BEDFORMS E STRATIFICAZIONE CON FLUSSI UNIDIREZIONALI

Original slides by R.J.Cheel

Introduction to Clastic Sedimentology

Chapter 5

http://spartan.ac.brocku.ca/~rcheel/teaching/sedimentology/

Chapter 5. Bed forms and stratification under unidirectional flows

Bed forms: a bedding surface feature that is an individual element of the morphology of a mobile granular or cohesive bed that develops due to local deposition and/or erosion in response to the interaction of a flowing current of air or water.

Bed forms range from ergs (sand seas) to low, several grain diameter high ridges on an otherwise flat bed.

The behavior of bedforms, in response to a current, determines their internal structure which may display a variety of forms of internal stratification.

All bed forms and internal stratification are *primary sedimentary structures*.

Ergs (sand seas, Merzouga - Morocco)


Ripples

Primary sedimentary structures: any sedimentary structure that forms at the time that the sediment is deposited (and reflects the processes acting at the time of deposition).

Such structures indicate something of the nature of conditions in the environment at the time that the sediment was deposited.

eg.

Nature of the current (rivers, wind, waves).

Strength of the current

Current direction(s)

Direction to original top (useful in tectonically deformed terrains)

Bed forms under unidirectional flows

a) Flow Regime Concept

Introduced by engineers to classify open channel flows on the basis of:

Flow Froude Number ($F = \frac{U}{\sqrt{gD}}$)

Classification based on rate and type of sediment transport and the bed forms that are present.

Flow Regime	Bed forms	Characteristics
Lower	Lower plane bed, ripples, dunes	**F** < 0.84 – 1. Low rate of sediment transport, dominated by contact load. Bed forms out of phase with the water surface.
Upper	Upper plane bed, in-phase waves, chutes and pools	**F** > 0.84 – 1. High rate of sediment transport. Bed forms in-phase with the water surface.

The flow regime concept is widely thought to be flawed for a variety of reasons.

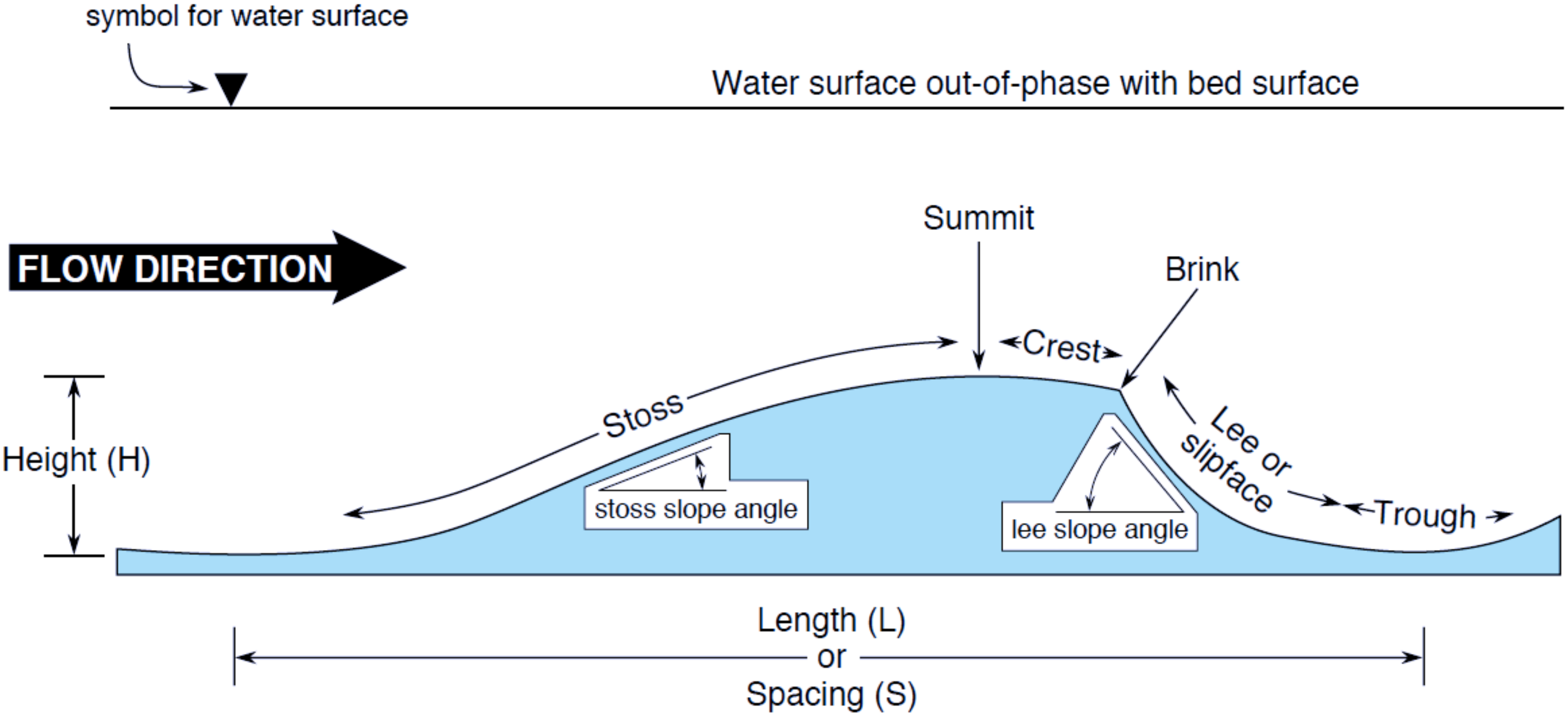
In-phase waves can form at Froude numbers as low as 0.84.

Upper plane beds can form at Froude numbers as low as 0.4.

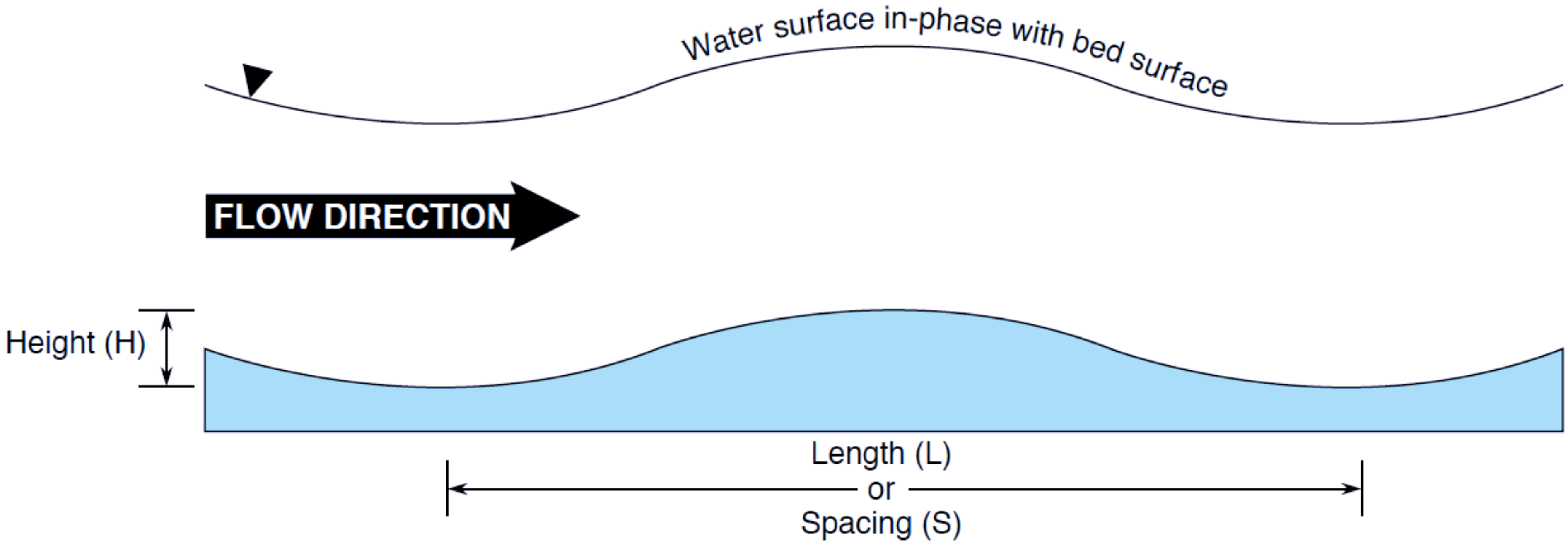
Upper plane beds can form in full pipes (no free water surface).

b) Bed form terminology

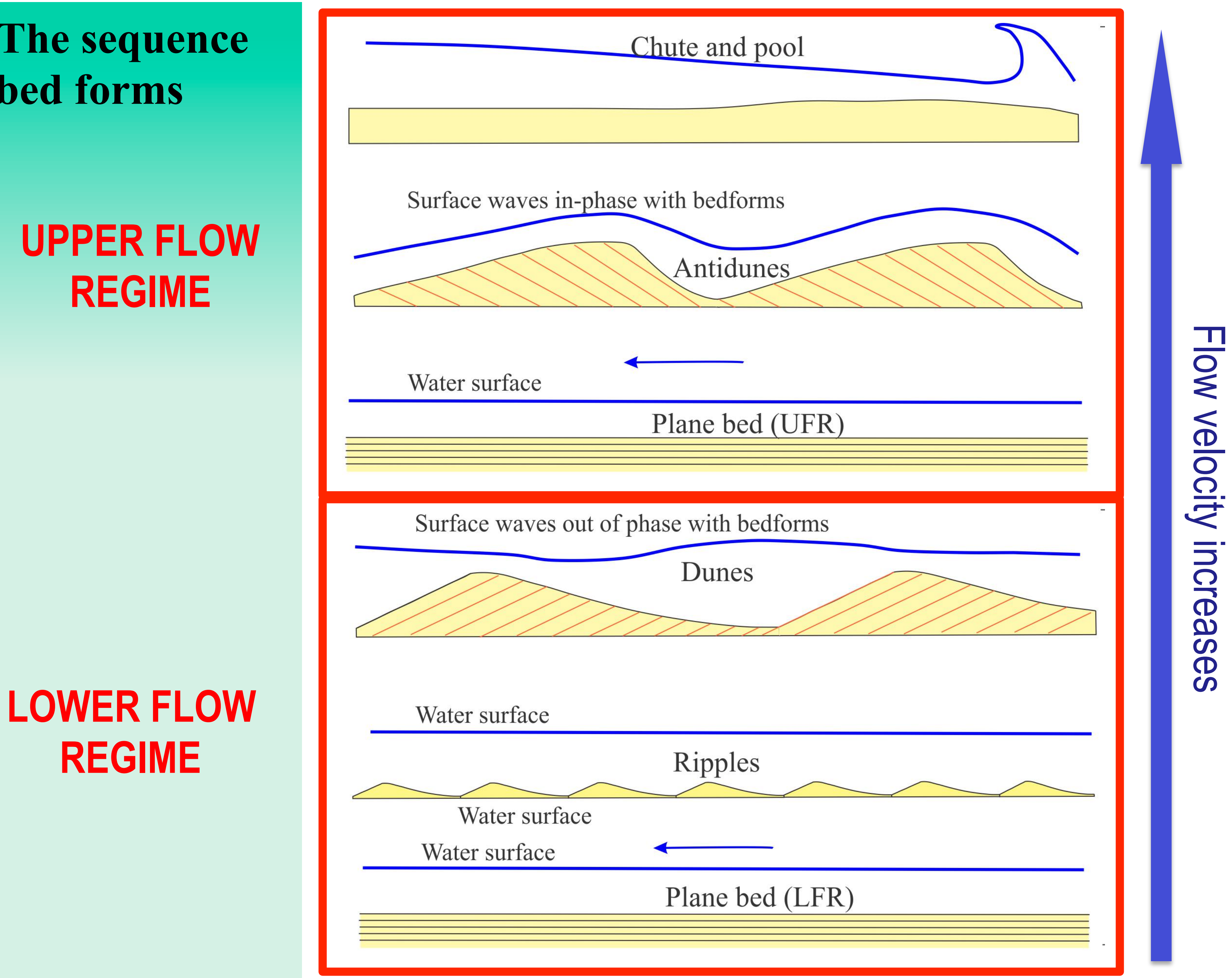
Anatomy of an asymmetrical bedform



Anatomy of a symmetrical bedform



b) The sequence of bed forms

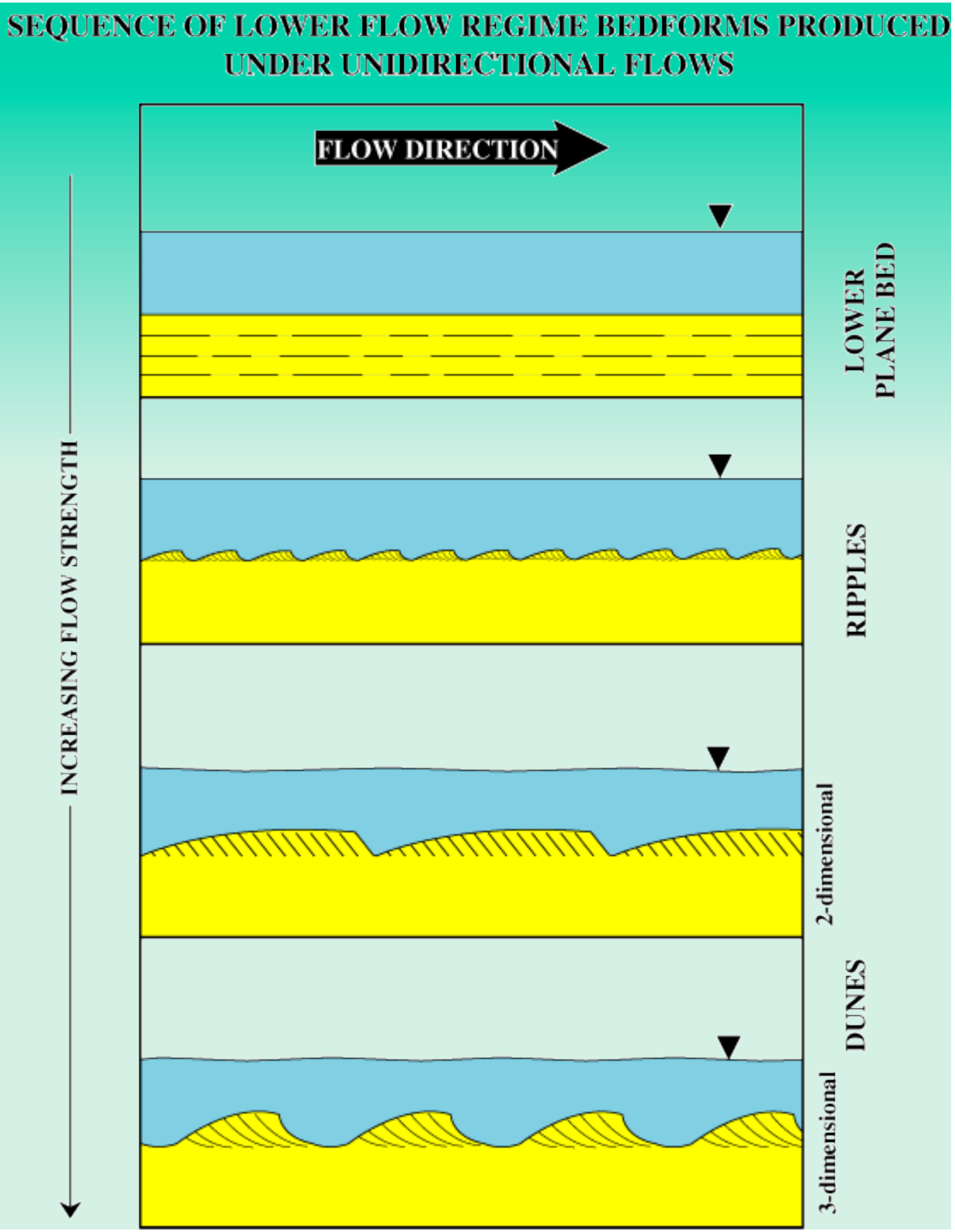


b) The sequence of bed forms (DETAILS)

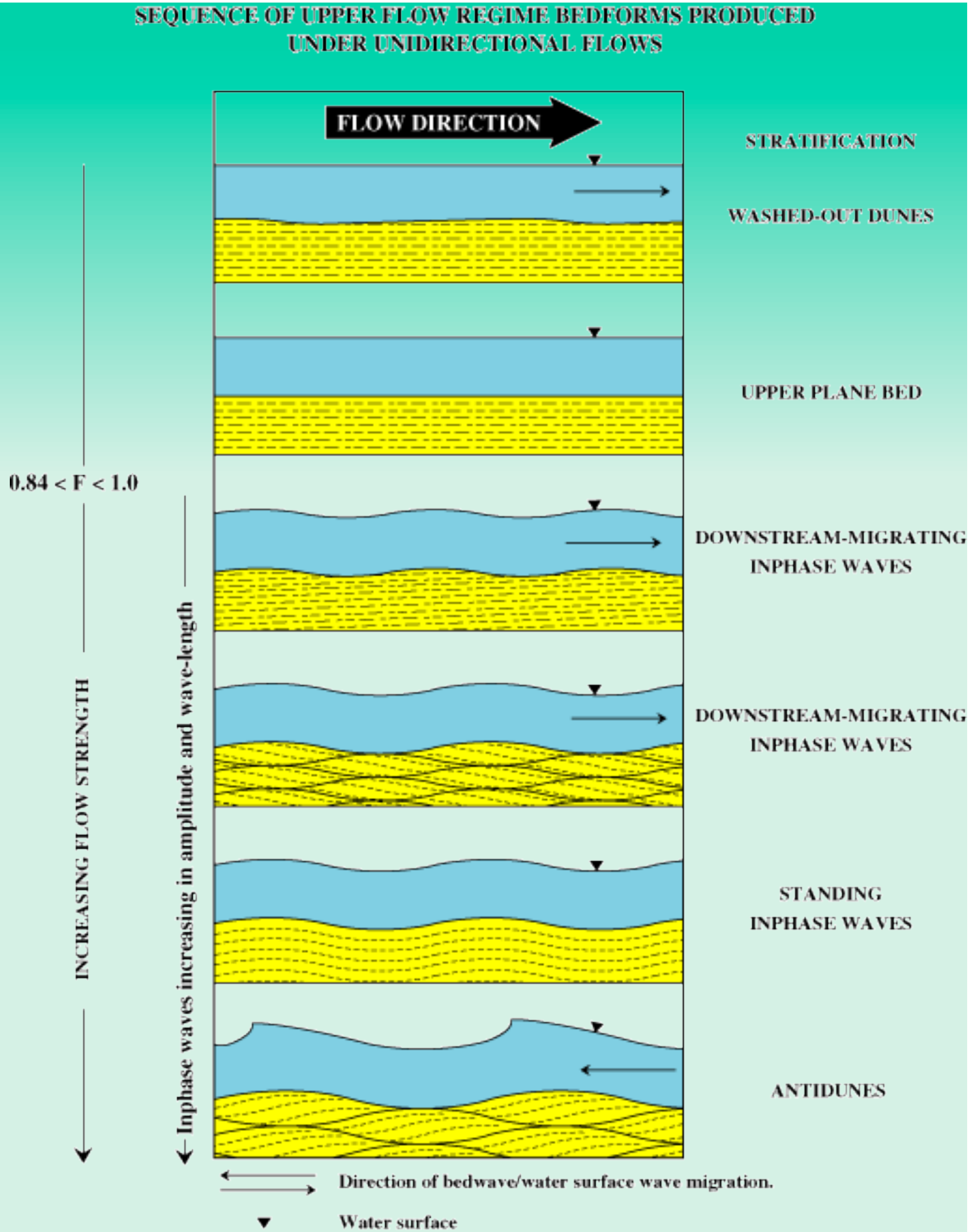
Water flowing over a flat bed of sand will, with increasing flow strength, develop a sequence of bed forms that differ in terms of morphology and behavior.

The sequence shown would develop with increasing velocity and constant flow depth.

Note that not all of the lower flow regime bed forms will develop for a given sand size.



With even further increase in flow strength:



c) Description of bed forms

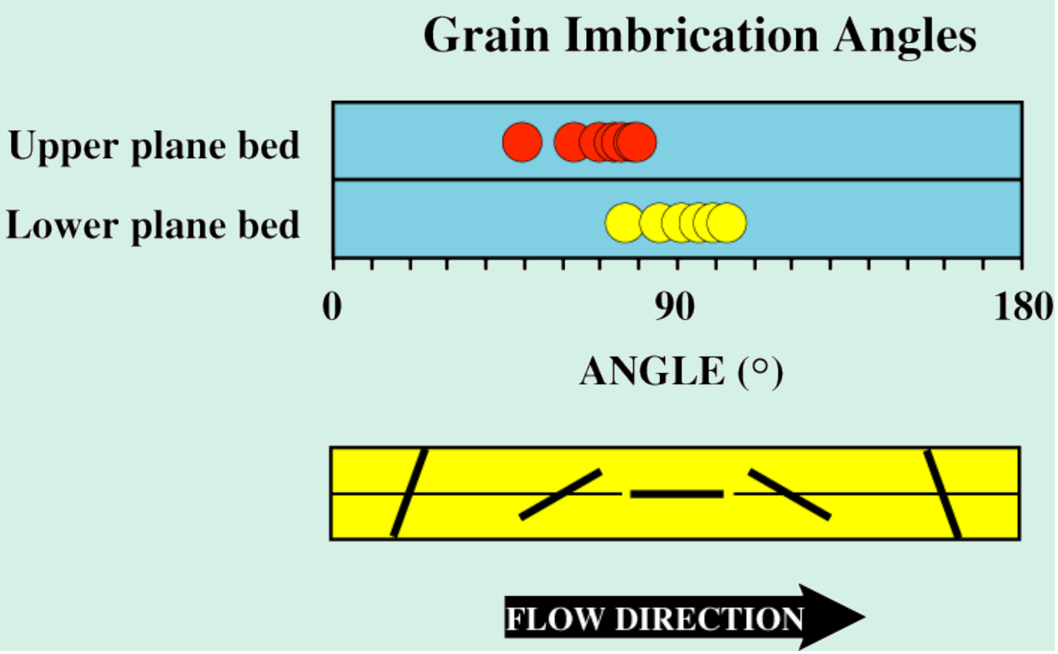
i) Lower plane bed

Flat and featureless.

Sediment transport largely as contact load.

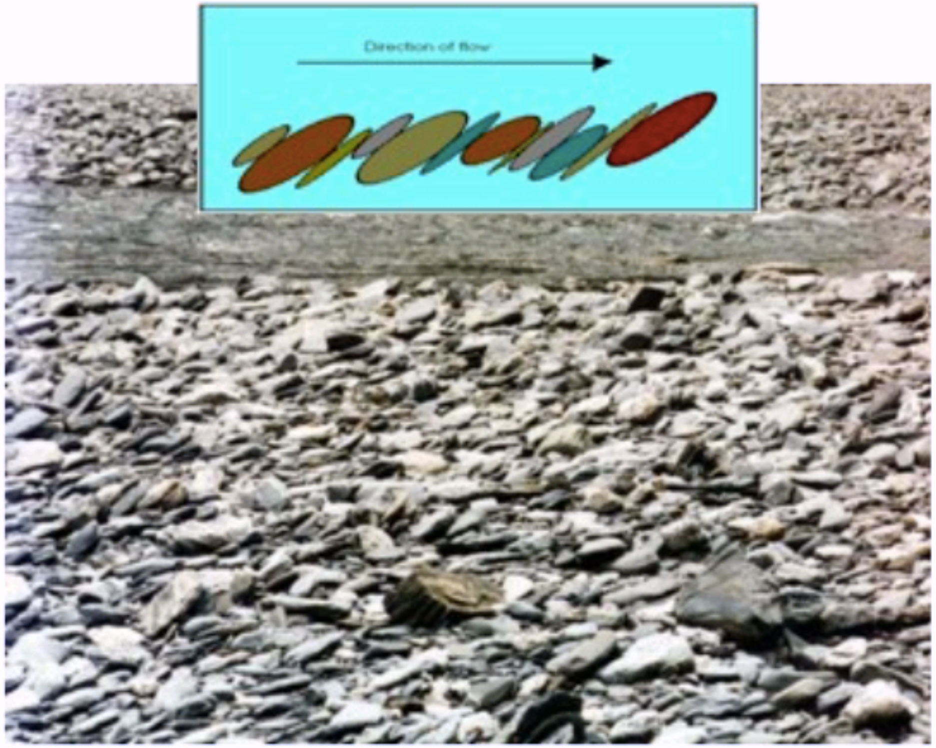
Develops on sands with d > 0.70 mm; rough turbulent boundaries.

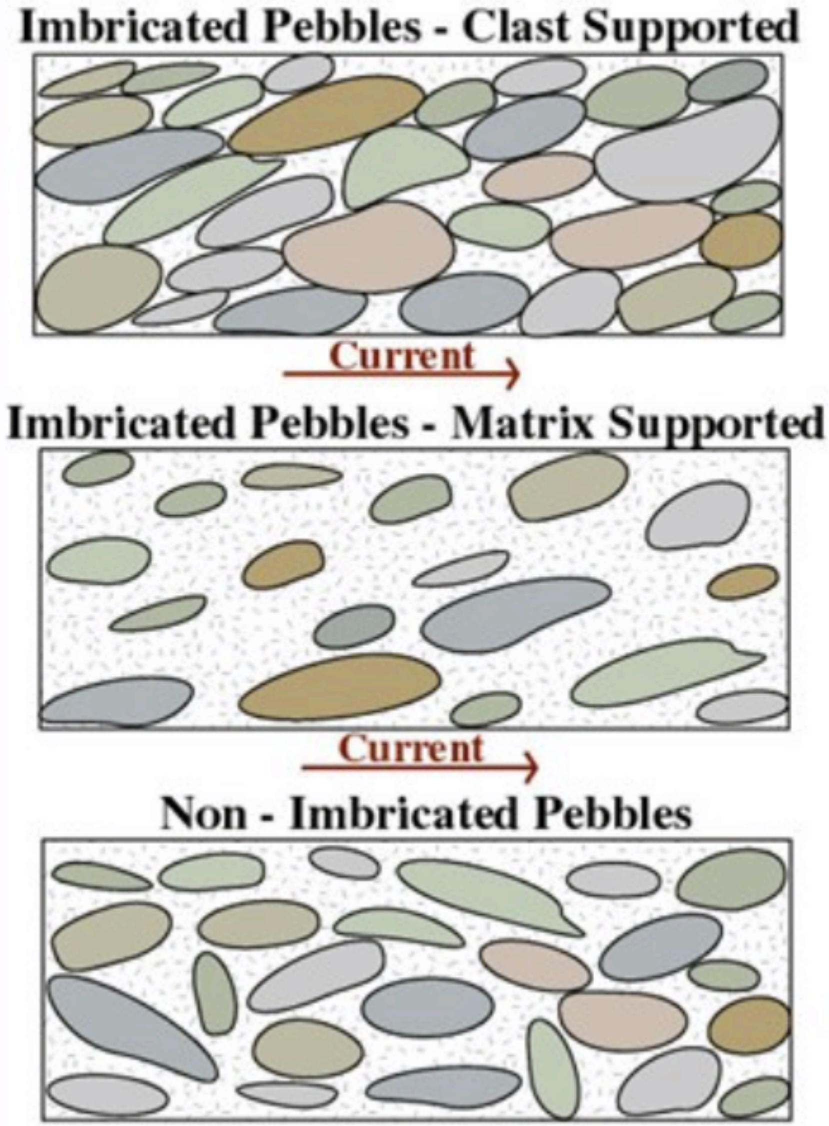
May be characterized by low angle imbrication or very poorly developed imbrication.



Shapes of clasts

When discoid clasts are moved in a flow of water they are preferentially oriented and may stack up in a form known as **imbrication**



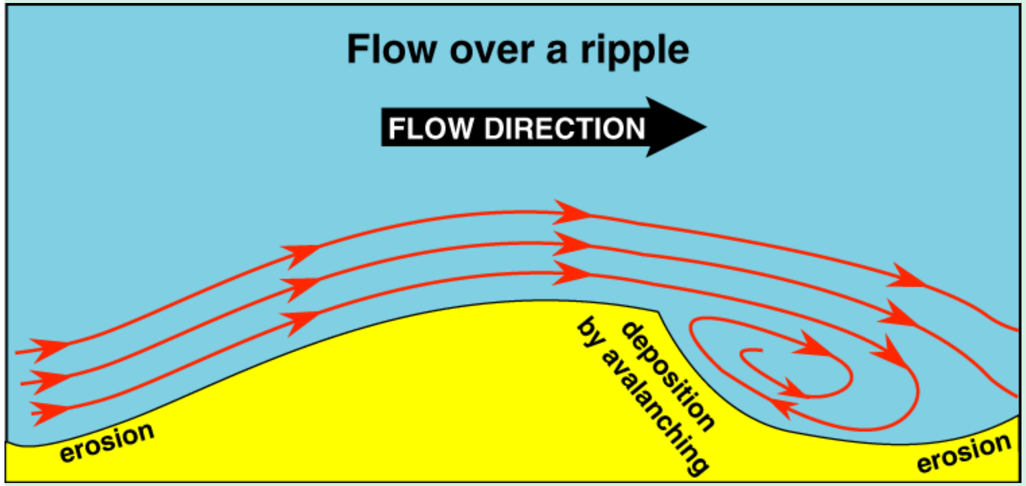


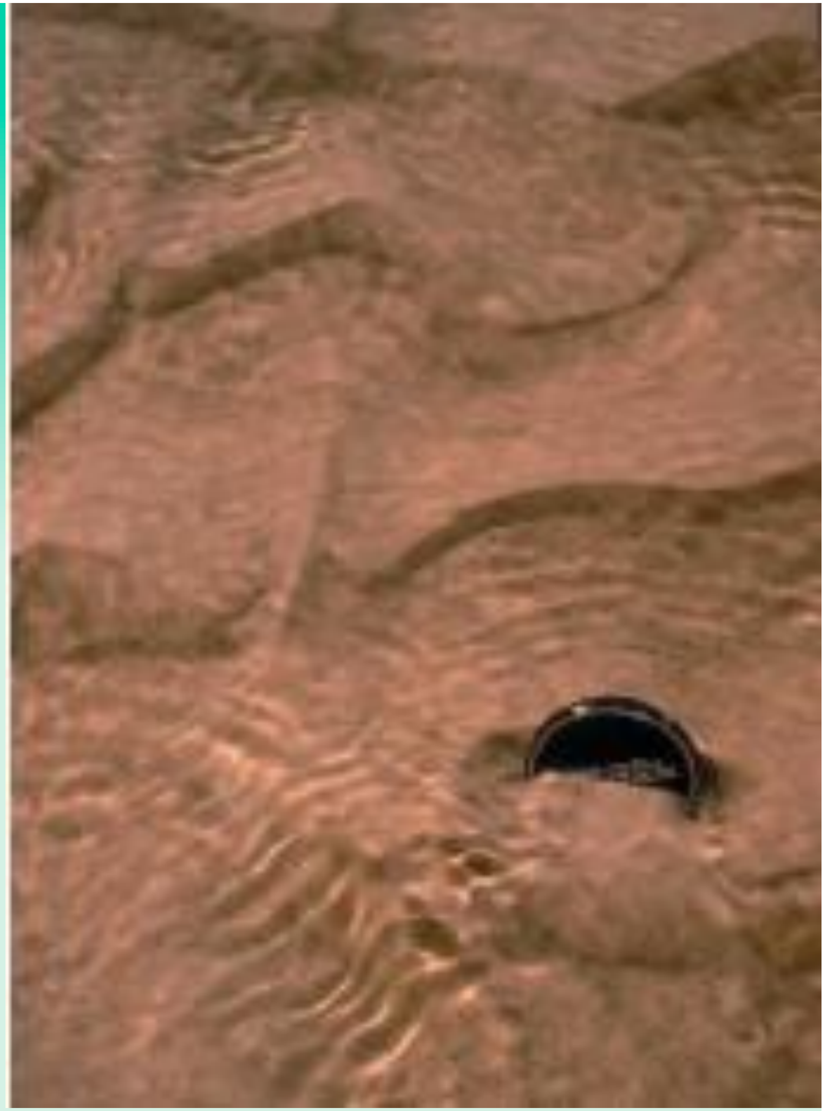
ii) Ripples

Small scale, asymmetric bed forms.

Develop on sands with d < 0.7 mm.

Migrate downstream (in the direction of the lees slope).





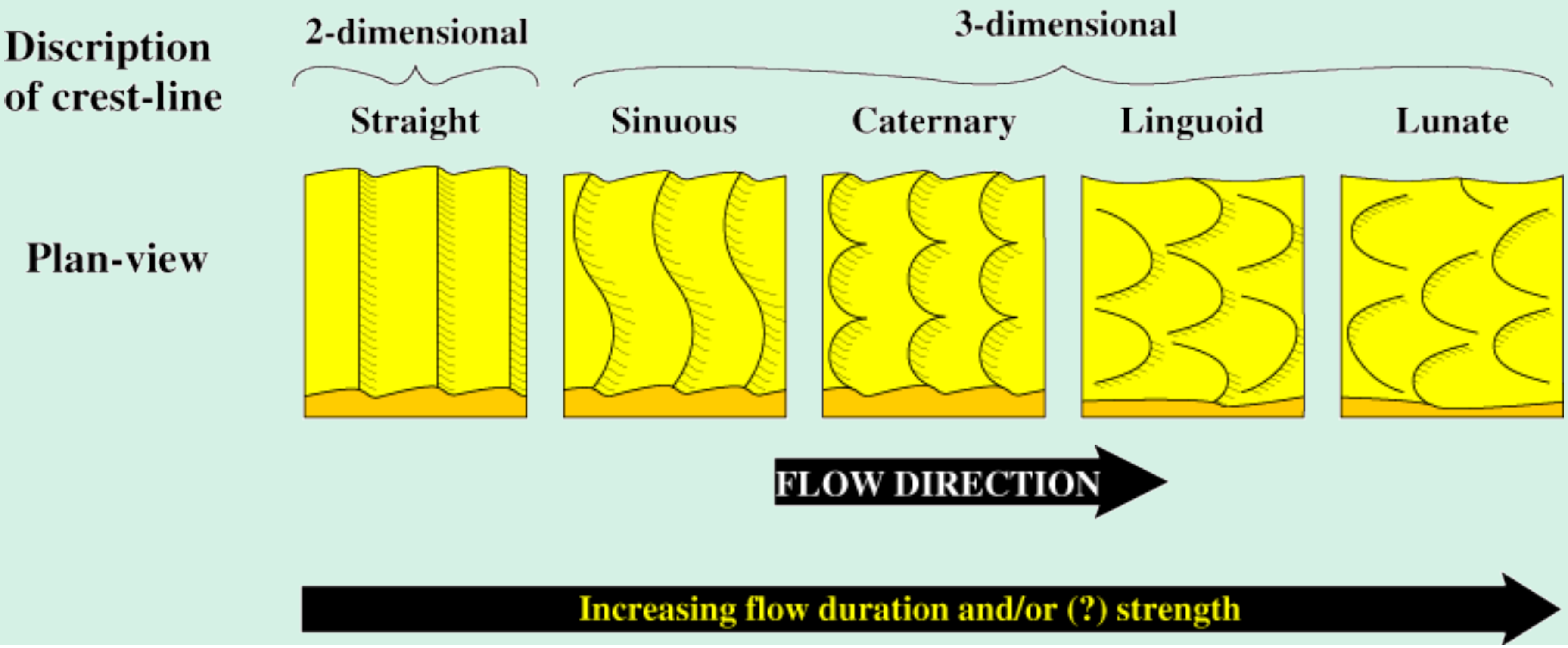
Can be used to determine paleocurrent direction.

