TIDAL SEDIMENTATION

What causes tides?

Tides are created by the imbalance between two forces:

1. Gravitational force of the Moon and Sun on Earth
   - If mass increases (↑), then gravitational force increases (↑)
   - If distance increases (↑), then gravitational force greatly decreases (↓↓)
2. Centripetal (center-seeking) force required to keep bodies in nearly circular orbits

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Gravitational forces on Earth due to the Moon

- Force decreases with increasing distance
- Force is directed toward the Moon's center of mass

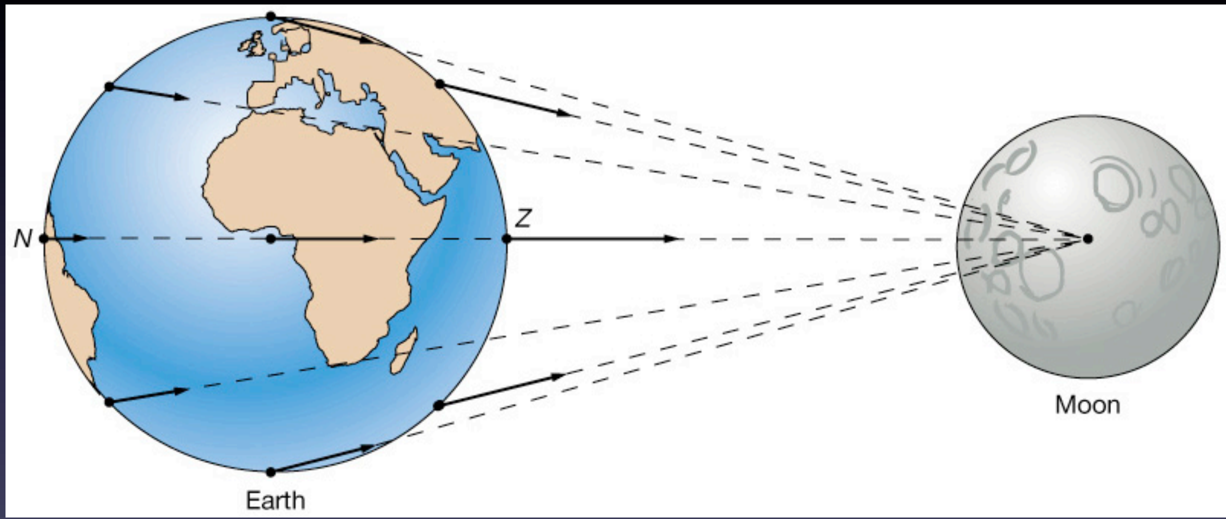


Figure 9-2

Centripetal forces on Earth due to the Moon

- Force is the same everywhere on Earth
- Force is directed perpendicular to Earth's center everywhere on Earth

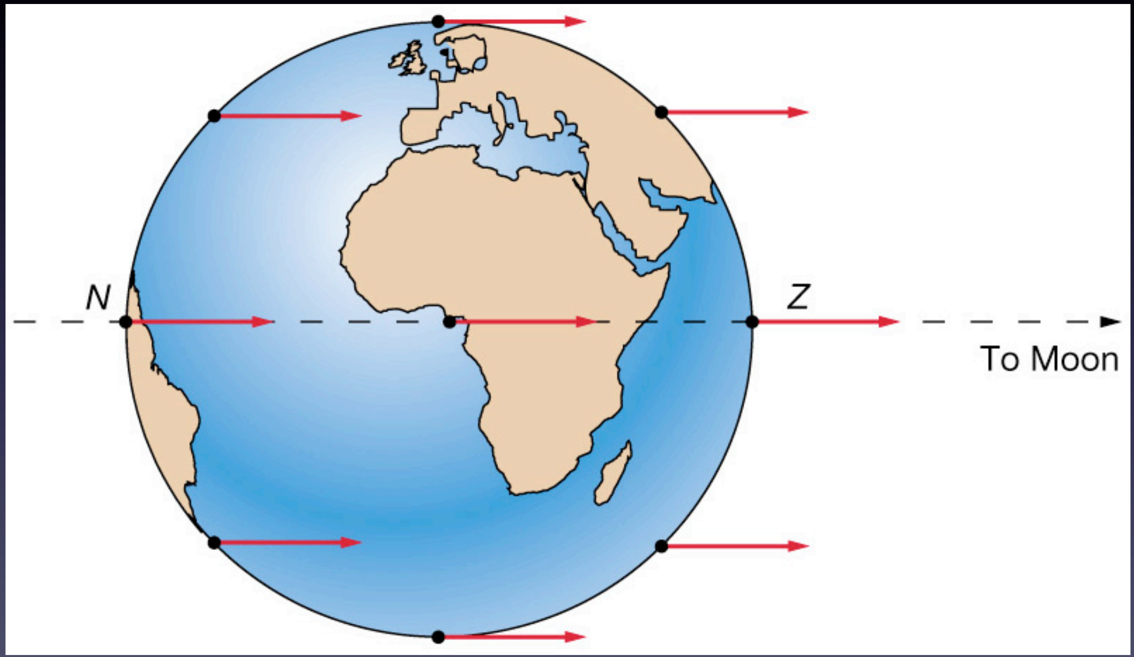


Figure 9-3

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Resultant forces

- Resultant forces are:
  - The difference between gravitational (G) and centripetal (C) forces
  - Directed away from Moon on the side of Earth opposite Moon
  - Directed toward Moon on the side of Earth facing Moon

