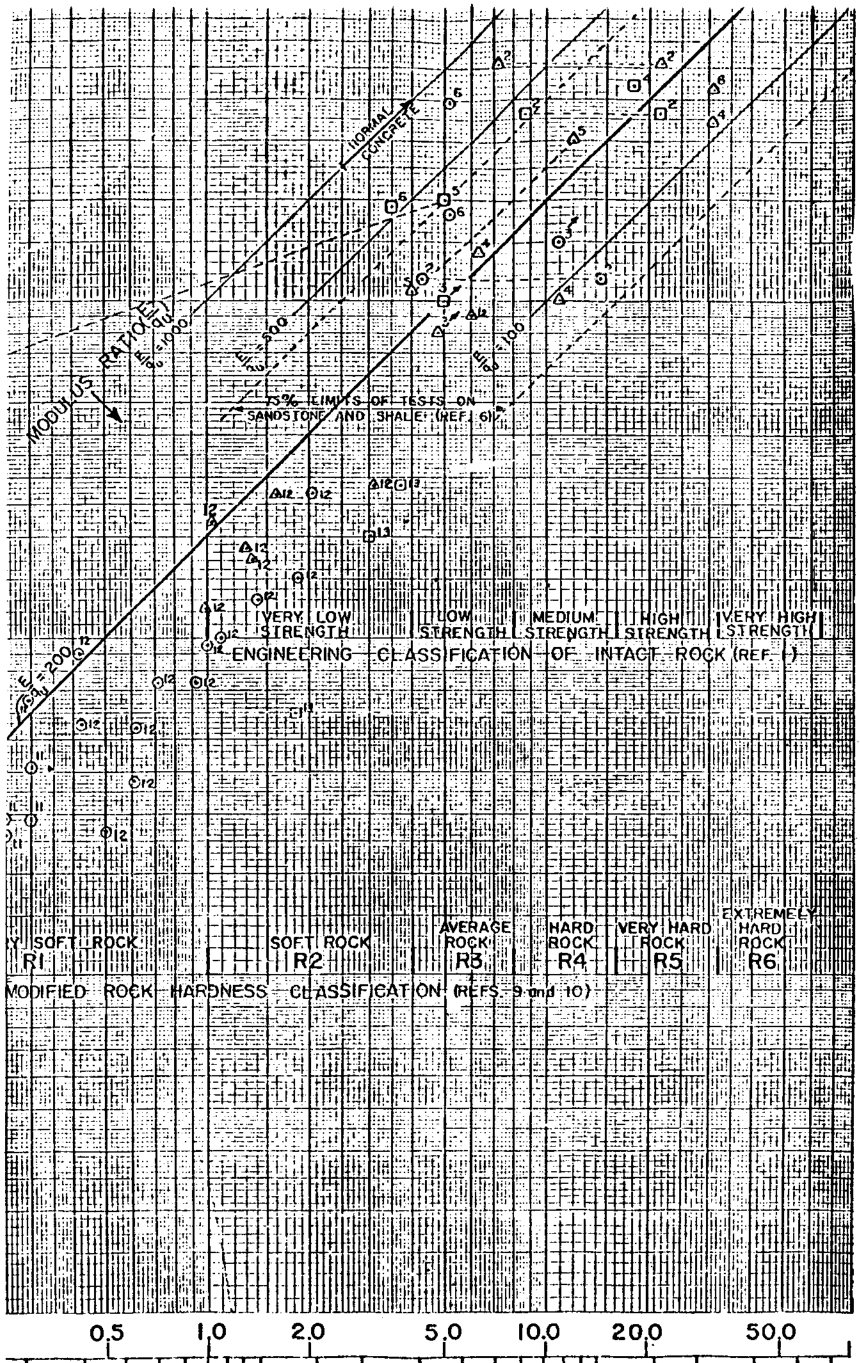


Fig. 5. Illustration of roughness on a joint plane (after Piteau, 1971).