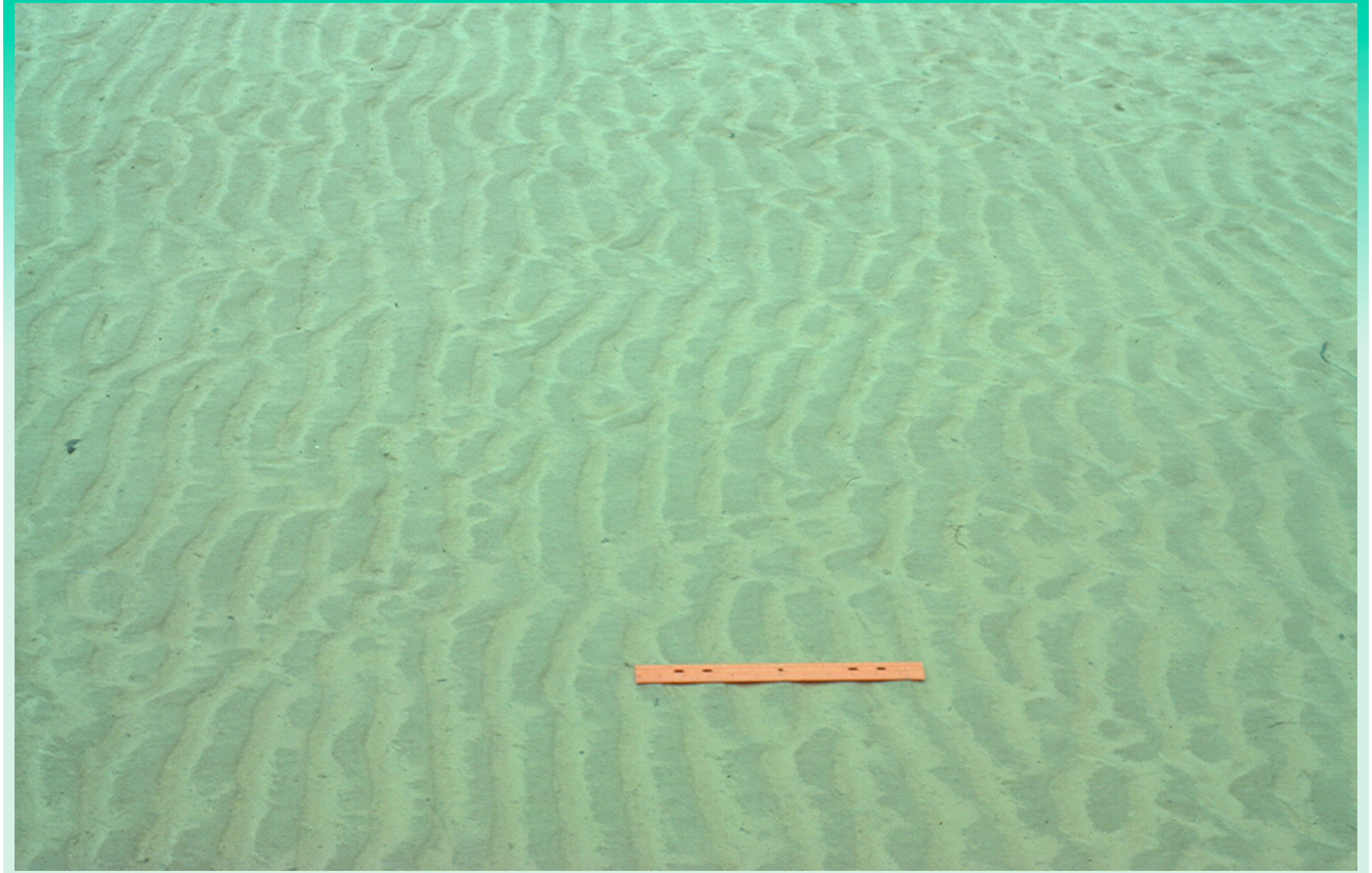
0.05 < L < 0.6 m

0.005 < H < 0.05 m

Scale with grain size: L $\approx$ 1000d

Plan form: varied with flow strength and duration of flow





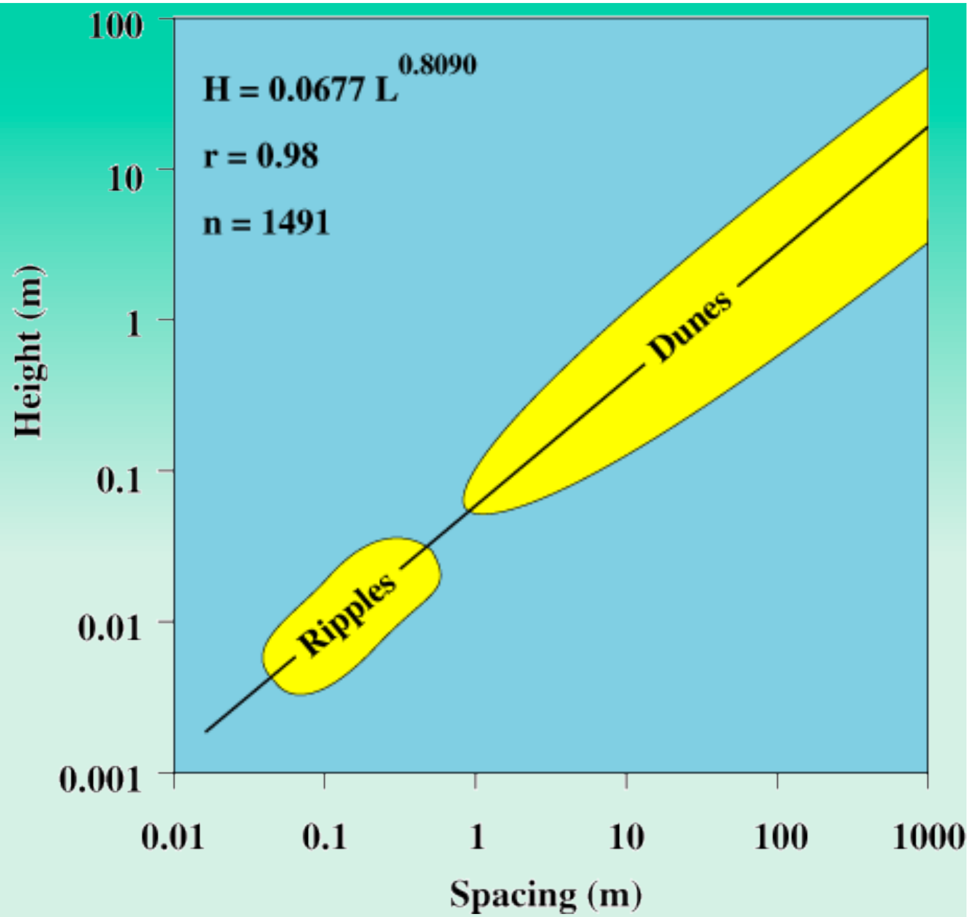
iii) Dunes

Large, asymmetric bed forms.

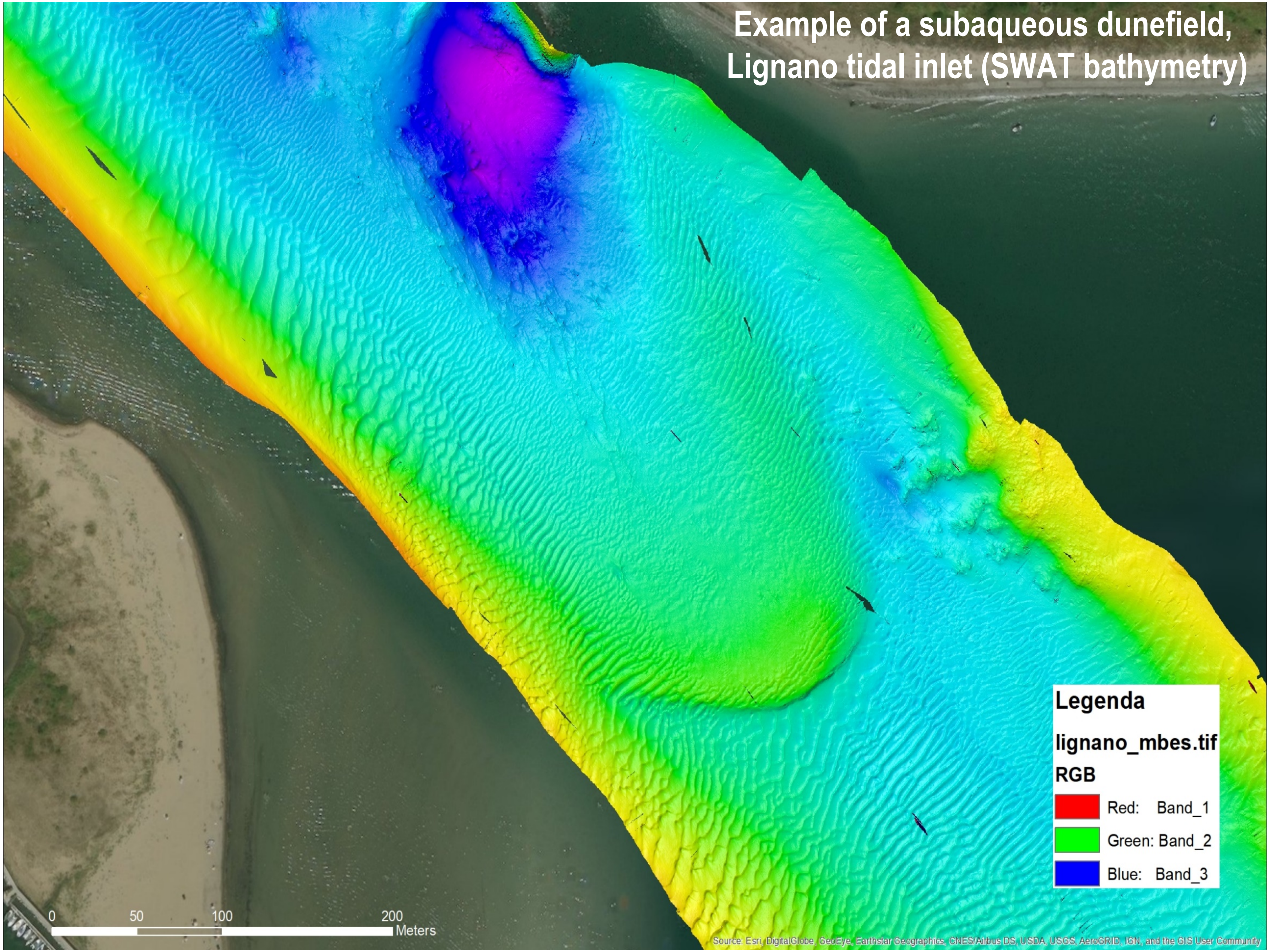
Not “large ripples” but a dynamically different bed form.

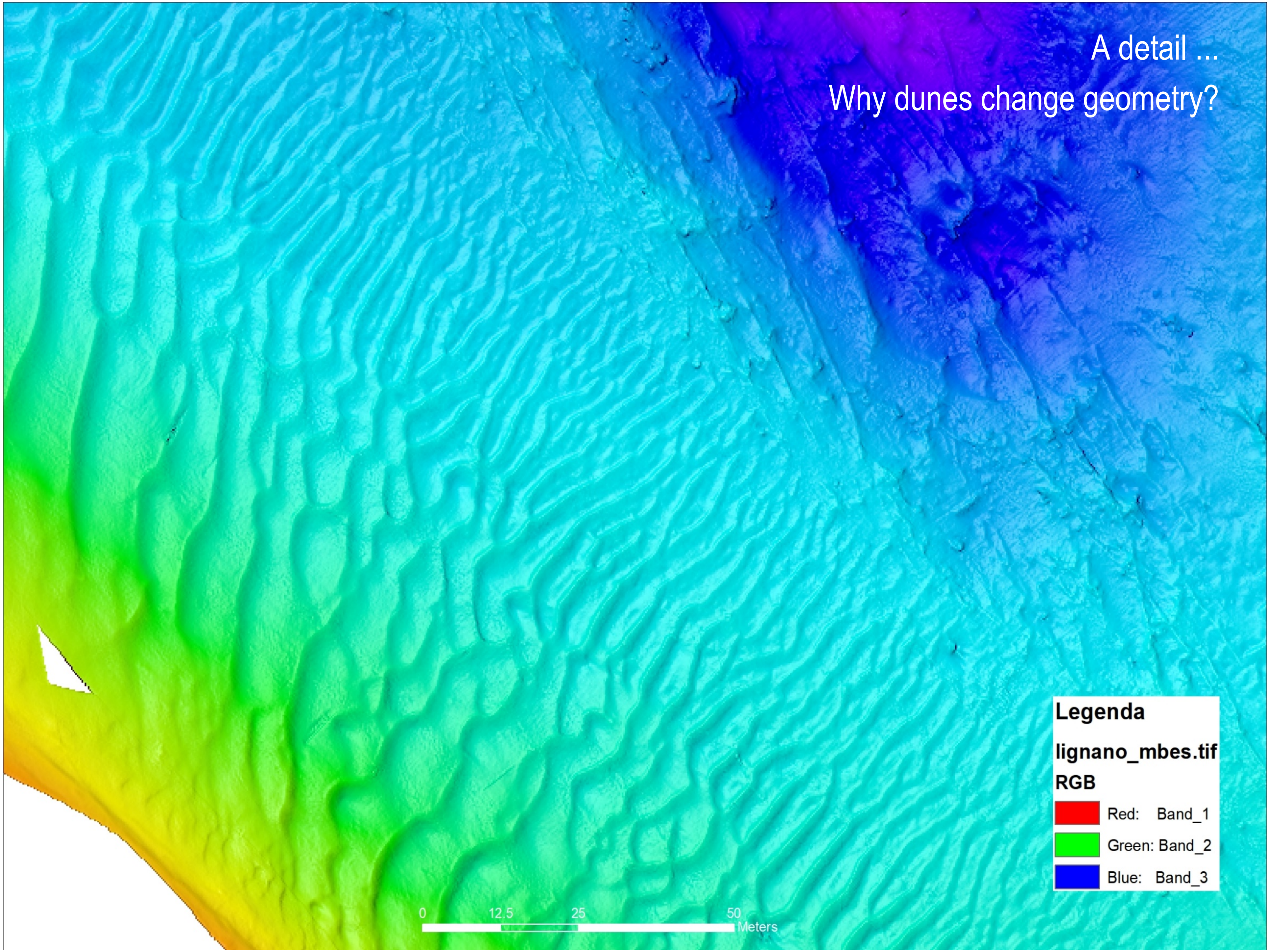
Range from L = 0.75 m to > 100m.

Range from H = 0.075 to >5 m



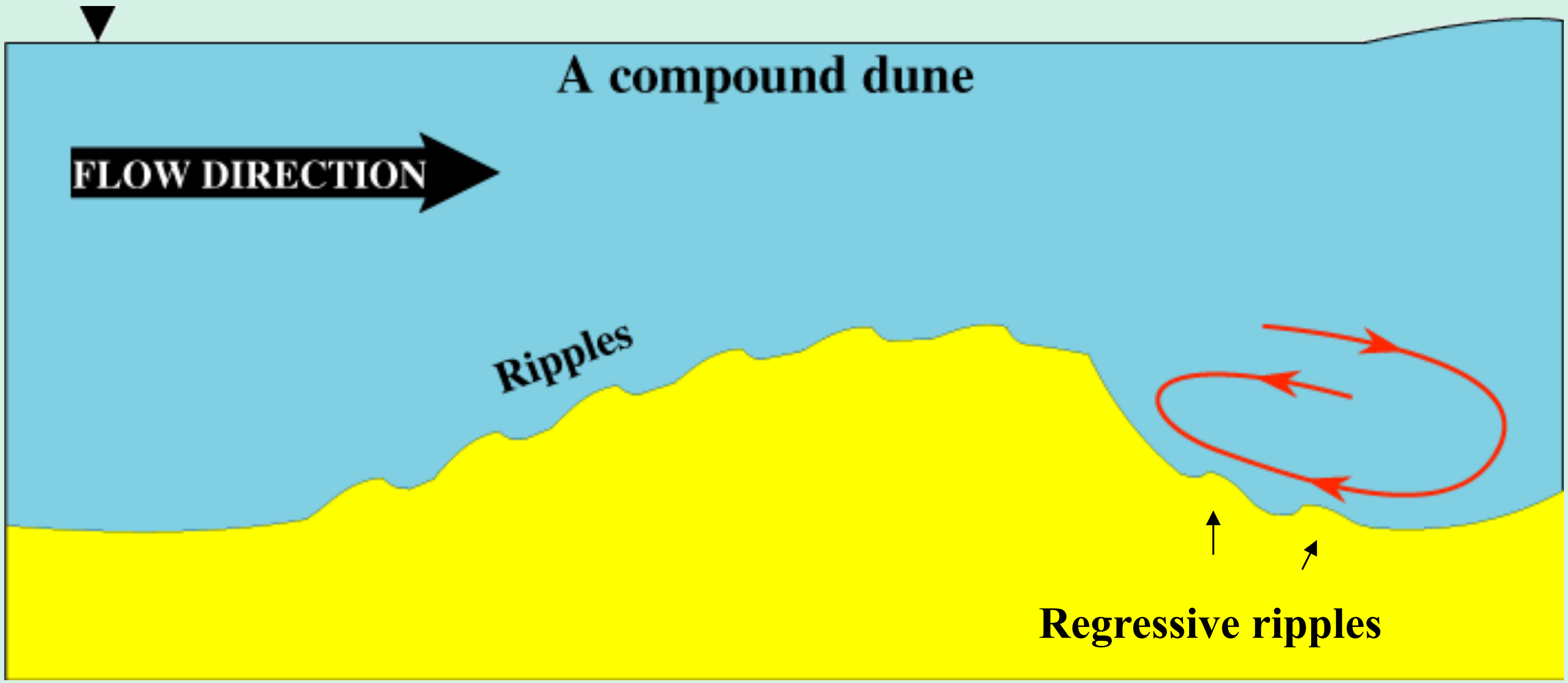
Most common in sands coarser than 0.15 mm.


Example of a subaqueous dunefield,
Lignano tidal inlet (SWAT bathymetry)
Legenda
lignano_mbes.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
0
50
100
200
Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


A detail ...
Why dunes change geometry?
Legenda
lignano_mbes.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
0
12.5
25
50
Meters

Ripples are sometimes superimposed on dunes to form compound dunes.

Flow separation over the dune crest leads to the development of an eddy that may produce a high enough upstream velocity over the bed to produce upstream-migrating ripples (**regressive ripples**).



Overall, plan form varies with flow strength.

Lowest flow strength dunes have long, straight to sinuous crests (2D dunes).

Lee slope near angle of repose (25°- 30°)

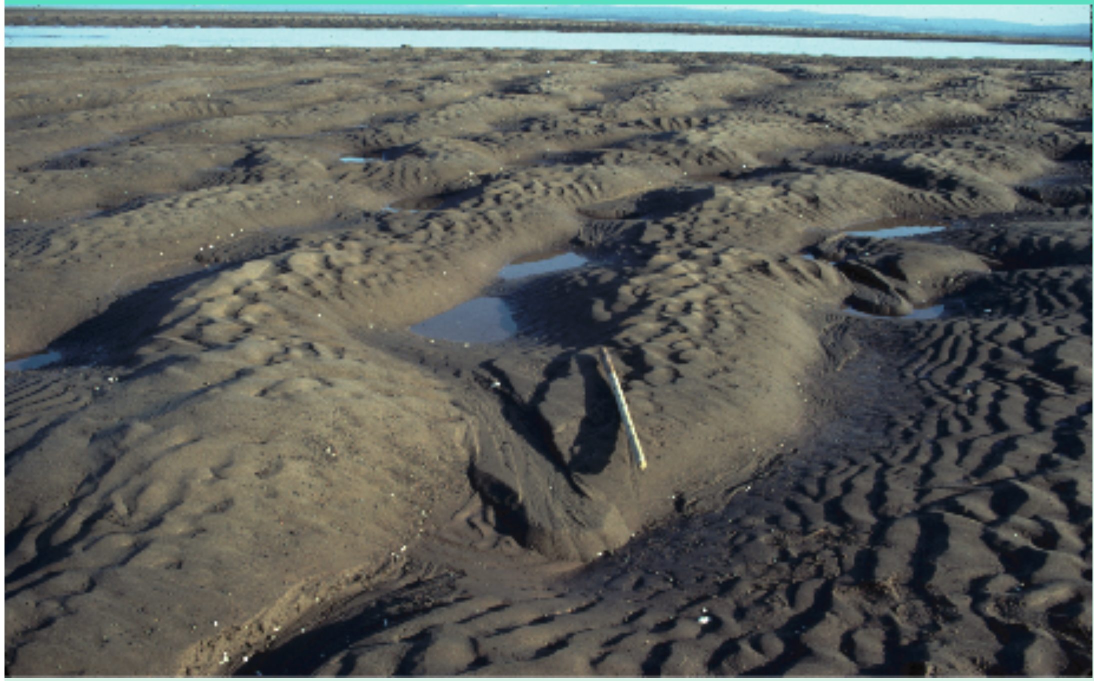
Gradational transition to 3-D dunes:

Complex crest-lines: sinuous to lunate.

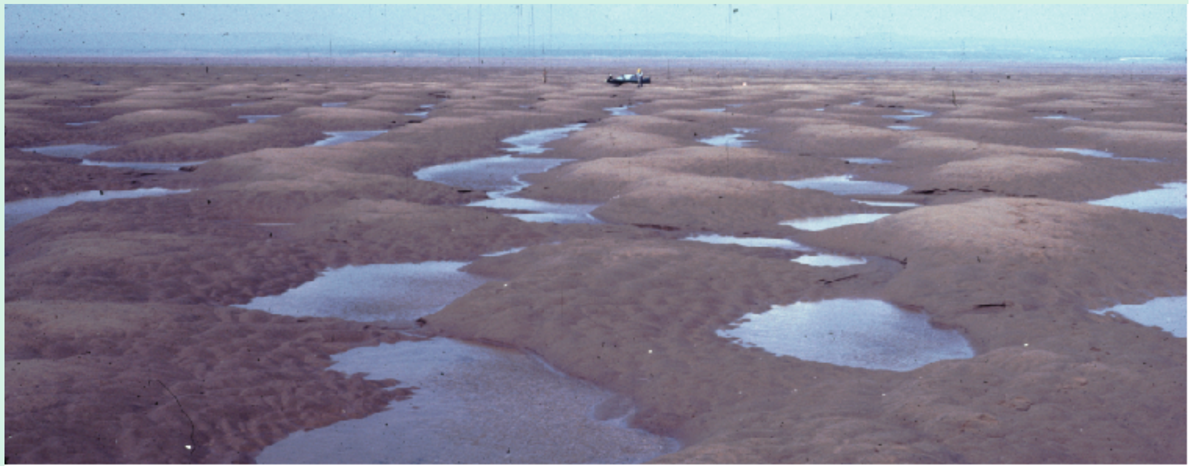
Shorter in length and higher.

Lee slope angle < 25°

Scour pits in the trough are typical of 3-D dunes.



These intertidal dunes from Cobequid Bay pond water in their scoured troughs after the ebb tide recedes.



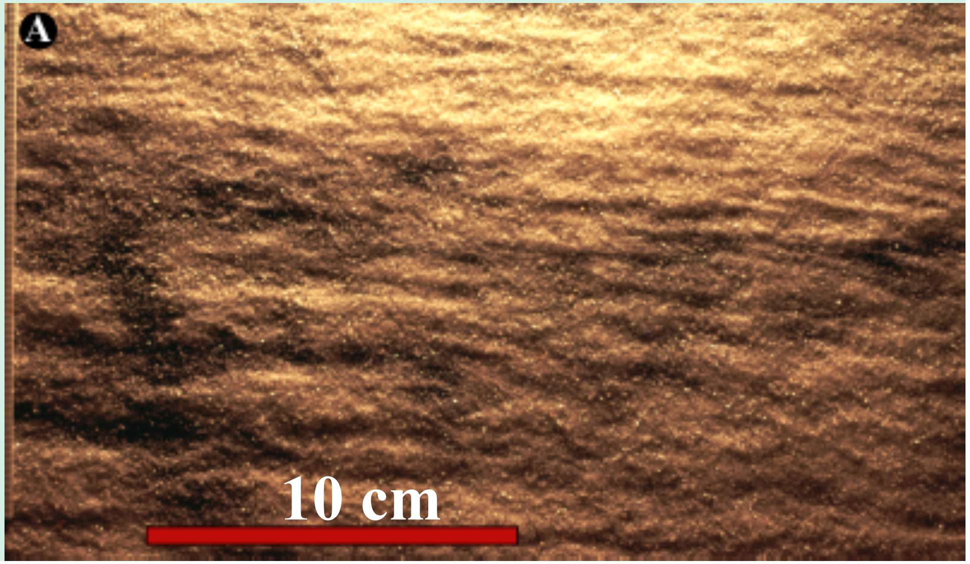
iv) Washed-out dunes

As flow strength increases dunes become longer and lower, “washing out” into the next bed form.

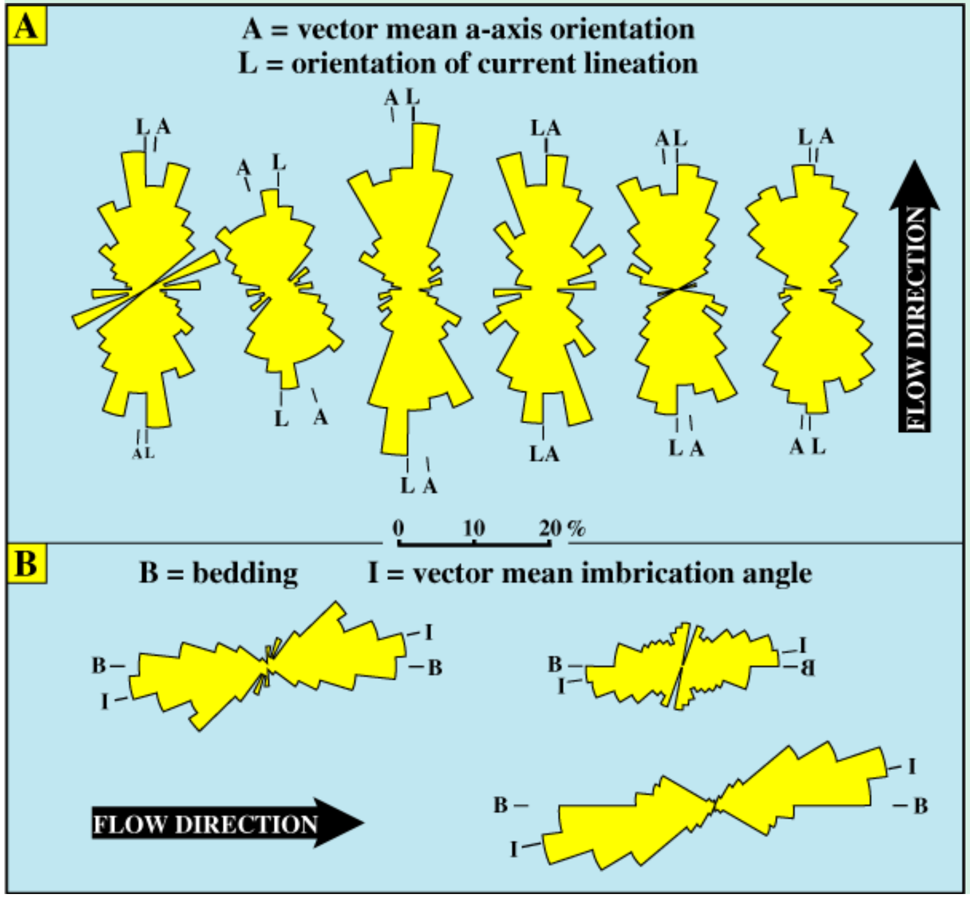
v) Upper plane bed

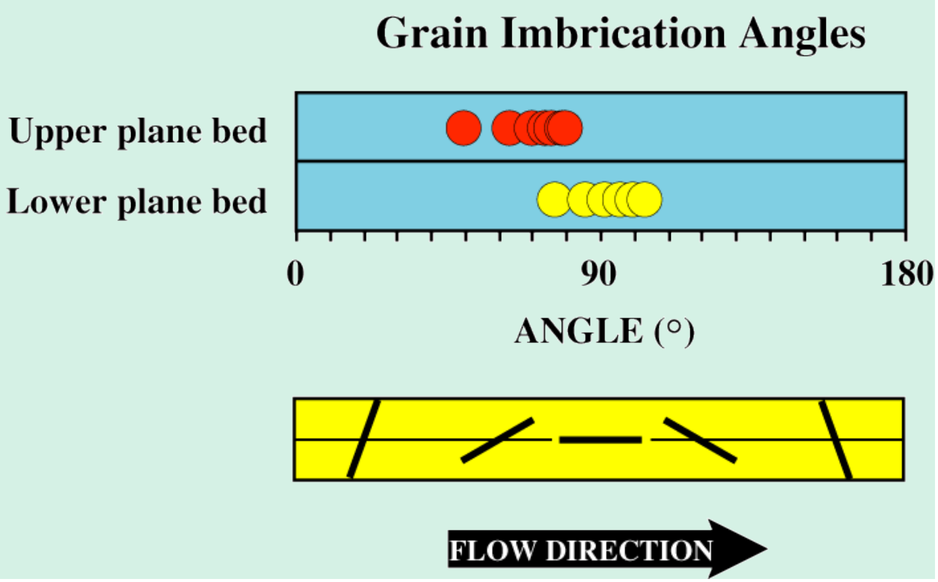
A flat bed with intense sediment transport.

Regular relief as flow parallel mounds a few grain diameters high (termed ***current lineations***).



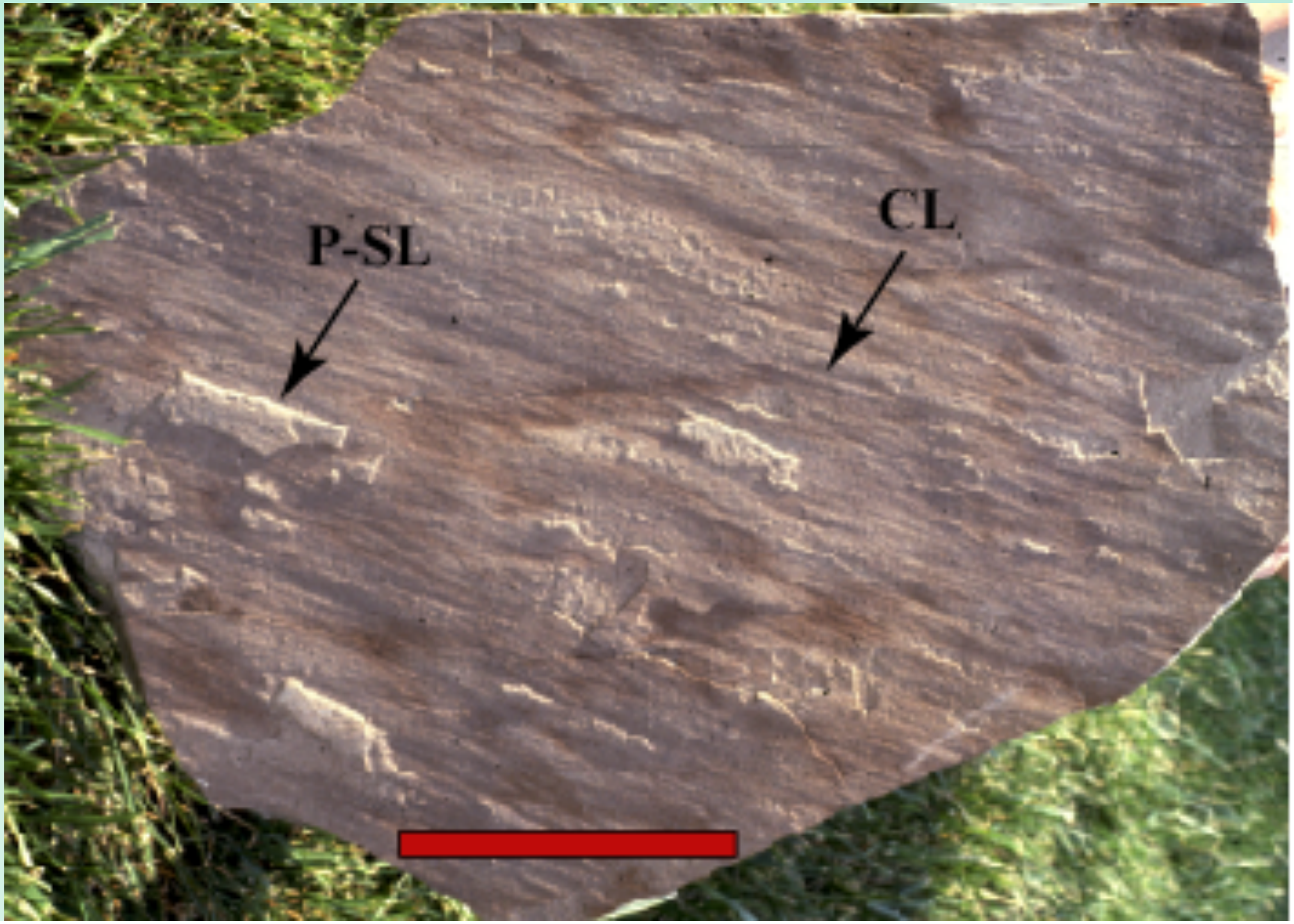
Grain long axes in upper plane bed deposits are distinctively flow parallel and imbricate upstream (10° to 30° from bedding is the normal range).

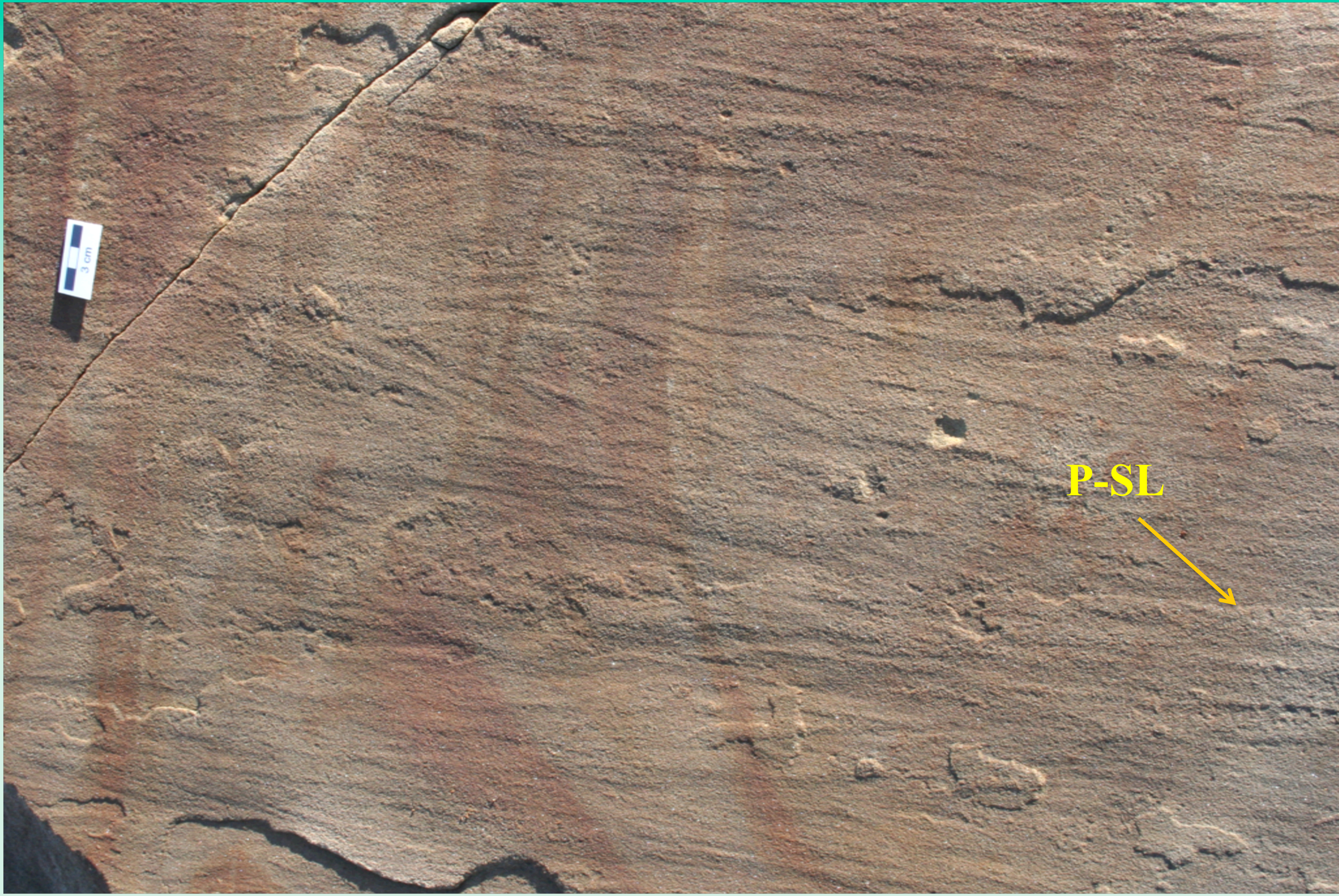




Flow parallel a-axes orientation results in *parting-step lineation* (P-SL) on bedding plane surfaces that are parallel to current lineation (CL).

