

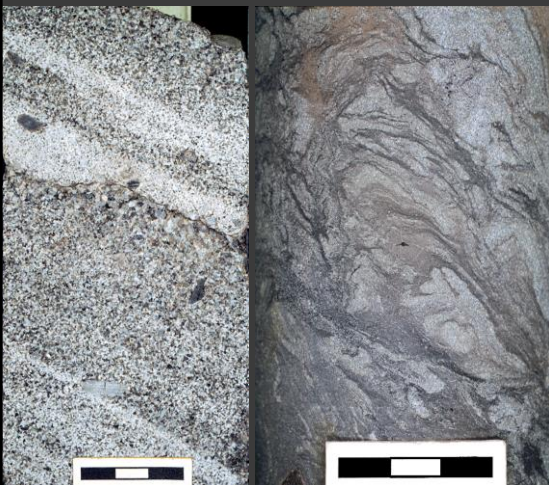
LECTURE 2 – IDENTIFICATION OF SEDIMENTARY STRUCTURES



Sedimentary Structures: General Characteristics

- Physical sedimentary structures can be grouped into three main subdivisions:

- Stratification types
- Irregular structures
- Bedding plane markings



Sedimentary Structures: Stratification Features



- Stratification can be subdivided into two main groupings:
 - Current Generated
 - Oscillation Generated



Sedimentary Structures

Current-generated structures
(depositional)

Current-generated structures (erosional)

Wave-generated structures

Possible tidal indicators

Soft-sediment deformation
and other



Sedimentary Structures

Current-generated structures
(depositional)

Current-generated structures (erosional)

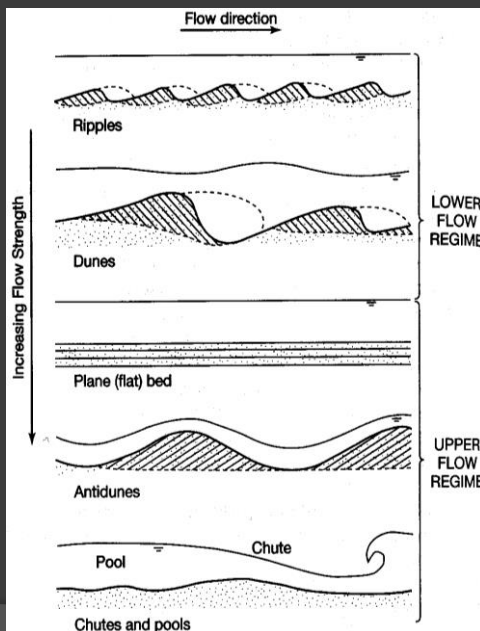
Wave-generated structures

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Current-Generated Structures



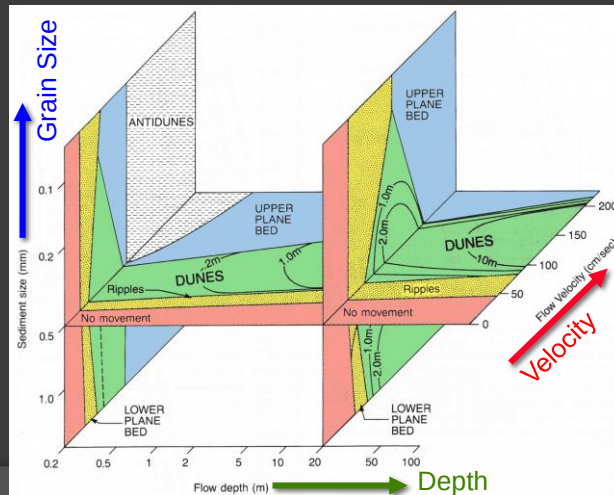
Current Flow Regime Model: depicts the progressive development of bedforms as flow strength increases.

Dependent upon **flow depth** and **grain size**.

Blatt et al., 1980

Current-Generated Structures

Flow regime model for currents shows the **progressive formation of bedforms and** hence, **stratification** in response to fluctuations in:



Flow Velocity

Flow Depth

Grain Size

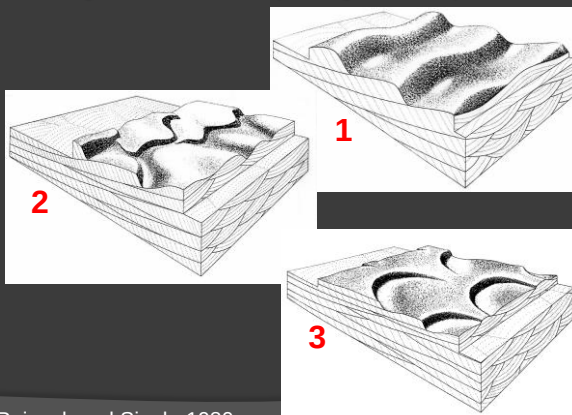
(typically restricted to sand-sized calibres)

Rubin and McCulloch, 1980

Current Ripples

Current Ripples: **small-scale, asymmetric bedforms** of variable spacing, but with **heights of 5 cm or less**.

May have a variety of crest morphologies in plan view: 1) Straight-crested, 2) Linguoid, 3) Lunate



Crest morphology does NOT affect **cross-sectional expression in core**.

Orientation of CR DOES affect expression: **rotate core to identify ambiguous ripples**

Reineck and Singh, 1980

Current Ripples



Examples of:

- 1) straight-crested
- 2) lunate
- 3) linguoid

ripples



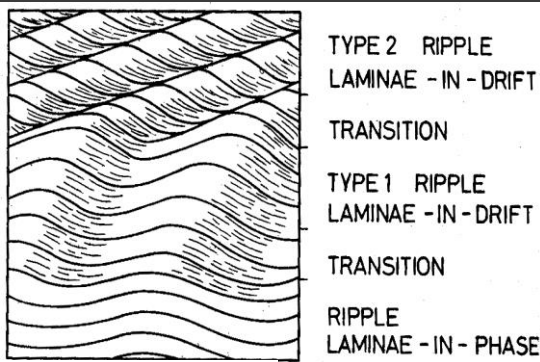
Current Ripples

Recognized by flat to low-angle inclined bedsets consisting of foreset cross-stratification.

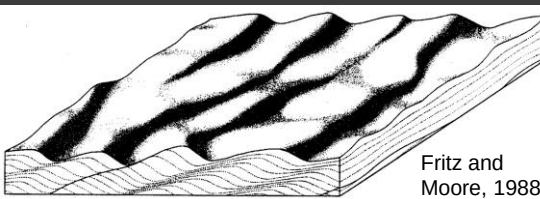
Foresets vary in inclination:
typically **steeper than 15°** (25°-28° normal)



Aggradational Current Ripples



Jopling and Walker, 1968



Aggradational current ripples: steep angle of climb of ripple crests during migration.