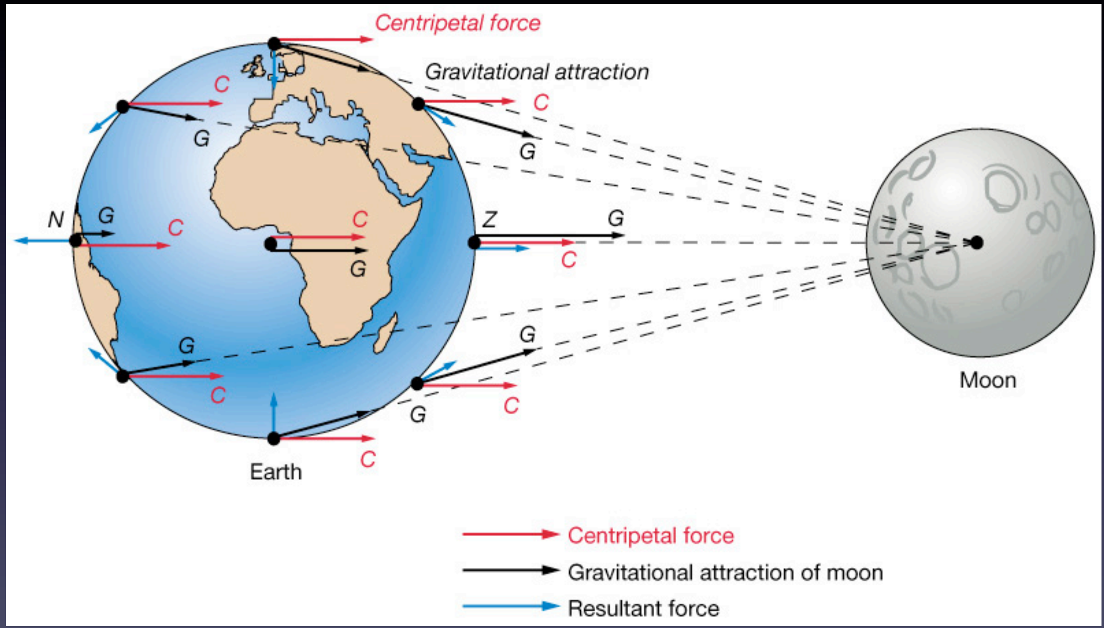


Figure 9-4

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Tide-generating forces

- Tide-generating forces are the horizontal component of the resultant force
- Maximized along a "latitude" of 45º relative to the "equator" between the zenith and nadir

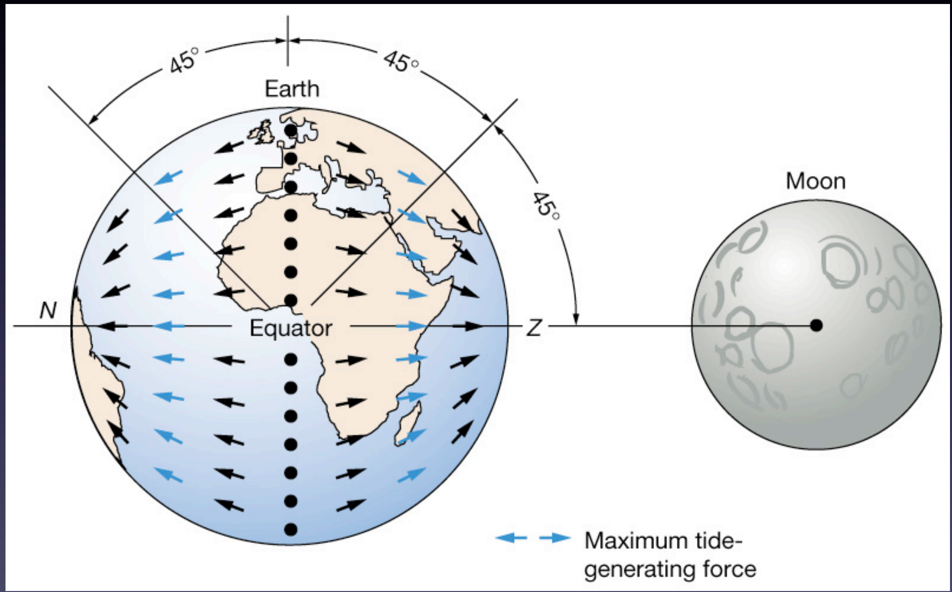


Figure 9-5

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Tidal bulges

- Tide-generating forces produce two bulges:
  1. Away from Moon on side of Earth opposite Moon
  2. Toward Moon on side of Earth facing Moon
- Earth rotates into and out of tidal bulges, creating high and low tides

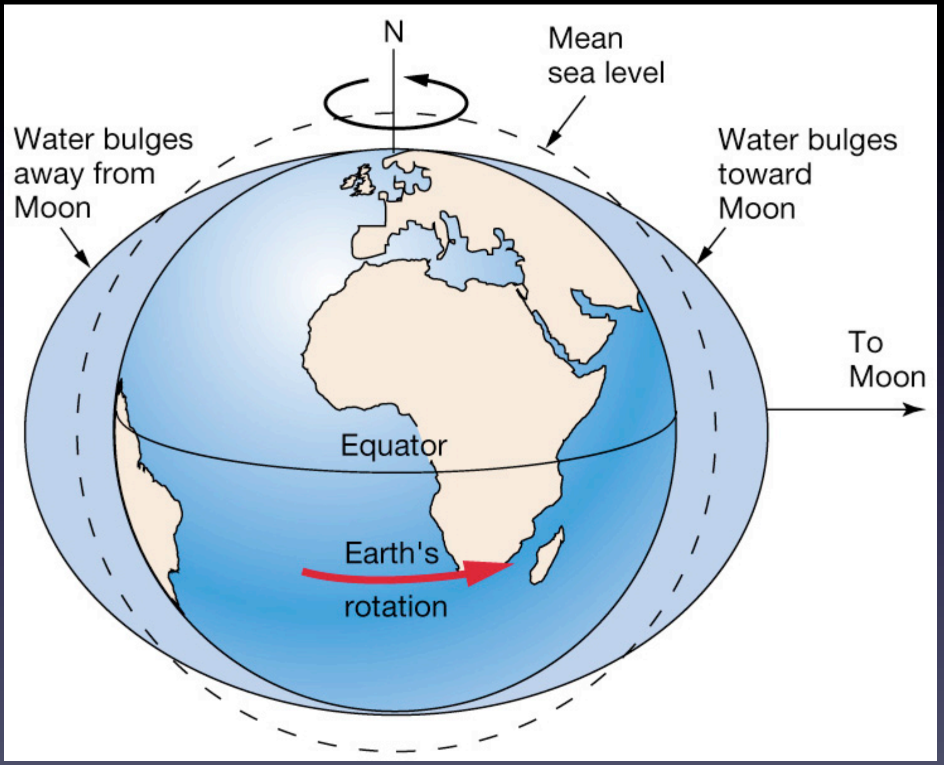


Figure 9-6

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

The lunar day

- Tidal bulges follow Moon as it rotates around Earth
- Lunar day is 50 minutes longer than a solar day because the Moon is moving in its orbit around Earth

