LAB 5: SEDIMENTARY STRUCTURES & PALAEOCURRENT ANALYSIS

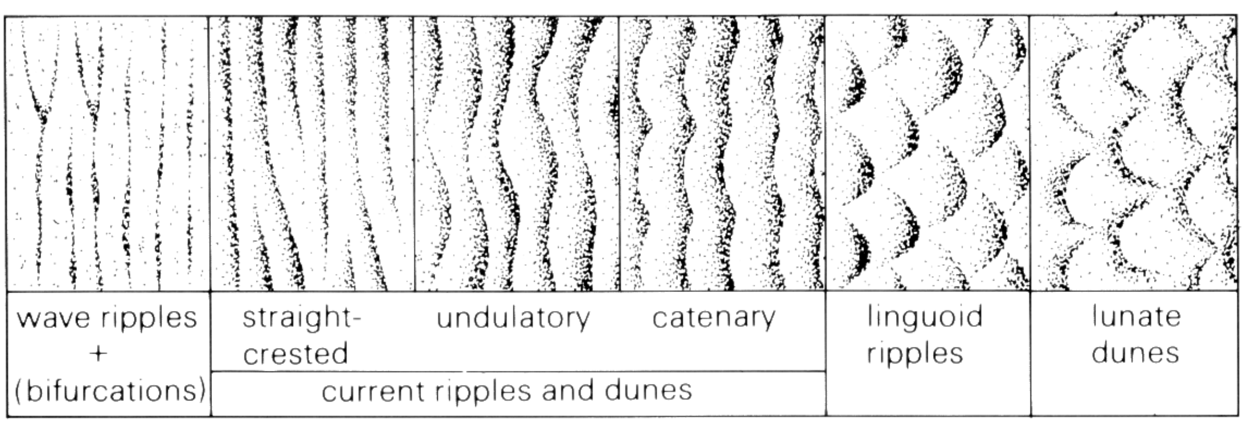
Sedimentary Structures

Sedimentary structures are an important attribute of sedimentary rocks because they can be used to deduce the processes and conditions of deposition, the direction(s) of the currents that deposited the sediments and even the original *way-up* of the strata. Structures developed through physical and/or chemical (inorganic) processes before, during and after deposition can be categorized as either ***depositional***, ***erosional*** or ***post-depositional***. Those formed by organisms are termed ***biogenic***.

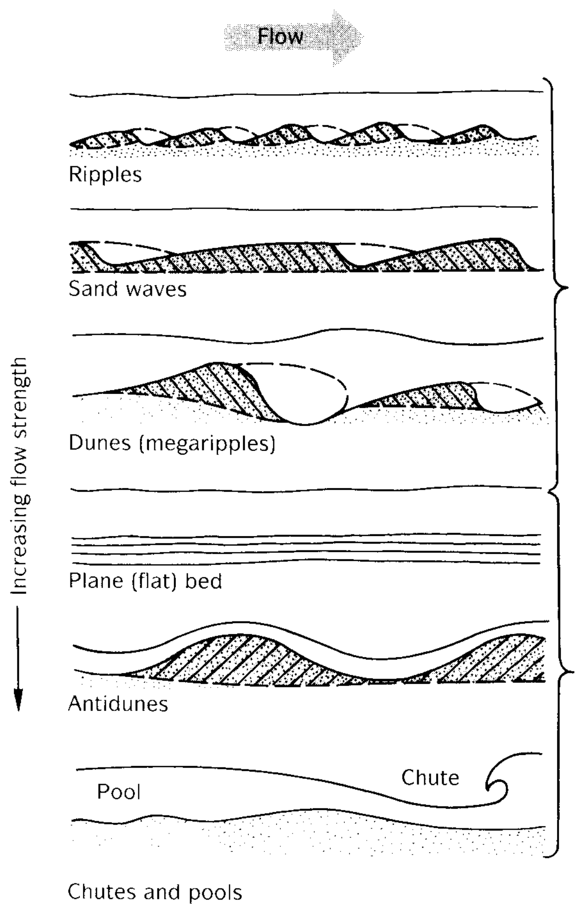
Depositional structures occur on the upper surface of and within sedimentary beds. The simplest depositional structure is ***plane bedding***, which is ubiquitous to sedimentary rocks. Finer-scale plane bedding (<1 cm in thickness) is known as ***lamination***. Both are produced by changes in the pattern of sedimentation and may be defined by changes in colour, mineralogy or grain size. Bed/laminae boundaries may be sharp, irregular or gradational and can be modified by soft-sediment compaction, tectonic movements and the subsequent development of cleavage. Bed thickness is also an important parameter and is gauged as follows:

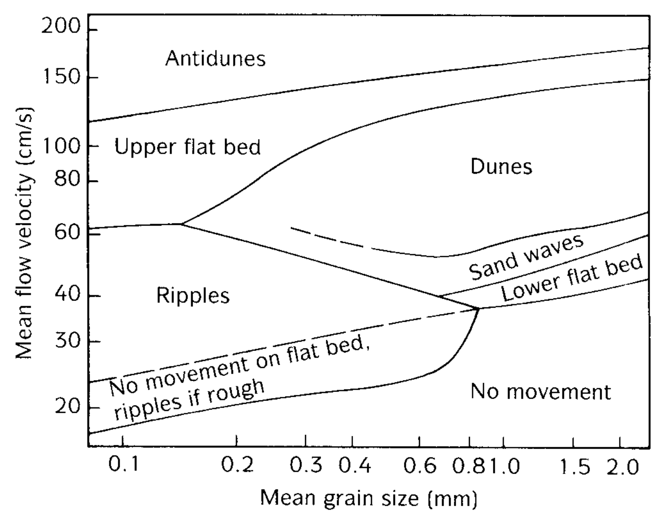
	Very thickly bedded
1 metre------------	Thickly bedded
0.3 metres---------	Medium bedded
10 centimetres----	Thinly bedded
3 centimetres-----	Very thinly bedded
10 millimetres----	Thickly laminated
3 millimetres-----	Thinly laminated

