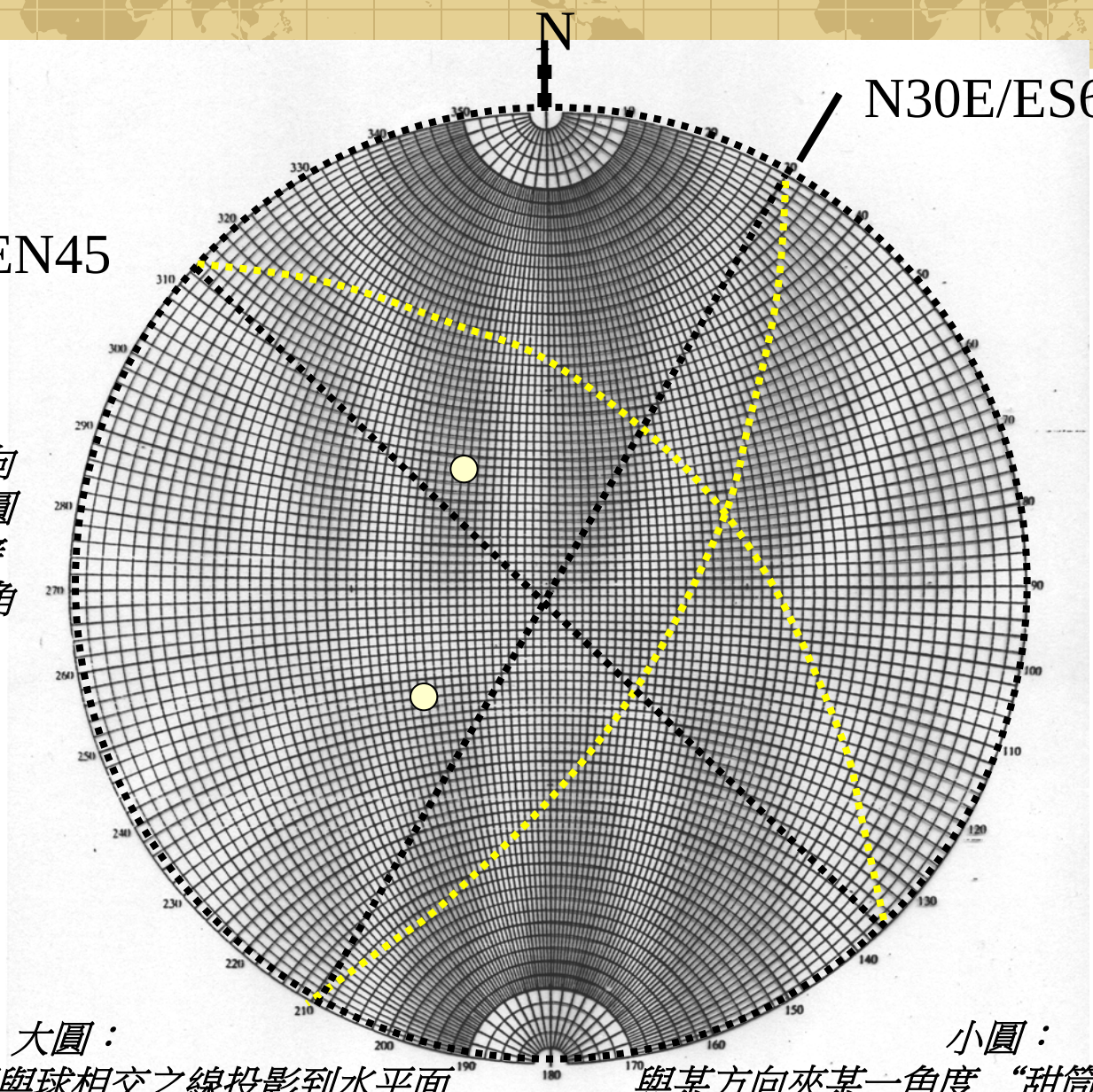


旋轉到兩個法線向量落在同一個大圓上(共平面)，直接讀兩法線向量夾角

兩向量交角

大圓：
某個南北走向的面與球相交之線投影到水平面

小圓：
與某方向夾某一角度 “甜筒” 投影到水平面

Figure 2.11 Equatorial equal-angle net.

