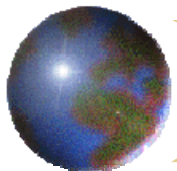


## *2 Discontinuities of rock mass*

*Topic 1 Discontinuities of rock mass*

*Topic 2 Hemispherical projection*

*Topic 3 Rock mass classification*



# 主要造岩礦物

造岩礦物約200種  
岩石約1000種

## ● 矽酸鹽類造岩礦物

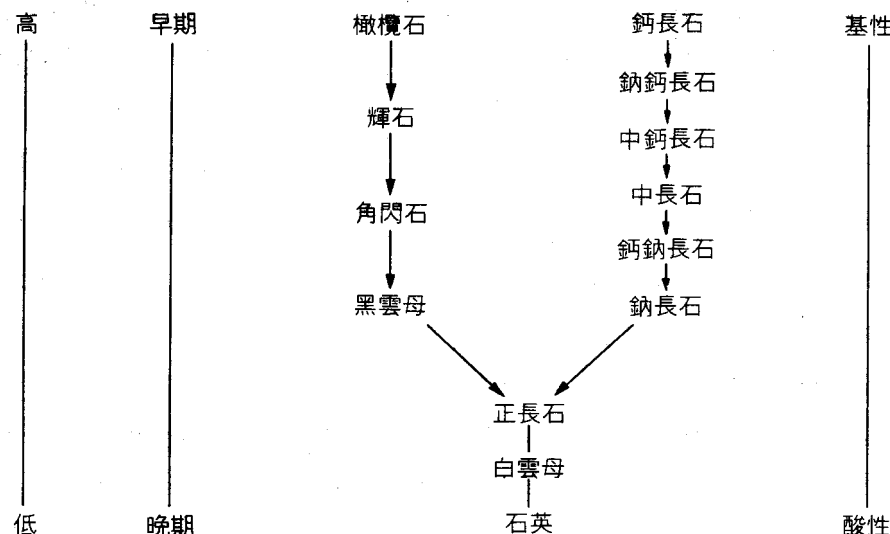
- 依離子鍵結方式，矽酸鹽類礦物可分為六大類
- 依顏色區分，則可分為深色（鐵礦）矽酸鹽類及淺色矽酸鹽類礦物
- 依礦物結晶作用，可分為連續的斜長石類及不連續的鐵鎂矽酸鹽類礦物二種

土木工程關心的造岩礦物約16種,岩石約40種

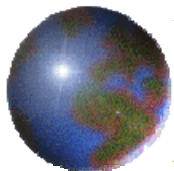
## ● 非矽酸鹽類造岩礦物：碳酸鹽類礦物(方解石、石膏)、氧化物、硫化物(**Pyrite**黃鐵礦)、金屬礦物

| 矽酸鹽分類 | 矽氧四面體的排列 | 陰離子方程式                              | 共有氧離子數目 | 代表礦物 |                                                                     |
|-------|----------|-------------------------------------|---------|------|---------------------------------------------------------------------|
|       |          |                                     |         | 名稱   | 化學成份                                                                |
| 島狀    |          | $(\text{SiO}_4)^{4-}$               | 0       | 橄欖石  | $(\text{Mg,Fe})_2\text{SiO}_4$                                      |
| 對狀    |          | $(\text{Si}_2\text{O}_7)^{6-}$      | 1       | 硬柱石  | $\text{CaAl}_2\text{Si}_2\text{O}_7(\text{OH})_2\text{H}_2\text{O}$ |
| 環狀    |          | $(\text{Si}_3\text{O}_9)^{6-}$      | 2       | 矽灰石  | $\text{Ca}_3\text{Si}_3\text{O}_9$                                  |
| 鍊狀    |          | $(\text{SiO}_3)^{2-}$               | 2       | 輝石   | $(\text{Fe,Mg})\text{SiO}_3$                                        |
| 片狀    |          | $(\text{Si}_4\text{O}_{11})_n^{6-}$ | 2 或 3   | 角閃石  | $\text{Ca}_2\text{Mg}_5(\text{Si}_4\text{O}_{11})_2(\text{OH})_2$   |
| 架狀    |          | $(\text{Si}_4\text{O}_{10})_n^{4-}$ | 3       | 雲母   | $\text{KA}_2\text{Si}_2\text{Al}(\text{OH})_2$                      |
| 架狀    |          | $(\text{SiO}_2)_n$                  | 4       | 石英   | $\text{SiO}_2$                                                      |

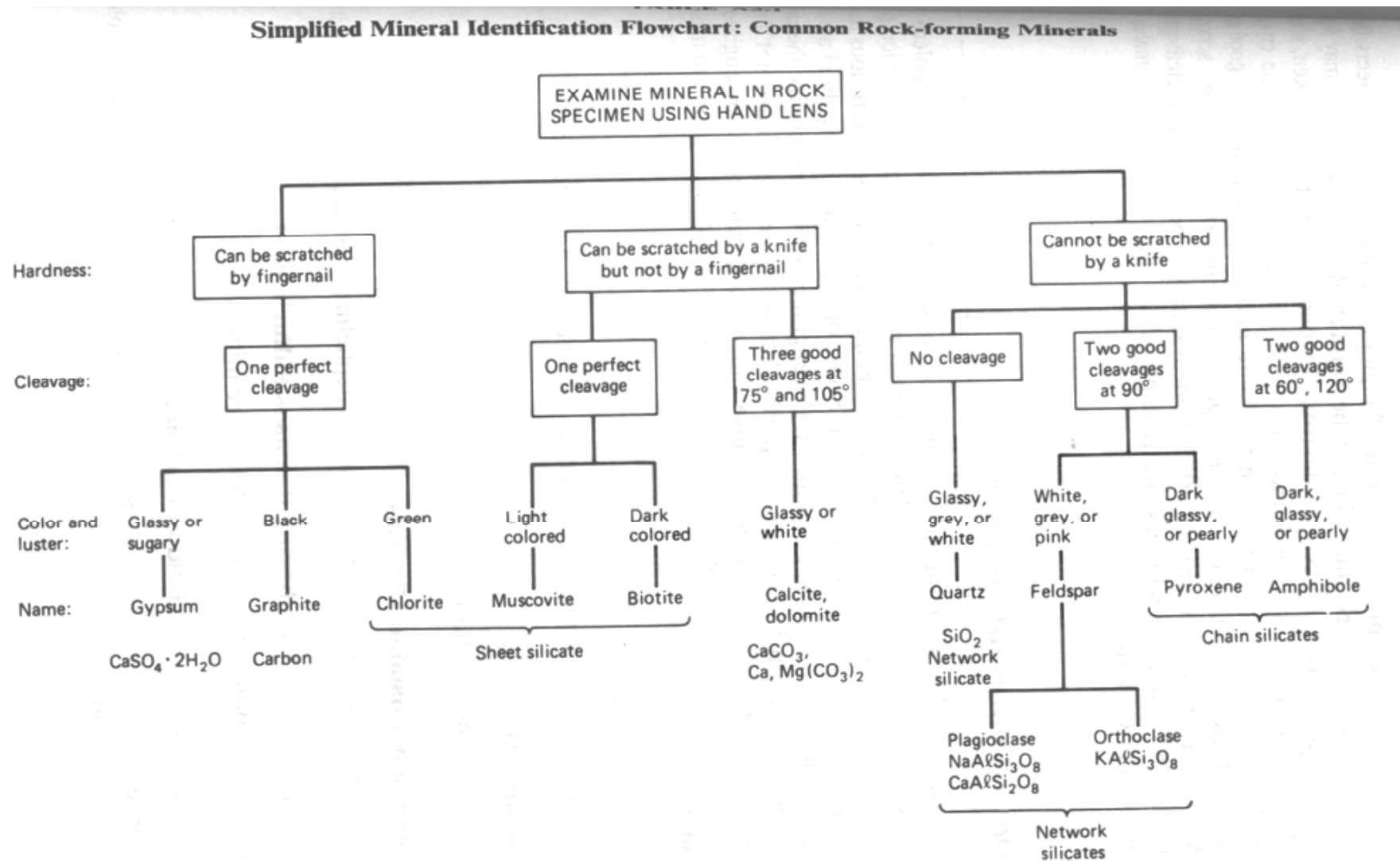
結晶溫度 結晶順序 鐵鎂礦物不連續系列 斜長石連續系列 岩石鹼基性

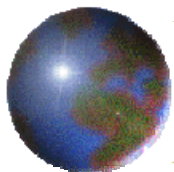


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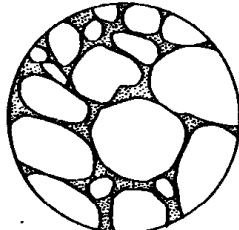