Ripples, ***sand waves*** and ***dunes*** are ***bedforms*** which develop with increasing flow velocity, mainly in sand-sized sediments, limestones or sandstones, and even some chemical sedimentary rocks. Ripples are formed by either unidirectional currents or wave/wind action and are generally asymmetrical, with steep ***lee*** (downstream) and gentle ***stoss*** (upstream) sides. Sand waves and dunes form by the same processes as ripples, only on a much larger scale. Ripples and dunes are further classified on the basis of crest shape as follows:

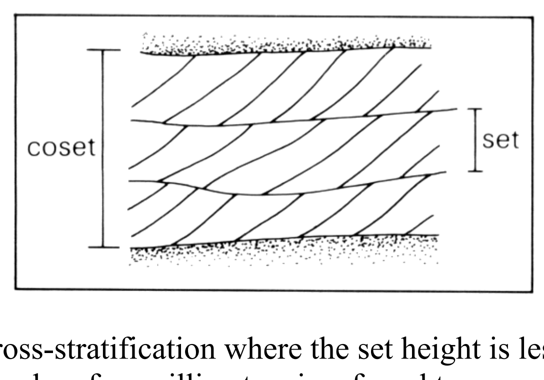


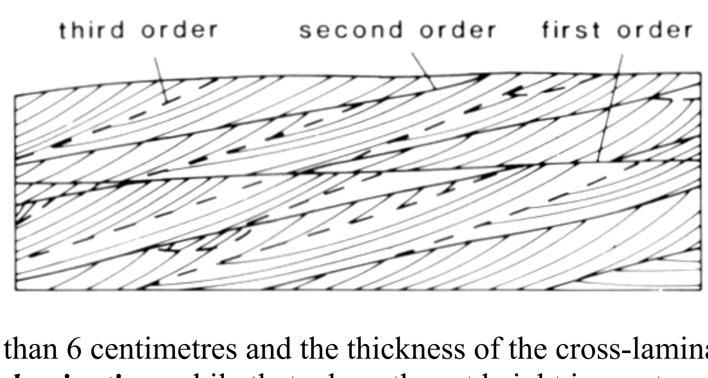
With increased flow velocity, dunes are eventually destroyed and the turbulent flow, which is out of phase with the bedforms, changes to a sheet-like flow, now in phase with the bedforms. Intense sediment transport takes place along ***plane (flat) beds***, which are produced by planar laminated sands. At even higher velocities, plane beds are replaced by undulating bedforms known as ***antidunes***, whose crests are in phase with surface waves. Finally, at the highest flow velocities, antidunes are washed out and replaced by ***chutes*** and ***pools***.





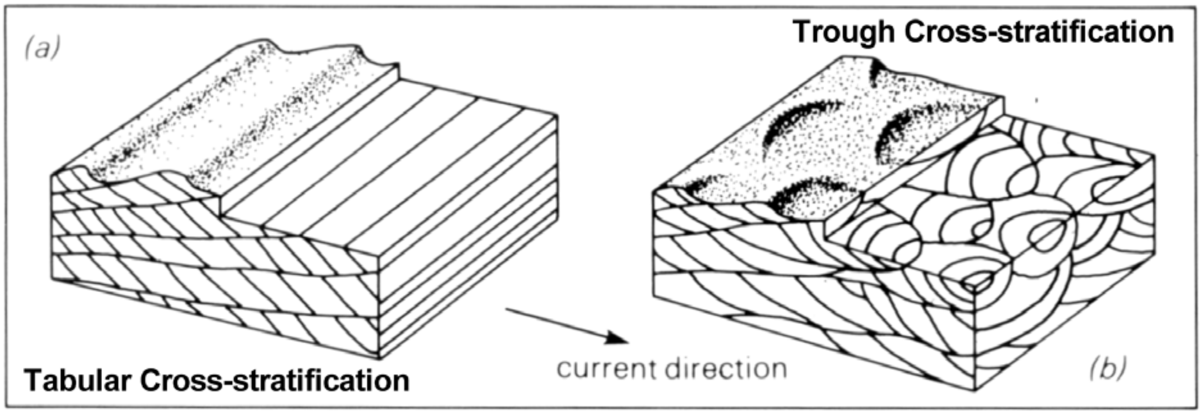
Cross-stratification is an internal sedimentary structure consisting of stratification at an angle to the principal bedding, primarily formed as a result of deposition during the down current/wind migration of ripples, sand waves and dunes. It forms either a single ***set*** or many sets (***coset***) within one bed.