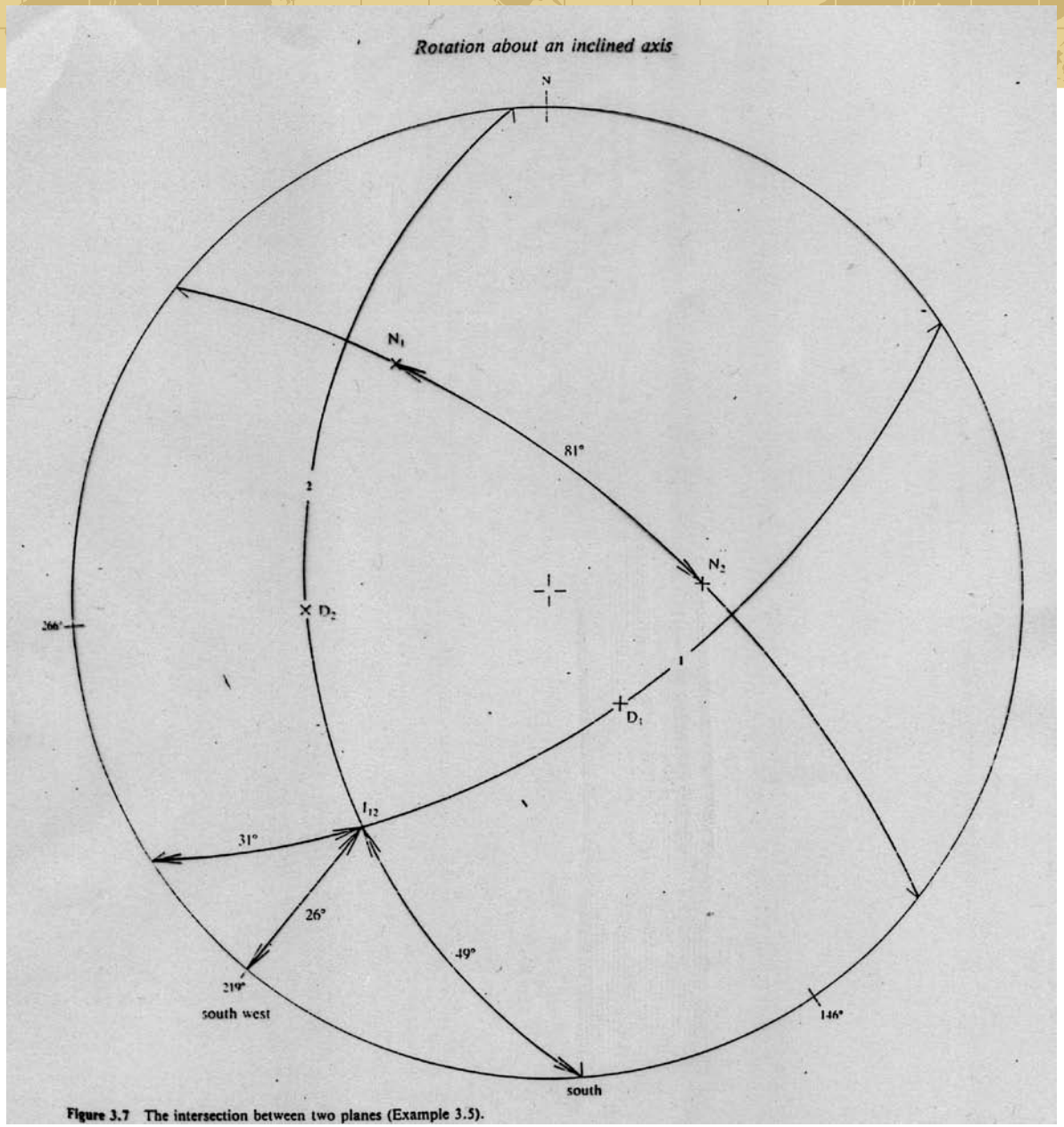


Figure 3.7 The intersection between two planes (Example 3.5).

HW2

- Ch 3, problems 3 , 4, and 5

Apparent dip and True dip

HW3

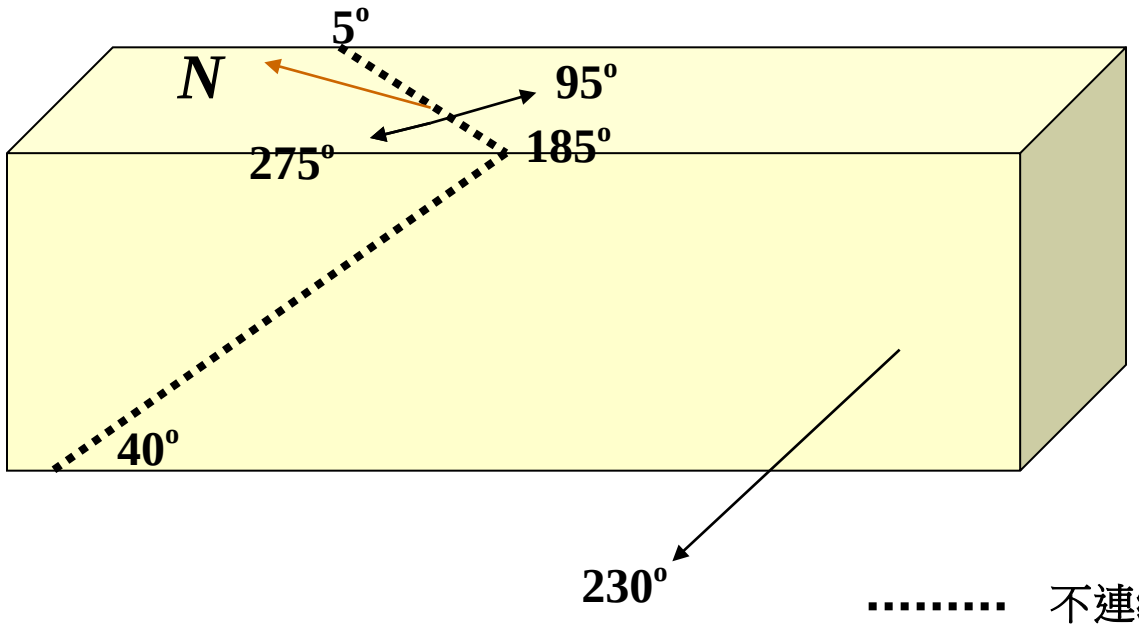
- Resolve Ch 3 problem 6 using stereographic projection

$$\tan\beta_a = \sin\delta \cdot \tan\beta_t$$

$$\delta = 0^o, \beta_a = 0^o$$

$$\delta = 90^o, \beta_a = \beta_t$$

δ Angle between dip direction of discontinuity and outcrop surface



..... 不連續面與隧道壁面之相交軌跡

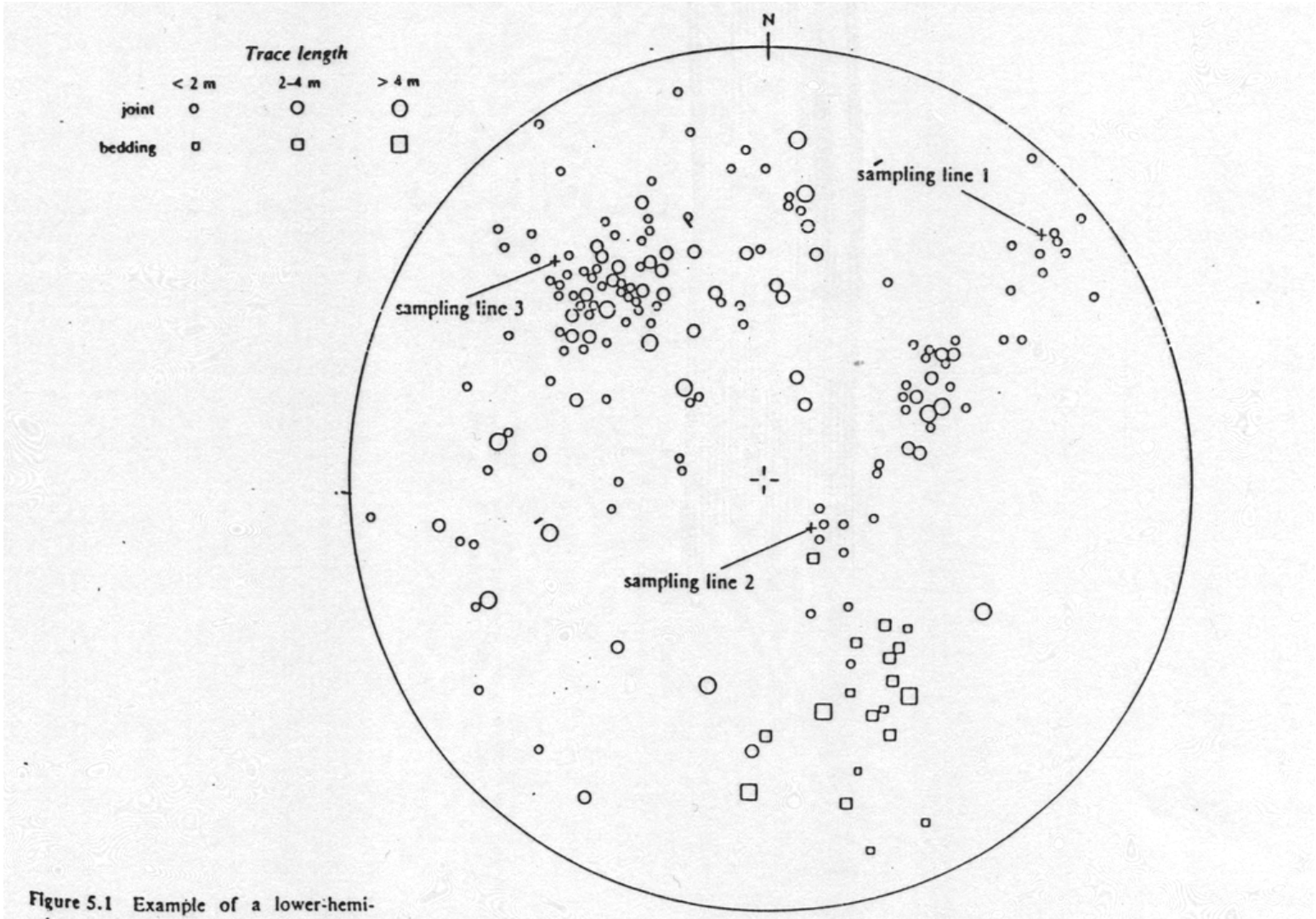


Figure 5.1 Example of a lower-hemisphere plot of discontinuity normals.