MODULUS OF ELASTICITY - E
COMPRESSIVE STRENGTH - q_u
kg/cm² ≐ tons/s.f. ≐ 100 KN/m²
x 10³ p.s.i.
MODULUS RATIO (E/q_u)
E/q_u = 1000
E/q_u = 500
E/q_u = 200
E/q_u = 100
NORMAL CONCRETE
75% LIMITS OF TESTS ON SANDSTONE AND SHALE (REF. 6)
VERY LOW STRENGTH
LOW STRENGTH
MEDIUM STRENGTH
HIGH STRENGTH
VERY HIGH STRENGTH
ENGINEERING CLASSIFICATION OF INTACT ROCK (REF.)
EXTREMELY SOFT ROCK R0
VERY SOFT ROCK R1
SOFT ROCK R2
AVERAGE ROCK R3
HARD ROCK R4
VERY HARD ROCK R5
EXTREMELY HARD ROCK R6
MODIFIED ROCK HARDNESS CLASSIFICATION (REFS. 9 and 10)
200 < E/q_u < 400
APPROXIMATE RANGE FOR SOIL (REF. 7)
VERY SOFT S1
SOFT S2
MEDIUM S3
STIFF S4
VERY STIFF S5
HARD S6
COHESIVE SOIL CLASSIFICATION (REF. 8)
15 - A.
15 - B



LEGEND

- ○ CLAYSTONE, □ SILTSTONE } ARGILLACEOUS SEDIMENTARY ROCKS/ SHALE (FISSILE), MUDSTONE (MASSIVE), ETC.
- △ SANDSTONE: SILICEOUS SEDIMENTARY ROCKS
- ○ GLACIAL TILL
- ▽ LIMESTONE

Modulus values by G. MacLeod

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CORRELATION BETWEEN COMPRESSIVE STRENGTH AND ELASTIC MODULUS FOR VARIOUS HARDNESS IN SEDIMENTARY ROCKS, FIG. 2(b)