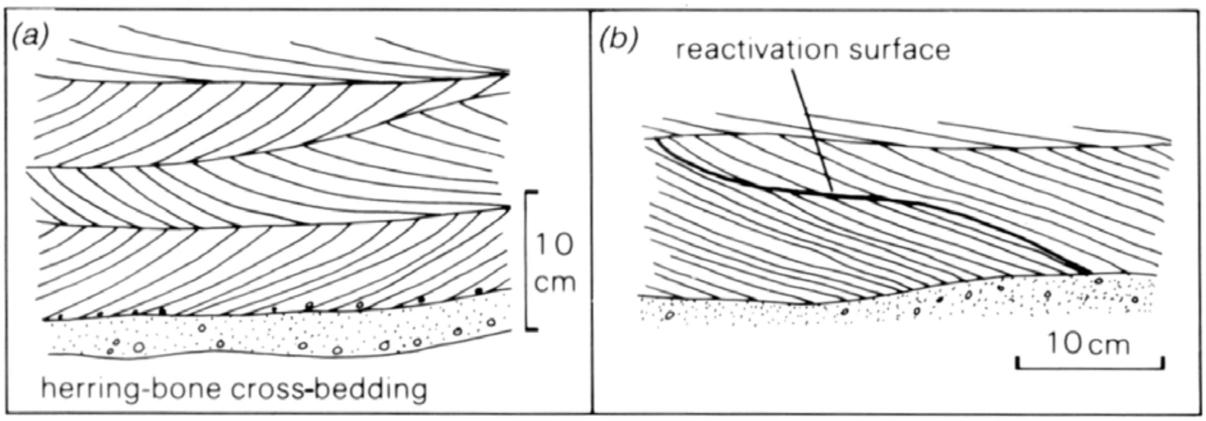


Cross-stratification where the set height is less than 6 centimetres and the thickness of the cross-laminae is only a few millimetres is referred to as ***cross-lamination***, while that where the set height is greater than 6 centimetres and the individual cross-beds are a centimetres or more in thickness is known as ***cross-bedding***. The shape of the cross-strata reflects the shape of the lee slope and depends on the characteristics of the flow, water depth and sediment grain size. The steeply dipping parts of the cross-strata are known as ***foresets*** and can have either angular or tangential contacts with the horizontal. In the latter case, the shallowly dipping parts are called ***bottom sets***. A coset where cross-bed dips of adjacent sets are oriented in opposite directions is referred to as ***herringbone cross-bedding*** (see figure below). This pattern is indicative of deposition by tidal currents.

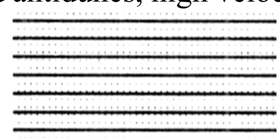
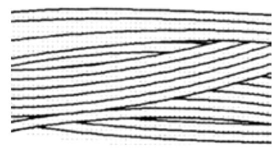
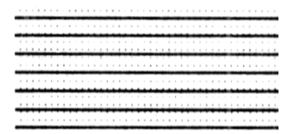
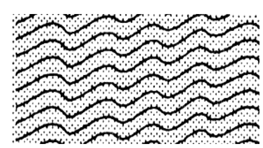
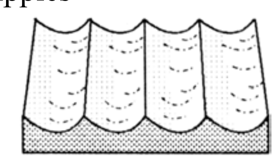
There are two common types of cross-stratification, based on their three-dimensional shape: ***tabular*** and ***trough***, as depicted in the following figure:



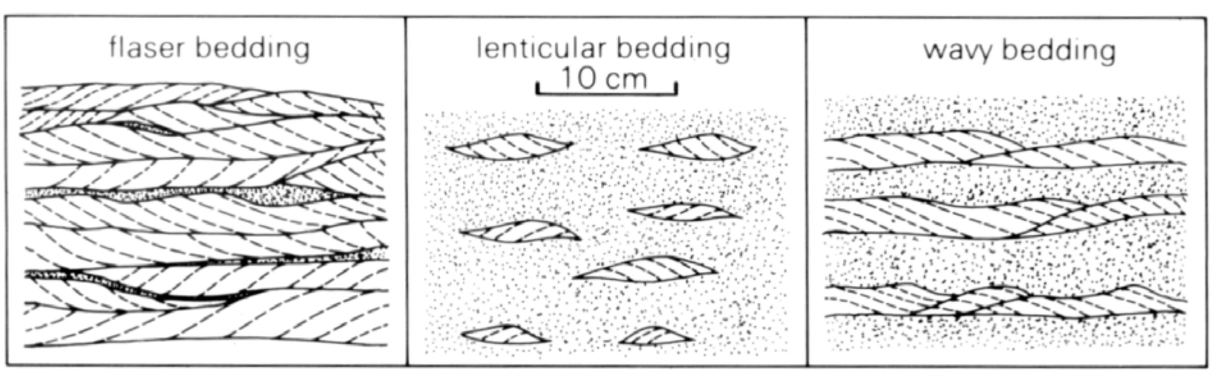
Some cross-bed sets contain tiny erosional surfaces know as ***reactivation surfaces***. These represent short-term changes in the flow conditions that interrupted the migration of the ripple and caused modification to the shape of the bedform.



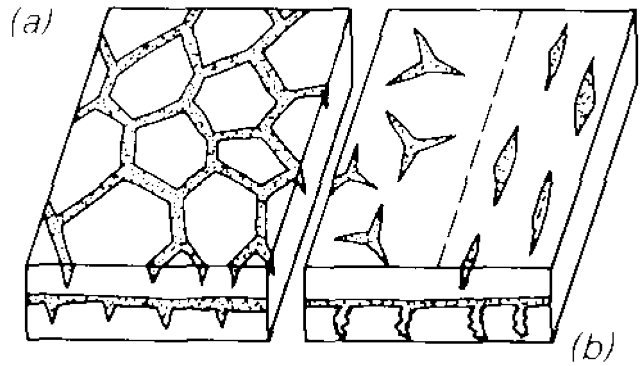
While the flow producing the above bedforms is generally ***unidirectional***, two other types of flow also occur (see table, next page). ***Oscillation flow*** occurs when the current moves alternatively back and forth producing ***symmetrical (oscillation) ripples***. A feature of storm-dominated sandy shelves is ***hummocky cross-stratification***. This bedform is composed of low mounds and hollows of very fine sand and silt that have sharp bounding surfaces but no apparent directionality. It is produced by ***combined flow***, that is flow comprising both unidirectional and oscillation flow. This type of flow occurs at water depths of 5 to 15 metres where strong storm waves produce water displacement of several metres and velocities of greater than 1 m/s.

	UNIDIRECTIONAL FLOW ——————>	COMBINED FLOW DIRECTION ——————> <——————>	OSCILLATION FLOW DIRECTION <——————>
	Water flows constantly in one direction (*e.g.* a river)	Oscillation flow with superimposed unidirectional flow (*e.g.* shelf waves plus storm current)	Wave energy fluctuates water back and forth (*e.g.* tidal flat)
High flow energy environment (Upper Flow Regime)	Plane beds and antidunes, high velocity laminations 		
Moderate flow energy environment (Upper-Lower Flow Regime)	Large straight-crested & lunate ripples and large cross beds (see p. 35)	Hummocky Cross Stratification 	Plane Bed 
Low flow energy environment (Lower-Lower Flow Regime)	Small straight-crested & linguloid ripples and small cross beds (see p. 35)	Climbing Ripples 	Symmetrical (Oscillation) Ripples 

Three other types of depositional structures are confined to tidal regions, where sand- and mud-sized fractions commonly mix: ***flaser bedding***, where cross-laminated sand contains streaks of mud (usually in the ripple troughs), ***lenticular bedding***, where mud dominates and the cross-laminated sand occurs in lenses, and ***wavy bedding,*** where thin ripple cross-laminated sandstones alternate with mudrock in nearly equal proportions.

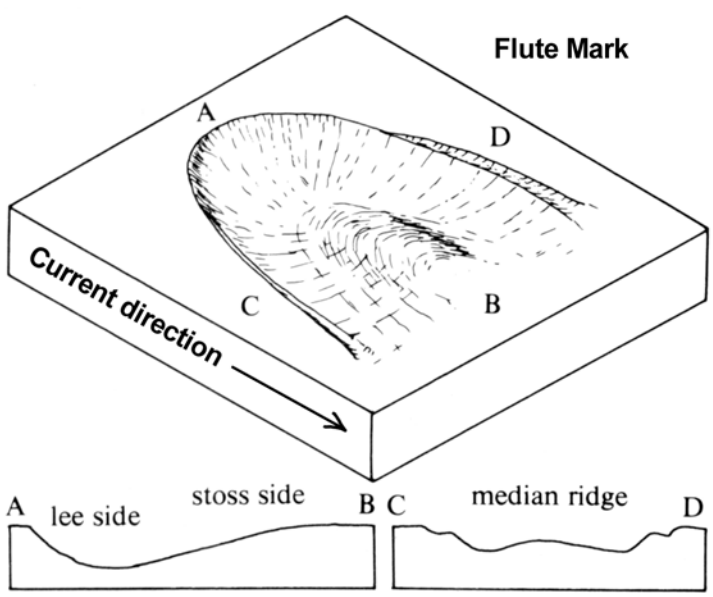


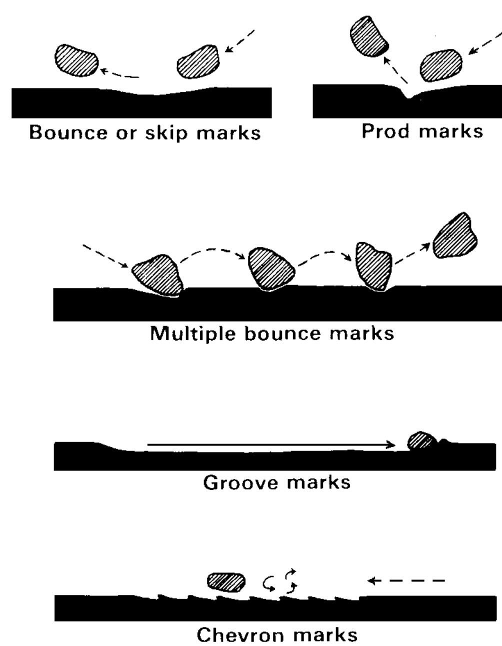
Some other common depositional structures particularly useful in determining the *way-up* of strata include ***graded bedding***, where coarser particles at the base of a bed give way to finer particles higher up, ***shrinkage (mud) cracks*** and ***polygonal structures***, formed through the desiccation of fine-grained sediments on exposure to air or through subaqueous dewatering (***syneresis***) and ***rain spots***, formed through the impact of raindrops on soft, fine-grained sediment.



Shrinkage cracks formed by (a) desiccation (complete with polygons) and (b) through syneresis (incomplete)

Erosional structures include ***sole marks*** (***flute casts*** and ***tool marks***), ***scour marks*** (and scoured surfaces) and ***channels***. Sole marks are so named because they occur on the undersurfaces of some sandstones, turbidites and other beds, and are generally casts or molds of depressions that were formed in the underlying sediments. Flutes form through the erosion of muddy sediment surfaces by eddies in the passing turbulent current and are subsequently infilled with sediment as the flow decelerates. The resulting casts can be recognized by their elongated teardrop shape, with tapered ends pointing downstream. Tool marks (***bounce*** or ***skip***, ***prod***, ***groove*** and ***chevron***) form when objects (mud clasts, plant debris, etc.) being carried by a current leave an impression on the sediment surface, which is subsequently eroded and elongated by the current. As with flutes, casts eventually form as a result of sediment infilling. ***Groove casts***, one of the more common tool marks, are elongate ridges which form as a result of the infilling of grooves cut by objects (twigs, pebbles, etc.) dragged along by a current and range in width from a few millimetres to several tens on centimetres.



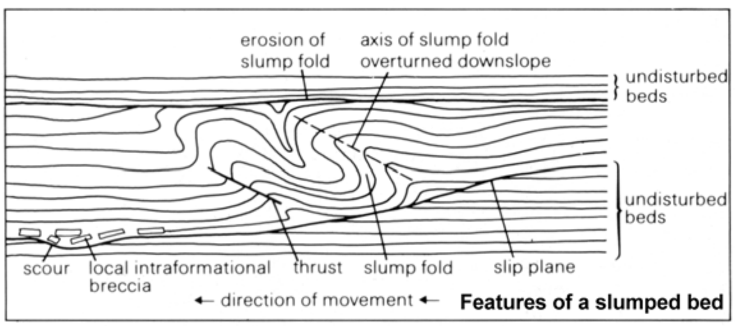


Scour marks occur on the base of or within a bed and form where currents are strong enough to erode into the underlying sediments. They are elongate (parallel to current direction), generally less than a metre in width and cut down several centimetres. With increasing size, scours grade into channels, and like scours, can be recognized by their cross-cutting relationship with the underlying sediments. Both are reliable indicators of palaeocurrent direction.

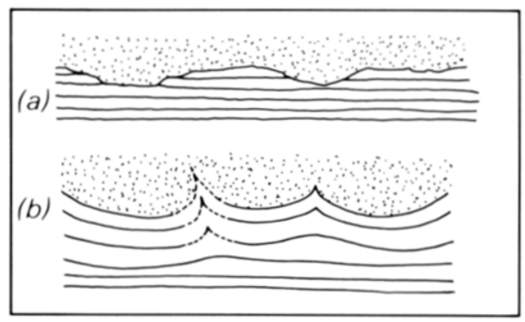
A variety of sedimentary structures are formed after deposition, some as a result of mass movement and others through internal reorganization due to loading and/or dewatering. Post-depositional chemical and physiochemical processes can also lead to a variety of unique sedimentary structures.

If deposited on or near a slope, sediment tends to move downslope. When little or no deformation results from this movement, it is termed a ***slide***. Where the sediment mass is internally deformed (shows folding) as a result of the movement, then the term ***slump*** is more appropriate (see figure below). The terms ***disrupted***, ***convolute*** and ***contorted bedding*** are used to describe bedding (or cross-stratification) that has been deformed, but where there has been not large-scale movement of the sediment itself. Such deformation can arise from shearing by currents and frictional drag exerted by moving sand.

Load structures are formed through differential sinking of one bed into another. ***Load casts***, for example, are common on the soles of sandstone beds overlying mudrock, occurring as bulbous rounded structures without preferred orientation. ***Flame structures*** (see upper left cover figure,), on the other hand, form when flame-like protuberances of mud are injected up into overlying sandy sediments. ***Pseudonodules***, known figuratively as ***ball and pillow structures***, also form when masses of sand load downward into the underlying mud and are then pinched off.



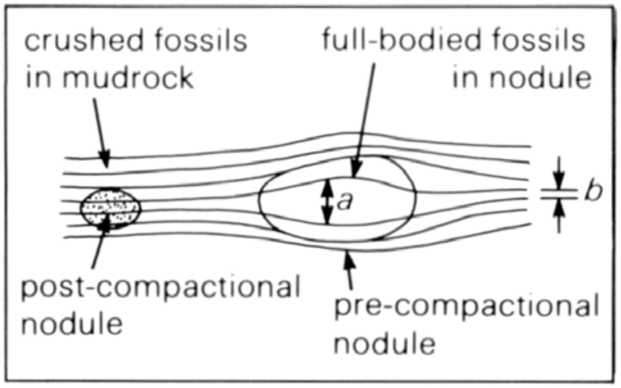
Features of a slumped bed

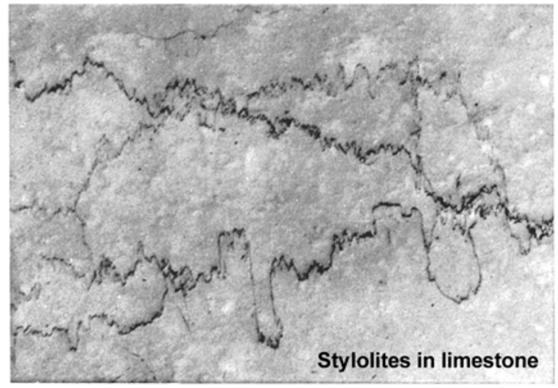


(a) Scoured vs. (b) Loaded surface

Dissolution resulting from loading and/or tectonic pressure is particular to several types of sedimentary rocks. The effects are commonly seen within and at the junctions of limestone beds in the form of ***stylolites***, sutured to irregular dissolution seams with insoluble material concentrated along them. The occurrence of pressure dissolution can also be demonstrated by the partial loss of fossils across stylolites.

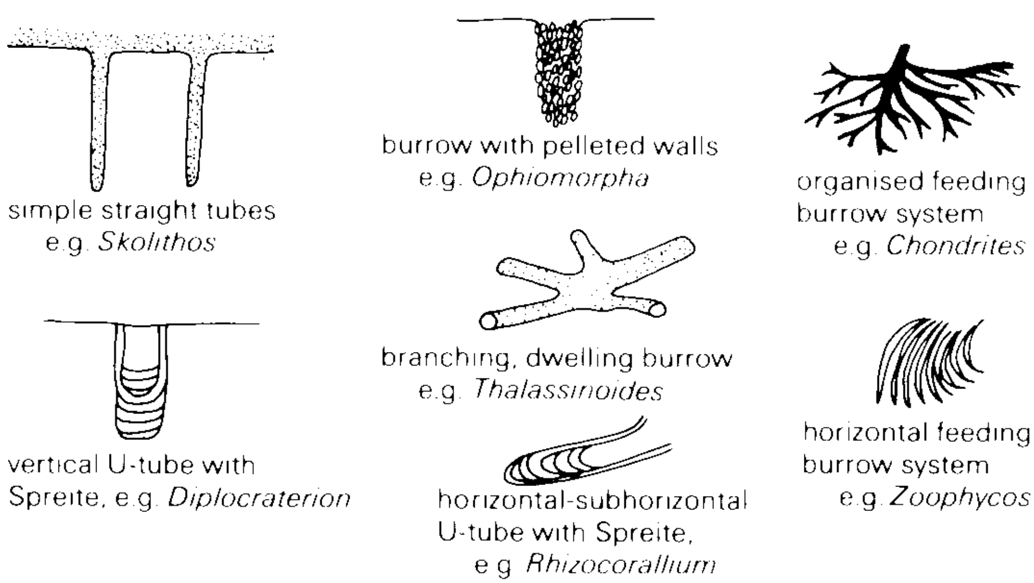
Nodules or ***concretions*** are common post-depositional structures formed largely as a result of local cementation in mudrocks, limestones and sandstones. Some are nucleated around fossils/shells but the majority are unrelated to any pre-existing inhomogeneity in the enclosing sediment. Nodules may be randomly dispersed or concentrated along a particular horizon and vary from spherical through flattened and elongate to irregular in shape. They typically comprise fine-grained varieties of calcite, dolomite, siderite, pyrite, quartz and gypsum/anhydrite.





Biogenic sedimentary structures are formed through the activities of animals and plants and vary widely from indistinct disruptions of bedding/laminations (***bioturbation***) to discrete ***trace fossils*** (***ichnofossils***). The term ***ichnofabric*** refers to the sediment's texture and internal structure arising from bioturbation and a ***bioturbation index*** [from 0 (no disruption) to 6 (complete disruption)] is often used to describe the degree of disruption. Trace fossils are best considered in terms of their mode of formation: crawling, grazing and resting (on bedding surfaces) and feeding and dwelling (within the beds). A summary of their main features appears below:

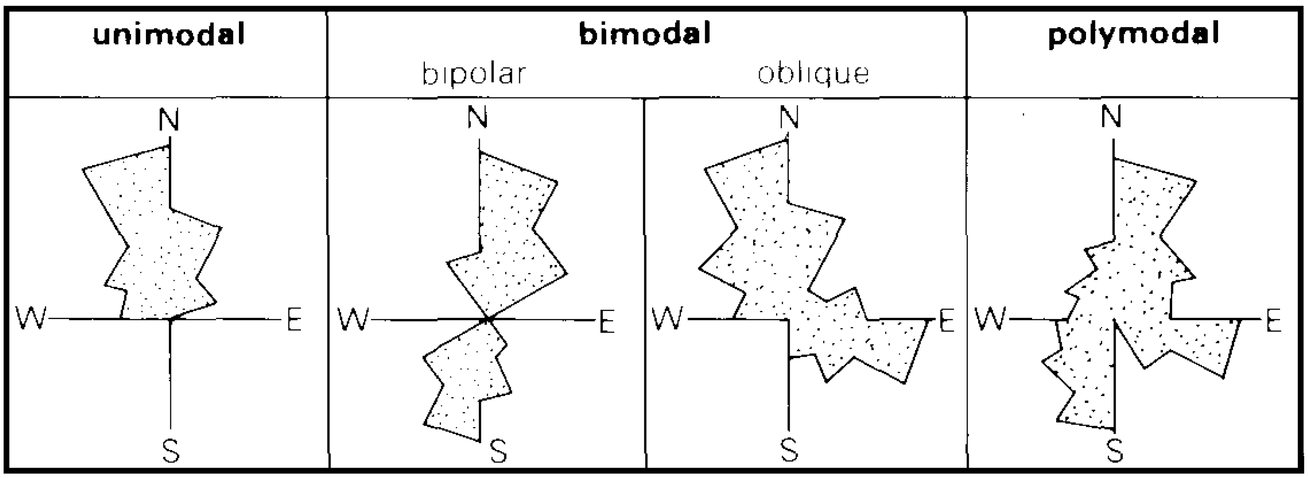
- **crawling traces**: trails, uncomplicated pattern; linear or sinuous.
- **grazing traces**: more complicated surface trails, symmetrical or ordered pattern; coiled, radial, meandering.
- **resting traces**: impression of where animal rested during life (but not a fossil mold).
- **dwelling structures**: simple to complex burrow systems but without suggestion of systematic working of sediment; burrows can be lined or pelleted.
- **feeding structures**: simple to complex burrow systems commonly with well-organised and defined branching pattern indicating systematic reworking of sediment.



Palaeocurrent Analysis

The measurement of palaeocurrents is a vital part of the study of sedimentary rocks in that they provide information on palaeogeography, palaeoslopes, current and wind directions and they are useful in facies interpretation. Of the sedimentary structures commonly seen in the field, cross-stratification and sole marks have proven to be the most reliable. With planar cross-bedding, the palaeocurrent direction is simply the direction of maximum angle of dip. For trough cross-bedding, the palaeocurrent direction is parallel to the trough axis. Palaeocurrent directions can also be easily determined from groove and flute casts (see figures above).

Palaeocurrent measurements are grouped into classes of 10º, 15º, 20º or 30º intervals (depending on the number of readings and their variability) and then plotted on a ***rose diagram***. Azimuths are conventionally plotted in the direction to which the current flowed. There are four types of palaeocurrent patterns, ***unimodal***, ***bimodal*** and ***polymodal***, depicted below:



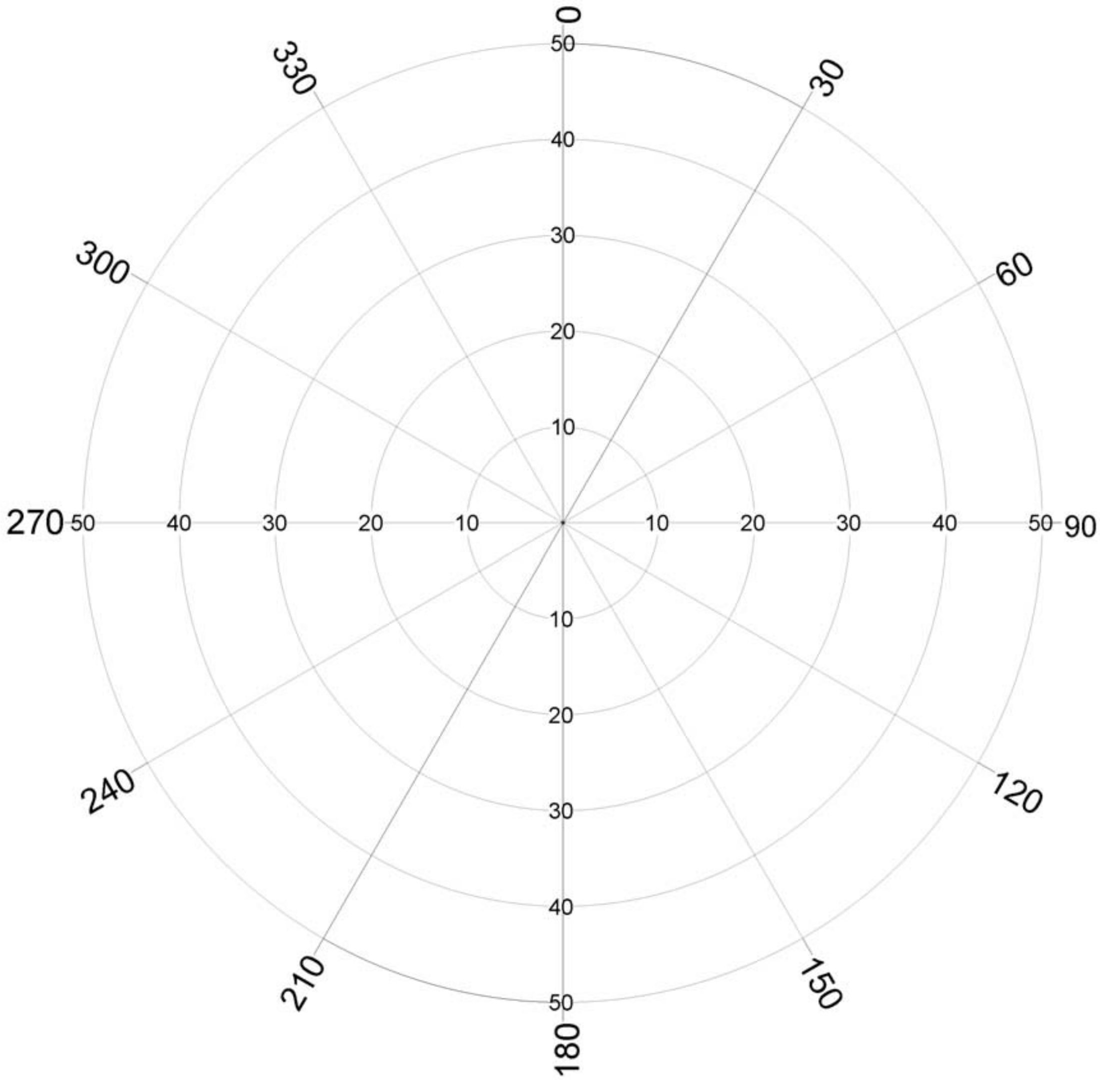
As tectonism may have changed the shape and/or orientation of the sedimentary structure(s), it may be necessary to correct your measurements before plotting. The most common correction is for the effects of tilting of the strata of which the sedimentary structures are a part. The following table summarizes the environmental significance of palaeocurrent patterns:

ENVIRONMENT	LOCAL CURRENT VECTOR	REGIONAL PATTERN
Alluvial - Braided	Unimodal, low variability	Often fan shaped
- Meandering	Unimodal, high variability	Slope controlled; often centripetal basin fill
Eolian	Uni-, bi- or polymodal	May swing round over hundreds of miles around high-pressure systems
Deltaic	Unimodal	Regionally radiating
Shorelines and shelves	Bimodal (due to tidal currents), sometimes unipolar or polymodal	Generally consistently oriented offshore, offshore or longshore
Marine turbidite	Unimodal (some exceptions)	Fan shaped or, on a larger scale, trending into or along trough axes

Please refer to pages 48-51 in Prothero and Schwab for further details on palaeocurrent analysis.

LAB 5 ASSIGNMENT

1. The data sets appearing on the following three pages each consist of 15 sedimentary structure measurements, as noted. Analyze these measurements by completing the table and plotting up a rose diagram. Specify what type of paleocurrent pattern is indicated and suggest a *possible* depositional environment for each. **(4 marks each)**

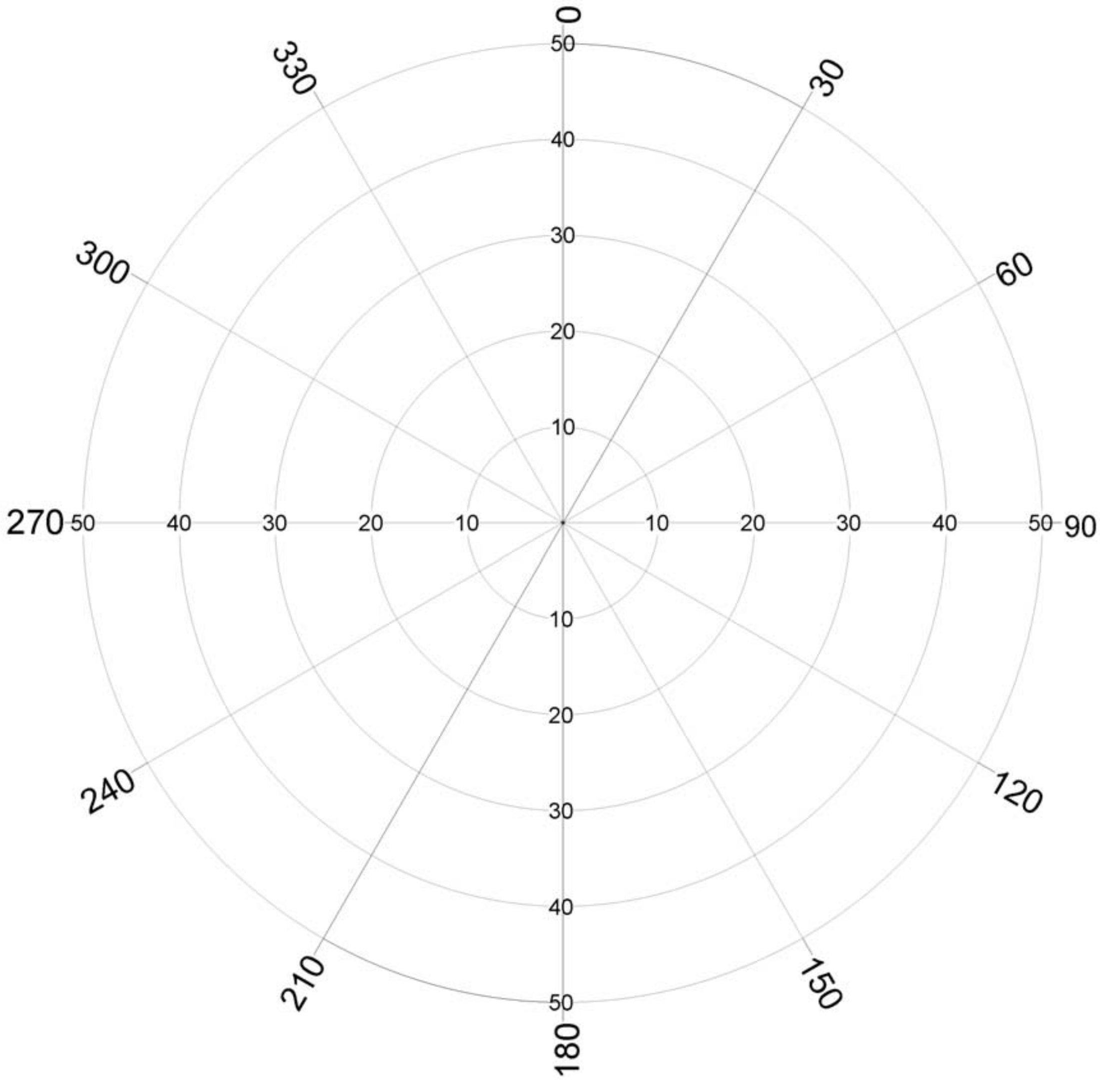


Data set #1 – groove cast trends:

4º, 12º, 18º, 28º, 31º, 35º, 45º, 47º, 58º, 61º, 80º, 98º, 117º, 125º, 335º.

Class (º)	# of Observations	Percent (%)
0 – 29º		
30 – 59º		
60 – 89º		
90 – 119º		
120 – 149º		
150 – 179º		
180 – 209º		
210 – 239º		
240 – 269º		
270 – 299º		
300 – 329º		
330 – 359º		

Paleocurrent pattern: __________________________ **Depositional Environment:** ________________________

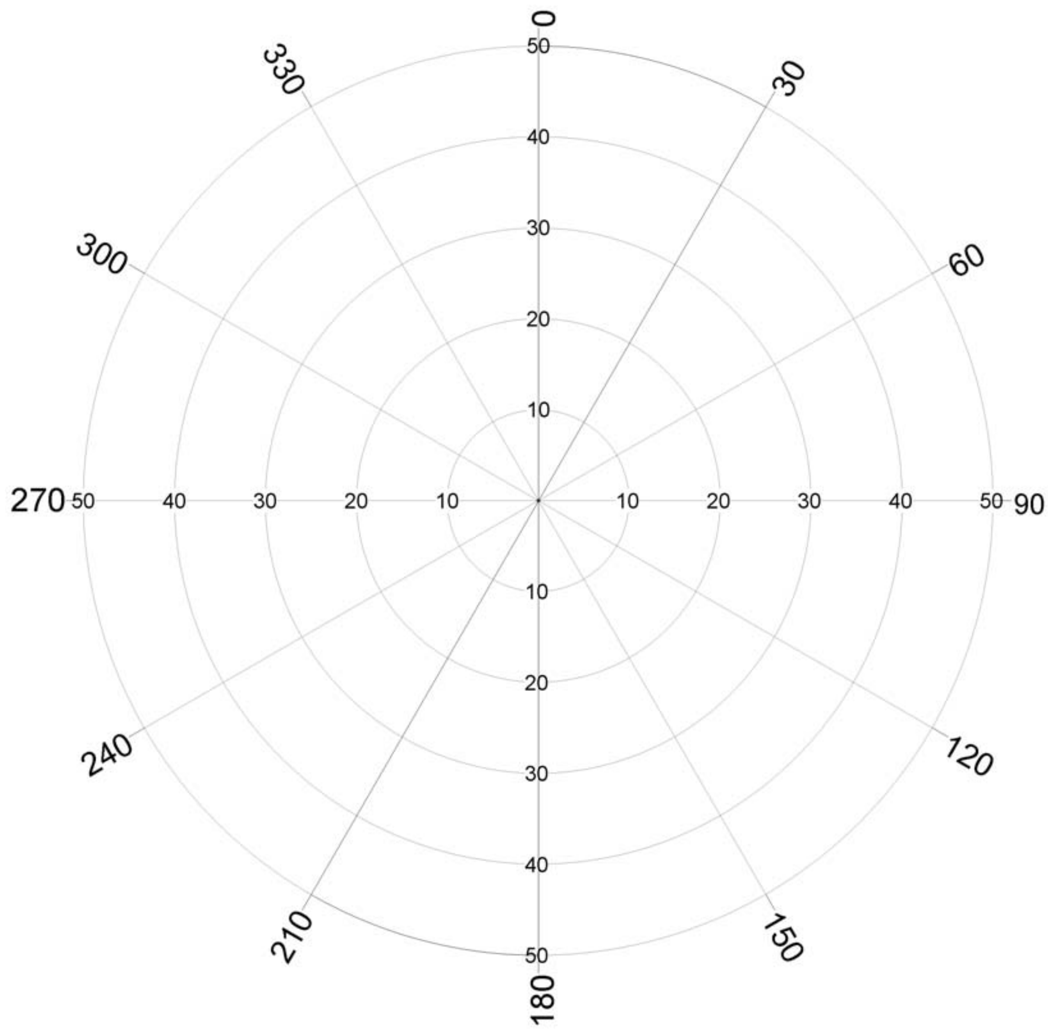


Data set #2 – maximum dip direction of *herringbone* cross-bedding:

34º, 42º, 61º, 66º, 72º, 79º, 84º, 99º, 145º, 212º, 239º, 253º, 257º, 261º, 269º.

Class (º)	# of Observations	Percent (%)
0 – 29º		
30 – 59º		
60 – 89º		
90 – 119º		
120 – 149º		
150 – 179º		
180 – 209º		
210 – 239º		
240 – 269º		
270 – 299º		
300 – 329º		
330 – 359º		

Paleocurrent pattern: __________________________ Depositional Environment: ________________________



Data set #3 – maximum dip direction of *truncated* cross-bedding:

12º, 23º, 29º, 56º, 68º, 90º, 102º, 119º, 134º, 156º, 178º, 198º, 245º, 336º, 340º.

Class (º)	# of Observations	Percent (%)
0 – 29º		
30 – 59º		
60 – 89º		
90 – 119º		
120 – 149º		
150 – 179º		
180 – 209º		
210 – 239º		
240 – 269º		
270 – 299º		
300 – 329º		
330 – 359º		

Paleocurrent pattern: __________________________ Depositional Environment: _____________________