Note: current ripples, oscillation ripples, and combined flow ripples **may all show aggradation!!**

Aggradational Current Ripples

Indicate current traction transport in lower flow regime *coupled with high sedimentation rates*

Steepness of the "climb" is an indication of the sedimentation rate



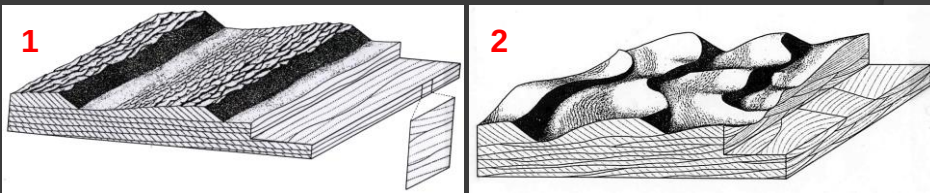
Subaqueous Dunes

Dunes: larger-scale (height > 5 cm), asymmetric bedforms.

Typically form in sand of medium-grain sizes or coarser (can form in pure upper fine) when subaqueous.

Bedforms may correspond to:

- 1) Straight-crested forms (2-D crests) = planar-tabular cross-bedding
- 2) Sinuous crested- forms (3-D crests) = trough cross-bedding



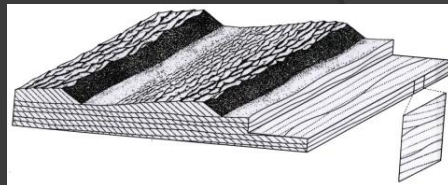
Harms et al., 1982

Dunes: Planar-Tabular X-B (PXB)

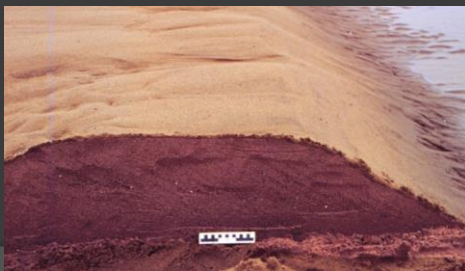
Planar Tabular Cross-Bedding:

Sharp, flat basal erosion surfaces. Minimal toeset development.

Foreset dip up to angle-of-repose: 32° in medium-grained sand in water. Uniform dips.



Harms et al., 1982



Dunes: Planar-Tabular X-B (PXB)

PXB: Foreset dips consistent

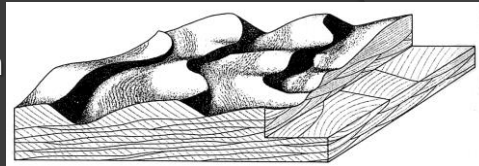
Look similar to TXB except at bedding plane contacts.



Dunes: Trough X-B (TXB)

Harms et al., 1982

Trough cross-bedding: sits on sharp, *undulatory* basal erosion surfaces. Have well-developed toesets.



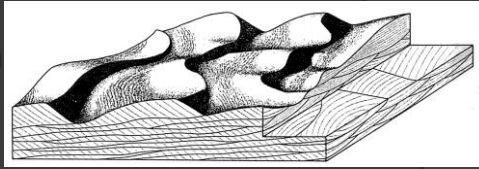
Foreset dip up to angle-of-repose: 32° in medium-grained sand in water.



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Harms et al., 1982

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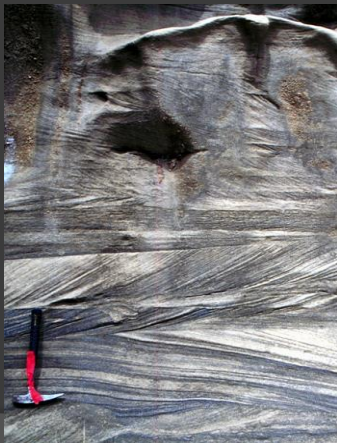
Foreset dip up to angle-of-repose: 32° in medium-grained sand in water.



Dunes: Trough X-B (TXB)

Outcrop shows troughs perpendicular to flow.

In core, TXB commonly appears similar to PXB! TXB may show **increase in dips upward** through bedform, with tangential laminae increasing to foreset angles.

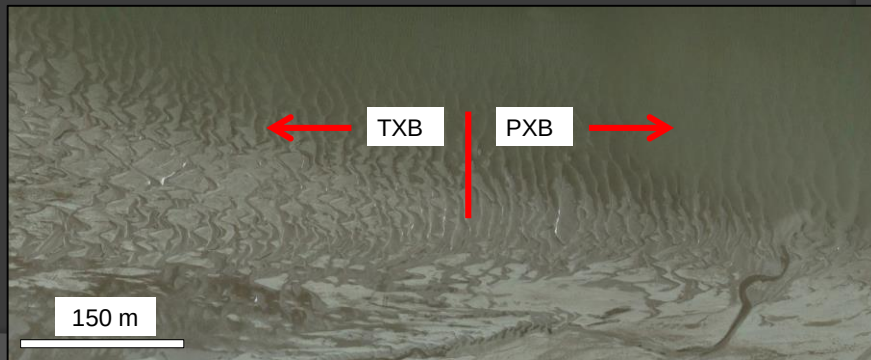


PXB vs. TXB

In medium grained sand, develop TXB at ~ 0.6 m/s, and PXB at ~ 0.5 m/s!

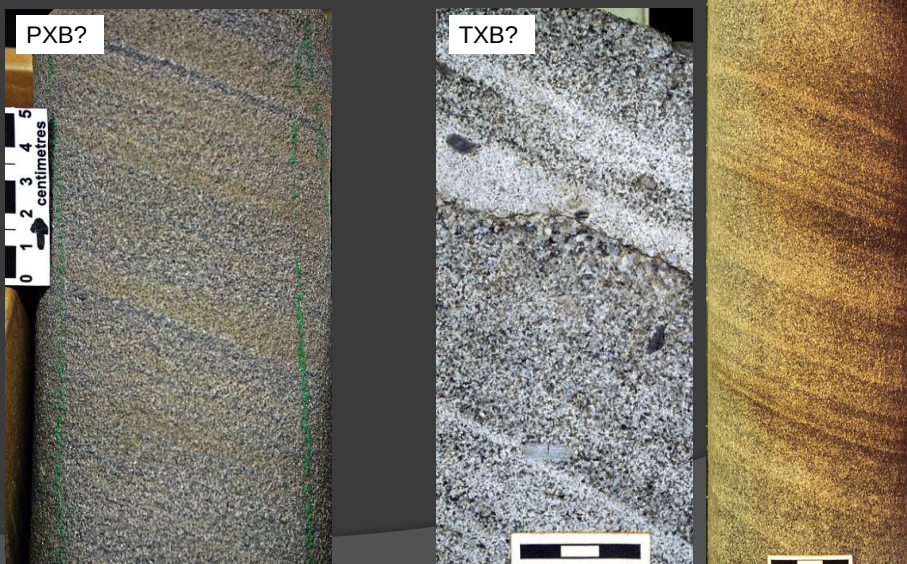
Essential to ID stratification as dune-scale cross-bedding, otherwise differences between dune types are negligible.