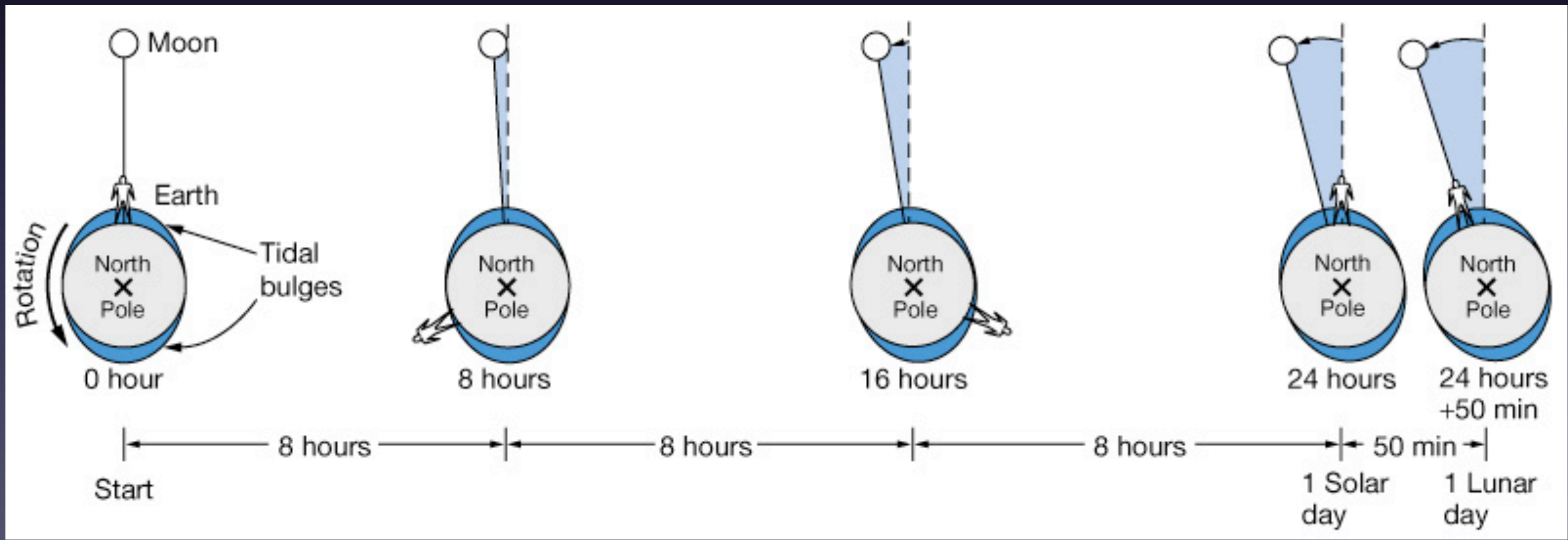


Figure 9-7

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Relative sizes and distances on Earth, Moon, and Sun

- The Sun is much more massive than the Moon but much further away
- Solar bulges are 46% the size of lunar bulges

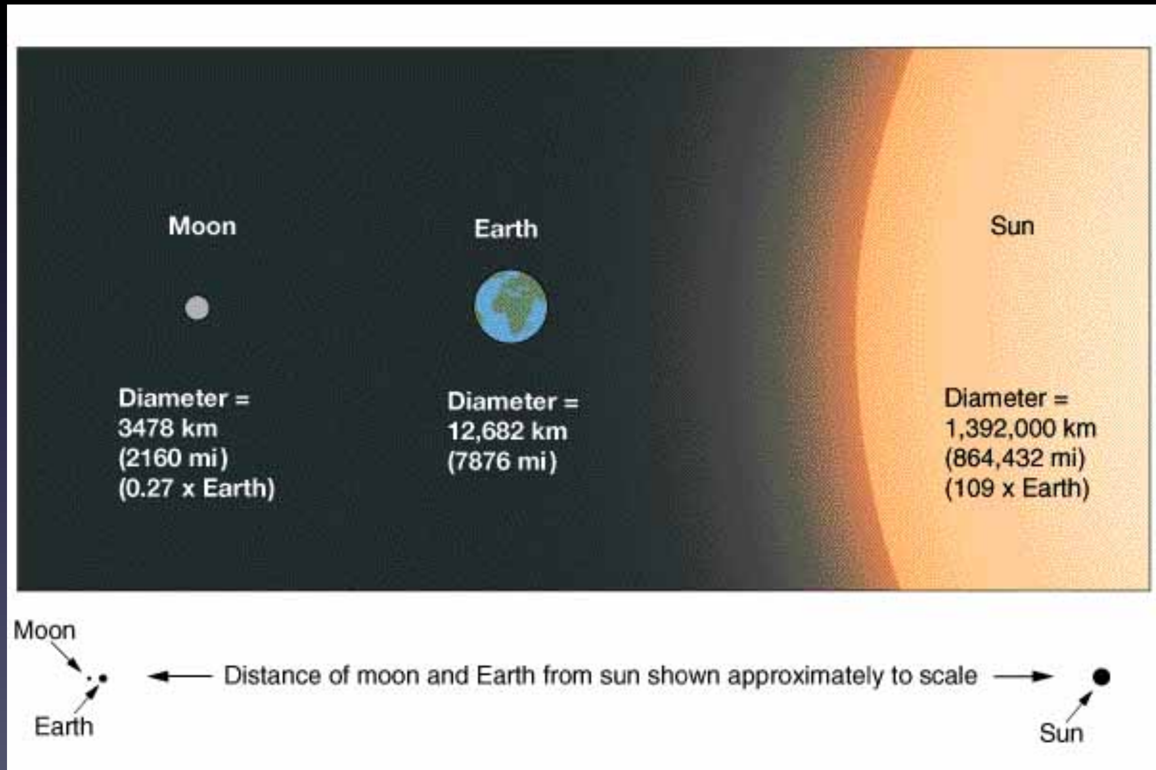


Figure 9-8

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

The monthly tidal cycle (29½ days)

- About every 7 days, Earth alternates between:
  - **Spring tide**
    - Alignment of Earth-Moon-Sun system (syzygy)
    - Lunar and solar bulges constructively interfere
    - Large tidal range
  - **Neap tide**
    - Earth-Moon-Sun system at right angles (quadrature)
    - Lunar and solar bulges destructively interfere
    - Small tidal range

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Earth-Moon-Sun positions and the monthly tidal cycle