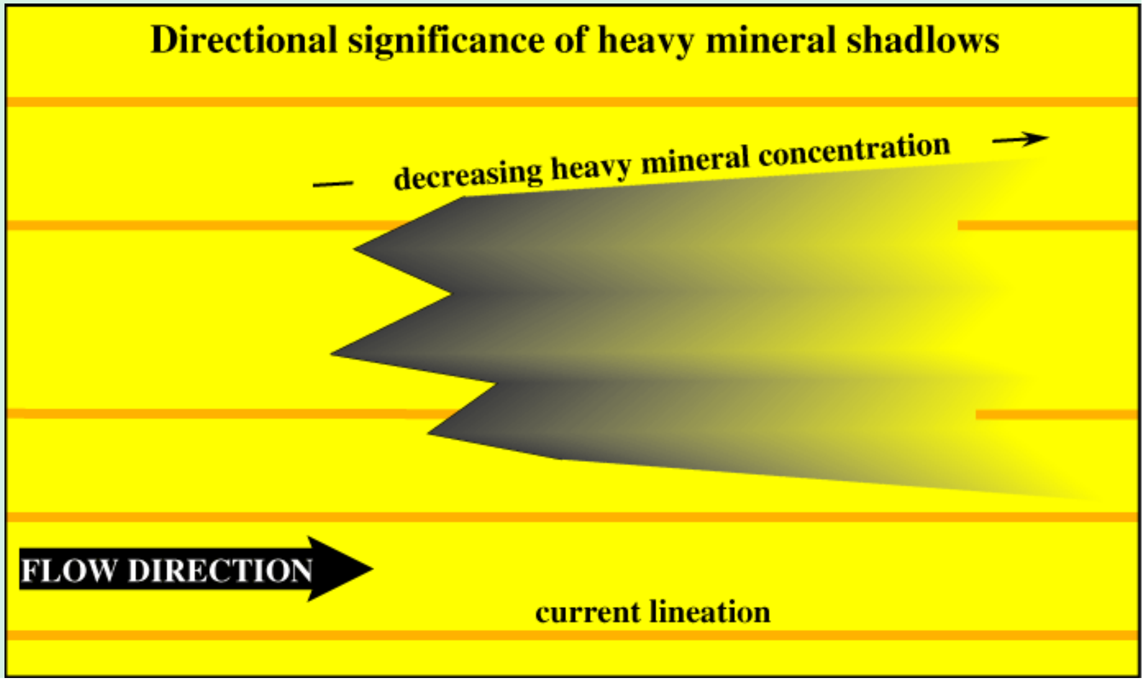
The alignment of a-axes causes the sandstone to preferentially break along that direction.

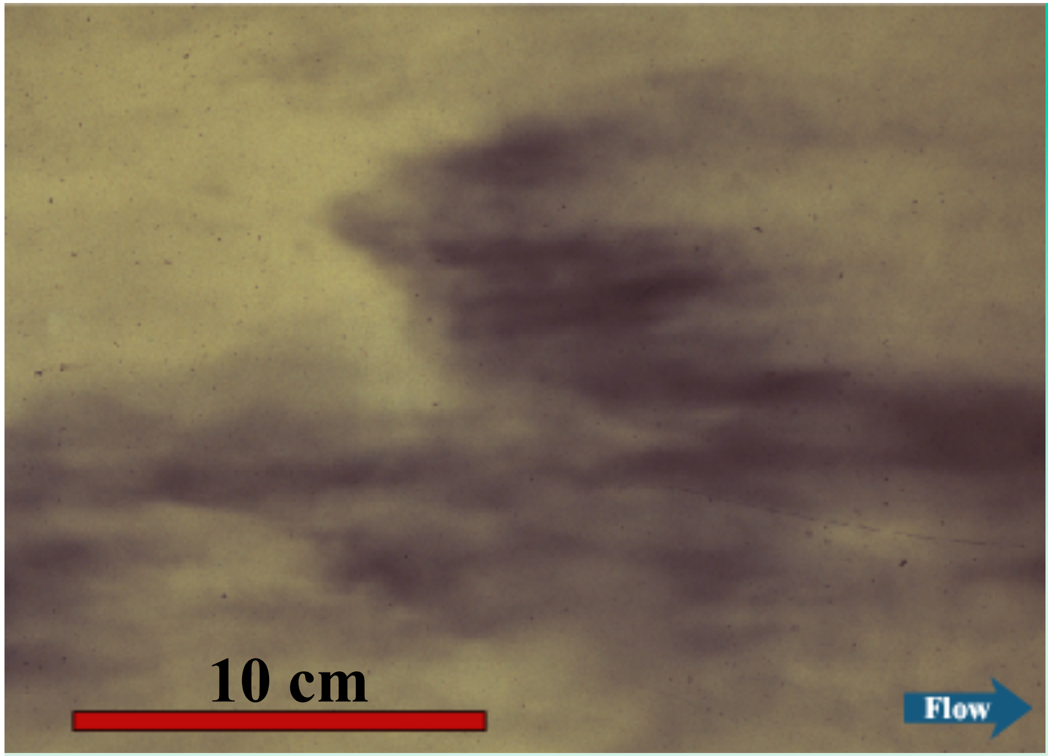



3 cm
P-SL

Heavy mineral shadows may be present when opaque heavy minerals are included in the sand bed (as little as 3% opaque heavy minerals is sufficient for shadows to form).

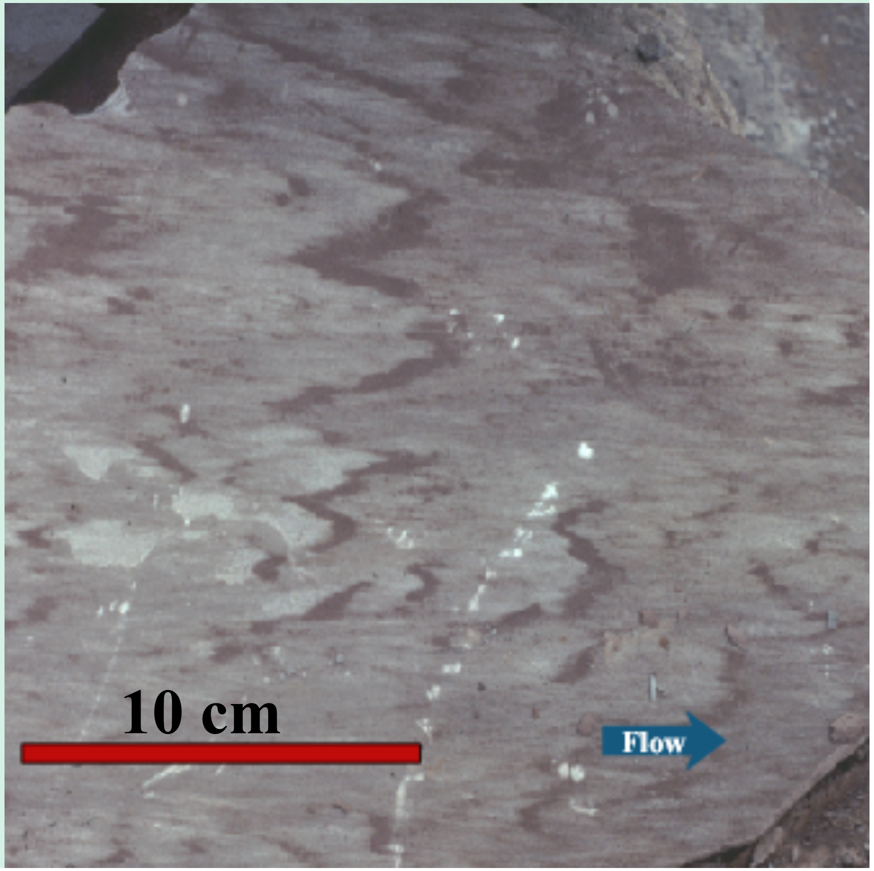
These are paleocurrent indicators: flow is towards the sharply defined side of the shadow, parallel to current lineations.





← Heavy mineral shadows in a flume.

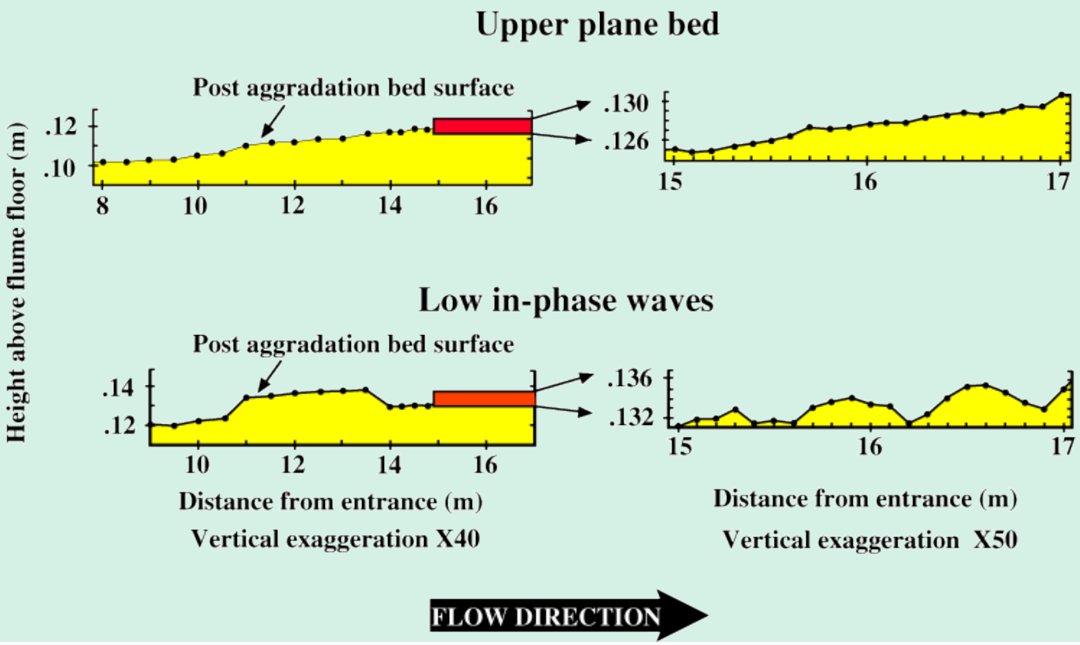
Heavy mineral shadows on a bedding surface of the Silurian Whirlpool Sandstone of southern Ontario. →



Some workers observe that low relief, downstream-migrating bed waves are ubiquitous to upper plane beds (contrary to my own experience with fine and very fine sand beds).

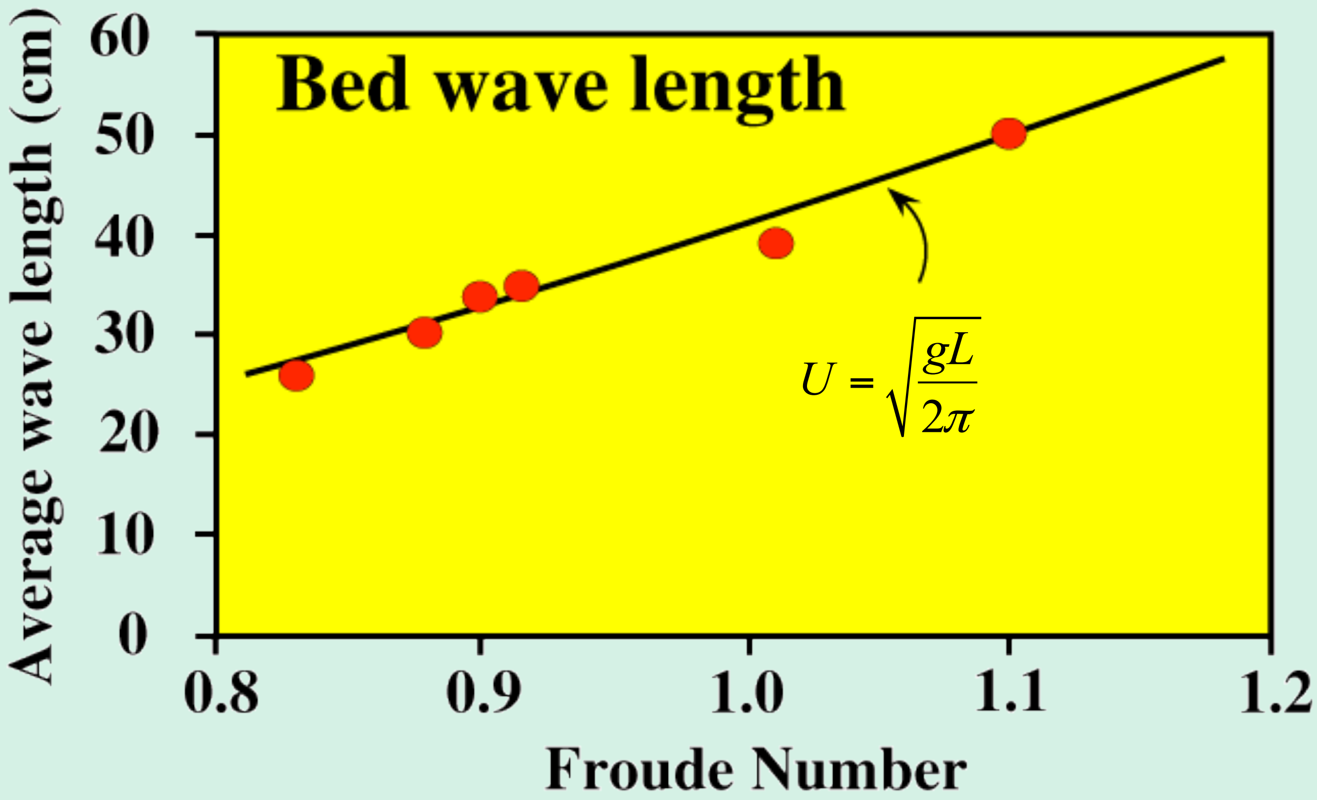
vi) In-phase waves

With increasing flow strength the bed becomes molded into symmetrical, sinusoidal waves that are more-or-less parallel to similar but higher amplitude water surface waves (note the small vertical scale of the sinusoidal waves below).



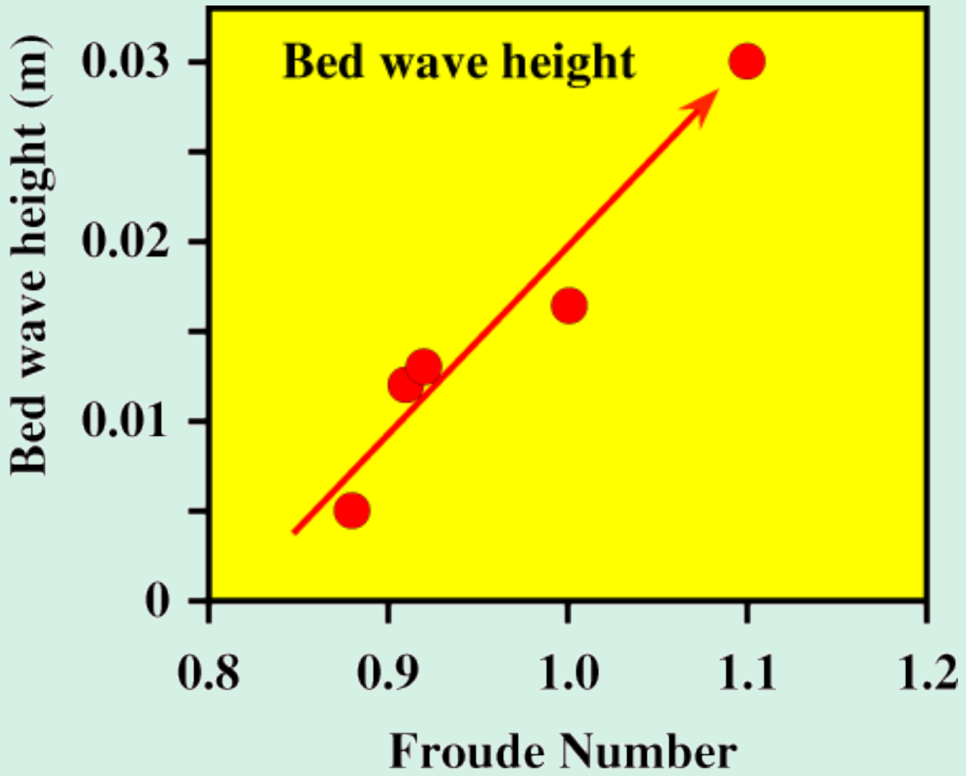
In-phase waves are so named because the bed surface is "in phase" with the water surface.

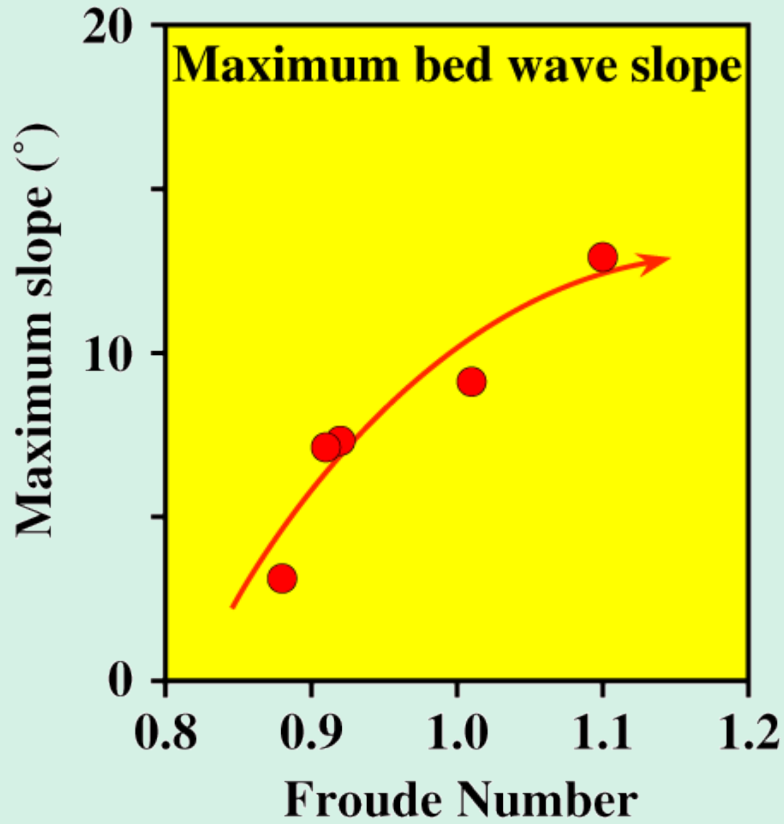
Wave length is related to the flow velocity by: $U = \sqrt{\frac{gL}{2\pi}}$



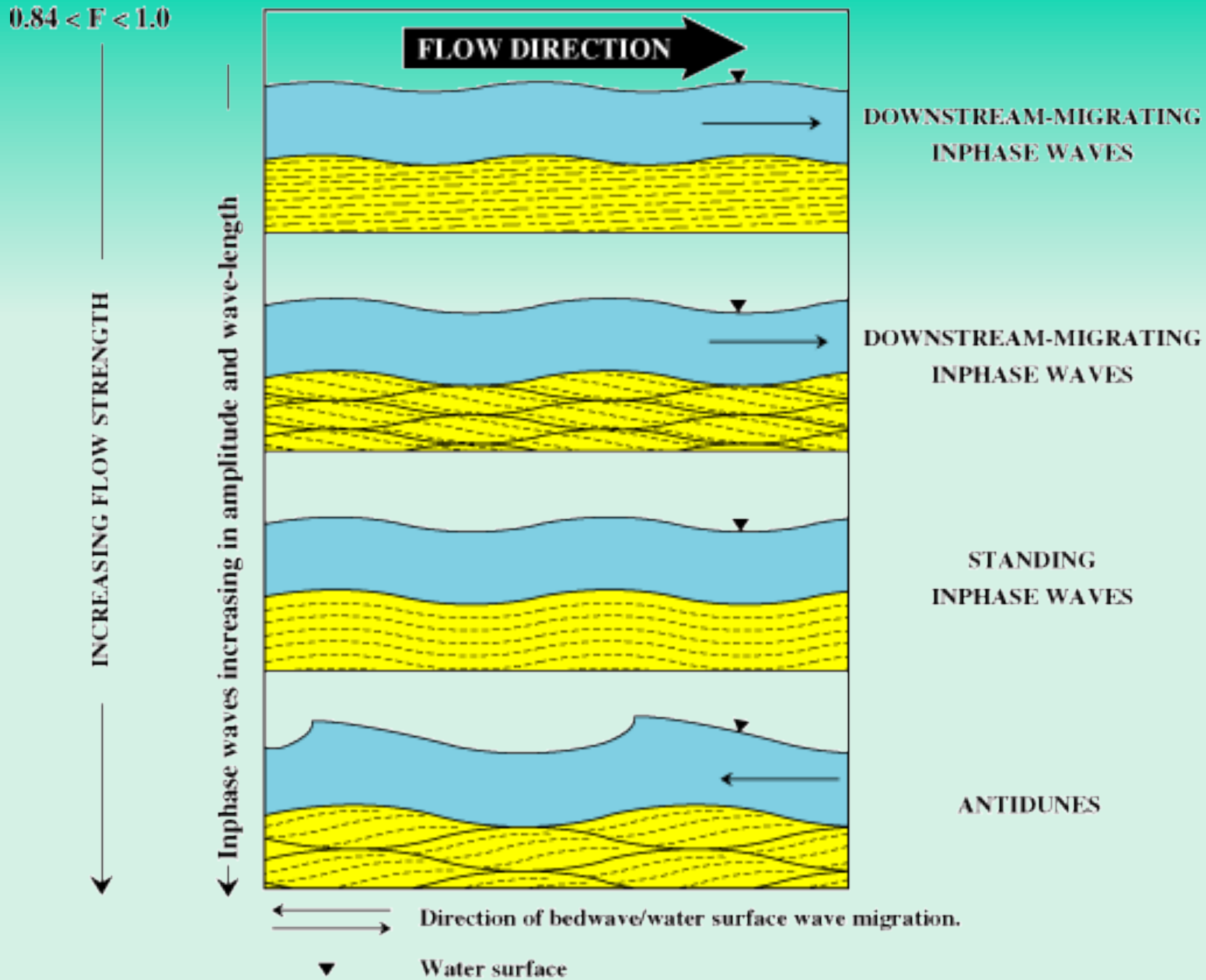
Bed wave height also increases with increasing flow strength.

Wave height increases more than wave length so that the maximum slope on the bed also increases with increasing flow strength.

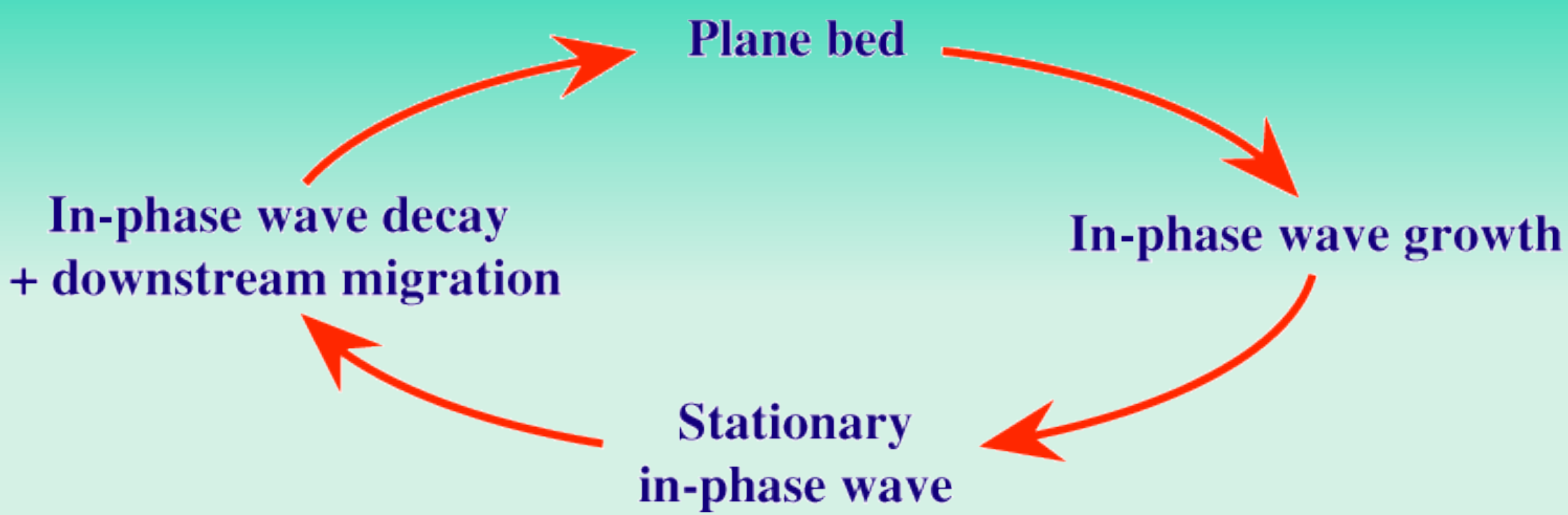


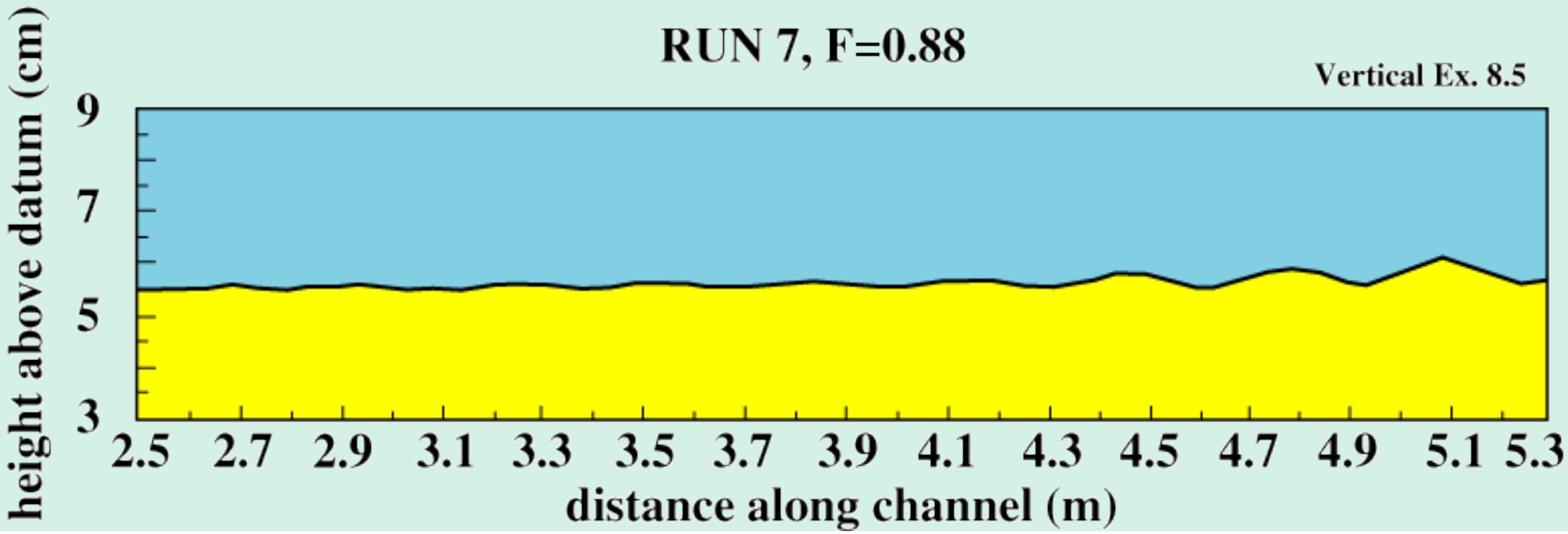


With increasing flow strength in-phase waves vary as shown:

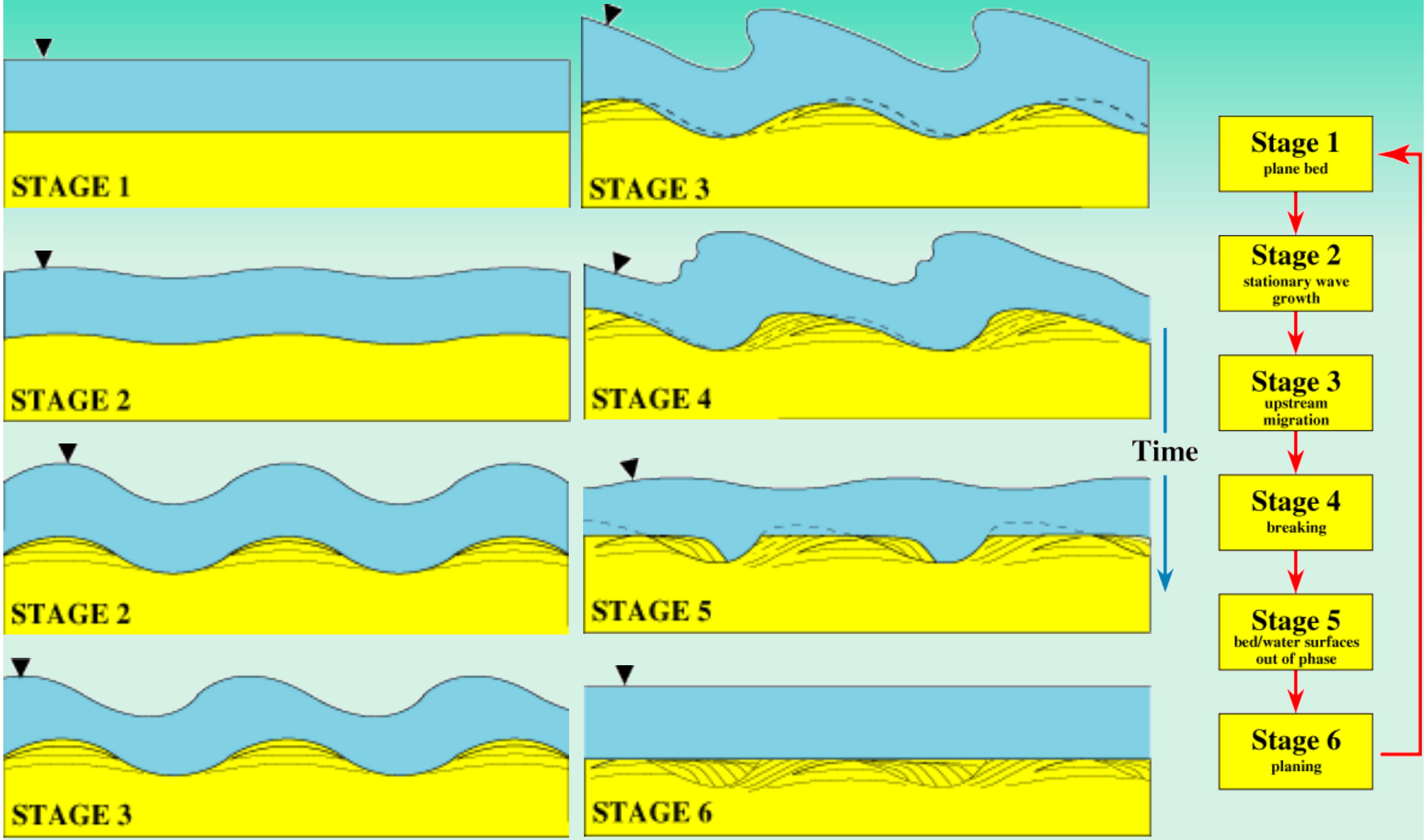


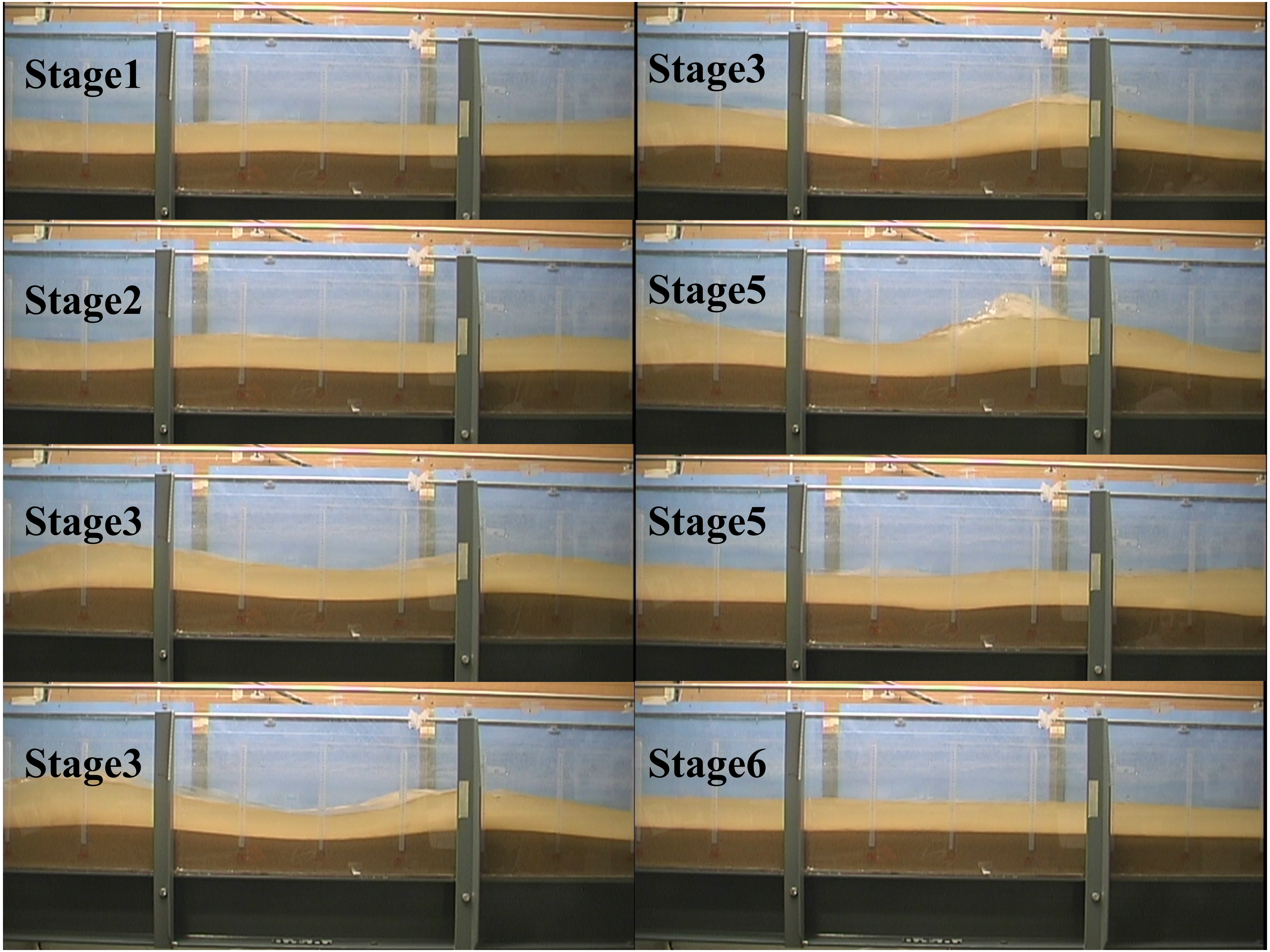
The first bed waves to form behave in the cyclical manner shown below.





True antidunes (upstream migrating waves) have the following cyclical behavior:



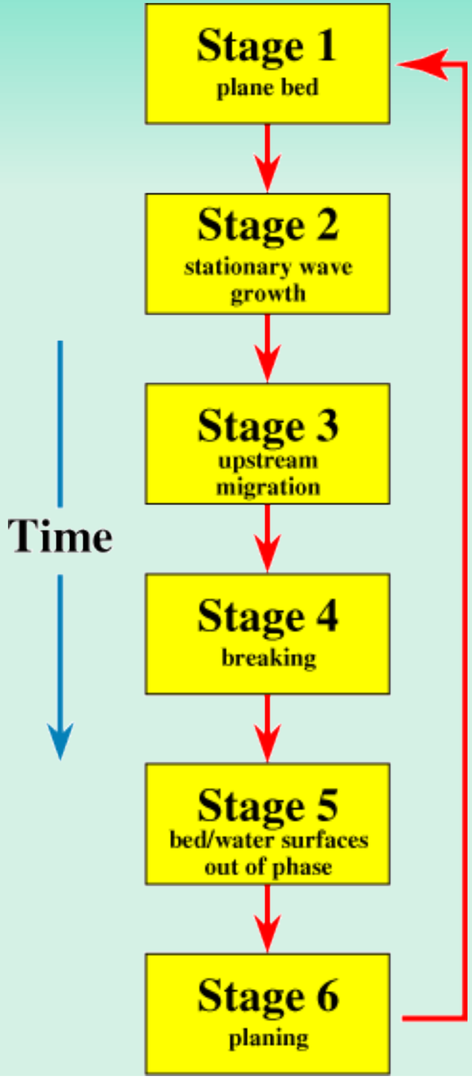

Stage1
Stage3
Stage2
Stage5
Stage3
Stage5
Stage3
Stage6

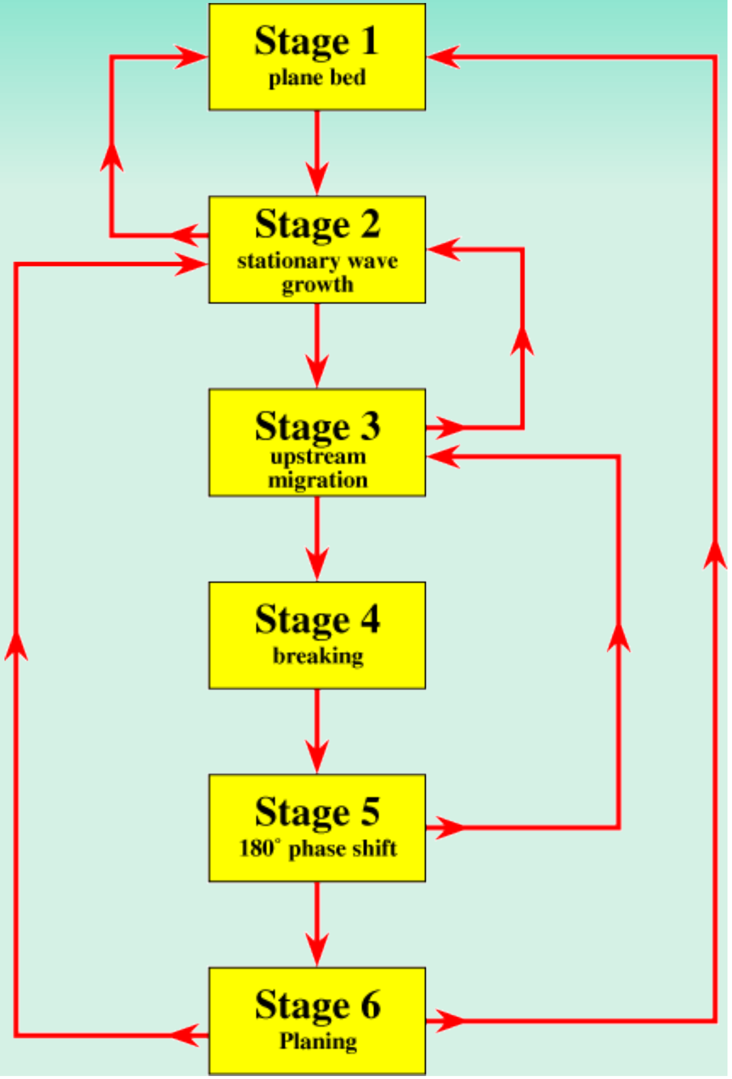
1. **video clip of ANTIDUNES:**
https://www.youtube.com/watch?v=zgesmtodrUM

2. Video clip of
BEDFORMS IN UNIDIRECTIONAL FLOW:
https://www.youtube.com/watch?v=zgesmtodrUM

Complete cycles are typical at the highest flow strengths.