# 造岩礦物鑑定流程

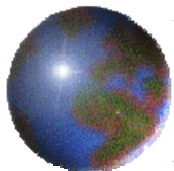




# 岩石的特徵

|      | 火 成 岩                                                                                                     | 沈 積 岩                                                                                                           | 變 質 岩                                                                                                          |
|------|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| 岩石構造 | 缺少層理，成塊狀，不規則的火成岩體。一次次的熔岩流也可成層狀構造。當熔岩流流動時，已經結晶出的礦物平行排列成流紋構造。                                               | 多具層理，及含交錯層、波痕、底痕、泥裂痕等沈積構造。                                                                                      | 原岩為沈積岩，經低度變質作用，尚可殘留有層理。經高度變質，層理受破壞，由礦物平行排列而有葉理構造。                                                              |
| 岩石組織 | 礦物顆粒彼此緊密鑲嵌。<br>如圖：<br> | 磨圓的顆粒，空隙處由膠結物充填。<br>如圖：<br> | 長形或片狀，礦物顆粒平行排列。<br>如圖：<br> |
| 化石   | 深成岩多不含化石，熔岩流、火山灰中偶含化石。                                                                                    | 常含化石。                                                                                                           | 原岩中若含有化石，可能經變質作用變形，甚至破壞。                                                                                       |

摘自廖志中“應用工程地質”講義

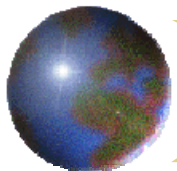


# 火成岩分類

| 岩理<br>Texture        | 主 要 礦 物                                                                                                                                                    |                        |                      |                                              |                               |                                    |
|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------------|----------------------------------------------|-------------------------------|------------------------------------|
|                      | 長石和石英<br>(正長石為主)                                                                                                                                           | 長石<br>(正長石為主)<br>無或少石英 | 正長石及<br>斜長石<br>無或少石英 | 長石<br>(斜長石為主)<br>無石英                         | 鐵鎂礦物及<br>斜長石<br>無石英           | 鐵鎂礦物<br>無長石<br>及石英                 |
| 火山碎屑狀<br>Pyroclastic | 凝灰岩 Tuff<br>集塊岩 Agglomerate<br>火山角礫岩 Volcanic Breccia <div>             粒徑直徑小於 4 ㎞<br/>             圓礫 }<br/>             角礫 } 粒徑直徑大於 4 ㎞           </div> |                        |                      |                                              |                               | 屬於此三類<br>岩理的基性<br>火成岩甚少<br>或全無所聞   |
| 玻璃狀<br>Glassy        | 黑曜岩 Obsidian<br>浮石 Pumice<br>塊狀玻璃質<br>多孔狀玻璃質                                                                                                               |                        |                      |                                              | 玄武岩質<br>玻璃<br>Basalt<br>Glass |                                    |
| 微晶狀<br>Aphanitic     | 流紋岩<br>Rhyolite                                                                                                                                            | 粗面岩<br>Trachyte        | 二長安山岩<br>Latite      | 安山岩<br>Andesite<br>石英安山岩<br>Dacite<br>(少量石英) | 玄武岩<br>Basalt                 |                                    |
| 粒狀<br>Granular       | 花崗岩 Granite<br>(以鉀長石為主)<br>花崗閃長岩<br>Granodiorite<br>(斜長石較多)                                                                                                | 正長岩<br>Syenite         | 二長岩<br>Monzonite     | 閃長岩<br>Diorite                               | 輝長岩<br>Gabbro                 | 橄欖岩<br>Peridotite<br>(含橄欖石<br>及輝石) |

二氧化矽減少

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# 沈積岩分類

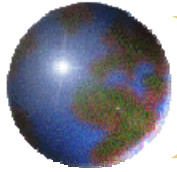
(一)碎屑狀岩石

| 岩石名稱                          | 主要礦物或岩石組成        | 原來未膠結時的碎屑     | 顆粒的直徑          |
|-------------------------------|------------------|---------------|----------------|
| 礫岩<br>Conglomerate            | 石英與岩石碎塊          | 圓礫            | 大於 2 糎         |
| 角礫岩<br>Breccia                | 岩石碎塊             | 角礫            | 大於 2 糎         |
| 砂岩<br>Sandstone               | 石英               | 富於石英之砂        | 2 ~ 1/16 糎     |
| 1 石英砂岩<br>Orthoquartzite      | 石英及長石            | 富於長石之砂        |                |
| 2 長石砂岩<br>Arkose              | 石英、長石、粘土、岩屑、火山碎屑 | 不潔之砂、多粘土及岩石碎屑 |                |
| 3 混濁砂岩<br>Graywacke           | 石英、粘土            | 粉砂 Silt       | 1/16 ~ 1/256 糎 |
| 粉砂岩<br>Siltstone              | 粘土礦物及石英          | 泥土與粉砂         | 小於 1/256 糎     |
| 頁岩<br>Shale<br>(粘土岩 Claytone) | 方解石              | 方解石粒與貝殼       | 多變化            |
| 碎屑狀石灰岩<br>Clastic Limestone   |                  |               |                |

(二)有機質與化學沉澱岩石

| 岩石名稱                                 | 主要礦物或岩石組成       | 原來物質的性質         | 主要物質的化學成分                                                                            |
|--------------------------------------|-----------------|-----------------|--------------------------------------------------------------------------------------|
| 石灰岩和石灰礁<br>Limestone & Reef Rock     | 方解石             | 貝殼、化學與有機碎屑沉積物   | $\text{CaCO}_3$                                                                      |
| 白雲岩<br>Dolostone                     | 白雲石             | 受溶液作用的石灰岩或石灰質軟泥 | $\text{CaMg}(\text{CO}_3)_2$                                                         |
| 泥炭與煤<br>Peat & Coal                  | 有機物質            | 植物碎片            | C、H 及 O                                                                              |
| 燧石<br>Chert                          | 蛋白石，石髓          | 矽質殼及化學沉積物       | $\text{SiO}_2$ 與 $\text{SiO}_2 \cdot n\text{H}_2\text{O}$                            |
| 蒸發岩與鹽岩<br>Evaporites & Salt Deposits | 岩鹽<br>石膏<br>硬石膏 | 海洋或鹽湖的蒸發剩餘物     | 主要有<br>$\text{NaCl}$<br>$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$<br>$\text{CaSO}_4$ |

摘自廖志中“應用工程地質”講義

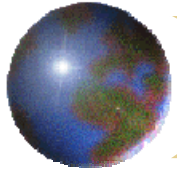


# 變質岩的分類

| 岩 石 名 稱                                      | 岩 理             | 未變質前的原岩                    | 主 要 礦 物                                            |
|----------------------------------------------|-----------------|----------------------------|----------------------------------------------------|
| 非葉理狀或微葉理狀 ( Unfoliated or Faintly Foliated ) |                 |                            |                                                    |
| 角 頁 岩<br>( Hornfels )                        | 角頁岩狀            | 任何細粒岩石                     | 變化甚多                                               |
| 石 英 岩<br>( Quartzite )                       | 花崗變晶狀<br>( 細粒 ) | 砂岩                         | 石英                                                 |
| 大 理 岩<br>( Marble )                          | 花崗變晶狀           | 石灰岩、白雲岩                    | 方解石、鈣<br>鎂矽酸鹽類                                     |
| 接觸變質岩(矽卡岩)<br>( Skarn )                      | 花崗變晶狀<br>( 粗粒 ) | 石灰岩、白雲岩<br>和岩漿熔液           | 多變化、主<br>要為鐵、鈣<br>、鎂之矽酸<br>鹽類如石榴<br>子石、綠簾<br>石、輝石等 |
| 角 閃 岩<br>( Amphibolite )                     | 片岩狀至花崗變晶<br>狀   | 玄武岩、輝長岩<br>、凝灰岩、白雲<br>岩質頁岩 | 角閃石、斜<br>長石、石英<br>、石榴子石                            |
| 粒 變 岩<br>( Granulite )                       | 花崗變晶狀           | 頁岩、硬砂岩與<br>火成岩             | 長石、輝石<br>、石榴子石<br>及其他矽酸<br>鹽類                      |

| 葉理狀 ( Foliated )                    |          |                           |                                |
|-------------------------------------|----------|---------------------------|--------------------------------|
| 板岩與千枚岩<br>( Slate and<br>Phyllite ) | 板岩狀      | 頁岩、凝灰岩                    | 雲母、石英<br>、粘土                   |
| 綠泥石片岩<br>( Chlorite Schist )        | 片岩狀至板岩狀  | 玄武岩、安山岩<br>、頁岩、凝灰岩        | 綠泥石、斜<br>長石、綠簾<br>石            |
| 雲母片岩<br>( Mica Schist )             | 片岩狀      | 頁岩、凝灰岩、<br>流紋岩            | 白雲母、石<br>英、黑雲母                 |
| 角閃石片岩<br>( Amphibole<br>Schist )    | 片岩狀      | 玄武岩、安山岩<br>、輝長岩、凝灰<br>岩   | 角閃石、斜<br>長石                    |
| 片 麻 岩<br>( Gneiss )                 | 片麻岩狀     | 花崗岩、頁岩、<br>閃長岩、流紋岩<br>、片岩 | 長石、石英<br>、雲母、角<br>閃石、石榴<br>子石等 |
| 混 合 岩<br>( Migmatite )              | 粗條紋狀、多變化 | 火成岩與變質岩<br>之混合物           | 長石、角閃<br>石、石英、<br>雲母           |