15-C

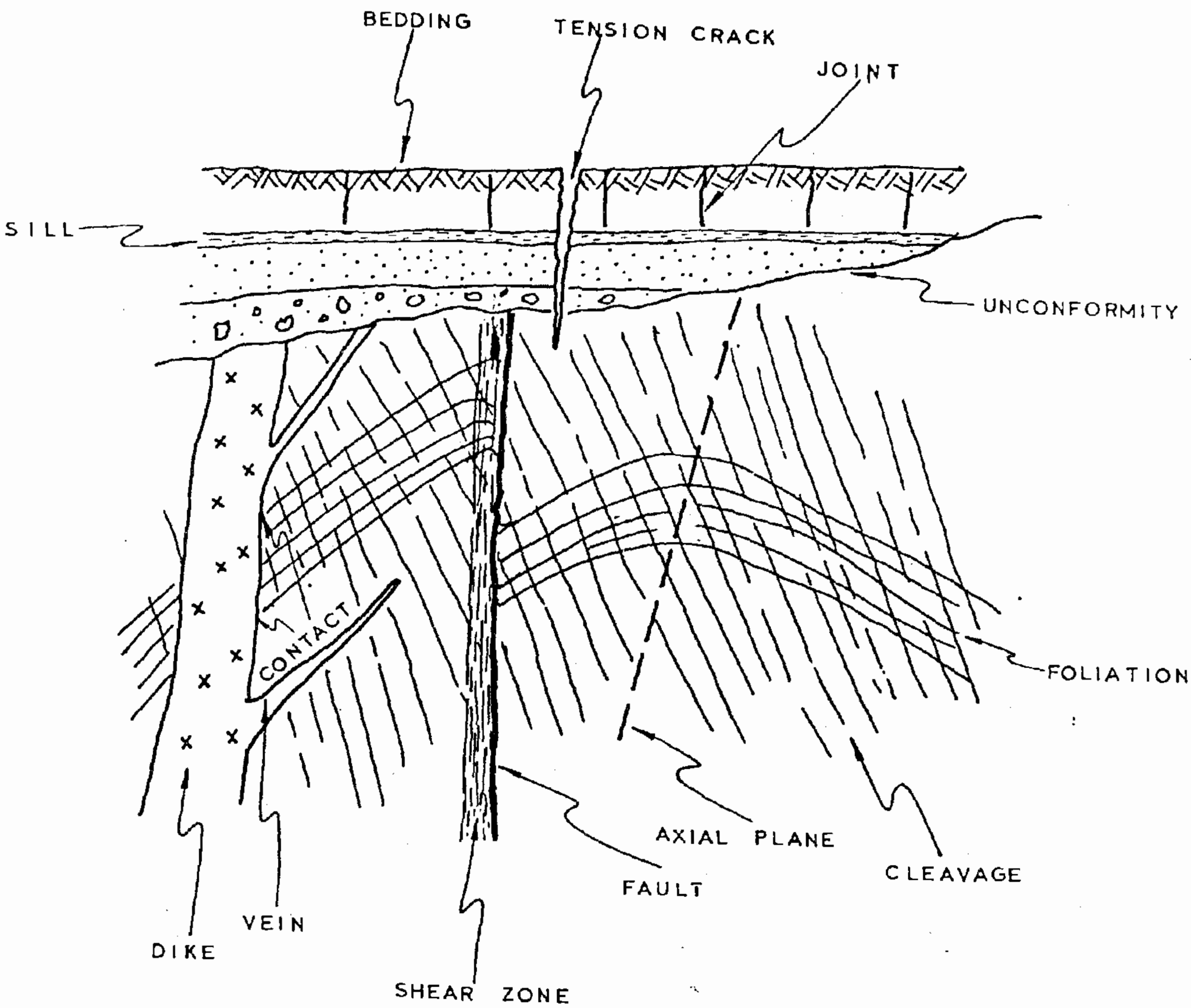

Fig. 3. Various types of geologic structural features to be considered in geological mapping (after Cruden, 1974).

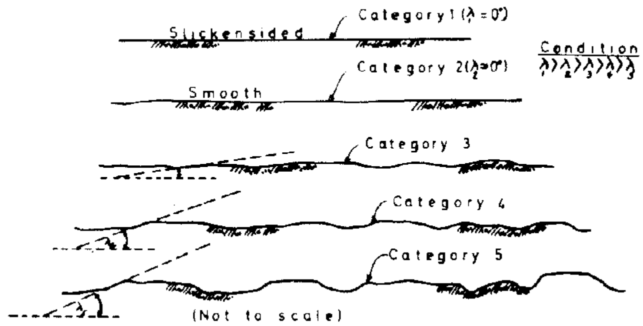

Fig. 6. Illustration of relative roughness of the five categories, (after Piteau, 1971).

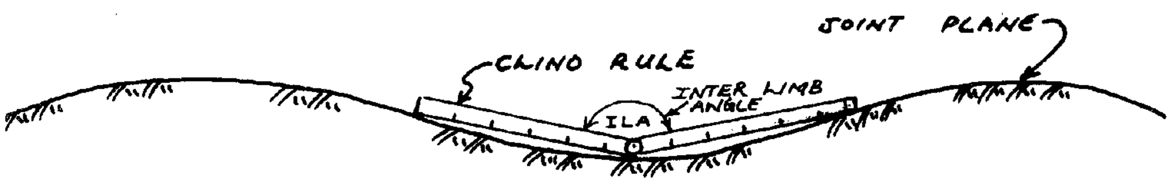

Fig. 7. Measurement of waviness with a clino rule.