TXB and PXB tend to look similar in core.



PXB vs. TXB

TXB and PXB can look similar in core.



Eolian Dunes

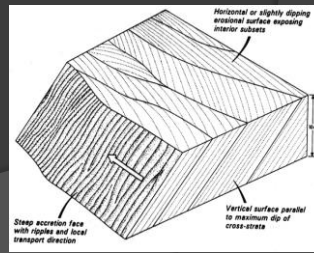
Dunes formed by eolian processes are typically larger.

Foreset angles may be much steeper than those formed in water.

Angles up to 45° have been identified.



Harms et al., 1982

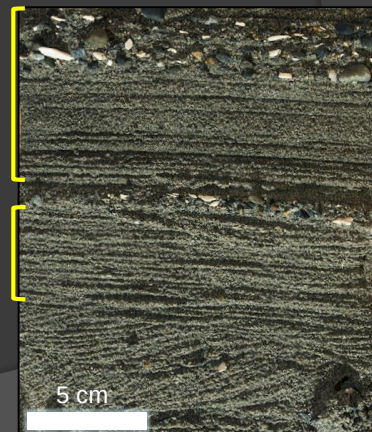
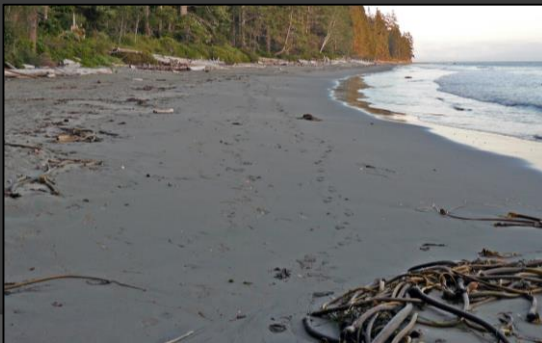
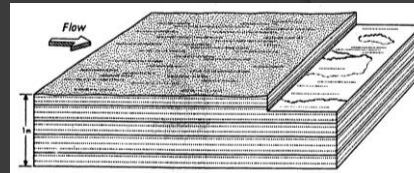


Plane-Bed Lamination

Harms et al., 1982

If flows are very shallow, high velocity and / or occur in finer-grained (vf or fL) sand, **sheet flow conditions are established.**

Laminae: **horizontal, planar & parallel.**



Plane-Bed Lamination

In core, laminae are also **horizontal**, **planar** and **parallel**.

Bedding planes may show **current lineation** (rarely seen in core).



Sedimentary Structures

Current-generated structures
(depositional)

Current-generated structures (erosional)

Wave-generated structures

Possible tidal indicators

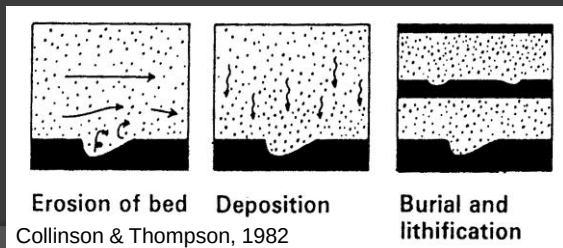
Soft-sediment Deformation
and Other



Sole Marks: Flute/Gutter Casts

Flute and gutter casts may occur on **current-scoured sst bases** overlying muddy substrates.

Flute casts (asymmetric & taper downstream) are less deep and are shorter than gutter casts (not asymmetric). **Flutes and small gutters can be ID'd in core.** Not necessary to distinguish between the two.



Sole Marks: Tool Marks

Tool marks: preserved as casts on the bases of sandstone.

Include **scratch, drag, or prod marks** made in the underlying bed by debris swept along by currents.

Hard to identify in core.



Sedimentary Structures

Current-generated structures
(depositional)

Current-generated structures (erosional)

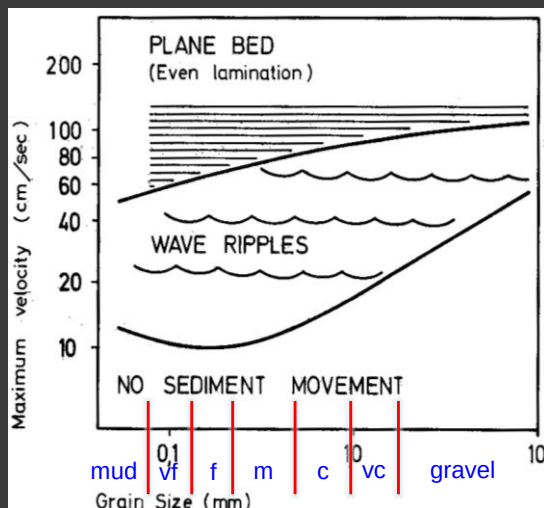
Wave-generated structures

Possible tidal indicators

Soft-sediment Deformation
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Wave-Generated Structures



Allen, 1970

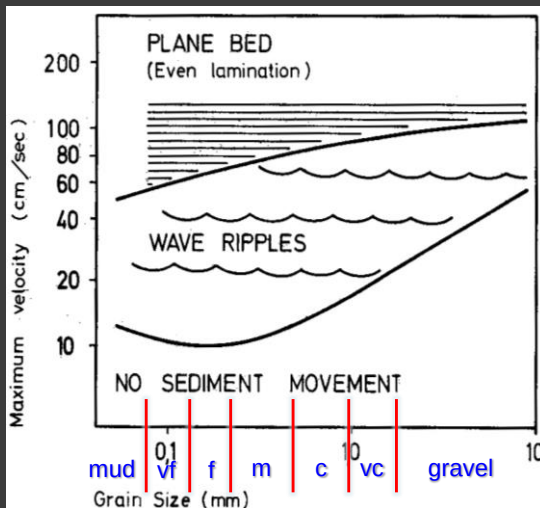
Cannot form wave
ripples above 90 cm/s

Wave (oscillatory) **flow regime model**: water movement *via* circular motion beneath wave.