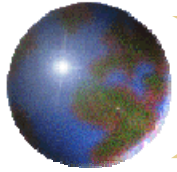
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# 不連續面的種類

- 原生弱面 (Primary discontinuities)
  - 包含層面(Bedding plane)及不整合面
- 次生弱面 (Secondary discontinuities)
  - 指成岩之後，岩石再受到大地應力或地質作用產生之斷層、節理、劈理(Cleavage)、片理(Schistosity)等



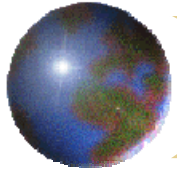


# 層面 (Bedding Plane)

- 層理是岩層於沉積時形成不同岩性或相同岩性的界面，其形成的原因可能有三：

- (1) 沉積物質的種類，顆粒的改變
- (2) 沉積環境的改變
- (3) 火成岩形成時間不同





# 不整合面 (Unconformity)

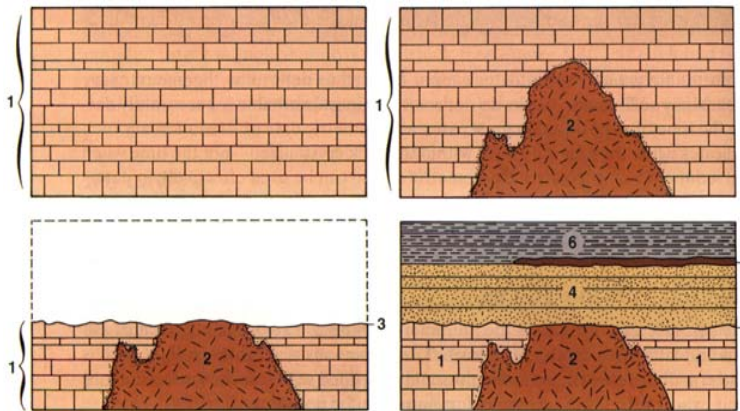
- 新地層與老地層之間，時間上不連續所產生的界面，稱為不整合面，可分為下列三種：

(1) 交角不整合 (Angular Unconformity)

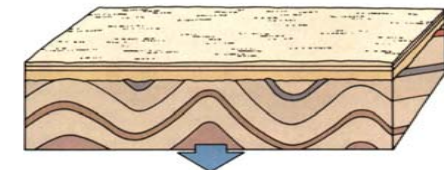
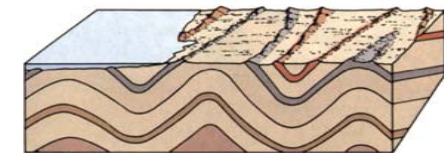
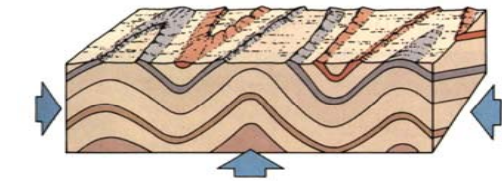
(2) 假整合 (Disconformity)

(3) 非整合 (Nonconformity)

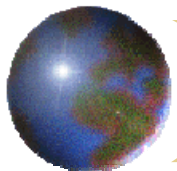
當新地層與老地層之間，雖然時間上中斷，但兩者界面大致平行者，是為假整合



老地層為火成岩或變質岩，經侵蝕沉積作用，使新的沉積岩覆蓋其上為非整合

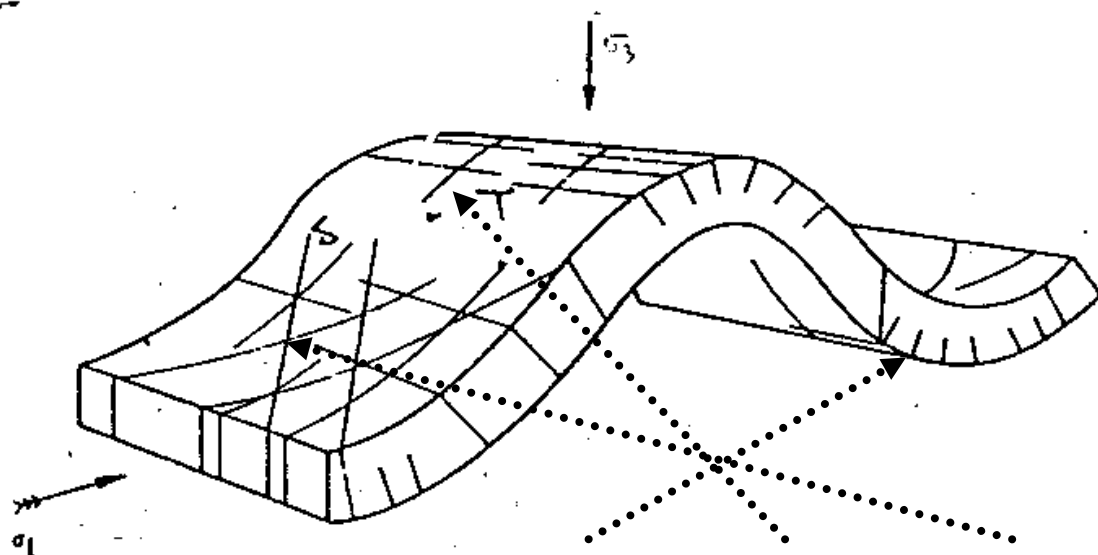


老地層與新地層有一夾角，彼此並不平行者，是為交角不整合



# 節理 (Joint)

- 節理是岩層形成之後，因應力改變所形成之裂面，而沿此裂面無彼此相對運動者
- 節理的產生主要是受剪力與張力作用而形成的，剪力節理的節理面通常是閉合的；而張力節理通常是開開口的
- 節理產生的原因可歸納為下列幾種：
  - 大地應力作用
  - 收縮作用
  - 解壓作用

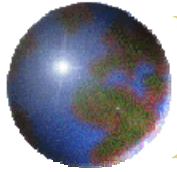


走向節理、傾向節理、共軛節理



在極為發達之柱狀節理與板狀節理之交錯組合切割之下，玄武岩塊極易崩落，堆積於崖下之海蝕平台上。

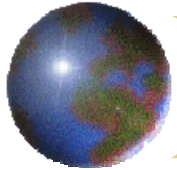




## 板岩劈理 (Cleavage)

- 當岩石受到輕至中度變質作用時，礦物重新定向性的排列，所形成的界面是為劈理，並垂直於最大主應力方向，整齊排列，形成間距小的劈理面，常見於屬細顆粒的板岩，故常稱為板岩劈理



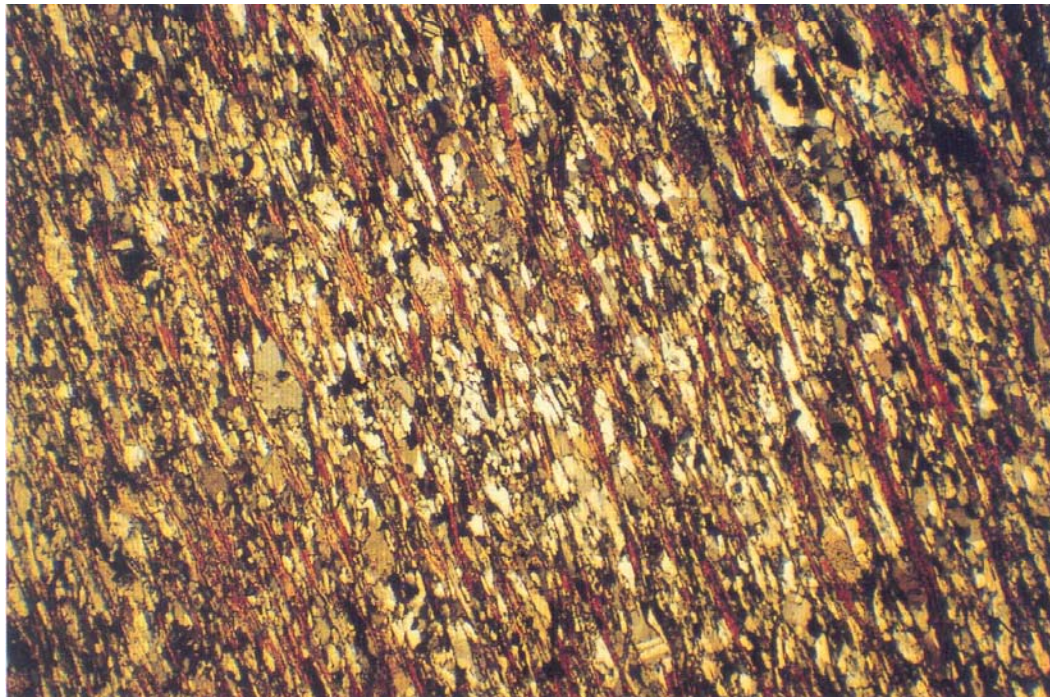


# 片理 (Schistosity)

- 當岩石受到高度變質作用時，礦物重新排列且呈片狀(如白雲母)

■ 伊利石-絹雲母(小)-白雲母(大)