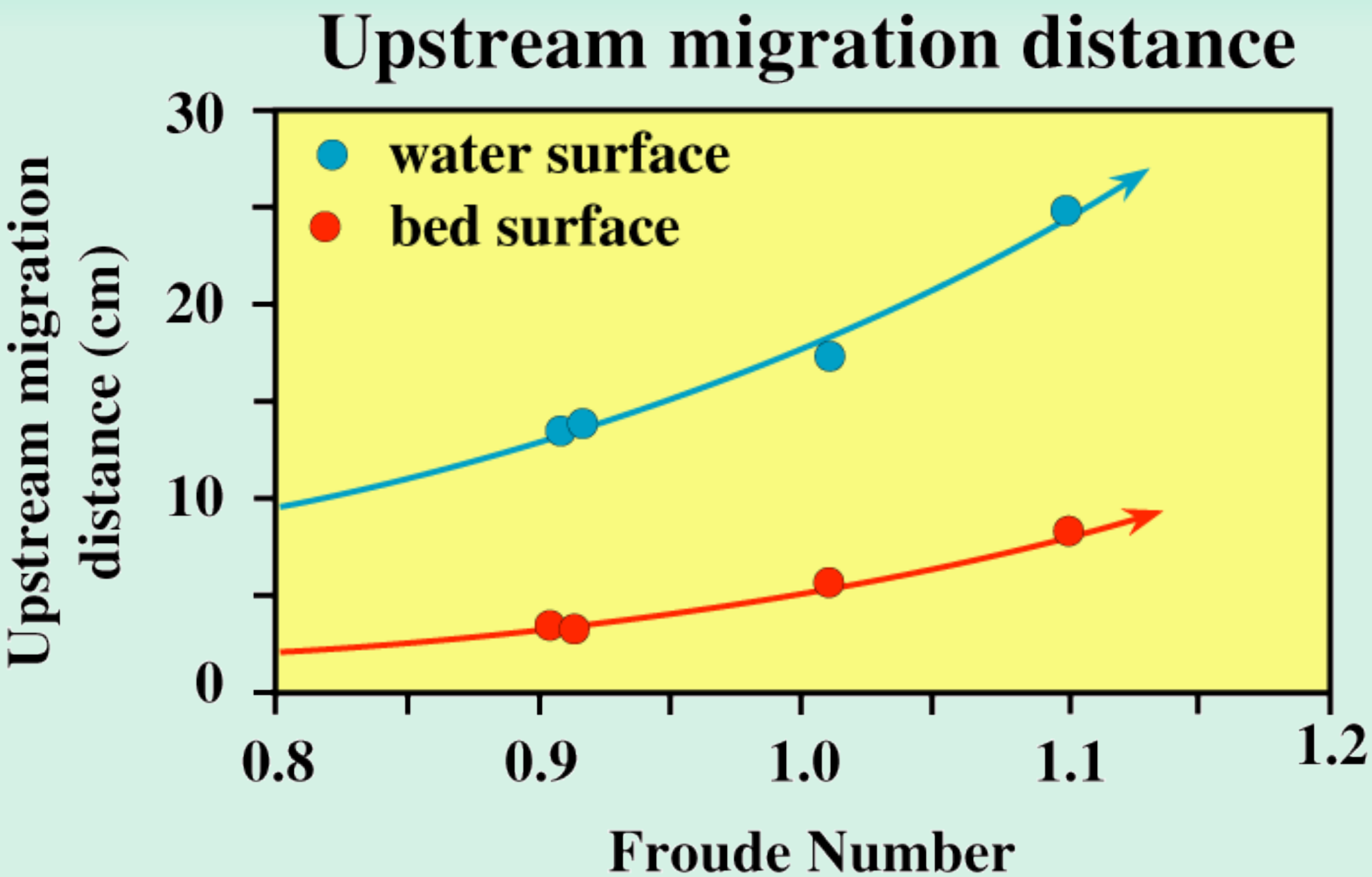
At lower flow strengths incomplete cycles of behavior are typical, extending to higher stages more frequently as flow strength increases.





With increasing flow strength the frequency of breaking and planing phases increase.

With increasing flow strength the distance that the bed waves migrate upstream increases.



In summary, with increasing flow strength, in-phase wave display the following behavior:

Increasing length

Increasing Height

Increasing maximum bed slope

More frequent breaking

Increasing upstream migration distance

SUPERCRITICAL FLOW (high Froude Number, F)

It commonly occurs in regions with high gradients and slope breaks:

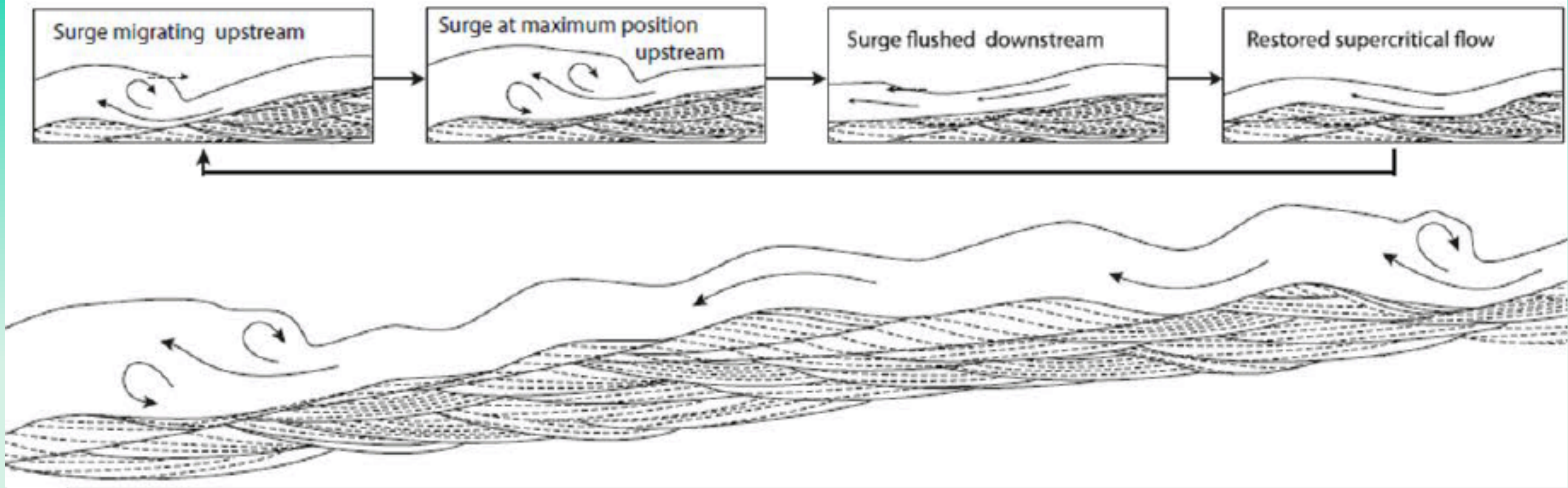
- Continental: fluvial environments
- Marine: straits, deltas or deep water (turbidity) environments

The most diagnostic sedimentary structures are:

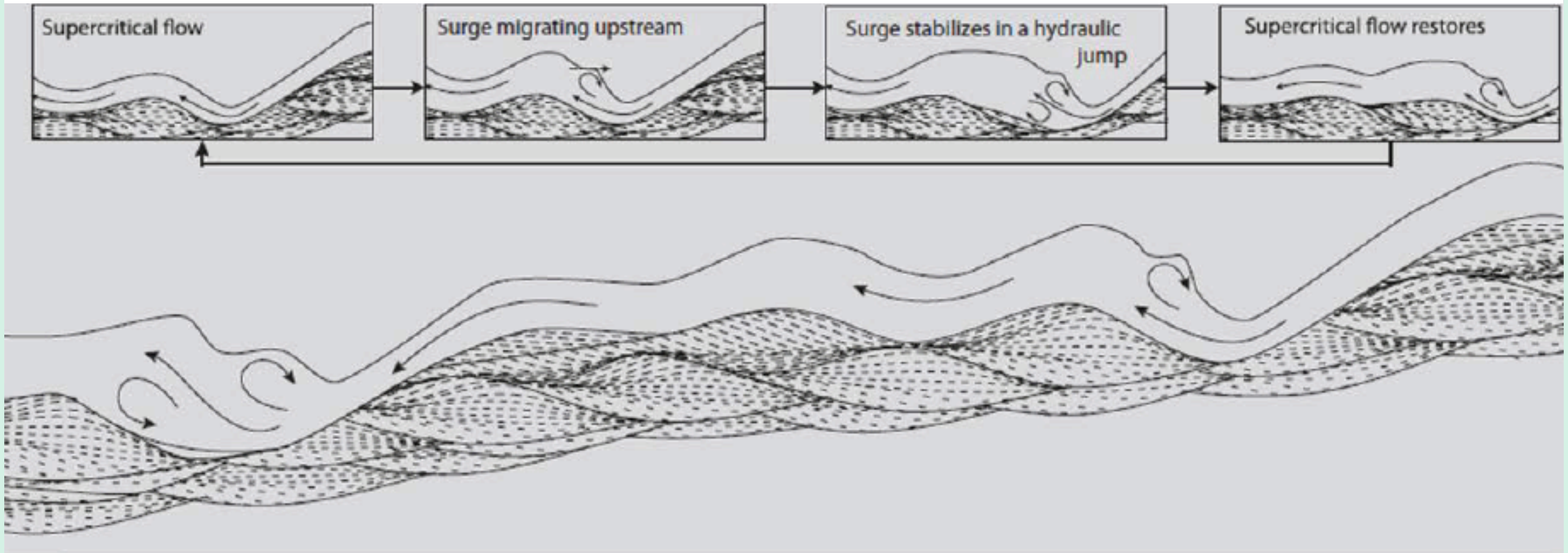
- **antidunes**
- **chutes and pools**
- **cyclic steps**

and are primarily recognized by low- to moderate-angle cross-stratification with dips generally opposing that of associated dune cross-stratification.

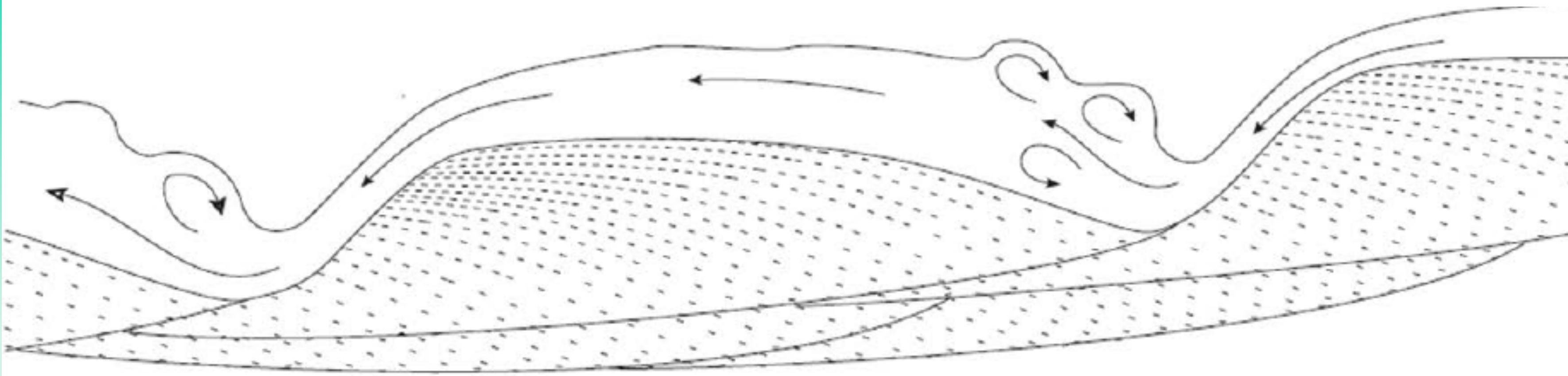
- **antidunes**

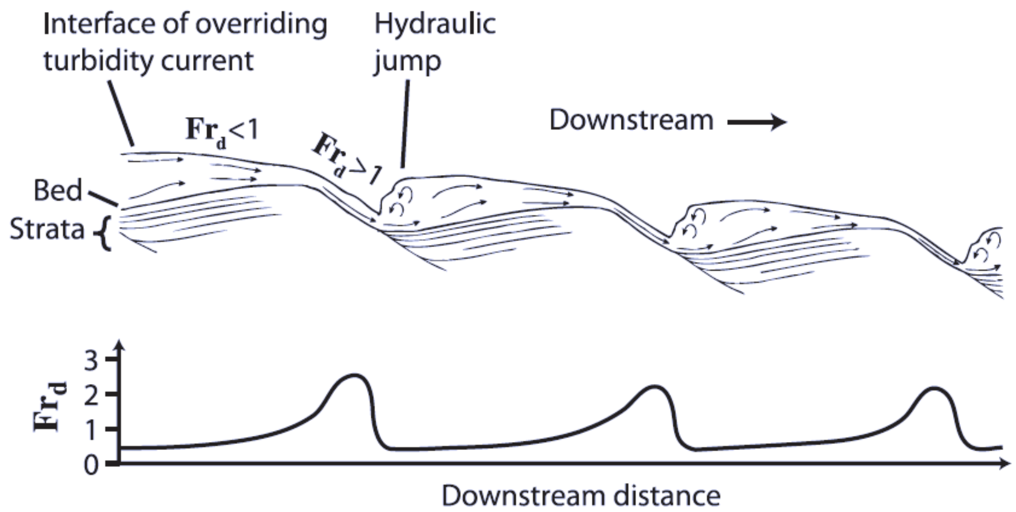


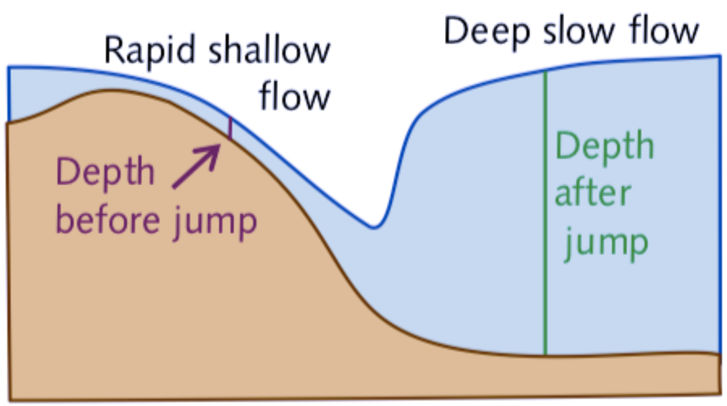
- **chutes and pools**



- **Cyclic steps**







HYDRAULIC JUMP = Risalto idraulico

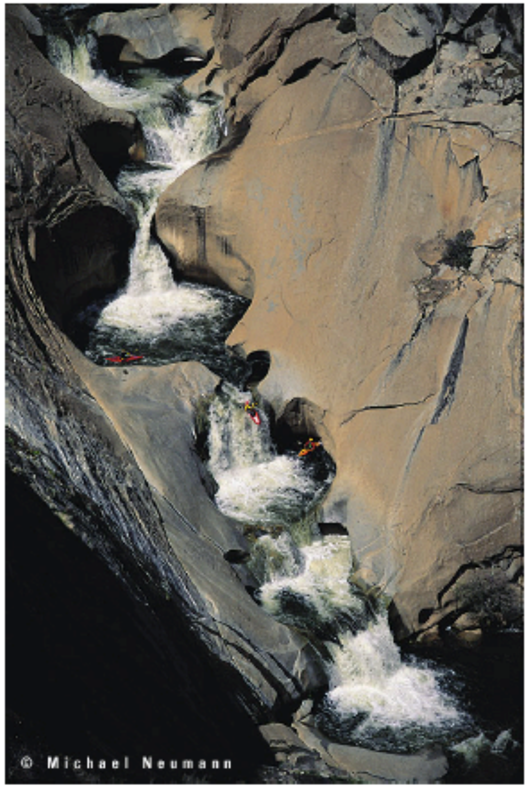
A SPECIFIC CASE: turbidite

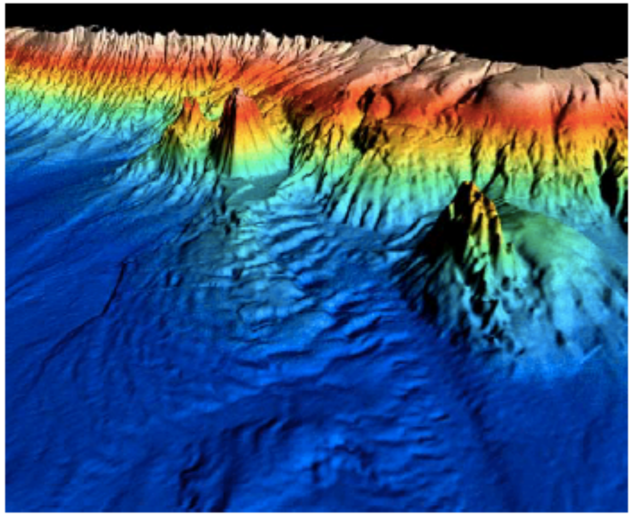
The flow dynamics of turbidity currents influence the evolution of architectural elements of deep-water depositional systems.

Flow dynamics can be characterized by the densimetric Froude number, $\mathbf{F}_d$, which is a dimensionless ratio of inertial to buoyancy forces in a current:

$$\text{Densimetric Froude Number } \left(F_d = \frac{U}{\sqrt{\frac{\Delta\rho}{\rho} gh}} \right)$$

where U is depth-averaged current velocity, g is gravitational acceleration, $\Delta\rho/\rho$ is the submerged specific gravity of the current, and h is current depth.





Gary Parker
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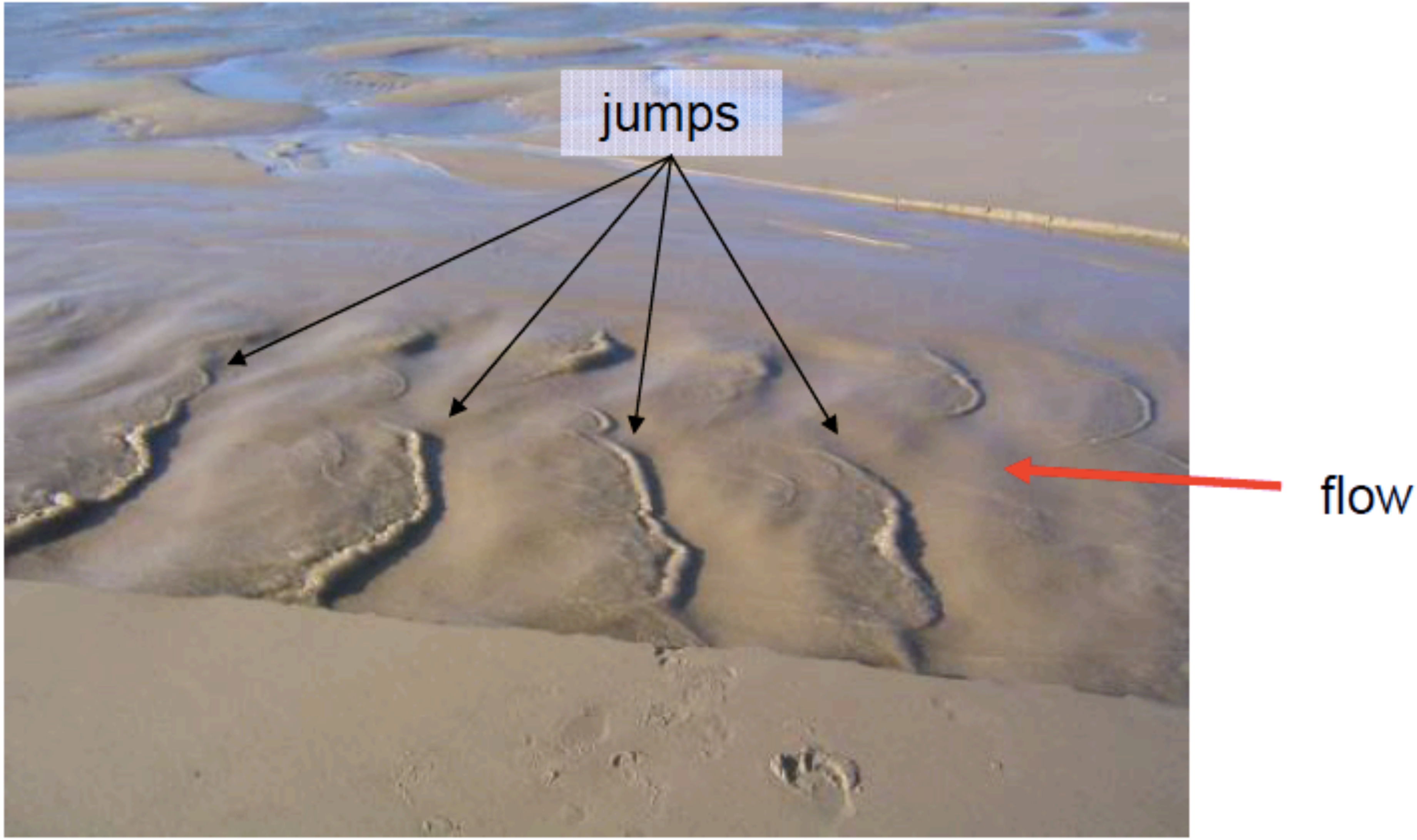
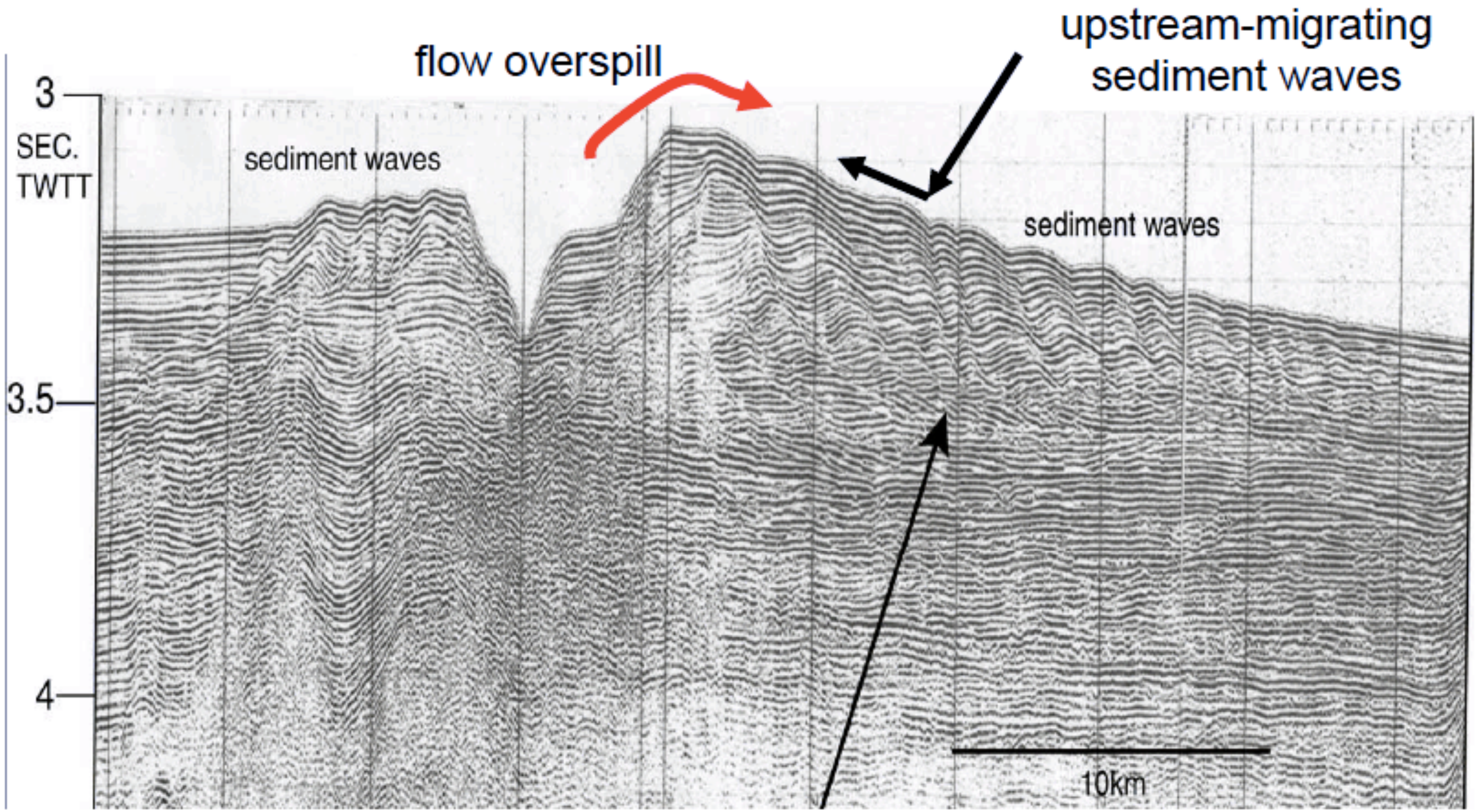
Department of Geology,
University of Illinois Urbana USA

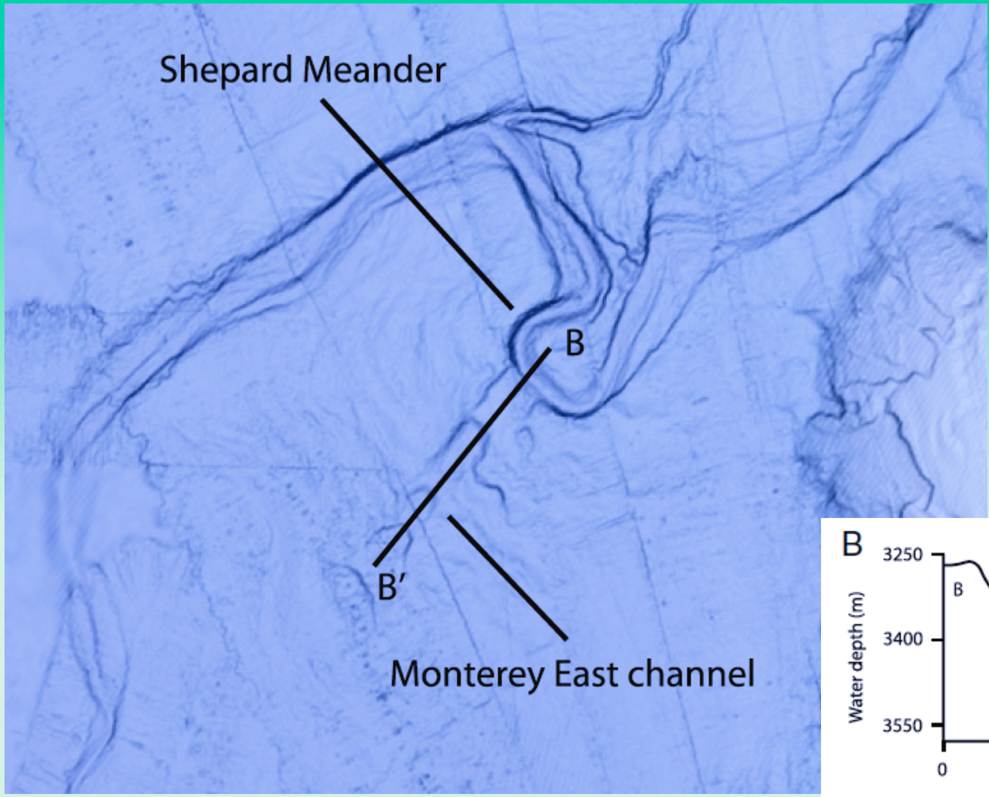


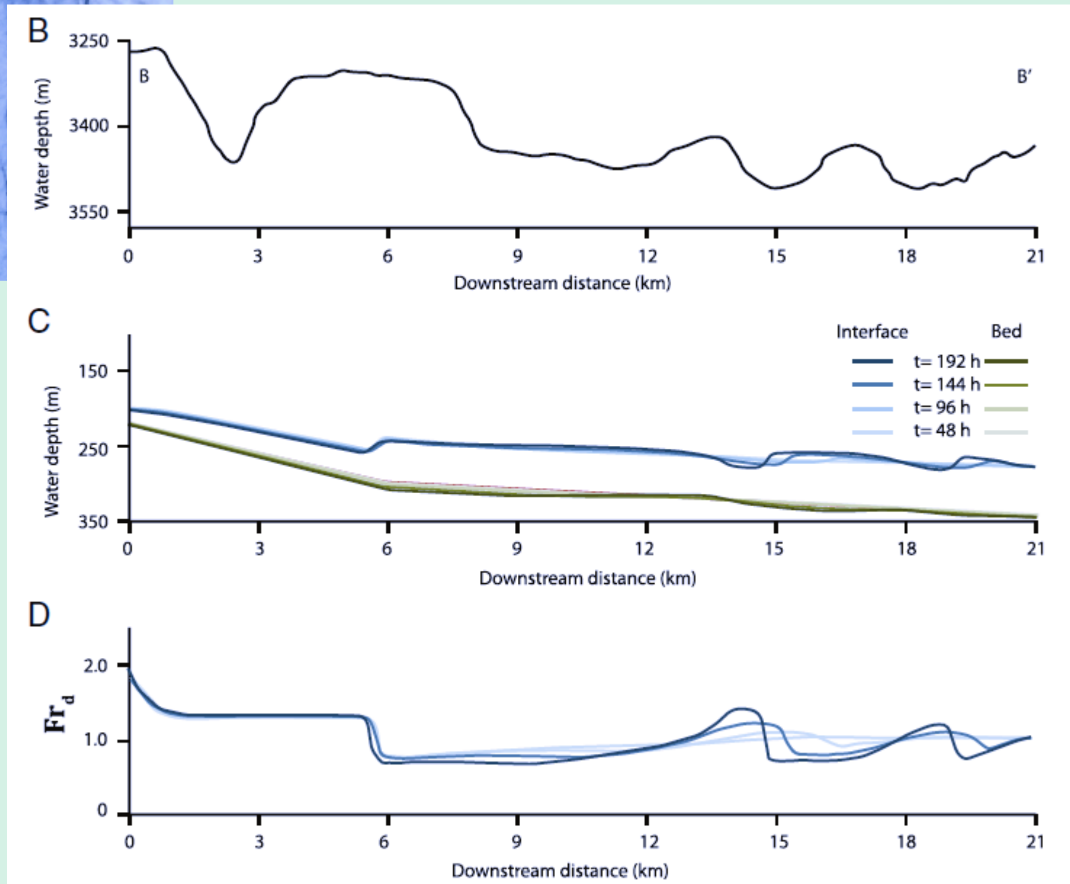
Trains of cyclic steps in a coastal outflow channel on a beach in Calais, France.
Image courtesy H. Capart.



Levee on the Toyama Submarine Channel.
Main flow is into the page.

Monterey Canyon - overwash





d) Bedform stability diagrams.

John Southard and his group at MIT have developed the following scheme for defining the hydraulic conditions for bed form stability.

The conditions under which a given bed form will develop depends on a combination of fluid and sediment properties:

Flow velocity (U)

Flow depth (D)

Water temperature (specifically fluid density and viscosity)

Grain Size (d)

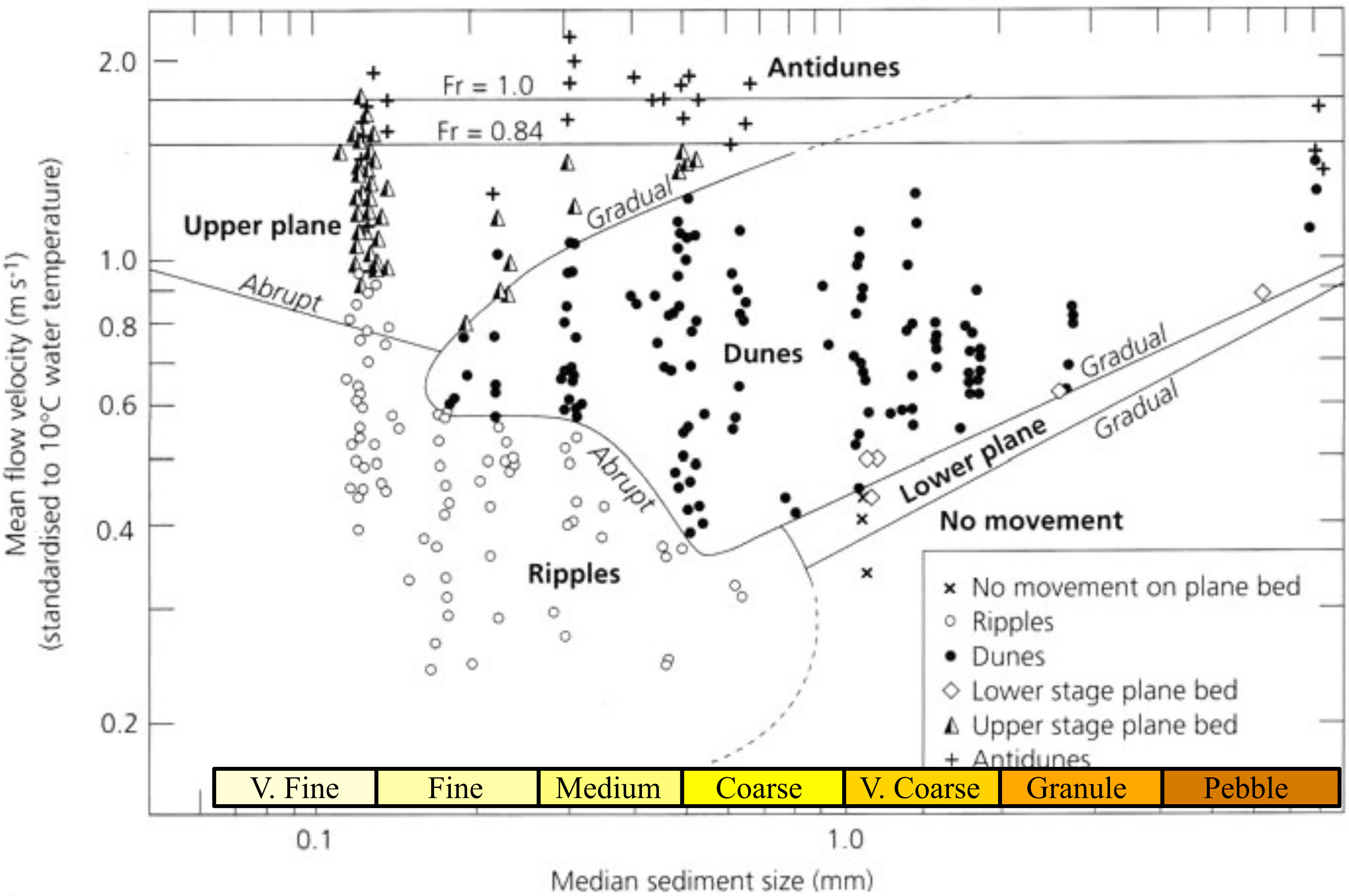
Grain density (ρ_s)

Sediment sorting coefficient
Particle shape
} Considered to be of secondary importance.

