3.5 Observation and Description of Geological Structures in the Field

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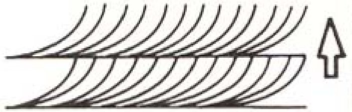
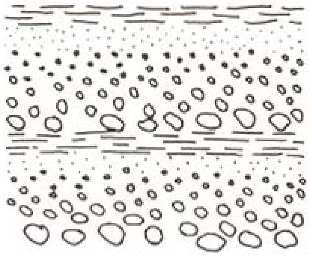
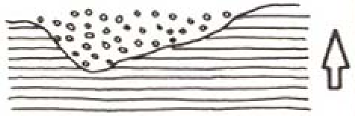
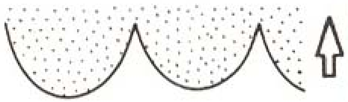
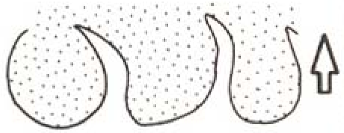
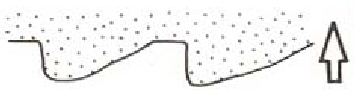
3.5.1 Stratigraphic way-up indicators

Way-up/younging is the direction in which stratigraphically younger beds/units are found. The stratigraphic way-up is of fundamental importance in determining the structure of an area. It is based upon a knowledge of stratigraphy and of small-scale sedimentary structures which indicate the stratigraphic way-up and the sequence of deposition.

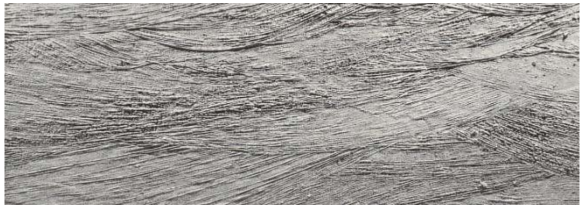
Structure way-up: refers to the bedding/cleavage relationships that indicate the position within a major fold structure (e.g. on the overturned limb of a recumbent fold). This may have no relationship to stratigraphic way-up.

Facing is the direction within a structure i.e. along the fold axial plane or cleavage plane, in which younger beds/units are found. This terms is generally applied to folds, or cleavage relationships.

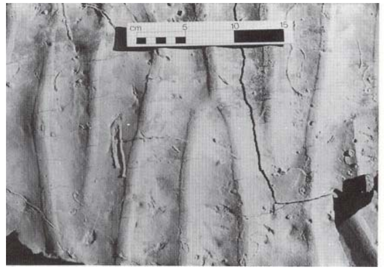
DESCRIPTION	PRIMARY STRUCTURE
CROSS-STRATIFICATION Tabular cross-stratification	
Trough cross-stratification	
NORMAL GRADED BEDDING Coarse grains at the base passing upwards into finer grain sizes; typical of turbidite sequences.	
SCOUR STRUCTURES Scour surface at base of sandstone bed overlying mudrock. Coarse-grained lag deposit may occur in the scour.	
LOAD STRUCTURES Sandstone overlying mudrock Load Casts	
Flame Stuctures Upward injection of mud into the sandstone	
FLUTE CASTS Developed on the underside of Bedding units in Sandstones. Good Palaeocurrent indicators.	Palaeocurrent → 

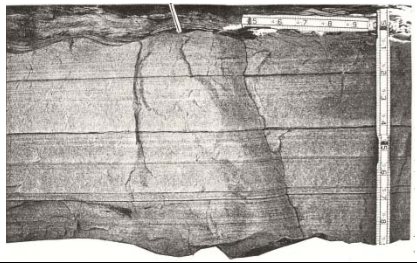
McClay (1987)

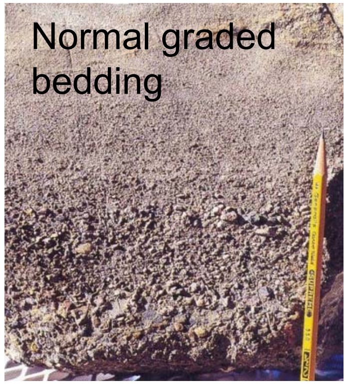
Cross-stratification

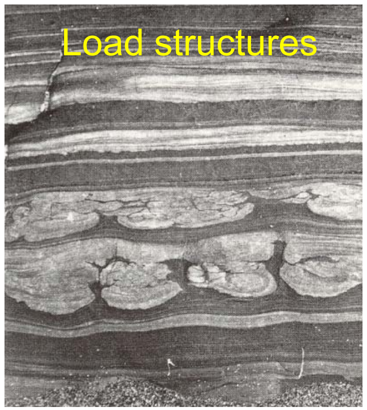


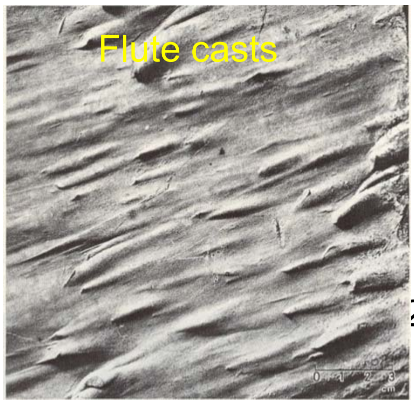
Ripple marks on bedding plane

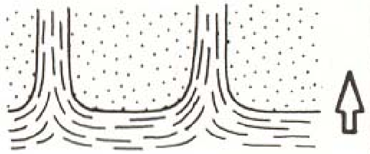
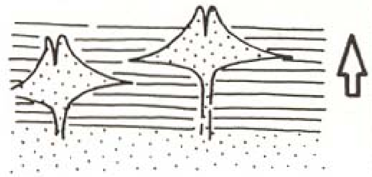
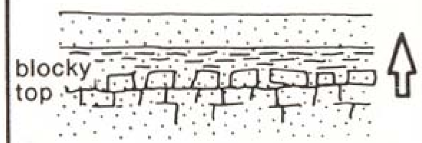




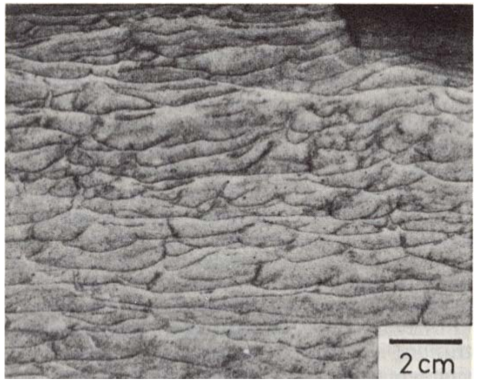




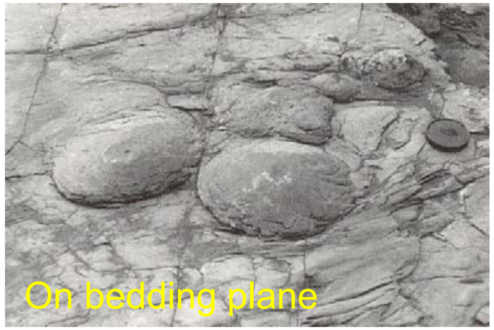


DESCRIPTION	PRIMARY STRUCTURE
Dewatering Structures Pillar structures formed in sandstones and siltstones as water escaped upwards. Dish and pillar structures	
Dewatering Structures Sand volcanoes in mudrocks or siltstones. May be underlain by sandstone dykes.	
Shrinkage Structures Mudcracks infilled with overlying sandstone. Dish structures in mudrock that has undergone desiccation.	 
Volcanic Structures Lobate Pillow structures in lavas.	
Volcanic Structures Blocky, rubbly and weathered tops to lava flows. McClay (1987)	

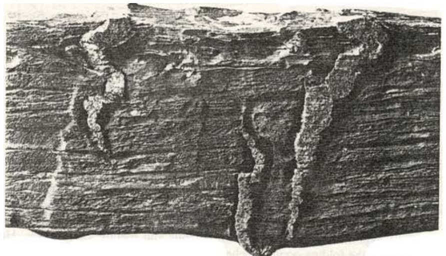
Dish and pillar structures



Sand volcanoes



Mudcracks



Allen (1980), p.557

Collinson & Thompson (1989), p.149

3.5.2 Syn-sedimentary folds/faults versus tectonic folds/faults

From 楊昭男(1995)台灣的地質構造現象,經濟部中央地質調查所,149 pp.

1. 原生構造與次生構造

在地質學裡，所謂的地質構造(geological structures)乃是指岩石或組成岩石的顆粒之排列狀態。吾人現在所觀察到的這種排列狀態，可能是在沉積或成岩作用時即形成，也可能是在岩石生成後，受到外力的作用及環境的改變顆粒重新排列的結果。地質構造因此可依其生成時間分爲**原生構造**(primary structures)與**次生構造**(secondary structures 或 tectonic structures)。次生構造是構造地質學研究的主要對象，而原生構造一般是用做判斷岩石有無變形及變形方式的基準。

原生構造：即岩石在未固化或成岩時，組成岩石的顆粒之排列狀態。

次生構造：即岩石形成後，由於受到構造應力(tectonic stress)的作用及環境的改變，使組成岩石的顆粒之排列狀態或顆粒的內在結構(組構，fabric)發生改變而產生新的排列狀態。次生構造的主要基本類型爲節理、斷層、褶皺、葉理與線理。

2. 原生褶皺與原生斷層

當沉積在未固結時或成岩之前，因重力影響而向下滑動，使岩層產生斷裂或彎曲的構造現象泛稱爲**崩移構造**(slump structure)。因爲崩移而產生的岩層彎曲與錯開分別稱爲**崩移褶皺**(slump fold)與**崩移斷層**(slump fault)。

崩移褶皺	可靠性	次生褶皺	可靠性
褶皺構造被上覆岩層所截切，截切的部位沒有斷層的現象。	A	就一個區域性構造而言，褶皺的發育局限在某些地區。	A
整個褶皺構造有被生物鑽洞的現象。	A	在一個大型褶皺的周圍，褶皺的伸向及軸面成有規律的排列。	A
褶皺構造被逸水（dewatering）構造切穿。	A	褶皺構造內，岩層的裂面及岩脈有規律地排列，形成馬鞍形捲帆構造（saddle reef）。	A
岩石的碎塊或化石缺乏變形的徵象。	A	非片狀礦物內部有優向排列的結晶組構而片狀礦物可能形成扇狀的軸面劈理。	A
褶皺構造的軸面方向沒有軸面劈理的發育，卻被後來形成的劈理所截切。	B－C	在褶皺構造的翼部有擦痕（slickenside）而在軸部有變質線理。	B
在褶皺包絡面內褶皺的褶皺軸相當地散亂，沒有統一的方向。	B－C	褶皺構造與脆性逆衝斷層共生褶皺是因爲岩層沿著斷坡（ramp）滑動而產生的。	B
偃臥褶皺的軸面與褶皺包絡面斜交且呈覆瓦狀的排列。	C	在褶皺包絡面內，褶皺爲急折形（kink-like）且其軸面與褶皺包絡面直交。	B
在與褶皺共生的伸張構造與壓縮構造內均無礦脈的發育。	C	褶皺軸面連續地穿過好幾層不同岩性的岩層。	B
		小型褶皺與大型褶皺爲寄生（parasitic）的關係。	B
		由片狀礦物所構成的軸面劈理成扇狀的排列。	C

註：A 爲可靠性最高；B 爲可靠性介於 A 與 C 之間；C 爲可靠性最低。惟在判斷時最好同時用幾個準則，避免單憑一個準則。

楊昭南 (1995)

(1)原生褶皺與次生褶皺的區別

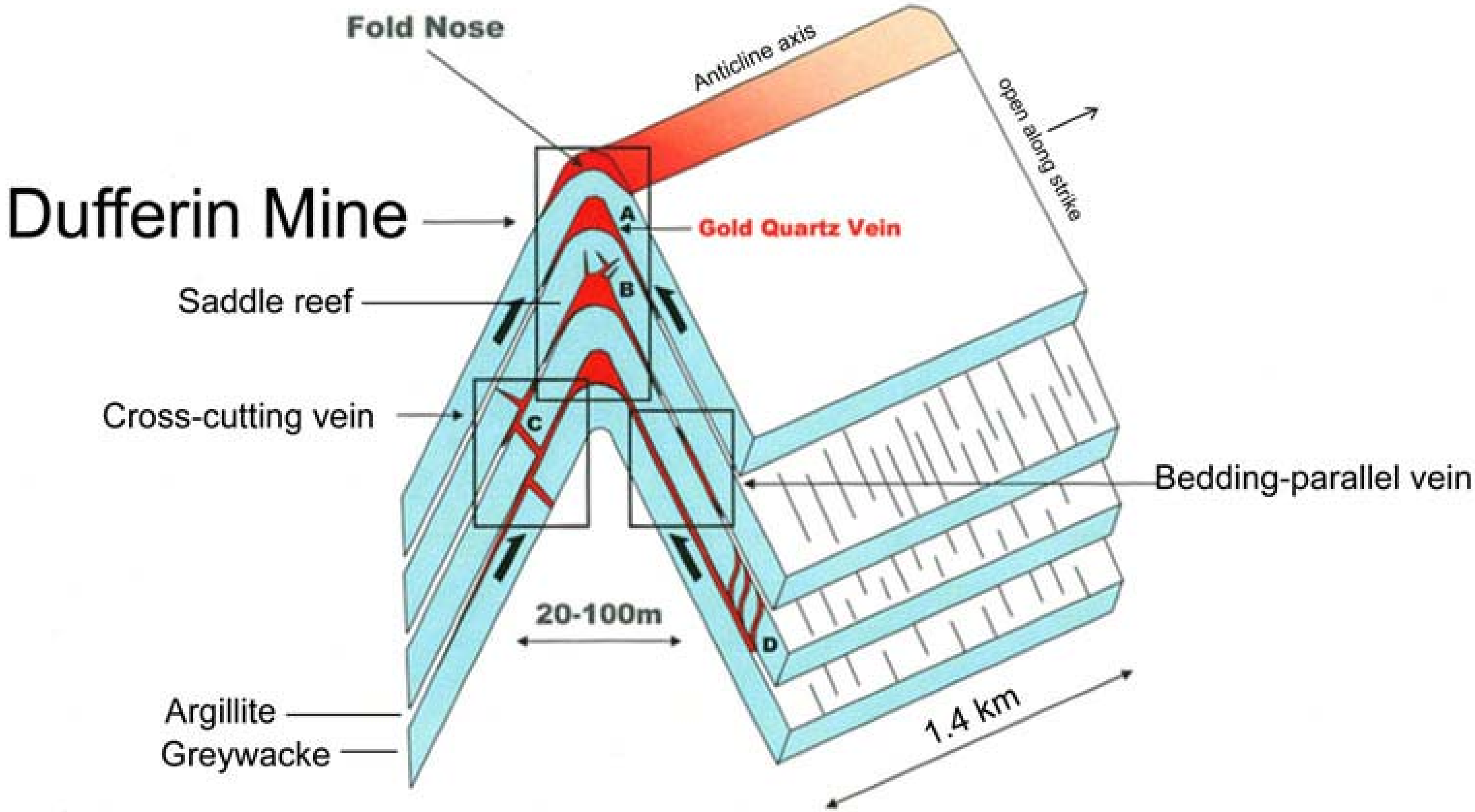
崩移褶皺的形態、波長及大小與由構造應力產生的次生褶皺（tectonic folds）有很多相似之處，因此僅由褶皺的形態、波長與大小，很難區別一個褶皺究竟是崩移褶皺抑或是次生褶皺，而必須從其它的現象著手。麥克萊（McClay, 1987）曾列舉出區別崩移褶皺與次生褶皺的準則，茲將其列於表一，供讀者參考。

Syn-sedimentary fold

原生褶皺：
南橫檜谷

劈理以高角度切過約呈水平的褶皺軸面

Saddle reef



Schematic diagram for turbidite-hosted gold mineralization

January 27, 2011
Gold Mineralization Extended to 358m Depth in 14 Saddle Reefs Veins at Dufferin Mine Project

From: http://www.strikepointgold.com/s/QwikReport.asp?IsPopup=Y&printVersion=now&X1=439673,424771,413263,402849,402844

⑵原生斷層與次生斷層的區別 楊昭男 (1995)

原生斷層與次生斷層的區別，主要在於原生斷層是沉積物在未固結或成岩之前形成的，而次生斷層則是在岩石成岩之後受到構造應力作用才形成。因此斷層形成時，岩石的固結狀態是分辨斷層爲次生的抑是原生的主要考慮因素。

Syn-sedimentary faults (古亭坑層)

一般而言，原生斷層具有下列的特徵：

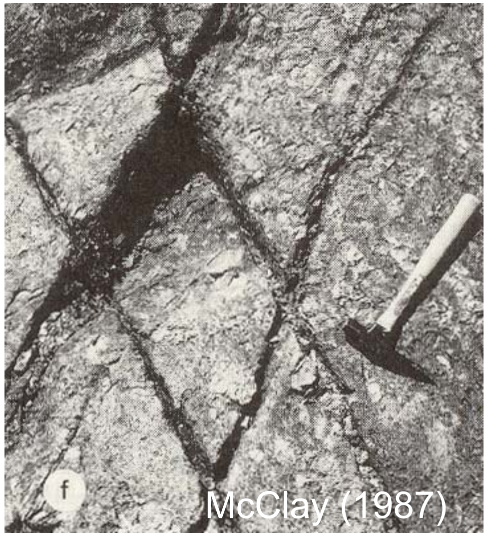
— 典型的斷層面，一般不切穿所有的地層，且上面未被斷層切穿的岩層與下面的岩層是整合性地接觸。
— 斷層面的形狀通常爲弧形。
— 在水平剖面上，斷層線通常呈曲線而不是直線。
— 在斷層下滑的那一側，斷層旁的沉積物常堆積成不等邊三角形的錐狀岩體。
— 斷層帶內沒有斷層岩、礦物脈(vein)等產物。
— 小區域內沿斷層面通常沒有混雜其他沉積物侵入的現象。
— 常與其他原生構造共生，如崩移作用產生的原生褶皺、旋捲層理(convolute lamination)及砂火山(sand volcanoes)等。

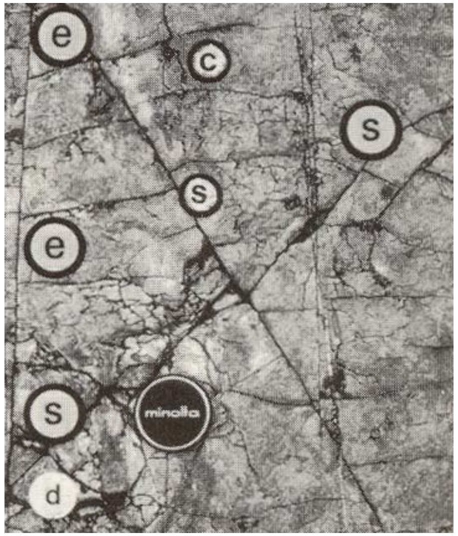
Joints

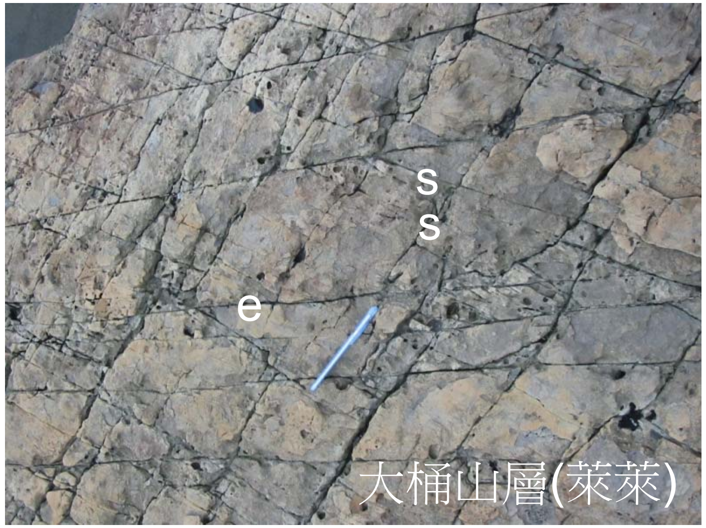
3.5.3 Joints, veins and stylolites

節理(joint)一般又稱爲裂理(fracture)，是指岩石中的裂隙，且裂隙兩側的岩石沿著裂隙方向沒有明顯的錯動。但如果有肉眼可觀察得到的位移，則可稱爲小斷層。裂隙中如果有礦物的充填，稱爲脈(vein)，由石英充填的裂隙稱爲石英脈，由方解石充填的裂隙稱爲方解石脈。在臺灣，節理是最普遍常見的地質構造。有些的節理大都被礦液充填而形成礦脈，在中央山脈、雪山山脈的變質岩區的脈大都爲石英脈，而在麓山帶非變質岩區所見的大都爲方解石脈。如果裂隙中空，則稱爲裂縫(fissure 或 gash fracture)。雖然節理在臺灣是最普遍的地質構造，但也是被研究的最少的地質構造。在一般的地質報告中，大多只報導節理的位態，對於節理形成的先後次序、形成原因、形成機制及其與岩層厚度及岩性的關係等，很少作進一步地探討。其實就實質上的應用，這些研究對工程地質、礦床探勘是十分有用的。

e: extension joints
s: shear joints







在一個新鮮的節理面上，有時可見到一些凹凹凸凸但規則排列的條紋(markings)。一般認爲這些條紋是岩石在破裂時，裂面由點到面擴張(propagation)所留下的痕跡。常見的條紋構造有**羽毛狀條紋**(plumose marking)與**肋骨狀條紋**(rib marking)(圖 6.1)。

羽毛狀條紋：以節理面的中線爲軸線，梳紋(hackle)對稱性地從軸線向兩側像羽毛般地射出。羽毛柄端所在的點爲裂面的起點，羽毛尾爲裂面的終點。

肋骨狀條紋：以羽毛狀條紋的羽柄爲中心，與梳紋線幾乎垂直而呈同心圓排列的階梯狀構造。其排列有如人之肋骨，故稱之爲肋骨狀條紋。一般認爲同心圓的圓心爲裂面開始破裂的起點。

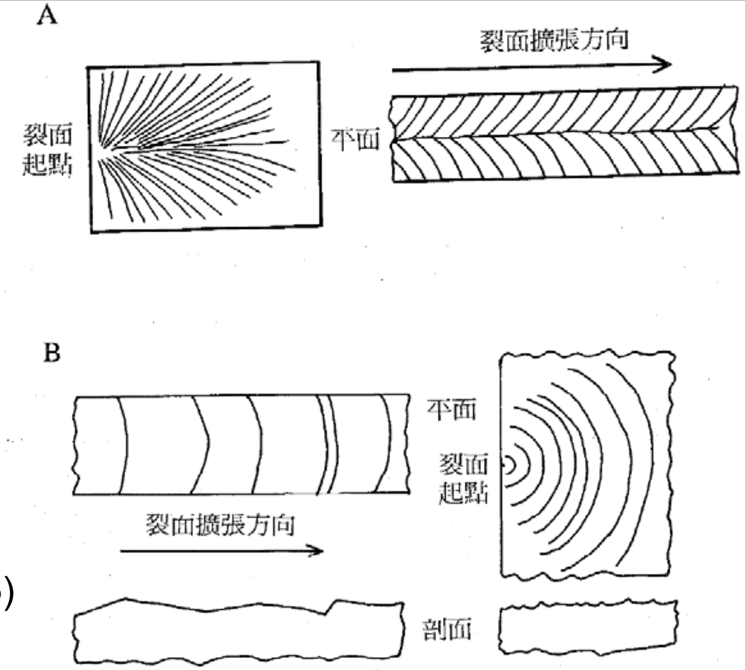


圖 6.1　節理面上的條紋構造，可指示裂面擴張之方向。 A ：羽毛狀條紋構造； B ：肋骨狀條紋構造。

楊昭南 (1995)

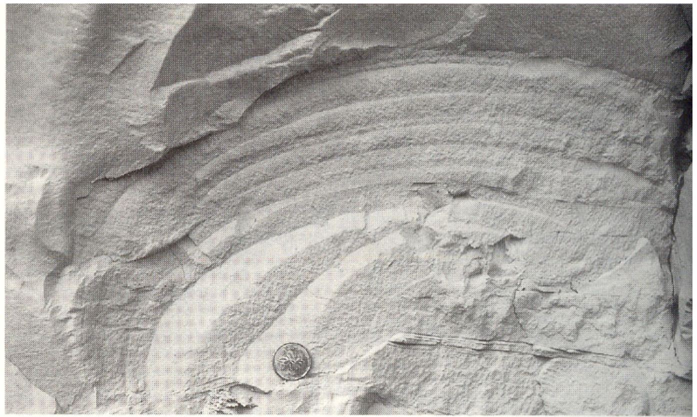


Fig. 7.3a　Plume structures on a joint surface in glacial clays.

McClay (1987)

Hancock（1985）依據岩石的張力強度、岩石所受的軸差應力大小、以及岩石破裂面的位態與最大主應力方向間的夾角關係，將節理分成以下三類（圖 6.2）：

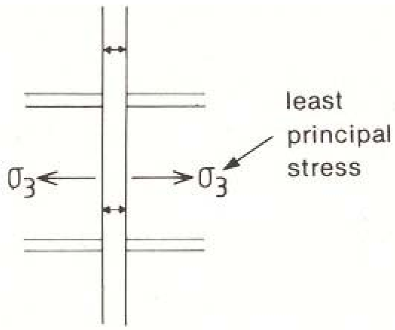
伸張節理（extension joint）：岩石破裂時之有效軸差應力（$\sigma_1 - \sigma_3$）< 4 σ_t，而且最小有效主應力 $\sigma_3' = -\sigma_t$（σ_t 爲岩石的抗張強度）的情況下形成。其形成之裂面與 σ_1 的方向平行且垂直於 σ_3 方向。這類以張力爲主，使岩石發生張力破壞而產生的節理，一般文獻中稱之爲張力節理（tension joint）。

剪力節理（shear joint）：岩石破裂時的有效軸差應力（$\sigma_1 - \sigma_3$）> 8 σ_t，最小有效主應力 $\sigma_3' > 0$ 的情況下形成，若 $\phi = 30^\circ$ 則其形成的共軛裂面夾角爲 60°。

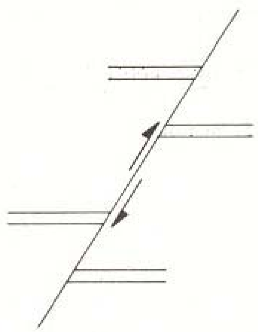
混合節理（hybrid joint）：岩石破裂時的有效軸差應力（$\sigma_1 - \sigma_3$），介於 4 σ_t 至 8 σ_t 之間，最小有效主應力 $\sigma_3' < 0$ 的情況下形成，其形成共軛裂面夾角介於 0° 至 60° 之間。

McClay (1987)

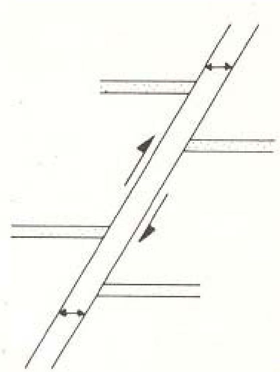
Extension joint cutting across shear joints(?)