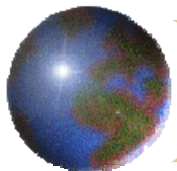
變質度增加



8-13b 同8-13a的顯微鏡照相，交叉偏光。彩色片狀礦物為白雲母，粒狀礦物多為石英，少數為斜長石。

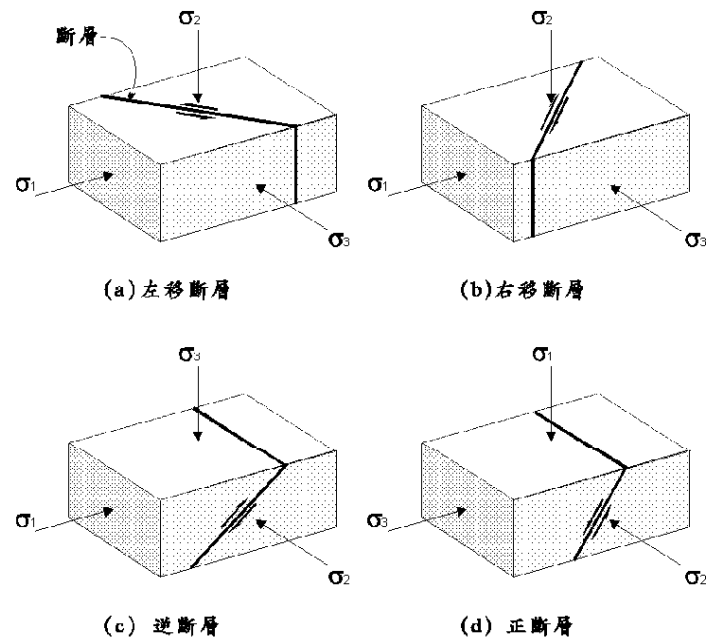
摘自台灣的變質岩(地調所,1998)

- 最大主應力與片理或劈理垂直
- 不連續面排列方向一致，若其方位不利於工址則甚易造成岩體的不穩定（尤其岩石含雲母等片狀礦物）
- 具變形及強度的異向性，而常視之為橫向等向性材料



# 斷層 (Fault)

- 地層受力後使岩層產生相對的移動而形成的斷裂面，位移可自數公分至數公里



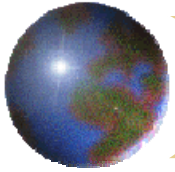
主應力方向與斷層種類關係



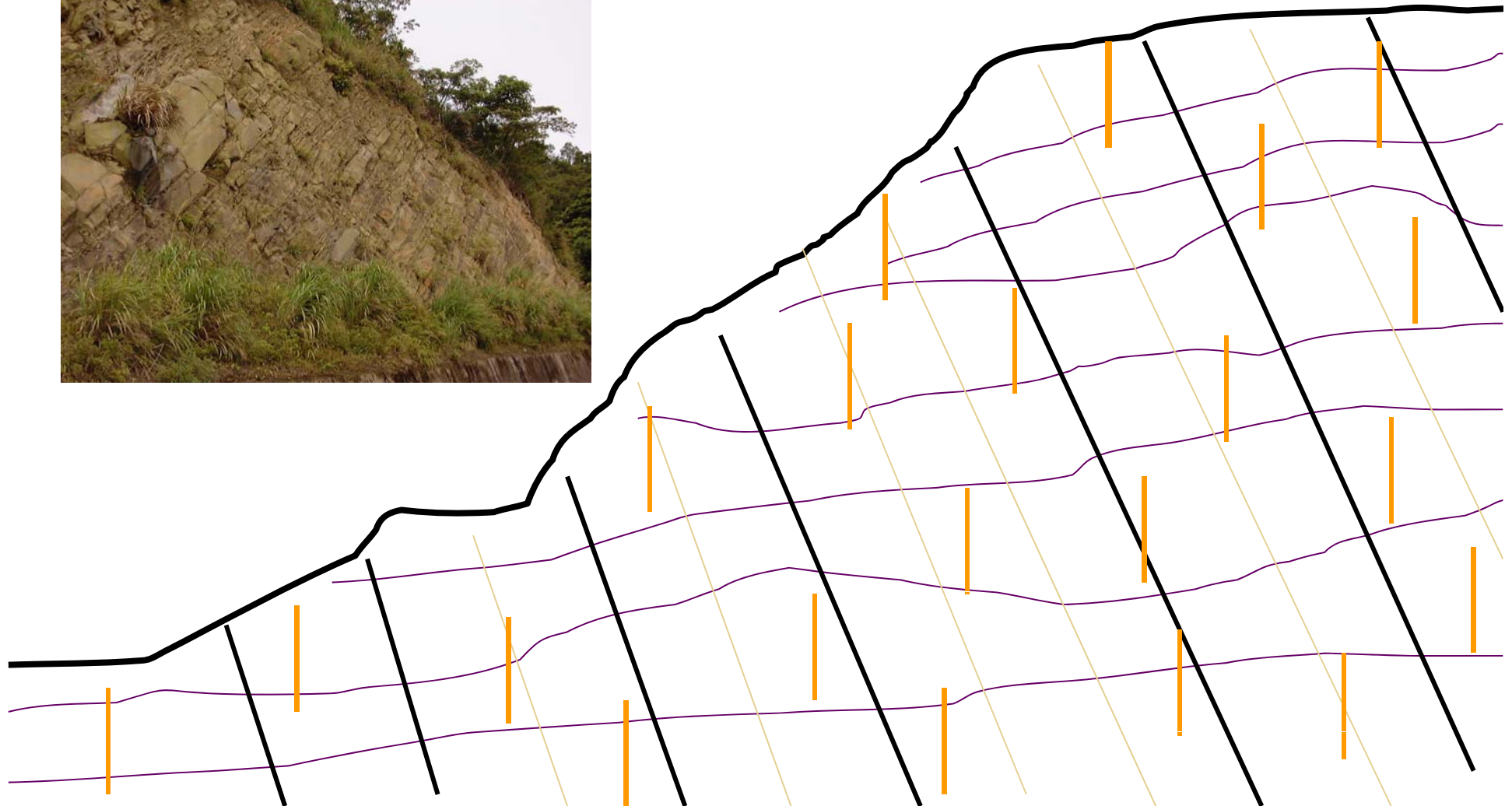
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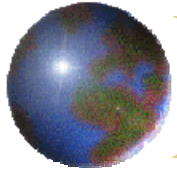
請自行參閱3.2.1與3.2.2



## *How to evaluate the variable properties and geometry of the above mentioned discontinuities ?*



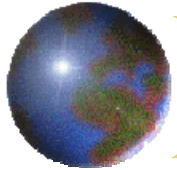
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## 岩體的不連續面特性 (ISRM,1981)

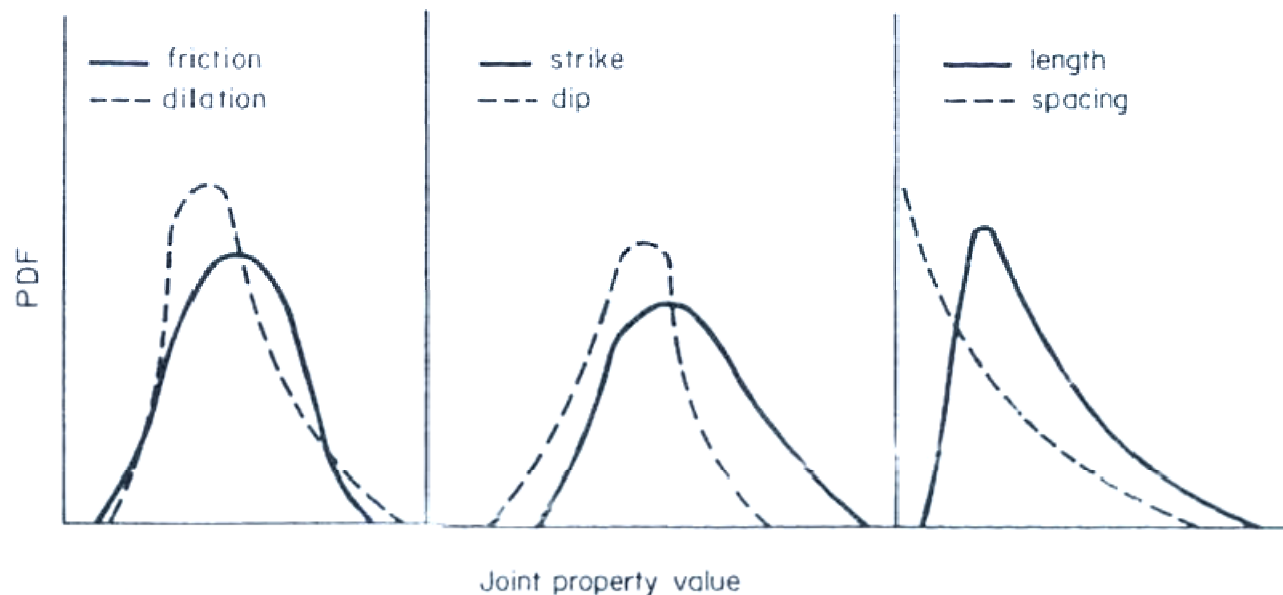


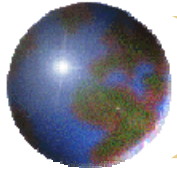
**International Society for Rock Mechanics Commission on Standardization of Laboratory and Field Tests. 1978. Suggested methods for the quantitative description of discontinuities in rock masses. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.* 15, 319-368.**