Flow rates are measured as **orbital velocities**.

Increasing orbital velocities, decreasing grain sizes and shallow water lead to plane bed lamination.

Wave-Generated Structures



Allen, 1970

Cannot form wave ripples above 90 cm/s

Common wave-generated structures include:

Wave Ripples

Combined Flow Ripples

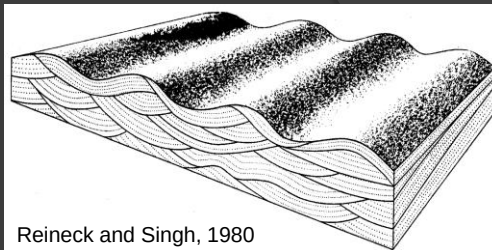
Hummocky Cross Stratification (HCS)

Swaley Cross Stratification (SCS)

Swash-zone stratification (plane beds)

Wave Ripples

Wave (oscillation) ripples: generally **symmetrical bedforms**. Reflect minimal migration.



Reineck and Singh, 1980



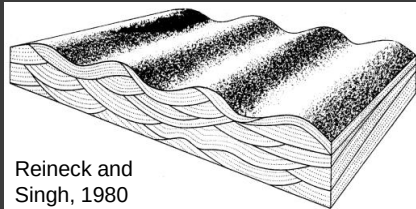
Some are slightly asymmetric, because propagating waves produce a slight onshore shift of sediment.



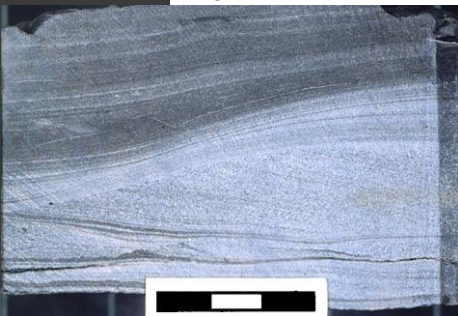
Patara Beach, Turkey

Wave Ripples

Oscillatory ripples show **lens-like shapes**, with **parallel to gently inclined cross-laminae**.

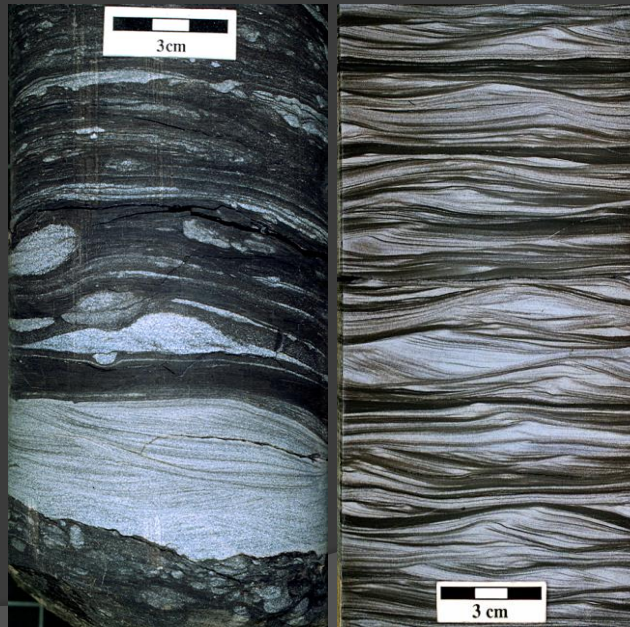


Reineck and Singh, 1980



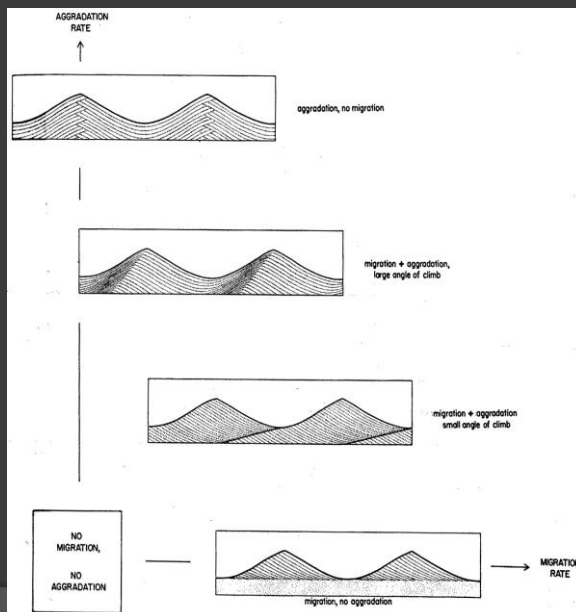
Wave Ripples

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Aggradational Wave Ripples

Aggradational wave ripples: form under **oscillatory flow** and in conjunction with **high rates of deposition**.

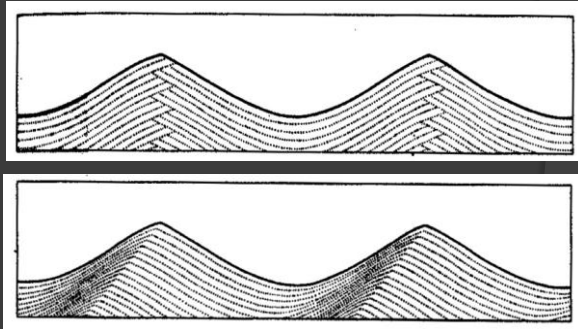


Harms et al., 1982

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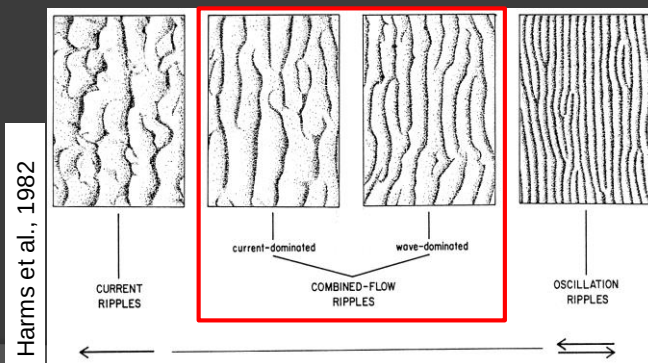


Harms et al., 1982

Combined Flow Ripples

Combined flow ripples: form in environments where **currents** and **waves** shift sediment concurrently.

Form along a continuum from purely current ripples to wave ripples.



Combined Flow Ripples

Combine flow ripples: manifest as lens-like wave-ripples with internal cross-lamination.