Extension joint

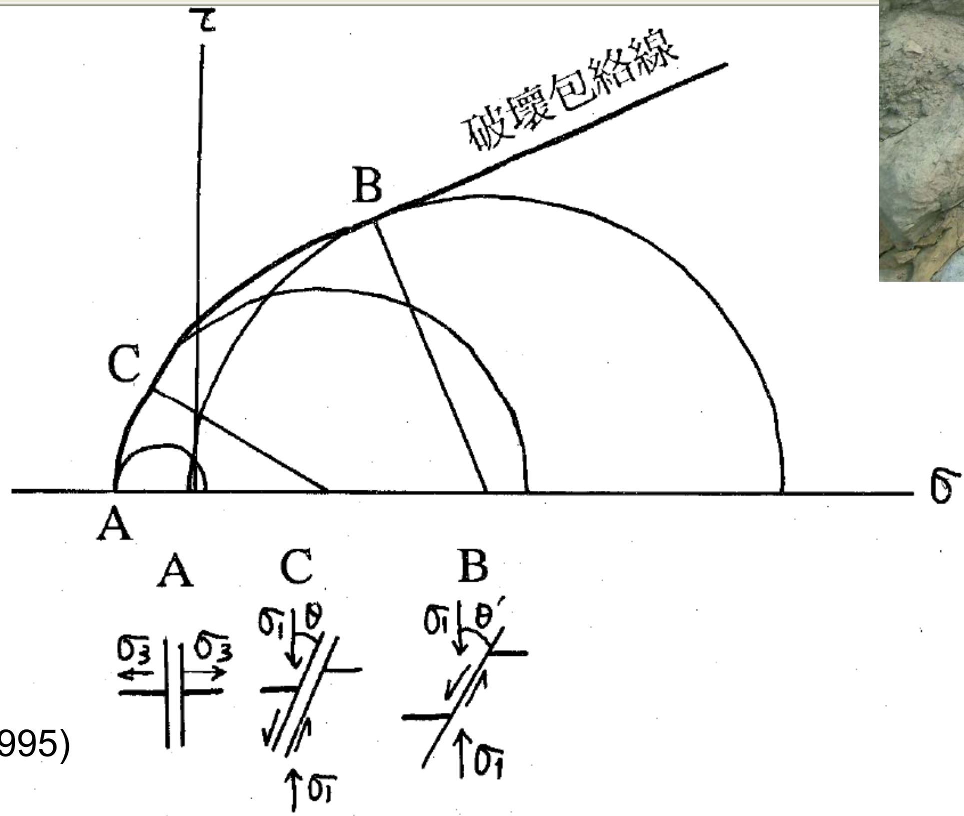


Shear joint



Hybrid joint

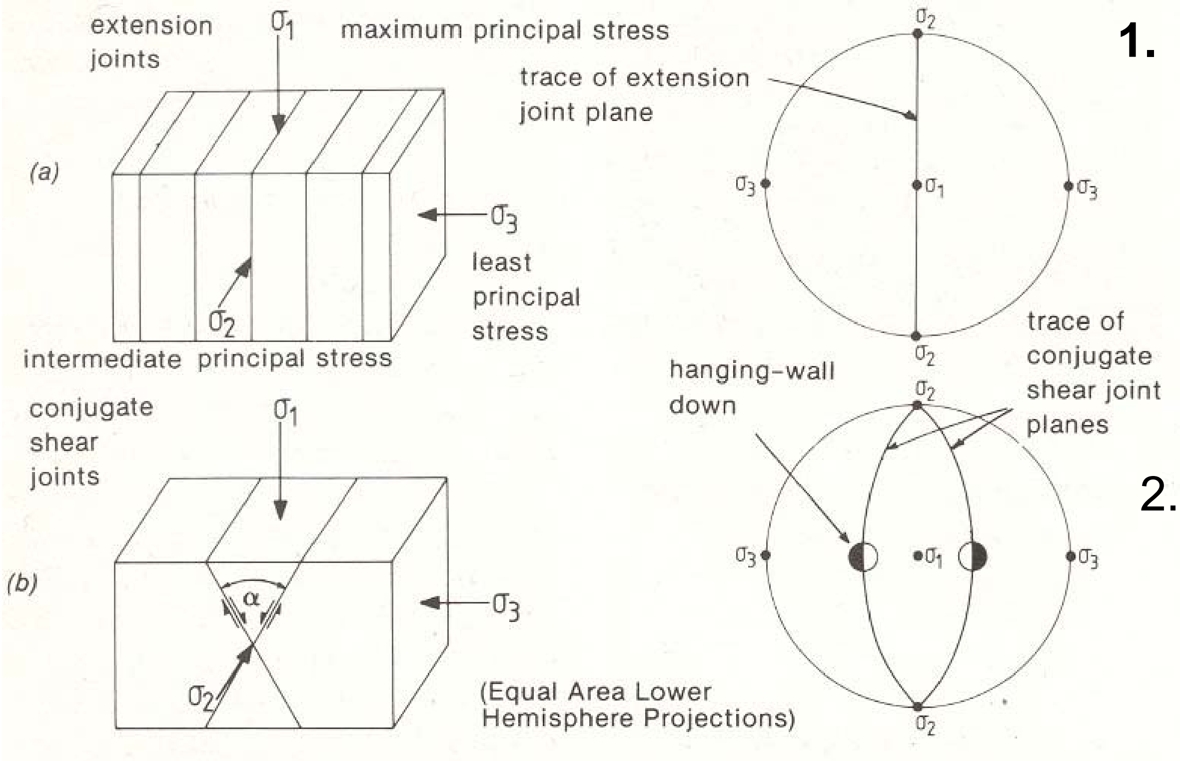
Irregular extension joints – are those in which extension occurs in all directions (often due to hydraulic fracturing as a result of high pore fluid pressures.



楊昭南 (1995)

圖 6.2　以莫爾應力圓表示產生(A)張力節理、(B)剪力節理及(C)混合節理之應力狀態。σ_1，σ_2，σ_3 分別代表最大、中間與最小主應力軸。箭頭指示節理形成時，節理兩側岩石之相對運動方向。此圖顯示張力節理與 σ_3 垂直，剪力節理與 σ_1 之交角 $\theta' > 22.5°$，而混合節理與 σ_1 之交角 $\theta < 22.5°$。

Analysis of joint systems

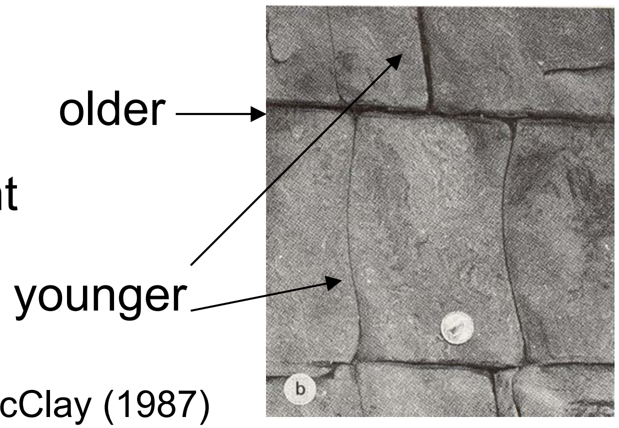


McClay (1987)

1. **Extension joints**: on a stereographic projection, σ_3 is the pole to the joint plane which contains the σ_1 and σ_2 axes. Extension joints alone will not give σ_1 and σ_2 orientation.

2. **Shear joints**: line of intersections of the conjugate joints gives the σ_2 axis. σ_1 bisects the acute angle between the joint planes and σ_3 is at 90° to both σ_3 and σ_2.

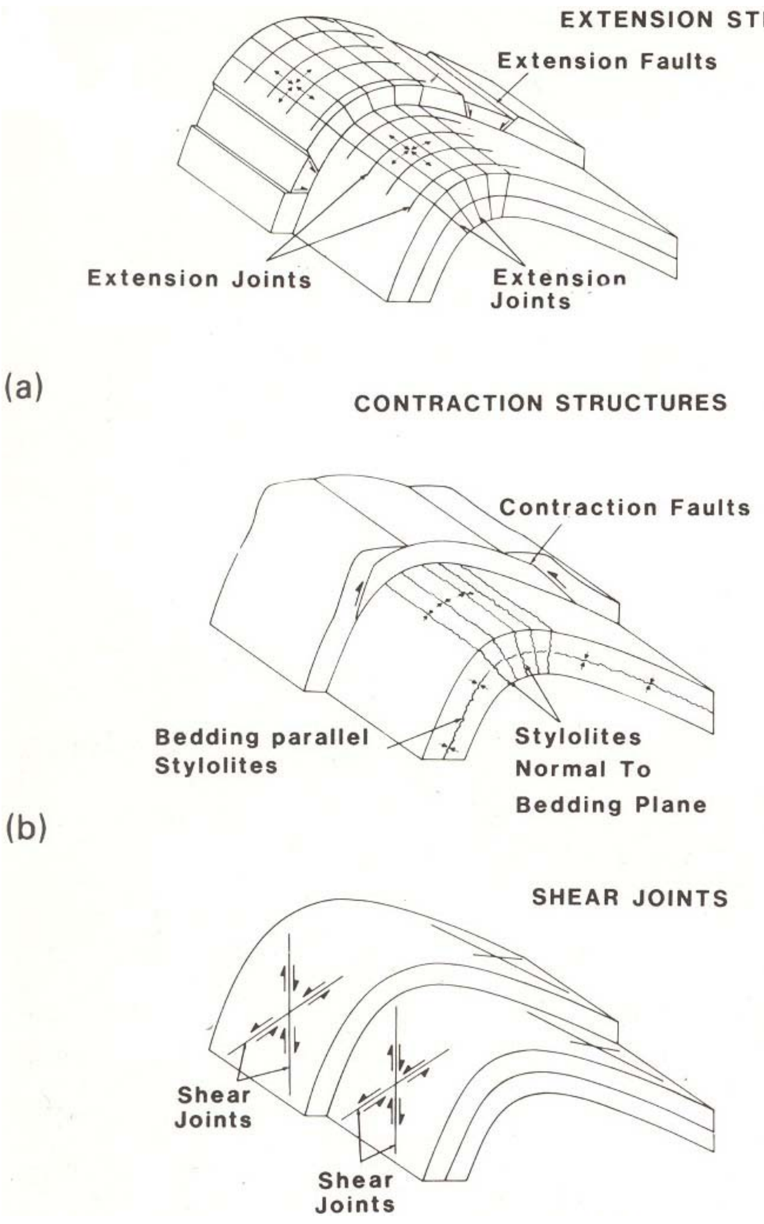
3. **Age relationships** between joints: younger joints generally abutt against and do not cut older joints. Typically T or H patterns result with the younger joint (the upright of the T or the cross-bar of the H) abutting against the older joints.



McClay (1987)

For cylindrical folds

Joints in fold and fault systems



Extension joints are commonly parallel or normal to the fold axis.

Shear joints are commonly developed on the fold limbs.

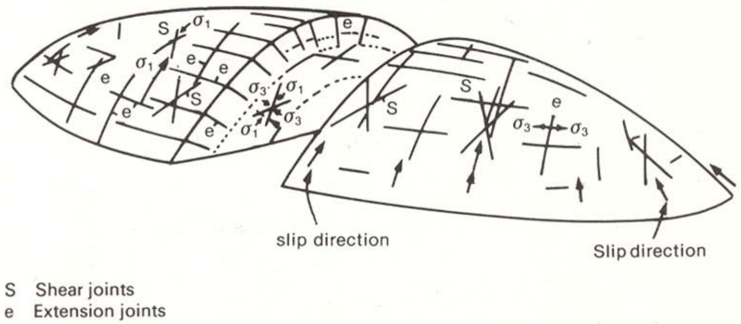


Fig. 7.5a Fracture patterns developed around a non-cylindrical fold. Note that the conjugate shear fractures (s) and extension fractures (e) vary with slip direction around the fold.

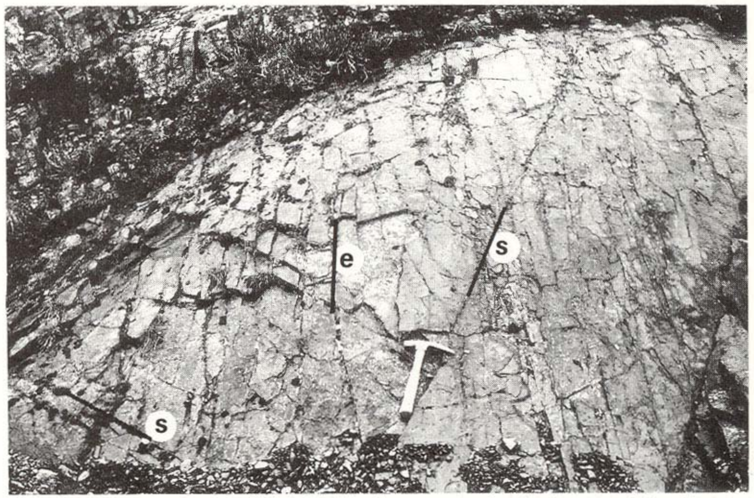
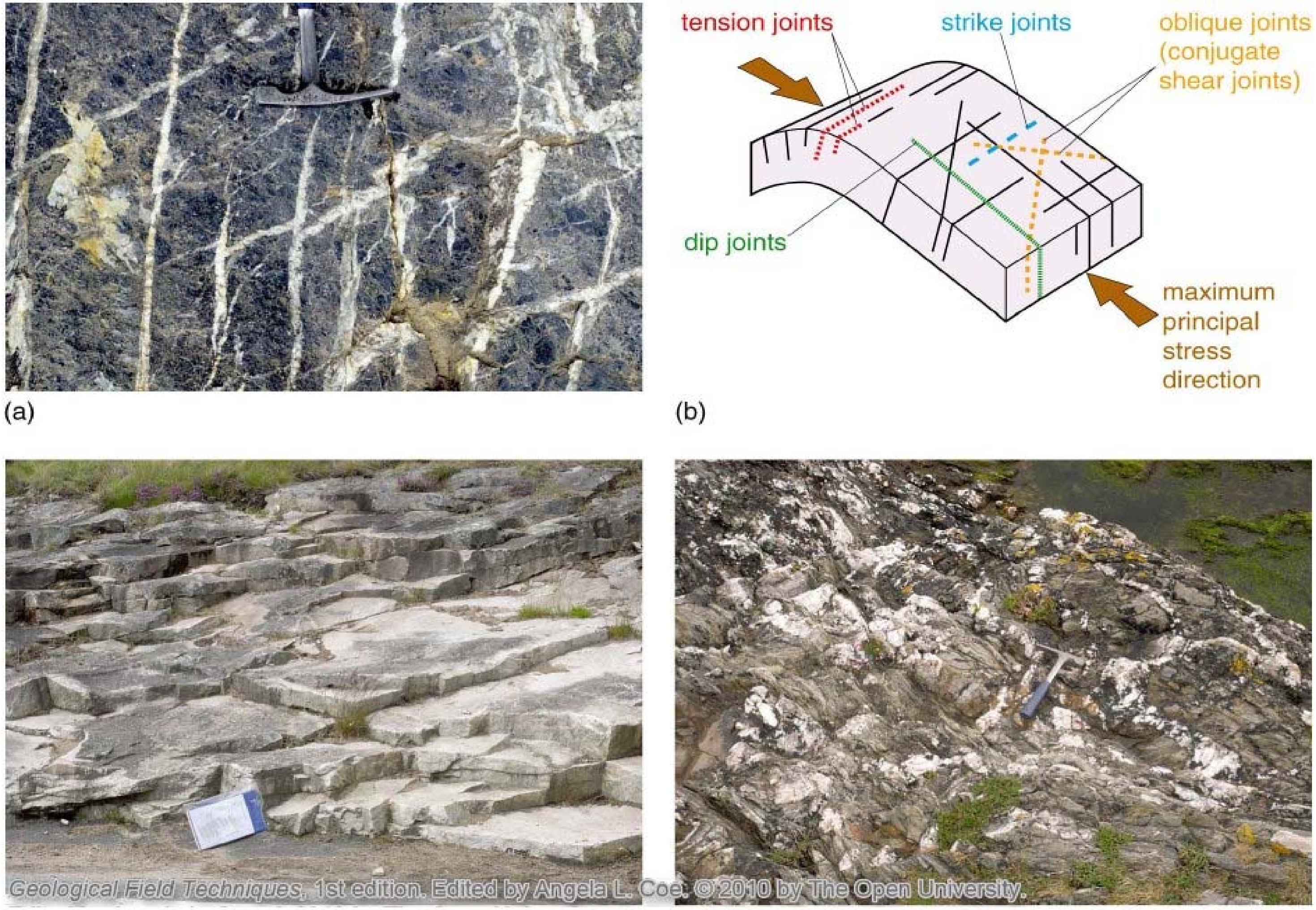


Fig. 7.5b Example of a non-cylindrical fold in siltstones, showing development of shear fractures (s) and extension fractures (e).

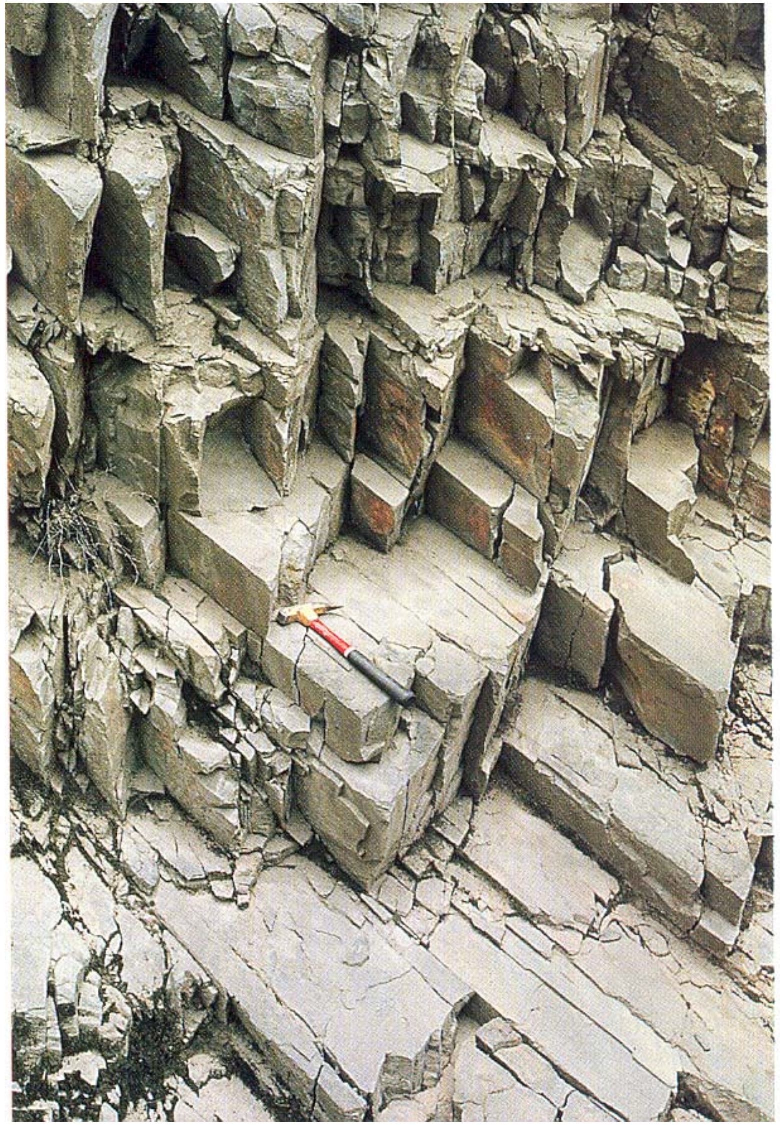
McClay (1987)



(a) (b) (c) (d)

Figure 8.4 (a) Conjugate veins, with a characteristic X-shaped pattern and minor offsets (Switzerland). (b) Diagram of shear and extensional fractures on a fold (based on McClay 1991); (c) Unloading joints in granite exposure near Balmoral, Scotland, UK: two sets are subvertical, almost at right angles to each other, while the third set is roughly parallel to the land surface. (d) Chaotic veins in this exposure suggest hydraulic fracturing under high fluid pressure (Wales, UK). (a, c and d: Tom W. Argles, The Open University, UK.)

Conjugate shear joints in 3D



四稜砂岩牛鬥(陳肇夏攝台灣地質寫真V2)

For this picture, what kind of data should be collected in the fields?

What is the approximate orientations of the stress system during the formation of the joints assuming that the strata have not been deformed since the joints developed?

Veins

1. Extensional veins form normal to σ3 and have fibres perpendicular to the vein walls.
2. Shear or hybrid vein systems have fibres that are oblique to the vein walls.
3. The fibre axis in fibrous veins is approximately parallel to the σ_3 orientation at any stage during the fibre growth. Hence curved fibres in underformed veins reflect the change in vein orientation with respect to the σ_3 axis.
4. En-echelon vein systems are commonly found in semi-brittle shear zones where they can be used to analyze the kinematics and displacements of the shear zones.

McClay (1987)

Note:
Veins indicate high, albeit transient, pore pressures during deformation and are commonly associated with pressure-solution seams.

Stylolites

Stylolites are surfaces of dissolution associated with contractional or shear strains..

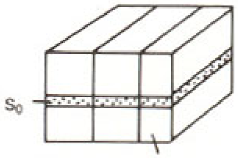
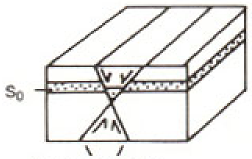
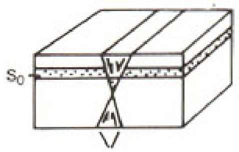
縫合面

1. Tectonic stylolites are commonly associated with joints and veins and is usually found in fine-grained carbonate. They also appear in sandstones.
2. The stylolitic seam often appears dark and contains a residue of insoluble material (carbonaceous matter, clay and ore minerals).
3. Stylolites generally form normal to σ_1, but oqlique

What is the orientations of σ_1 during the formation of the stylolites shown in both pictures?

McClay (1987)

Data to be collected from observations on joints, veins and stylolites

Structure	What to measure	What observations to record	Results of analysis
Joints J_1  Extension Joints	Dip direction (or strike and dip)	Fracture type (dilational, shear, or hybrid).	For conjugate shear-fractures—stress systems.
	Dip direction of conjugate fracture array (if developed).	Conjugate fracture system.	
 Conjugate Shear Joints (Angle 60-90°)	Line of intersection of conjugate arrays	Bedding and uniformity of bedding dip. Fracture spacing. Bed thicknesses. Length of fractures relative to bed thicknesses. Nature of fracture surface.	Bed competencies. History of fracture movement.
		Nature of fracture infilling (quartz; carbonate; fibrous or massive).	
 Conjugate Hybrid Joints (Angle <60°)	Line of bedding intersection on fracture plane		Gives apparent dip of bedding. Used to calculate true bedding attitude.
Additional information required for analysis.	Dip direction of bedding (fractures are best analysed in areas of uniform bedding). Orientation of fold axis. Orientation of fold axial plane.	Relationship of fracture to bedding. Relationships of fractures to fold. Cylindrical Non-cylindrical	Analysis of fracture systems with respect to bedding and fold limbs. Gives fracture systems: a–c, b–c, etc.

McClay (1987)

3.5.4 Faults and shear zones

Shear zones

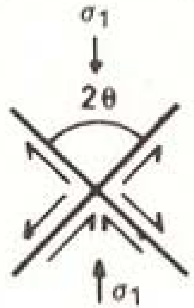
Shear zone: a relatively narrow zone with subparallel boundaries in which shear strain was localized. Shear zones form under a variety of deformation conditions in three main types:

Ductile shear zones: In this zones there is no discontinuity across the zone, and shear strain magnitude varies smoothly across the zone. The fabric of rocks within these zones has been modified by plastic deformation processes.

Brittle-ductile shear zones: There is a discontinuity within the ductilely deformed rocks of the shear zone. This discontinuity may be a discrete fracture on which sliding has occurred, or it may be an array of en-echelon extension gases.

Brittle shear zones (faults and fault zones): In a brittle shear zone the rock has been deformed by brittle deformation processes. If the "zone" is a discrete planar fracture on which slip occurred, it is called a fault. If a brittle shear zone is composed of a number of subparallel anastomosing faults separating lens-shaped blocks of underformed rock, or if it is a tabular band of finite width containing brittlely shattered or pulverized rock, it is called a fault zone.