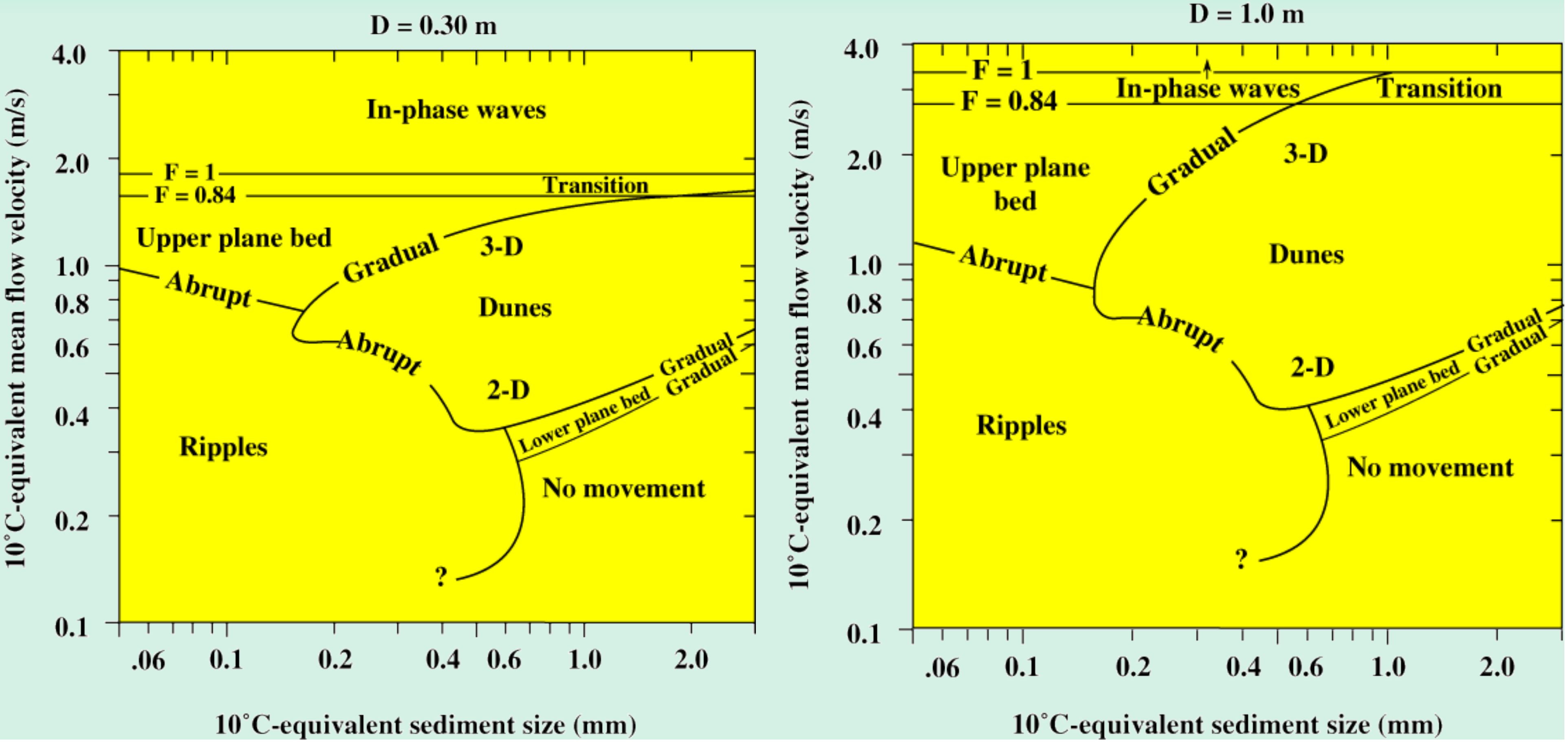
Stability diagrams are based on a very large number of experimental observations and observations in natural settings.

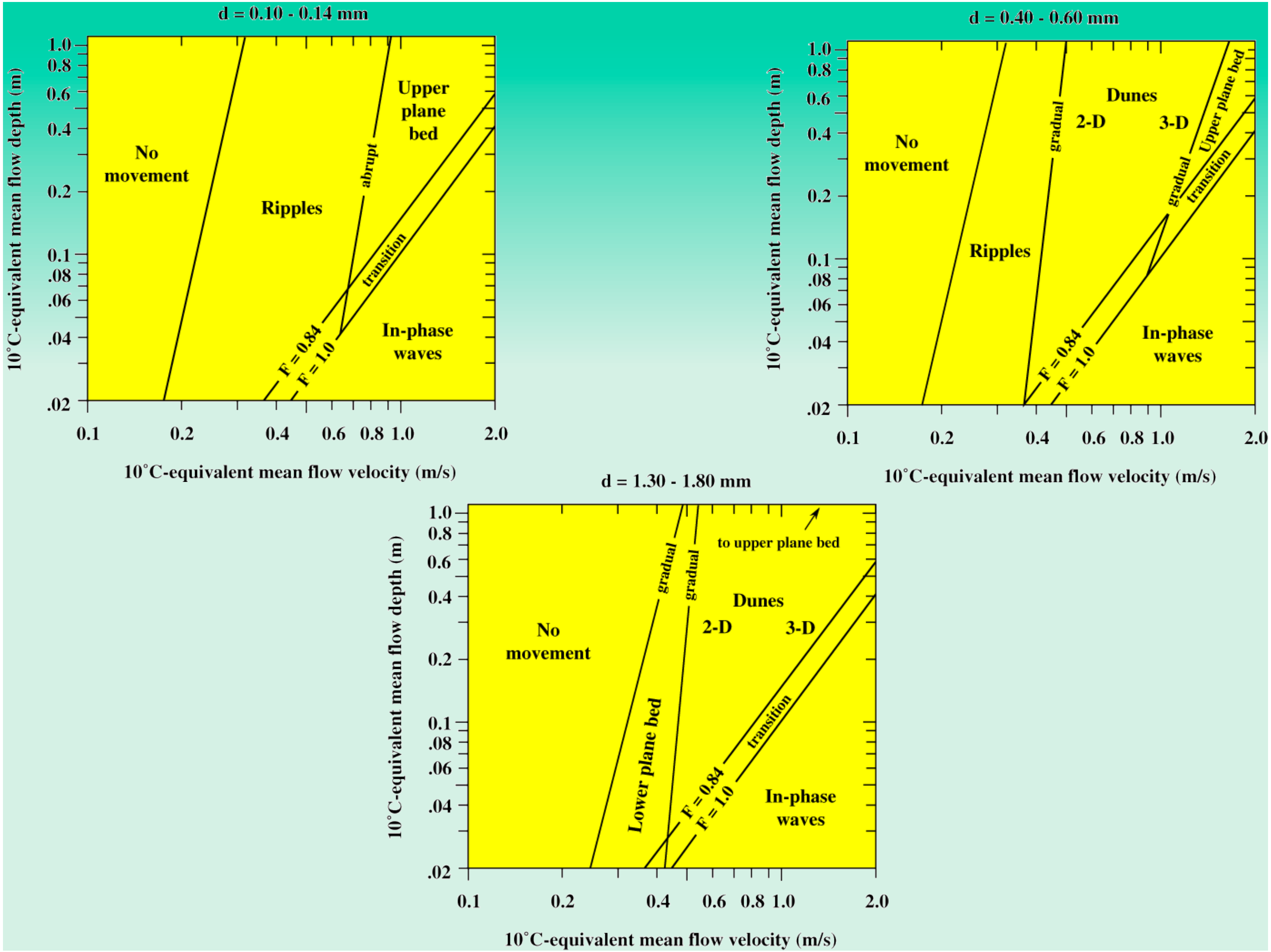
Stability fields are shown on velocity versus grain size diagrams or depth versus velocity diagrams.

All diagrams apply to quartz-density sand and are normalized to water at 10°C.



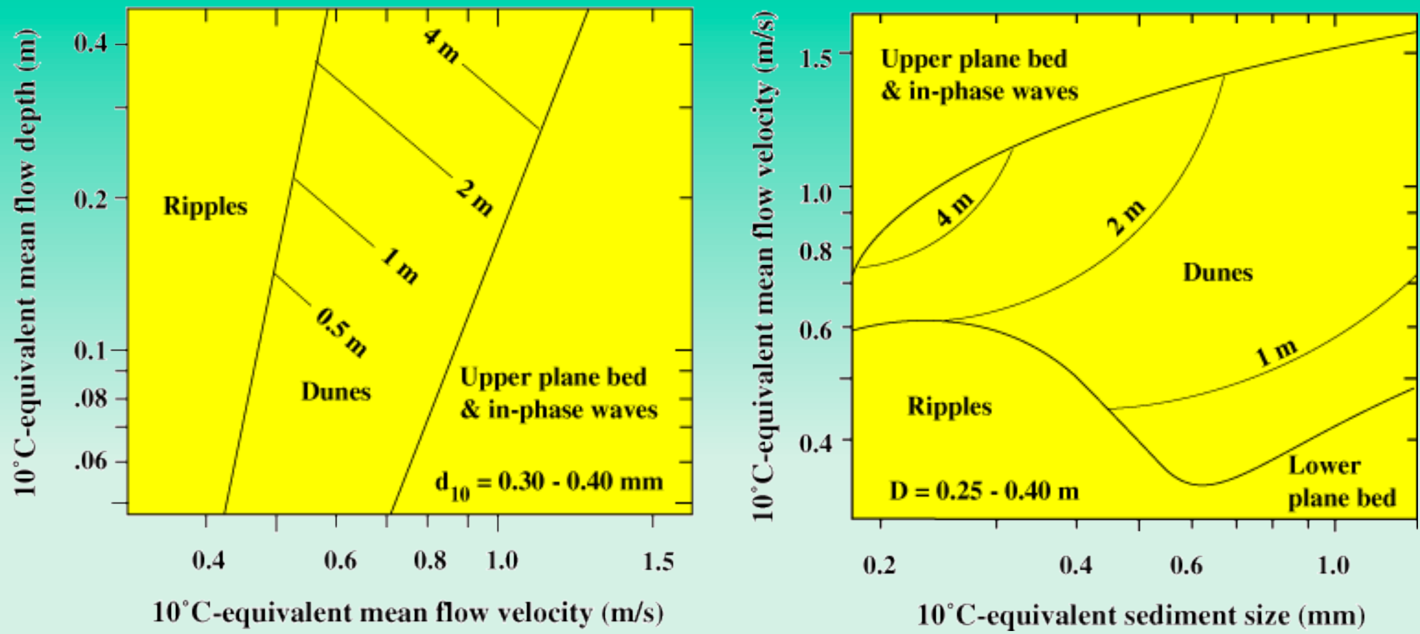
Antidunes
Fr = 1.0
Fr = 0.84
Upper plane
Abrupt
Gradual
Dunes
Ripples
Abrupt
Lower plane
Gradual
Gradual
No movement
× No movement on plane bed
○ Ripples
● Dunes
◇ Lower stage plane bed
Upper stage plane bed
+ Antidunes
V. Fine
Fine
Medium
Coarse
V. Coarse
Granule
Pebble
2.0
1.0
0.8
0.6
0.4
0.2
0.1
1.0
Mean flow velocity (m s⁻¹)
(standardised to 10°C water temperature)
Median sediment size (mm)


D = 0.30 m
In-phase waves
F = 1
F = 0.84
Transition
Upper plane bed
Gradual
3-D
Abrupt
Dunes
Abrupt
2-D
Gradual
Gradual
Lower plane bed
Ripples
No movement
?
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
.06
0.1
0.2
0.4
0.6
1.0
2.0
10°C-equivalent mean flow velocity (m/s)
10°C-equivalent sediment size (mm)
D = 1.0 m
F = 1
F = 0.84
In-phase waves
Transition
Upper plane bed
Gradual
3-D
Abrupt
Dunes
Abrupt
2-D
Gradual
Gradual
Lower plane bed
Ripples
No movement
?
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
.06
0.1
0.2
0.4
0.6
1.0
2.0
10°C-equivalent mean flow velocity (m/s)
10°C-equivalent sediment size (mm)

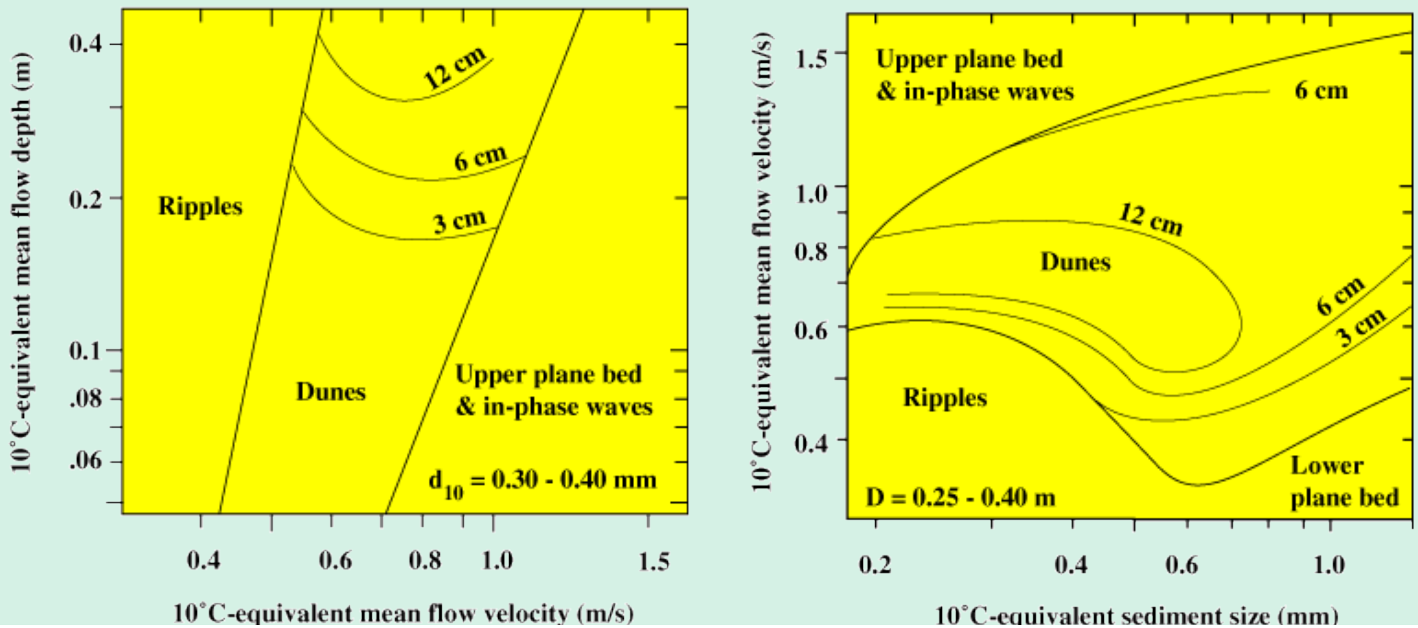


d = 0.10 - 0.14 mm
No movement
Ripples
abrupt
Upper plane bed
transition
F = 0.84
F = 1.0
In-phase waves
10˚C-equivalent mean flow depth (m)
10˚C-equivalent mean flow velocity (m/s)
d = 0.40 - 0.60 mm
No movement
Ripples
gradual
Dunes
2-D
3-D
Upper plane bed
gradual
transition
F = 0.84
F = 1.0
In-phase waves
10˚C-equivalent mean flow depth (m)
10˚C-equivalent mean flow velocity (m/s)
d = 1.30 - 1.80 mm
No movement
Lower plane bed
gradual
gradual
to upper plane bed
Dunes
2-D
3-D
transition
F = 0.84
F = 1.0
In-phase waves
10˚C-equivalent mean flow depth (m)
10˚C-equivalent mean flow velocity (m/s)

Dune spacing (length)



Dune height



Important points to remember:

Ripples form only in fine sand or finer.

Lower plane bed only forms in coarse sand or coarser.

Upper plane bed and dunes stability fields become larger with increasing depth.

$$F = \frac{U}{\sqrt{gD}}$$

Limits the range of velocity over which they are stable.

Dune spacing: increases with depth;
increases with velocity (washing out);
increases with increasing grain size.

Dune height: increases with depth;
increases and then decreases with velocity (washing out);
increases with decreasing grain size.

Cross stratification under unidirectional flows

Formed by deposition on various bed forms.

The style of cross-stratification reflects the bed form that was present and the hydraulic conditions at the time.

a) Terminology

Stratum (pl. strata) Any layer of rock regardless of its thickness that is distinguishable from other strata on the basis of texture, lithology, structures, colour, etc.

May be simple (homogenous) or complex (i.e., divisible into units).

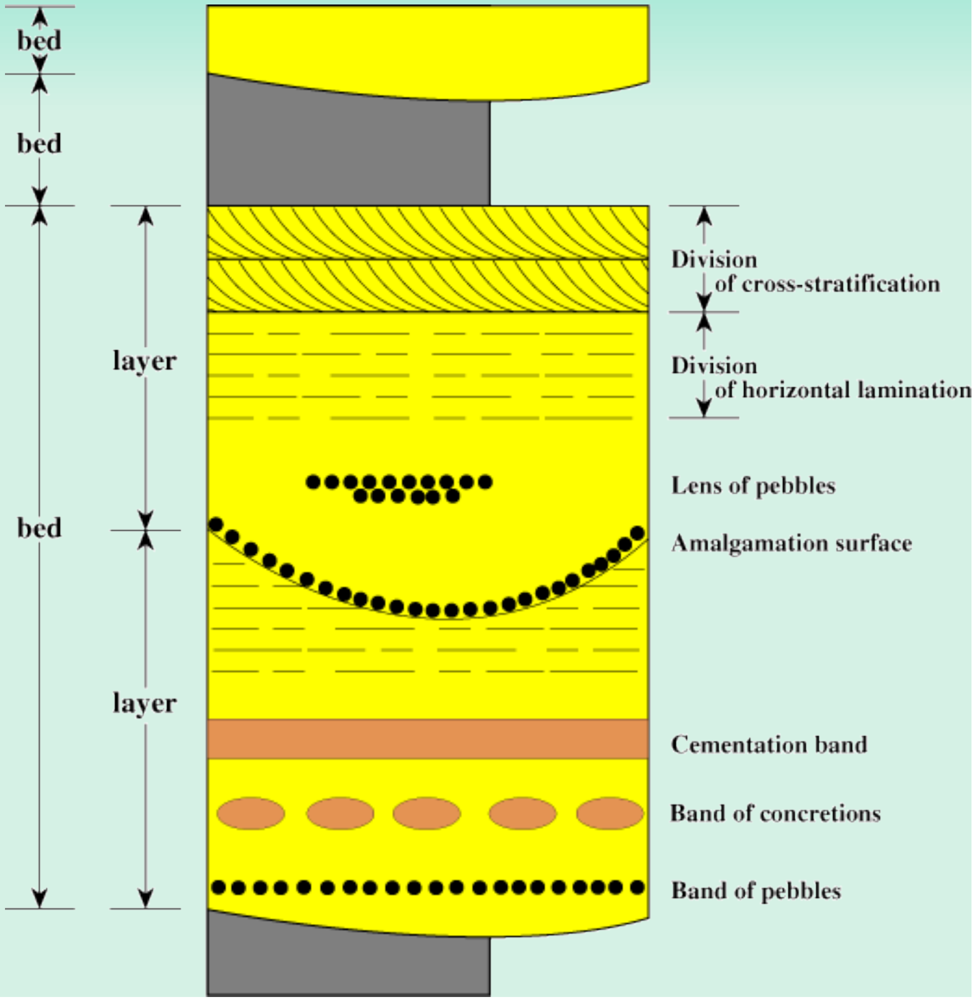
Bed: a stratum that is > 1 cm thick.

Lamination: a stratum that is < 1 cm thick.

Layer: a division of a bed that is distinguishable on the basis of its texture or composition.

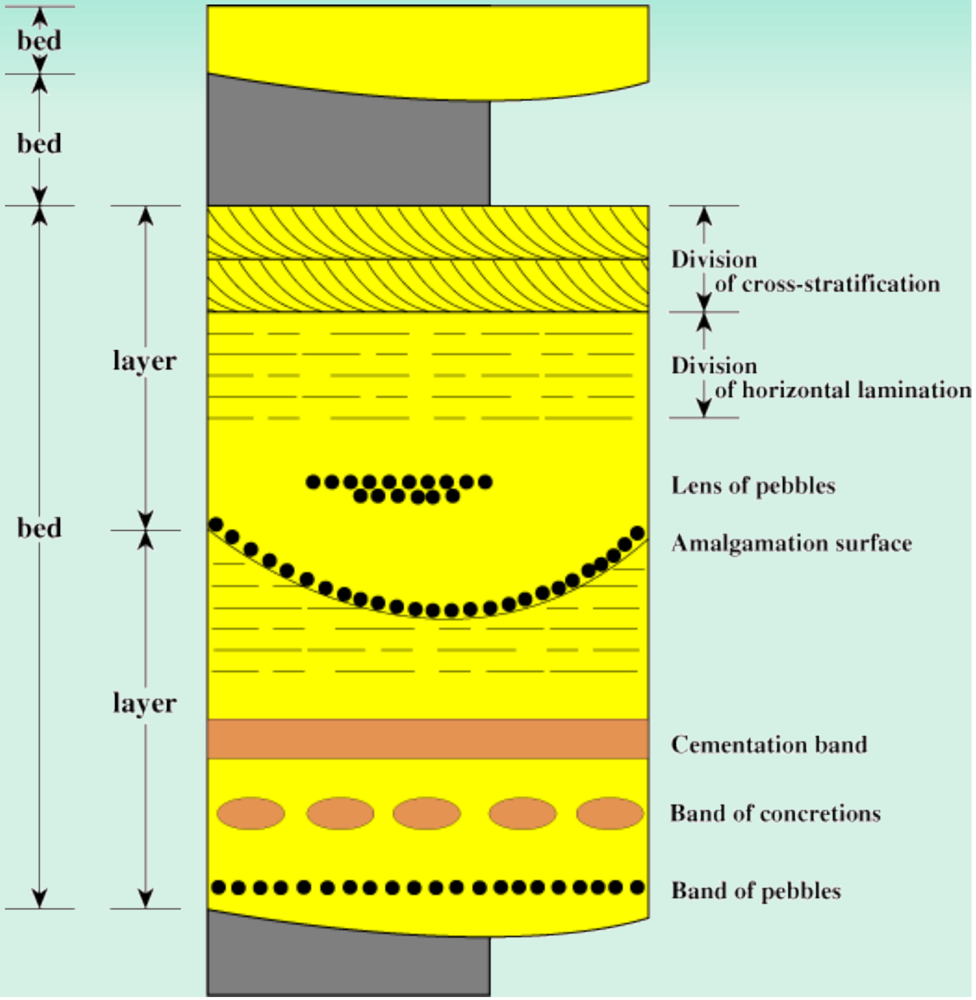
Division: a layer or part of a layer that is characterized by a particular association of sedimentary structures.

Band: a laterally continuous part of a stratum that is distinguishable on the basis of colour, texture or cementation.



Lens: like a band but laterally discontinuous.

Amalgamation surface: An erosional surface that separates two lithologically similar layers or beds.

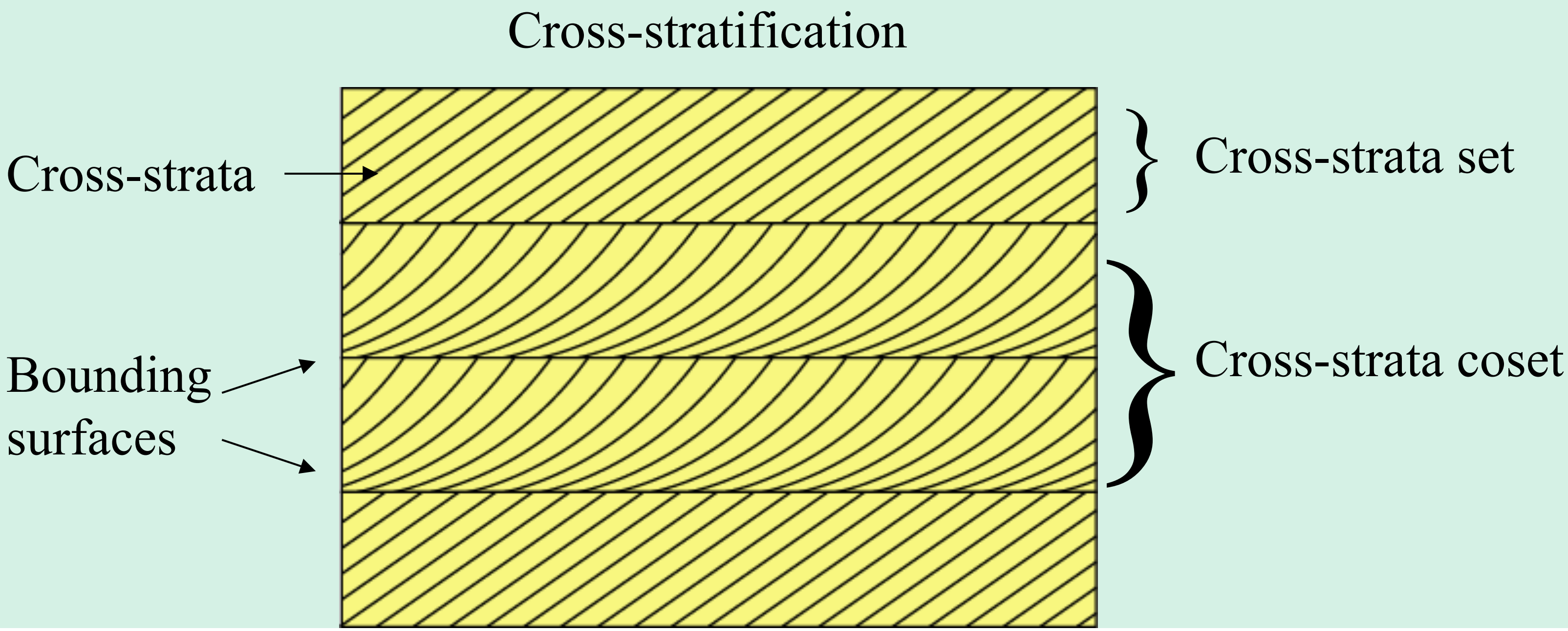


Cross-stratification: all stratification that is inclined from the horizontal due to primary processes (e.g., excluding tectonic tilting)

Cross-strata: inclined strata normally between *bounding surfaces* which are erosional surfaces that truncate underling cross-strata when present.

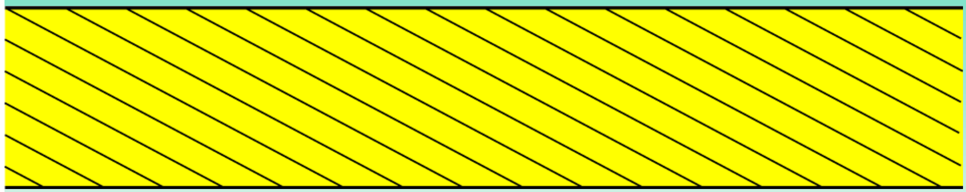
Cross-strata set: a single set of similar cross-strata.

Cross-strata co-set: sets of cross-strata of the same type in vertical sequence and separated by bounding surfaces.



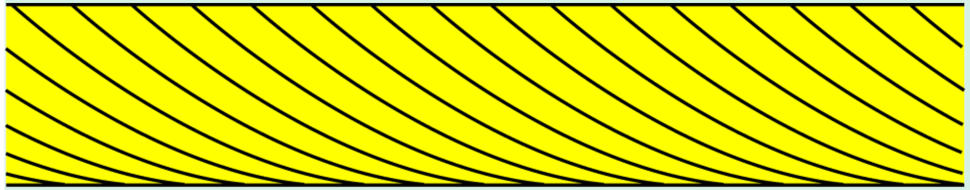
Major types of internal cross-strata

View in cross-section parallel to dip direction:



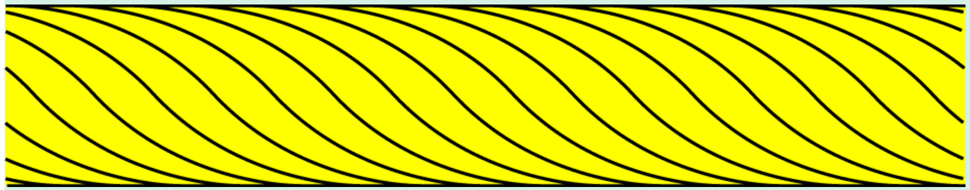
Angular internal cross-strata:

Angular contact with top and bottom bounding surfaces.



Tangential internal cross-strata:

Tangential contact bottom bounding surface, angular contact with top bounding surface.



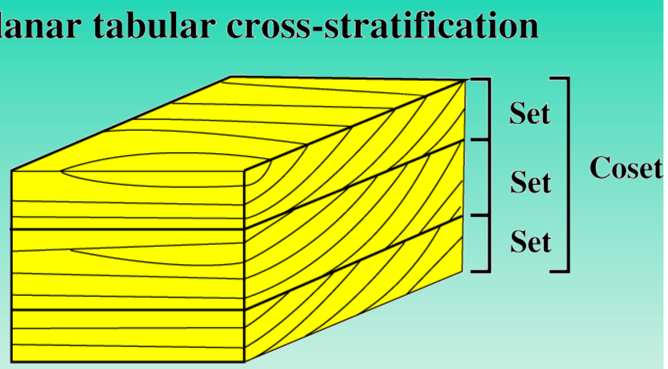
Sigmoidal internal cross-strata:

Tangential contact with bottom and top bounding surfaces.

Set types are distinguished on the basis of the geometry of their bounding surfaces.

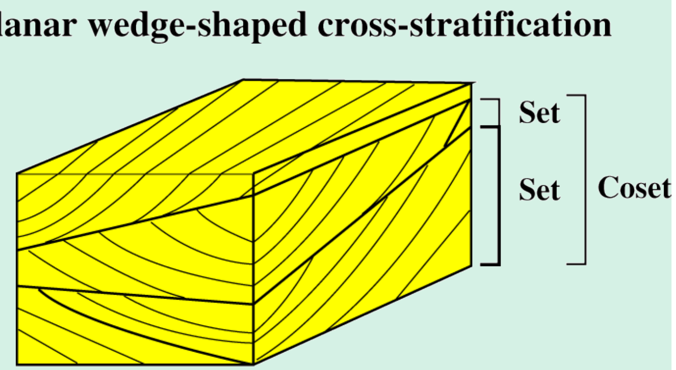
Planar tabular cross-stratificaton:

Bounding surfaces are parallel planes.



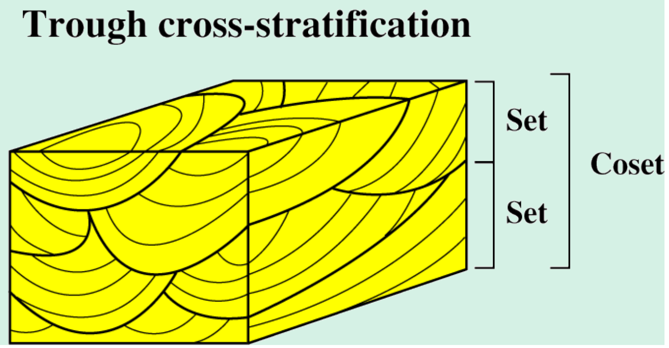
Planar wedge-shaped cross-stratificaton:

Bounding surfaces are planes that are not parallel.



Trough cross-stratificaton:

Bounding surfaces are curved or trough shaped.



Many forms of cross-stratification are produced by deposition on migrating bed forms.

The form of the cross-stratification varies with the behavior and morphology of the bed form.

The following Quicktime animations were produced by Dave Rubin of the United States Geological Survey and are available at:

http://walrus.wr.usgs.gov/seds/Movie_list.html

Cross-stratification formed by migrating straight-crested dunes:

Cross-stratification formed by migrating sinuous-crested dunes:

Cross-stratification formed by migrating straight-crested dunes:

Cross-stratification formed by migrating sinuous-crested dunes:

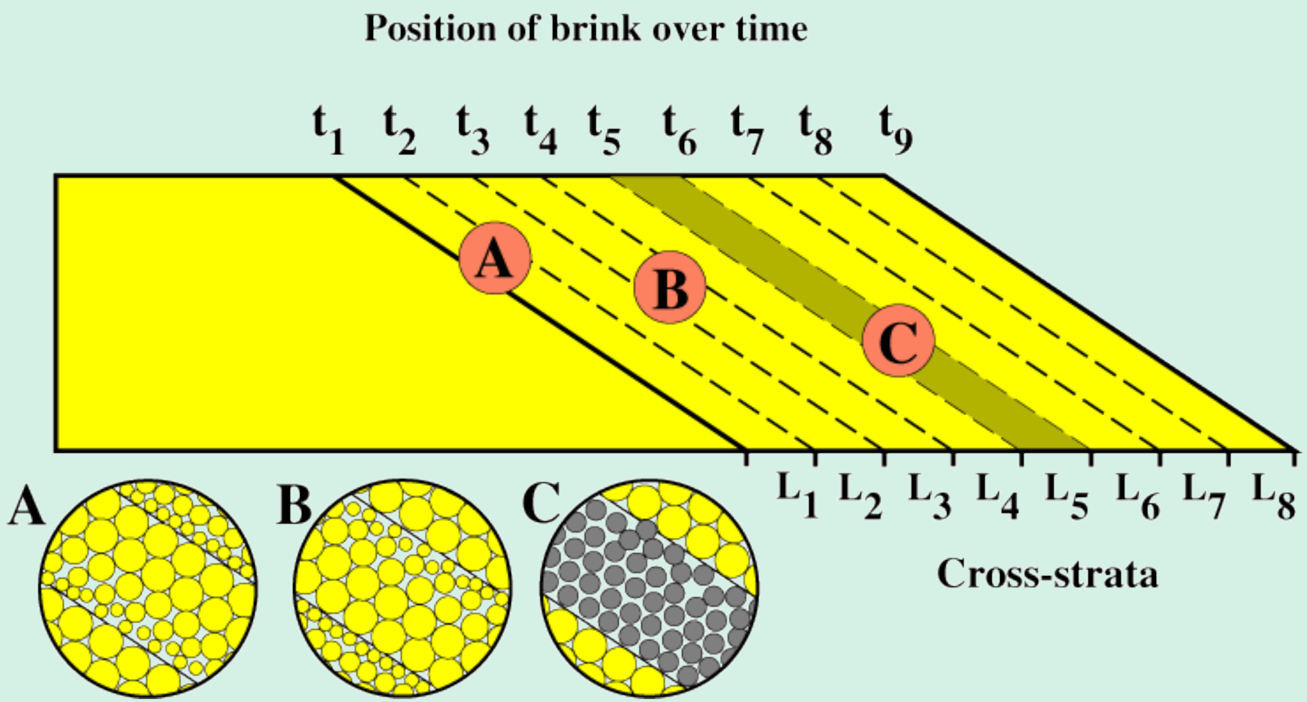
b) Why do we see internal cross-stratification?

Due to textural and mineralogical variation of the sediment making up the cross laminae or beds.

Cross-stratification reflects episodic depositon on the bedform.