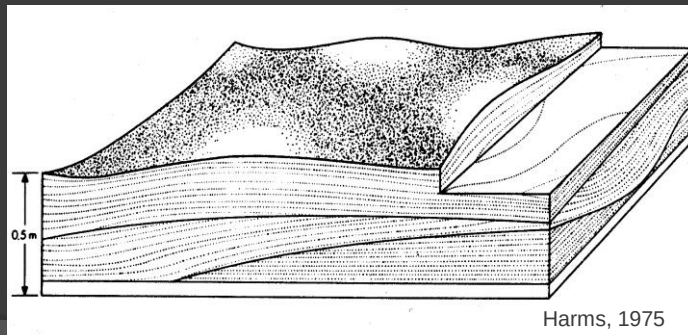
Cross-laminae indicate some migration of the ripple in response to a current.



Hummocky & Swaley Cross-Stratification (HCS & SCS)

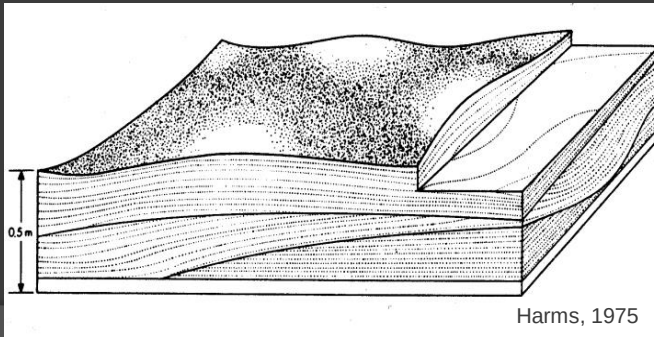
HCS and SCS forms in response to storm waves, and possibly under combined flow conditions

Hummocks show convex upward laminae, whereas swales display convex downward oriented laminae.



Hummocky & Swaley Cross-Stratification (HCS & SCS)

HCS typically forms in vf & fine-grained sand, characterized by **low-angle truncation surfaces**, overlain by **parallel to tangential, delicate laminae**.



Hummocky & Swaley Cross-Stratification (HCS & SCS)

In core, both HCS and SCS consist of **low-angle, undulatory parallel lamination**

HCS shows preservation of **convex upward lamination**



Hummocky & Swaley Cross-Stratification (HCS & SCS)

In core, both HCS and SCS consist of **low-angle, undulatory parallel lamination**

SCS records preservation of **the intervening swales**. Hummocks removed.



Hummocky & Swaley Cross-Stratification (HCS & SCS)

In the shallow marine realm, HCS commonly passes into **combined flow ripples**.

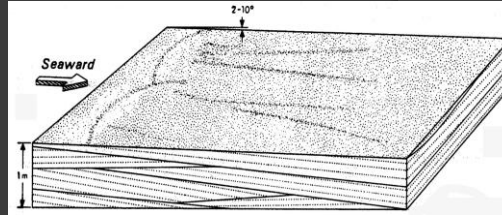


100/11-35-48-11W5; 1841.8 m

Swash Zone Cross-Stratification

Beaches (foreshores) are characterized by **swash zone cross-stratification (SZS)**.

SZS: well-sorted, low angle planar parallel lamination **in sandstones** (**plane beds!**)



Harms et al., 1982

Results from very high energy sheet-flow conditions.



Swash Zone Cross-Stratification

SZS: well-sorted, low-angle planar parallel lamination **in sandstones** (**plane beds!**) NOTE: *Not* cross-stratification.



Gravelly Foreshore



Gravelly foreshores show well-sorted and well-segregated clast-supported granule to pebble conglomerates.

Sandstone interbeds may still yield trace fossils, particularly *Macaronichnus segregatis*!

Sedimentary Structures

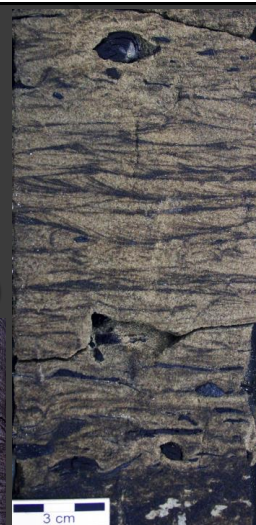
Current-generated structures (depositional)

Current-generated structures (erosional)

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Possible tidal indicators

Soft-sediment Deformation and Other



Possible Tidal Indicators

Tidal Bundles & Mud-draped
Tidal Bundles

Heterolithic Bedding

Flaser Bedding

Wavy Bedding

Lenticular Bedding



Tidal Bundles

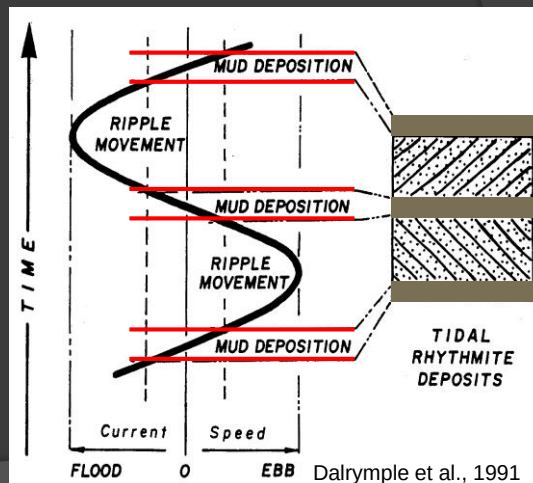
Dunes (PXB & TXB) may be subjected to **tidal modification**.

Depending upon the influence of tides on dune migration, bedforms may show:

Reactivation structures

Single (intertidal) or **Double** (subtidal) **Mud Drapes**

Foreset reversals
(Herringbone Cross-Stratification)