Geometrical properties of shear zones in the crust



Approximate depth	*Metamorphic facies*	*Structural features of shear zones*	*2θ, angle between conjugate shear zones*
> 10 km ductile shear zones	granulite, amphibolite blueschist	ductile flow, strong sigmoidal schistosity in zones.	120°–90°
5–10 km ductile, brittle-ductile shear zones.	greenschist, zeolite	ductile to semi-brittle; localised schistosity; en-echelon vein arrays; pressure-solution features.	90°–60°
0–5 km brittle shear zones	Anchimetamorphism, no metamorphism	Brittle; fault breccia and clay gouge; some pressure-solution features.	60°

McClay (1987)

Shear-zone and fault-zone rocks

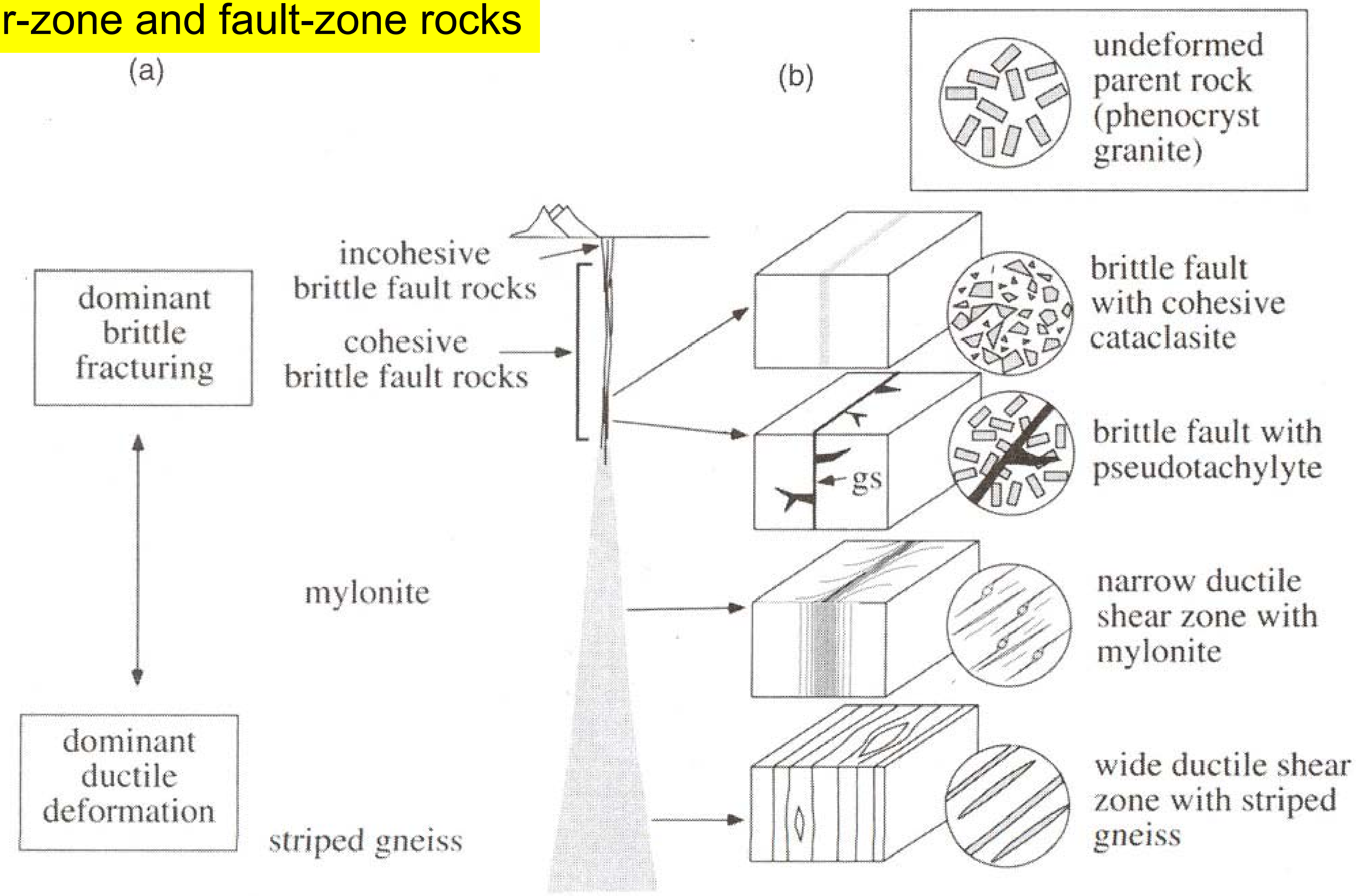


Figure 22–2 Schematic cross section through a shear zone, showing the vertical distribution of fault-related rock types, ranging from non-cohesive gouge and breccia near the surface through progressively more cohesive and foliated rocks. Note that the width of the shear zone increases with depth as the shear is distributed over a larger area and becomes more ductile. Circles on the right represent microscopic views or textures. From Passchier and Trouw (1996). Copyright © with permission from Elsevier Science.

from Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall, 697pp.

Fault rocks classification

Nature of matrix		Random-fabric	Foliated		Proportion of matrix
		Fault breccia (visible fragments > 30% of rock mass)	*Foliated fault breccia*		
		Fault gouge (visible fragments < 30% of rock mass)	*Foliated gouge*		
glass/devitrified glass		Pseudotachylite	*Foliated Pseudotachylite*		
tectonic reduction in grain size dominates; grain growth by recrystallisation and neomineralisation		Crush breccia Fine crush breccia Crush microbreccia	(fragments > 0·5 cm) (0·1 cm < fragments < 0·5 cm) (fragments < 0·1 cm)		0–10%
	cataclasite series	Protocataclasite	Protomylonite	mylonite series	10–50%
	cataclasite series	Cataclasite	Phyllonite varieties / Mylonite	mylonite series	50–90%
	cataclasite series	Ultracataclasite Flinty crush rock	Phyllonite varieties / Ultramylonite	mylonite series	90–100%
grain growth pronounced		?	Blastomylonite		

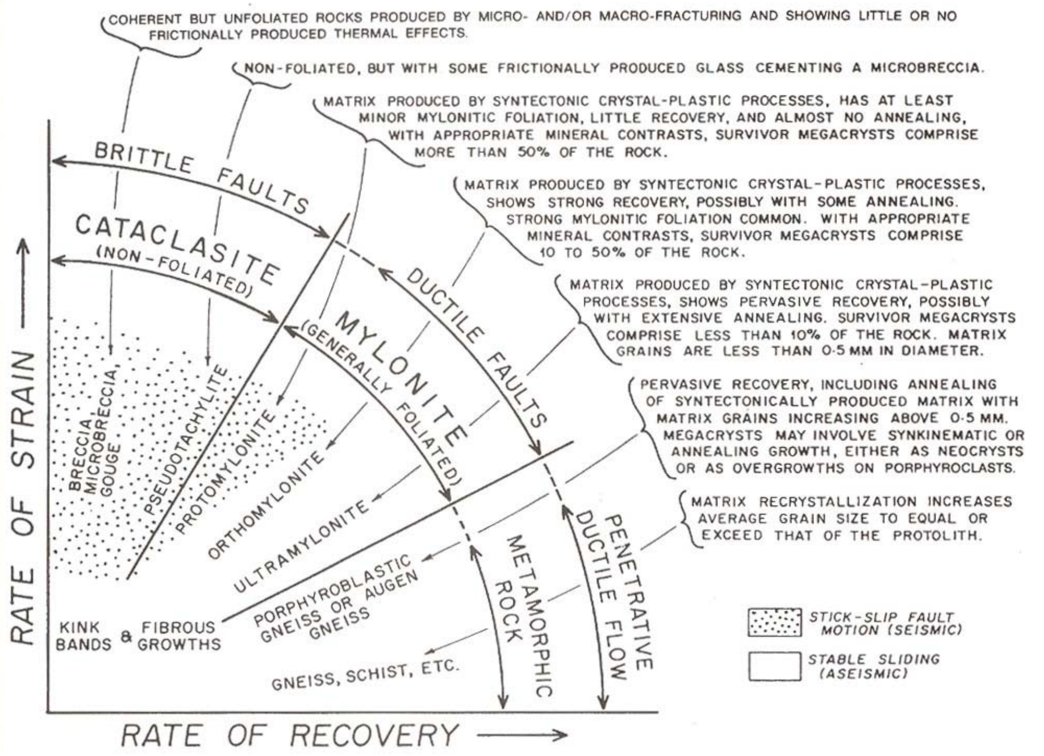
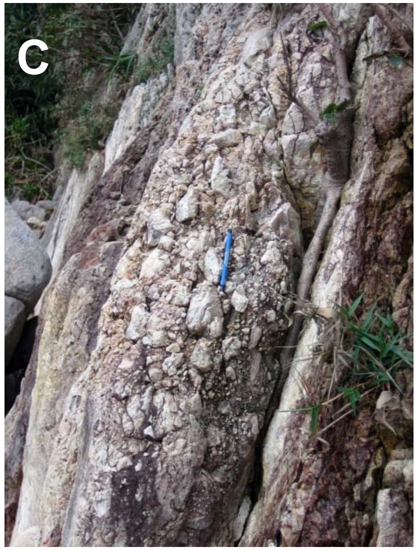


Figure 22–3 Terminology for high-strain shear-zone related rocks proposed by Wise et al. (1984). Copyright © The Geological Society of America, Inc.

Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall, 697pp.

Sibson (1977)

Fault breccia



Breccia in the Pirate Fault, Santa Catalina Mountains, Near Tucson, Arizona

A, B, C: 四稜砂岩 (龍洞)

Fault gouge

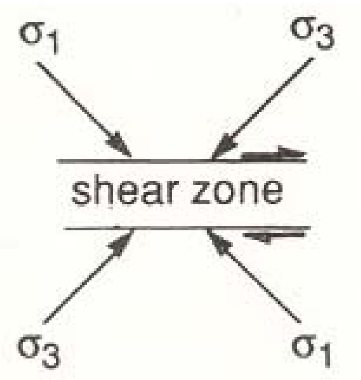
Press & Siever (2000) supplemental CD

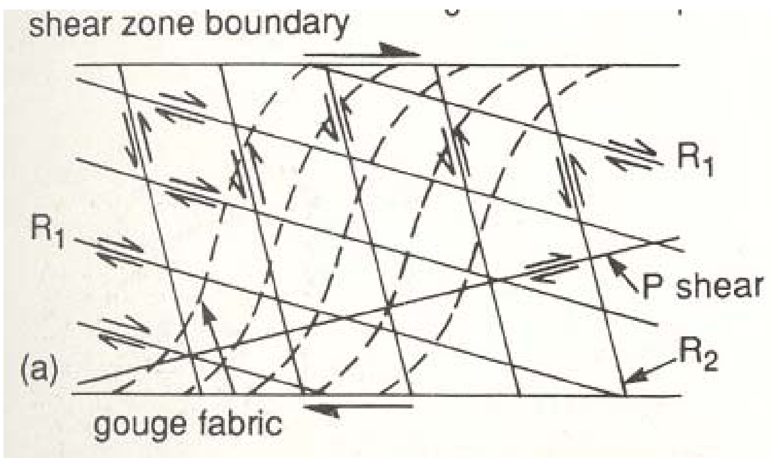
This sample (4x6 cm) is from a **mylonite zone.** The augen mylonitic gneiss illustrates the pervasive brittle and ductile deformation. Partially broken down and rotated orthoclase phenocrysts form the augens or porphyroblasts. The brittle deformation of the feldspars contrasts strongly with the ductile deformation of the quartz, which is smeared out in the thin darker layers. The tails on the orphyroblasts suggest a clockwise rotation.

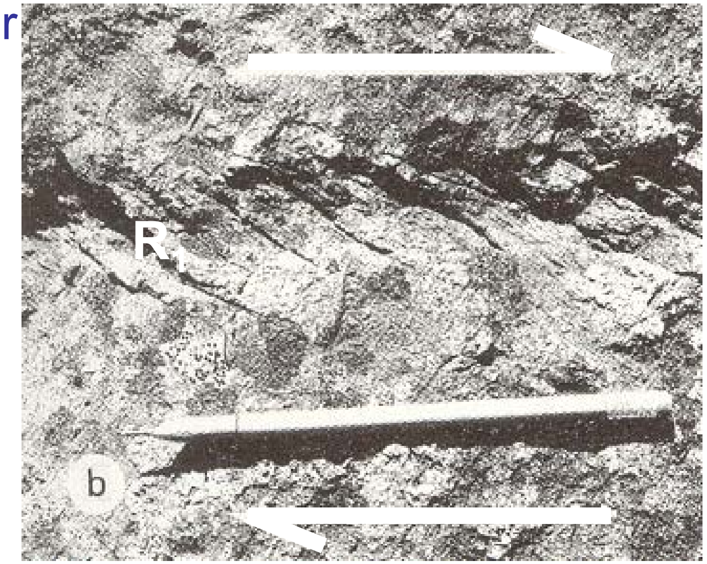
The description of a shear zone should include information on (a) the orientation (strike and dip) of the zone, (b) the relative movement across the zone (direction and amount of net slip), (c) the width of the zone, (d) the style of deformation (brittle or ductile) within the zone, (e) the nature of the transition between the zone and the wall rocks (is the boundary of the zone gradual or abrupt).

In a brittle shear zone

R_1: Riedel shear
R_2: conjugate Riedel shear





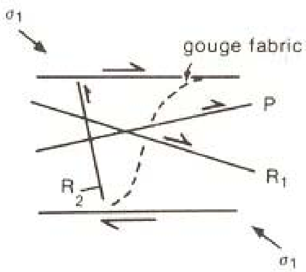


McClay (1987)

Riedel shears, R1 and R2: Fault like discontinuous fractures developed in a brittle shear zone and related to the positions of conjugate fracturing in the zone.

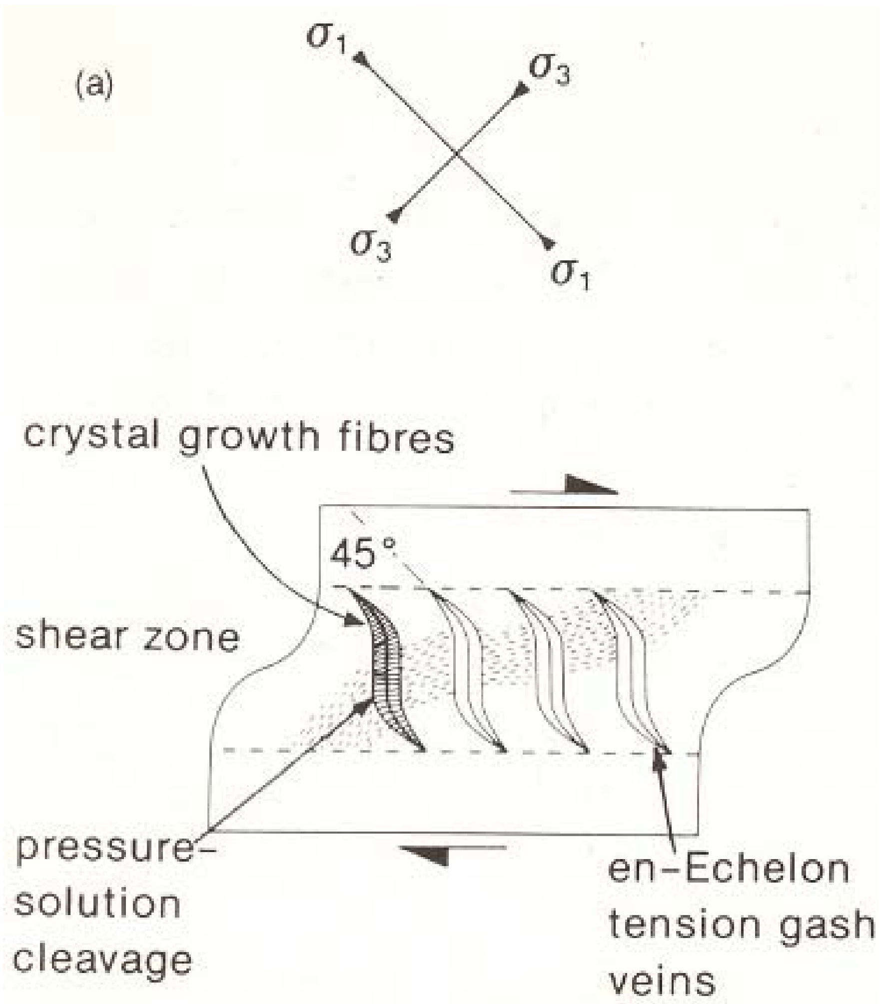
Data to be collected from observations on brittle shear zones

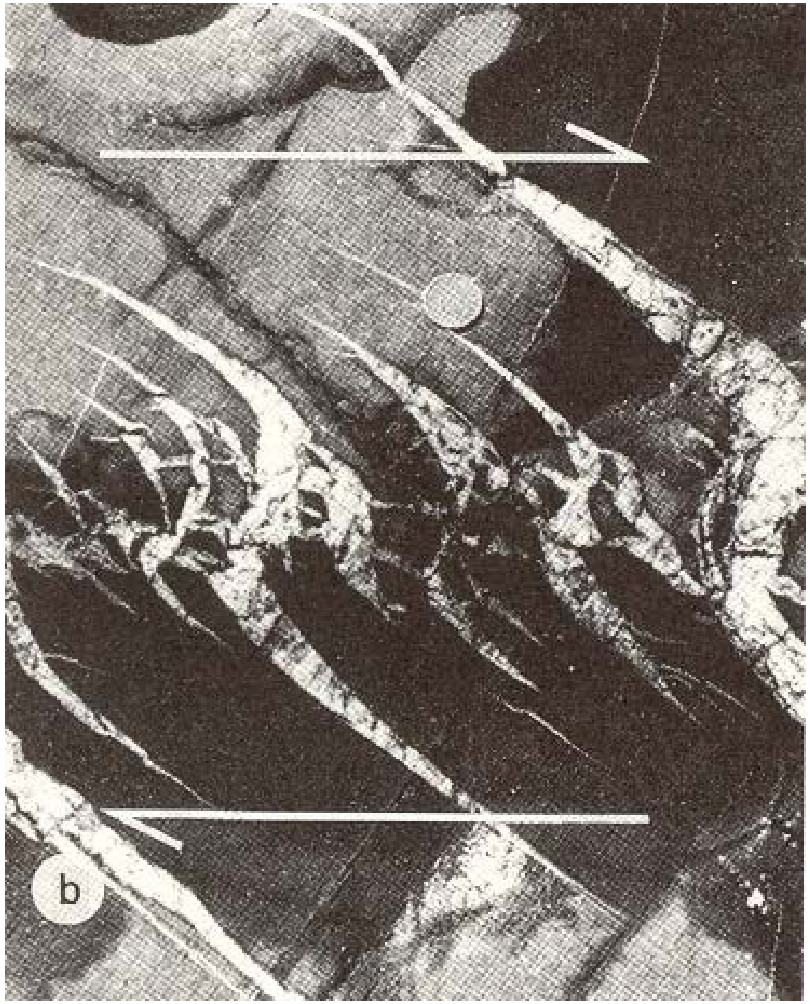
Table 6.6 Data to be collected from observations on shear zones.

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
Brittle shear zone  	Orientation of shear zone boundaries (Figs. 2.5–2.8). Orientation of Riedel fractures R_1 and R_2 (Fig. 6.19. & Figs. 2.5–2.8). Orientation of fabric in fault gouge. (Fig. 6.8) Orientation of P fracture (if developed). (Fig. 6.19) (Additional data—orientation of structures outside shear zone). (Fig. 6.23)	Nature of shear zone. (Fig. 6.19) Width of shear zone. Fault rocks developed. (Fig. 6.18, Table 6.4) Veining and/or pressure-solution. (Fig. 6.23 and 7.6b) Fracture orientations relative to shear zone. (Fig. 6.19a) Sense of shear, (Fig. 6.19a) Displacement. Structures outside shear zone.	Stress systems. (Fig. 6.19a) Sense of shear. (Fig. 6.19a) Displacement. Deformation processes.
	Orientation data on conjugate array. (Fig. 6.22)	Observations on conjugate array. (Table 6.5)	Stress systems. (Fig. 6.19a) Sense of shear. (Fig. 6.19a) Displacement. Deformation processes.

McClay (1987)

Semi-brittle shear zone (*en-echelon* tension gashes)

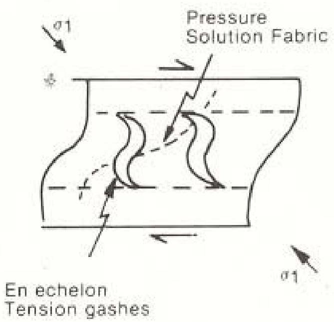




McClay (1987)

Data to be collected from observations on semi-brittle shear zones

Table 6.6 *Cont'd*

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
Semi-brittle shear zone (en-echelon tension gashes)  	Orientation of shear zone boundaries (Figs. 6.20 & 2.5–2.8). Orientation of crack tips. (Fig. 6.20a) Orientation of intersection of crack tips with shear zone boundary. (Fig. 6.20a) Orientation of pressure-solution fabric at shear zone margins. (Fig. 6.20a)	Nature of shear zone. (Figs. 6.20, 6.22) Width of shear zone. Nature of veins—fibrous or massive. (Figs. 6.20a, 7.6) Nature of foliation in shear zone. (Figs. 4.1, 4.2) Sense of shear. (Fig. 6.20a) Displacement. Photograph/sketch of shear zone. Structures outside of shear zone.	Stress systems. (Fig. 6.20a) Sense of shear. (Fig. 6.20a) Displacement. Strain in shear zone. Deformation processes.
	(Additional data on orientation of structures outside shear zone). Orientation data on conjugate array. (Fig. 6.22)	Observations on conjugate array.	Stress systems. (Fig. 6.20a) Sense of shear. (Fig. 6.20a) Displacement. Strain in shear zone. Deformation processes.

McClay (1987)

Ductile shear zones

Mesoscopic and microscopic kinematic indicators

(1)標誌層的錯開方向　　楊昭男 (1995)

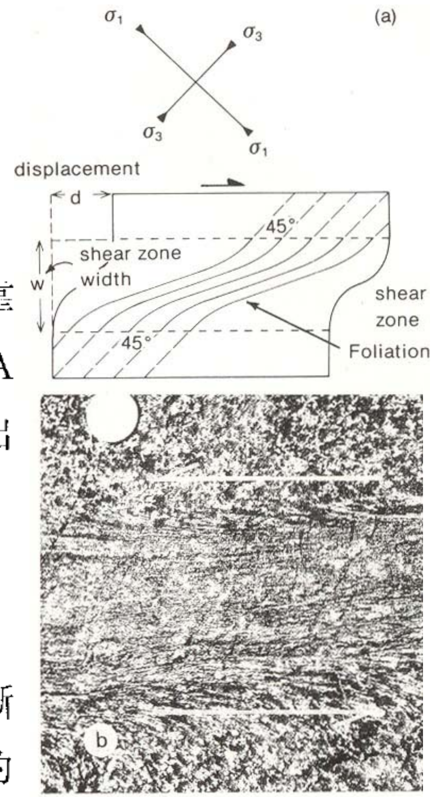
穿過剪切帶的標誌層往往呈 S 型彎曲，標誌層在剪切帶的外側有明顯位移，靠近剪切帶時則漸與剪切面平形，根據互相錯開的方向可確定剪切方向（圖 7.7A）。但應用這一方法時，要注意先存標誌層與剪切帶之間的方位關係，否則會得出錯誤的結論。

(2)不對稱褶皺

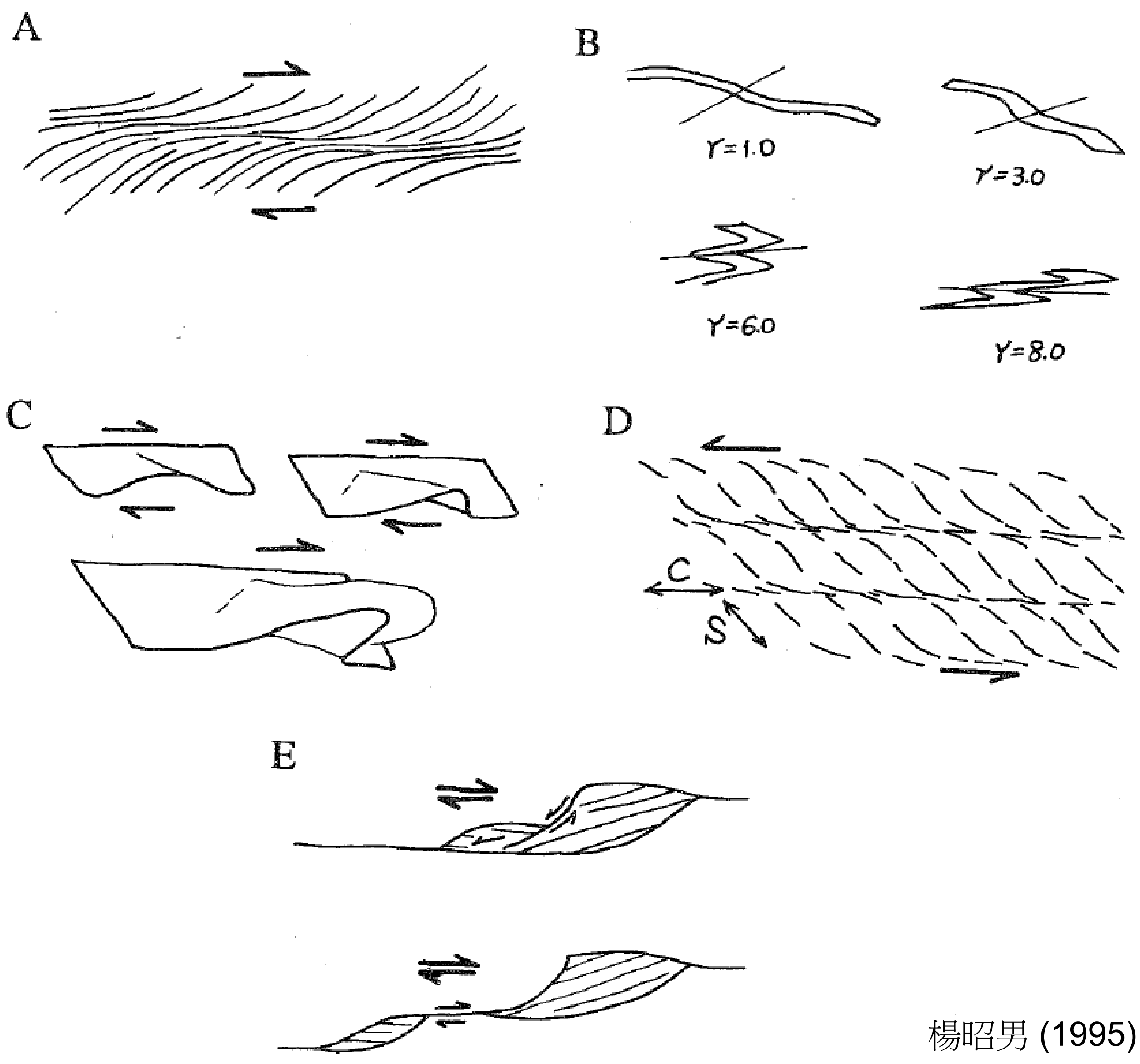
當岩層受到與層面不平行的剪切作用時，導致岩層彎曲旋轉。隨著剪應變的漸進發展，褶皺幅度被動增大，形成一翼較長，傾斜較緩，另一翼較短，傾斜較陡的不對稱褶皺，由長翼到短翼的方向即是褶皺伸向，代表剪動方向(圖 7.7B)。但要特別注意，在剪應變很大時，褶皺形態將變化，變形初期與剪切作用協調的不對稱褶皺的伸向會反轉，如原爲 S 型褶皺轉爲 Z 型，上述法則就不再適用了。

(3)劍鞘狀褶皺

在剪動帶內形成的褶皺，在漸進的剪動下，褶皺樞紐線呈不等量的位移而形成劍鞘狀褶皺(sheath fold)，劍鞘的前端指示滑動的方向（圖 7.7C）。



McClay (1987)



楊昭男 (1995)

圖 7.7　指示剪切運動方向的各種標誌：(A)標誌層的錯開方向；(B)不對稱褶皺，γ 表示剪應變，數字爲應變值；(C)劍鞘狀褶皺；(D) S-C 面理；(E)“雲母魚”構造。