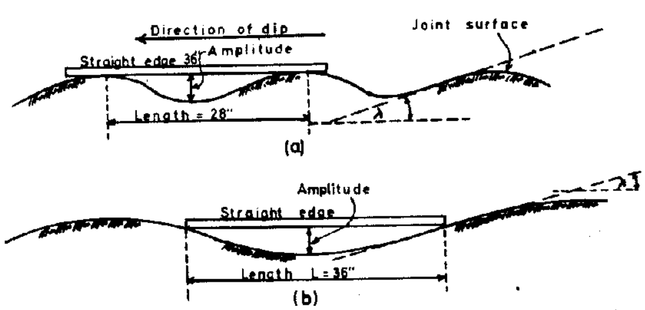

Fig. 8. Measurement of waviness of a joint plane (after Piteau, 1971).

Photo 1 Preliminary survey of the traverse area (See man for scale at bottom of photo).

Photo 2 Establishing the traverse station by inserting a nail on which to attach the 100-foot measuring tape.

Photo 3 Identification of the traverse station

Photo 4 Stretching out the measuring tape along the traverse line.

Photo 5 Measuring the traverse trend with a brunton compass

Photo 6 Measuring the traverse plunge with a brunton compass.

Photo 7 Determining the rock hardness using the geological hammer.

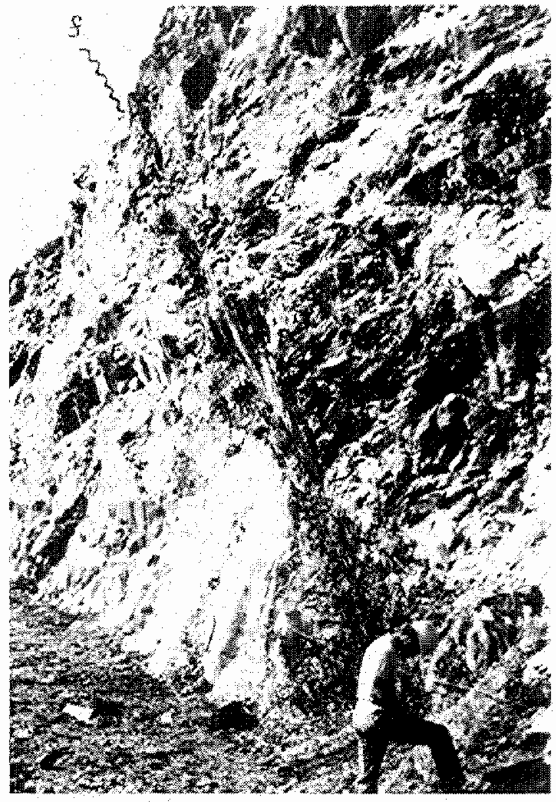

Photo 8 Identifying a major discontinuity which intersects the traverse line.

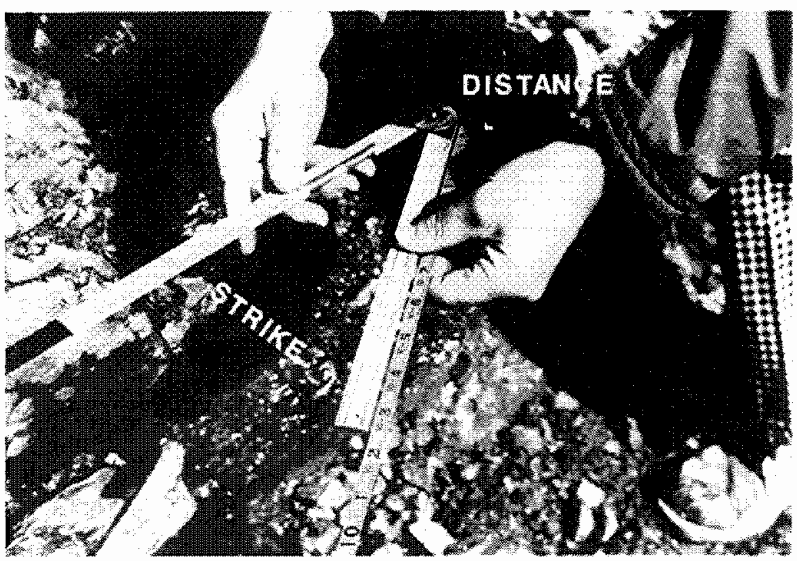

Photo 9 Measuring the location (distance) and strike of a discontinuity with a clino rule.