HW4

- *The results of scanline survey (in the previous page) are shown in the table. Please plot the poles of 15 discontinuities and estimate the number of sets of joints and the averaged orientations.*

Intersention distance(m)	Dip Direction (Degrees)	Dip Angle (Degrees)	Semi-trace length(m) above or left of scan line	Semi-trace length(m) below or right of scan line	Termination I=1, A=2 ,O=3	
0	247	50	0.09	0.01	2	2
0.55	190	85	0	0.05	2	2
0.83	204	85	0.03	0.06	2	2
1.00	230	85	0.02	0.02	2	2
1.50	348	90	0.03	0.08	2	2
1.77	306	50	0.09	0.01	2	2
2.54	318	75	0.04	0.19	2	2
2.72	240	60	0.13	0.01	2	2
3.07	240	65	0.06	0.01	2	2
3.33	226	45	1.96	1.63	2	2
3.65	240	45	0.01	0.1	2	2
3.74	250	60	0.12	0.03	2	2
4.99	350	70	0.1	0.01	2	2
5.87	290	50	0.04	0.04	2	2
6.57	16	65	0.03	0.04	2	2

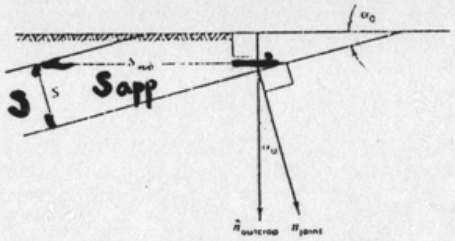
Detail of scanline:
Trend 60
Plunge 15
Length 6.69

Details of rock face:
Dip direction 286
Dip angle 38
Non-overhanging
Height m
Width m

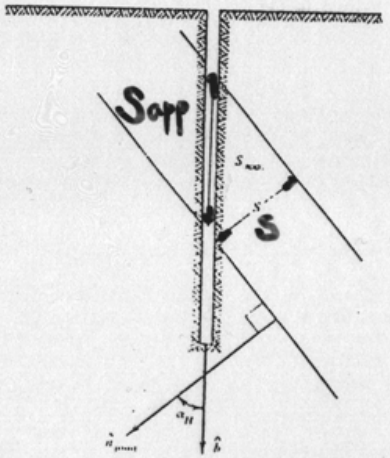
Rock type
薄層砂岩夾薄葉層頁岩
Condition of exposure:
中度風化
內寬 tight

Bias in Occurrence of joints (Spacing)

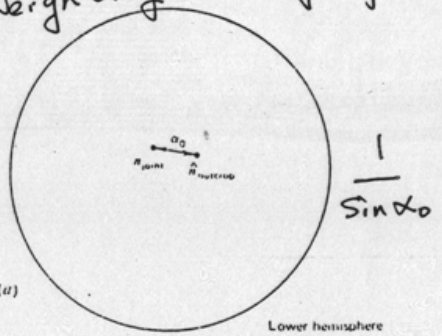
$S = S_{app} \cdot \sin\alpha_o$



$S = S_{app} \cdot \cos\alpha_H$



Weighting "a single joint" " numbers of joints"



$\frac{1}{\sin\alpha_o}$

$\frac{1}{\cos\alpha_H}$

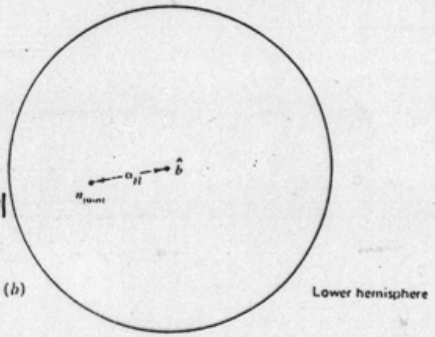


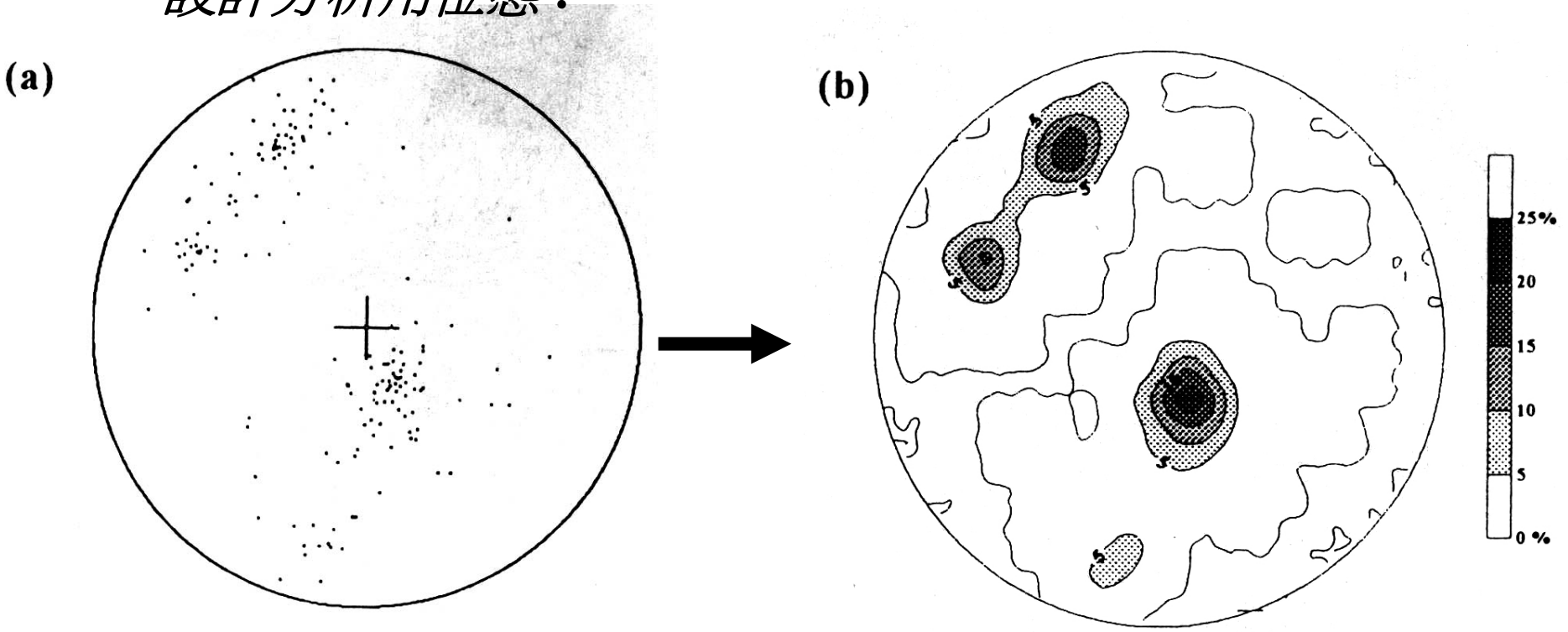
Figure 5.7 Bias in occurrence of joints in (*a*) outcrops.