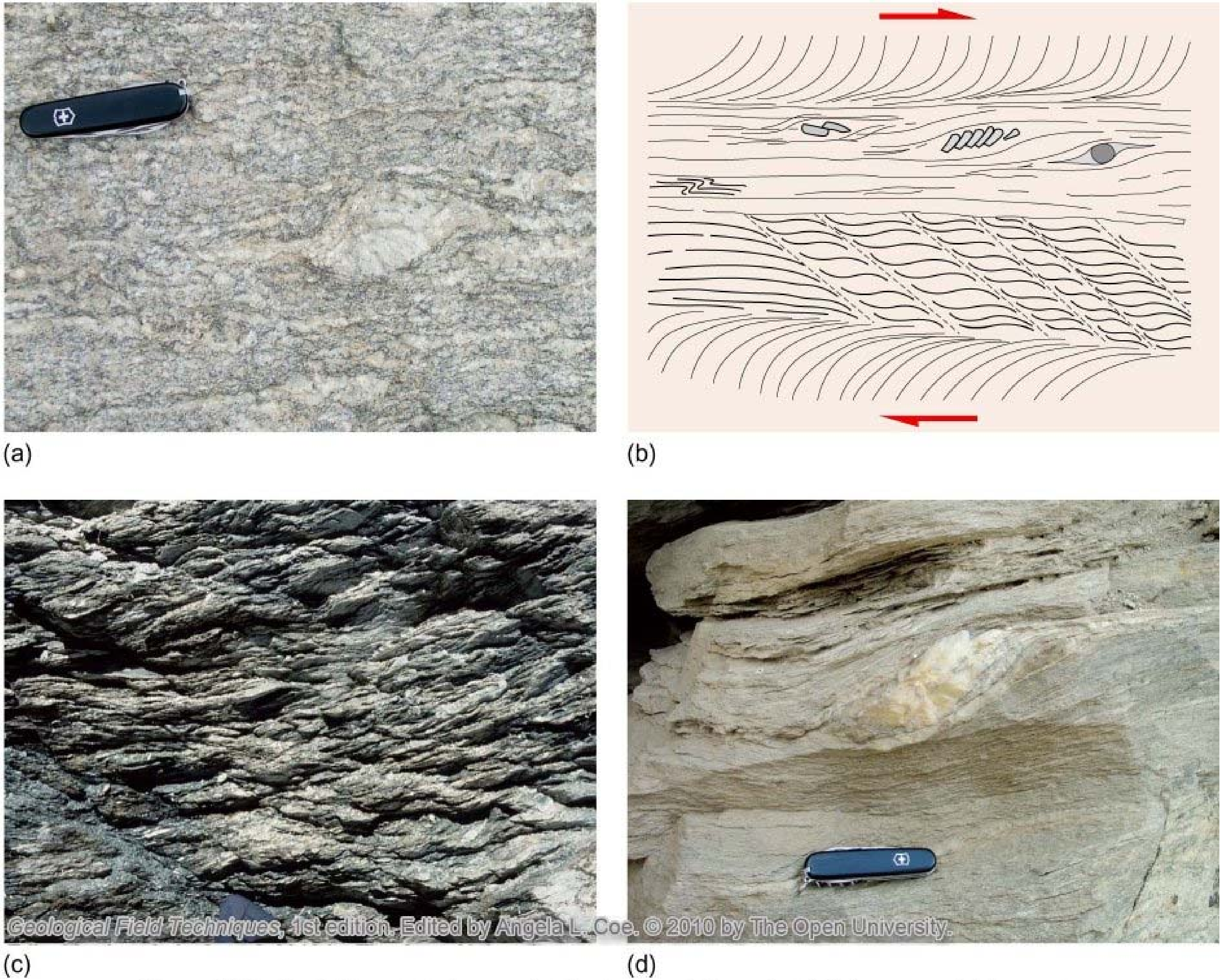


Figure 8.20 Ductile kinematic indicators, all indicating dextral ('top-to-the-right') shear sense. (a) Asymmetric tails on feldspar porphyroclasts in a mylonite, northwest India. (b) Composite sketch depicting various features used for determining shear sense (width *c.* 40 cm). (c) S-C fabric (shear band cleavage) in a mica schist, Switzerland. Camera case near the base is 25 cm across. (d) Asymmetric pressure shadows on a boudin in a gneiss, northwest India. (a, c and d: Tom W. Argles, The Open University, UK.)

(4) S-C 面理

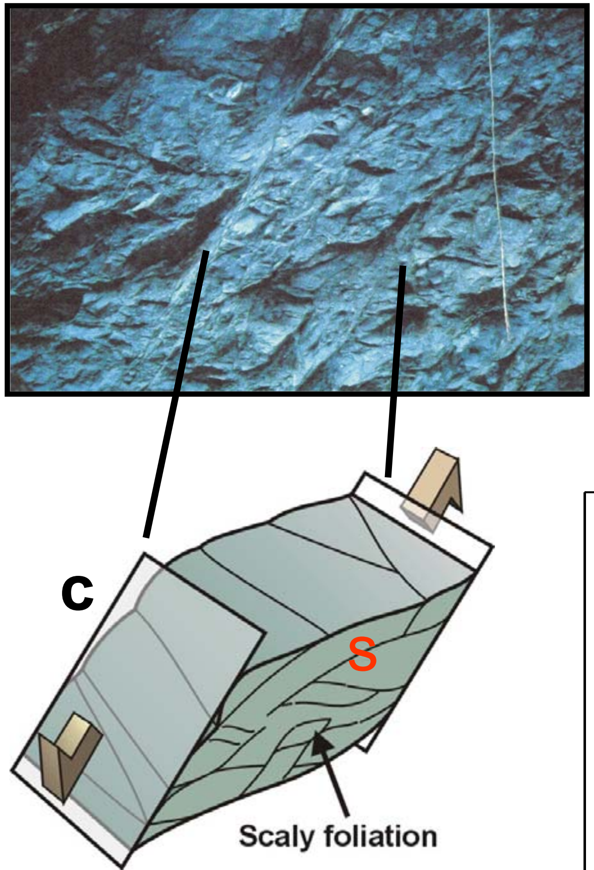
韌性剪切帶內常發育兩種面理。一種是平行於剪切帶內的總額應變橢球體的XY 面的剪切帶內面理(S)，在剪切帶內呈 S 形展布。另一種是糜稜岩面理(C)，它們實際上是一系列平行於剪切帶邊界的間隔排列的小型高度剪切應變帶。常由更細小的顆粒或雲母等礦物所組成。S 面理和 C 面理所交的銳夾角，指示剪切帶的剪切方向（ 圖 7.7D ）。隨著剪應變加大，剪切帶內面理(S)逐漸接近以致平行於糜稜岩面理(C)。

(5)“雲母魚”構造

“雲母魚”構造(mica-fish structrue)也稱 II 型 S–C 面理(S–C 面理稱 I 型面理)。此類構造大多發育於石英雲母片岩中，先存的雲母片，其中的(001)解理(mineral cleavage)處於不易滑動的情況下，在剪切作用過程中，與(001)解理斜交的方向上形成與剪切方向相反的微型犁式(listric)的正斷層，隨著變形的持續，上下雲母碎片發生滑移、分離和旋轉，形成不對稱的”雲母魚”（ 圖 7.7E ）。”雲母魚”兩端發育有細碎屑的層狀矽酸鹽類礦物和長石等組成的尾部。細碎屑的尾部將相鄰的”雲母魚”連接起來。形成一種臺階狀結構，是良好的運動學標誌。這種細碎屑的尾部代表强剪切應變的微剪切帶，它組成了 C 面理。與 S–C 面理一樣，其銳夾角指示剪切方向。此外，利用不對稱的”雲母魚”及其上的反向微型犁式正斷層也確定剪切方向（ 圖 7.7E ）。

楊昭男 (1995)

Shear band-geometry (S-C面理): Some shear-zone rocks contain small, subparallel, evenly spaced (at 1-10 cm intervals) shear zones. These small shear zones form within a larger host shear zone and deflect or cut schistose foliaiton. S-plane (S for schistosity) is the schistose foliation and C-plane (C for "cisaillement," the French word for shear) means the shear bands. C-planes are parallel to the shear-zone boundaries, and the S-planes are inclined to the shear-zone boundaries. S-planes dip away from the direction of shear and curve into shear bands, thereby creating a sigmoidal pattern of foliation that gives shear sense.



Chang et al. (2003)
張中白教授提供

Scaly foliation associated with shear deformation in the argillaceous matrix

墾丁層

McClay (1987)

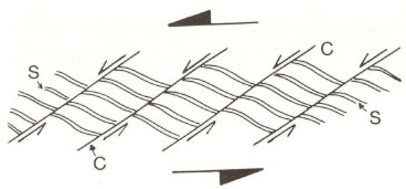


Fig. 6.26a The geometry of C and S fabrics as seen in shear zones. The C plane is the shear plane and S is the schistosity plane. The C plane has an extensional geometry with respect to the sense of shear. (Fig. 6.26b on p. 112)

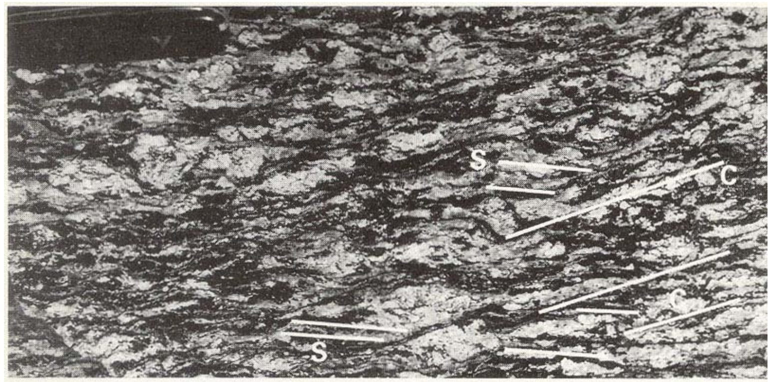


Fig. 6.26b C and S fabrics in a mylonitic granite. A sinistral sense of shear is indicated. C is the shear plane and S is the schistosity plane. (Fig. 6.26a on p. 111)

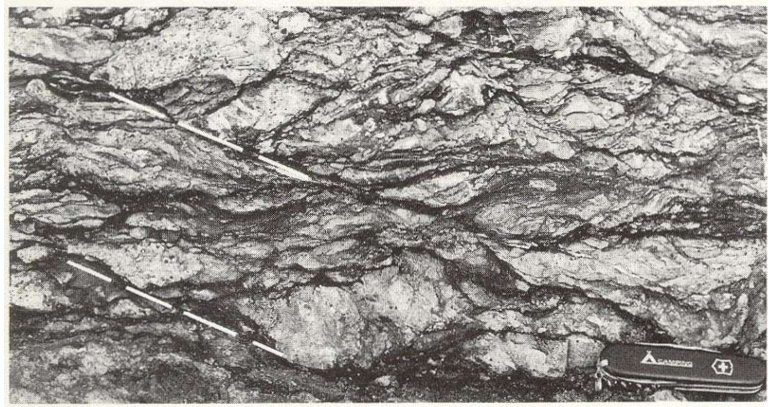
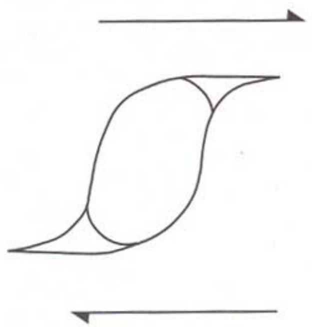


Fig. 6.27b Low-angle shear bands developed in strongly foliated melange (foliation horizontal). (Fig. 6.27a on p. 111)

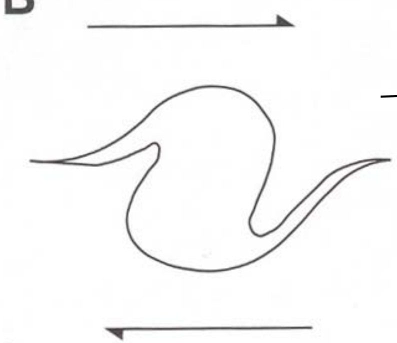
(6)旋轉斑晶系

在糜稜岩中的韌性基質剪切流動的影響下，碎斑及其外緣較弱的動態重結晶的集合體或細碎粒會發生旋轉，而改變其形狀，形成不對稱的具有楔形尾巴的旋轉斑晶系(rotated porphyroblasts)。根據斑晶尾巴的形狀，可分辨 σ 型和 δ 型兩類 (圖 7.8A 、 B) 。σ 型斑晶系的楔狀尾巴的中線分別位於斑晶尾參考面 (圖 7.8A 中的 x) 的兩側。δ 型斑晶系的尾巴細長，根部彎曲，在與斑晶連接部位的基質呈港灣狀，斑晶兩側尾巴的發育都是沿中線由參考面的一側穿過參考面至向另一側。斑晶的尾巴的尖端指示剪切帶的剪切方向。如果尾巴太短，則不能用來確定剪切方向。

A σ- structure



B δ- structure



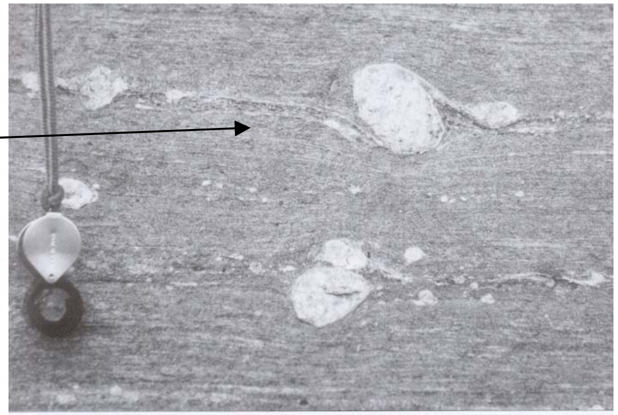
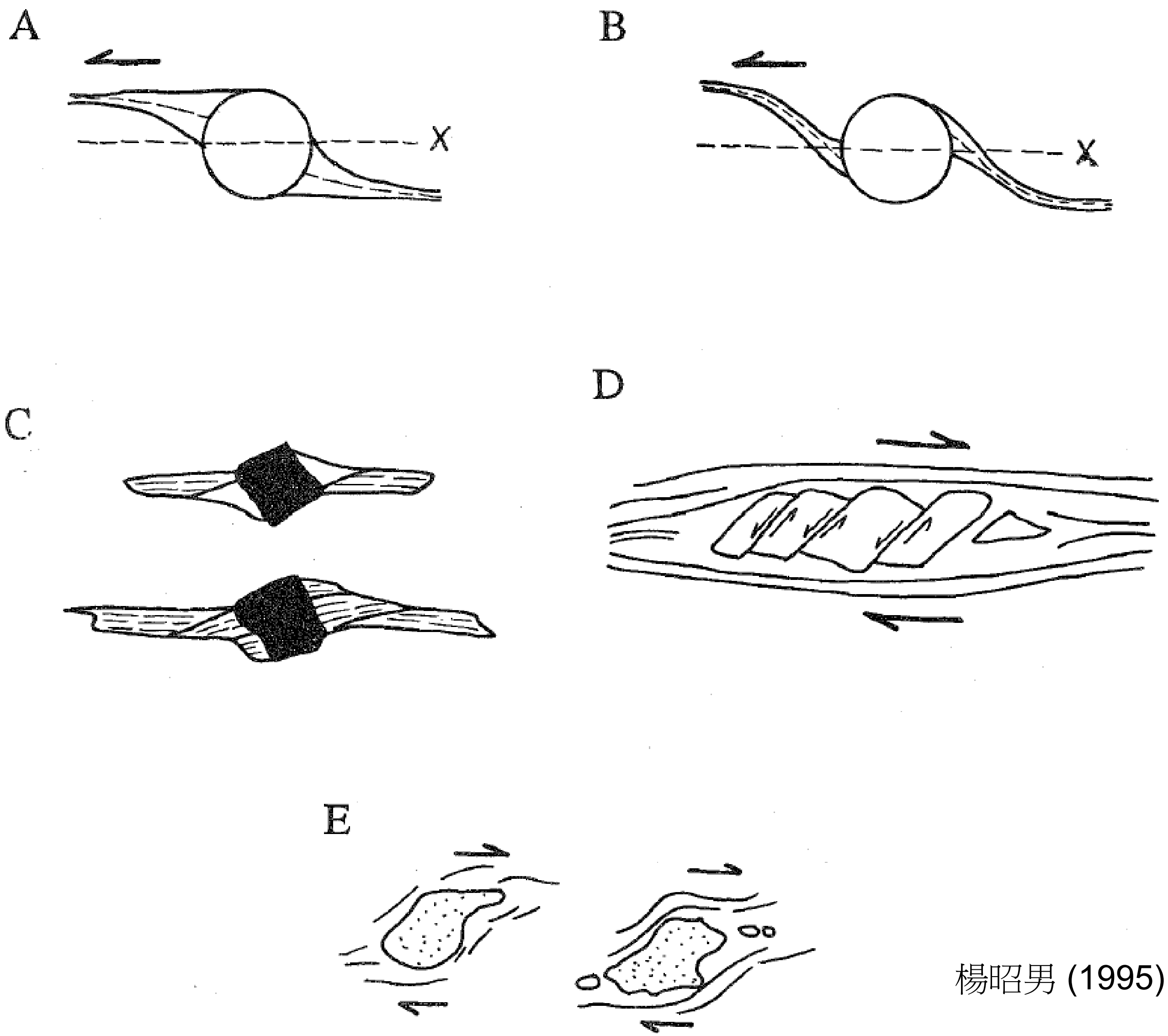


Figure 34.35. Rotated elliptical feldspar porphyroclasts in a fine grained gneiss showing δ-structure as the result of anticlockwise rotations in a shear zone of left-hand shear sense, Grenville Front, Ontario, Canada.

Marshak et al. (1988)

Ramsay & Lisle (2000) The Techniques of Modern Structural Geology: Volume 3: Applications of Continuum Mechanics in Structural Geology. Academic Press.



楊昭男 (1995)

圖 7.8　指示剪切運動方向的各種標誌：(A)旋轉碎斑系 σ 型；(B)：旋轉碎斑系 δ 型；(C)：不對稱的壓力影；(D)：骨牌構造；(E)：曲頸狀構狀。

(7)不對稱的壓力影

韌性剪切帶的壓力影構造(pressure shadow)都呈不對稱狀，堅硬單體兩側的纖維狀的結晶尾呈單斜對稱，據此可以確定剪切方向（ 圖 7.8C ）。

(8)骨牌(domino)構造

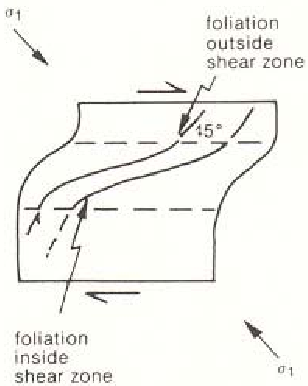
糜稜岩中的較强硬的碎斑(如長英質糜稜岩中的長石碎斑)。在漸進剪切作用下，產生破裂並旋轉，使每個碎片向剪切方向傾斜，尤如一疊骨牌被推倒，形成類似骨牌構造(domino structrue)。其裂面與剪切帶的銳夾角指示剪切帶的剪切指向（圖 7.8D ）。

(9)曲頸狀構狀

糜稜岩中的碎斑或礦物集合體、侵入岩體中的捕虜體等，在漸進剪切作用下，使其一側被拉長（ 或拉斷 ），形成曲頸瓶狀。曲頸彎曲方向表示剪切帶的剪切方向（ 圖 7.8E ）。

除上述各種構造外，還有其它指示運動方向的標誌，如石英和方解石的 C 軸組構的不對稱性也能表示剪切指向。有關這方面的內容在岩石組構學中有詳細的介紹。

Data to be collected from observations on ductile shear zones

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
Ductile shear zone 	Orientation of shear zone boundaries (Figs. 6.21 & 2.5–2.8). Orientation of foliations at shear zone boundaries. (Fig. 6.21) Orientation of lineations in shear zone (ML). (Figs. 2.11 to 2.14)	Nature of shear zone. (Fig. 6.21a) Width of shear zone. Nature of foliation. (Figs. 4.1, 4.2) Sense of shear.(Figs. 6.21, 6.26, 6.27) Displacement.	Stress systems. (Fig. 6.21a) Strain distribution. Sense of shear. (Fig. 6.21a, 6.26, 6.27) Displacement. Deformation processes.
	Orientation/vergence of folds in shear zone. (Fig. 3.9)	Nature of folds/vergence. (Fig. 3.9)	
	Strain of deformed objects across shear zone. (Appendix III)	Strain in deformed objects. (Appendix III) Photograph/sketch of shear zone.	
	(Additional data on orientation of structures outside shear zone).	Structure outside shear zone.	
	Orientation data on conjugate array. (Fig. 6.22)	Observations on conjugate array. (Table 6.5)	Stress systems. (Fig. 6.21a) Strain distribution. Sense of shear. (Fig. 6.21a, 6.26, 6.27) Displacement. Deformation processes.

McClay (1987)

Faults zones

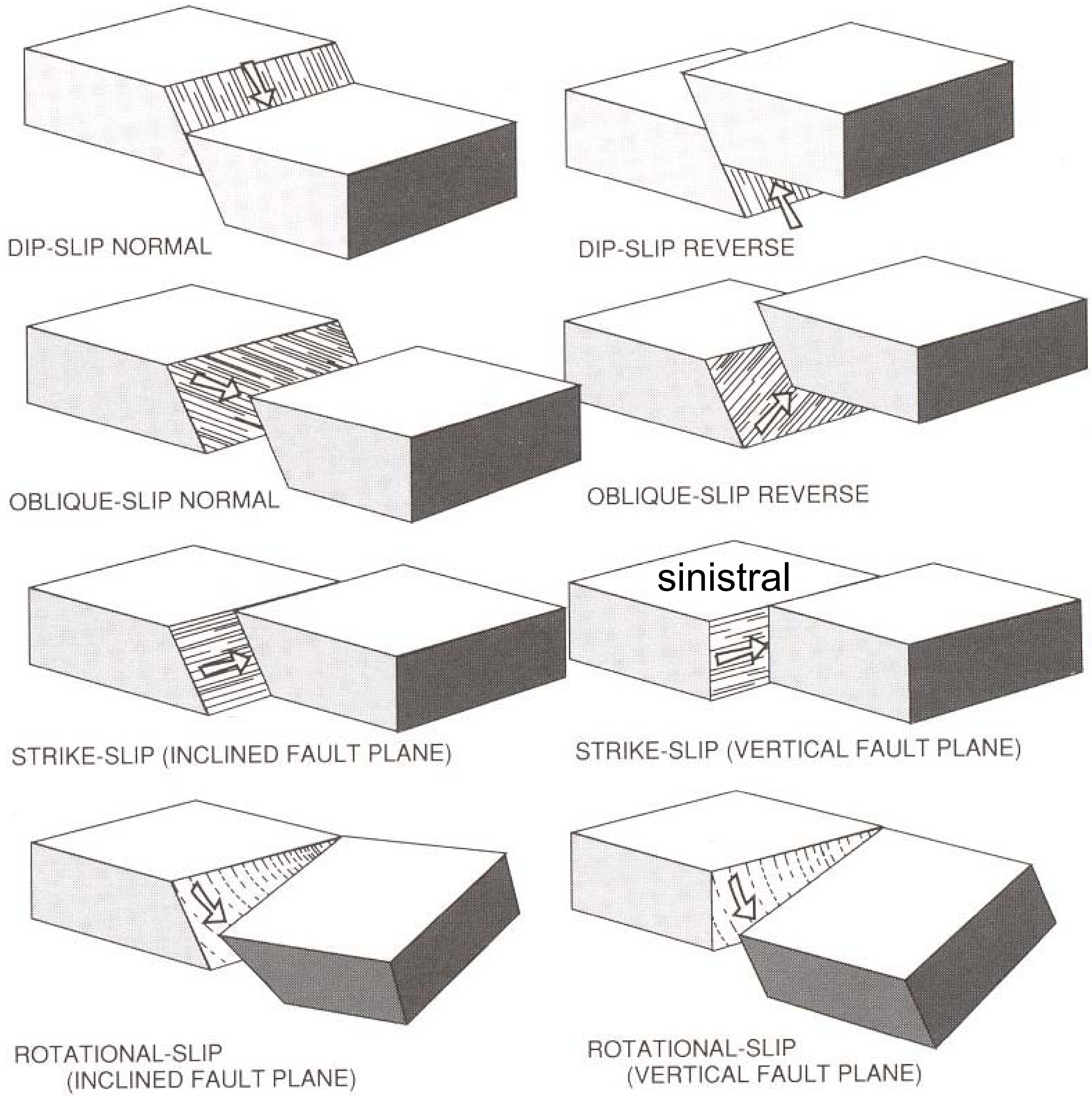
Different kinds of faults

Dip-slip faults

Oblique-slip faults

Strike-slip faults

Scissors fault



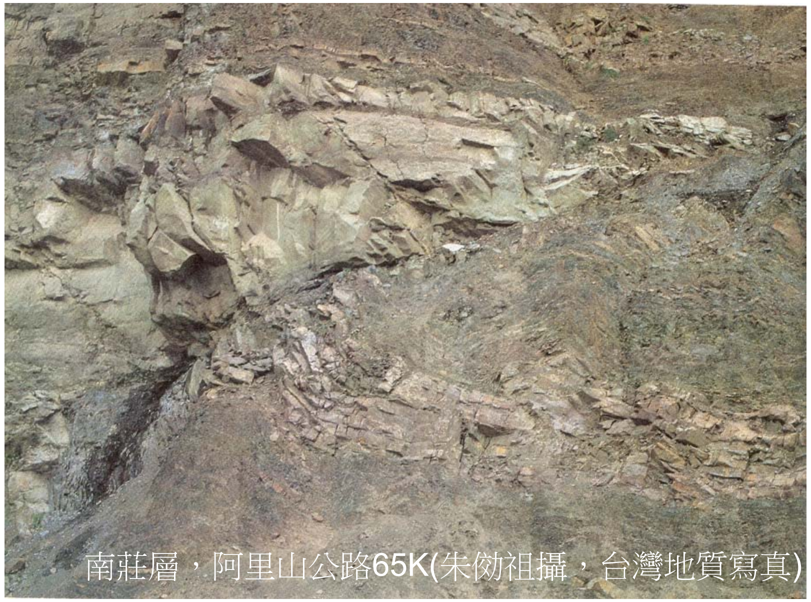
Powell (1992)

Descriptive terms for faults and fractures

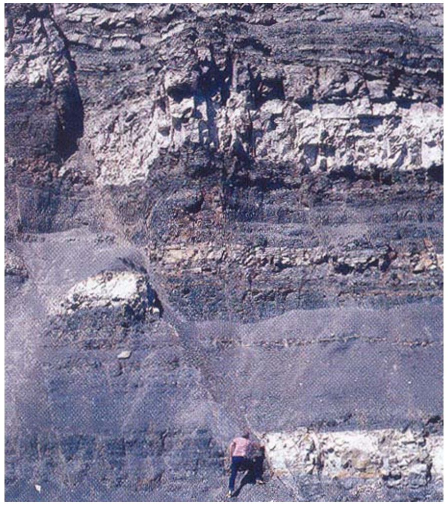
Horizontal faults	Faults with a dip of about 0°; if the fault has a dip between about 10° and 0° it is called *subhorizontal*.
Listric faults	Faults that have a steep dip close to the Earth's surface are and have a shallow dip at depth; because of the progressive decrease in dip with depth, listric faults have a curved profile that is concave up.
Moderately dipping faults	Faults with dips between about 30° and 60°.
Shallowly dipping faults	Faults with dips between about 10° and 30°; these are also known as *low-angle faults*.
Steeply dipping faults	Faults with dips between about 60° and 80°; these faults are also called *high-angle faults*.
Vertical faults	Faults that have a dip of about 90°; if the dip is between about 80° and 90° the fault can be called *subvertical*.