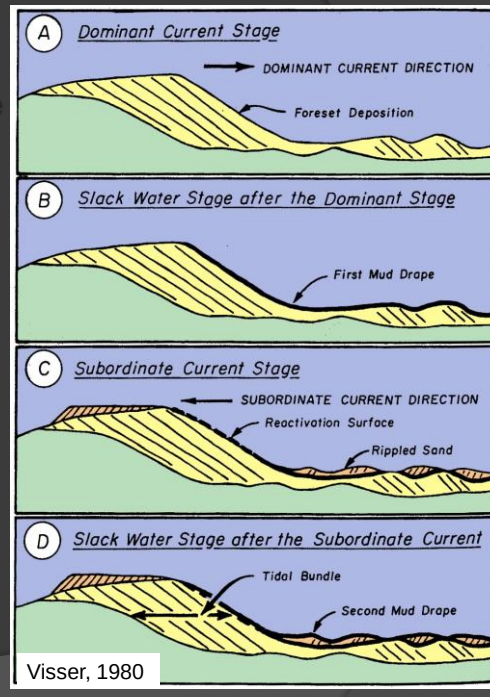
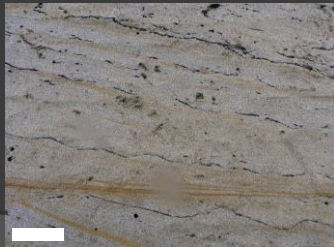
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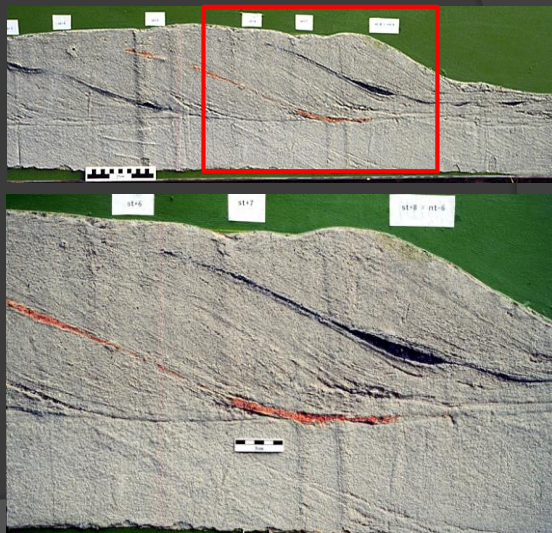


Tidal Bundles

Tidal bundles from a modern estuary: strong subordinate flows have cut **low-angle reactivation surfaces** (coloured) back across the bedform.

Intertidal dune stained during low tide to mark incremental migration of the dune.

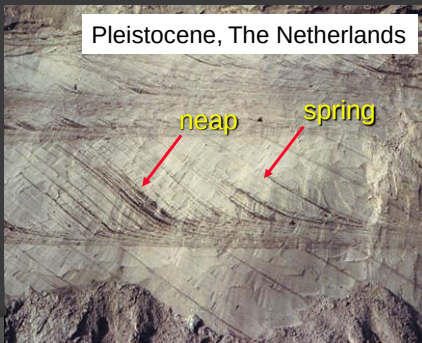
Note: NO mud drapes preserved, **despite** being "tidally bundled".



Mud-Draped Tidal Bundles

Neap-spring cyclicity in Pleistocene-aged tidal bundles with mud draped foresets.

Similar structures occur in Cretaceous, McMurray Fm, Alberta.



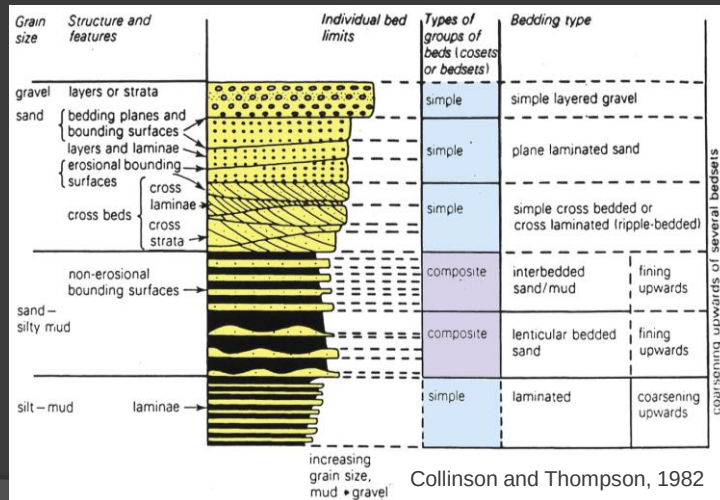
Mud-Draped Tidal Bundles

Reactivation surfaces are hard to identify in core; typically one must rely on (rhythmic) mud-drapes along foresets to ID tidal influence



Heterolithic Bedding

Heterolithic bedding: composite bedsets that record **rhythmic or cyclic alternations of two or more bed types**.



Heterolithic Bedding

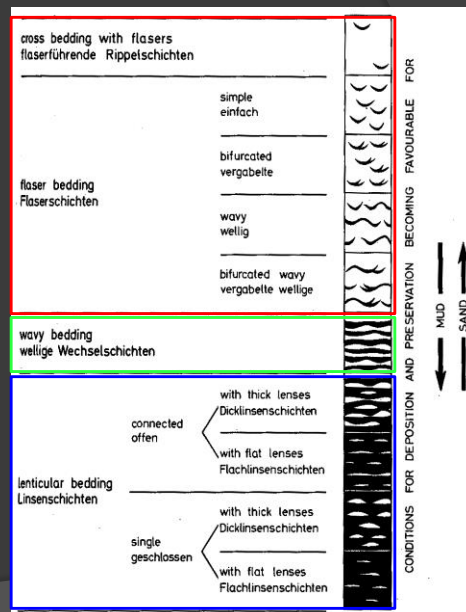
Three common forms of heterolithic bedding:

Flaser bedding

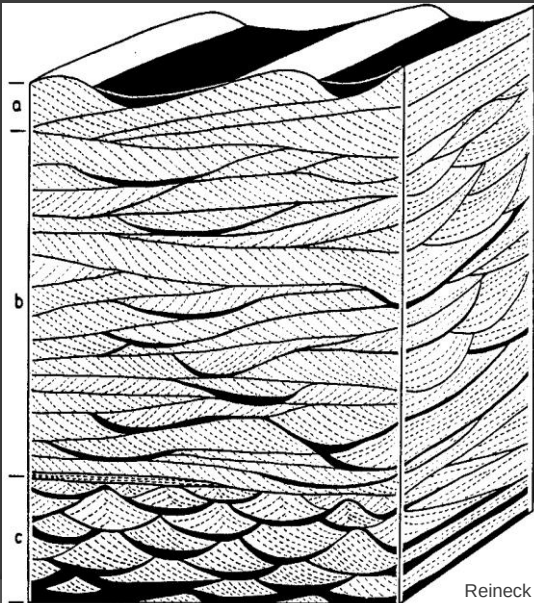
Wavy bedding

Lenticular bedding

Reineck and Wunderlich (1968)



Flaser Bedding



Flaser bedding:
predominantly ripple
laminated sandstone with
mud confined to the ripple
troughs.

Ripples may be current-
generated, oscillatory or
combined flow.

Flaser bedding is NOT
confined to tidal settings.

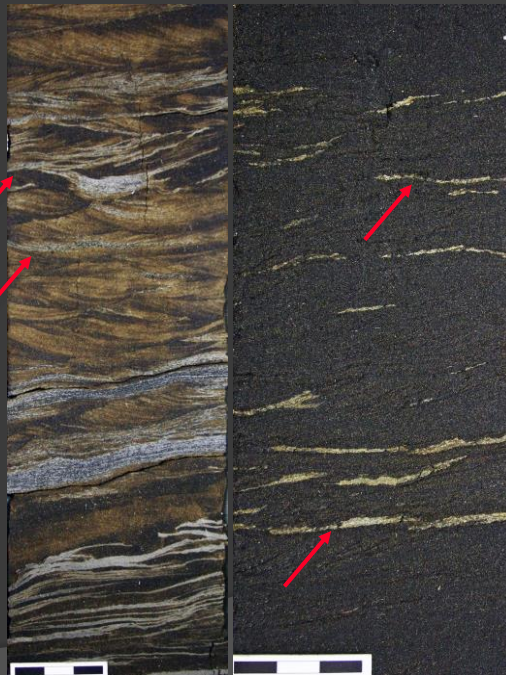
Reineck and Singh, 1980

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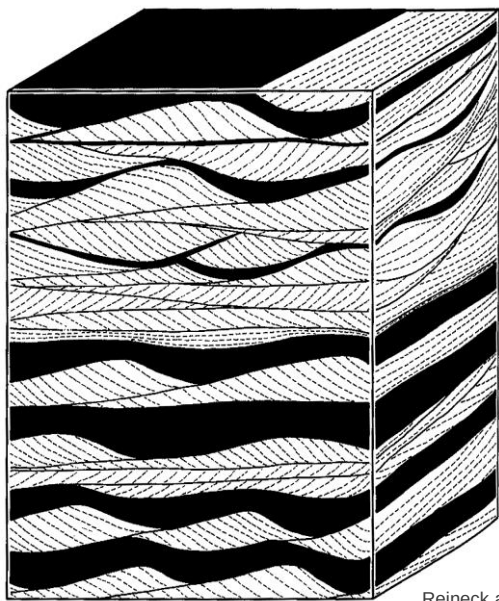
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Wavy Bedding



Reineck and Singh, 1980

Wavy bedding: **continuous beds of rippled sandstone with continuous mud beds mantling the ripples.**

Ripples may be current-generated, oscillatory or combined flow

Wavy bedding is NOT confined to tidal settings.

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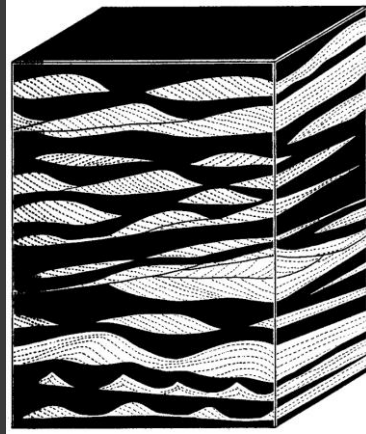
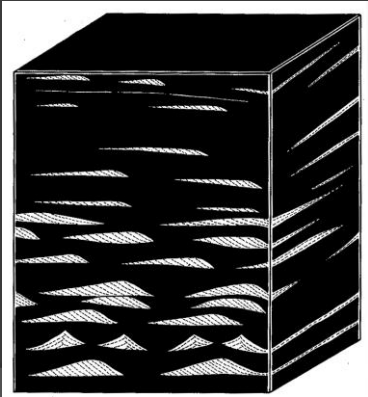
Wavy bedding is NOT confined to tidal settings.



Lenticular Bedding

Lenticular bedding: ripples encased in mud.

Sand forms semi-continuous beds or constitute starved ripples.



Reineck and Singh, 1980

Ripples may be current-generated, oscillatory or combined flow.

Lenticular bedding is NOT confined to tidal settings.

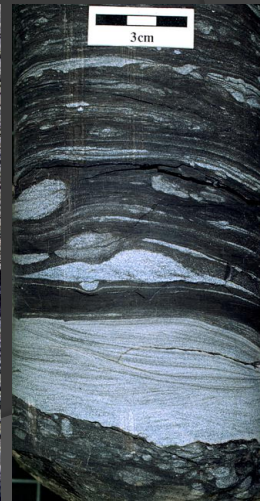
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Possible tidal indicators

Soft-sediment Deformation
and Other



Soft-Sediment Deformation Structures

Loading / Ball & Pillow
Structures

Convolute Bedding

Dish & Pillar Structures



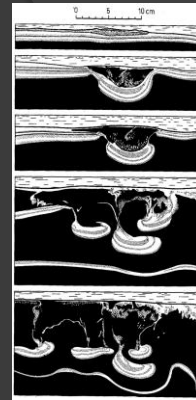
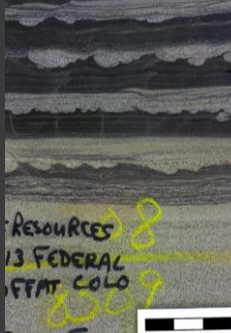
Loading / Ball & Pillow Structures

Rapid emplacement of sand or other dense media onto soft, plastic media commonly results in loading and foundering.

Loading: the *disruption of the base* of the overlying unit.

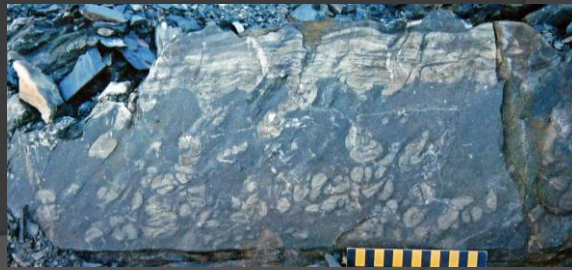
Flames: the *upward injection* of mud into the base of the overlying unit.

Flame structures



Kuenen, 1965

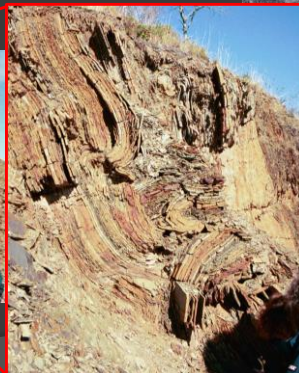
Ball & Pillow
Sussex Fm, NB



Convolute Bedding

Soft-sediment deformation: deformation of stratification and convolute bedding due to increased pore-water pressures, down-slope creep, and/or slope failure.

May also develop **gravity faults** in firm sediments.