Photo 10 Measuring the dip and continuity or size of a discontinuity.

Photo 11 Measuring the inter-limb angle (ILA) of waves on the plane of a discontinuity.

Fig. 14. Recording information on the"discontinuity sheet". (Card type 02).

Photo 12 Measuring the pitch of a fold axis (F.A.) of waves on the plane of discontinuity.

APPENDIX A

GLOSSARY OF DEFINITIONS OF STRUCTURAL TERMS

AND

SYMBOLS

GLOSSARY OF DEFINITIONS OF STRUCTURAL TERMS AND SYMBOLS

Described in the following are the various types of geological structure that, to a larger or lesser extent, will effect the stability of rock slopes. The geological classifications are based essentially on their genetic and geometric relationships and general nature and character of their occurrence as well as whether they are primary* or secondary* structures. It is suggested that in adopting geological terminology relating to types of geological structure occurring at the mine site, one should utilize the terms which are described in the following.

A-1 PRIMARY STRUCTURE

(i) Bedding: is regular layering in sedimentary rocks marking the boundaries of small lithological units or beds.

(ii) Foliation: a parallel structural fabric formed in metamorphic rocks.

(a) Schistosity: well-developed foliate structure of easy splitting formed primarily by micaceous minerals.

(b) Gneissosity: imperfectly developed foliate structure between bonds of feldspathic granular material.

* Primary structures are geologic structural features that are formed contemporaneous with the first stages in the formation of a rock; they are a function of the geological processes governing the origin of the rock.

**Secondary structures are geologic structural features which form subsequent to the formation of the rock due to tectonic movements, dissolution, cooling, contraction, etc.

A-2 SECONDARY STRUCTURE

(i) Faults: surfaces of rupture on which there is evidence that the walls have had significant shear displacement relative to one another. Frequently rock on both sides of the fault planes are shattered resulting in fault breccia consisting of finely shattered rock; the fault planes are frequently smooth or polished to a slick surface called slickensides which may or may not contain scratches or striae which indicate one of two possible directions that the last movement took place. Fault breccia reduced to a fine soft powder is called gouge; if the result of pulverization is a streaky compact rock consisting of microscopic mineral grains the material is called mylonite. The fault zone, which is the disturbed material between the fault planes, is usually thinner for faults where spacing is close than when faults occur at considerable distance apart. Fault zones can vary in character, consisting of alternating sheared and crushed zones or slightly to highly altered sections which may or may not be entirely clay-like in behaviour. It is worthy to note that reverse faults are almost invariably flatter than normal faults (Anderson, 1951) and are subject to much more severe breakage with the result that the shear strength has been reduced. Fault zone breakage in hard rocks is usually more extensive than in soft rocks. Although fault displacements in many soft rocks may be several hundreds of feet the fault zone may consist of only a thin seam; for engineering purposes this characteristic is important to recognize.

(ii) Shears: are fractures along which there is minimal breakage due to minor shear displacement and no observable offset; shear movement is recognized by slickensided, striated or polished surfaces on the faces of the fractures. Several shears together form a shear zone.

(iii) Joints: are fractures along which there has been no breakage of the walls of the joints or evidence of any displacement parallel to the plane of the fracture. Field studies of several workers have shown that rocks are invariably jointed in preferential directions and occur in parallel groups which we designate joint sets. In instances where jointing is considered to have random distribution, it is usually the case that several sets occur simultaneously or a set has been superimposed on earlier sets and the resulting complexity gives the appearance of randomness. Where there is a tendency for joint sets to be uniformly related, the term joint system is used and when these persist over great areas we designate this jointing as the regional joint pattern.