Reverse faults

Thrust Fault, Wyoming (Photograph by Kurt N. Constenius)
Thrust fault and repeated sedimentary layers in Ram's Horn Peak, Hoback Range, Wyoming. Repeated sections of the red-brown Jurassic Nugget Sandstone over younger, gray, Jurassic Twin Creek Limestone show evidence of large-scale lateral movements along thrust faults.



Normal faults

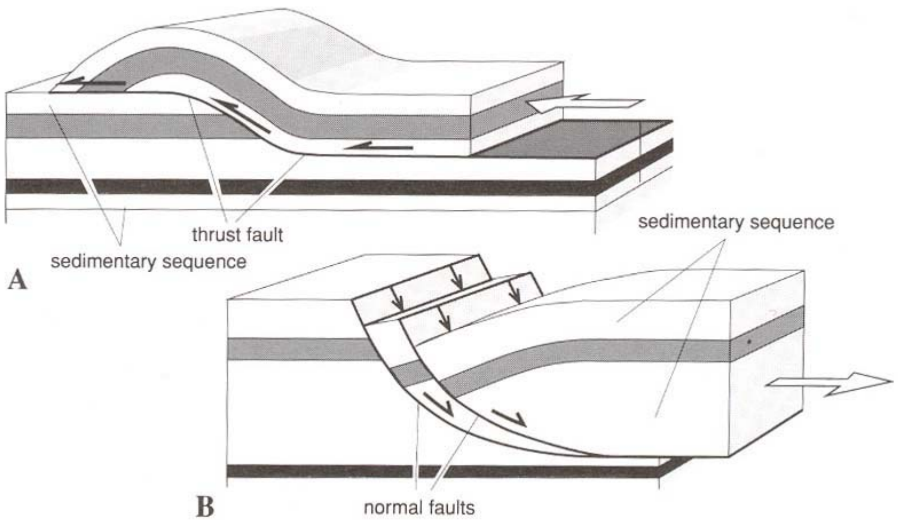


Hamblin & Christiansen (2001)

View is 10 m in width

McClay (1987)

Listric thrust faults



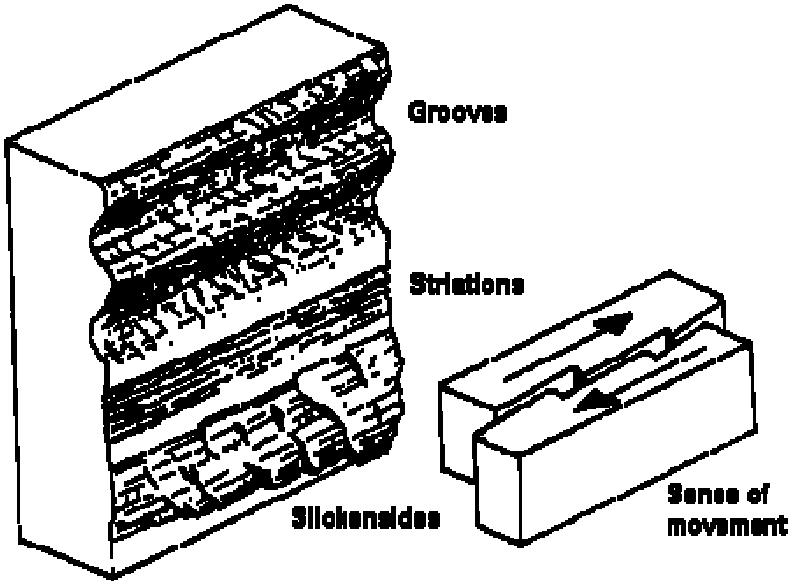
Powell (1992)

Listric normal faults

Dextral strike-slip fault

Kinematic indicators in fault zones

Only slickensides provide evidence of the sense of movement. The asymmetric surface roughness features are steepest downhill or down the shear direction.



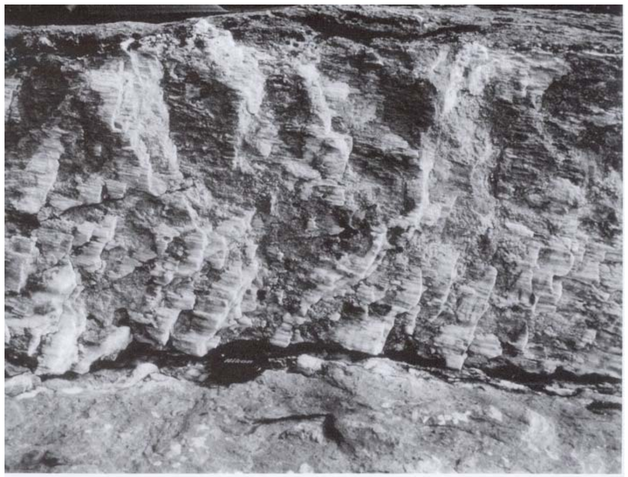


Figure 32.1. A steeply dipping fault surface at Ogmore-by-Sea, South Wales. The slickenfibre lineations provide information on the direction of fault slip. The stepped geometry of the calcite fibres indicates a sinistral sense of movement. Such data on the orientations of fault planes and of the associated lineations permit the estimation of palaeostresses.

Ramsay & Lisle (2000)

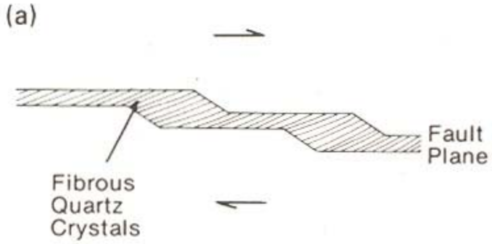


Fig. 5.6a Slickensides developed as fibrous crystals of quartz joining opposite sides of a stepped fault plane.

Fig. 5.6b Slickensides of fibrous quartz in sandstones. The movement direction is up in the photograph.

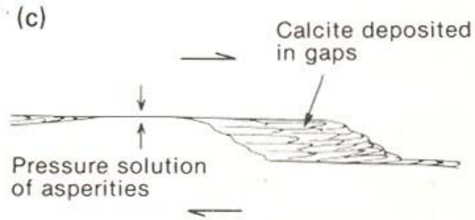
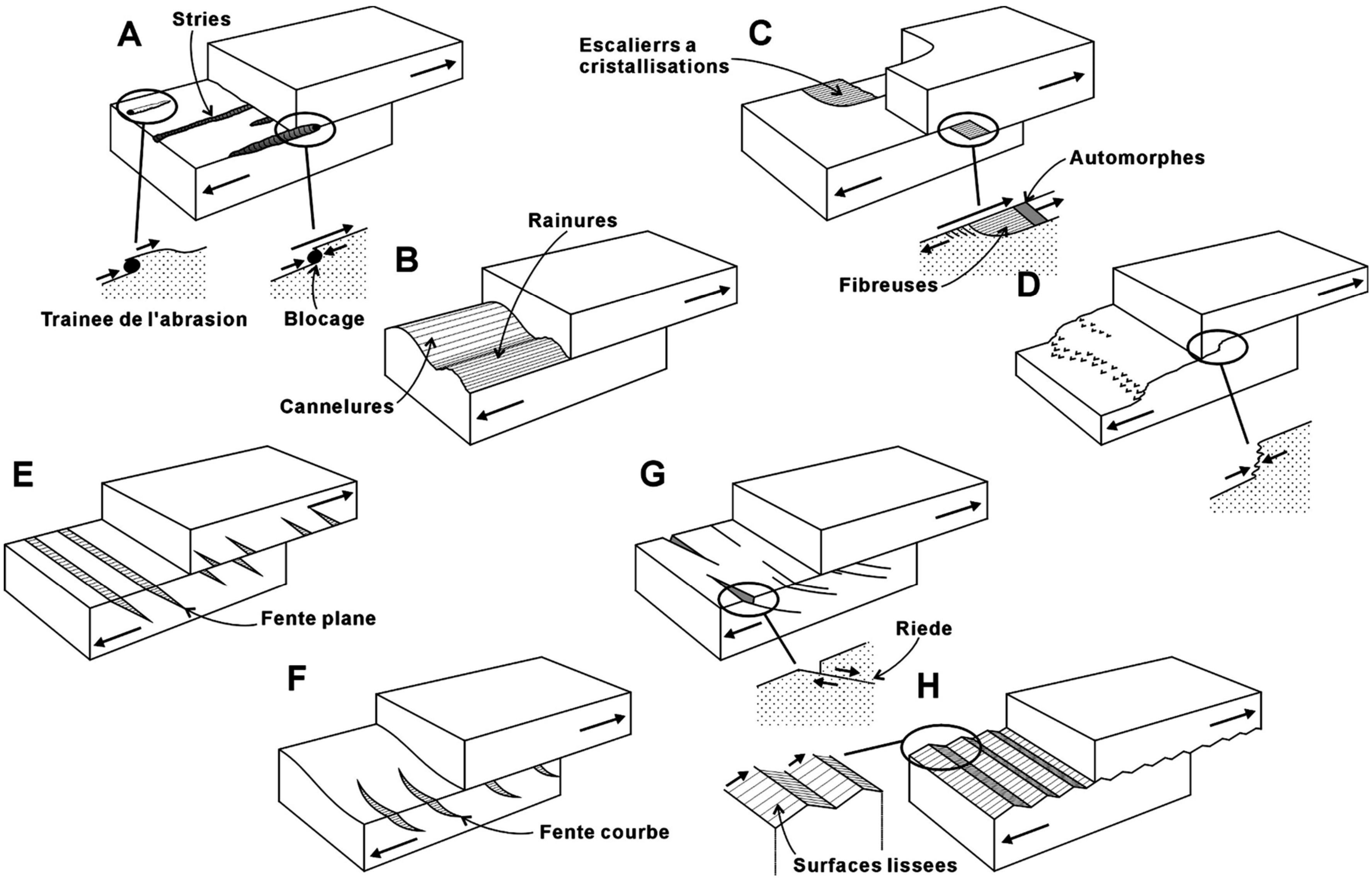


Fig. 5.6c Slickolites developed in limestones by pressure solution which removes the bumps (asperities) in the fault surface, and redeposits the calcite in the spaces between the stepped fault surfaces.

Fig. 5.6d Grooving on a fault plane in limestones.

McClay (1987)

Fault surfaces displaying the direction of slip lineation



Courtesy of Chung-Pai Chang

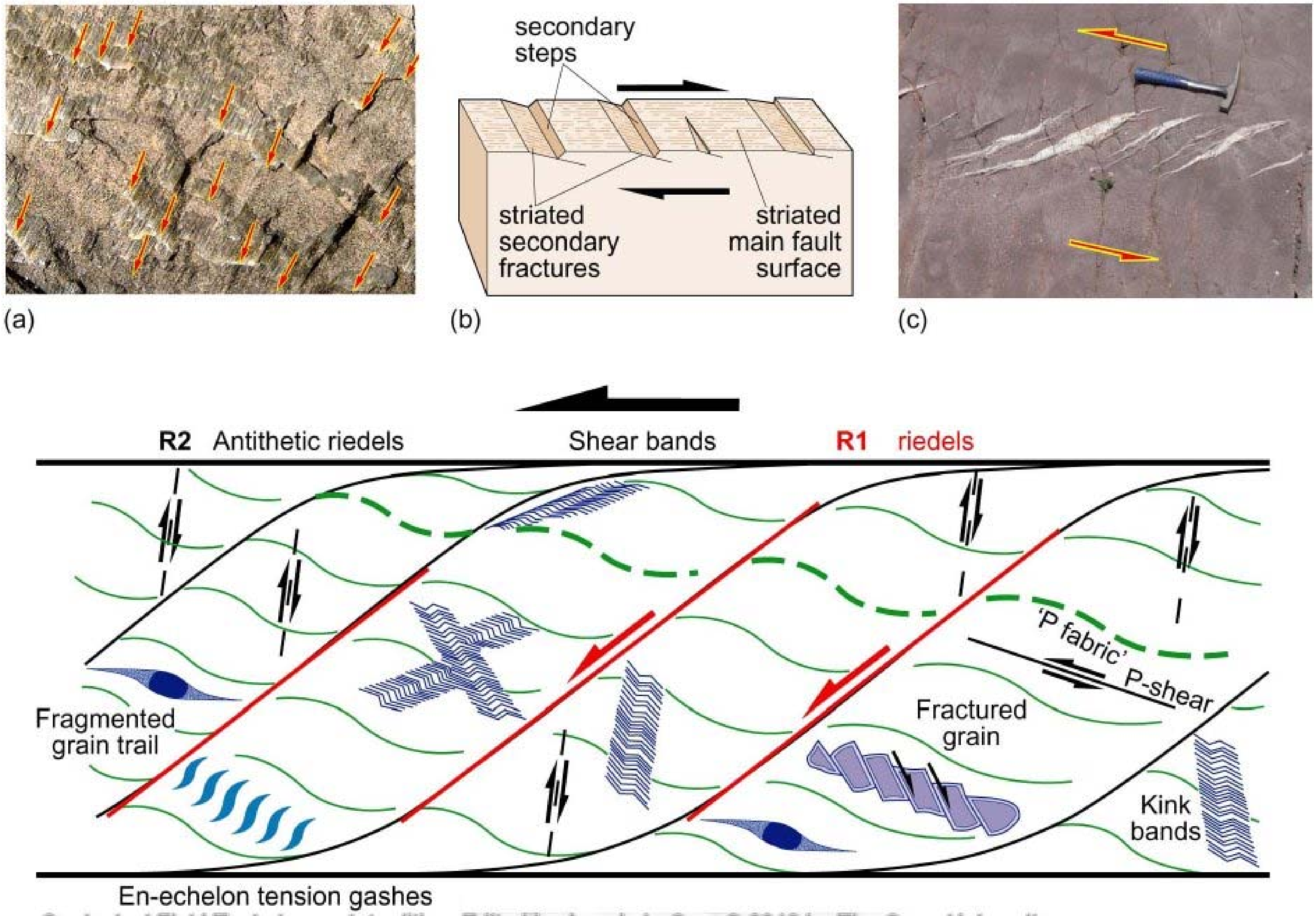
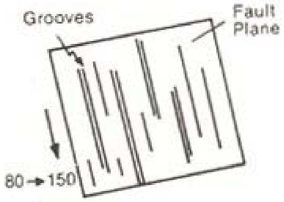
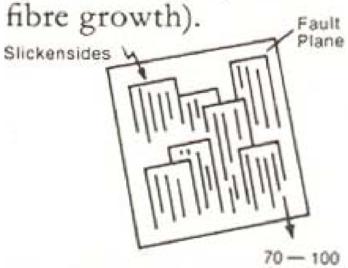
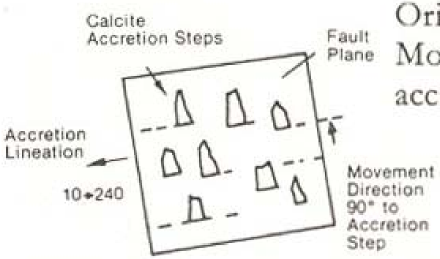


Figure 8.9 (a) Arrows mark individual steps and indicate slip direction of the missing block on this slickenside in southwest Wales, UK. Field of view 6 cm across. (b) Secondary fractures may develop that produce a stepped effect opposite to that in (a). (c) The pattern of en échelon vein arrays indicates relative shear sense, confirmed in this example by the deflection of dark solution seams through the shear zone that caused vein formation (southwest Wales, UK). (d) Some features within a wider shear zone that can be used to diagnose sense of shear (Riedel fractures, antithetic Riedel fractures, gouge fabrics, broken clasts). (a and c: Tom W. Argles, The Open University, UK.)

Data collected on lineations associated with fault surfaces

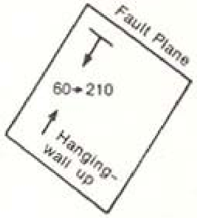
Structure	What to measure	What observations to record	Results of analysis
Grooving (no crystal fibre growth). 	Plunge of lineation. Orientation of fault surface. Orientation of displaced units	Nature of grooving. Fault rocks. Sense of movement from steps in fault plane. Width of fault zone. Displacement. Stratigraphic separation.	Sense and direction of movement of fault (solutions for exact displacements are not common).
Slickensides (crystal fibre growth). 	Plunge of lineation. Orientation of fault surface. Orientation of displaced units	Nature of fibre growth. Sense of movement from fibres and steps in fault plane. Fault rocks. Width of fault zone. Displacement. Stratigraphic separation.	Sense and direction of movement of fault (solutions for exact displacements are not common).
Slickolites 	Plunge of lineation. Orientation of fault surface. Orientation of displaced units Movement direction 90° to accretion steps.	Nature of fibre growth. Sense of movement from fibres and steps in fault plane. Fault rocks. Width of fault zone. Displacement. Stratigraphic separation.	Sense and direction of movement of fault (solutions for exact displacements are not common).

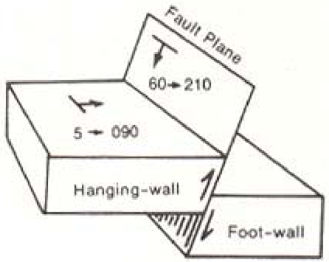
McClay (1987)

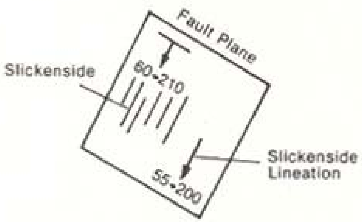
Data to be collected from contractional faults

Table 6.2 Data to be collected from contractional faults.

McClay (1987)







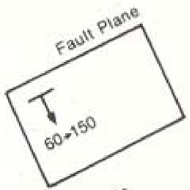
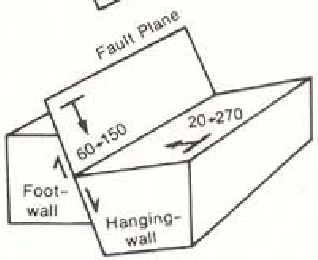
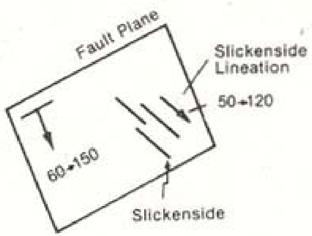
Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
	Orientation of fault plane (dip direction) (Figs. 2.5–2.8).	Nature of fault plane: fault rocks. (Fig. 6.18, Table 6.4) Curvature/stepped nature of fault plane? Width of fault zone. (Fig. 6.11)	Deformation processes. Listric/planar/stepped fault. (Fig. 6.11a)
	Orientation of displaced units on both sides of fault (Figs. 2.5–2.8).	Stratigraphic separation/overlap. Sense of movement. Sense of shear.	Displacement direction. (Fig. 5.6) Minimum slip. Amount of contraction.
	Lineations on fault plane: grooving, slickensides, slickolites (Figs. 2.4–2.13, 5.6 and 6.4).	Nature of lineations on fault plane (fibrous slickensides?). (Table 5.3) Movement sense. (Fig. 5.6)	Movement direction. (Fig. 5.6)
		Relationships to other faults. Cross-cutting relationships: Imbricate fan? duplex? out of sequence? Ramps? Associated folding. (Figs. 6.11a and 3.13)	Fault sequences. Kinematic development.
	Orientation data on synthetic structures: faults and fractures (Figs. 2.5–2.8, 2.11–2.13),	Nature of synthetic structures. Movement directions. (Fig. 5.6)	Fault systems. Movement patterns. Stress systems. (Fig. 6.1)
	Orientation data on antithetic structures: faults and fractures (Figs. 2.5–2.8, 2.11–2.13).	Nature of antithetic structures. Movement directions. (Fig. 5.6)	Fault systems. Movement patterns. Stress systems. (Fig. 6.1)

McClay (1989)

Data to be collected from extensional faults

Table 6.1 Data to be collected from extensional faults.

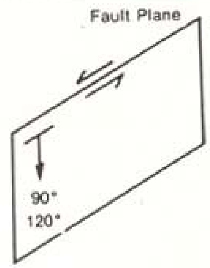
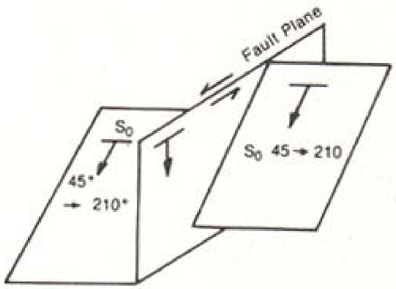
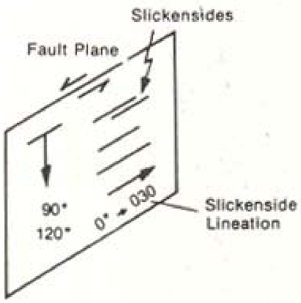
McClay (1987)

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
	Orientation of fault plane (dip direction) (Figs. 2.5–2.8).	Nature of fault plane: fault rocks. Curvature of fault plane? Width of fault.	Deformation processes. Listric/planar faulting. (Fig. 6.8)
	Orientation of displaced units on both sides of fault (Figs. 2.5–2.8).	Stratigraphic separation. (Fig. 6.2) Sense of movement. Sense of shear.	Displacement direction. (Fig. 6.6) Minimum slip. Amount of extension.
	Lineations on fault plane: grooving, slickensides, slickolites (Figs. 2.10–2.13; Figs. 5.6 & 6.4).	Nature of lineations on fault plane (fibrous slickensides?). (Table 5.3) Movement sense. (Fig. 5.6)	Movement direction. (Fig. 5.6)
		Relationship to other faults. Cross-cutting relationships. Associated folding. (Fig. 3.13)	Fault sequences. (Fig. 6.8) Kinematic development.
	Orientation data on synthetic structures (Fig. 6.8c): faults and fractures (Figs. 2.5–2.8; 2.11–2.13).	Nature of synthetic structures. Movement directions. (Fig. 5.6)	Fault systems. (Fig. 6.6) Movement patterns. Stress systems. (Fig. 6.1)
	Orientation data on antithetic structures (Fig. 6.8c): faults and fractures (Figs. 2.5–2.8, 2.11–2.13).	Nature of antithetic structures. Movement directions. (Fig.5.6)	Fault systems. (Fig. 6.6) Movement patterns. Stress systems. (Fig. 6.1)

Data to be collected from wrench faults

McClay (1987)

Table 6.3 Data to be collected from wrench faults.

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
	Orientation of fault plane (dip direction) (Figs. 2.5–2.8 and 6.1).	Nature of fault plane fault rocks. (Fig. 6.18 and Table 6.4) Width of fault zone.	Deformation processes.
	Orientation of displaced units on both sides of fault (Figs. 2.5–2.8).	Movement direction. (Fig. 5.6) Sense of shear.	Displacement direction. (Fig. 5.6) Amount of slip/offset.
	Lineations on fault plane: grooving, slickensides, slickolites (Figs. 5.6, 6.4; 2.11–2.13).	Nature of lineations on fault plane (fibrous slickensides?). (Table 5.3) Movement sense. (Fig. 5.6)	Movement direction. (Fig. 5.6)
		Relationships to other faults. Cross-cutting relationships. Associated folding.	Fault sequences. (Figs. 6.16 and 6.19) Kinematic development. (Fig. 6.16a)
	Orientation data on synthetic structures Riedel shears R_1, R_2, P shear (Fig. 6.16a). Second and third order faults Associated folds (Fig. 6.16a).	Nature of synthetic structures. (Fig. 6.16a) Movement directions. (Fig. 5.6)	Fault systems. (Fig. 6.16a) Movement patterns. (Fig. 6.16a) Stress systems. (Fig. 6.16a)

Fault array analysis

Fault array (two or more fault sets) analysis: In addition to attitude data on fault arrays, a description of an array should also provide information on the size of faults, spacing of faults, the magnitude of displacement on individual faults, and the character of the fault surface, the relationship of the fault array to other structures (e.g., folds and larger faults)

Communicate information on slip direction and shear sense on a fault array:

Rake (pitch) histogram: plotting rakes of slip lineations on an array of faults on a histogram. The vertical axis represents number of measurements and the horizontal axis represents rake in class interval of 5-10 degree. If the majority of slip lineations have low rakes, for example, then the fault array is composed of strike-slip fault.

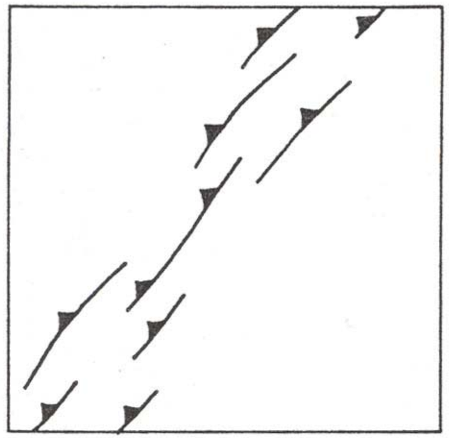


Figure 12-13. Sketch map of a relay array of thrust faults.

Marshak et al (1988)

Annotated equal-area plot: The orientation of a fault on an equal-area plot can be represented by the orientation of the pole to the fault. Use symbols to represent different fault types (e.g., e: extensional faults, c: contractional faults, n: normal faults, r: reverse faults, s: strike-slip fault.

Slip-linear Plot

An equal-area plot on which the symbol for the pole to a fault plane is decorated by a line that indicates direction of slip, or an arrow that indicates the direction and sense of slip. Good for representing the kinematics of a fault array.