Figure 5.7 Bias in occurrence of joints in (*b*) drill holes.

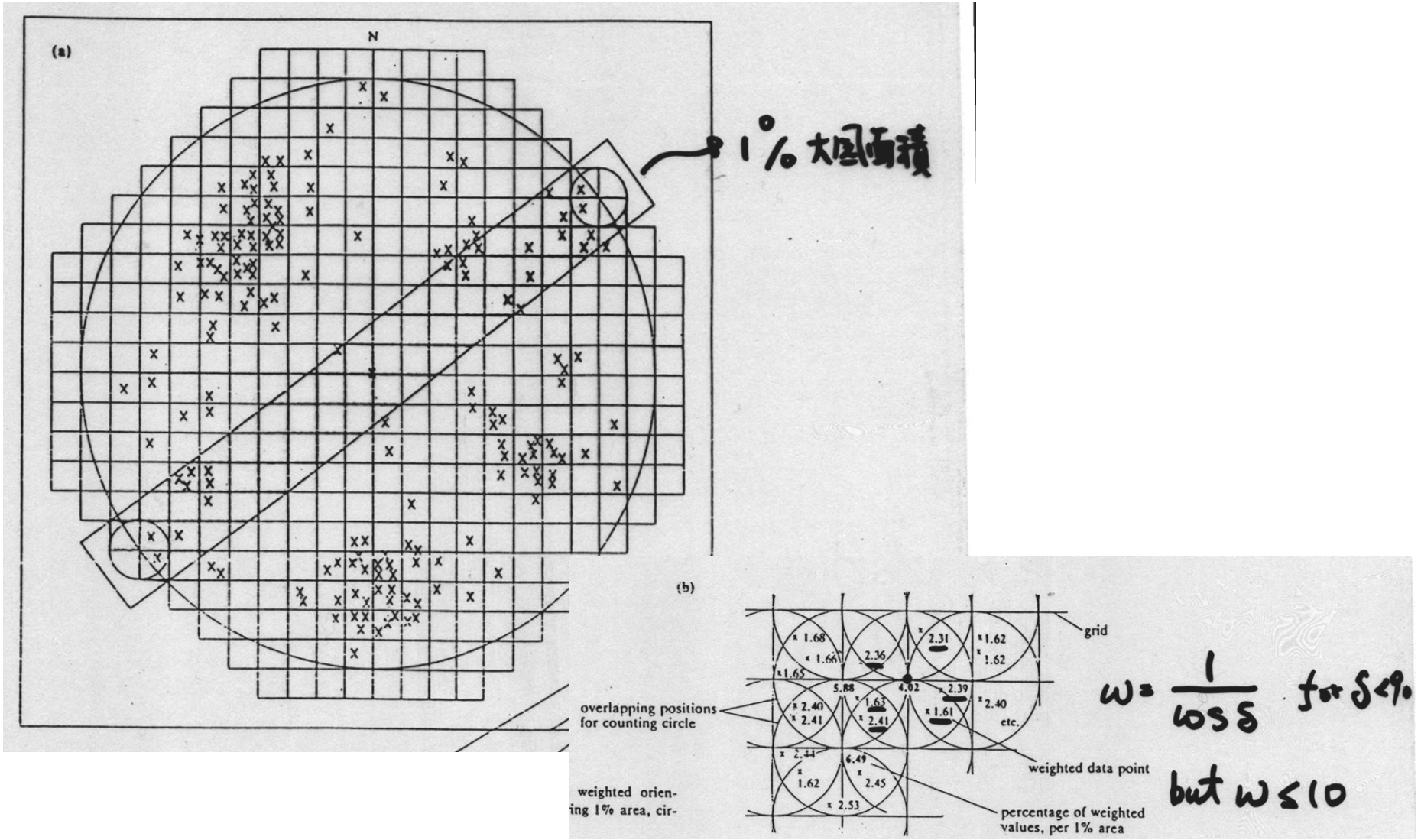
"Sampling bias"

不連續面平均方位計算:等密度投影

設計分析用位態？



兩組節理的平均方位: 165°/55°，320°/20°


(a)
N
1% 大圓面積
(b)
grid
overlapping positions for counting circle
weighted data point
percentage of weighted values, per 1% area
etc.
$w = \frac{1}{\cos\delta}$ for $\delta < 9°$
but $w \leq 10$