It is usually the case that joints in general which persist over great areas, thereby constituting the regional joint pattern, are generally referred to as tectonic joints. However, there are certain joint structures that are of different geologic origin which are worthy of recognizing when conducting the structural analyses.

(a) Tectonic Joints: are joints which are preferentially developed on a regional scale due either to crustal warping, uplift, tectonic forces, compressive stresses in cooling igneous masses and so forth. Tension joints, for example, will develop over broad areas on the crest of anticlinal folds. Preferential joint patterns sometimes can be traced for miles in metamorphic belts. It is suggested that unless any of the specific joint types which are described in the following can be identified in the structural survey, that the joints be simply called tectonic joints for lack of better classification.

(b) Bedding Joints: are fractures that occur parallel to bedding in sedimentary rocks. This type of joint is represented by primary bedding and contact planes between beds of weakly cemented or somewhat diagenetically altered layers. Bedding joints are particularly characteristic in the type of sedimentary sequence which contains spotty intercalations of sand-clay and intermediate-grain size variety of rocks. It includes boundary planes or zones between intercalated layers that define the structure of the sedimentary sequence as a whole, beds and seams that may change volume sharply with change in moisture content, highly plastic layers in the rock sequence and highly fractured rocks confined to a section of the stratification. The principal danger of these bedding discontinuities lies in their potential transformation to slip planes because of reduction of shear strength and they are natural paths for filtration and infiltration and drainage of groundwater, leading to secondary weakening of the contact and undermining of the slope by flushing out of fines (Komarnitski, 1968). Bedding shears, which are typical of folded sediments, are analogous to bedding joints but are of greater continuity and generally lower shear strength.

(c) Cross Joints: are joints developed across the stratification in sedimentary rocks. They occur as jointing in lamina, thin beds and groups of beds, but a large portion terminate abruptly at contacts between beds and are characterized by a variety of orientations, the majority of which dissect the beds perpendicular or almost perpendicular to the strata planes. Cross joints are usually inversely proportional in number to the thickness of beds in which the joints occur. The origin of these joints is usually related to tectonic forces or forces that develop in rocks during changes in properties during diagenesis of the sediments.

(d) Columnar Joints: are common features of volcanic rocks, such as dolerite, and are tension features wholly related to shrinkage or contraction of the rock mass during cooling. Typically the rock columns formed by the joints are rudely hexagonal in section and develop at right angles to the boundary of the volcanic flow. The continuity of these joints is small; rockfalls in vertically columnar-jointed rocks are common, due mainly to toppling-type failures.

(e) Sheet Joints: are fractures that develop parallel to or sub-parallel to the ground surface which are believed to have resulted from unloading and elastic rebound of the earth's surface. If unloading is due to glacioisostatic rebound due to melting of glacial ice, these features usually are closely spaced near surface and quickly disappear with depth. However, if unloading is due in a large part to denudation processes, these features may persist with depth and could extend over the entire height of the pit slope.

(iv) Unconformities: are surfaces of erosion that separate younger strata from older rocks. These horizons can often be of a weak nature and the variations in attitude of these planes can be great depending on the relief of the older pre-existing surface.

(v) Geological Contacts: are surfaces where two different kinds of rocks come together, one or both of which are not sedimentary. Geological contacts, such as those between sediments and igneous intrusive bodies, can be weak, can have great continuity and in many instances can provide considerable control on groundwater conditions in the slope.

(vi) Cracks: are tension fractures caused by activities of man. These features could be openings along pre-existing discontinuities and/or cracks propagated through intact material; they are usually found at the crest of benches or behind the crest of the pit slope.

(vii) Cleavage: is definite, closely spaced parallel surfaces along which a rock breaks readily. This secondary structure is commonly found occurring parallel to axial planes of folds in bedded structure.