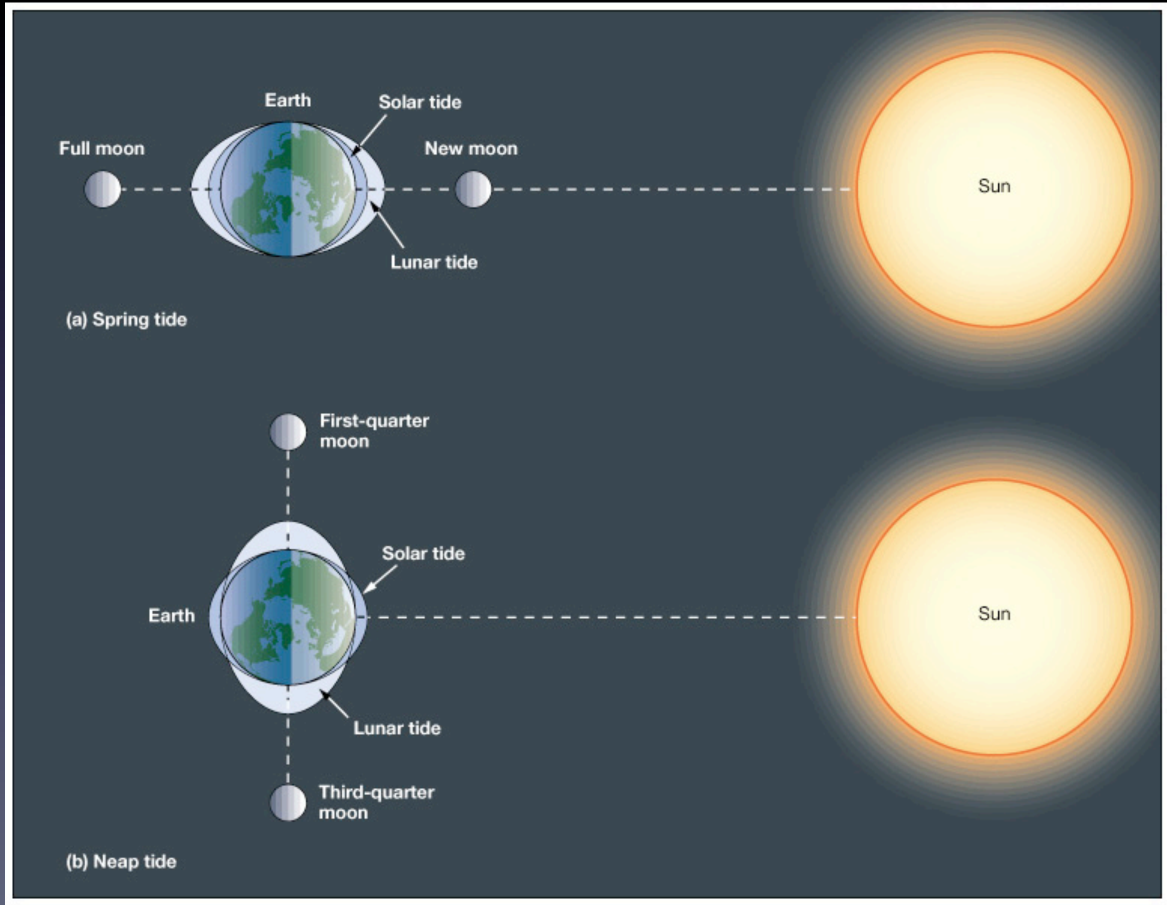


Figure 9-9

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Effect of declination

- The plane of the Moon's orbit is tilted 5° with respect to the ecliptic
- The center of the tidal bulges may be up to a maximum of 28.5° from the Equator