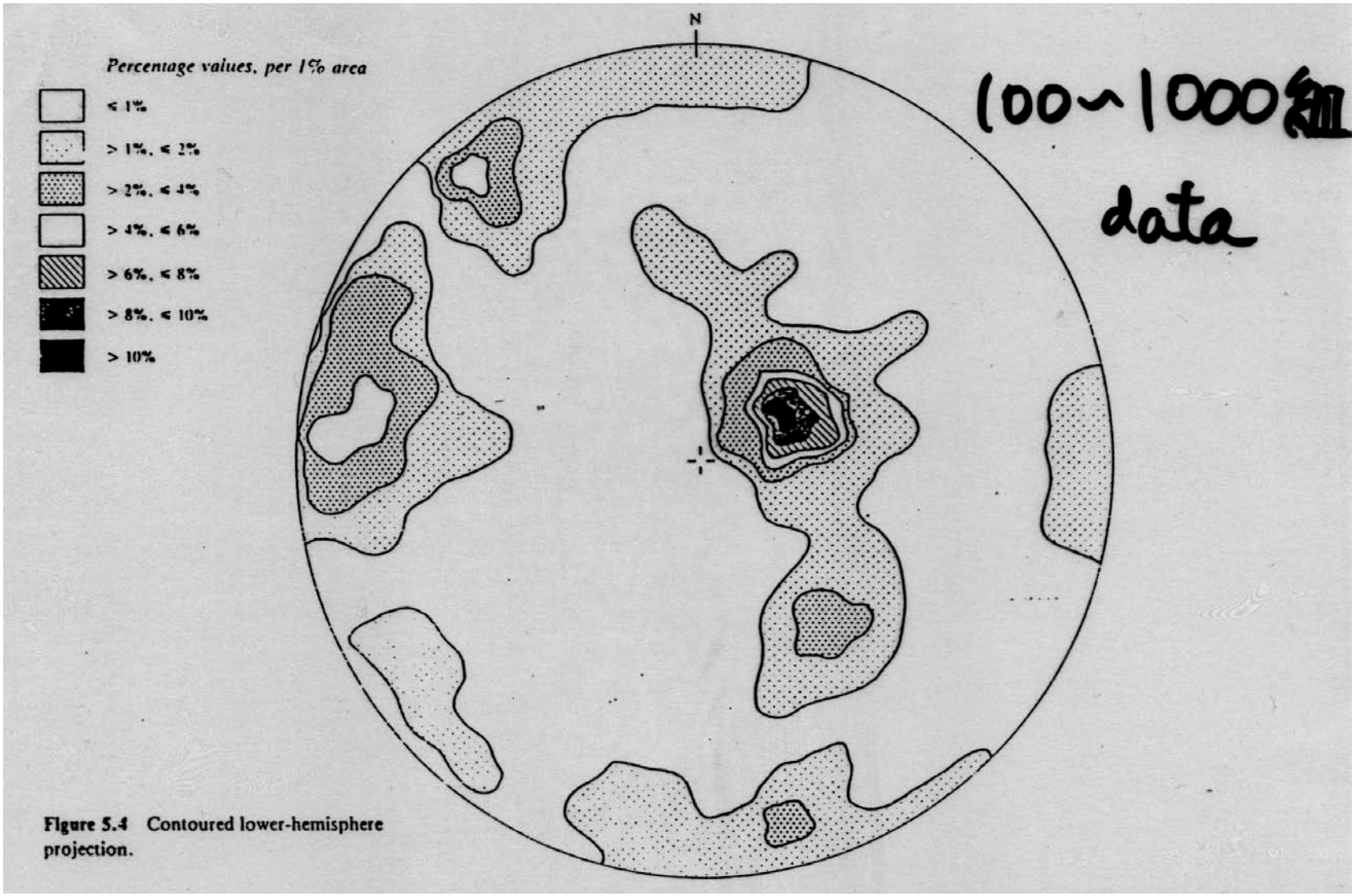


Figure 5.4 Contoured lower-hemisphere projection.

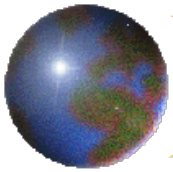


FIGURE 15-4
Examples of symbol and contour plots of pole projections in equal-area stereographic projections.

169 Original Poles

N

W

E

S

Symbol Plot

Lower Hemisphere
Equal Area Projection

Legend:
J = Joint
B = Foliation
F = Fault

① 集中傾向 → 平均傾向？

② 分組 → 主成

N

S_2

S_3

W

E

S_1

S_3

S

Contour Plot

Lower Hemisphere
Equal Area Projection
Fisher Distribution Applied

Legend (%)

1 to 3
3 to 6
6 to 9
9 to 12

Peak Orientations
Dip/Dip Direction

S1	48/054
S2	76/148
S3	86/248

4. 岩面方位分析：（不連續面幾何性質）其之間有間距、持續性、

a. 繪於立體投影圖上（normal vector）

b. 集中則為一組（可能為層面或平行節理）

c. 一組可以每個節理 normal 向量合成平均 normal，

即為 prefer orientation．$(\hat{l}_R, \hat{m}_R, \hat{n}_R)$

如第 i 個節理 $l_i\hat{x} + m_i\hat{y} + n_i\hat{z}$

平均則為 $l_R\hat{x} + m_R\hat{y} + n_R\hat{z}$

$$\left(l_R = \frac{\Sigma l_i}{|\bar{R}|} \quad m_R = \frac{\Sigma m_i}{|\bar{R}|} \quad n_R = \frac{\Sigma n_i}{|\bar{R}|}\right)$$

$$\left(|\bar{R}| = \sqrt{(\Sigma l_i)^2 + (\Sigma m_i)^2 + (\Sigma n_i)^2}\right)$$

例

(1,0,0)

(0,1,0)

(0,0,1)

sampling bias

$W_i = \frac{1}{\cos\delta}$

$W_{ni} = \frac{W_i N}{N_{ni}}$

$(N_{ni} = \Sigma W_i)$

而其離散程度之評估如下：

$$K_F = \frac{N(\text{組節理})}{N - |\bar{R}|}$$

當 n 組節理均同向時 $|\bar{R}| = N$

即 $K_F \to \infty$ 否則 K_F 之最小為 1.