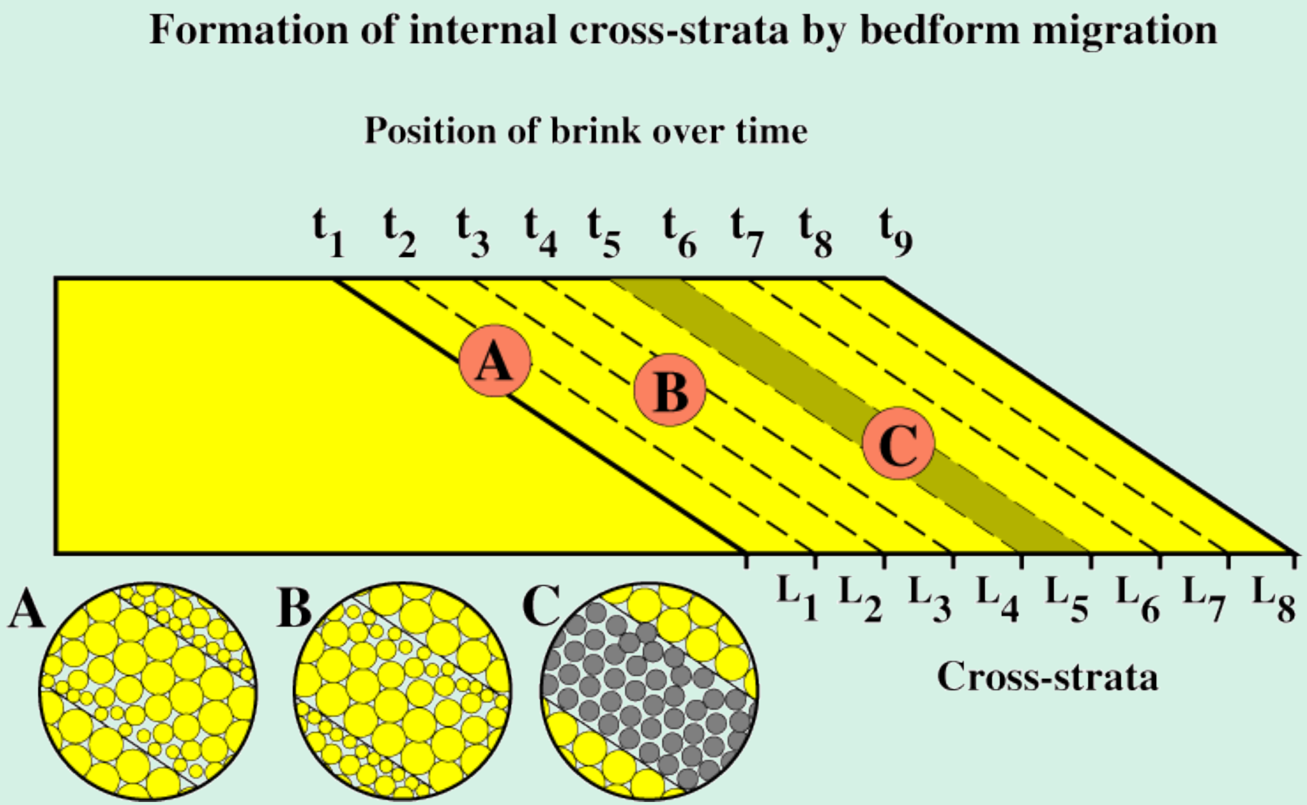
Well-sorted sand of only quartz may not display cross-stratification.

Formation of internal cross-strata by bedform migration



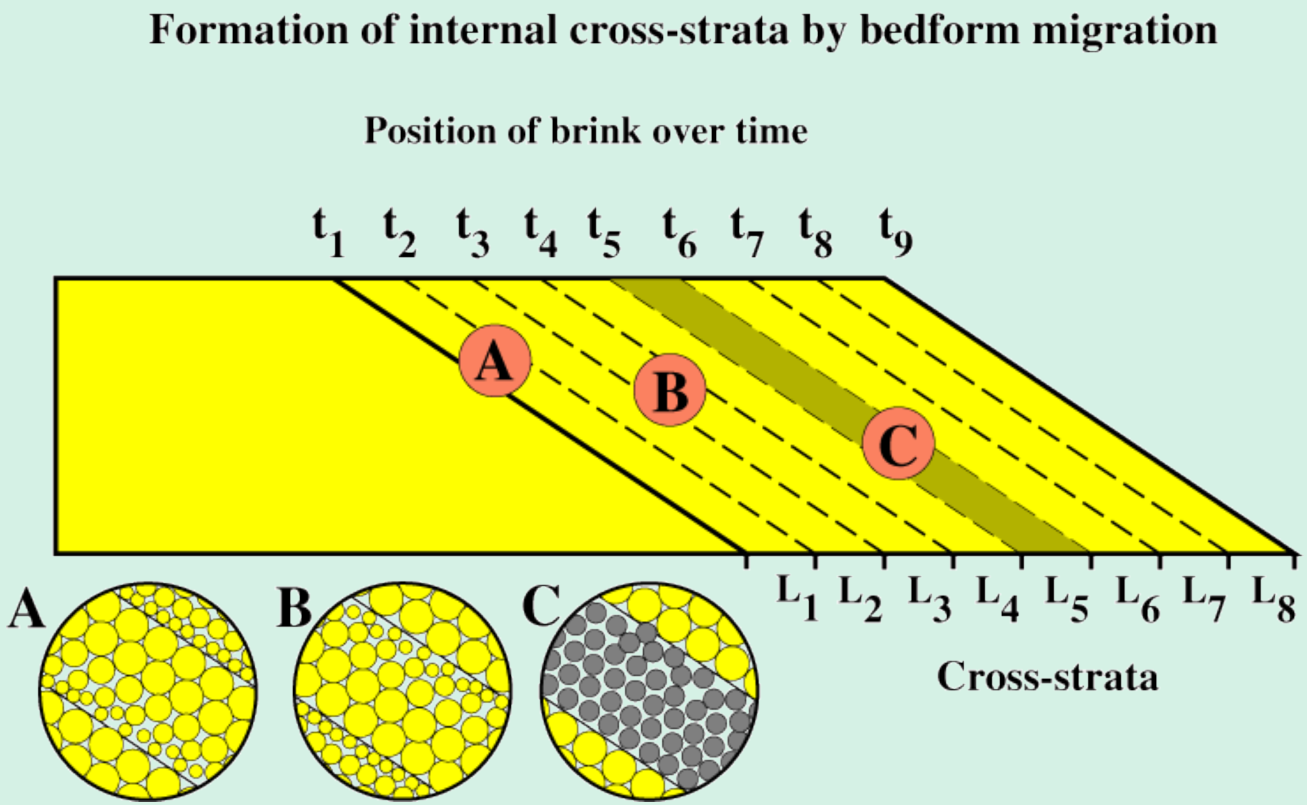
A. Fining upward cross-laminae may reflect pulses of deposition from suspension onto the bed form's lee slope.

Coarsest grains settle first followed by increasingly finer grains forming a layer that fines upward.



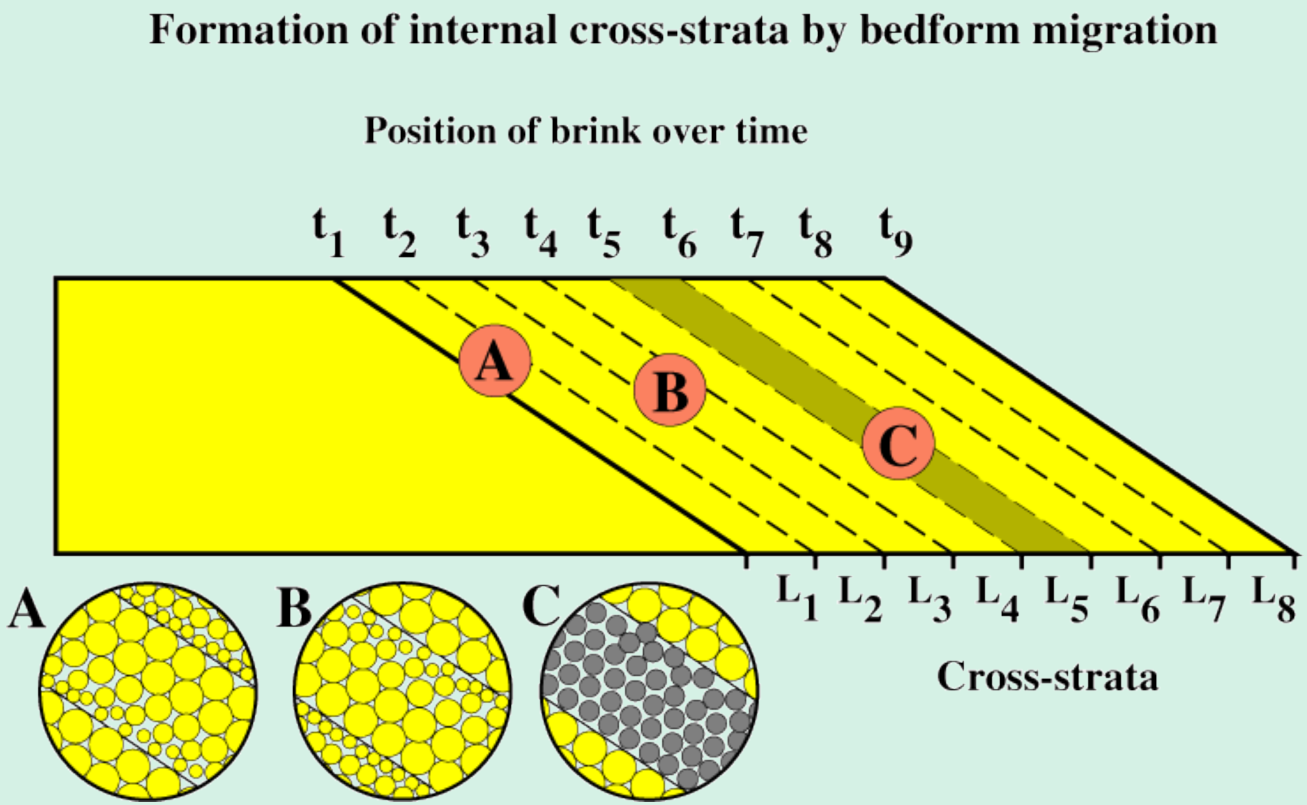
B. Coarsening upward laminae may develop with avalanching down the bed form's lee slope.

Dispersive pressure, which acts upwards, away from the bed, is proportional to the size of the grains, pushing large grains further upward than fine grains.



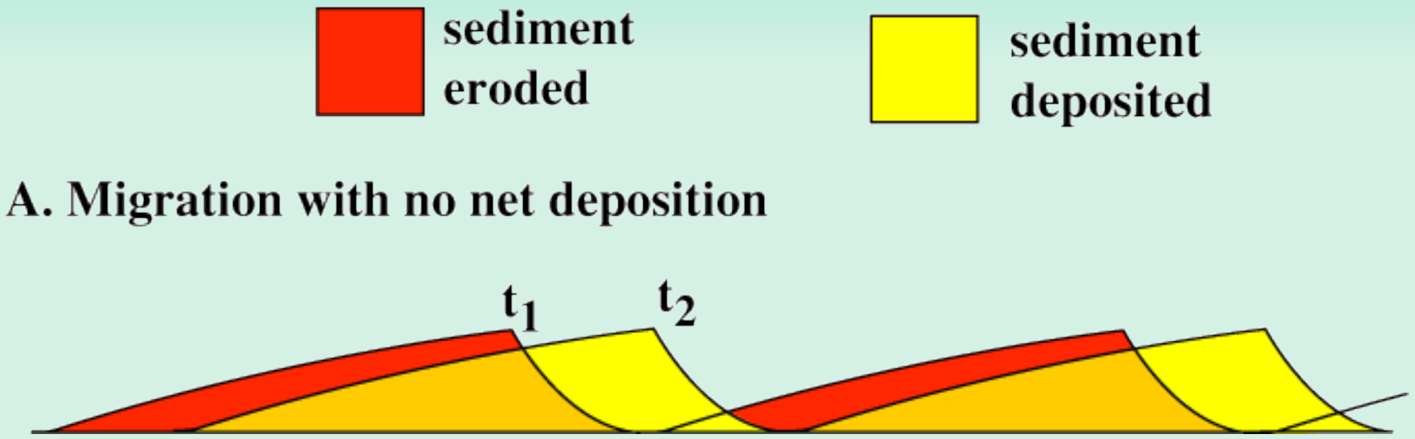
C. Layers enriched in particular mineral, particularly opaque, heavy minerals, may deposit episodically on the lee face as accumulations enriched in those minerals pass over the brink.

Note that the form of internal cross-strata is determined by the geometry of the bed form.



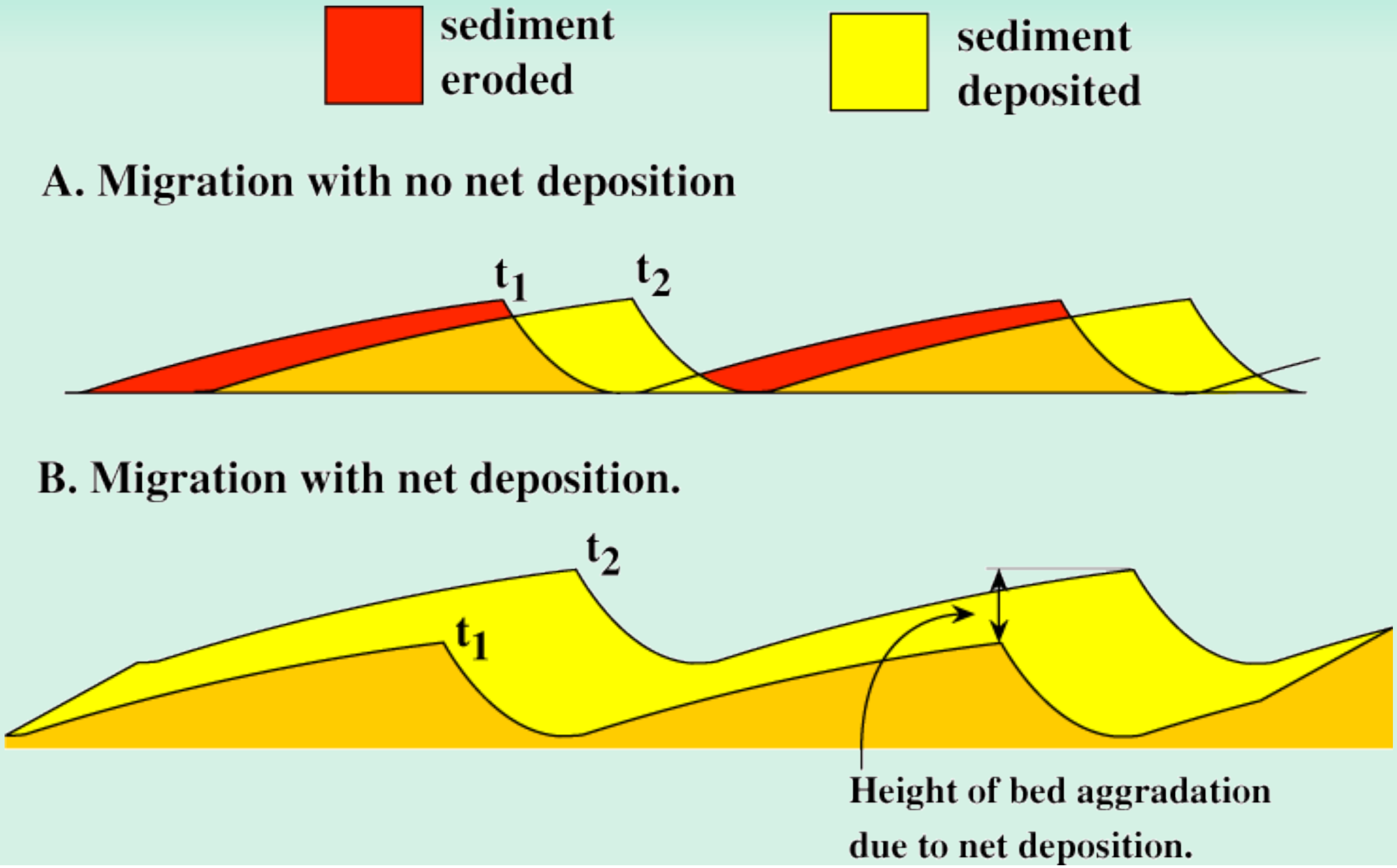
As a bed form migrates there is erosion in the trough and stoss slope and deposition on the lee slope.

To preserve internal cross-stratification requires preservation of part of the bed form.



Without net deposition (aggradation) on the bed the bed forms will migrate through each other and preserve only a thin veneer in the migrating troughs.

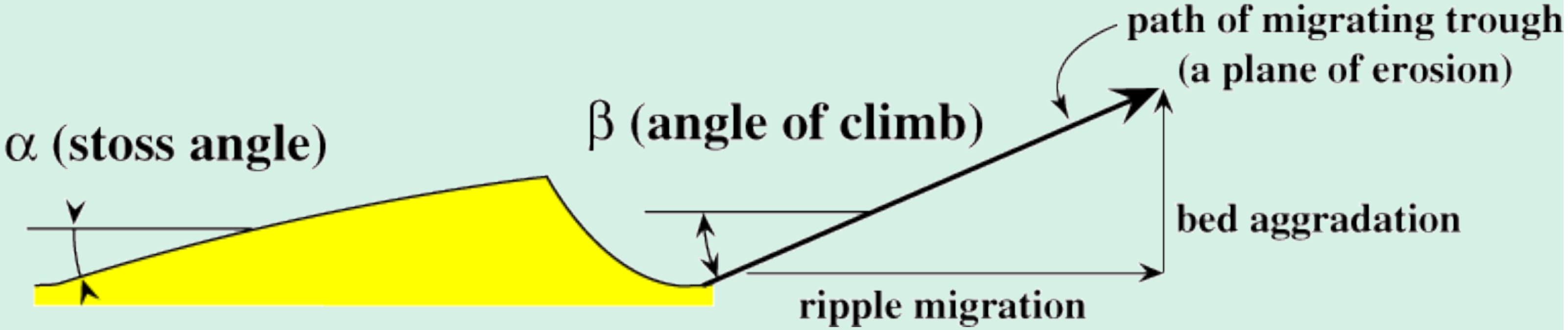
With net deposition the bed aggrades and the internal deposits of the bed forms are preserved.



The proportion of the internal structure of a bed form depends on the stoss slope angle and the *angle of climb* of the bed form.

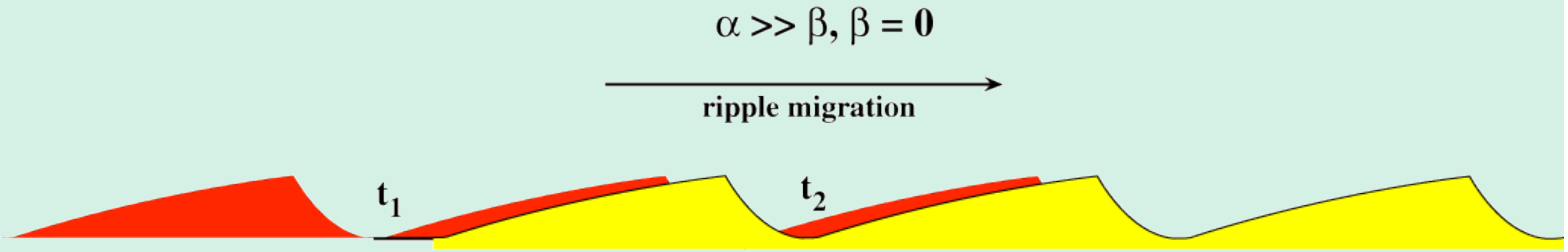
These examples refer to ripples but can also apply to dunes (which commonly have a low angle of climb).

A. Definitions



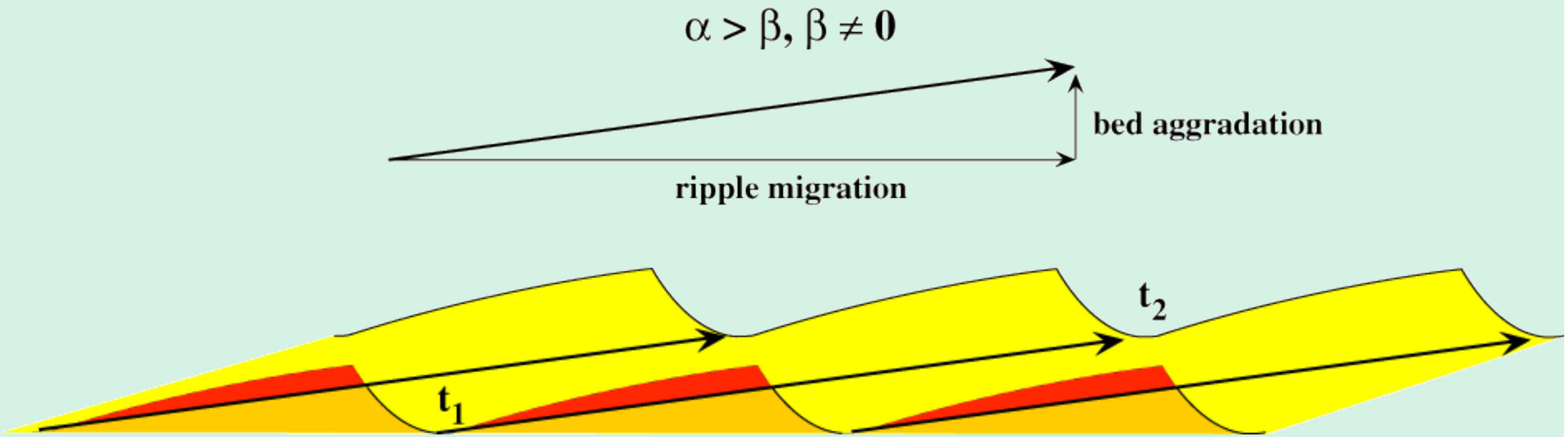
With no aggradation, only ripple migration, ripples migrate through each other and do not preserve internal cross-strata.

B. No preservation of ripples with migration and no net deposition.



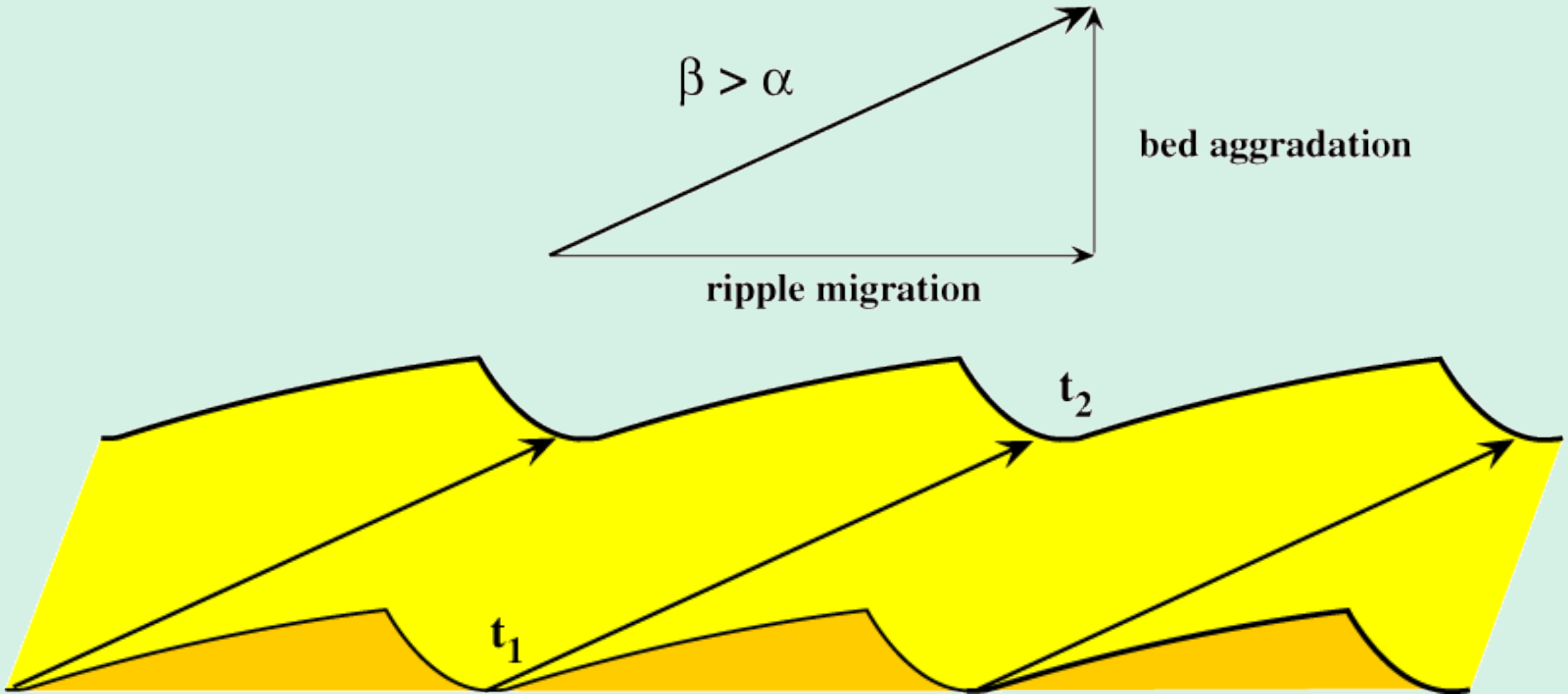
When the angle of climb is less than the stoss slope angle, a migrating ripple erodes (red, below) only part of the internal sediment of the next downstream ripple.

C. Partial preservation of ripples with migration and relatively little net deposition.

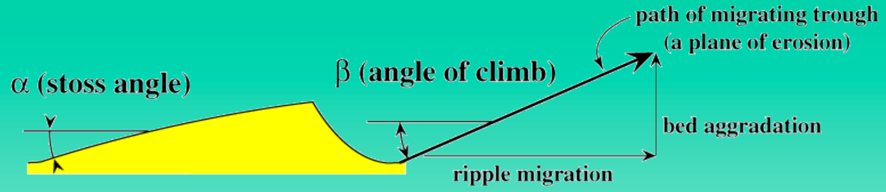


When the angle of climb excedes the stoss slope angle the entire set of cross-strata deposited on the lee slope is preserved, along with stoss slope deposits.

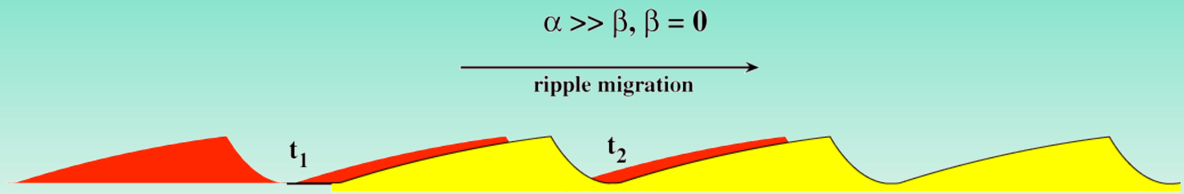
D. Complete preservation of ripples with migration and considerable deposition.



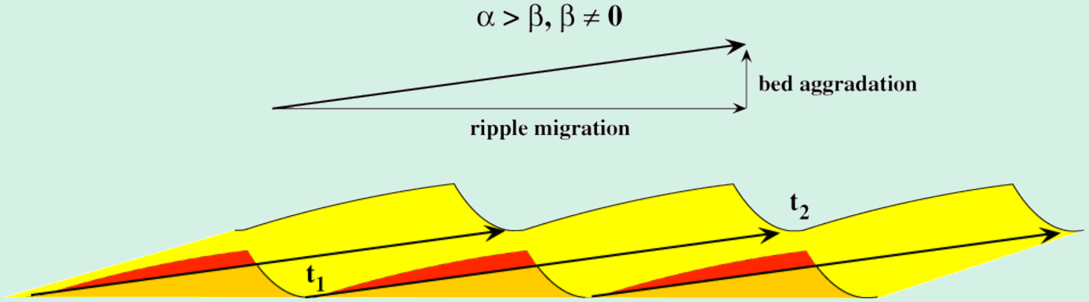
A. Definitions



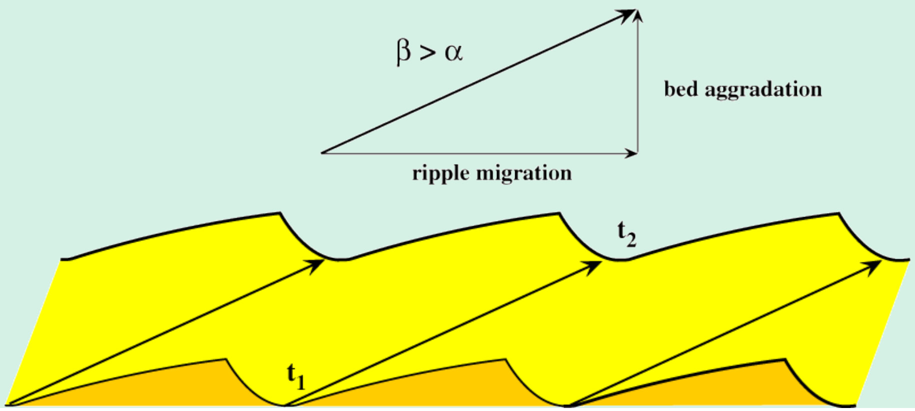
B. No preservation of ripples with migration and no net deposition.



C. Partial preservation of ripples with migration and relatively little net deposition.

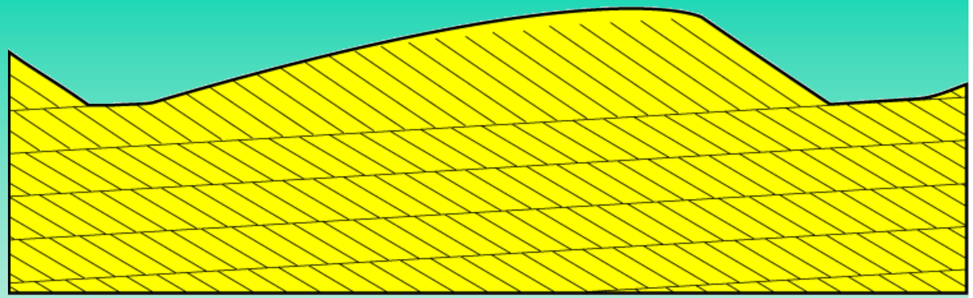


D. Complete preservation of ripples with migration and considerable deposition.

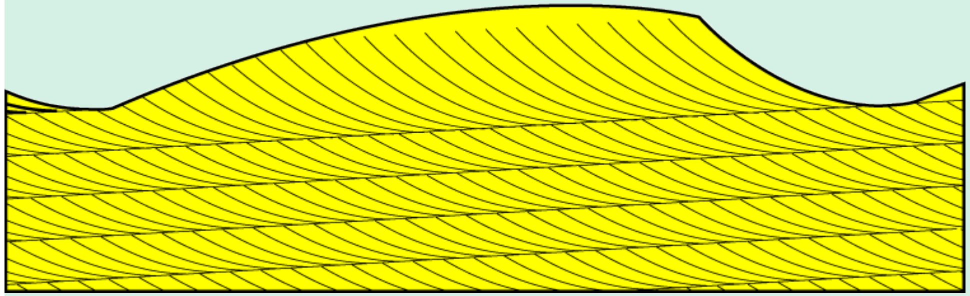


Angular internal cross-strata produced by bed forms lacking rough scour and with completely eroded stoss sides.

A. Angular lee slope dominated by avalanching with partial preservation of lee slope deposits forming angular internal cross-strata.

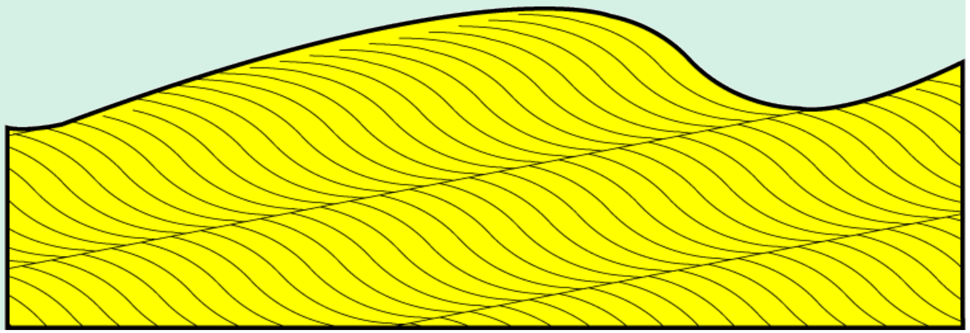


B. Concave lee slope with avalanching plus fallout from suspension with partial preservation of lee slope deposits and tangential internal cross-strata.



Tangential cross-strata with scour in troughs and completely eroded stoss sides.

C. Concave lee slope with avalanching plus fallout from suspension with complete preservation of lee slope deposits and sigmoidal internal cross-strata.



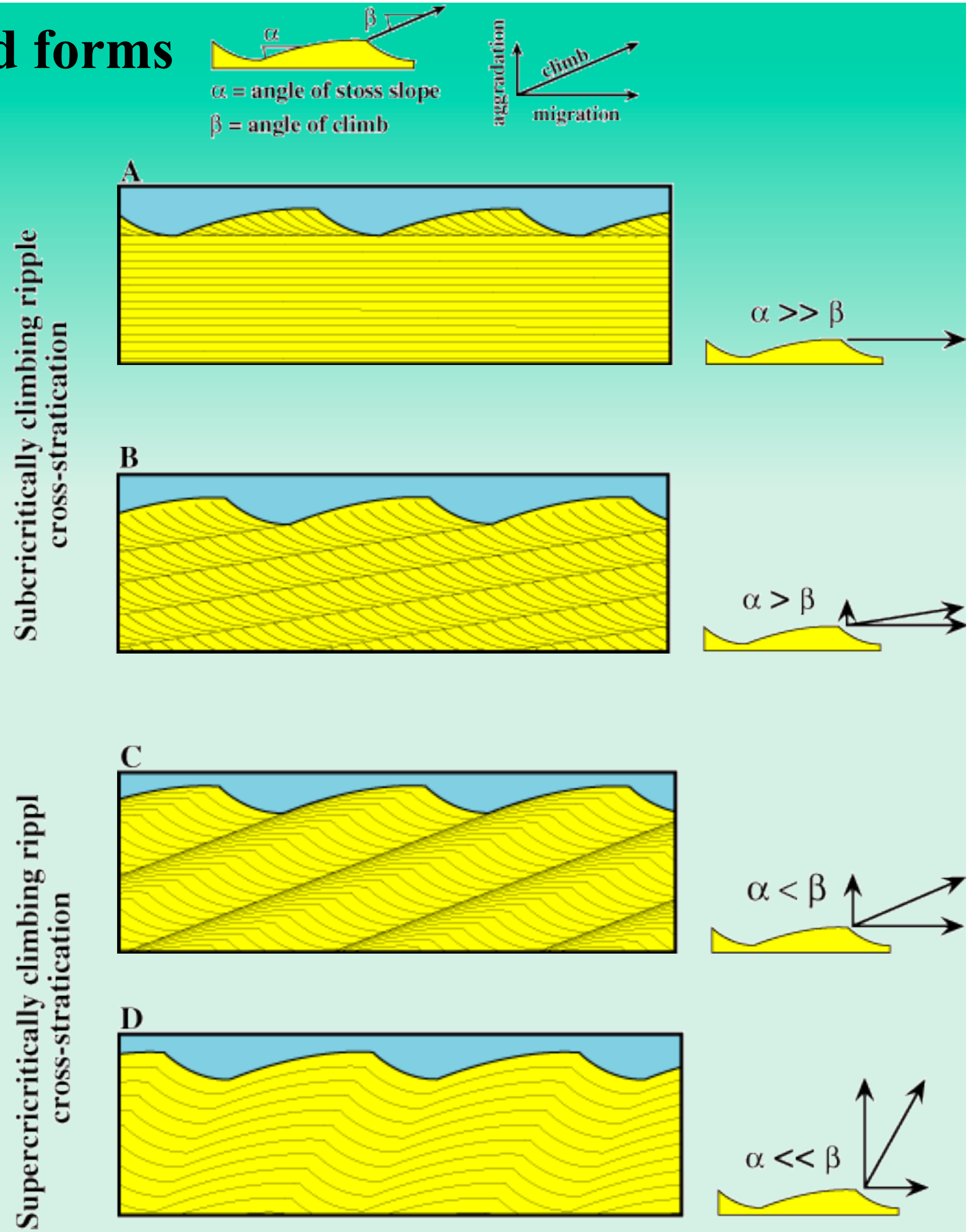
Sigmoidal cross-strata with scour in troughs and partial stoss side preservation.

c) Cross-stratification and bed forms

i) Ripple cross-stratifcation

Set thickness ranges from millimetres to a few centimetres.

Specific style depends on the relationship between the aggradation rate and the migration rate of the bed forms.