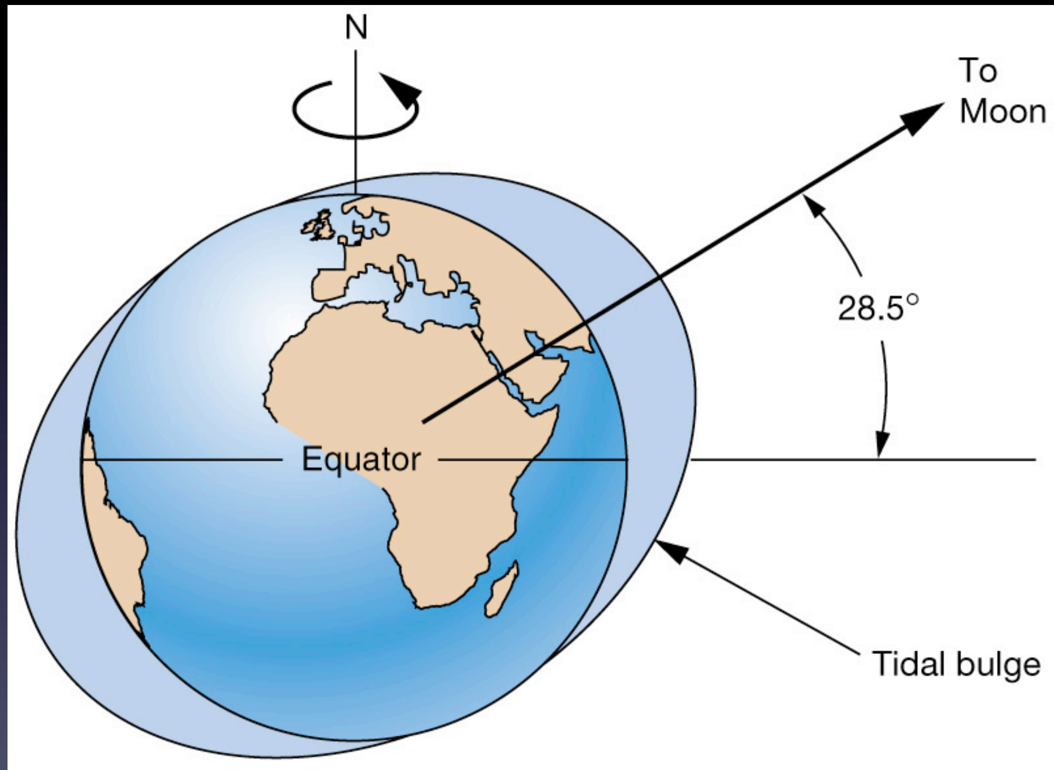
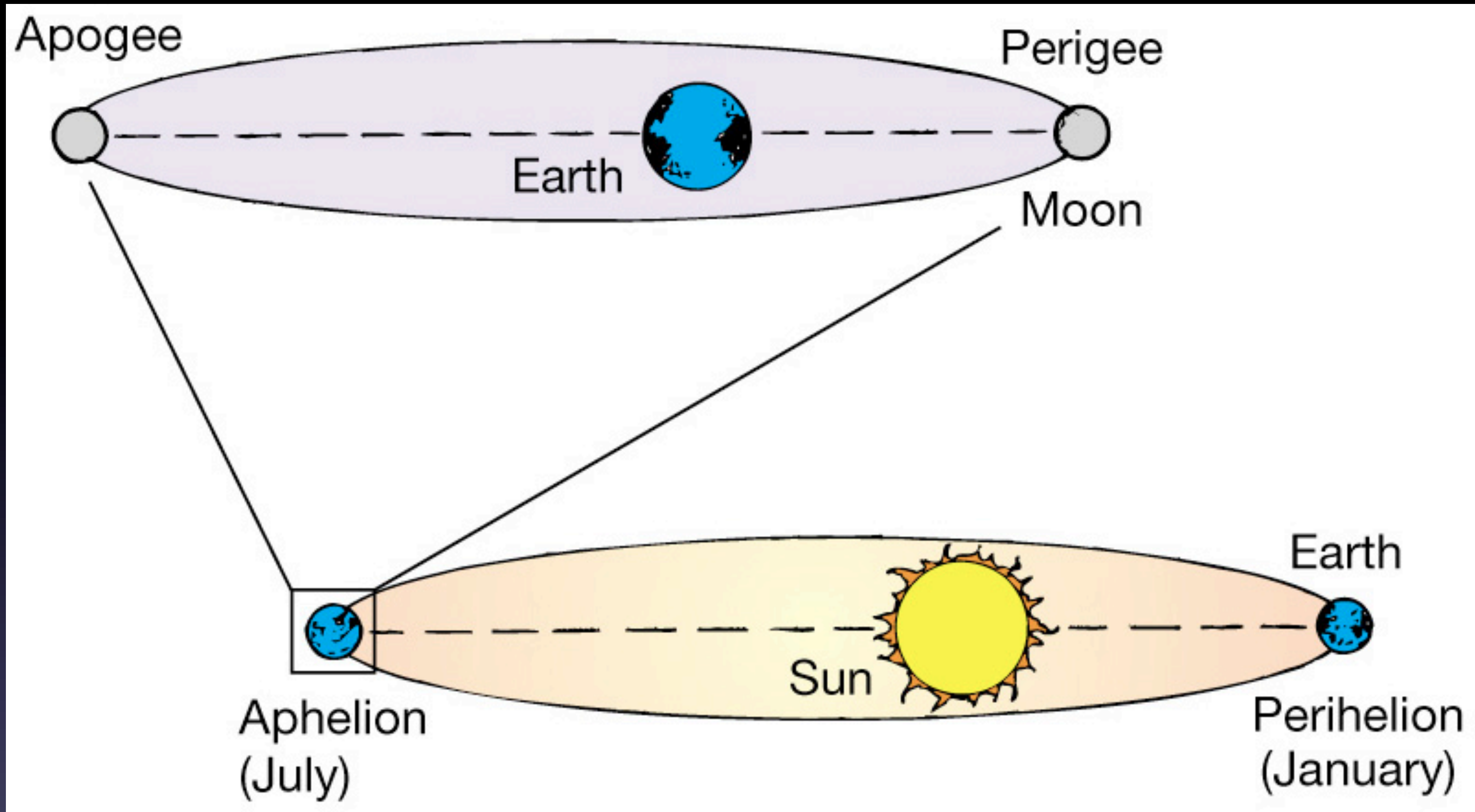


Figure 9-11

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Effect of elliptical orbits

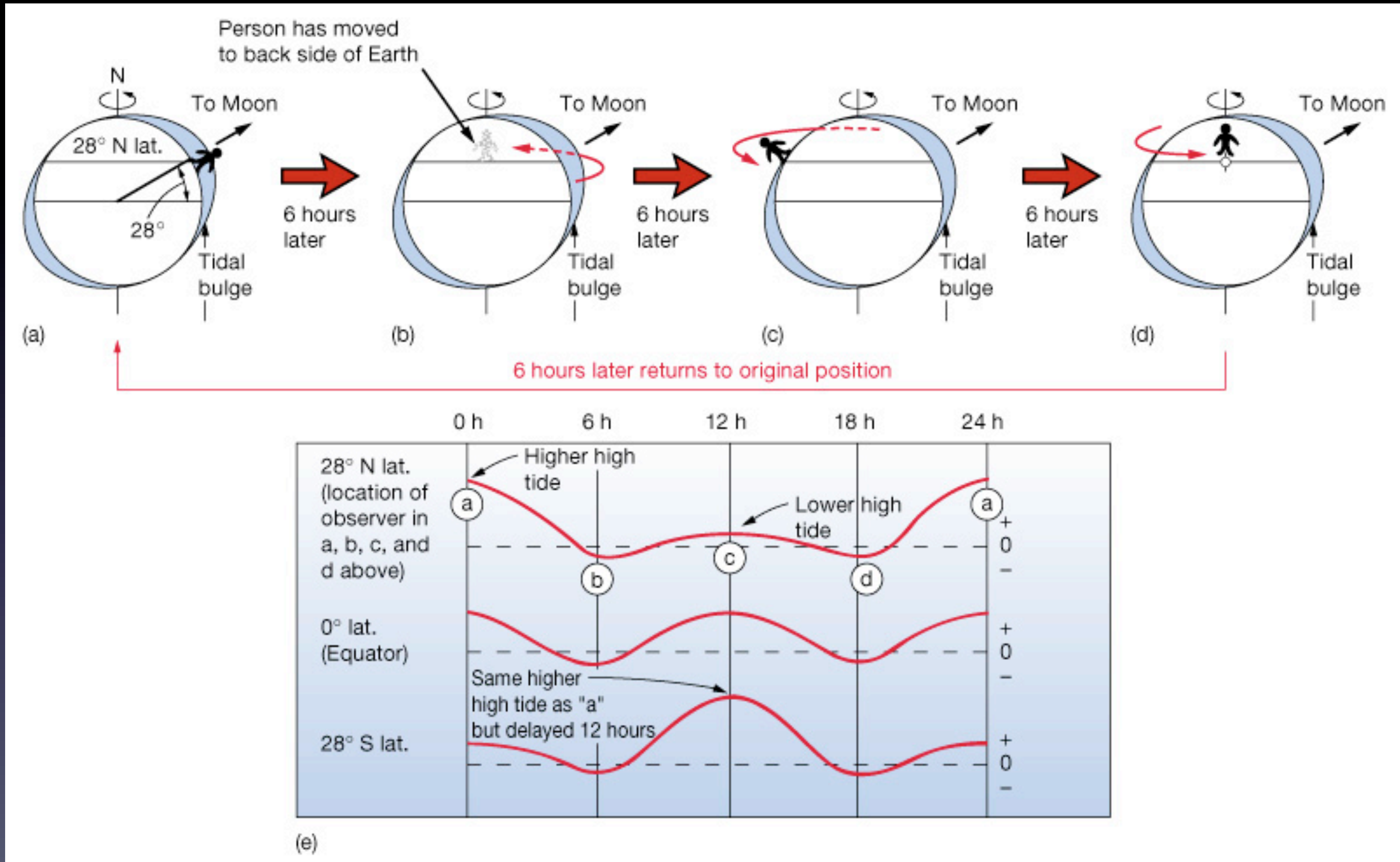


- Tidal ranges are greater when:
  - The Moon is at perigee
  - The Earth is at perihelion