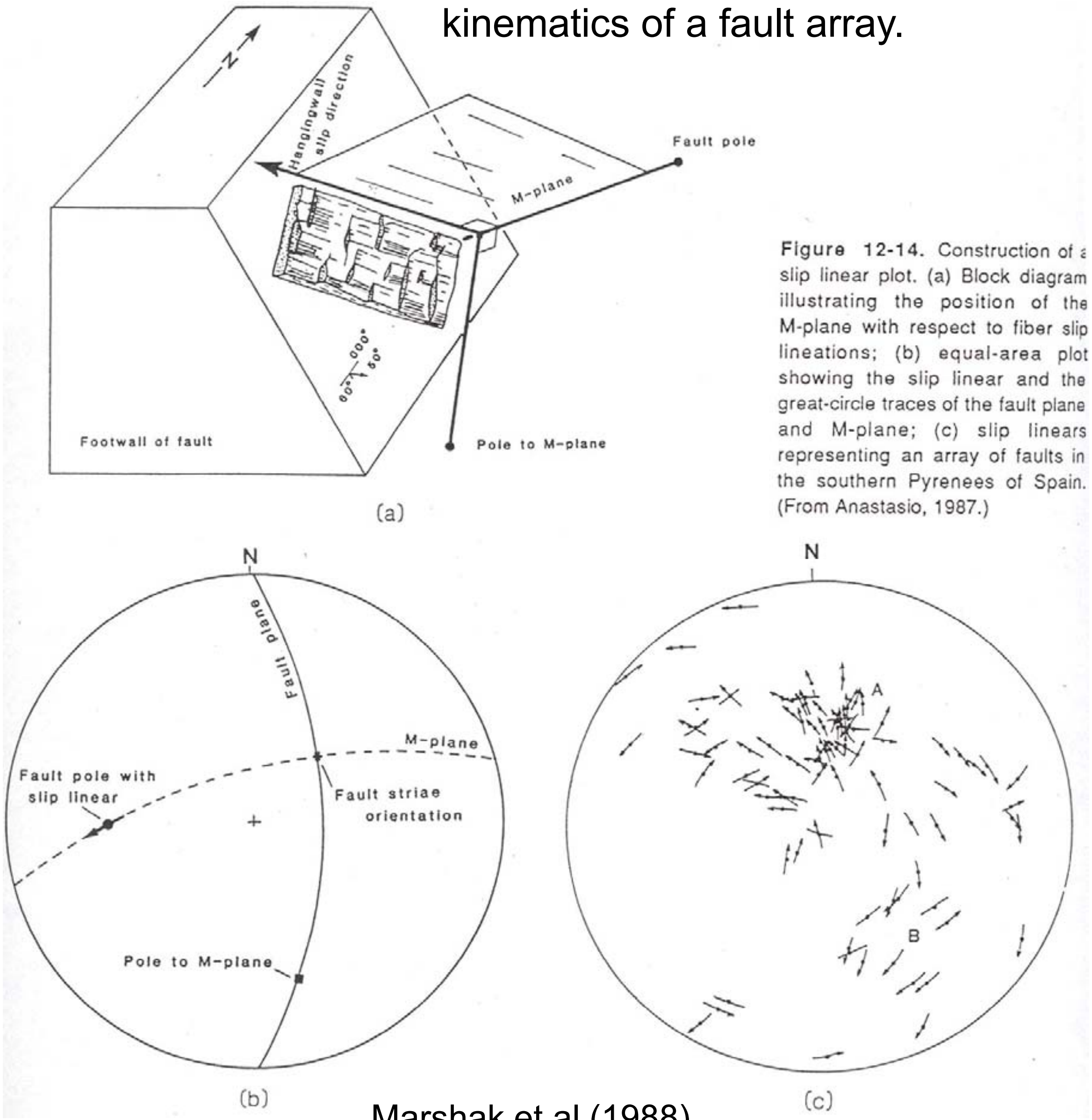


Figure 12-14. Construction of a slip linear plot. (a) Block diagram illustrating the position of the M-plane with respect to fiber slip lineations; (b) equal-area plot showing the slip linear and the great-circle traces of the fault plane and M-plane; (c) slip linears representing an array of faults in the southern Pyrenees of Spain. (From Anastasio, 1987.)

Marshak et al (1988)

If a large number of slip linears from faults in a region are plotted on a single equal-area plot, the diagram graphically indicates the kinematics of movement on the array. In general, radial slip linears indicate dip-slip faults and arrows parallel to the primitive are strike-slip.

For example, there are two clusters (A and B) of slip linears shown in the diagram (Fig. 12-14c).

Cluster A: faults dip to the south, movement of the hanging-wall block is directly up-dip, so these faults are reverse faults.

Cluster B: Faults dip steeply to the northwest, movement of the hanging-wall block is mainly toward the southwest, so these faults are strike-slip faults.

Exercise: Construction of a slip-linear plot

A fault is orientated 000°, 60°E. Slip fibers on the fault plunge 50° in a northeasterly direction. The hanging wall of the fault moved relatively up dip. Construct a slip-linear plot representing this fault.

Method:
Step 1: Refer to the figure on the preceding page. This figure shows a fault coated with imbricate slip fibers that give the direction and sense of movement. Visualize the problem; the fault is an oblique-slip fault with a component of reverse motion.
Step 2: On an equal-area diagram (Fig. 12-14b), plot the great-circle trace representing the fault plane, the pole to the fault plane, and the point representing the plunge and bearing of the slip fibers.
Step 3: Construct a plane, called M-plane ("M" stands for "movement"), which contains the slip fiber lineation and the pole to the fault plane. At the point representing the pole to the slip plane, draw a short line segment along the great-circle trace of the M-plane. This line segment is the slip linear representing the direction of slip on a fault.

Step 4: If the sense of movement on the fault is known, an arrow can be added to the line segment indicating the relative movement of the hanging-wall block. In this example, the hanging-wall block moved toward the southwest, so the slip linear points toward the southwest.
Step 5: To interpret an arrow on a slip linear, you must keep in mind the orientation of the fault plane (indicated by the pole position) as you look at the line segment or arrow. From just the slip linear in Figure 12-14b, we know that fault plane dips moderately to the east and that the hanging-wall block moved up and to the southwest. Therefore, we immediately know that it is an oblique-slip fault on which there has been a component of right-lateral shear and a component of reverse shear.

Determination of principal stress directions from fault arrays

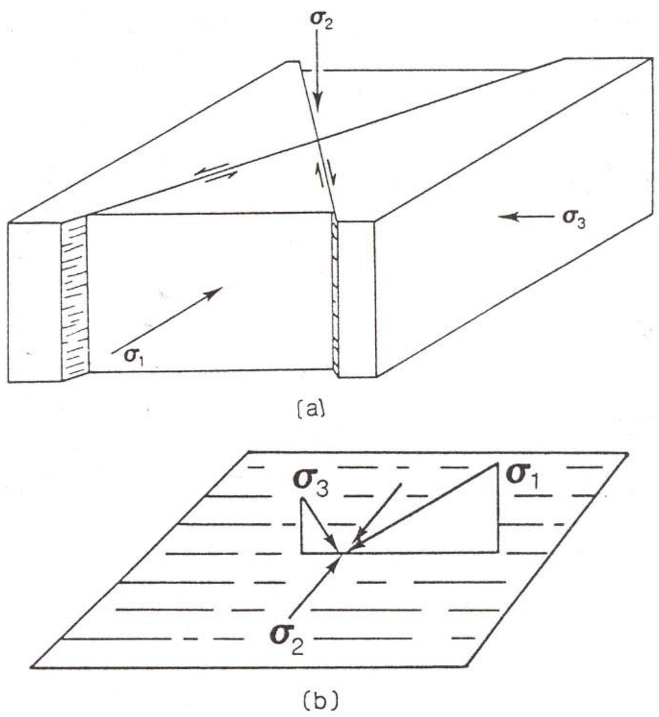


Figure 12-15. Ideal orientations of fault planes with respect to principal stresses. (a) Block diagram showing the orientation of principal stresses with respect to two conjugate strike-slip faults; (b) diagram showing principal stresses with respect to slip lineations on a single fault plane.

Marshak et al (1988)

Stereographic plots showing directions of movement and principal stress direction

Anderson theory of faulting: assumes that σ_2 lies in the plane of fault, and that σ1 is oriented at 30°-45° to the fault, and σ3 is oriented at 45°-60° to the fault; the configuration of the three principal stresses with respect to the surface of the earth determines whether the fault initiates as normal, thrust, or strike-slip.

Exercise: Determination of principal stress directions from a conjugate fault array.

Two fault sets are observed in a region. Set A is oriented N88°W, 40°NE and has slip lineations oriented 26°, N56°E. Set B is oriented N44°W, 82°SW and has slip lineations oriented 61°, S30°E. What were the orientations of the principal stresses which produced these fault sets?

Method:
If the faults define a simple conjugate array, then σ1 bisects the acute angle of intersection, σ2 is parallel to the intersection of the two sets, and σ3 bisects the obtuse angle of intersection.

Step 1: Plot the faults as great circles on an equal-area net (Fig. 12-16). Plot the slip lineations as lines (La and Lb) that lie in the fault planes.

Step 2: Construct a great circle perpendicular to the intersection of the two fault sets. This great circle is oriented N42°E, 62°SE. The slip lineations should lie on or near to this great circle. If they do not, then the fault geometry is not truly conjugate.

Step 3: By counting along the great circle drawn in Step 2, find the acute bisectrix of the two fault sets. This line, which is 53°, N86°E, gives the orientation of σ1.

Step 4: Along the same great circle, find the obtuse bisectrix of the two fault sets. This line, which is 23°,S29°W, is the orientation of σ3.

Step 5: The line of intersection between the two fault sets gives σ2.

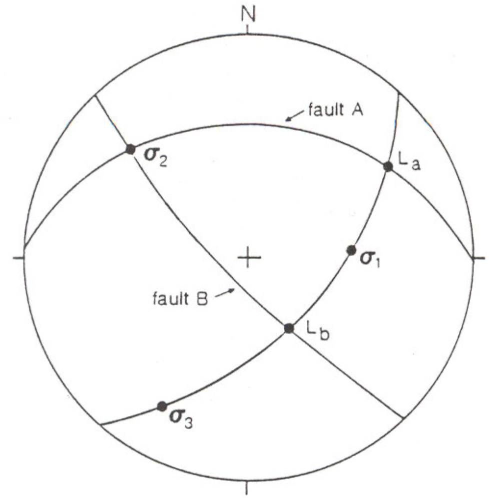


Figure 12-16. Equal-area plot showing estimation of principal stresses from data on two faults of a conjugate system. L_a and L_b are slip-lineation attitudes.

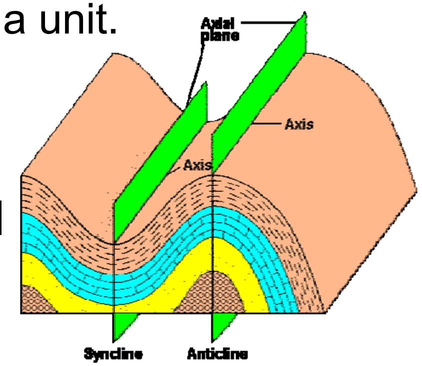
Marshak et al (1988)

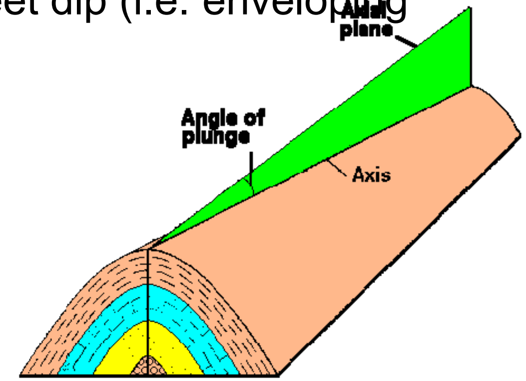
3.5.5 Fold structures

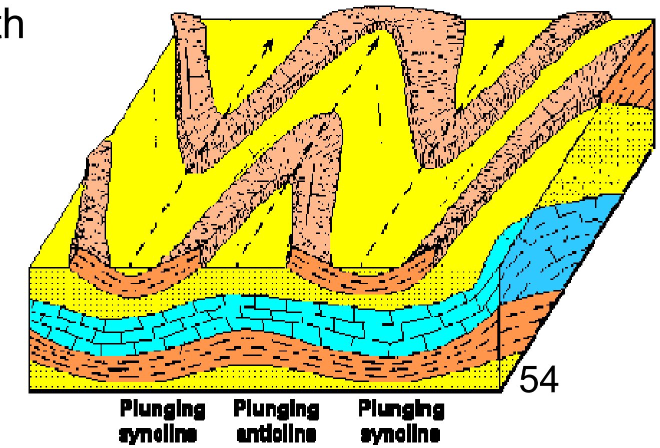
Basic fold nomenclature:

1. **Fold axis** (or **fold hinge line**): the line of maximum curvature on the folded surface; If the fold-axis is inclined to the horizontal, the "dip" of the axis is called the **plunge**. Plunging folds are the rule rather than the exception.
2. **Fold axial plane**: the plane containing the fold axis within a particular fold. Many fold axial planes are curved – not planar, and the term "**axial surface**" is preferable.
3. A fold is **symmetric** if the limbs either side of the axial plane are of equal length, and the fold is **asymmetric** if they are not.
4. A fold is **cylindrical** if it has the same shape in the profile plane at all points along the fold axis. A **non-cylindrical** fold has a varying profile shape along the fold axis.
5. **Enveloping surface** for a series of folds. The enveloping surface is drawn tangential to the fold hinges (or through the inflexion points) of a fold train (a series of folds within a particular unit or series of units). This concept is important when mapping areas with abundant small amplitude, short wavelength folds which obscure the overall sheet dip (i.e. enveloping surface) of a unit.

Cyclindrical folds





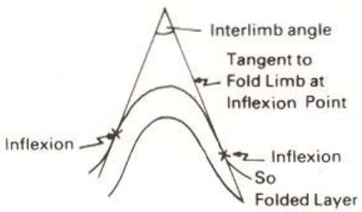


Folds are classified on the basis of several geometric factors:

•Tightness of folding: The tighness (interlimb angle measured between inflexion points) of folds can be described as **open** (limbs dip gently), **tight** (limbs dip steeply) or **isoclinal** (limbs are parallel).

•Orientation of axial plane: The orientation of the axial plane relative to the horizontal together with the orientation of fold limbs allow subdivision into **upright** (axial plane vertical, limbs symmetric), **overturned** (axial plane moderately inclined, one limb overturned), or **recumbent** (axial plane near horizontal, one limb inverted).

Table 3.1 Terms used to describe the tightness of folds



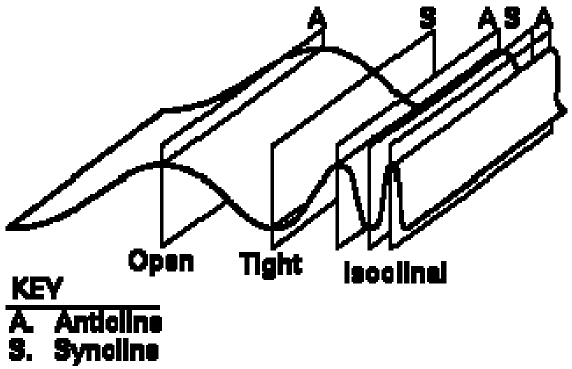
Interlimb angles	*Fold tightness*
180°–120°	Gentle
120°–70°	Open
70°–30°	Close
30°–0°	Tight
0°	Isoclinal
less than 0°	Elasticas
-ve angle	or Ptygmatic

McClay (1987)

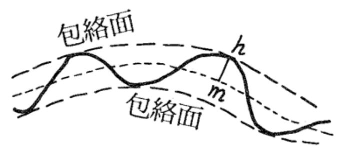
Table 3.2 Terms describing the attitude of folds

Dip of the fold axial surface or plunge of the fold axis	*Dip of hinge surface (i.e. attitude of axial plane)*	*Plunge of hinge line (i.e. attitude of fold axis)*
0°	Recumbent fold	Horizontal fold
1°–10°	Recumbent fold	Sub-horizontal fold
10°–30°	Gently inclined fold	Gently plunging fold
30°–60°	Moderately inclined fold	Moderately plunging fold
60°–80°	Steeply inclined fold	Steeply plunging fold
80°–89°	Upright fold	Sub-vertical fold
90°	Upright fold	Vertical fold

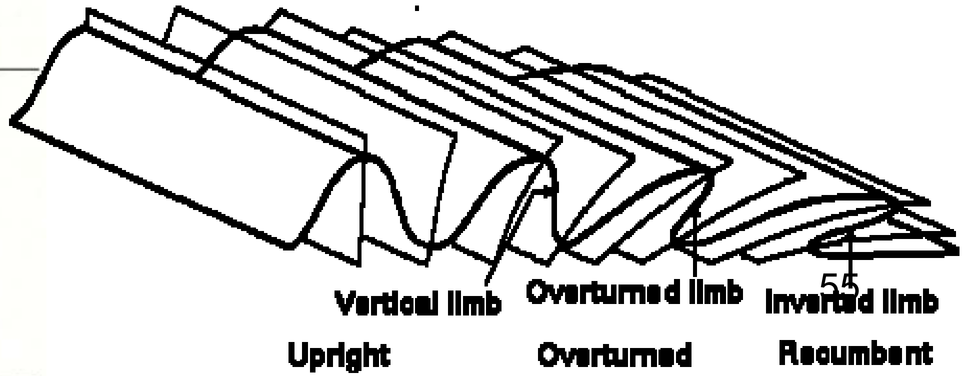
Two attitudes are used to describe the orientation of a fold: (a) the plunge of the fold axis, and (b) the dip of the axial plane.



Enveloping surface



楊昭南(1995)



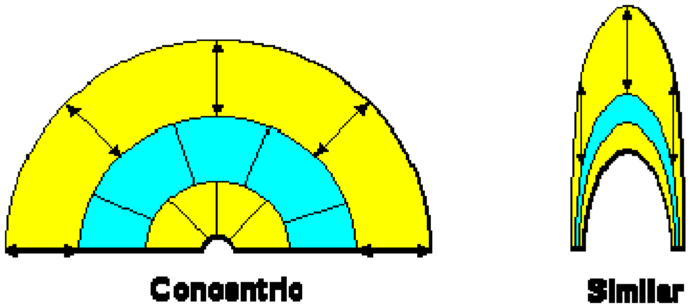
Common types of folds (as described in the profile plane)

1. Parallel (concentric) folds: Orthogonal thickness (i.e. thickness perpendicular to the folded surface) is constant. Brittle units tend to form **concentric** folds.

2. Similar folds: Thickness parallel to axial plane is constant. Thinly-bedded, clay-rich units, or rocks under ductile deformation tends to develop similar folds.

Fig. 3.3a Parallel folds. Folded quartzo-feldspathic layer in amphibolites. Field of view *ca.* 2·5 m.

parallel (concentric), harmonic



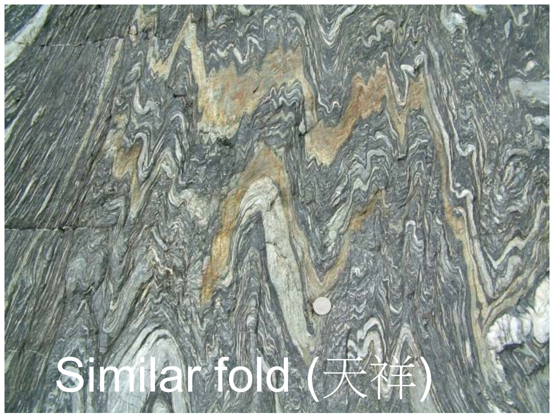
harmonic

Fig. 3.3b Similar folds (thickness parallel to the axial plane is constant) in deformed psammitic schists. Note that these folds are also harmonic in that there is continuity along the axial planes.

McClay (1987)

An open, upright, (harmonic) parallel fold

Photo by John Simmons, The Geological Society of London, www.geolsoc.org.uk



3. Harmonic folds: Axial planes are continuous across a number of layers.

4. Disharmonic folds: Axial planes are not continuous from one layer to the next.

Fig. 3.3c Disharmonic folds of sphalerite layers in galena. There is no continuity along the axial planes between layers. Field of view *ca.* 1 m.

5. Intrafolial folds: Folds contained within the layering or foliation.

Intrafolial and isoclinal

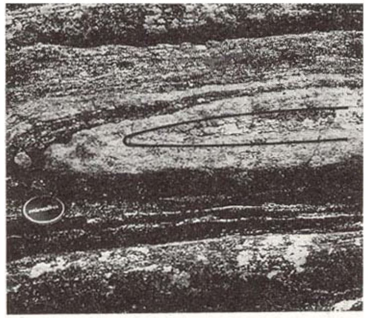


Fig. 3.3d Intrafolial isoclinal fold of a quartzo-feldspathic layer in gneisses. The fold is contained within the geneissic foliation.

6. Ptygmatic or elastica folds: Tight folds in which the fold limbs fold back on themselves so that the angle between the fold limbs at the hinge of the fold has a negative value.

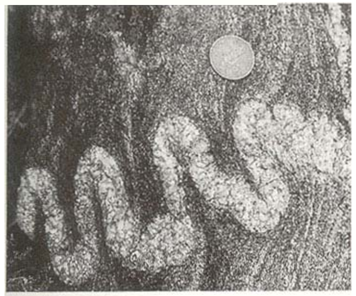


Fig. 3.3e Ptygmatic folds in a deformed pegmatitic vein in gneisses.

7. Chevron folds: Angular folds with planar limbs and sharp hinges.

Fig. 3.3f Chevron folds in deformed turbidites. Note the sharp hinges and planar limbs of the folds. Field of view *ca.* 15 m.

8. Isoclinal folds: Folds in which the limbs are strictly parallel.

9. Polyclinal folds: Folds with more than one axial plane, e.g. box folds or conjugate kink bands.

Fig. 3.3g Polyclinal fold in deformed mylonites and showing several axial planes.

10. Kink bands: Sharp angular folds bounded by planar surfaces.

Fig. 3.3h Asymmetric reverse kink bands in a deformed schist.

McClay (1987)

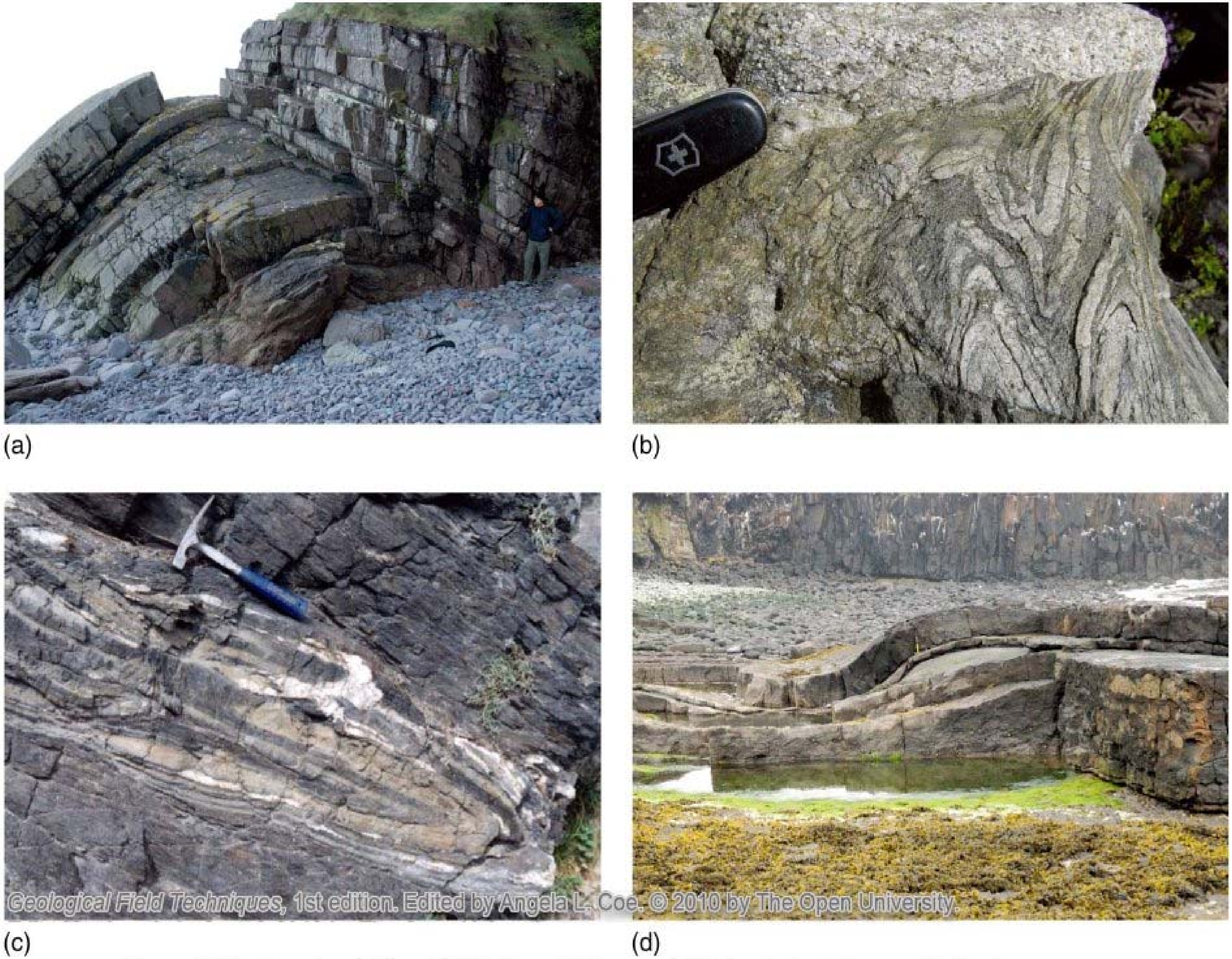
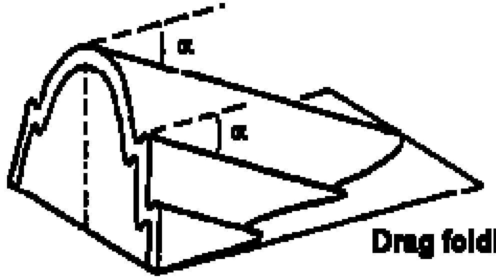


Figure 8.22 Examples of different fold tightness. (a) An open fold in low-strain strata, near Minehead, Somerset, UK. (b) Tight folds indicating high strain are cross-cut by an undeformed (later) granite (top), Glen Gairn, Scotland. (c) Isoclinal folds show intense strain in metamorphosed mudstones (dark) and sandstones (pale brown), southern Spain. (d) Monocline in Carboniferous sedimentary rocks, Northumbria, UK. Hammer near centre for scale. (a and d: Angela L. Coe, The Open University, UK. b and c: Tom W. Argles, The Open University, UK.)