## *Quantitative description of discontinuities in rock masses*

- Orientation
- Spacing
- Persistence
- Roughness
- Wall strength
- Aperture
- Filling
- Seepage
- Number of sets
- Block size





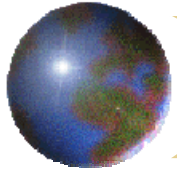
## ISRM 建議之不連續面特性相關定義

### Discontinuity

The general term for any mechanical discontinuity in a rock mass having zero or low tensile strength. It is the collective term for most types of joints, weak bedding planes, weak schistosity planes, weakness zones and faults. The ten parameters selected to describe discontinuities and rock masses are defined below:

1. *Orientation* - Attitude of discontinuity in space. Described by the *dip direction* (azimuth) and *dip* of the line of steepest declination in the plane of the discontinuity. Example: *dip direction/dip* (015°/35°).
2. *Spacing*—Perpendicular distance between adjacent discontinuities. Normally refers to the mean or modal spacing of a set of joints.
3. *Persistence*—Discontinuity trace length as observed in an exposure. May give a crude measure of the areal extent or penetration length of a discontinuity. Termination in solid rock or against other discontinuities reduces the persistence.
4. *Roughness*—Inherent surface roughness and waviness relative to the mean plane of a discontinuity. Both roughness and waviness contribute to the shear strength. Large scale waviness may also alter the dip locally.
5. *Wall Strength*—Equivalent compression strength of the adjacent rock walls of a discontinuity. May be lower than rock block strength due to weathering or alteration of the walls. An important component of shear strength if rock walls are in contact.
6. *Aperture*—Perpendicular distance between adjacent rock walls of a discontinuity, in which the intervening space is air or water filled.
7. *Filling*—Material that separates the adjacent rock walls of a discontinuity and that is *usually* weaker than the parent rock. Typical filling materials are sand, silt, clay, breccia, gouge, mylonite. Also includes thin mineral coatings and healed discontinuities, e.g. quartz and calcite veins.
8. *Seepage*—Water flow and free moisture visible in individual discontinuities or in the rock mass as a whole.
9. *Number of Sets*—The number of joint sets comprising the intersecting joint system. The rock mass may be further divided by individual discontinuities.
10. *Block Size*—Rock block dimensions resulting from the mutual orientation of intersecting joint sets, and resulting from the spacing of the individual sets. Individual discontinuities may further influence the block size and shape.

Strength

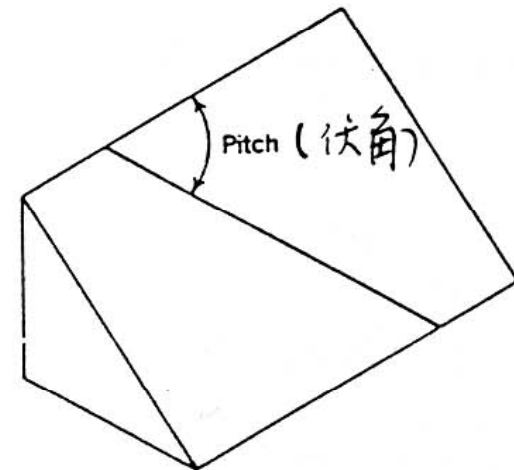
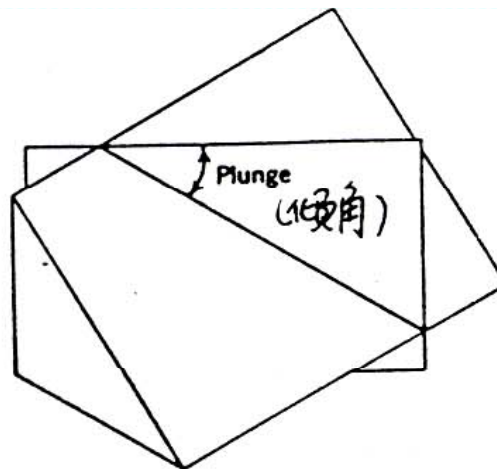
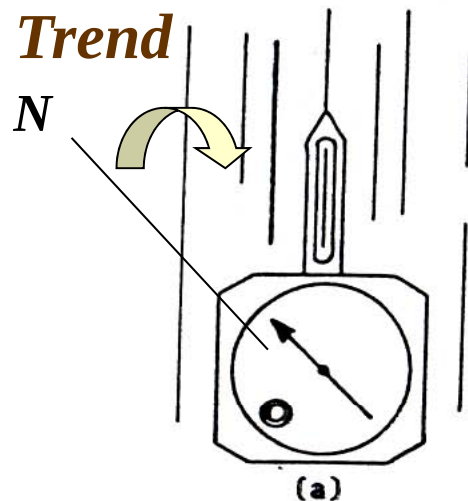


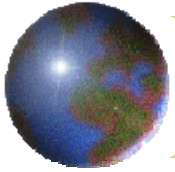
# Orientation



*How to express a vector ?*

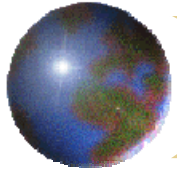
- The orientation of any given line in three dimensional space can be recorded in terms of its **Trend** ( $\alpha$ ) and **Plunge** ( $\beta$ ) (eg.240/45)
- **Pitch** : The acute angle measured in some specified plane between a given line and the strike of the plane





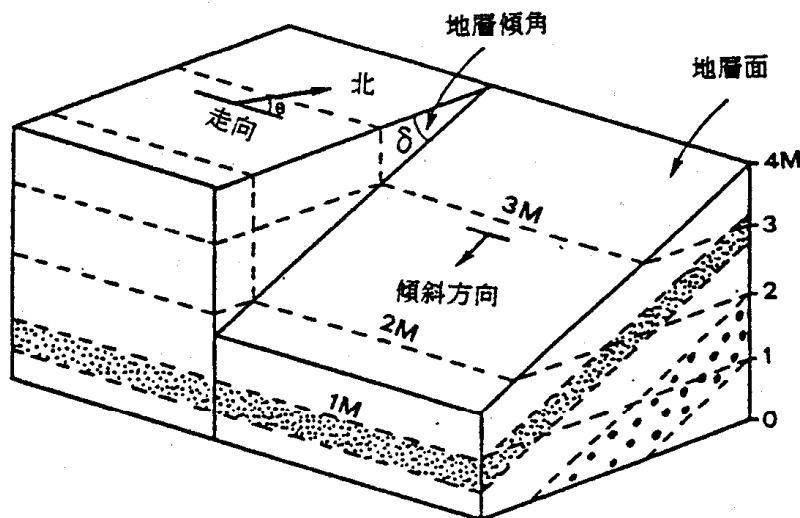
# *Striation*

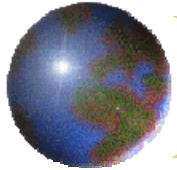




# Orientation

- **Normal vector of a plane**
- **Using the line of maximum dip of an inclined plane  $\alpha_d$  and  $\beta_d$  (dip direction) to express the orientation of a plane (e.g. 270/45).**
- **Alternatively, using strike and dip angle to express the orientation of a plane (e.g. NS/S45).**