Figure 9-12

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Predicted idealized tides



After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Summary of tides on an idealized Earth

- Most locations have two high tides and two low tides per lunar day
- Neither the two high tides nor the two low tides are of the same height because of the declination of the Moon and the Sun
- Yearly and monthly cycles of tidal range are related to the changing distances of the Moon and Sun from Earth
- Each week, there would be alternating spring and neap tides

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Tides in the ocean

- Cotidal map shows tides rotate around amphidromic points
- More realistic pattern of tides in the ocean

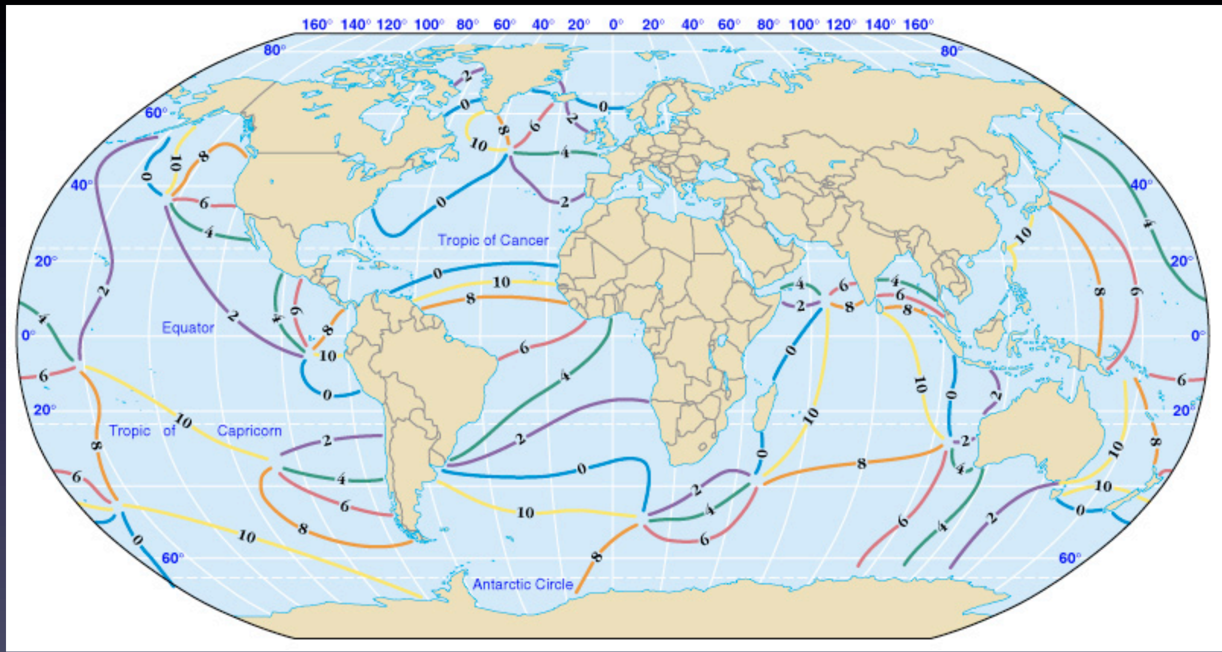


Figure 9-14

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Tidal patterns

- **Diurnal**
  - One high and one low tide each (lunar) day
- **Semidiurnal**
  - Two high and two low tides of about the same height daily
- **Mixed**
  - Characteristics of both diurnal and semidiurnal with successive high and/or low tides having significantly different heights

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Tidal patterns (i.e. USA)