⇒ weighted. normal vector

normal 之標準偏差 $\bar{\Phi}$：

$$\bar{\Phi} = \frac{1}{\sqrt{K_F}}$$

統計分布

$$WS\Phi = 1 + \frac{1}{K_F}\ln(1-P)$$

當 n 組節理均同向時 $\bar{\Phi} \to 0$

當 " 離散 " $\bar{\Phi} \to 1$

Normal 中超過 Φ 之機率 P

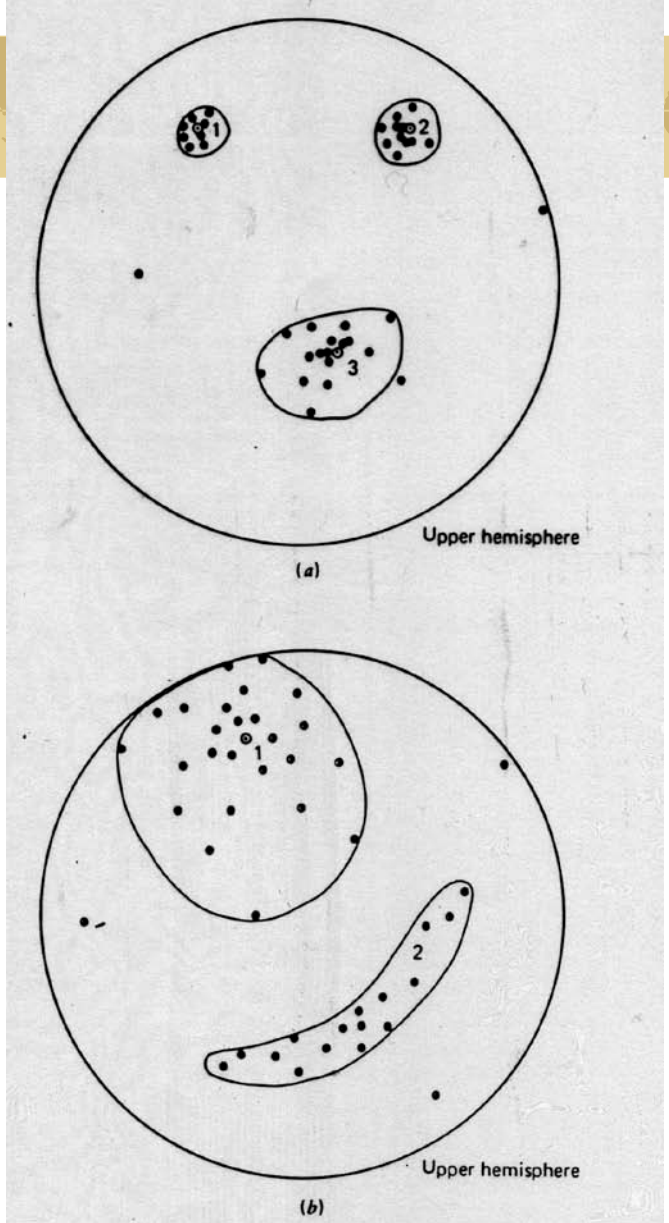
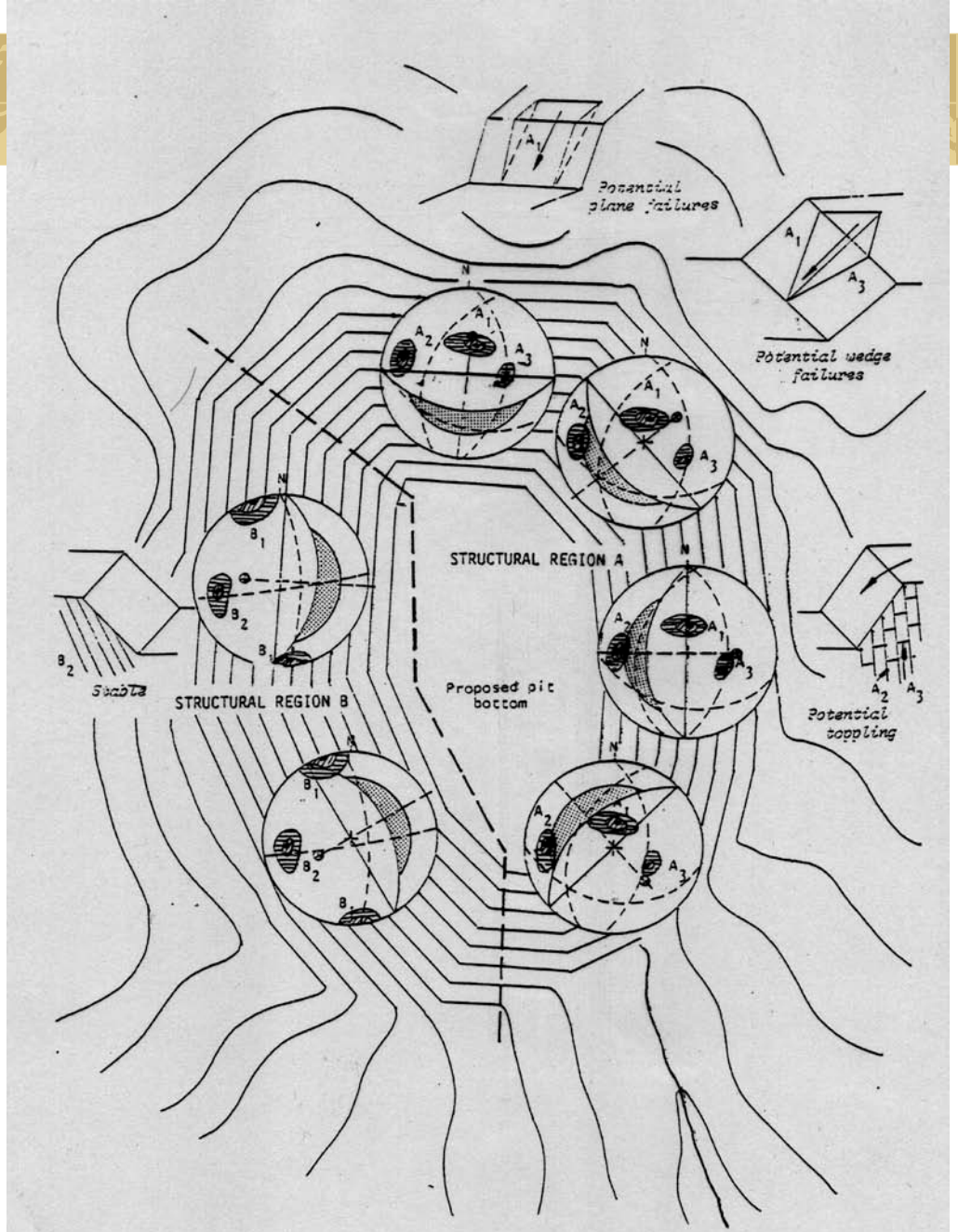
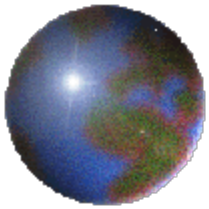


Figure 5.6 Distributions of normals to discontinuities, plotted on stereographic projections. (*a*) Two-well-defined sets and a third more disperse set. (*b*) One very disperse set and a second set distributed in a great circle girdle.



Presentation of structural geology information and preliminary evaluation of slope stability of a proposed open pit mine.



2 Rock mass structure

Topic 1 Discontinuities of rock mass

Topic 2 Hemispherical projection

Topic 3 Rock mass classification

The design approaches for rock engineering

Numerical: **difficult and often cumbersome, however, possible with discontinuous numerical rock mechanics programs such as UDEC.**

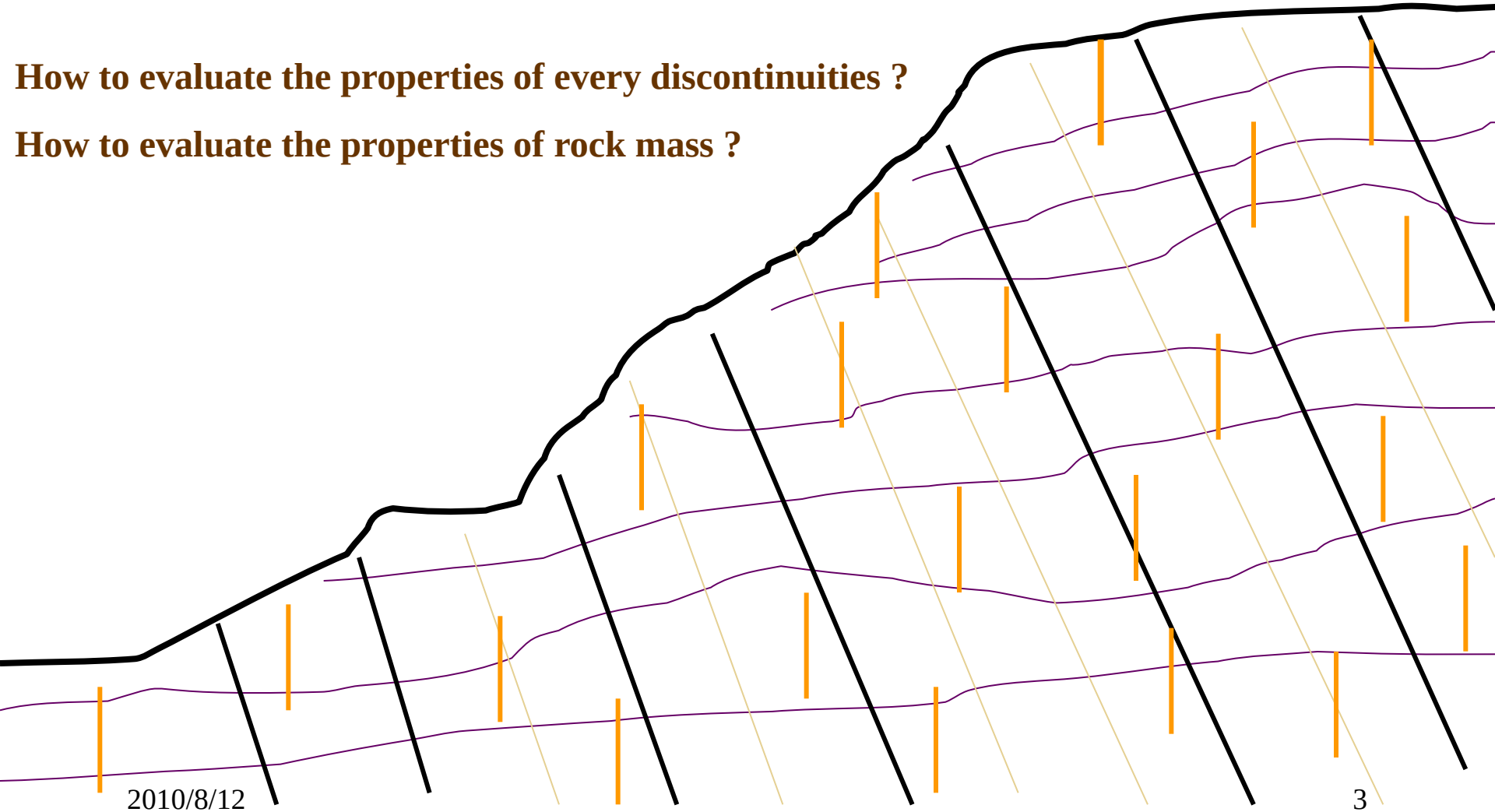
Analytical: **only in relatively simple cases possible for a discontinuous rock mass.**