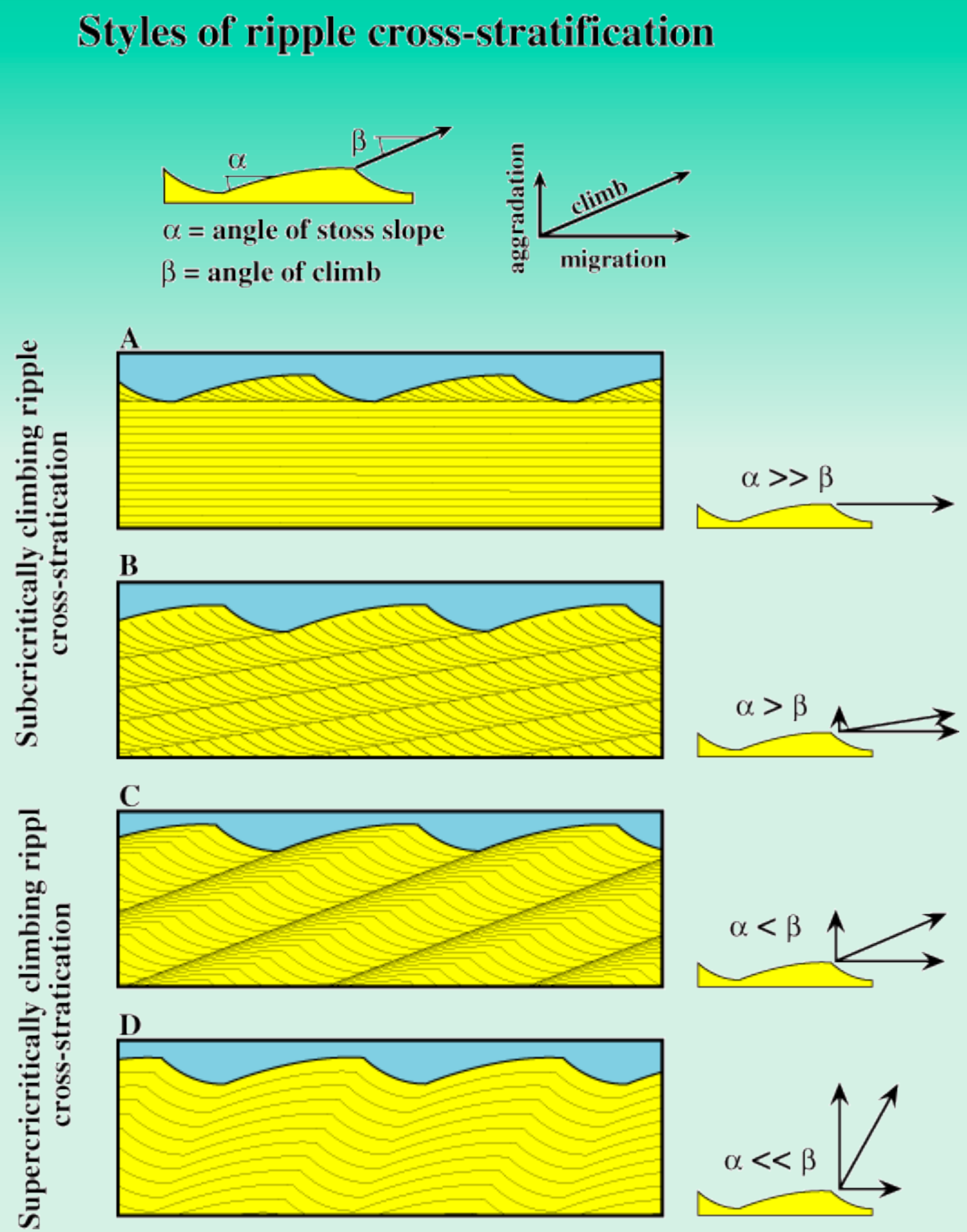
Another terminology:

Translatent strata

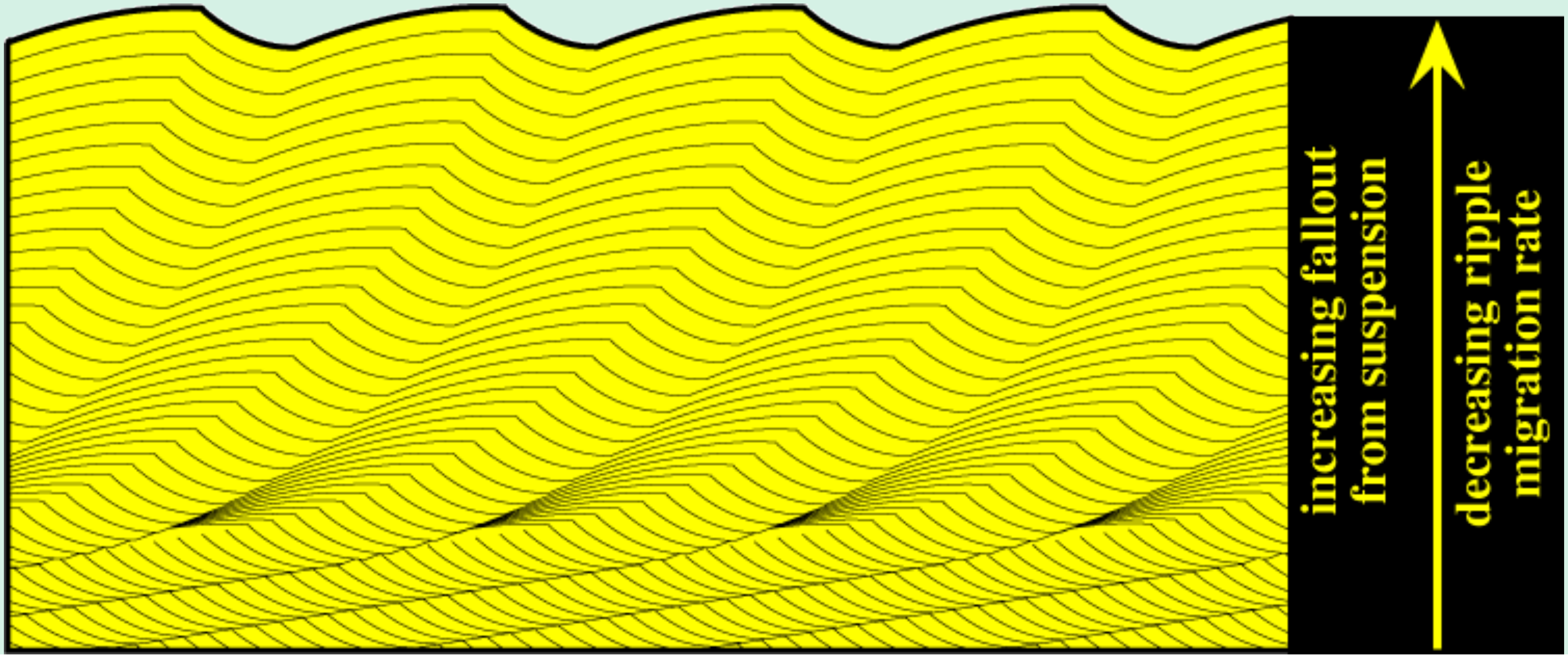
Type A climbing ripple cross-stratification

Type B climbing ripple cross-stratification

Sinusoidal climbing ripple cross-stratification

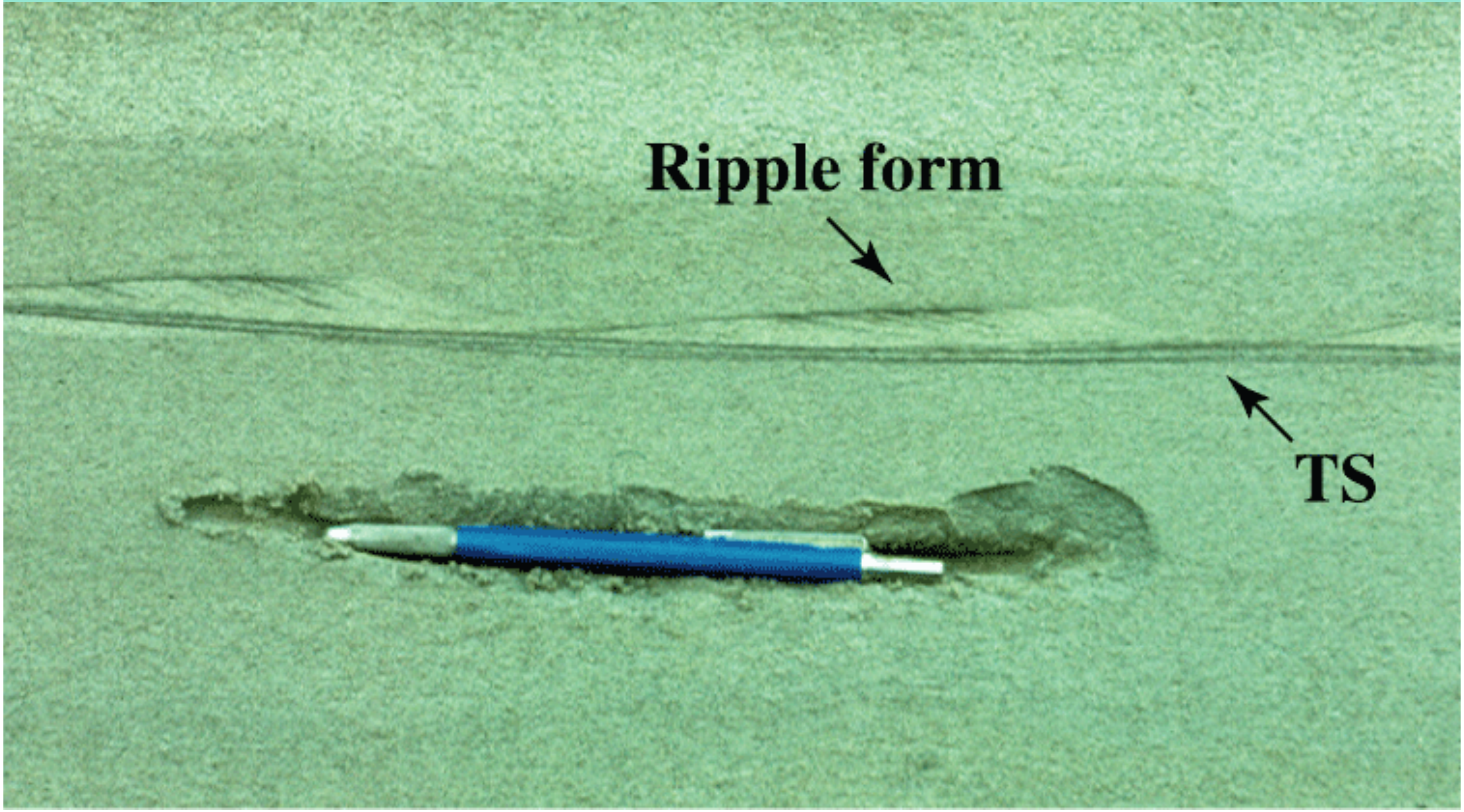


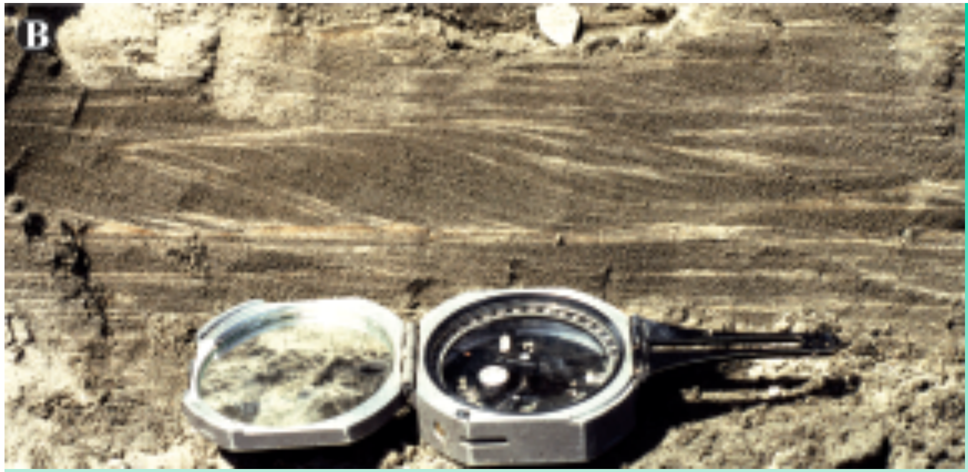
Changes in the style of climbing ripple cross-lamination reflect changes in migration rate and/or aggradation rate over time.



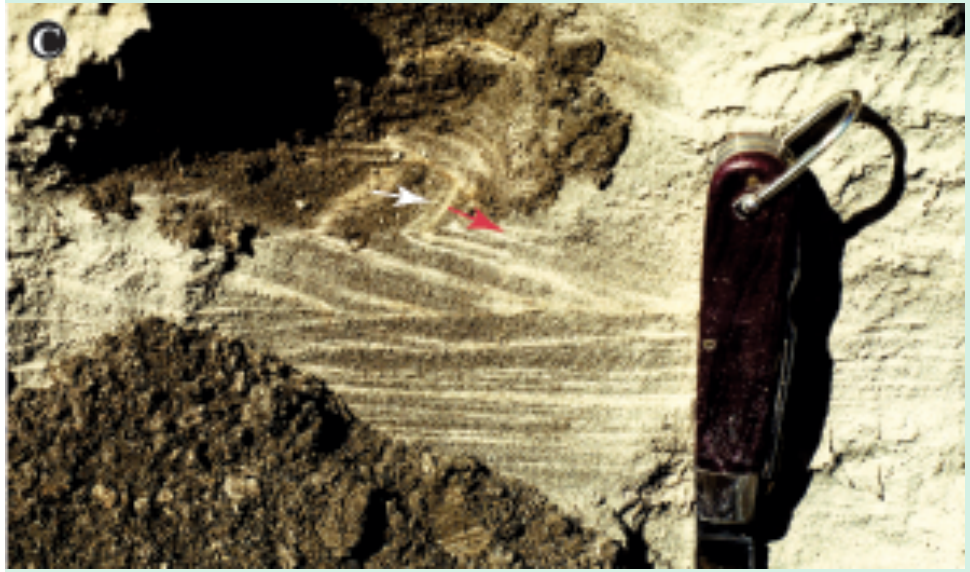
Example of translatent strata (TS) produced by the migration of ripples (see ripple form).

The current flowed from left to right.

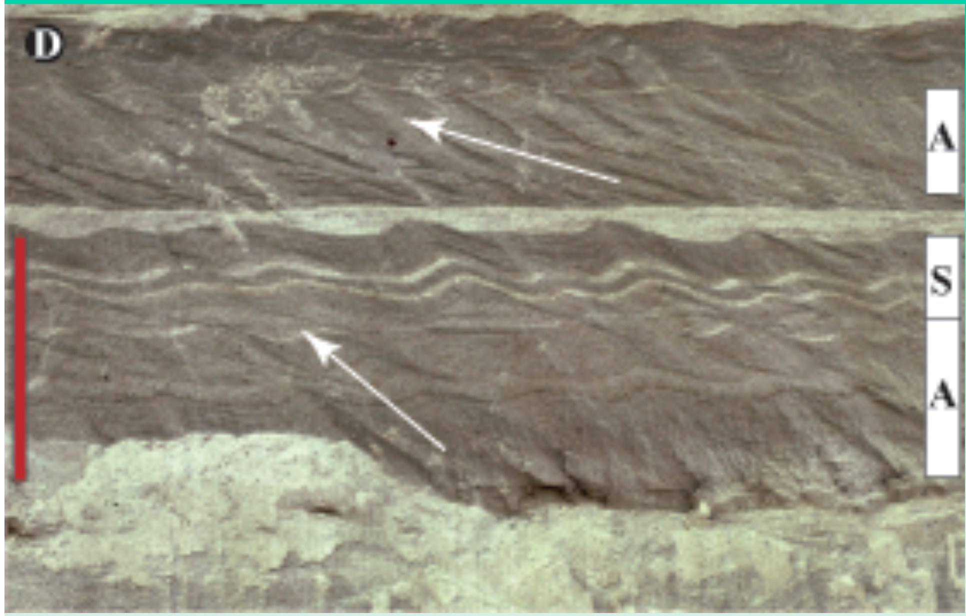




Cross-section of ripple cross-lamination; flow from left to right.



Plan view of internal cross-laminae. Note that the current flowed at right angles to the strike (trend) of laminae, in the direction that they dip (i.e., from left to right).

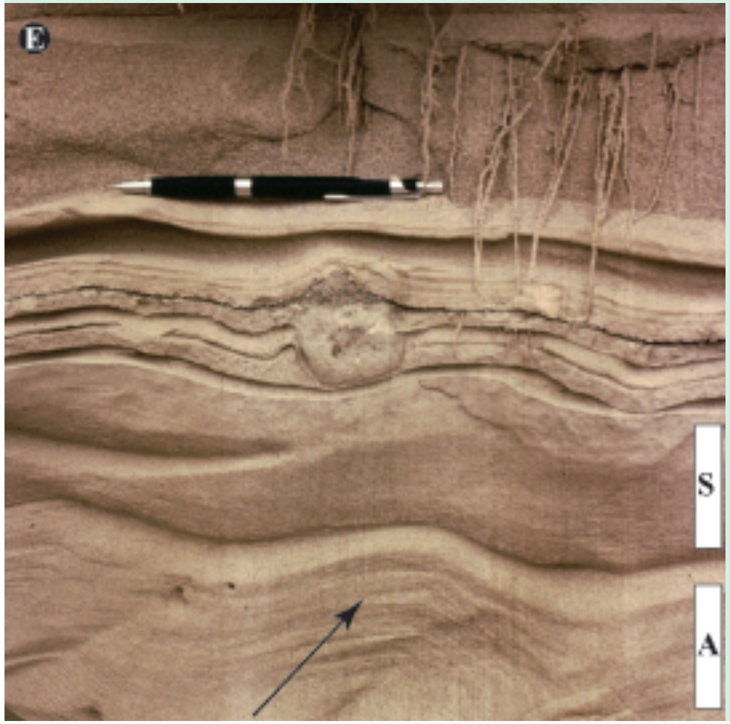


Climbing ripple cross-stratification.

"A" denotes type A climbing ripples and "S" indicates sinusoidal climbing ripples.

White arrows indicate approximate angle of climb.

The red bar is approximately 75 cm long.



Type A and sinusoidal climbing ripples (black arrow indicates angle of climb of type A ripples).

Note the drop-stone below the pen for scale.

ii) Cross-stratificaton formed by dunes.

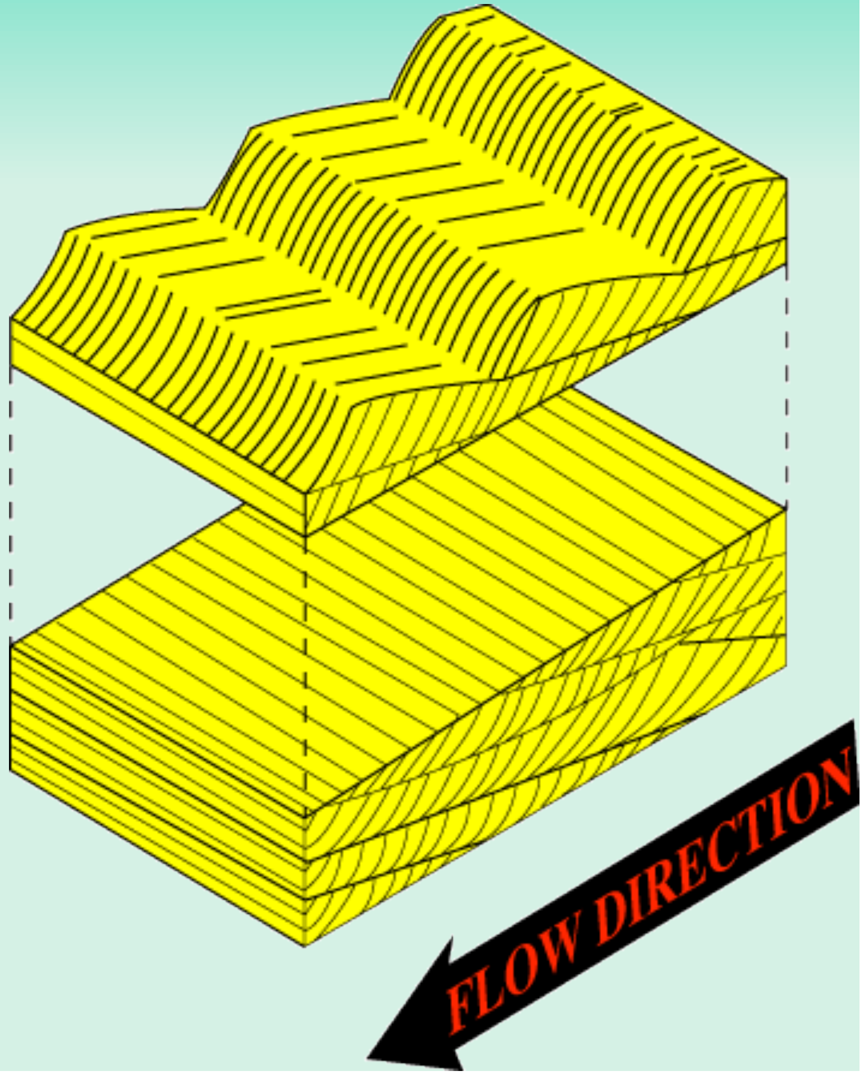
Sets are centimetres to metres thick.

The form of cross-stratification depends on the geometry of the dunes.

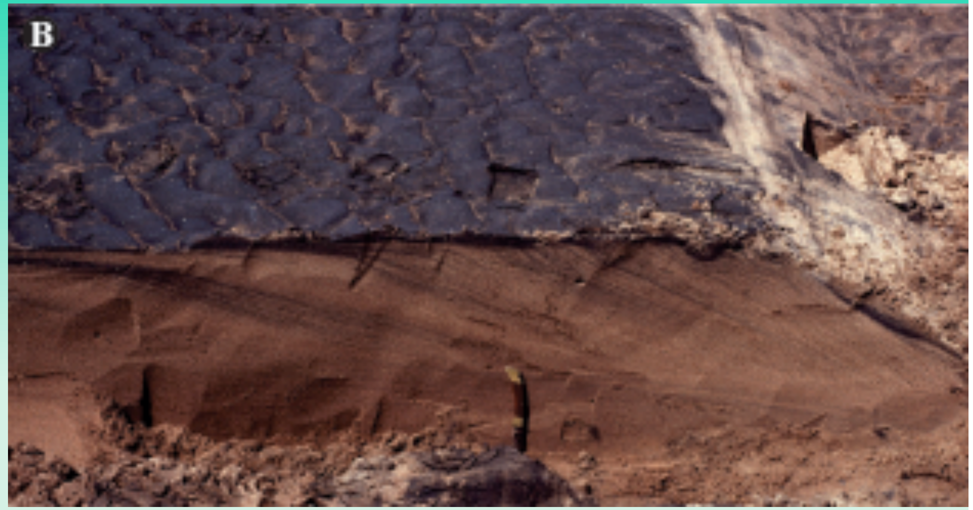
Planar tabular cross-stratification

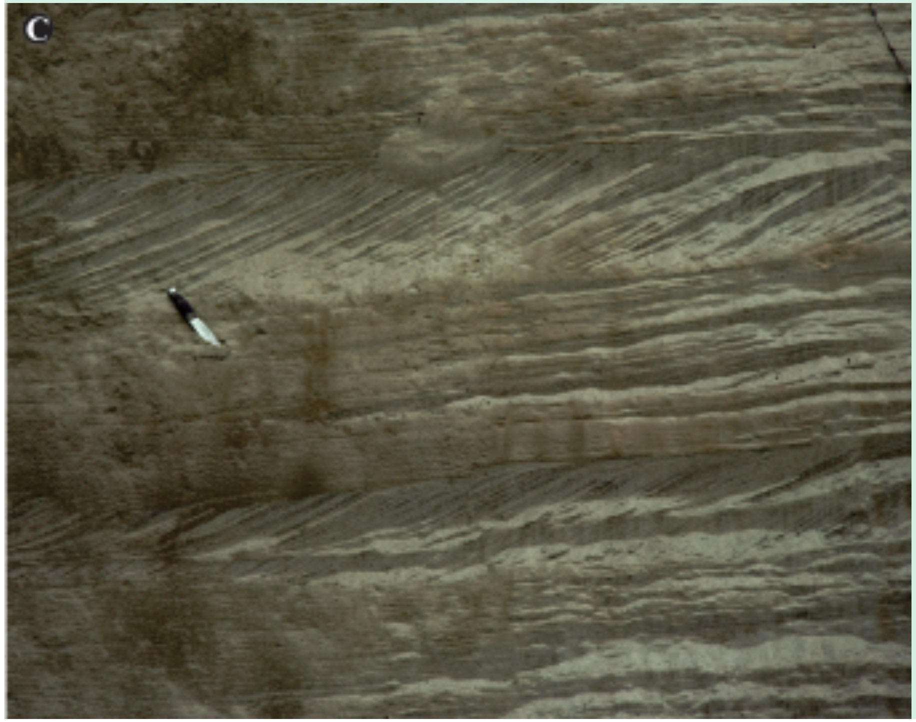
Formed by 2-D dunes.

Cross-stratification formed by migrating straight-crested dunes:



Planar cross-bedding within dunes





Sets of planar tabular cross-beds interbedded with horizonatlly bedded sands.

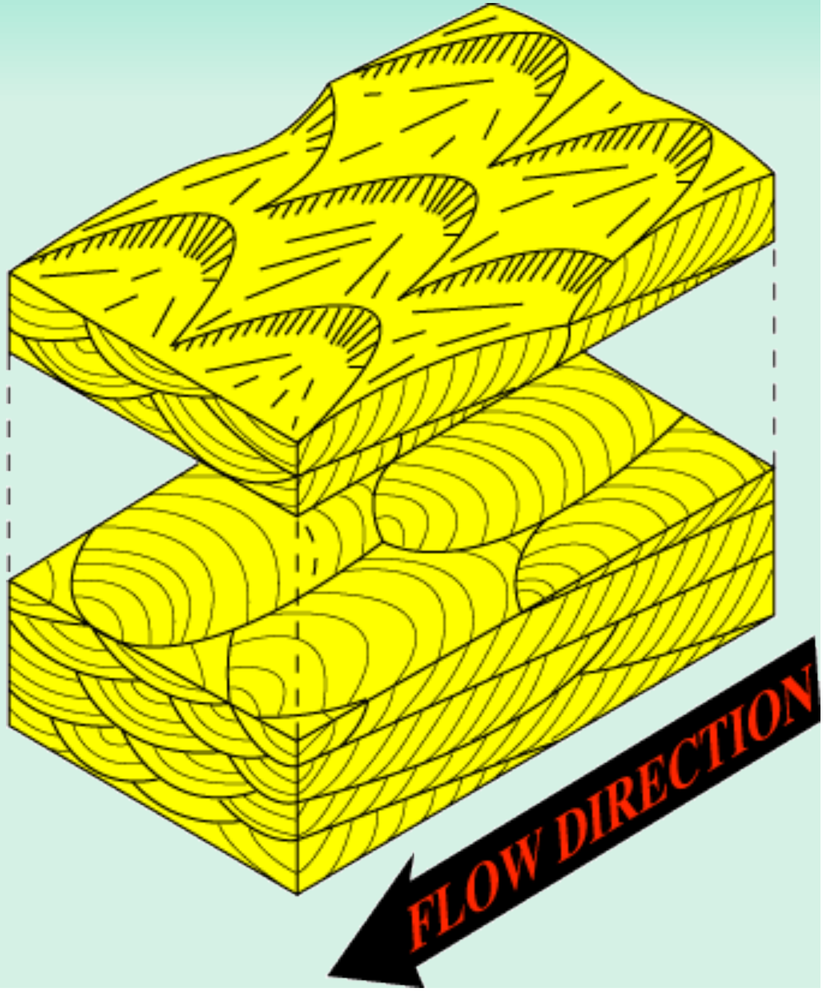
Trough cross-stratification

Formed by 3-D dunes

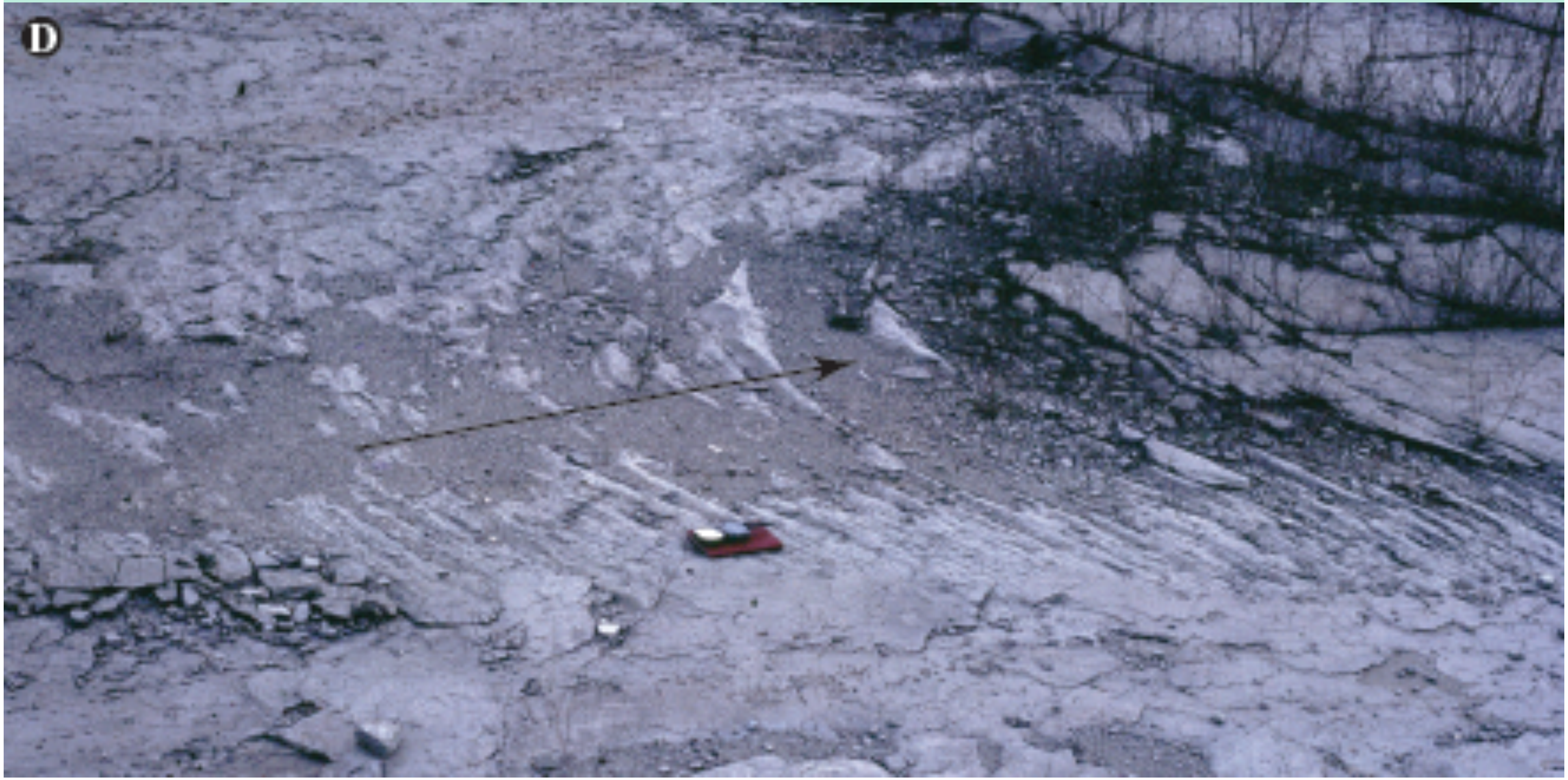
Trough shapes are visible on the vertical section oriented perpendicular to the flow direction.

Due to deposition in the trough scours as the bedform migrates.

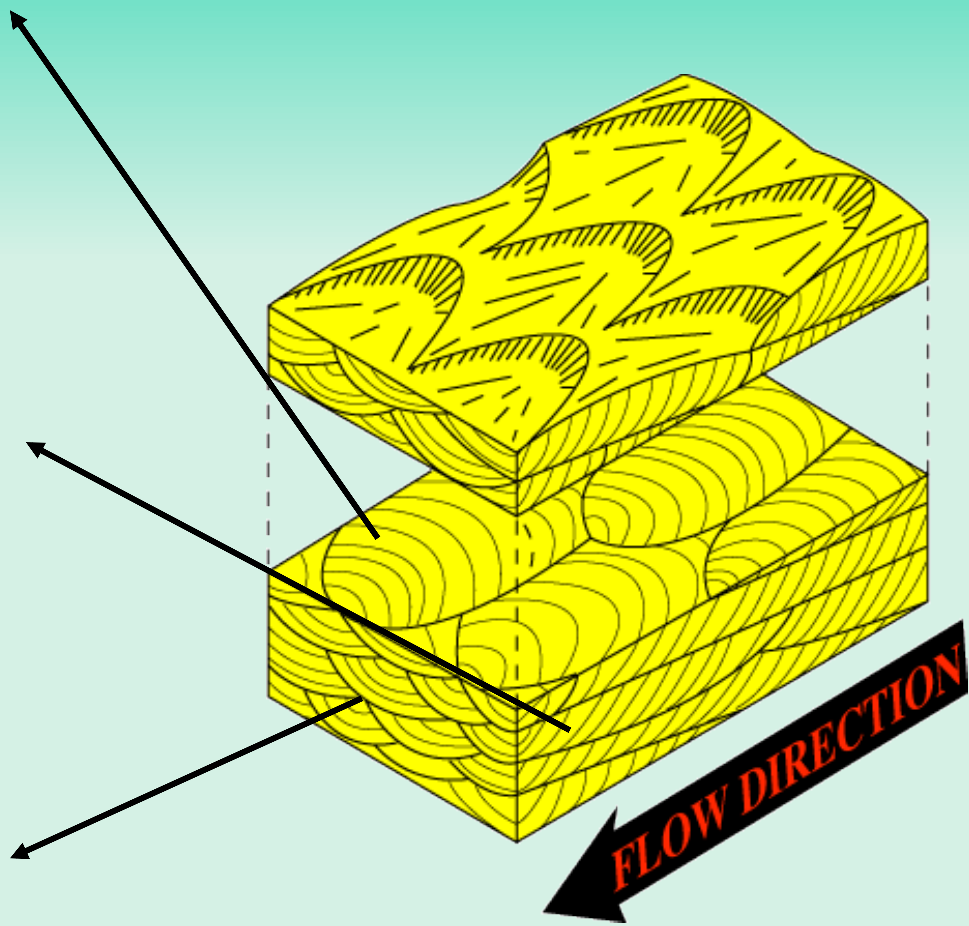
Cross-stratification formed by migrating sinuous-crested dunes:

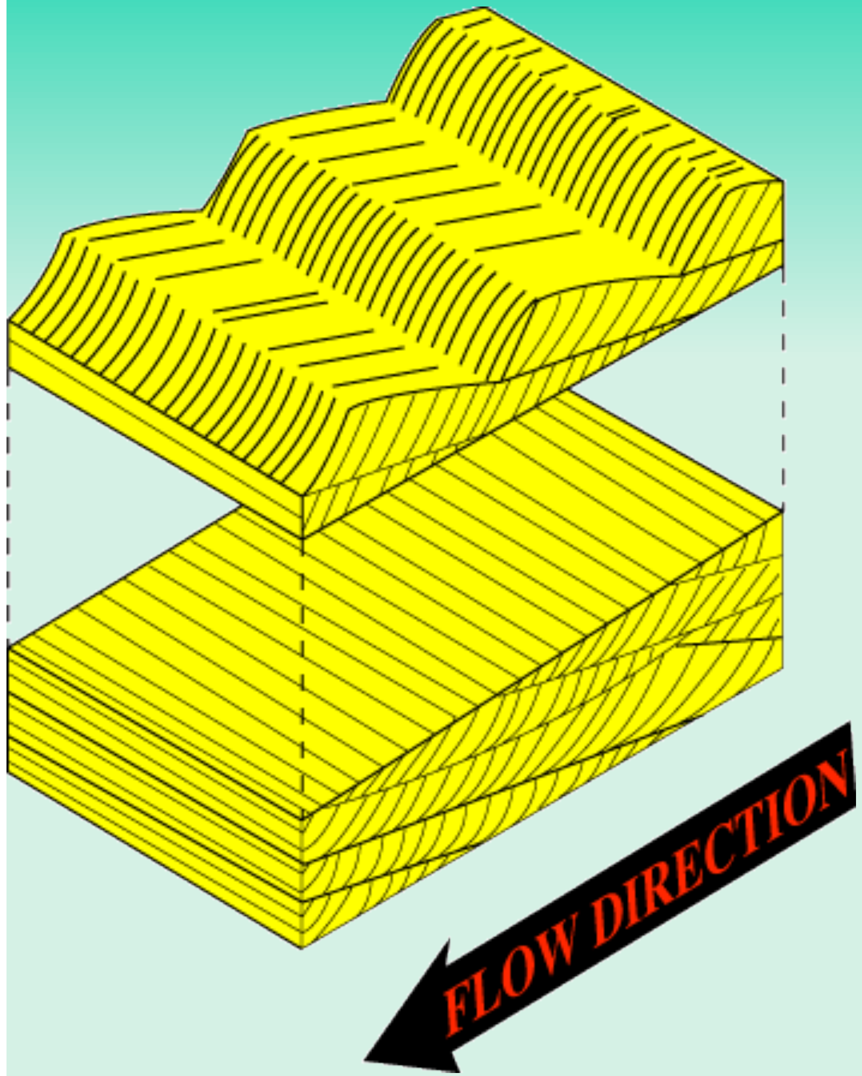


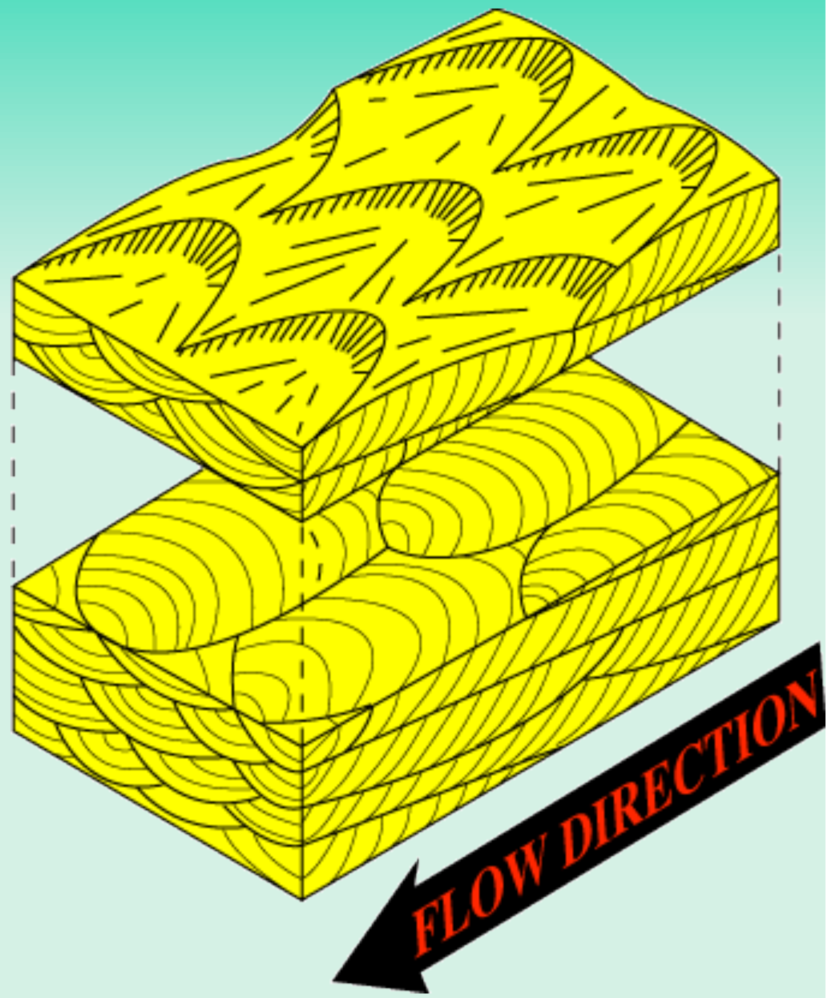
Plan view of trough-crossbedding from the Whirlpool Sandstone (Silurian; southern Ontario)



Trough cross-bedding in the Archean Missy Formation, northern Manitoba.