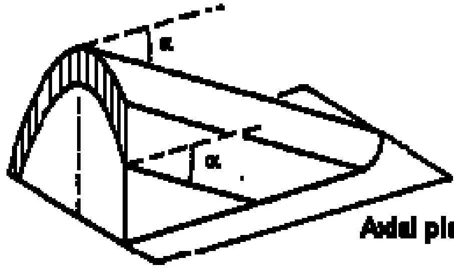
Folding is almost always accompanied by a number of associated minor structures. These include:



Drag folding

• **Drag folding**

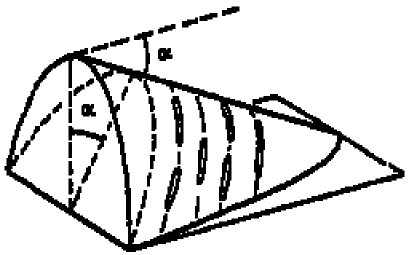
Minor folds with the same plunge and axial plane orientation as the larger fold structure.



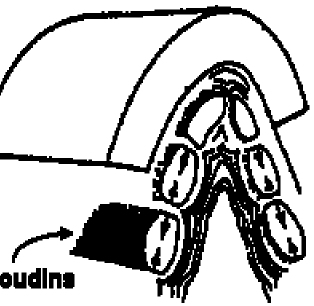
Axial plane cleavage

• **Axial plane cleavage**

Alignment of platey minerals normal to the major compressive stress responsible for folding and parallel to the axial plane. The intersection of axial plane cleavage with bedding produces a lineation with the same plunge as the fold axis.



Boudinage



boudins

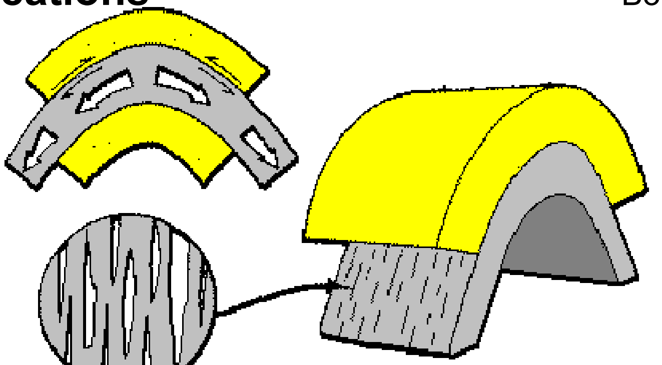
• **Boudinage**

Flow of less competent beds around thin competent beds fragmented into blocks by tensile

failure.

• **Bedding surface lineations**

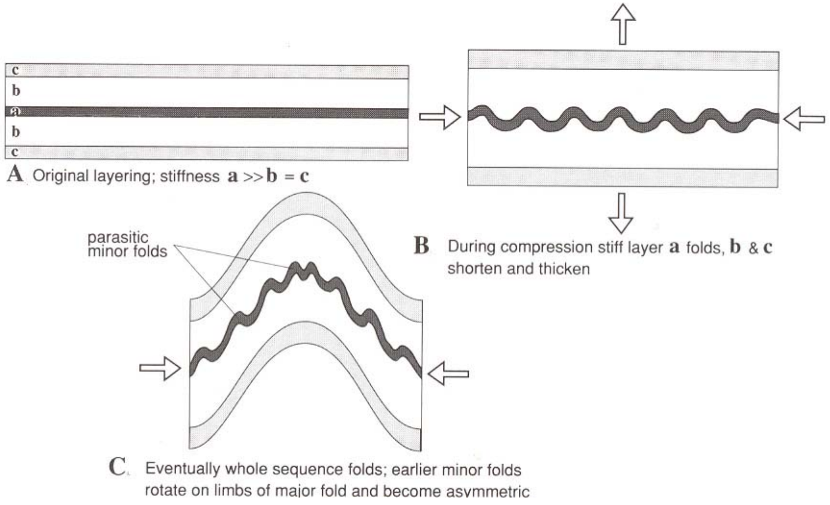
Striations developed by shear along bedding surfaces during folding.

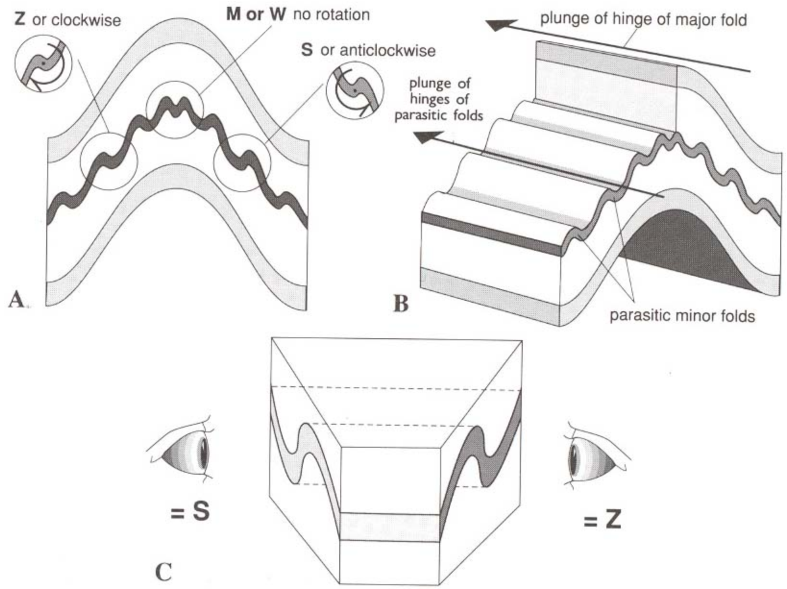


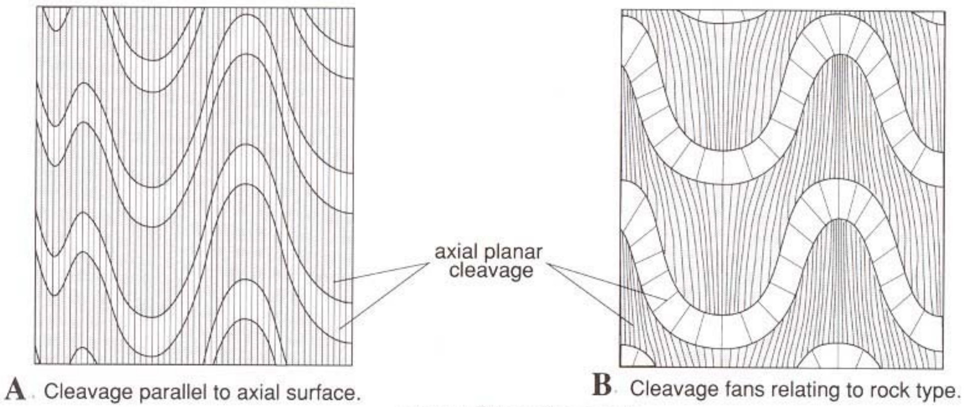
bedding plane lineations

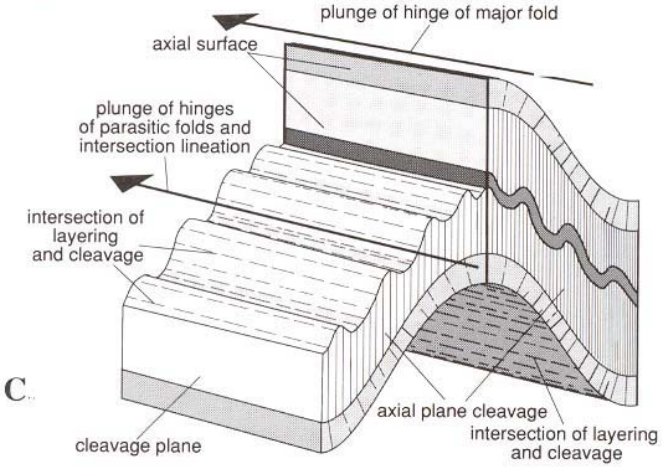
Boudinage in limestones, Wadi Dayquah, Oman

Parasitic minor folds





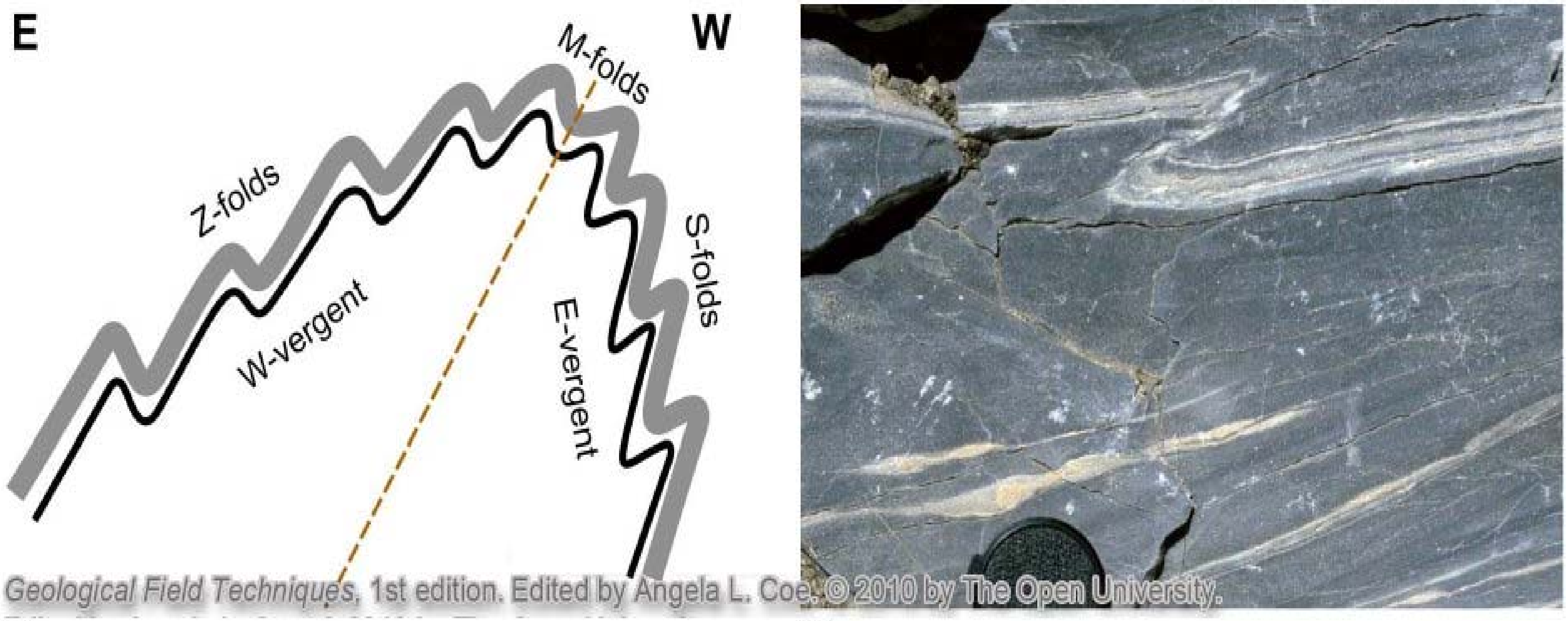




Axial plane fabrics

Powell, D (1992) Interpretation of Geological Structures through Maps: an Introductory Practical Manual, Longman Scientific & Technical, 176pp.

Z-folds in marble, Southern Cross-Island Highway (陳肇夏攝，台灣地質寫真V2)

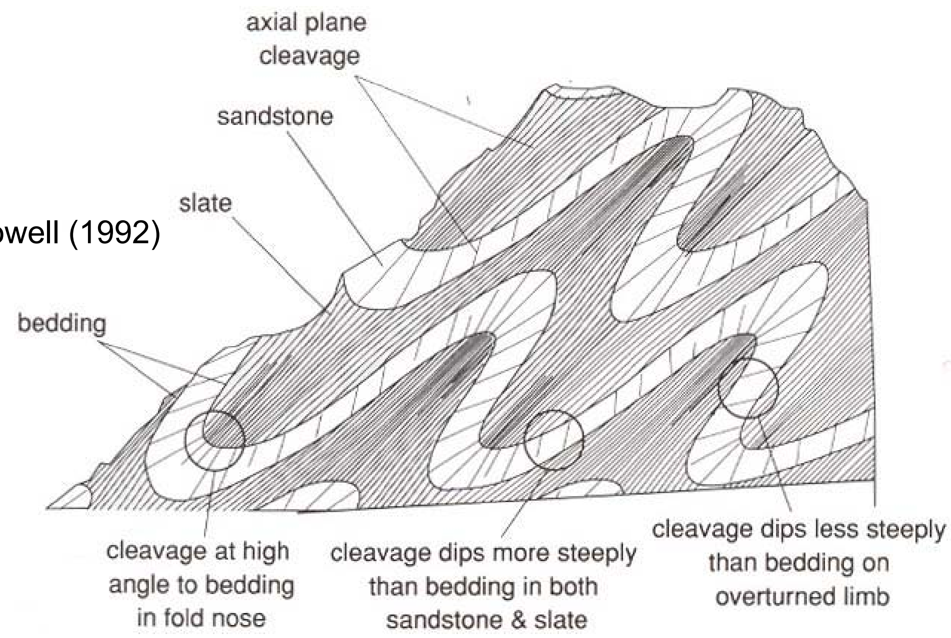


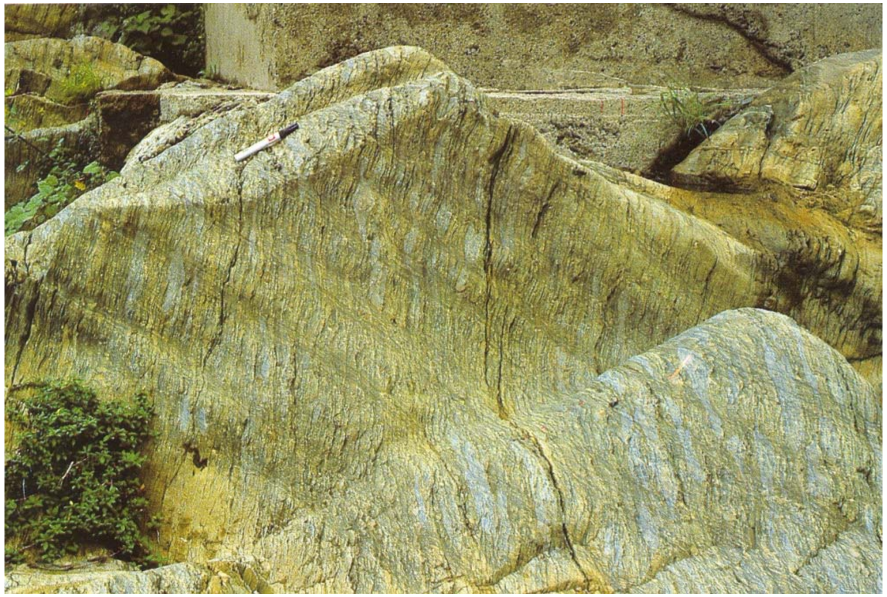
(a) (b)

Figure 8.24 Information from fold asymmetry. (a) Schematic cross-section showing an example of how fold asymmetry (and vergence) changes across a fold axial plane (red line). (b) Isolated asymmetric fold in calcareous mylonite, implying dextral (top-to-the-right) shear, Switzerland. (Tom W. Argles, The Open University, UK.)

Bedding and cleavage relation

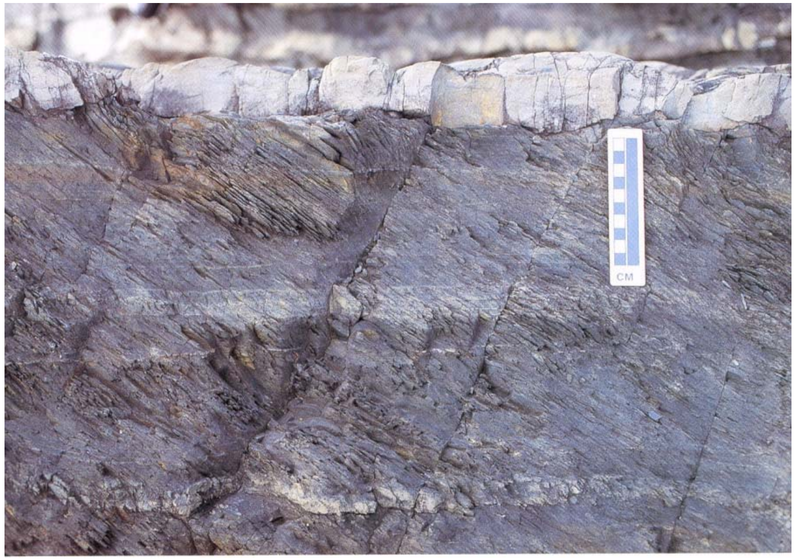
Powell (1992)





Fold axis is to the left of this outcrop

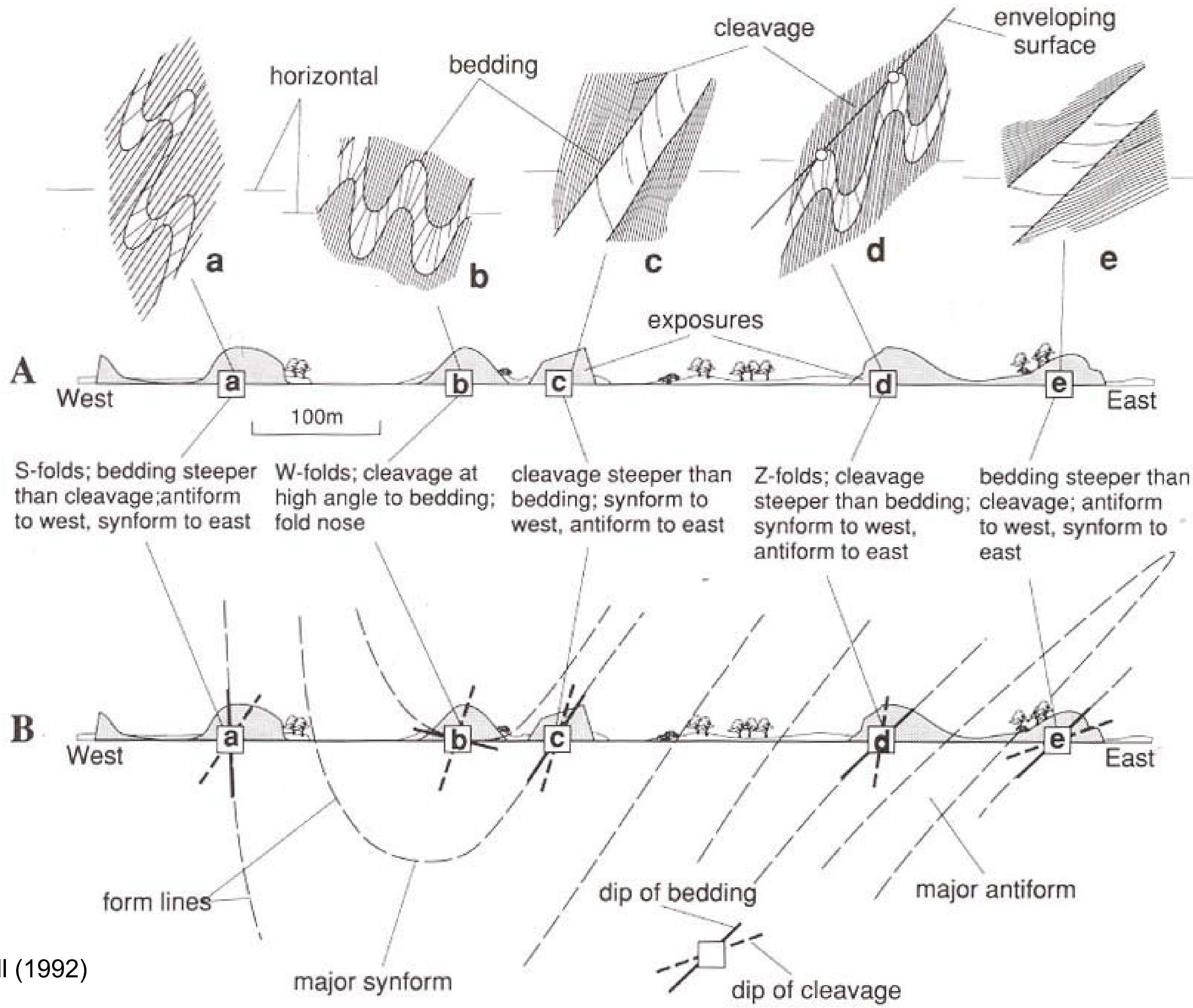
十八重溪層,濁水溪地利 (陳肇夏攝台灣的地質現象v2)



Taira et al. (1992)

Slaty cleavage developed in shales. Eocene-Upper Oligocene Muroto Formation, Kochi, Japan

Use of minor folds and cleavage/bedding relationships

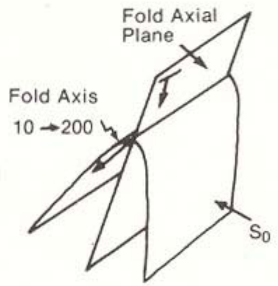
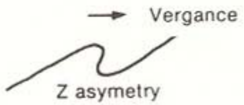
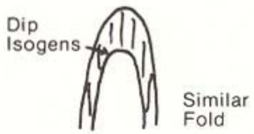
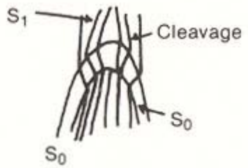
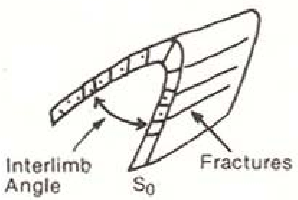


Powell (1992)

Data to be collected when mapping folds

McClay (1987)

Table 3.4 Data to be collected from observations when mapping folds from a single phase of deformation.

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
	Orientation of fold axial surface (dip direction) (Figs. 2.5–2.8).	Nature of axial surface. Relationships of axial planes in a group of folds.	Orientation of fold structure. (Table 3.2)
	Orientation of fold axis (plunge) (Figs. 2.11–2.13).	Nature of hinge line — straight or curved, Relationships of hinge lines in a group of folds.	
	Vergence (azimuth) (Figs. 3.9 & 3.10).	Vergence and sense of asymmetry. S, Z, M (parasitic folds) facing. (Figs.3.8, 3.5, 3.10)	Vergence boundaries. (Fig. 3.11) Axes of major fold structures. (Fig. 3.8) Tectonic transport direction. (Fig. 3.4)
	Profile section of fold (Figs. 3.2–3.4).	Thickness changes in profile section. Cylindricity. Fold type. (Figs. 3.3, 3.4, 3.5)	Fold classification: 2D or 3D, dip isogons. (Fig. 3.4) Projection of fold down plunge. (Fig. 9.6)
	Cleavage orientations around the fold (Fig. 4.3).	Nature of cleavage. (Fig. 4.1)	Mean cleavage approximates to fold axial plane. (Fig. 4.3b) Deformation mechanisms.
	Fracture patterns around fold (Figs. 7.4 & 7.5).	Nature of fractures — veining. (Figs 7.1 and 7.6)	Deformation mechanisms.
	Interlimb angle. (Table 3.1)	Nature of limbs — planar — curved. (Fig. 3.3)	Shortening across fold, (chevron folds).
	Limb lengths. Strain of deformed objects around the folded layer(s) (Fig. 3.12).	Asymmetry. (Fig. 3.8) Nature of strain in deformed objects. (Appendix III)	Quantification of asymmetry. Strain distribution, mechanisms of folding. (Fig. 3.12)

3.5.6 Foliations

劈理(rock cleavage)：岩石中，密集地平行排列的透入性次生面狀構造。岩石容易沿這些潛在的裂面，分裂成無數的薄板或薄片。

片理(schistosity)：變質岩中，因爲變質作用，再結晶或重新結晶的礦物平行排列所構成透入性或非透入性的面狀構造。構成面狀構造的礦物一般大到可以肉眼看出。

片麻岩葉理(gneissic foliation)：變質岩中，因爲變質作用使某種礦物集結在一起，形成很明顯但不是很連續的薄帶狀(banded)或絲帶狀(ribbon-like)構造。

糜稜岩葉理(mylonitic foliation)：在地殼深部的脆性剪切帶中（韌性斷層）形成的條紋狀葉理。

移位葉理(transposition foliation)：層理在褶皺發展過程中受到旋轉與拉薄，被新生的軸面葉理所置換，這種新生的軸面葉理稱爲移位葉理。

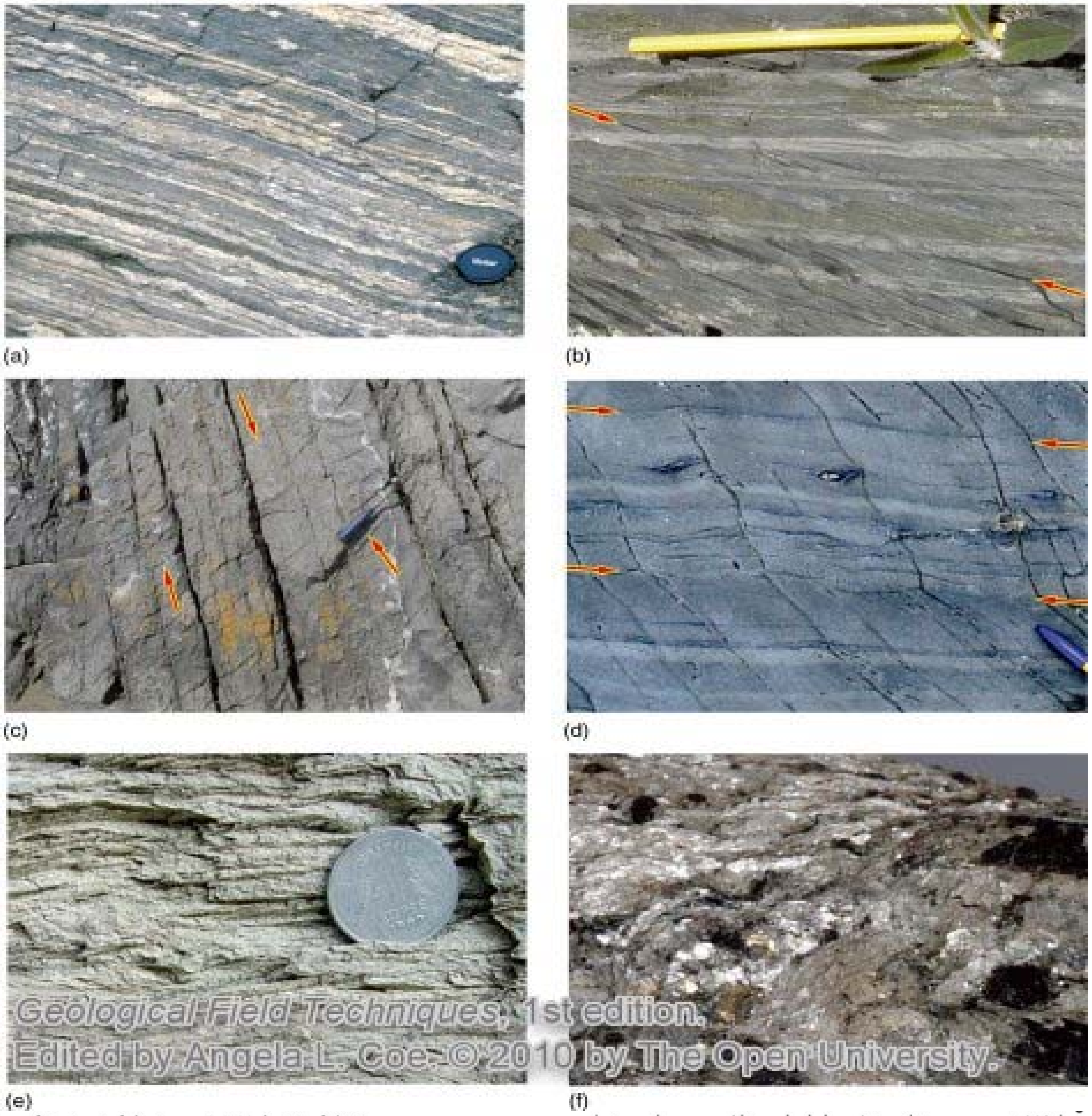


Figure 8.15 Examples of tectonic foliations. (a) Mylonitic foliation, northwest Himalaya. High strain is indicated by the strong planar fabric and tightly wrapped porphyroclasts with tails streaked out into the fabric. (b) Slaty cleavage, visible as fine lines running from top left to lower right (two separate cleavage planes are arrowed). The cleavage cuts obliquely across bedding (dark/pale subhorizontal layers) in these fine-grained mudstones and siltstones from Cumbria, UK. (c) Spaced fractures (arrowed) cut across subvertical bedding in a limestone, southwest Wales, UK. This fabric is sometimes referred to as 'fracture cleavage'. (d) Pressure solution cleavage (thin, dark lines) in siltstones, west Wales, UK. Note also the cleavage refraction, where cleavage orientation changes abruptly across some bedding planes (arrowed), reflecting grain-size changes. There is also a very fine (barely visible) slaty cleavage parallel to the solution cleavage. (e) Subhorizontal crenulation cleavage in schist, NW Himalaya, showing clear microfold hinges. (f) Close-up view looking down on schistosity planes showing visible mineral grains, including mica. The surface of the sample cuts through numerous, irregular, millimetre-scale foliation planes. View is 4 cm across. (a–f: Tom W. Argles, The Open University, UK.)