Classification: **classification systems are empirical relations that relate rock mass properties either directly or via a rating system to an engineering application.**

Discontinuities in rock mass, each with its own variable properties and geometry.

How to evaluate the properties of every discontinuities ?

How to evaluate the properties of rock mass ?

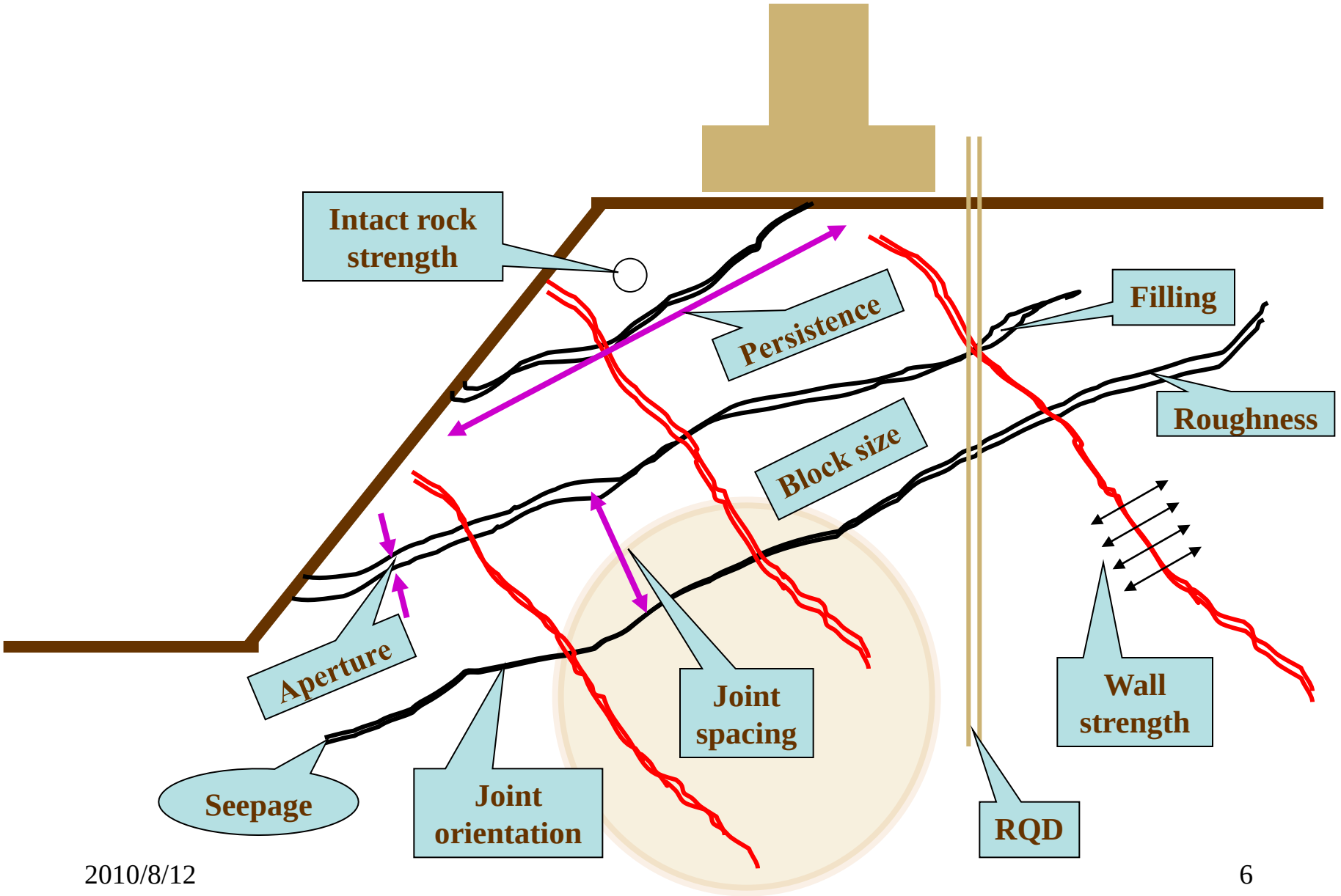


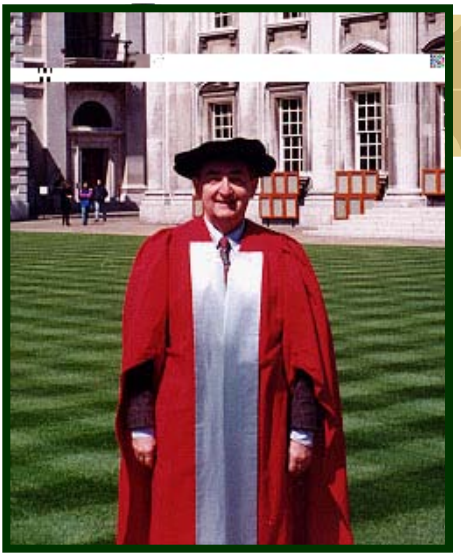
The objectives of rock mass classification

1. Identify the most significant parameters influencing the behavior of rock mass.
2. Divide a particular rock mass formation into groups of varying quality.
3. Provide a basis for understanding the characteristics of each rock mass class.
4. Relate the experience of rock conditions at one site to the conditions and experience encountered at others.
5. Derive quantitative data and guidelines for engineering design.
6. Provide a common basis for communication between engineers and geologists.