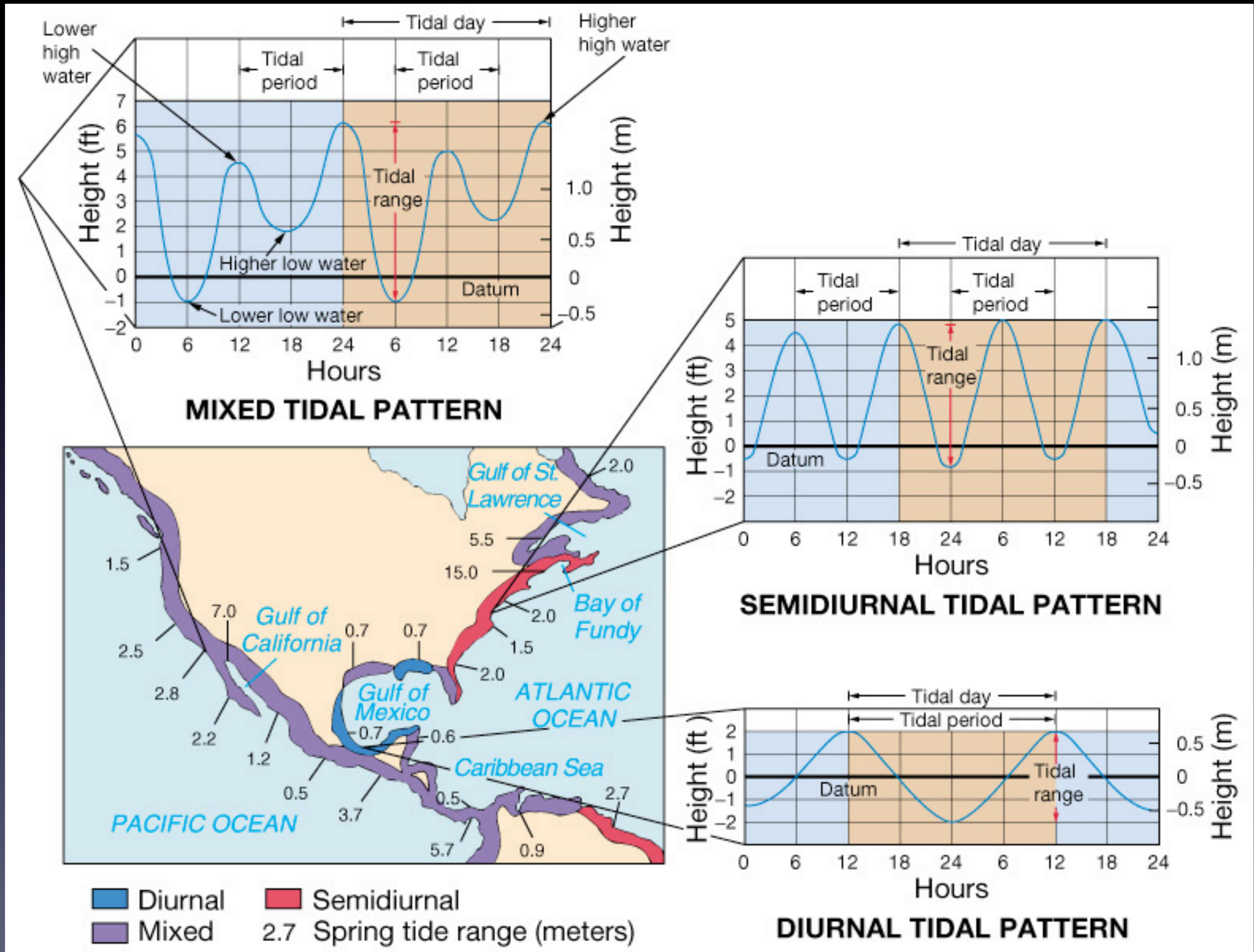


Figure 9-15

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Monthly tidal curves

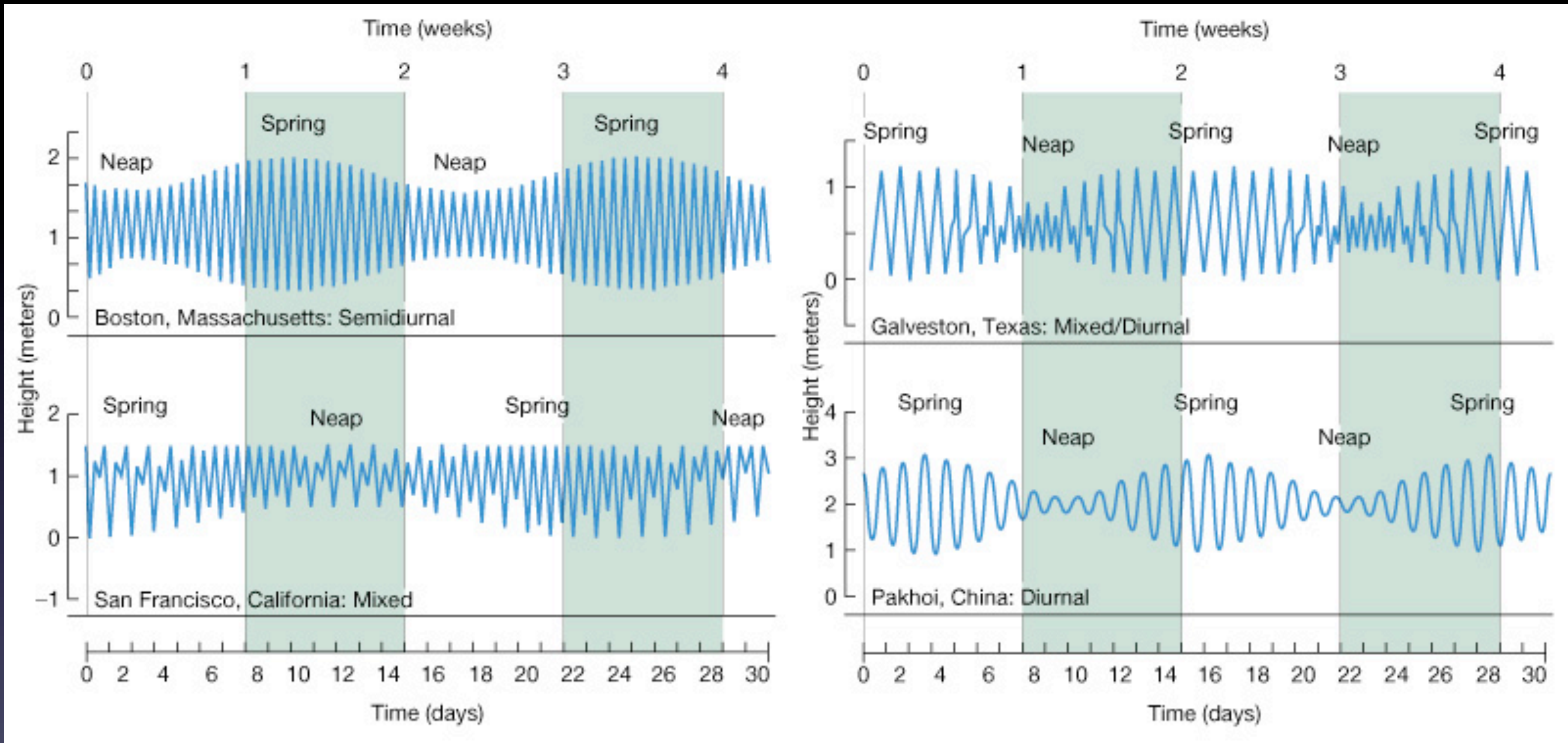


Figure 9-16

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

Coastal tidal currents

- Tidal currents occur in some bays and rivers due to a change in tides
  - Ebb currents produced by outgoing tides
  - Flood currents produced by incoming tides