Cleavage

Slaty cleavage

Fig. 4.1a Penetrative slaty cleavage in mudstones showing a well-defined fissility.

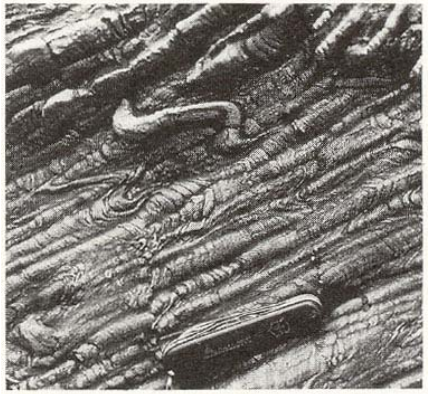


Fig. 4.1b Crenulation cleavage (parallel to penknife) formed by microfolding of thinly interbedded psammites (sandy units) and pelites

Crenulation cleavage

Fracture cleavage

Fig. 4.1c Well-developed fracture cleavage consisting of a closely-spaced array of vertical fractures in sandstones.

Pressure-solution cleavage

Fig. 4.2b Gneissic foliation showing the crude banding of quartzo-feldspathic and of mafic segregations.

Gneiss foliation

Fig. 4.2c Mylonitic foliation in a strongly sheared granite showing a well-developed planar fabric with deformed feldspar porphyroclasts in a matrix of fine-grained streaked out quartz and feldspar.

Mylonitic foliation

Table 8.3 Some common tectonic fabrics.

Fabric	Typical setting	Formed by	Clues in the field
Pressure solution cleavage	Upper crust, outer zones of mountain belts	Dissolution of soluble grains due to directed stress	Dark/pale colour striping; partially dissolved fossils, clasts; stylolitic surfaces
Slaty cleavage	Upper crust, outer zones of mountain belts; fine-grained rocks	Alignment of platy grains by rotation, dissolution and recrystallization during applied stress	Fine fabric that rock cleaves along; typically associated with folds
Fracture cleavage	Upper crust, outer zones of mountain belts; competent rocks	Tensional failure under high fluid pressure* in competent rock types	Spaced cracks in competent rock type
Mylonitic foliation	High strain faults and shear zones at all but shallowest depths	Extreme flattening and stretching in narrow, high-strain zones of shearing	Strongly planar fabric; other high-strain features (see text for examples)
Schistosity	Middle crust, inner zones of mountain belts; metamorphosed rocks	Mineral alignment under applied stress, during metamorphic crystallization	Visible mineral grains; millimetre- to centimetre-scale folia, rougher than slaty cleavage
Crenulation cleavage	Middle crust, inner zones of mountain belts; metamorphosed rocks	Microfolding of a pre-existing planar fabric (tectonic or sedimentary)	Microfold hinges, crenulation lineation (Section 8.3.5)

*Many of the mechanisms for cleavage formation (especially fracture cleavage) are a matter of debate.

The formation of **rock cleavage**

在伴隨有輕度到低度變質的岩石中，絕大多數的劈理與褶皺同時發育。劈理一般大致與褶皺軸面平行。在強岩（如變質砂岩）與弱岩（如板岩）組成的褶皺中，強岩中的劈理與弱岩中的劈理以不同的角度與層面相交，強岩中的劈理與層面的交角較弱岩中劈理與層面的交角大，而形成劈理的折射現象（圖 9.4A ）。且強岩中的劈理常呈向背斜內部收斂的扇形，而弱岩中的劈理則成向背斜內部發散的扇形（圖 9.4B ）。而由**總額應變**的度量結果，一般均顯示劈理與**總額應變橢圓體**(finite strain ellipsoid)的 XY 面大致平行，即與最小應變軸垂直，表示其與最大壓縮方向大致垂直。此外，在連續劈理的劈理領域中，有片狀礦物的平行排列及石英、長石成透鏡狀的現象，而間隔劈理中的劈理夾質領域則缺乏這種現象。

經過一百多年來理論與實驗的研究，目前對劈理的形成機制已有較爲清晰的瞭解。理論上，一般認爲劈理的形成是下列四種機制中的一種或多種共同作用的結果，包括：(1)片狀礦物或針狀礦物的機械性旋轉(mechanical rotation)，(2)片狀礦物或針狀礦物在變形過程中定向的重結晶作用(recrystallization)，(3)**壓溶作用**(pressure solution)，與(4)**微褶皺作用**(microfolding)。

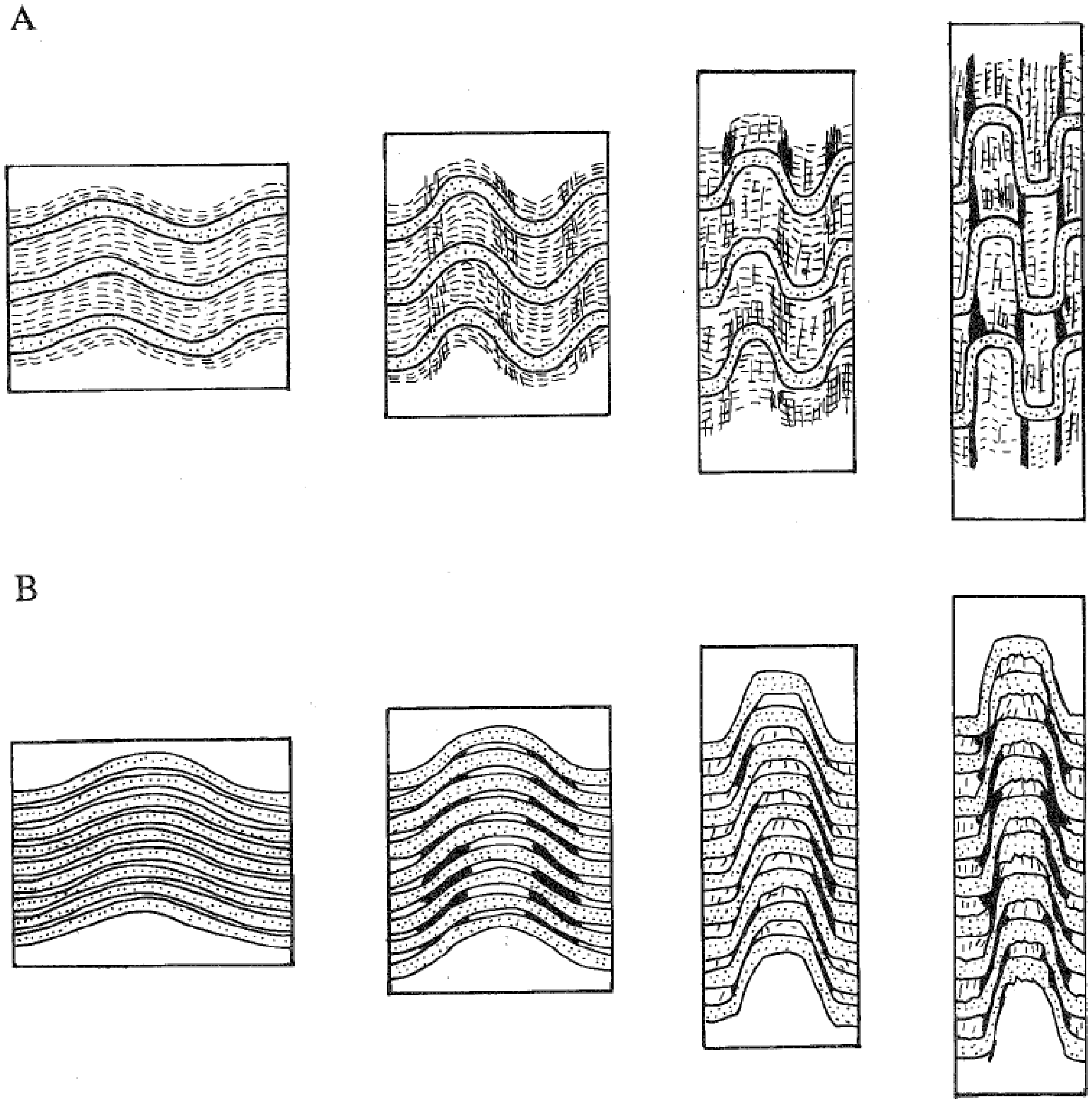


圖 9.5　微褶皺作用發育出來的劈理之形成過程。 A ：强岩層厚度小於弱岩層厚度之情形； B ：强岩層厚度大於弱岩層厚度之情形。（摘自 Price and Cosgrove, 1991 ）

(4)微褶皺作用

這種理論認爲夾鱗劈理的形成是因爲原本是薄互層的原岩遭受拱彎褶皺作用而產生小型褶皺，隨著褶皺振幅的加强，翼部逐漸變陡而遭受壓扁作用。在壓扁作用時，翼部的岩石顆粒產生壓溶作用而形成劈理領域，而軸部則形成劈理間夾質領域（圖 9.5 ）。

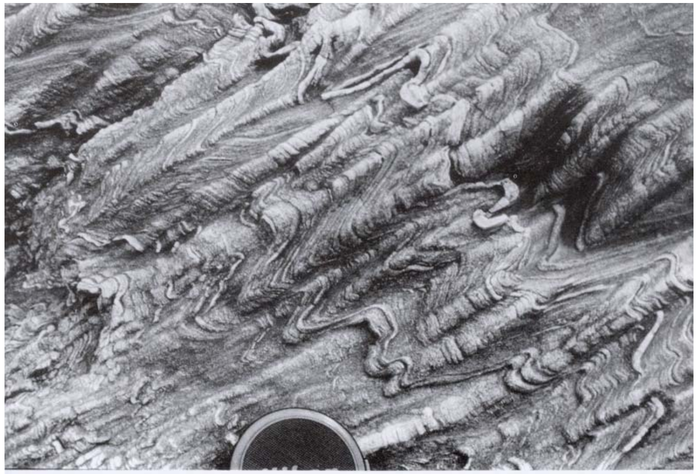
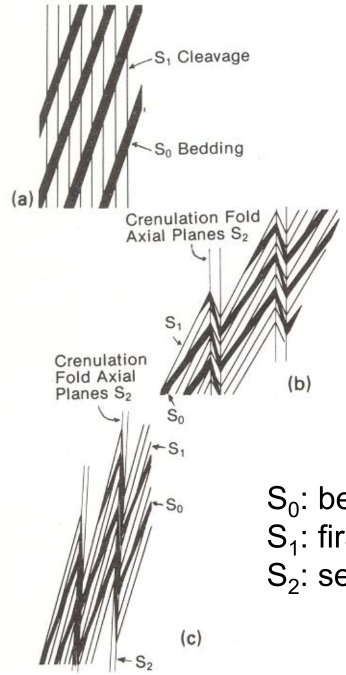


Figure 31.34. Crenulation cleavage, Precambrian metasediments, Holy Island, Rhoscolyn, N. Wales. An early foliation (anisotropy) has been folded. This deformation is associated with the formation of a tectonic striping, where the hinge zones of the folds have become relatively enriched in quartz.

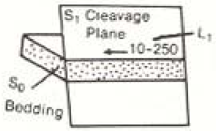
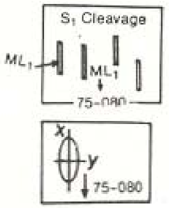
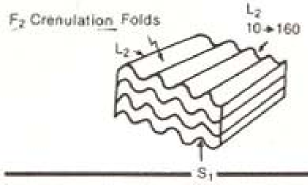
Ramsay & Lisle (2000)



S_0: bedding
S_1: first cleavage
S_2: second cleavage

Data to be collected from observations on the first cleavage (S_1)

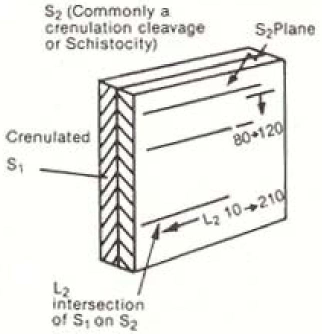
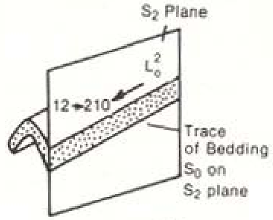
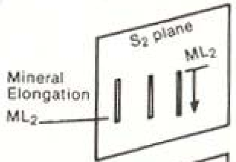
Table 4.1 Data to be collected from observations on the first cleavage (or schistocity), S_1 (commonly a slaty cleavage).

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
	S_1 dip direction (or strike and dip) (Figs. 2.5–2.7). Of cleavage or schistosity	Orientation of cleavage relative to bedding. (Figs 2.15 and 4.5) Sense of vergence. (Figs 3.9, 3.10) Facing. Cleavage refraction. (Fig. 4.4) Nature of cleavage. (Fig. 4.1)	Position relative to fold axis. (Fig. 4.5) Vergence of structure. (Fig. 3.9, 3.10) Facing of structure. Mean cleavage approximates to fold axial plane.
	L_1 bedding lineation on cleavage plane (plunge) (Figs. 2.11–2.13).	Nature of lineation. (Figs 5.1 to 5.4)	Orientation of fold axis (b_1 axis). (Fig. 4.3b)
	Mineral stretching ML_1 lineation on cleavage plane (plunge) (Figs. 2.11–2.13).		Orientation of stretching axis $\approx$ X axis of bulk strain ellipsoid (a_1 axis). (Fig. 3.2 and Appendix III)
	Orientation and magnitude of strain of deformed objects in the cleavage plane (Appendix A.III).	Nature of strain relative to cleavage. (Appendix III)	XY plane of strain ellipsoid. (Appendix III)
In polyphase terranes. 	L_2, on S_1. The intersection of subsequent cleavages on the first cleavage plane, i.e. crenulation lineations (plunges) (Figs. 2.11–2.13).	Nature of intersection of second-phase cleavage with first cleavage.	Orientation of second-phase fold axes (for folded first-phase cleavage planes). (Fig. 8.3)

McClay (1987)

Data to be collected from observations on the second cleavage (S_2)

Table 4.2 Data to be collected from observations on the second cleavage S_2(commonly a crenulation cleavage or schistosity).

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
	Dip direction (or strike and dip) (Figs. 2.5–2.7) of S_2.	Nature of S_2 cleavage: orientation of S_2 cleavage relative to S_1 cleavage and relative to bedding S_0. (Fig. 4.7) Sense of vergence. (Fig. 3.9, 3.10) Facing on cleavage.	Position relative to F_2 fold axis. (Fig. 4.5) Mean cleavage approximates to F_2 axial plane. Vergence and facing of F_2 structure.
	L_2 Intersection of first cleavage on second cleavage plane S_2 (Figs. 2.11–2.13).		Orientation of F_2 fold axis (b_2 axis) of folded S_1 surface. (Figs. 4.7, 5.1d)
	L_0^2 Intersection of bedding on second cleavage plane (Figs. 2.11–2.13).		Orientation of F_2 fold axis for folded bedding S_0 surface (note that this depends upon bedding S_0 and F_1 limbs). (Fig. 8.3)
	Mineral stretching ML_2 lineation on cleavage plane (Figs. 2.11–2.13).	Nature of lineation. (Fig. 5.1 to 5.4)	Orientation of stretching axis $\approx$ X axis of bulk strain ellipsoid for F_2 deformation (a_2 axis). Fig. 3.2 and Appendix III)
	Orientation and magnitude of strain in deformed objects in the cleavage plane (Appendix III).	Nature of strain relative to cleavage. (Appendix III)	XY plane of F_2 strain ellipsoid. (Appendix III)

McClay (1987)

3.5.7 Lineations

在強烈變形岩中，常常形成各種微型或小型的線理(lineation)，其形態與成因各異，主要有以下幾種：

1.交面線理

交面線理(intersection lineation)是兩組面理相交或面理與層理相交形成的線理（圖 10.1A ）。

2.皺紋線理

皺紋線理是由先存面理上微細褶皺的樞紐平行排列而成（圖 10.1B ）。皺紋線理的方向與其所屬的同期褶皺的樞紐方向一致。

3.拉伸線理

拉伸線理(stretch lineation)是拉長的岩石碎屑、 石、 粒、礦物顆粒或集合體等平行排列而顯示的線狀構造（圖 10.1C ）。它們是岩石組變形時發生塑性拉長而形成的。其拉長的方向與應變橢球中的最大主應變軸 X 軸方向一致。

4.礦物生長線理

礦物生長線理(mineral lineation)是由針狀、柱狀或板狀礦物順其長軸定向排列而成。礦物生長線理是岩石在變形變質作用中礦物在引張方向重結晶生長的結果（圖 10.1D ）。因而礦物及其纖維生長的方向往往指示岩石重結晶或塑性流動的拉伸方向。

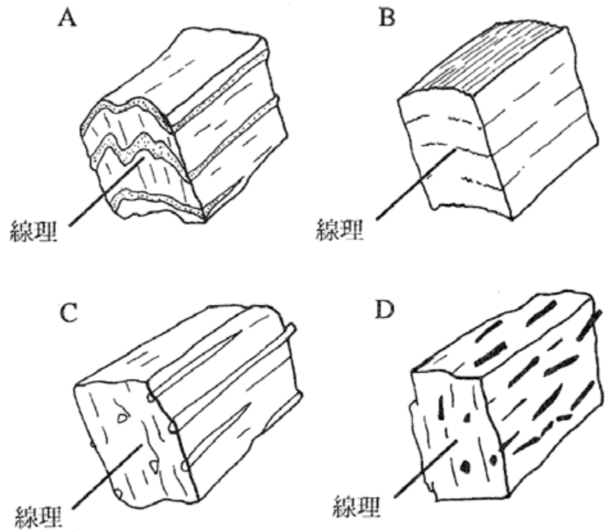


圖 10.1 線理的基本型態。A：交面線理；B：皺紋線理；C：拉伸線理；D：礦物生長線理。

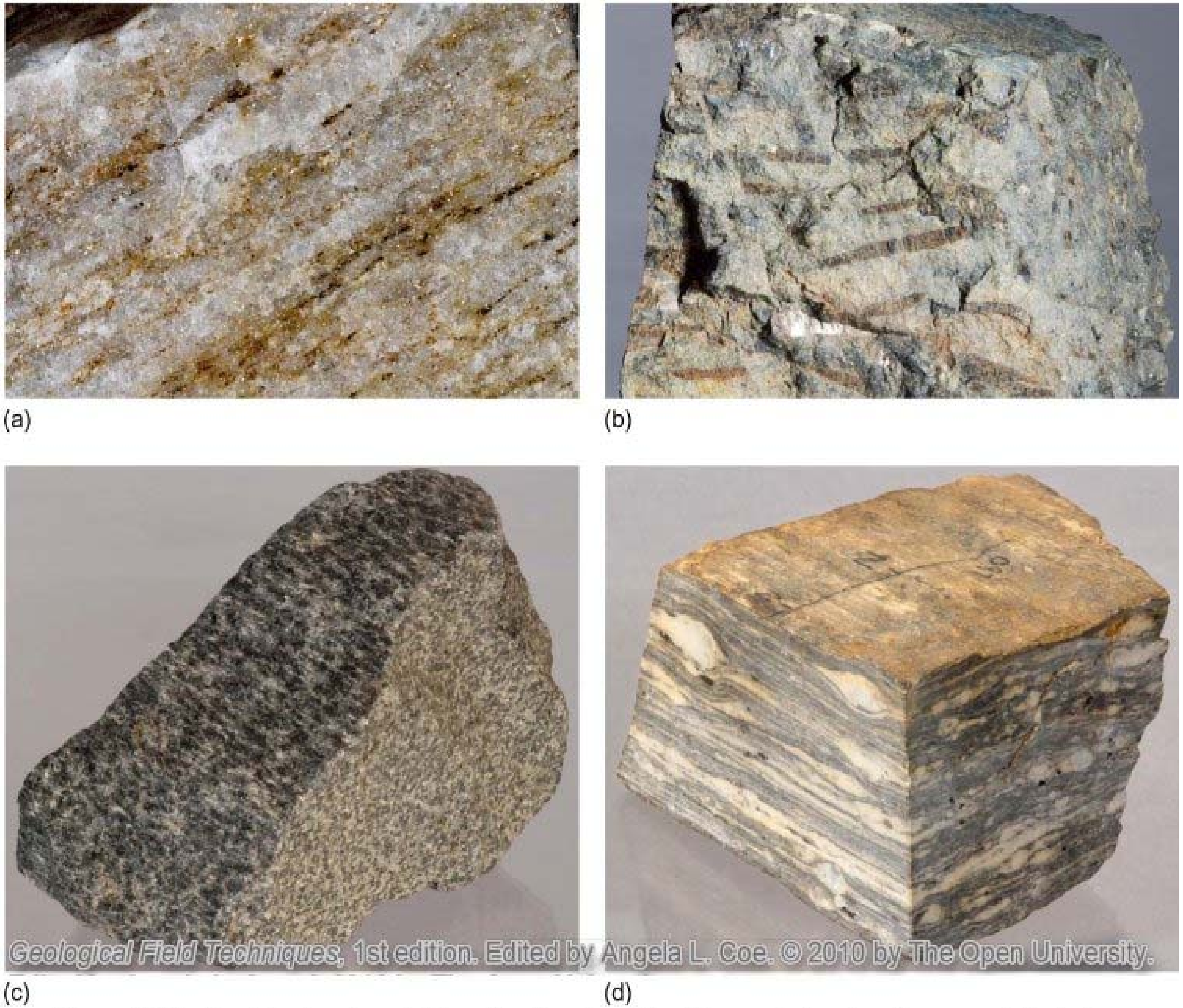
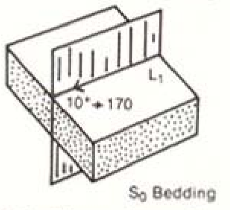
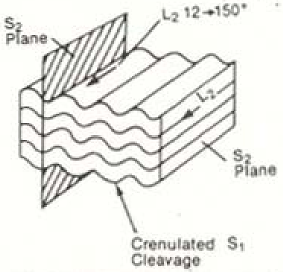


Figure 8.18 Stretching lineations. (a) Stretching lineation defined by stretched grains of quartz and biotite in a mylonitic quartzite (5 cm across). (b) Weakly aligned orthopyroxene grains roughly define the stretching direction in a mantle peridotite (base of sample is 10 cm across). (c) Stretching lineation defined by elongate amphibole crystals in an amphibolite that lacks foliation (base of sample is 8 cm across). (d) High-strain gneiss with orthogonal faces cut parallel (left face) and perpendicular (right face) to stretching lineation, which is faintly visible as colour streaking on the top surface (weathered foliation). Note that the left face (parallel to the lineation) appears much more sheared than the other cut face: this can be a useful feature to look for on an irregular exposure when searching for stretching lineations. Line on top surface is part of the marking originally used to orientate the specimen. (Right face is 5 cm across.)

Data to be collected from observations on intersection lineations (L_1, L_2)

Table 5.1 Data to be collected from observations on intersection lineations L_1, L_2, etc.

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
L_1 Bedding S_0 / cleavage S_1 intersection on either S_0 or S_1 surfaces.	Plunge of lineation L_1 (note: orientation data for S_0 and S_1 also required) (Figs. 2.11–2.13).	Nature of lineation. (Figs. 5.1 to 5.4) Orientation and nature of bedding and cleavage. (Fig. 4.1)	Lineation generally parallels F_1 fold axis (b_1). (Fig. 5.1b)
 L₁ Bedding/Cleavage Intersection	Strain of deformed objects parallel to lineation (Appendix III).	Nature of strain. Fibre growth parallel to lineation. Fractures parallel to lineation.	Y axis of F_1 strain ellipsoid. (Appendix III)
L_2 First cleavage S_1/ second cleavage S_2, intersection on either S_1 or S_2 surfaces (S_2 is generally a crenulation cleavage).	Plunge of lineation L_2 (note data for S_0, S_1 and S_2 are also required) (Figs. 2.11–2.13).	Nature of lineation. (Figs. 5.1 to 5.4) Orientation and nature of S_0, S_1, and S_2. (Fig. 4.1)	Lineation generally parallels F_2 fold axis b_2 (for S_1 surfaces). (Fig. 5.1b)
	Strain of deformed objects parallel to lineation (Appendix III).	Nature of strain. Fibre growth parallel to lineation. Fractures parallel to lineation.	Y axis of F_2 strain ellipsoid. (Appendix III)

McClay (1987)