<table>
<tr><td rowspan="11">geotechnical unit</td><td colspan="4">intact rock strength</td></tr>
<tr><td rowspan="9">discon-tinuities</td><td></td><td colspan="2">orientation (with respect to engineering structure)</td></tr>
<tr><td rowspan="3">rock block size and form</td><td colspan="2">amount of disc. sets</td></tr>
<tr><td colspan="2">spacing per disc. set</td></tr>
<tr><td colspan="2">persistence per disc. set</td></tr>
<tr><td rowspan="5">shear strength along discontinuity (condition of discontinuity)</td><td rowspan="4">surface characteristics of discontinuity wall</td><td>material friction</td></tr>
<tr><td>roughness (dilatancy)</td></tr>
<tr><td>strength</td></tr>
<tr><td>deformation</td></tr>
<tr><td colspan="2">infill material</td></tr>
<tr><td colspan="4">susceptibility to weathering</td></tr>
<tr><td colspan="4">deformation parameters of intact rock/rock mass</td></tr>
<tr><td>engineering structure</td><td colspan="4">geometry of engineering structure (size and orientation of a tunnel, height and orientation of a slope, etc.)</td></tr>
<tr><td rowspan="2">external influences</td><td colspan="4">water pressure/flow, snow and ice, stress relief, external stress, etc.</td></tr>
<tr><td colspan="4">type of excavation</td></tr>
</table>

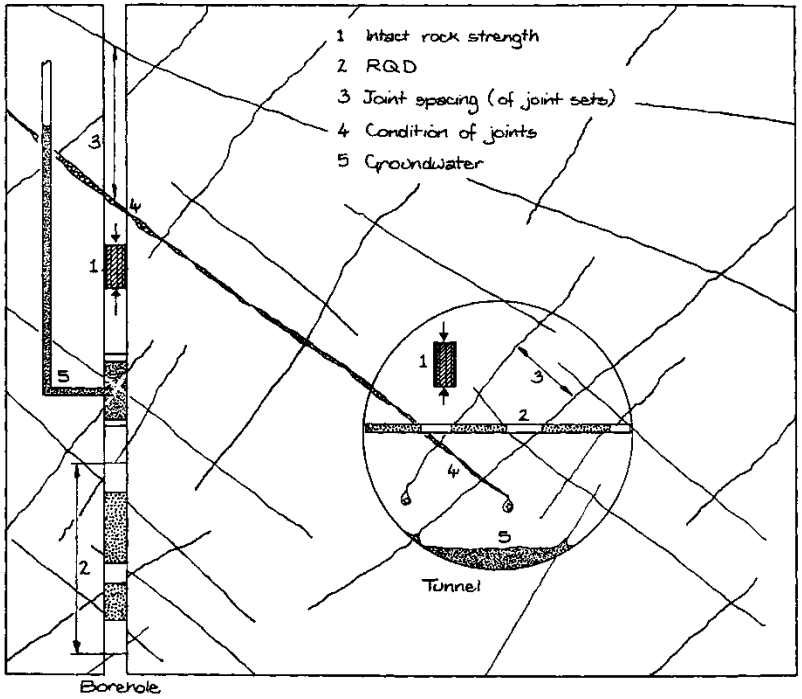
Rock mass parameters



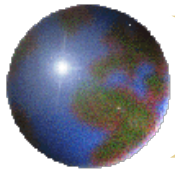


Rock Mass Rating (RMR) system: applied in tunnels, foundations and slopes design.

Z. T. Bieniawski



Parameter			Rating
Strength of Intact Rock			0~15
RQD			3~20
Spacing of discontinuities			5~20
Condition of Discontinuities	Persistence	0~6	0~30
	Aperture	0~6	
	Roughness	0~6	
	Infilling	0~6	
	Weathering	0~6	
Groundwater			0~15



RMR System

Item	Value	1973	1974	1976	1979	1989
Point load index	7 MPa	5	5	12	12	12
RQD	70%	14	14	13	13	13
Spacing of discontinuities	300 mm	20	20	20	10	10
Condition of discontinuities	Described	12	10	20	20	25
Groundwater	Dry	10	10	10	15	15
Joint orientation adjustment	Very favourable	15	15	0	0	0
	RMR	76	74	75	70	75

(After Beiniawski 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter			Range of values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa / 1 - 5 MPa / < 1 MPa
	Rating		15	12	7	4	2 / 1 / 0
2	Drill core *Quality RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%
	Rating		20	17	13	8	3
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous
	Rating		30	25	20	10	0
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence)	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
Rating	6	4	2	1	0
Separation (aperture)	None	< 0.1 mm	0.1 - 1.0 mm	1 - 5 mm	> 5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Ratings	6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very favourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

RMR System

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS									
Parameter			Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core *Quality RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

(After Beiniawski 1989)

RMR System

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)						
Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	
C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS						
Rating		100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number		I	II	III	IV	V
Description		Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
D. MEANING OF ROCK CLASSES						
Class number		I	II	III	IV	V
Average stand-up time		20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)		> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)		> 45	35 - 45	25 - 35	15 - 25	< 15

Slope mass rating (SMR) system (M. Romana)

(After Beiniawski 1989)

RMR System

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions					
Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very favourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

(After Beiniawski 1989)

Guidelines for excavation and support of 10m span rock tunnels in accordance with the RMR system

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
I - Very good rock *RMR*: 81-100	Full face, 3 m advance.	Generally no support required except spot bolting.		
II - Good rock *RMR*: 61-80	Full face , 1-1.5 m advance. Complete support 20 m from face.	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh.	50 mm in crown where required.	None.
III - Fair rock *RMR*: 41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face.	Systematic bolts 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown.	50-100 mm in crown and 30 mm in sides.	None.
IV - Poor rock *RMR*: 21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face.	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh.	100-150 mm in crown and 100 mm in sides.	Light to medium ribs spaced 1.5 m where required.
V – Very poor rock *RMR*: < 20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert.	150-200 mm in crown, 150 mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert.

(After Beiniawski 1989)

***3.7.3*自行參閱課本**

Q system

- **Based on case histories in Scandinavia**
- **Numerical values on a log scale**
- **Range 0.001 to 1000**

- **represents roughness and frictional characteristics of joint walls or infill material**

- **represents the structure of the rockmass**
- **crude measure of block or particle size**

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

- **consists of two stress parameters**
- **SRF can be regarded as a total stress parameter measure of**
  - **loosening load as excavated through shear zones**
  - **rock stress in competent rock**
  - **squeezing loads in plastic incompetent rock**
- **JW is a measure of water pressure**

where

RQD is the Rock Quality Designation
J_n is the joint set number
J_r is the joint roughness number
J_a is the joint alteration number
J_w is the joint water reduction factor
SRF is the stress reduction factor

(After Barton et al. 1974)