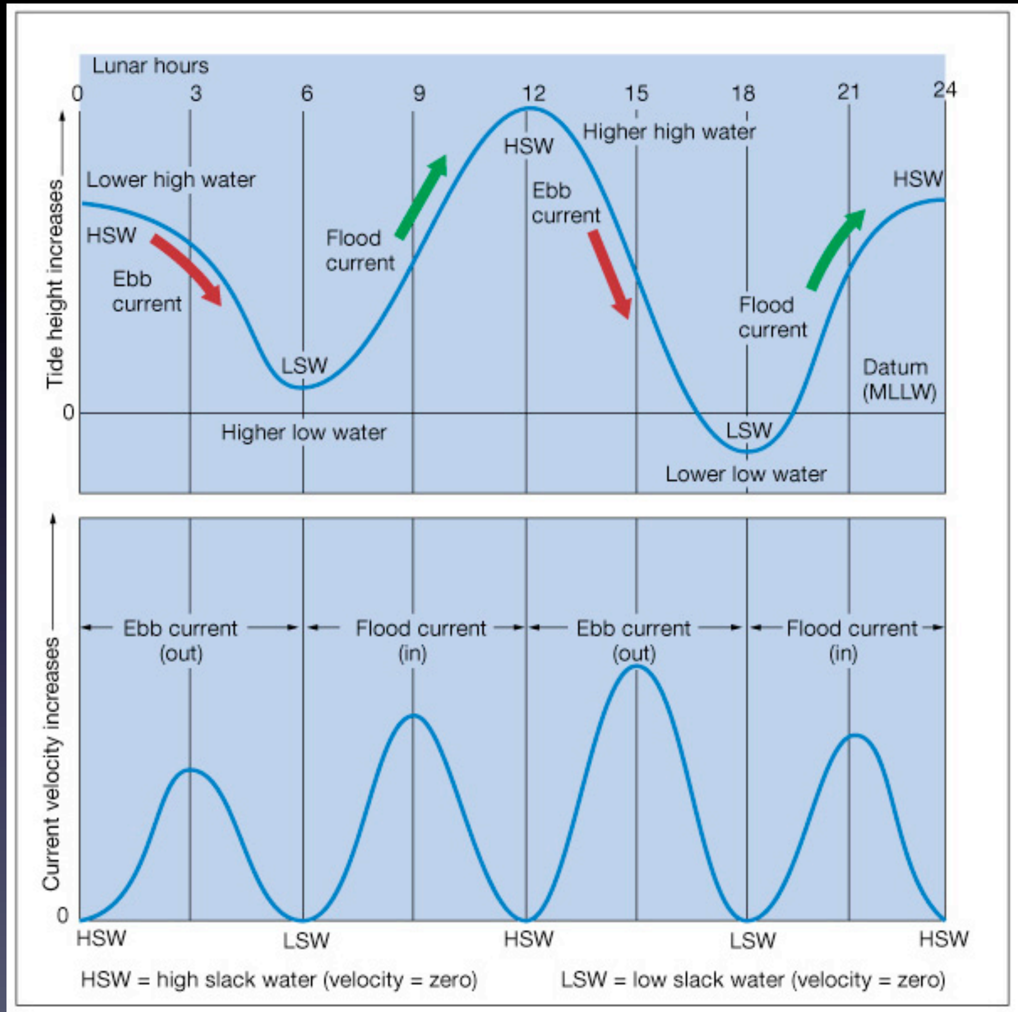


Figure 9-18

After Thurman & Trujillo (2002) Essential of Oceanography – VII Edition (Prentice-Hall)

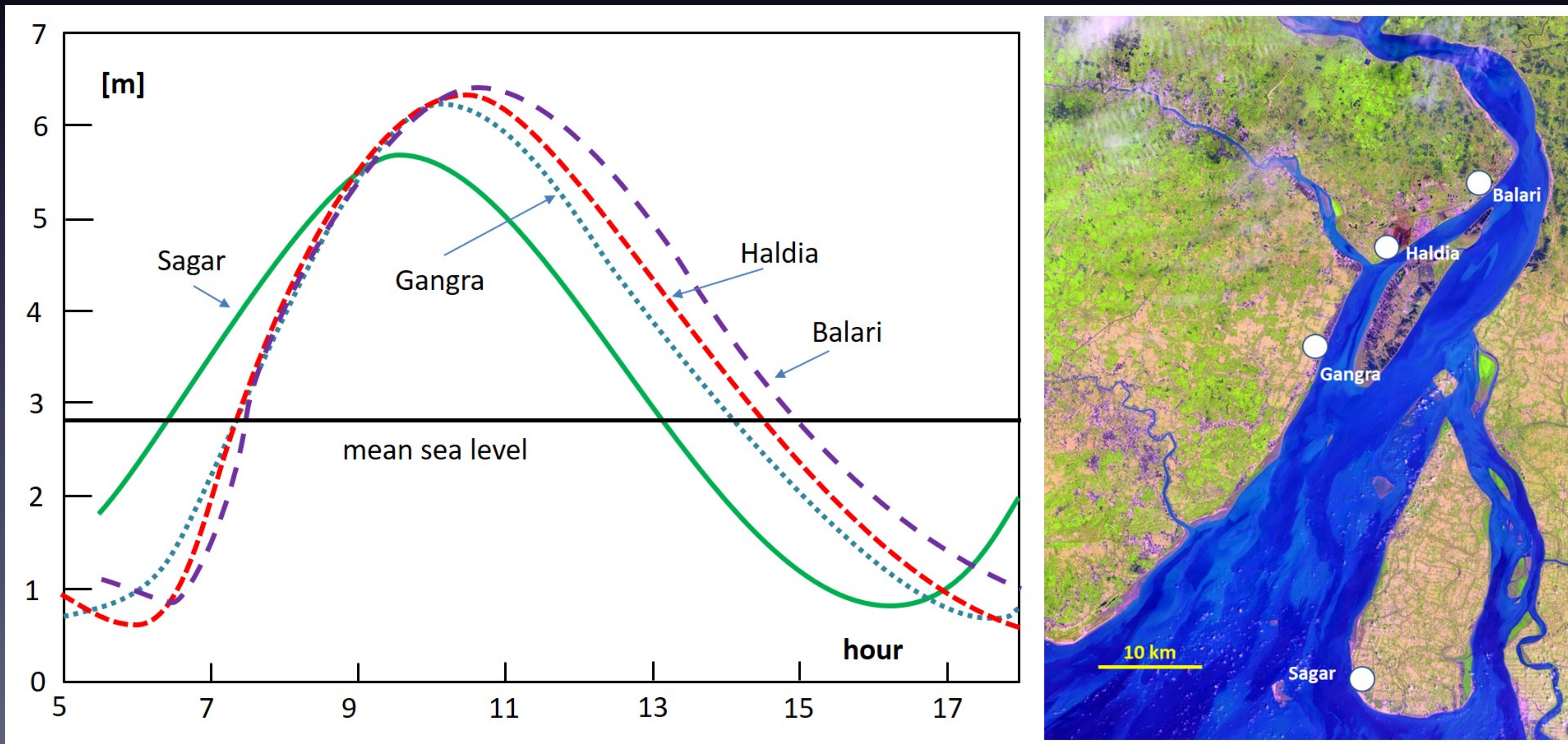
Time Velocity Asymmetry

- