Chapter four
Sedimentary structures

Introduction

Sedimentary structures; are large-scale features of sedimentary rocks that are best studied in the field, formed from aggregates of grains and generated by a variety of sedimentary processes. They occur abundantly in siliciclastic sedimentary rocks and also occur in nonsiliciclastic sedimentary rocks. Whereas "sedimentary texture" applies mainly to the properties of individual sediment grains.

Significance of sedimentary structures

1) Reflect environmental conditions that prevailed at or very shortly after the time of deposition, as a tool for interpreting ancient depositional environments (sediment transport mechanisms, paleocurrent flow directions, relative water depths, and relative current velocities).
2) To identify the tops and bottoms of beds and thus to determine if sedimentary successions are in the right depositional stratigraphic order or not.

Classification of sedimentary structure

Sedimentary structures are divided into primary and secondary classes (Table 4.1).
1. Primary sedimentary structures are generated at the time or shortly after deposition by *physical processes*.
2. Secondary sedimentary structures are formed after deposition mainly by *chemical processes*.
1. Primary sedimentary structures are divisible into:
A- Inorganic sedimentary structures.
B- Organic sedimentary structures.

Classification of Sedimentary Structures

I. Primary (physical)	Inorganic	Fabric	Microscopic
		Cross-bedding, ripples, etc.	Megascopic
	Organic	Burrows and trails	
II. Secondary (chemical)	Diagenetic	Concretions, etc.	

(Table 4.1) Classification of sedimentary structures.

1A. Primary inorganic sedimentary structures:

They include following groups (Table 4.2)

Classification of Inorganic Megascopic Primary Sedimentary Structures

Group	Examples	Origin
I. Predepositional (interbed)	Channels Scour-and-fill Flute marks Groove marks Tool marks	Predominantly erosional
II. Syndepositional (intrabed)	Massive Flat-bedding (including parting lineation) Graded bedding Cross-bedding Lamination Cross-lamination	Predominantly depositional
III. Postdepositional (deform interbed and intrabed structures)	Slump Slide Convolute lamination Convolute bedding Recumbent foresets Load structures	Predominantly deformation
IV. Miscellaneous	Rain prints ,Salt pseudomophs Shrinkage cracks, Sand Dikes	

(Table 4.2) Classification of primary inorganic sedimentary structures

1A-1: Predepositional (Interbeded) structures (Erosional):

It occur on surfaces ***between*** beds, before the deposition of the overlying bed by erosional processes. These are called **sole marks** (bottom structures). The convex structures on the upper bed are termed "**casts**." The concave hollows in the underlying bed are termed "**molds**".

1. Channels show a U-shape or V-shape in cross section and cut across earlier-formed bedding and lamination (Fig. 4.1A). They range in width and depth from a few centimeters to many meters. Larger channels extend for kilometers wide and hundreds of meters deep.

• They are **formed** by erosion (by currents) or mass movements.

• They **occur** in diverse environments ranging from subaerial alluvial plains to submarine continental margins. (e.g.: Fluvial and tidal channels, submarine channels).

• Channels are of great economic importance for several reasons. They can be petroleum reservoirs and aquifers, they can contain placer and replacement mineral ore bodies, and they can cut out coal seams.

2. Scour-and-fill structures are small scale channels whose dimensions are measured in decimetres rather than meters (Fig. 4.1B). They consist of small filled troughs (coarse- or fine-grained sediments) with their long axis point downcurrent.

• They are **formed** as a result of scour by currents and subsequent backfilling as current velocity decreases.

• They (in contrast to channels) **occur** as closely spaced groups in a row.

• They are primarily of fluvial origin and occur in river, alluvial-fan, or glacial outwash-plain environments.

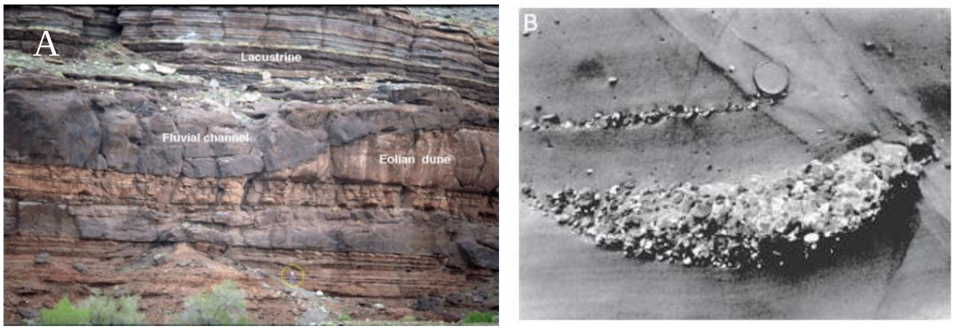


Fig. 4.1**.** A Fluvial channel. B Scour-and-fill structures. A small depression was scoured into underlying sand by currents, then filled with gravel and sand.

3. Flutes marks are heel-shaped hollows, scoured into mud bottoms. Each hollow is generally infilled by sand, contiguous (merges) with the overlying bed. They are about 1-5 cm wide and 5-20 cm long, and typically occur as groups (Fig. 4.2).The rounded part of the flute Points to the upcurrent end whereas the flared end points to the downcurrent **(excellent paleocurrent indicators)**.

• They **formed** by localized scouring action of a current moving over an unconsolidated mud bottom.

• They **typically occur** on the soles of turbidite deposits (at the base of Bouma sequences Fig. 3.11), but they are also occur in other environments

• They are used to determine current flow directions in ancient rocks.

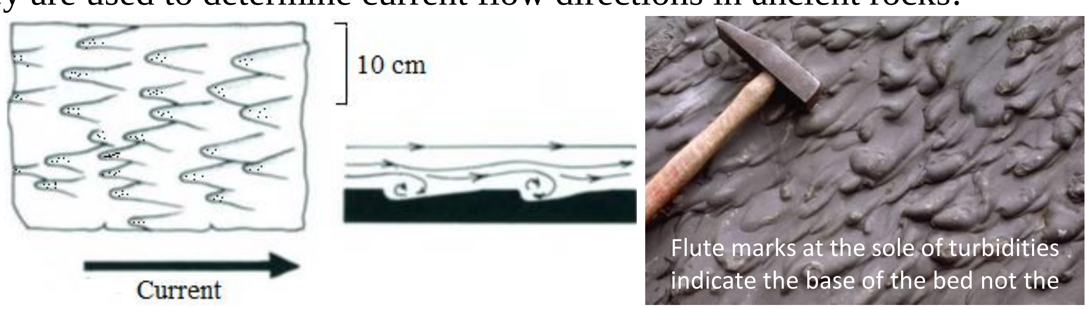


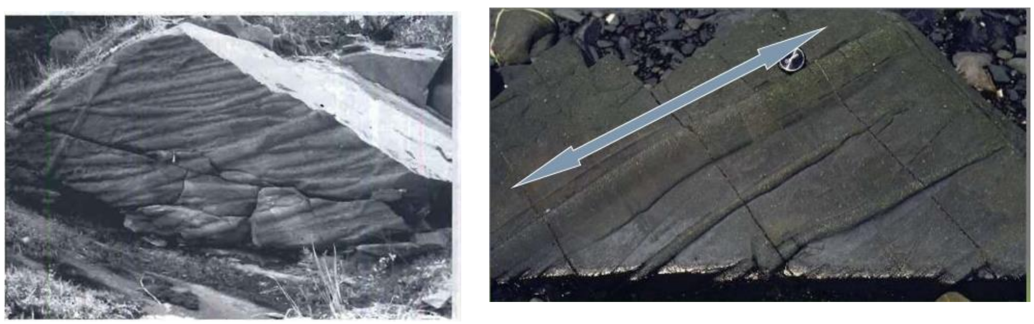
Fig. 4.2. (Left) Plane view sketch of flute marks and (Middle) cross-section showing scouring of fluted hollows in soft mud by current vortices, (Right) field photo.

4. Groove marks are elongate, thin, straight erosional marks, like flutes, tend to be cut into mud and overlain by sand. They are a few millimeters deep or wide and have a relief of a few millimeters to centimeters (Fig. 4.3), larger groove casts also occur. In cross-section, the grooves are angular or rounded.

• They **result** from infilling of erosional relief produced by a pebble, shell, piece of wood, or other object being dragged or rolled across the surface of cohesive sediment.

• They are oriented parallel to the flow direction of the ancient currents; thus, they give only the sense of paleoflow (paleocurrent significance).

• They are, like flutes, especially characteristic of turbidities sands.

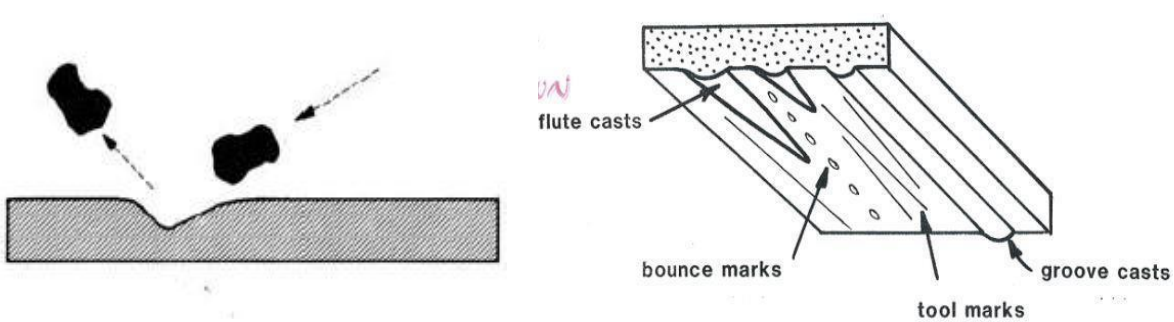


(Fig. 4.3) (Right) Large intersecting groove casts on the base of a graded turbidite sandstone. (Left) Groove casts oriented parallel to the flow direction.

5. Tool Marks are erosional bottom structures produced by tools (pebbles, wood and plant fragments, shells, and fish vertebrae) that make intermittent contact with the bottom, creating small marks. (Fig 4.4).

• They cut in soft mud bottoms like flutes and grooves and subsequently filled with coarser sediment to produce positive-relief casts.

• They are irregular in shape, both in plan and cross-section, and are roughly oriented parallel with the paleocurrent.

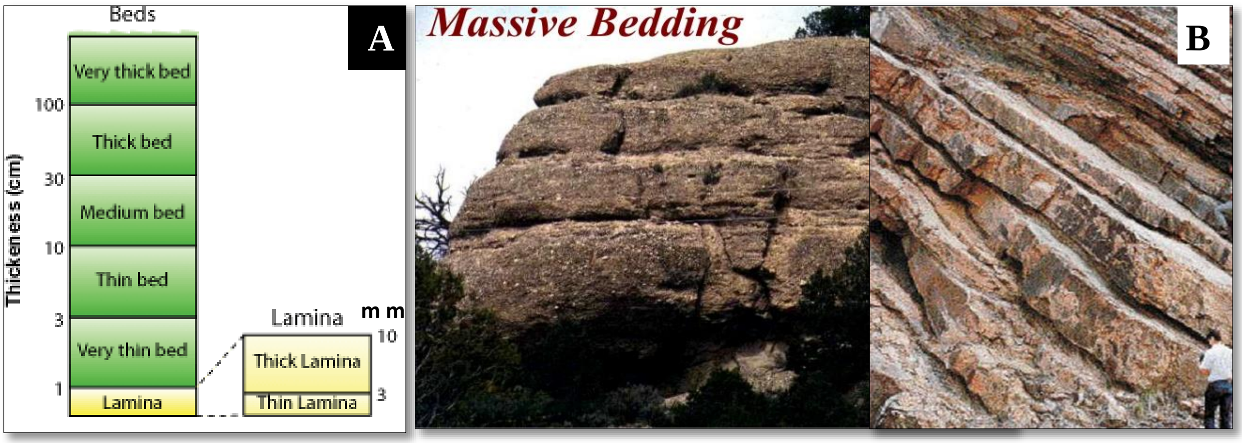


(Fig. 4.4) (Left) Cross section of Tool marks. (Right) Different Sole markings indicate the base of a bed not the top.

1A-2: Syndepositional (Intrabeded) structures (depositional):

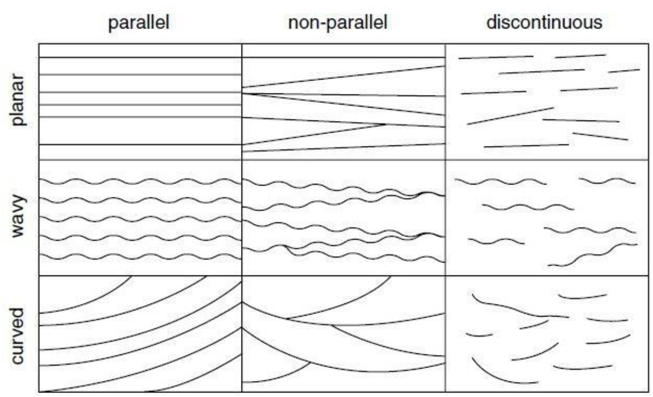
They are constructional structures that are formed during deposition, thus they are present ***within*** sedimentary beds.

Beds; are tabular or lenticular layer of sedimentary rock that can be distinguished from strata above and below by *difference* in color, composition and texture. Bedding (**Bed)** is thicker than 1 cm whereas lamination (**Lamina**) is thinner than 1 cm. Bedding is composed of beds; lamination is composed of lamina (Fig. 4.5A).



(Fig 4.5) A. Terms used for describing the thickness of beds and laminae (Ingram, 1954). B. Field photo of Massive bedding.

Beds also vary in their shape and definition so that planar, wavy and curved types are recognised, and these may be parallel to each other, non-parallel or discontinuous (Fig.4.6).



(Figure.4.6) Different types of bedding or lamination

Bedding planes or bedding surfaces; are primary surface in a sedimentary rock separating the upper and lower surfaces of beds, which represent period of non-deposition, erosion, or changes in composition (reflect changes in depositional conditions). Some bedding surfaces may be post-depositional features formed by diagenetic processes.

1. Massive Bedding; are beds that appear homogenous and lacking internal sedimentary structures (Fig.4.5B).

Causes of massive bedding:

A. Diagenesis; this is particularly characteristic of extensively recrystallized limestones and dolomites.

B. Bioturbation; primary sedimentary structures may be completely destroyed by intensive organic burrowing.

C. Primary features (Genuine Massive Bedding):

. Deposition in quite, low-energy environment (such as some claystones, marls and chalks).

. Reef rock also commonly lacks bedding.

. Deposits of mud flows (debris flows), grain flows, and the lower (A unit) part of turbidites (very rapid deposition).

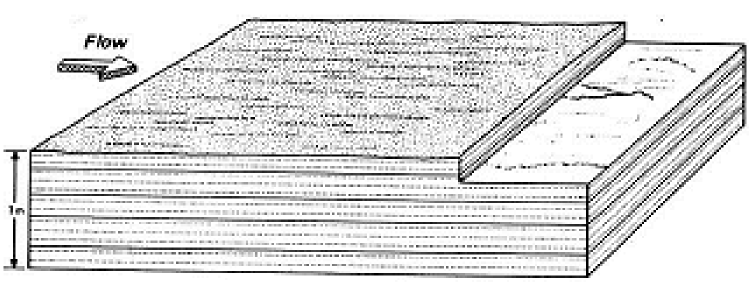
In sandstones massive bedding is rare. It is most frequently seen in very well-sorted sands, where sedimentary structures cannot be delineated by textural variations.

2. Flat-bedding (planar bedding); is planar beds that are deposited horizontally parallel to the bedding plane surfaces (Fig.4.7).

• It occurs in sand-size sediments (terrigenous and carbonate) in diverse sedimentary environments (fluvial channels, beaches, delta fronts and Aeolian sand sheets).

• Internal, bedding surfaces may show *parting lineations* in which sand grains are arranged with the long axes parallel to the flow direction.

• It is **attributed** to sedimentation from a planar bed form under *shooting flow* or a transitional flow regime with a *Froude number* of approximately **1** (Look at Fig. 3.5 Chapter three).



Planar stratification produced from upper flow regime, plane beds.
Internal, bedding surfaces may show parting lineations

(Fig.4.7) Flat-bedding (planar bedding).

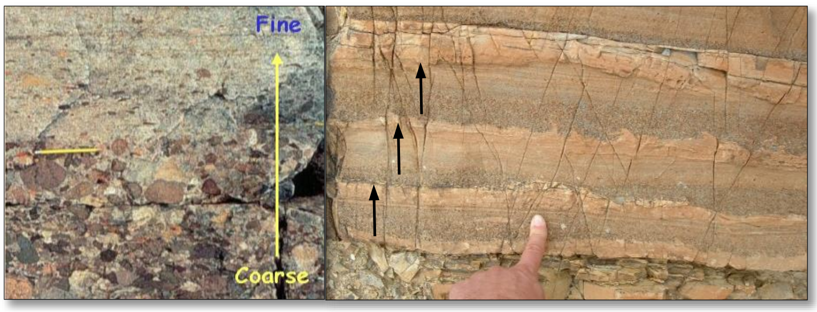
3. Graded bedding: is progressive (a gradual) change in grain size from bottom to top of a bed (Fig. 4.8).

• Graded beds range in thickness from a few Cm. to a few meters and commonly have sharp basal contact.

• It is commonly **occur** at the basal part of turbidities associated with flute and groove marks.

• It is commonly ***produced*** by turbidity currents as a sediment settles out of suspension, normally during the waning phase of a turbidity flow.

• It helps to determine the base and the top of a bed.



(Fig. 4.8) Graded bedding: (Left) Normal grading. (Right) Compound grading.

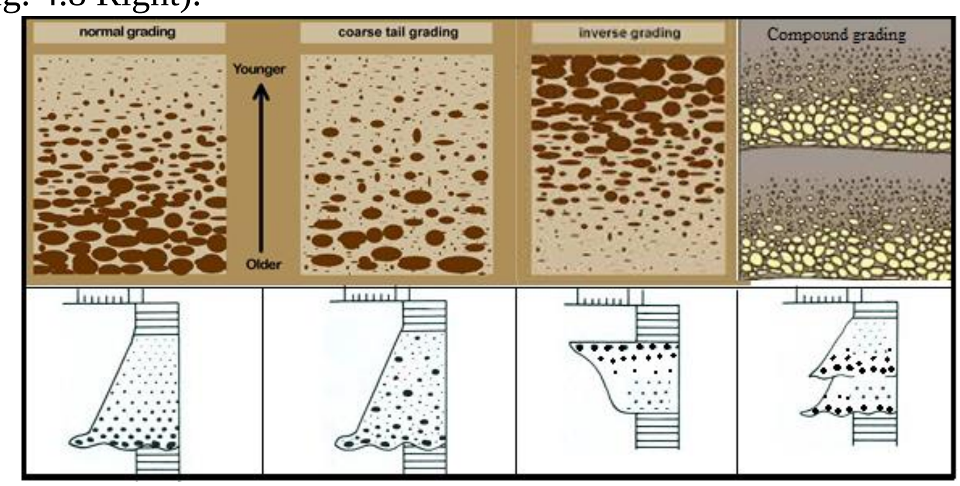
Types of graded bedding: (Fig. 4.9)

A. **Normal grading;** a gradual upward decrease in grain size through a bed (common) (Fig. 4.8 Left). It is commonly occur at the basal part of turbidites.

B. **Coarse tail-grading;** a gradual upward decrease in the size of coarse grains through a bed.

C. **Reverse grading;** when the grain size increase upward through a bed (not common).

D. **Compound (multiple) grading;** where there are several grade subunit in a bed occur (Fig. 4.8 Right).



(Fig. 4.9) Types of graded bedding.

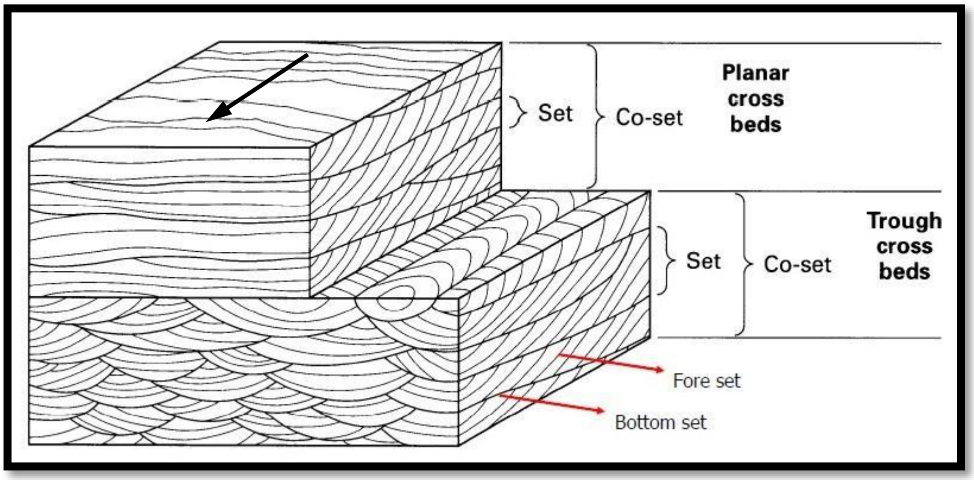
4. Cross-bedding; It is one of the most common and most important of all sedimentary structures (the most important paleocurrent indicators). Cross-bedding, consists of inclined dipping bedding, bounded by sub-horizontal surfaces.

• It is ubiquitous in traction current deposits in diverse environments.

• Individual beds range in thickness from a few tens of centimeters to a meter or more.

• It is used to determine current flow directions in ancient rocks (very excellent paleocurrent indicators).

• Each of cross bedded units (Isolated cross-bed) is termed ***a set***. Vertically contiguous sets are termed **cosets** (Fig. 4.10). The inclined bedding is referred to as a ***foreset***. Foresets may grade down with decreasing dip angle into a ***bottomset*** or ***toeset***.



(Fig. 4.10) Basic nomenclature of cross-bedding. Tabular planar cross-beds have subplanar foresets. Trough cross-beds have spoon-shaped foresets. Isolated cross-beds are referred to as sets. Vertically grouped foresets constitute a coset.

Cross-beds are divided on the basis of:

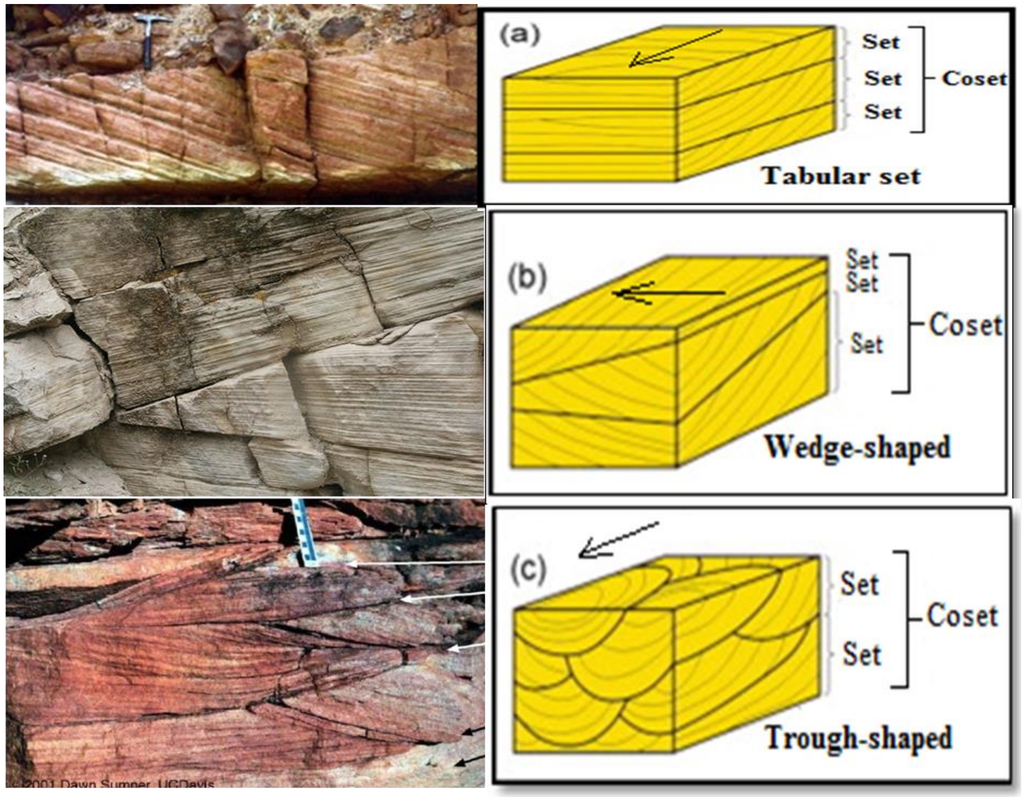
1. Overall geometry (foresets shape).
2. The nature of the bounding surfaces of the cross-bedded units.

They are divided into:

A. Tabular cross-bedding; consists of cross-bedded units bounded above and below by planar bounding surfaces (Fig. 4.11A). The foreset laminae are also commonly planar, but are curved at the basal surface.

B. Wedge-shaped cross bedding; consists of cross-bedded units having oblique bounding surfaces and foreset laminae (Fig. 4.11B).

C. Trough cross-bedding; consists of cross-bedded units having upward concave foreset lie within erosion scours which are elongated parallel to current flow, closed up current and truncated down current by further troughs. (Fig. 4.11C).

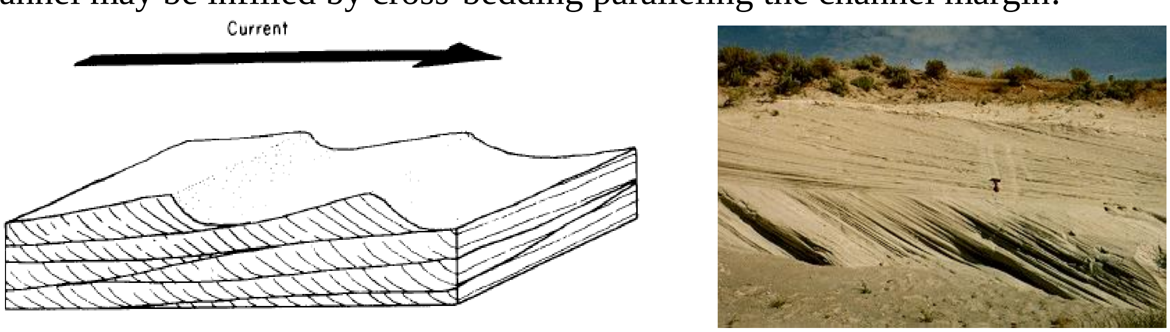


(Fig. 4.11) Types of cross bedding.

Formation of cross bedding:

Formed mainly by the migration of the crested dunes and megaripples (Fig. 4.12);

- Migration of *dune* during lower flow regime conditions.
- Migration of *antidunes* in *upper flow regime conditions* to deposit upcurrent dipping cross-beds (Look at Fig. 3.5 Chapter three).
- In river channels (braided type) a single set of cross-bedded strata deposited in the steep side of obstacles.
- Channel may be infilled by cross-bedding paralleling the channel margin.



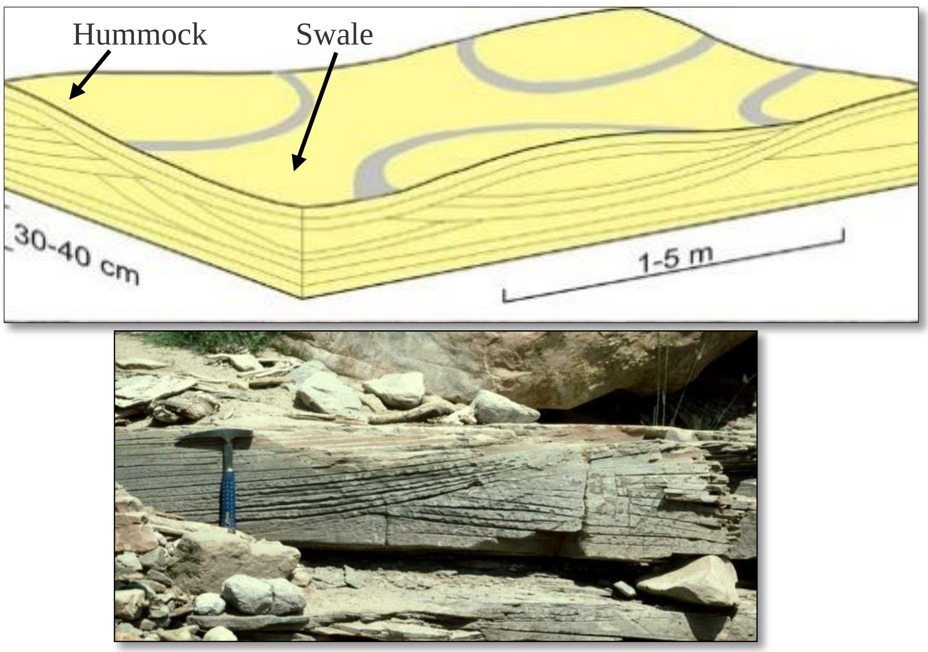
(Fig. 4.12) Formation of tabular planar cross-bedding occurs where dunes migrate down current

D. Hummocky cross-stratification (HCS); occur typically in fine-grained sandstone and characterized by undulating sets of cross-lamination that are concave-up (swales) and convex-up (hummocks) (Fig. 4.13). These cross-beds gently cut into each other with curved erosional surfaces.

• They *form* by storm waves in shallow-water, storm-dominated environments (transition zone between fair-weather wave-base and storm wave-base).

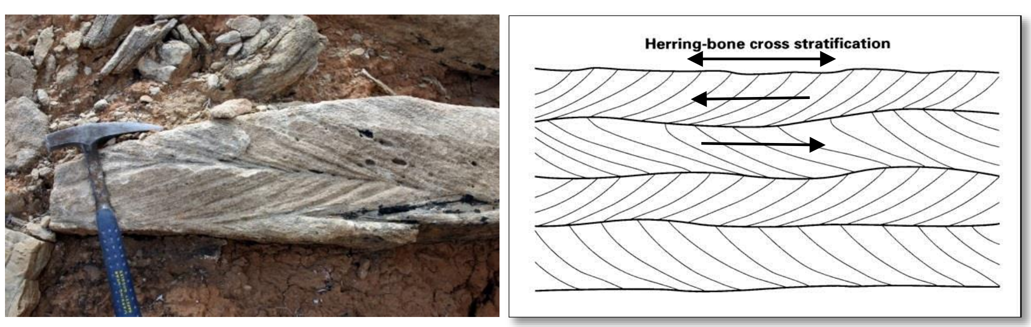
• They lack a specific orientation.

• Hummocky cross-stratified sequences are *storm deposits* (Tempestites)**.**



(Fig. 4.13) Hummocky cross-stratification (HCS).

E. Herring-bone cross bedding; is a type of cross-stratification formed in *tidal area* (tidal channels), where current periodically flow in the opposite direction which reflect the movement of ebb and flood currents (Fig. 4.14).



(Fig. 4.14) Herring-bone cross bedding.

5. Ripples and dune (large scale) bedforms:

Ripples; are small-scale alternating ridges and troughs formed on the surface of sediment layer by moving water or wind. They are ***generated*** under low flow regime condition ($F<1$).

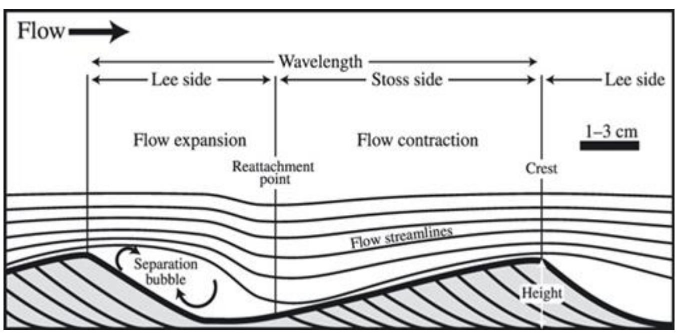
Types of ripples:

A. Symmetrical Ripples (wave or oscillation ripples) form in shallow water by wave action under oscillator1y (bimodal current) flow and tend to be nearly symmetrical in shape and have fairly straight crests

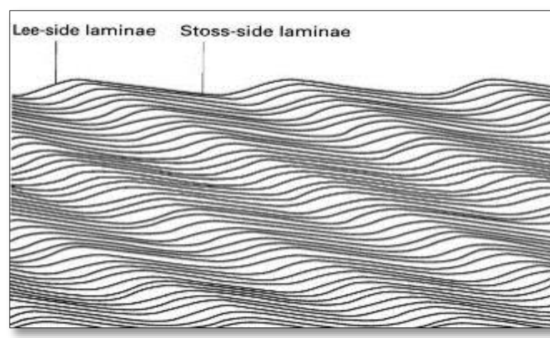
B. Asymmetrical ripples (current ripples) formed by wind or water flowing in one direction (unidirectional current). They are asymmetrical in shape, and the steep or lee side faces downstream in the direction of current flow (Fig. 4.15).

When ripples migrate on unconsolidated noncohesive sediment with simultaneous upward growth forming *climbing ripples* with cross lamination (Fig. 4.16).

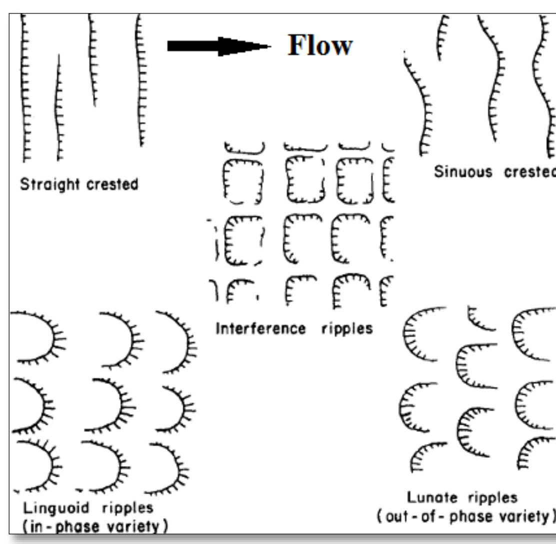
In plain view, the crests of current ripples have a variety of shapes: straight, sinuous, catenary, linguoid, and lunate. The plan-view shape of ripples is apparently related to water depth and velocity (Allen, 1968); (Fig. 4.17).



(Fig. 4.15) Nomenclature of asymmetrical ripple.



(Fig. 4.16) Climbing ripples cross-lamination



(Fig. 4.17) Nomenclature of rippled bed forms

In plain view (Allen, 1968).

Types of ripples bedding (ripples bedforms):

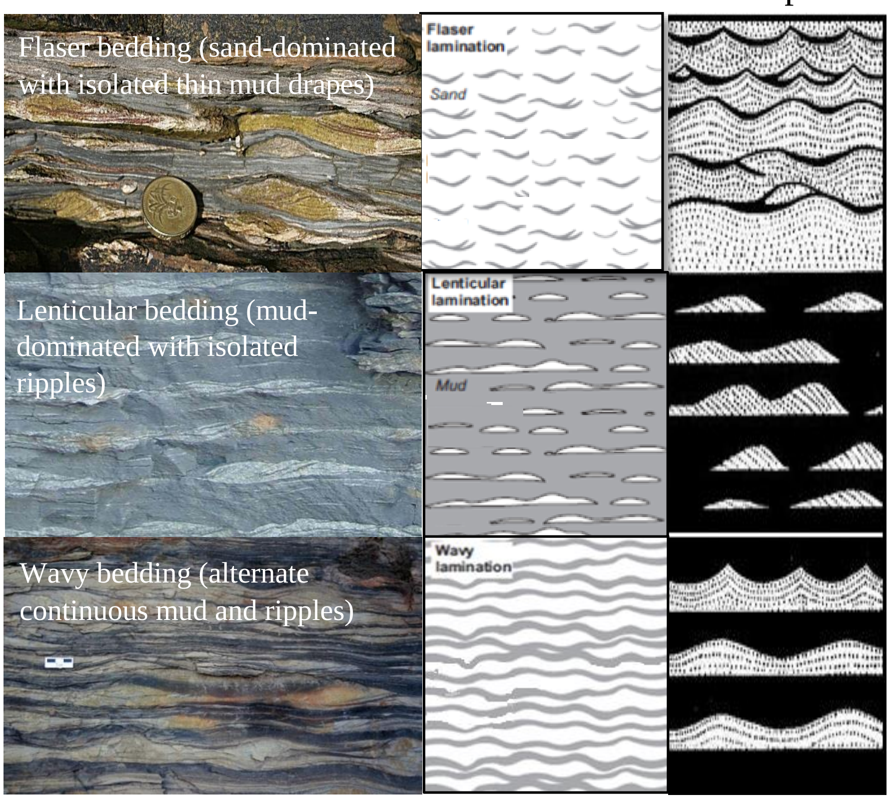
Ripples bedding; is characterized by alternating sand and mud laminae or beds including; flaser, lenticular and wavy bedding (Fig. 4.18).

A. Flaser bedding is where cross-laminated sand contains mud streaks, usually in the ripple troughs (sand more than mud). These are commonly forms in relatively high energy environments (sand flats)

B. Lenticular bedding is a structure formed is where mud dominates and the cross-laminated sand occurs in lenses (mud more than sand). They are commonly forms in relatively low energy environments.

C. Wavy bedding is a structure formed by interbedded mud and ripple cross-laminated sand in which the ripples or sand lenses are continuous in both a vertical and a horizontal direction. These are commonly forms in environments that alternate frequently from higher to lower energies (mixed flats).

Flaser and lenticular bedding *form* particularly on *tidal flats* and in *subtidal environments* where conditions of current flow or wave action that cause sand deposition alternate with slack-water conditions when mud is deposited.



(Fig. 4.18) Flaser, lenticular and wavy bedding.

1A-3: Posdepositional structures (deformational):

Are deformational structures, that disturb and disrupt pre- and syndepositional structures (inter- and intrabed structures). They develop during, or shortly after deposition of unconsolidated sediments. They indicate slumping or compression of layers before complete lithification.

Types of soft-sediment deformation structures;

1. Convolute Bedding and Lamination; are structure *formed* by complex folding or intricate crumpling of beds or laminations into irregular, generally small-scale anticlines and synclines (Fig. 4.19).

• Convolute bedding is most common in fine sands or silty sands.

• Convolute lamination is most common in turbidite successions (Look at Fig. 3.13), but it also occurs in other deposits.

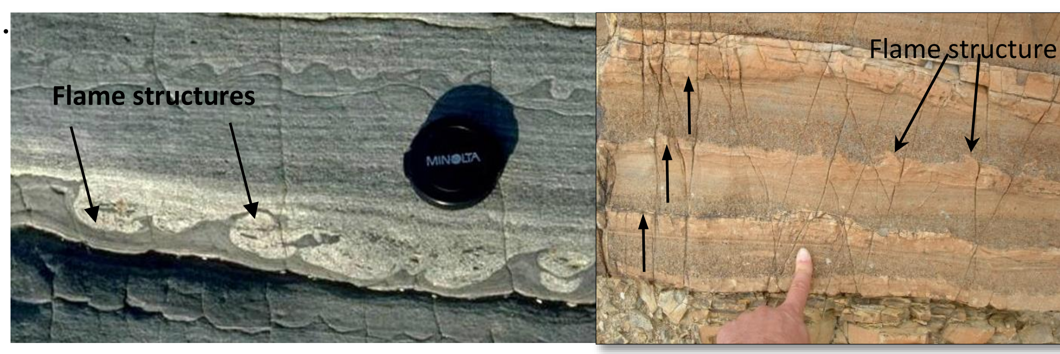
• It appears to be *caused* by plastic deformation of partially liquefied sediment soon after deposition.

(Fig. 4.19) Left and middle; convolute bedding in fine-grained sandstone. Right; Convolute lamination in fine-grained sandstone and shale, Note absence of deformation in the underlying layers.

2. Flame structures; are thin fingers (wavy or flame-shaped tongues) of mud injected upward into the overlying sands (Fig. 4.20).

• They are commonly associated with other structures caused by sediment loading.

• They are probably *caused* mainly by loading of water-saturated mud layers which are less dense than overlying sands and are consequently squeezed upward into the sand layers.



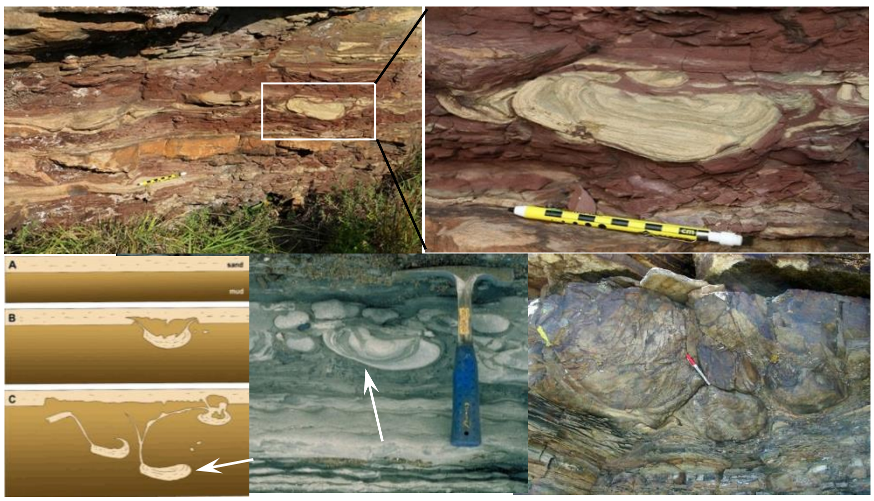
(Fig. 4.20) Right: Flame structures in sandstone shale succession. Left: Associated with turbidities (compound grading)

3. Ball and Pillow Structures; are load structures present in the lower part of sandstone beds, and less common in limestone beds, that overlie shales (Fig. 4.21).

• They consist of hemispherical or kidney-shaped masses (blobs) that show internal laminations.

• The balls and pillows may remain connected to the overlying bed, as in Figure 4.21, or they may be completely isolated from the bed and enclosed in the underlying mud (pseudonodules).

• They form when a dense wet sediment (sand) slumps down into less dense sediment (mud) below.

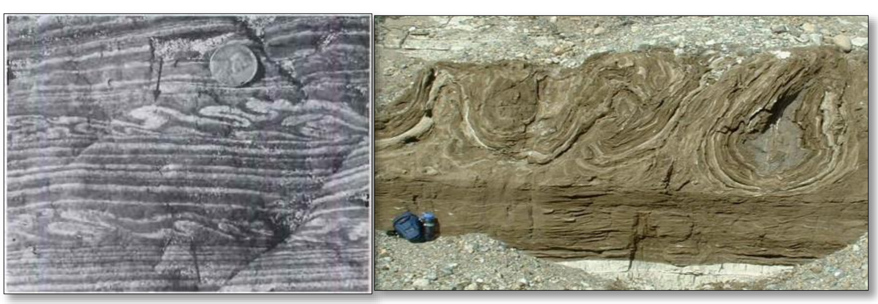


(Fig. 4.21) Ball and pillow structures

4. Slump structures (synsedimentary Folds and Faults); are structures produced by penecontemporaneous deformation of sand and mud generating slump folds and/or faults (Fig. 4.22).

• They *result* from movement and displacement of unconsolidated or semiconsolidated sediment, mainly under the influence of gravity and are found in areas with *steep slopes* and *rapid sedimentation*.

• They are mainly found in sandy shales and mudstones, but may also present in limestones, sandstones, and evaporites.

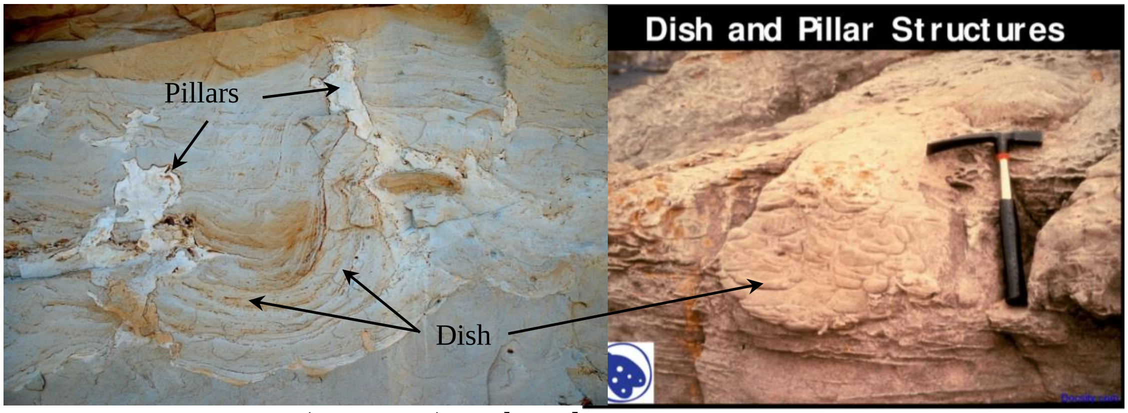


(Fig. 4.22) Left; small-scale decollement-type synsedimentary folds in thin, fine-grained sandstone layers interbedded with shale. Right; Slump folds

5. Dish and Pillar Structures; are dewatering structures *formed* by upward escape of water, commonly due to loading (Fig. 4.23). They are most abundant in sediment gravity-flow deposits (turbidites and liquefied flows, look at Fig. 3.13D) and indicate rapid deposition.

• **Dish** structures are thin, dark-colored, subhorizontal, flat to concave-upward, *clayey* laminations that occur principally in sandstone and siltstone units.

• **Pillars** are vertical to near vertical, cross-cutting columns and sheets of structureless or swirled *sand* that cut through either massive or laminated sands.



(Fig. 4.23) Dish and Pillar Structures.

1A-4 Miscellaneous Structures:

They are sedimentary structures of diverse origin that are not fit conveniently into a simple classification. These include *rain prints*, *salt pseudomorphs*, *shrinkage cracks (Mud cracks* and *Syneresis cracks), sand dikes* and *parting lineation.*

1. Rain prints; are small rounded or ovate (due to windblown rain) depressions range from 2 to 10 mm. in diameter, with small raised rims, which are commonly occur together with mud cracks (Fig. 4.24). They typically occur as closely spaced group.

• They *form* by impact of rain drops on soft mud and mark the top of sediments.

• They are good indicator of subaerial exposures especially in arid environments.

(Fig. 4.24) Left and middle; Rain drops prints. Right; Rain drops marks.

2. Salt pseudomorphs; are molds formed in soft mud by cubic halite crystals (concave "hopper" habit). The original crystals of halite have been dissolved away by non-saline water and the molds have been infilled by mud.

• They are preserved on the base of the overlaying bed as a cast (Fig. 4.25).

• They indicate evaporate condition.

(Fig. 4.25) salt pseudomorphs showing concave “hopper” habit.

3. Shrinkage cracks:

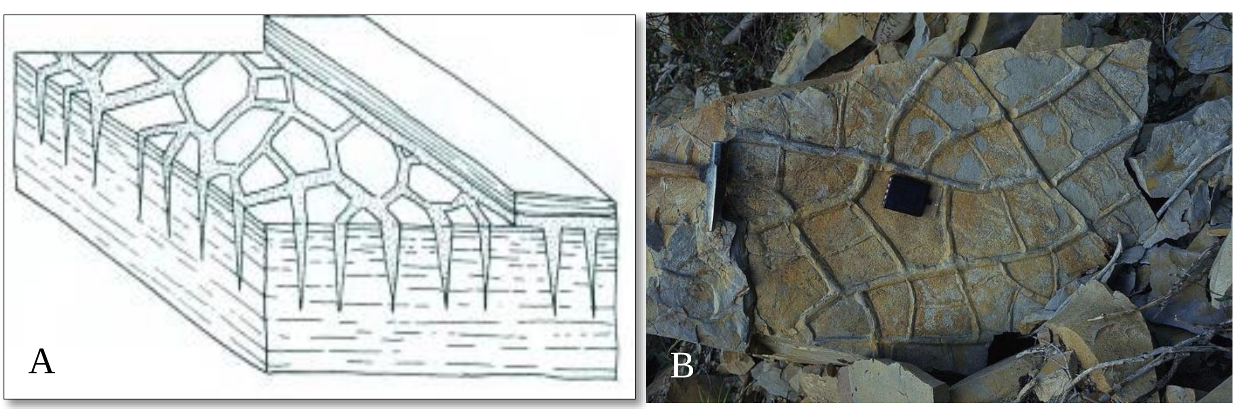
A. Desiccation cracks (Mud cracks); are downward-tapering cracks in mud, which are infilled by sand and displaying polygonal pattern in plain view (Fig. 4.26A). The area between the cracks is commonly curved upward into a concave shape.

• They ***form*** subaerially when mud exposed to **air** is dewaterd, shrinks and leaves a crack.

• They are commonly preserved on the tops of bedding surfaces as positive-relief fillings of the original cracks (Fig. 4.26B).

• They are good indicator of subaerial exposure and may be associated with raindrops or ripple marks, and vertebrate tracks (Fig. 4.24).

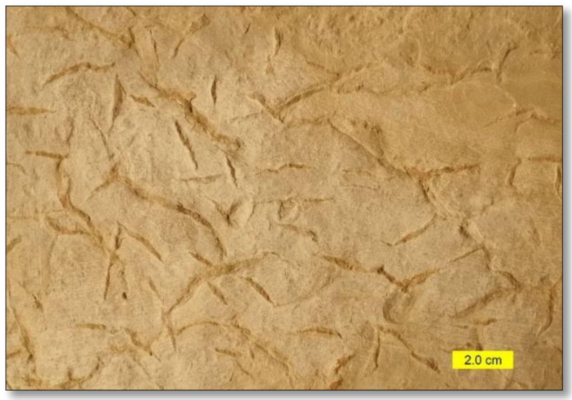
• They *occur* in both siliciclastic and carbonate mud (in estuarine, lagoonal, tidal-flat, river floodplain, Playa Lake, and other environments), where muddy sediment is exposed to air.



(Fig. 4.26) A. Formation of desiccation cracks. B. Ancient mud cracks.

B. Syneresis cracks; are subaqueous shrinkage cracks formed on bedding surfaces. In contrast to mud cracks, they are discontinuous and vary in shape from polygonal to spindle-shaped or sinuous, they are infilled by mud similar or only slightly coarser in grade than that in which they grow. Furthermore, synaeresis cracks are generally much smaller than desiccation cracks; typically only 1-2 mm across (Fig. 4.27).

- They commonly *occur* in thin mudstones interbedded with sandstones.
- They **form** under water (subaqueously) in clayey sediment by loss of pore water from clays that have flocculated rapidly or that have undergone shrinkage of swelling-clay mineral lattices because of changes in salinity of surrounding water.



(Fig. 4.27) Syneresis cracks from the Drakes Formation (Upper Ordovician) of Adams County, Ohio, USA.

4. Sandstone dikes; are tabular bodies of massive sandstone that cut across sedimentary strata (Fig. 4.28). They range in thickness from a few centimeters to more than 1 0 m. Though they are sometimes polygonally arranged, they can be **distinguished** from desiccation cracks by their tendency to die out upward and by the fact that they are rooted to the parent sand bed below.

- They are formed by injection of liquefied sand into overlying rock.

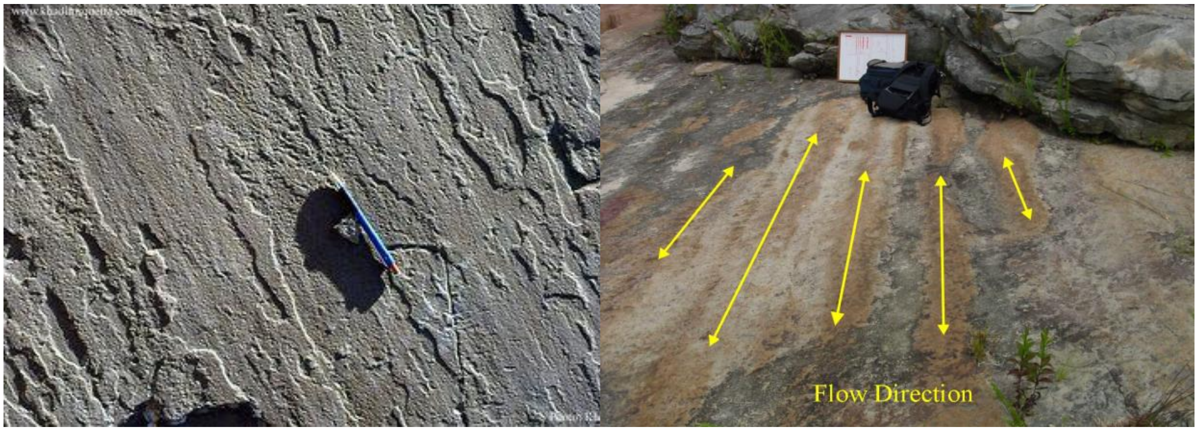
(Fig. 4.28) Sandstone dikes.

5. Parting lineation (current lineation); forms on the bedding surfaces of parallel laminated sandstones (flat "plane" bedding). It consists of subparallel ridges and grooves a few millimeters wide and many centimeters long (Fig. 4.29).

• The lineation is oriented parallel to current flow, and give only the sense of current flow.

• It is most common in ancient deposits in *thin*, *evenly bedded sandstones*.

• Its **origin** is related to, current flow and grain orientation, flowing over upper-flow regime plane beds (Look at Fig. 4.7 and Fig. 3.5 chapter three).



(Fig. 4.29) Parting (current) lineation.

1B. Primary organic sedimentary structures:

They are sedimentary structures produced by the activity of organisms with the sediments. These include; plant rootlets, **tracks** (vertebrate footprints "Fig. 4.30 left"), **trails** (due to invertebrates "Fig. 4.30 Middle"), **burrows** (in soft sediment "Fig. 4.30 Right"), and **borings** (in hard rock). These phenomena are collectively known as *trace fossils* and their study is referred to as *ichnology*.

(Fig. 4.30). Left; Dinosaur foot prints (vertebrate **tracks**).Middle; invertebrate **trail**. Right; Scolithos **burrow** in Cretaceous sandstone.

Trace fossils or Ichnofossils (Creek Ichnos, trace); are biogenic sedimentary structures produced by the activity of organisms (animals or plants) that left behind in sediments.

Biogenic structures include the following:

(1) Bioturbation structures (burrows, tracks, trails, root penetration structures).

(2) Biostratification structures (e.g. algal stromatolites).

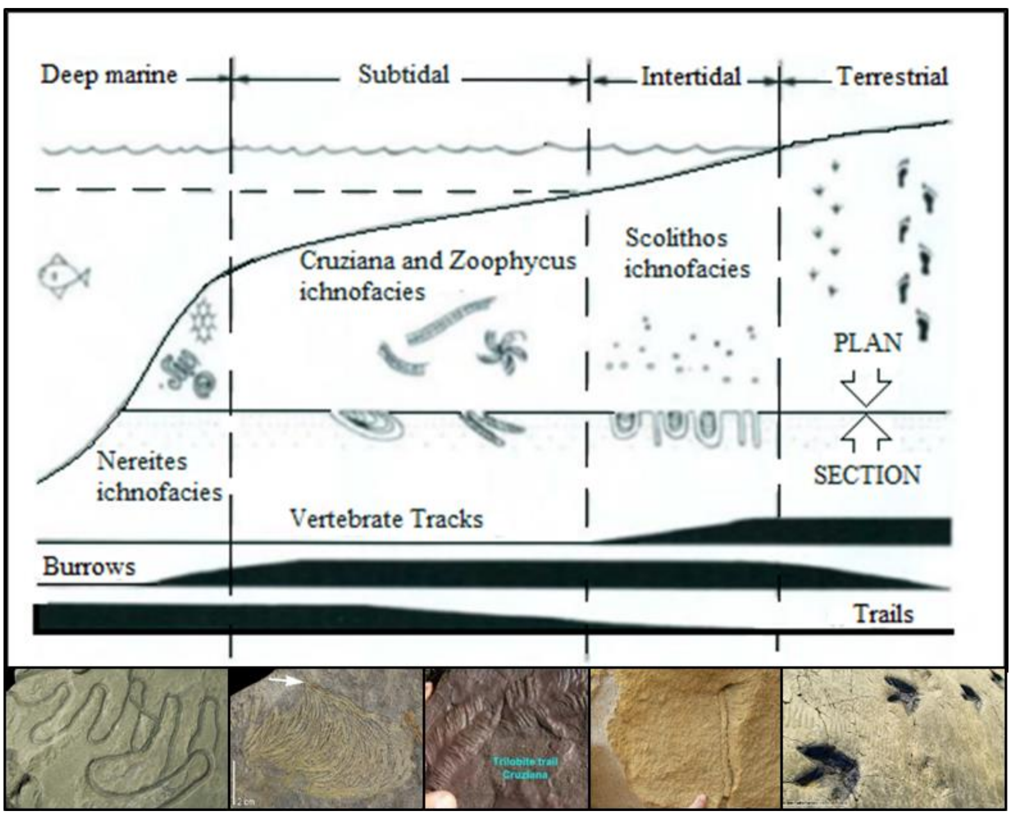
(3) Bioerosion structures (borings, scrapings, bitings).

(4) Excrement (coprolites, such as fecal pellets or fecal castings).

Ichnofacies (Seilacher, 1964)**;** are sedimentary facies characterized by a particular association of trace fossils that indicate a specific environment.

Paleoenvironmental reconstruction:

Some ichnofossils are restricted to particular environment. **The most useful aspect of trace fossils** is the broad correlation between *depositional environment* and *characteristic trace fossil assemblages*. Schemes relating ichnofacies to environments have been drawn up by Seilacher (1964, 1967) as shown in Fig. 4. 31.



(Fig. 4.31) Relationship between of characteristic trace fossils to sedimentary facies and depth zones in the ocean.

Stromatolites; are organically formed, laminated structures composed of fine silt or clay-size sediment or, more rarely, sand-size sediment.

- They are **formed** largely by the trapping and binding activities of blue-green algae (cyanobacteria).
- Most ancient stromatolites occur in limestones (Fig. 4.32).
- They **occur** mainly in the shallow subtidal, intertidal, and supratidal environments.

(Fig. 4.32) Ancient stromatolites in limestones.

2. Secondary sedimentary structures

They are structures formed by precipitation of mineral substances in the pores of semi-consolidated or consolidated sedimentary rock or by chemical replacement processes. These include *concretions, nodules, cone-in cone, stylolites and septarian*.

A. Concretions; are composed mainly of calcite or other minerals (e.g. dolomite, hematite, siderite, chert, pyrite and gypsum). They *form* by precipitation of minerals around some kind of nucleus, such as a shell fragment, and gradually build up a globular mass, which may or may not display concentric layering (Fig. 4.33). They are especially common in sandstones and shales but can occur in other sedimentary rocks.

(Fig. 4.33) Spherical concretions in sandstones.

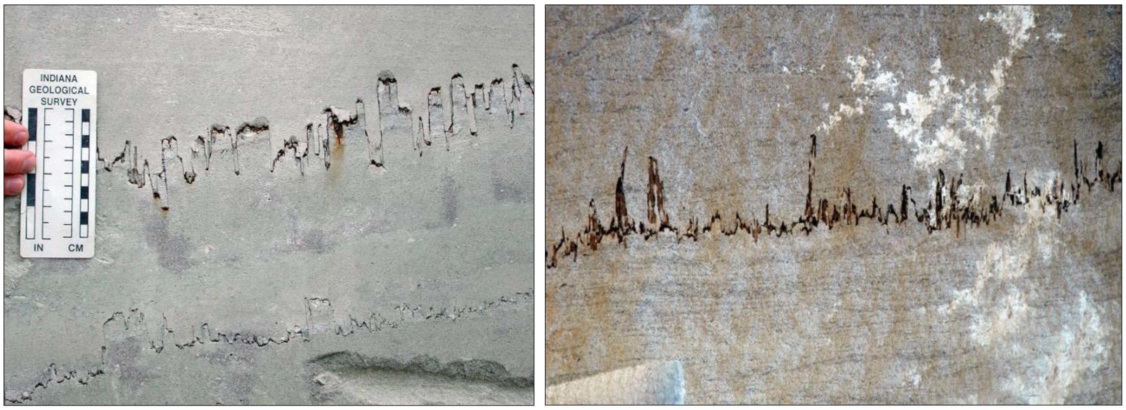
B. Nodules; are spherical or irregular rounded bodies having a warty or knobby surface. They generally have no internal structure except the preserved remnants of original bedding or fossils (Fig. 4.34). Common minerals that make up nodules include chert (e.g. chert nodules in limestones), apatite (e.g. phosphorite nodules), anhydrite, pyrite, and manganese (e.g. manganese nodules). The nodules appear to form by partially or completely replacing minerals of the host rock rather than by simple precipitation of mineral into available pore space.

(Fig. 4.34). Chert nodules in Permian Kaibab limestone.

C. Cone-in-cone; are cone-shaped forms consisting of concentric cones nested inside each other, composed, in most examples, of carbonate minerals with thin layers of clay between cones (Fig. 4.35). They generally occur in, persistent layer of fibrous calcite and are most common in shales and marly limestones.

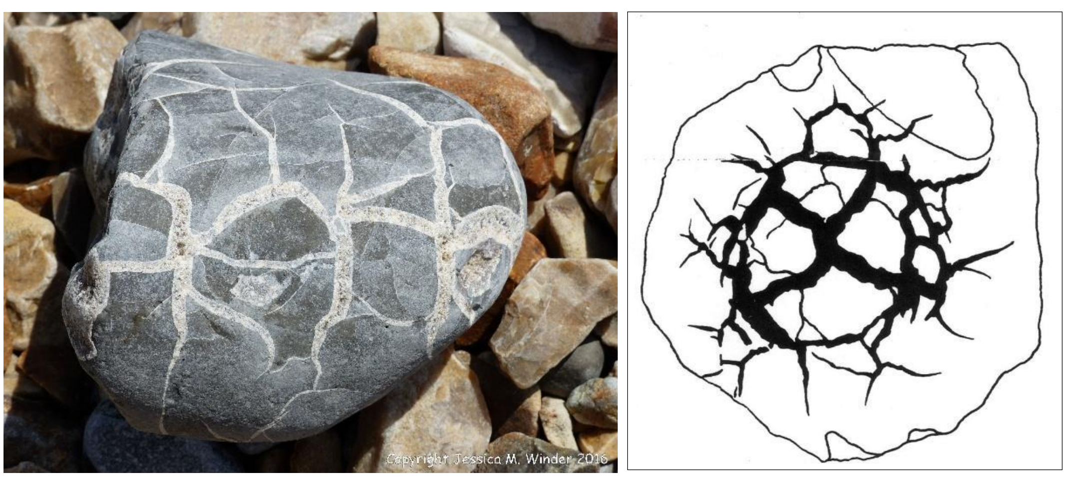
(Fig. 4.35). Cone-in-cone structures.

D. Stylolites; are suture like seams of clay or other insoluble material that commonly occur in limestones owing to pressure solution. The seams result from the irregular, interlocking penetration of rock on each side of the suture (Fig. 4.36). They are generally marked by concentrations of insoluble constituents such as clay minerals, iron oxide minerals, and fine organic matter.



(Fig. 4.36).Stylolites in limestones

E. Septarian; are large (10 to 100 cm), distinctly oblate nodules characterized by a series of radiating cracks that widen toward the center and die out near the margin and that is crossed by a series of cracks concentric with the margin (Fig. 4.37).



(Fig. 4.37).Septarian structure, length of specimen about 5 inches (12 cm).