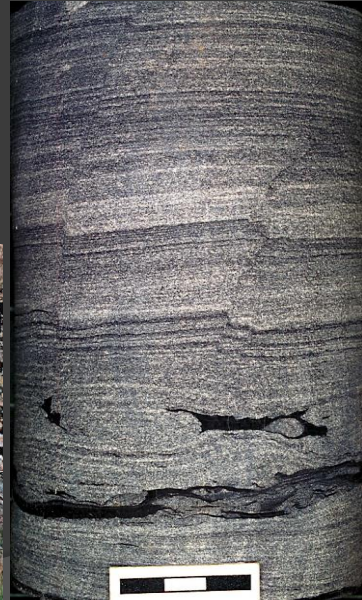


Convolute Bedding
Sussex Fm, New Brunswick



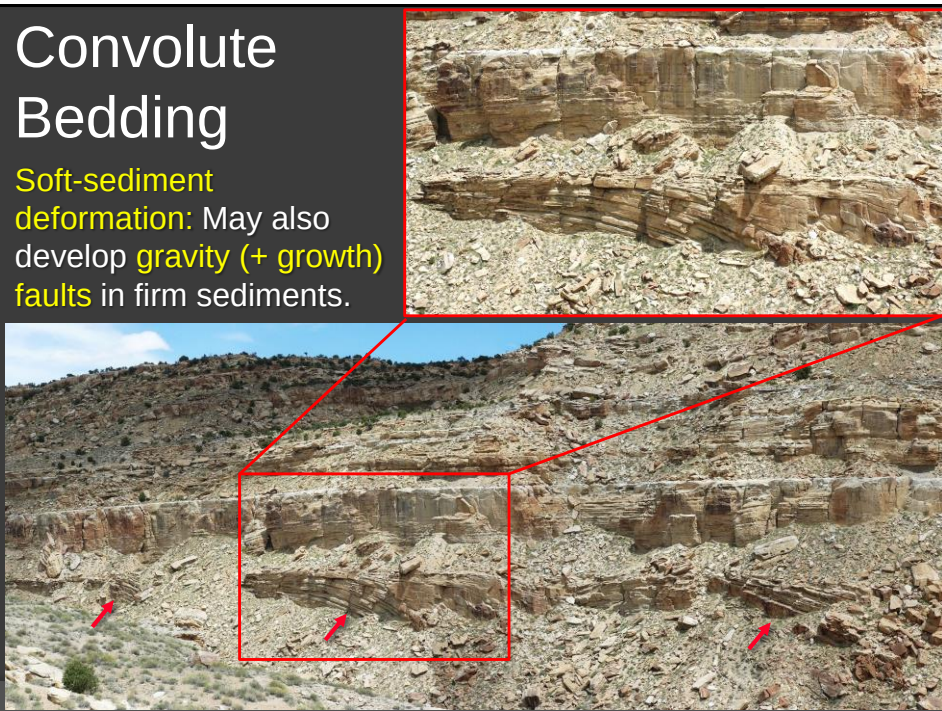
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Convolute Bedding

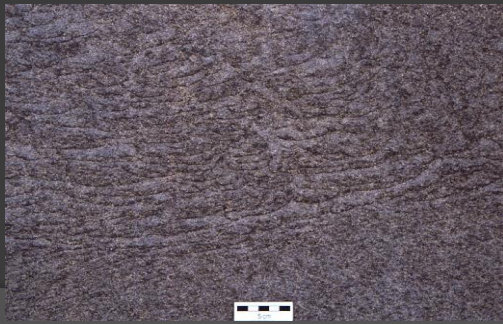
Soft-sediment deformation: May also develop gravity (+ growth) faults in firm sediments.



Dish-and-Pillar Structures

Rapid deposition of sand with silty or delicate clayey interlaminae = result in very rapid water escape.

Produces narrow pipes or **pillars**, with clayey deflected upwards at their edges to form **dishes**.



Sedimentary Structures

Current-generated structures
(depositional)

Current-generated structures (erosional)

Wave-generated structures

Possible tidal indicators

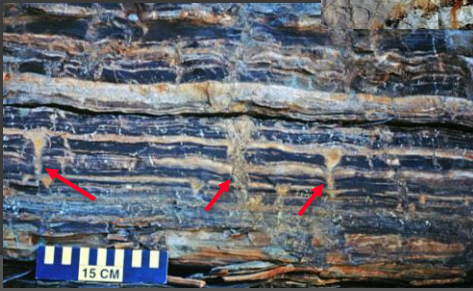
Soft-sediment Deformation
and Other



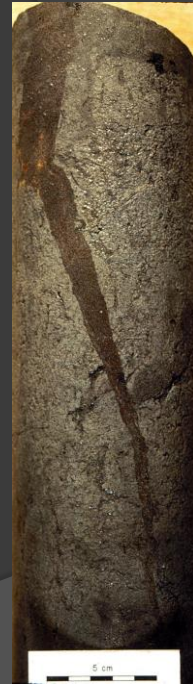
Other: Desiccation Cracks

Desiccation cracks: commonly **polygonal in shape on bedding planes, and form downward tapering "V"-shaped fractures**

Subaerial shrinkage cracks, reflecting **subaerial exposure**.



Desiccation Cracks
Sussex Fm, New Brunswick

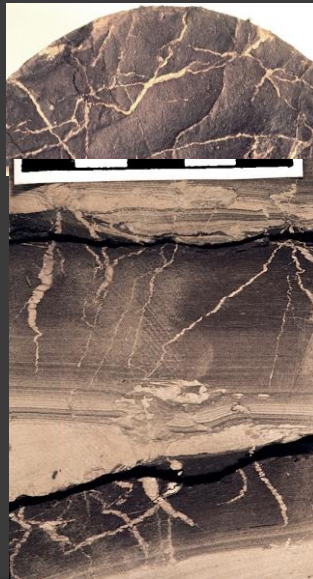


Other: Syneresis Cracks

Syneresis cracks: subaqueous shrinkage cracks, reflecting **clay shrinkage in response to salinity change**.

They are rarely polygonal on bedding planes and are strongly folded during burial.

Syneresis are most common in **brackish-water settings**.



Summary: Sedimentary Structures

1. Identification and interpretation of **primary sedimentary structures** imparts critical information on the conditions of sediment transport and deposition.
2. **Penecontemporaneous sedimentary structures** indicate conditions in the environment soon after deposition and are also important in helping to characterize facies and pinpoint the environment of deposition.
3. Careful analysis of core permits **identification** of small-scale structures (*e.g.*, ripples, *etc.*).
4. Large-scale structures **must be interpreted** from core on the basis of distinctive characteristics (*e.g.*, trough cross-stratification, tidal bundles, HCS, SCS, *etc.*)