FLOW DIRECTION


FLOW DIRECTION

iii) Upper plane bed horizontal lamination

More-or-less horiozontal laminae extending in all directions in outcrop.

Two kinds of laminae:

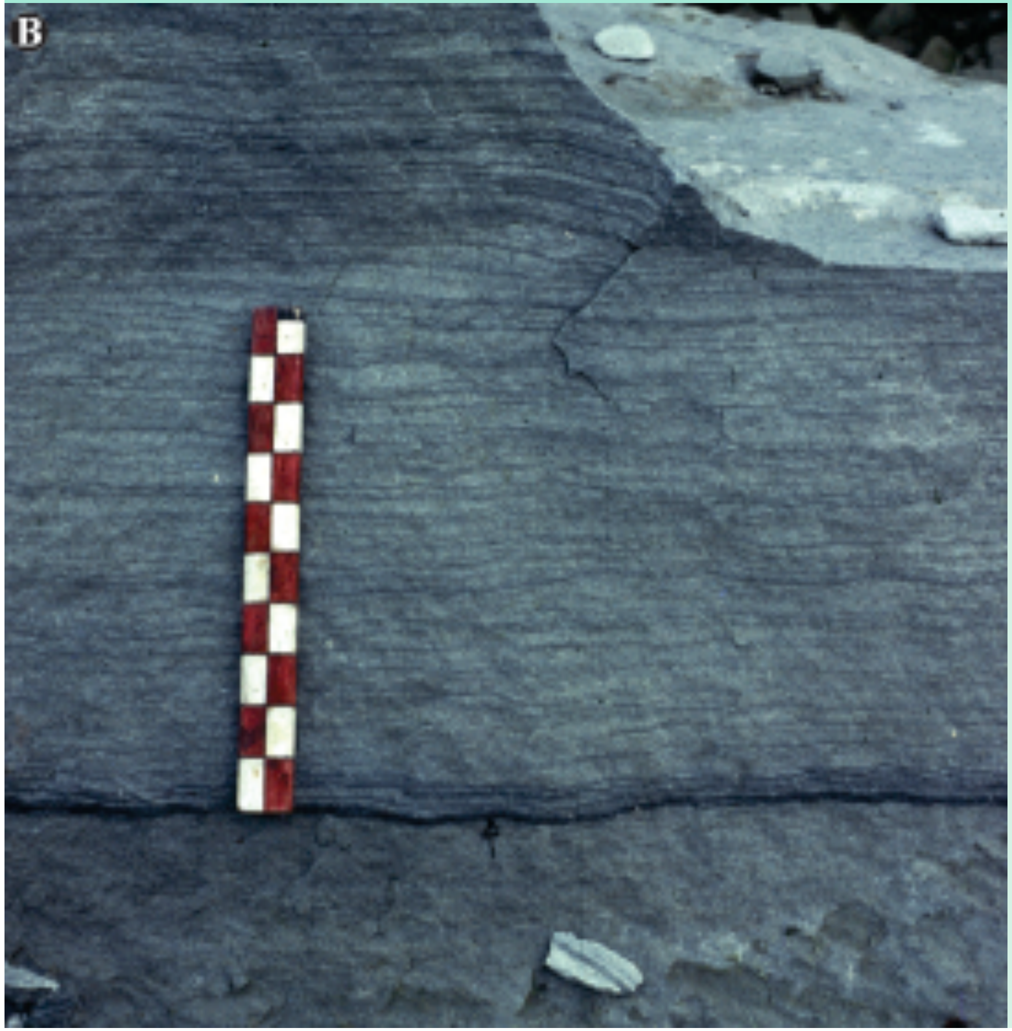
Textural laminae: less than a millimetre thick laminae that fine or coarsen upwards.

Heavy mineral sheets: one to several grains thick laminae that are enriched in opaque heavy minerals.

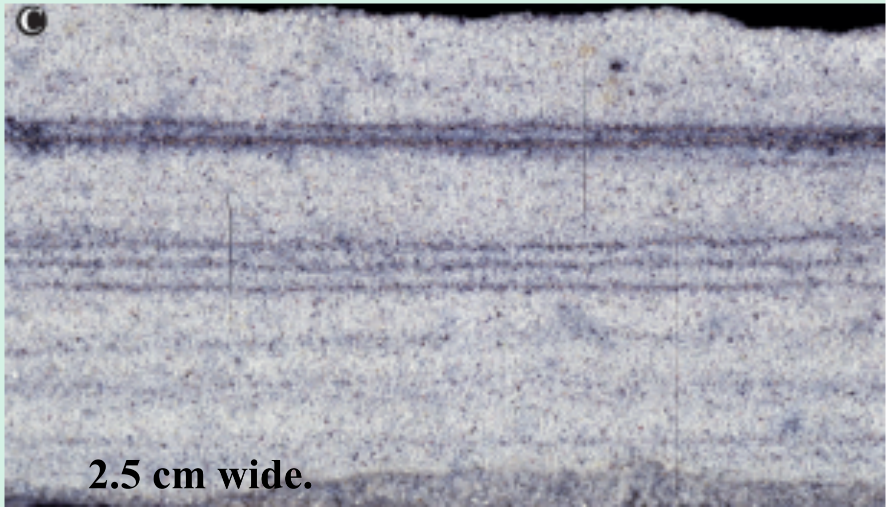
Horizontal lamination formed on an upper plane bed in Cobequid Bay, Nova Scotia.

Laminae are visible when enriched with opaque heavy minerals (heavy mineral sheets).

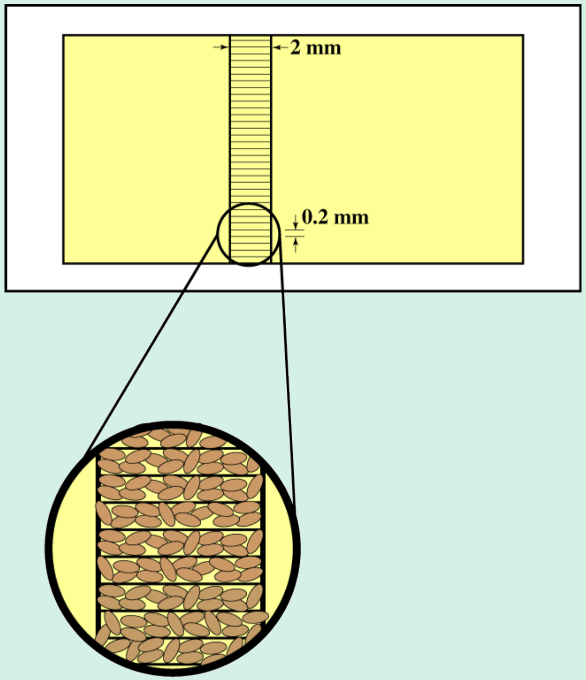
Horizontal lamination in the Silurian Whirlpool Formation.

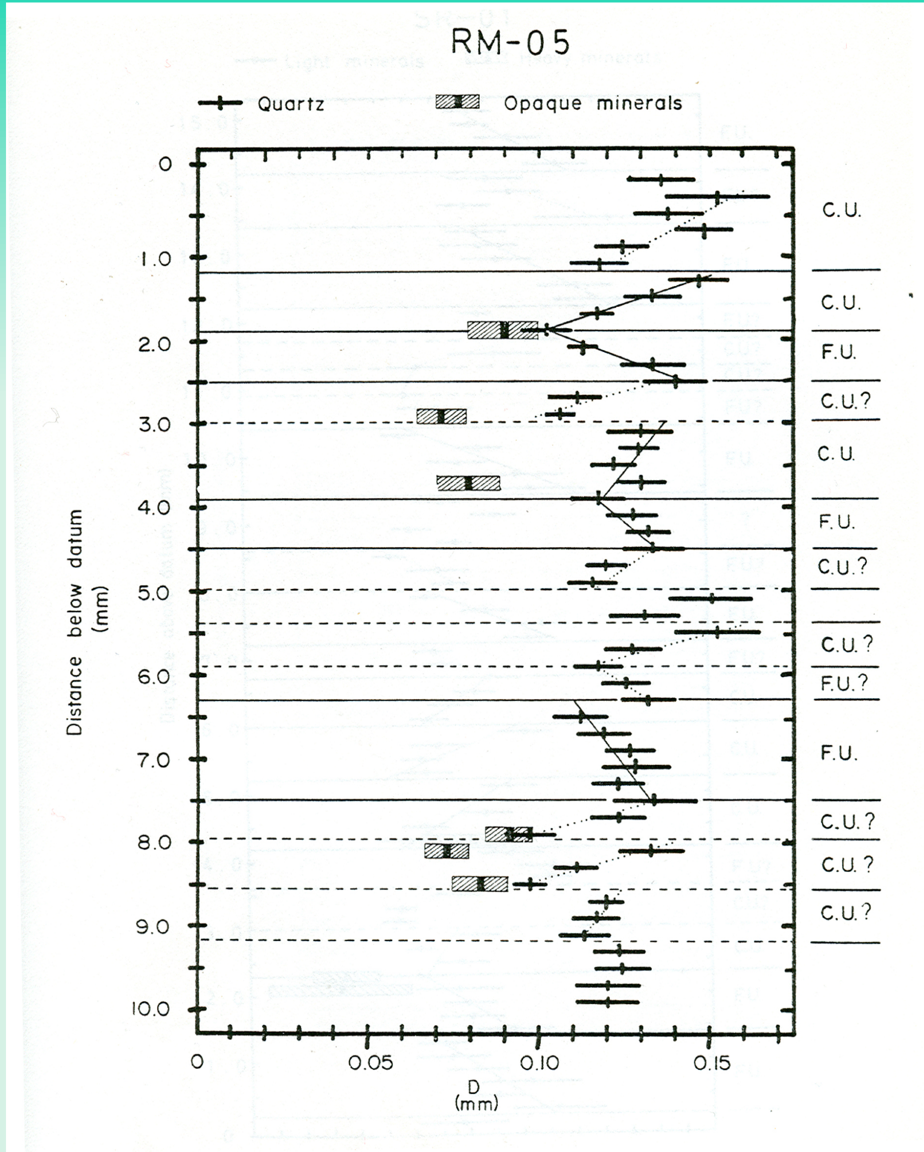


Notably dark layers may be due to as little as a few percent opaque minerals in the laminae.



Detailed measurements of grain size show fining and coarsening upward textural laminae with heavy minerals (e.g., magnetite) preferentially associated with the basal portions of CU laminae.

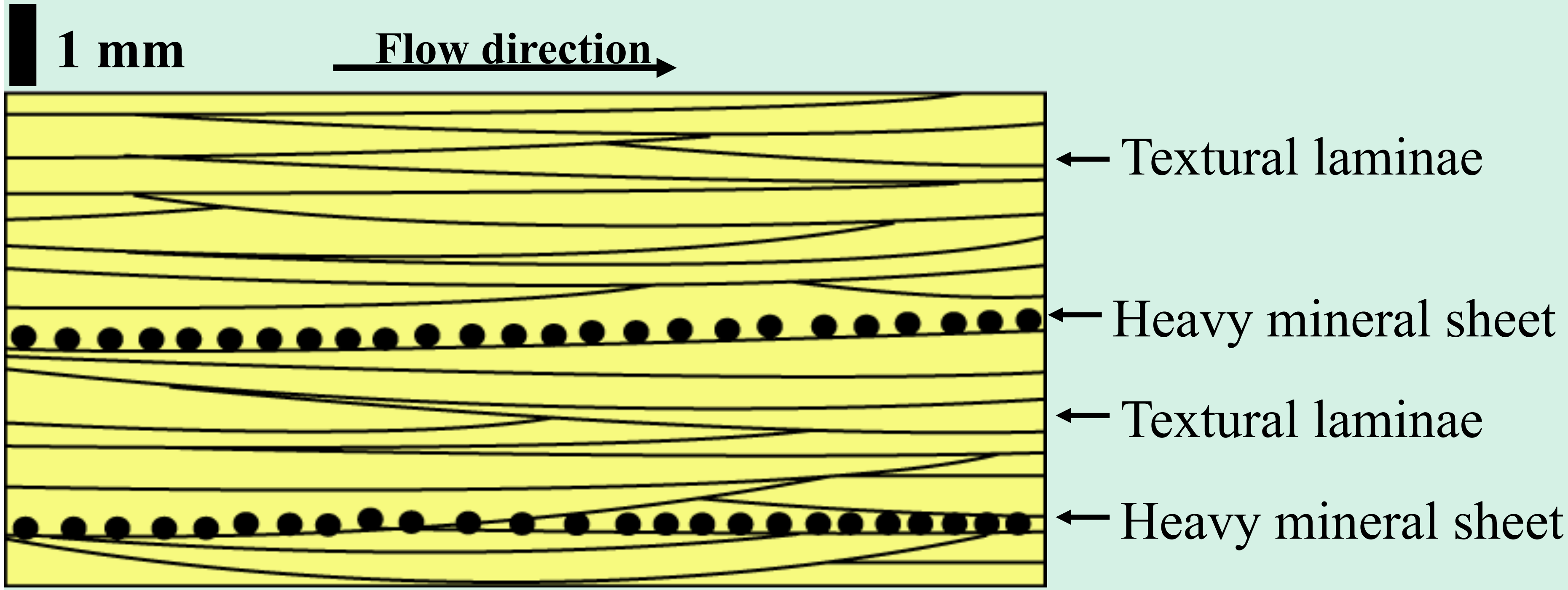




Correlation of laminae across thin sections shows:

Textural laminae persist for centimetres in the downflow direction.

Heavy mineral sheets persist indefinitely (on the thin section scale) in the downflow direction.



Suggested origin of laminae:

Fining upward laminae: uplift of sediment in transport by bursting and settling of grains back into the bedload, exceeding its capacity and depositing a lamination that fines upwards (largest settling velocities first followed by finer grains with lower settling velocity).

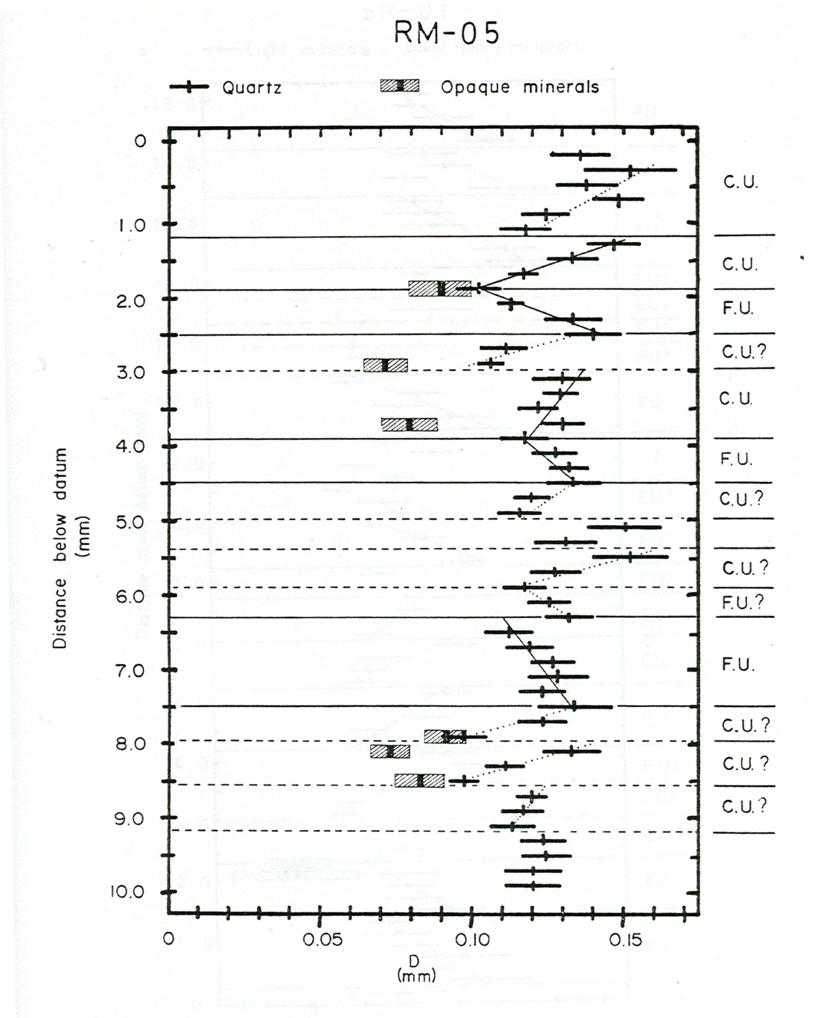
Coarsening upward laminae: increased bedload due to an incoming sweep, resulting dispersive pressure pushes largest grains away from the bed and as the sweep dissipates the deposits reflects the upward coarsening bedload layer.

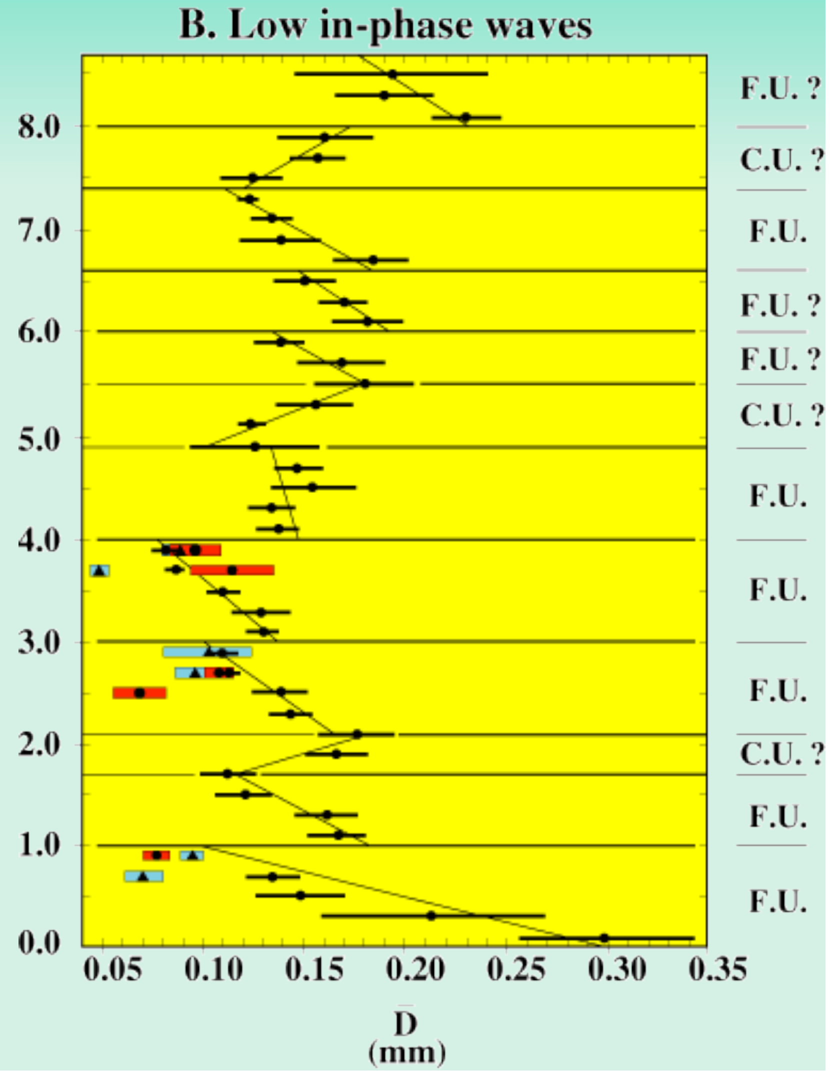
Heavy mineral sheets: deposited with the passage of heavy mineral shadows; high density grains do not uplift with bursts so they are largely absent from FU laminae.

Laterally extensive textural laminae (metres in the downstream direction) are likely formed by low, downstream migrating bed forms on the otherwise plane bed..

iv) In phase wave stratifcation

Low, downstream migrating waves produce near horizontal lamination which largely fine upward and heavy minerals are associated with the tops of FU laminae.

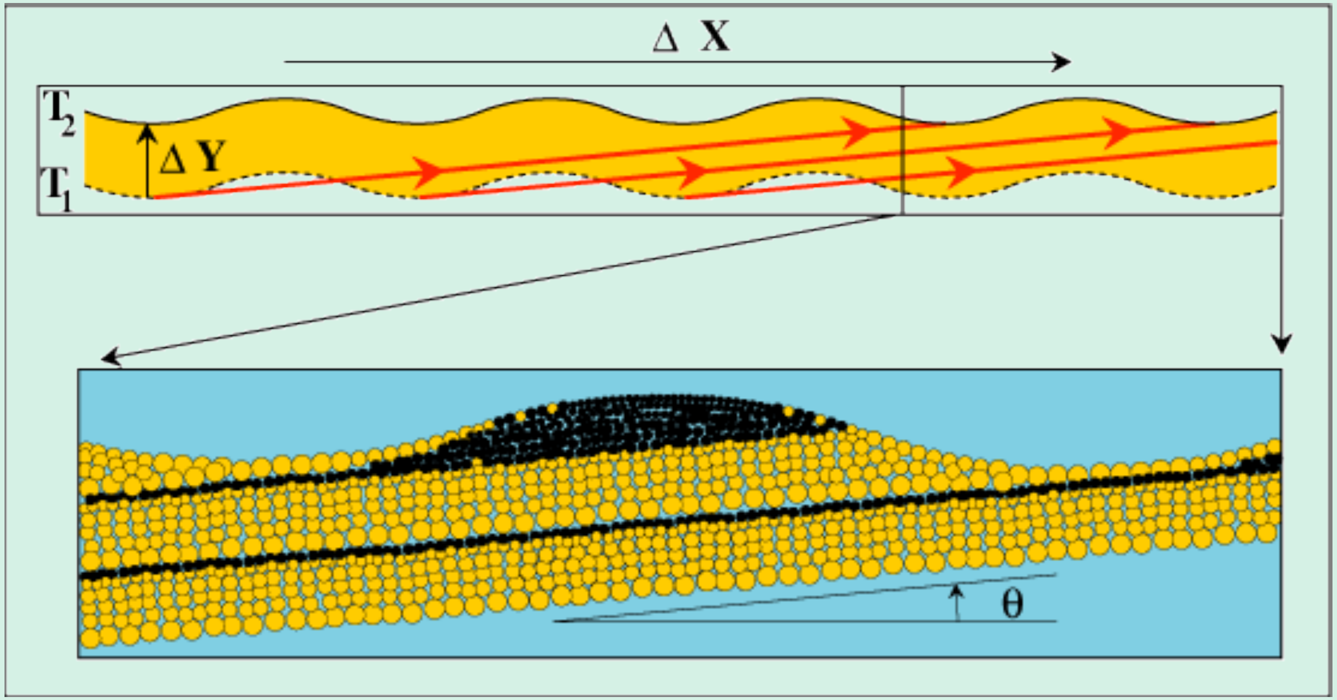




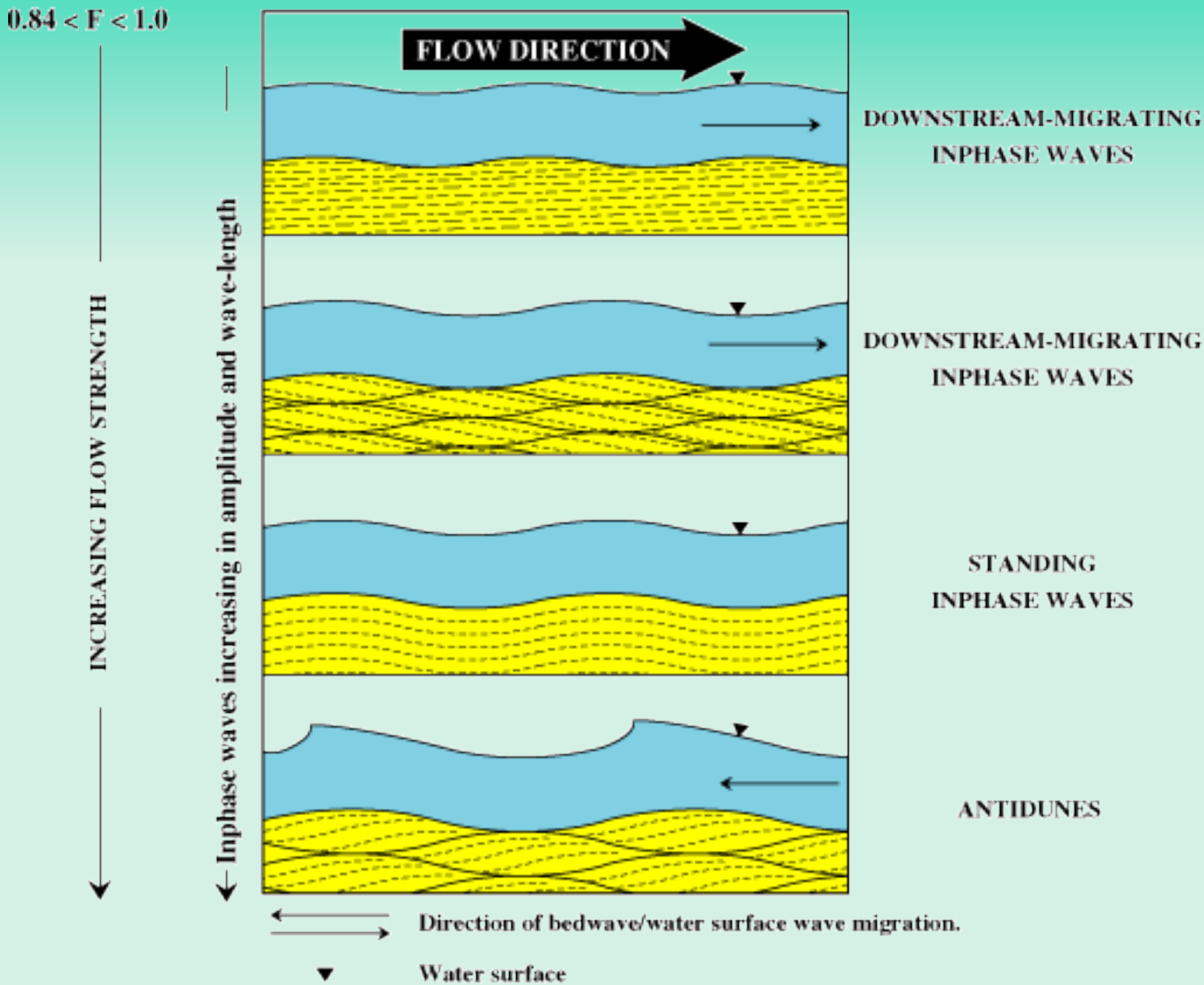
For low, downstream migrating bedwaves grain size is coarsest in the trough, fining towards the crest.

Heavy minerals tend to accumulate on the bed wave crest.

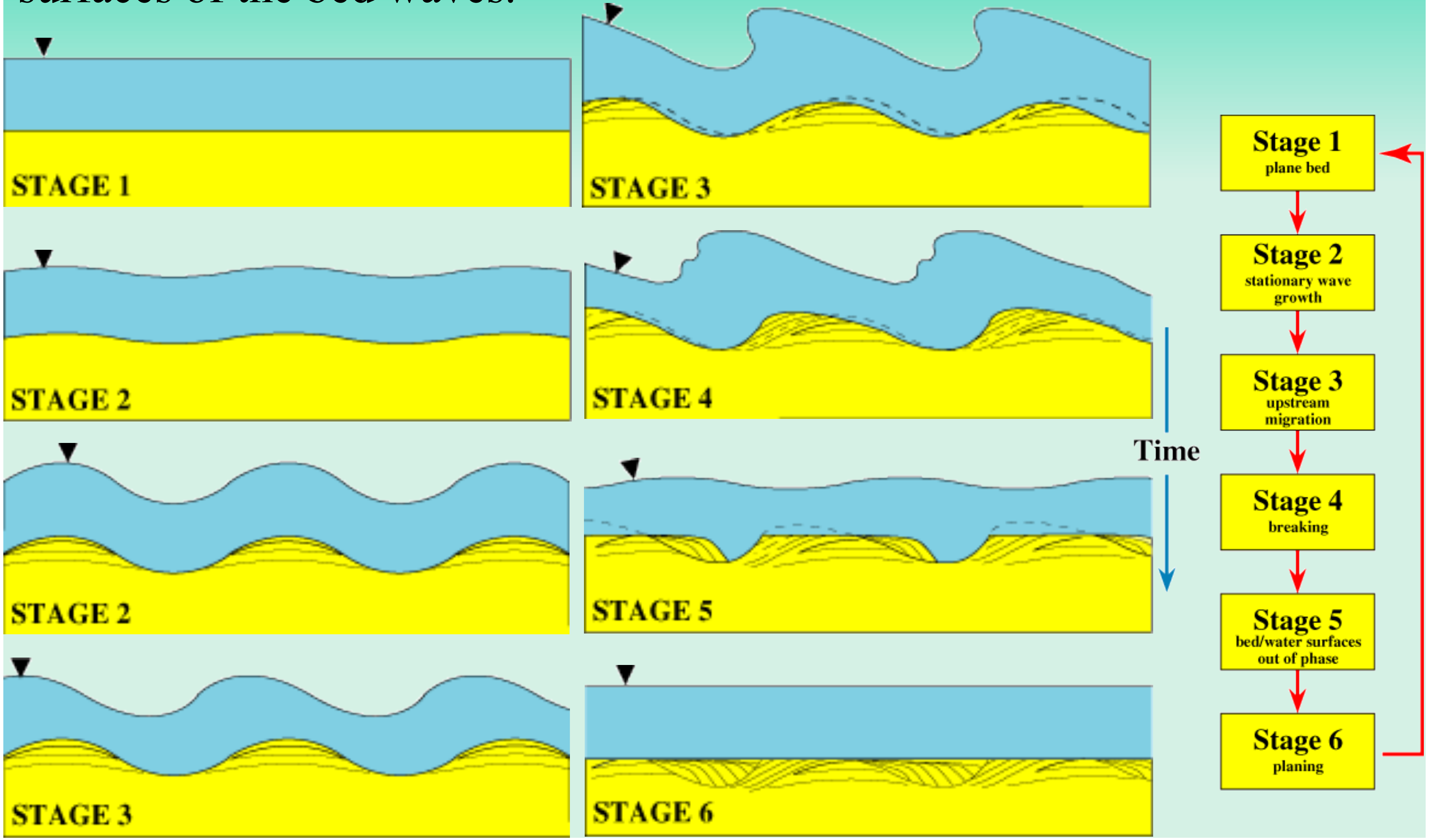
As the waves migrate downstream on an agrading bed they form FU laminae with heavy minerals on the top of laminae.

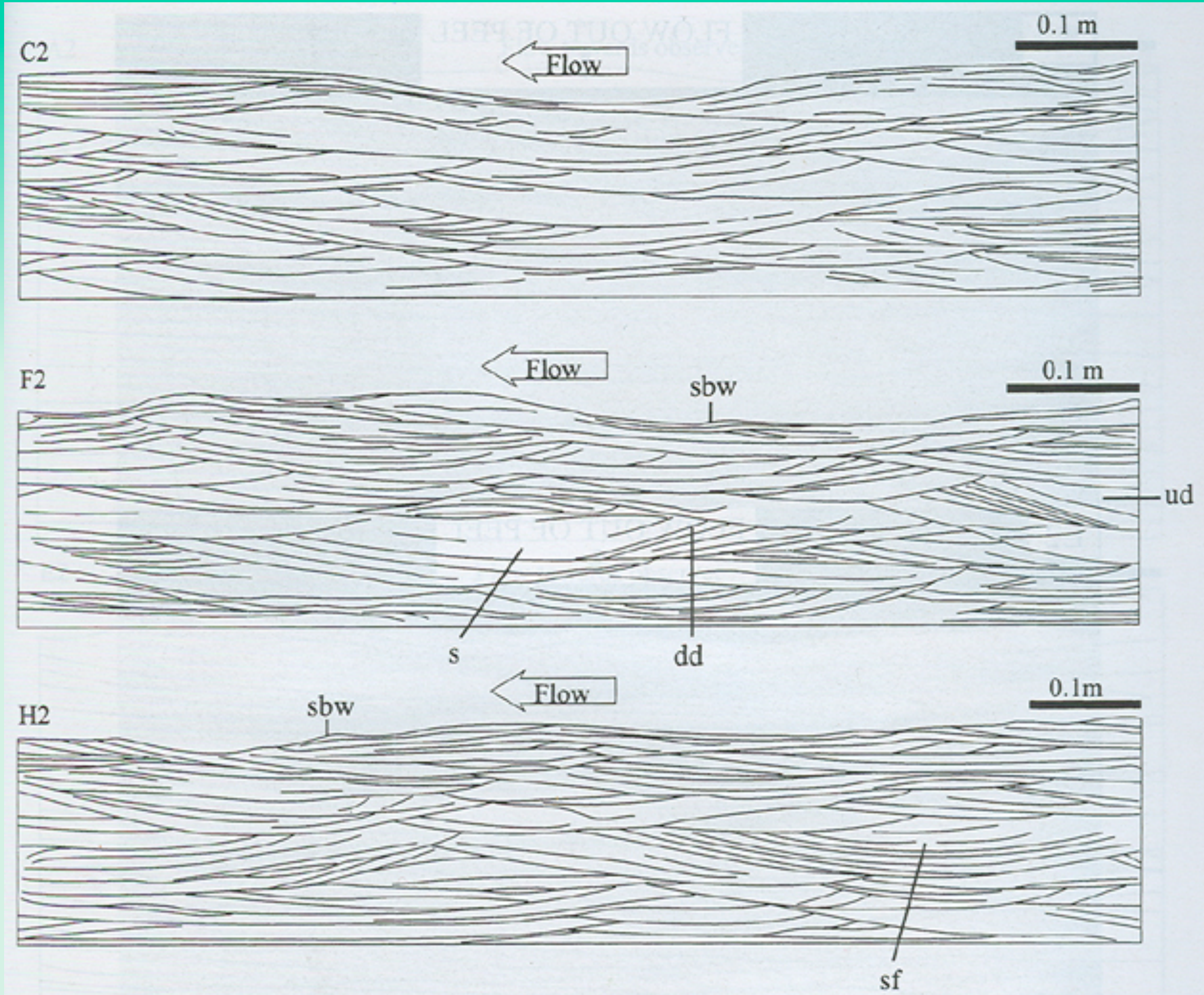


Ideally, the form of stratification reflects the size and behavior of the bed form.



True antidunes produce complex stratification with horizontal lamination, upstream dipping and downstream dipping laminae, all in lens-shaped packages that are formed by the sinusoidal erosional surfaces of the bed waves.




C2
Flow
0.1 m
F2
Flow
0.1 m
sbw
ud
s
dd
H2
Flow
0.1m
sbw
sf