## Measuring the orientation of a plane

### From outcrop

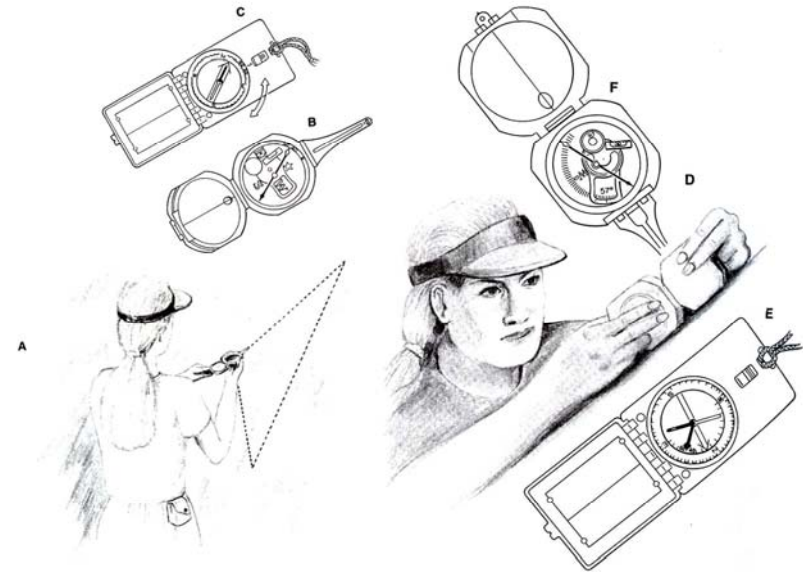
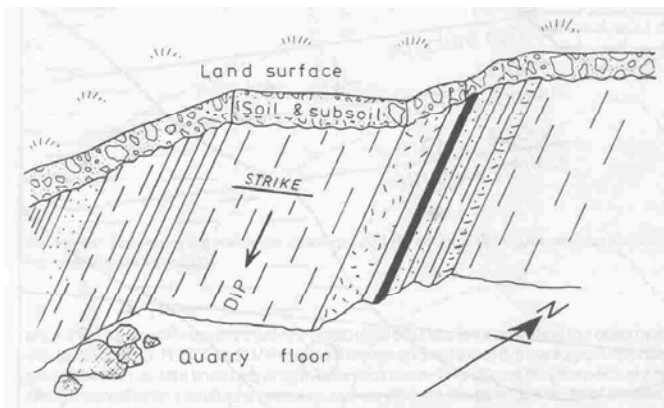
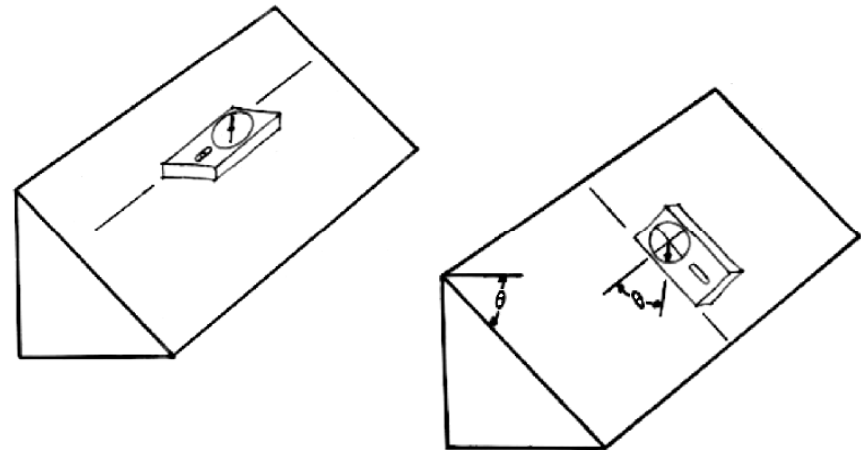
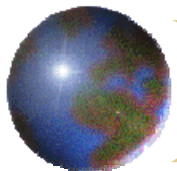


Figure D.4 Steps in measuring trend and plunge. See text for details.

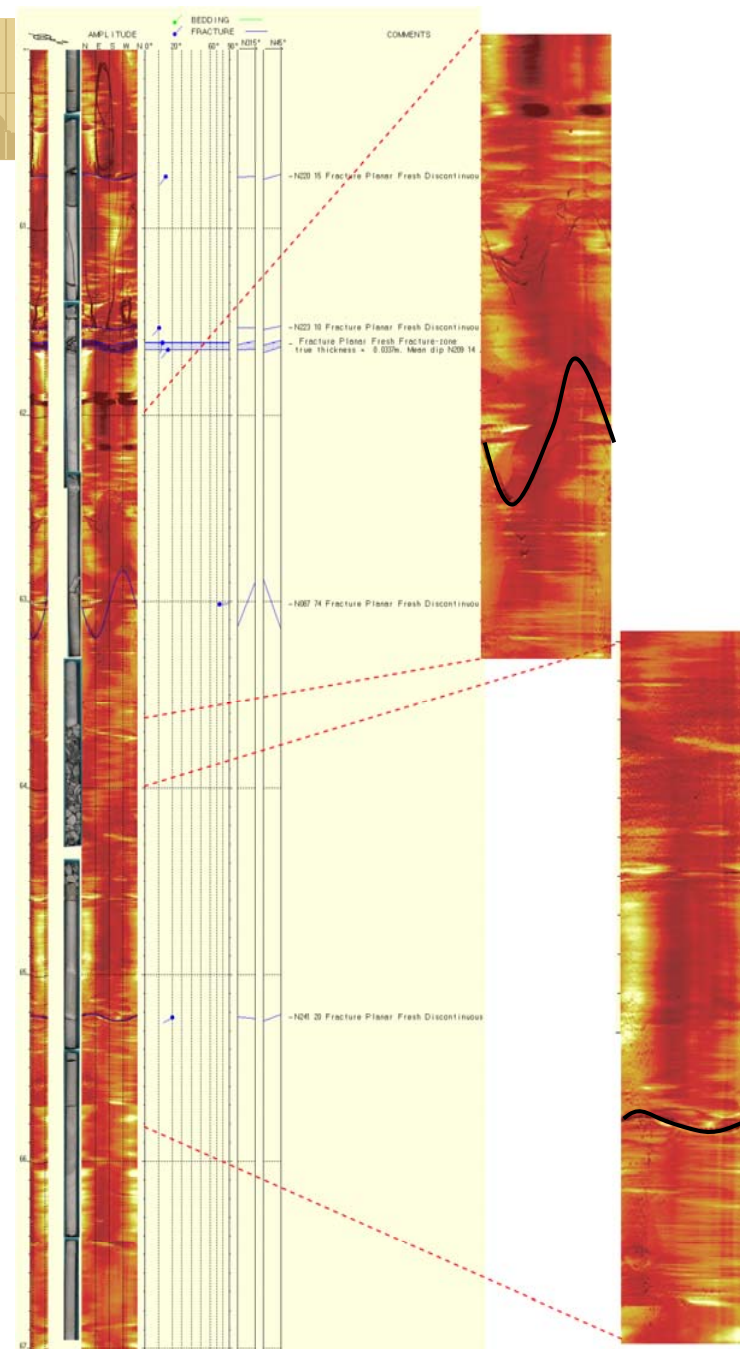




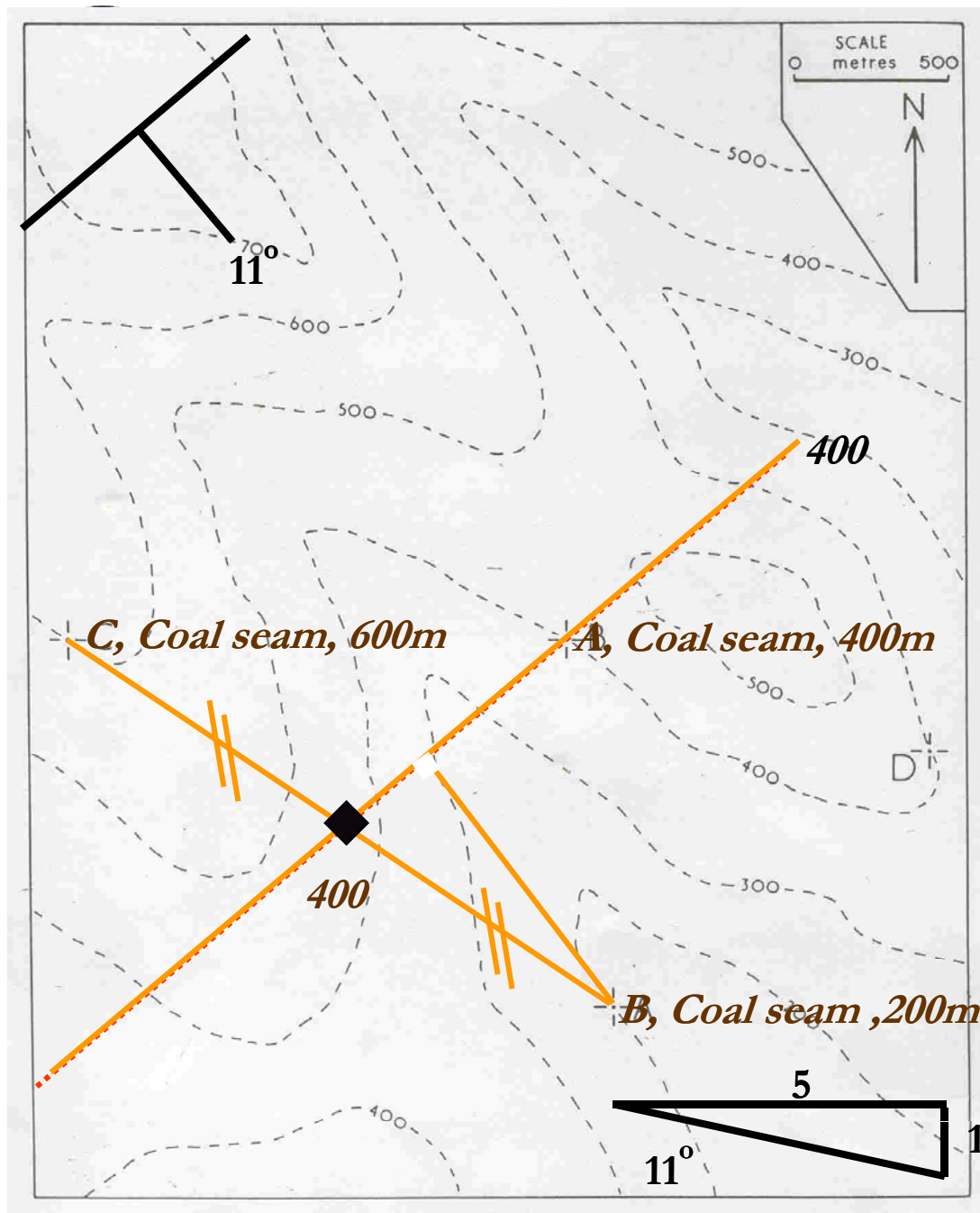
- 藉由鑽井取**core**或由井壁攝影量測不連續面位態
- 三點法可獲得較具代表性之位態資料
- 取得**150**個位態資料有其必要性



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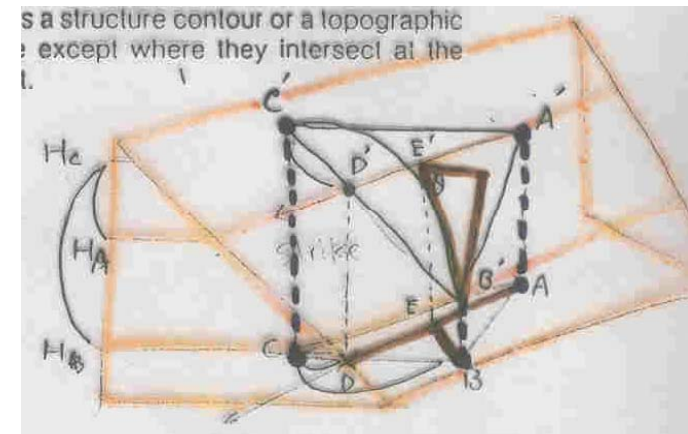
23

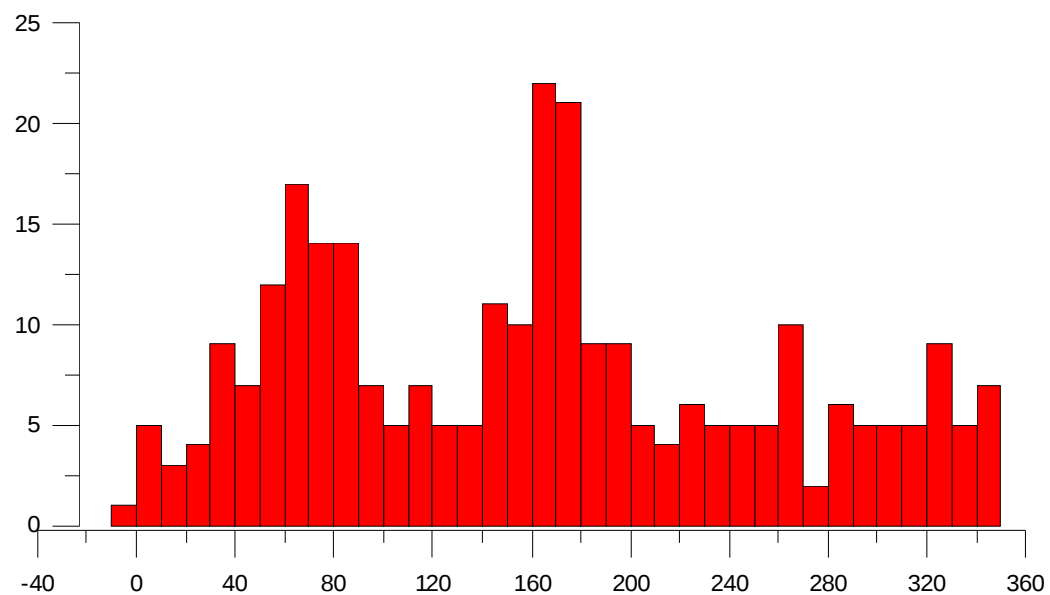
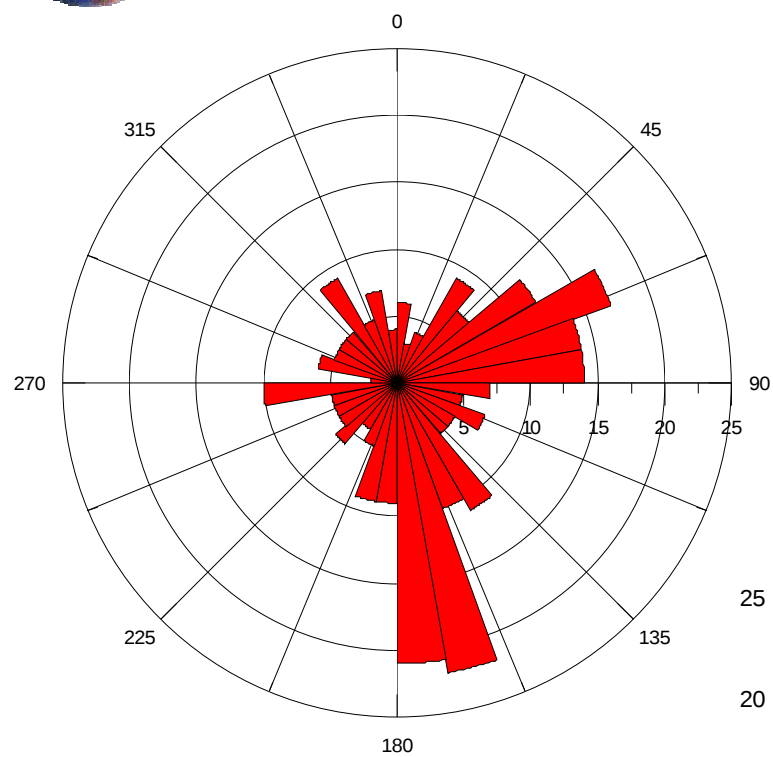
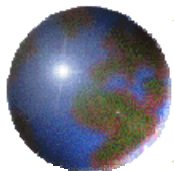


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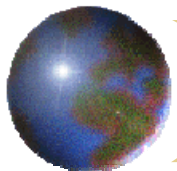
## “Three point method”





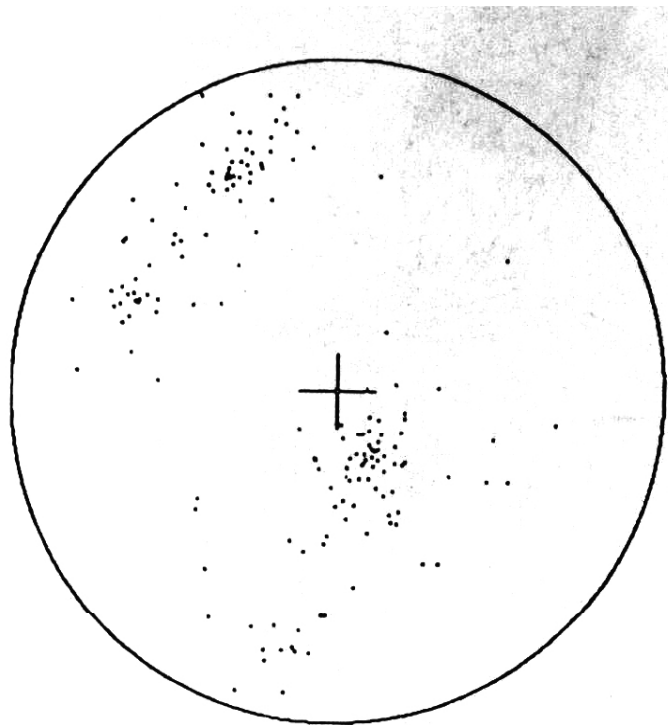
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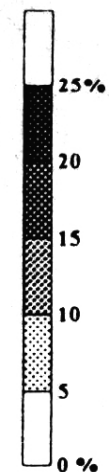
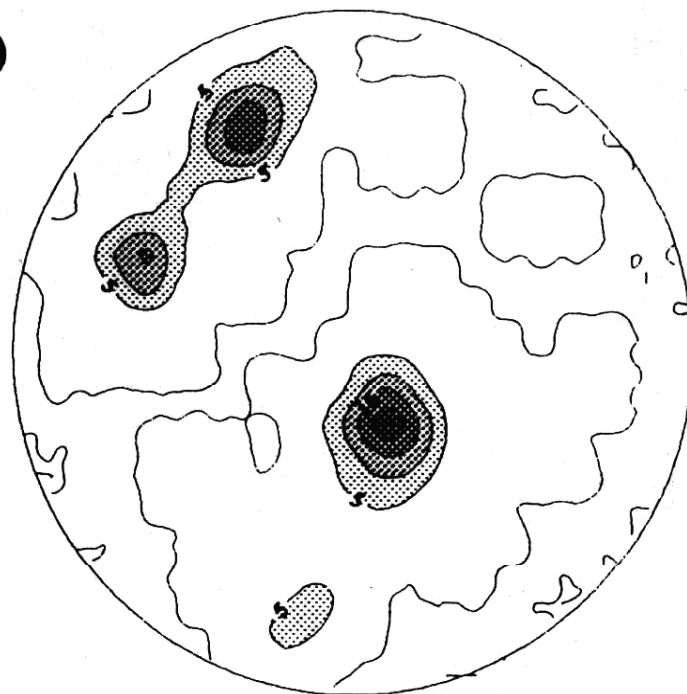


## 不連續面平均方位計算: 等密度投影

(a)



(b)



兩組節理的平均方位:  $165^{\circ}/55^{\circ}$  ,  $320^{\circ}/20^{\circ}$



***Provide a qualitative picture of joints and their relationship to engineering structure***

## ***Apparent dip and True dip***

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

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

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

$\delta$  Angle between dip direction of discontinuity and outcrop surface

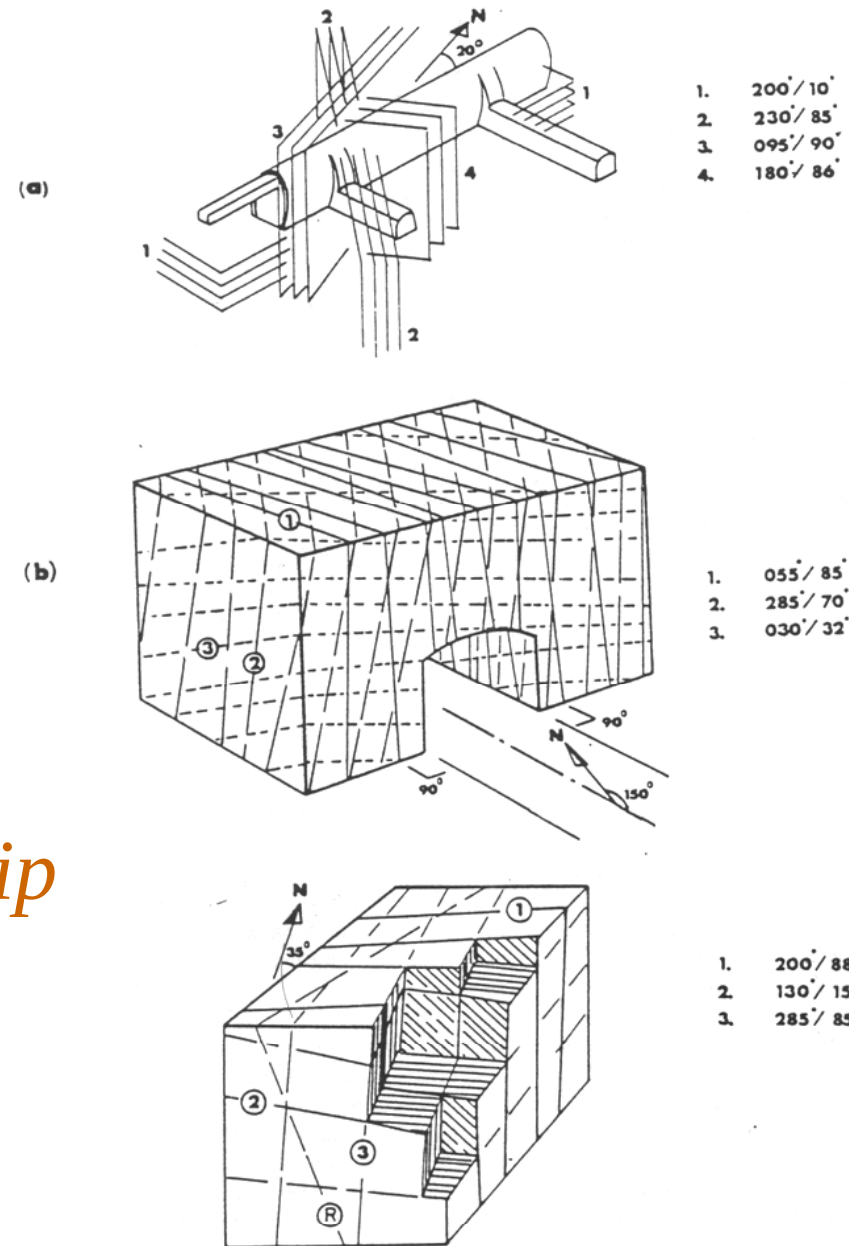
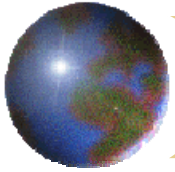


Fig. 2. Perspective views and block diagrams provide a qualitative picture of jointing and its relationship to engineering structures.



## Importance of joint orientation on slope engineering

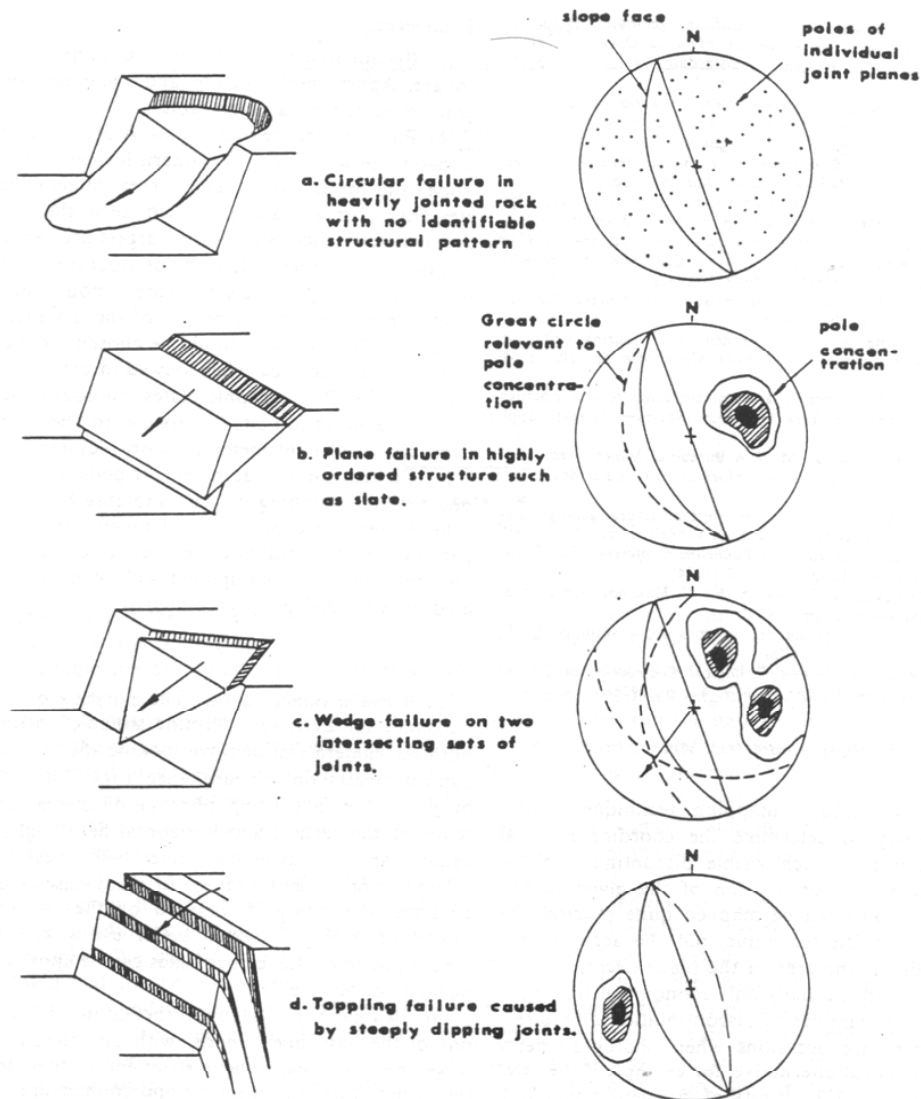
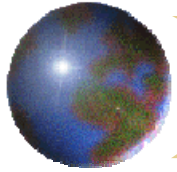
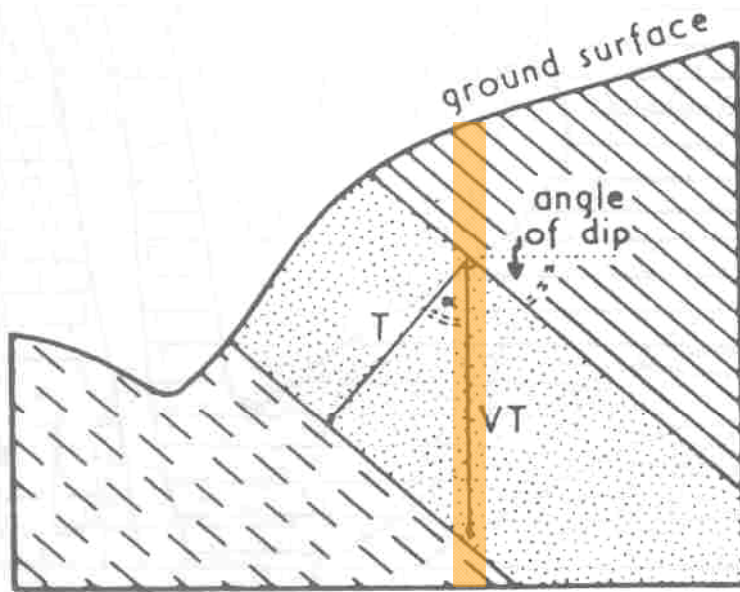


Fig. 6. Representation of structural data concerning four possible slope failure modes, plotted on equatorial equal-area nets as poles and great circles. [3].



# Spacing

## Apparent thickness and True thickness



$$T = VT * \cos \alpha$$

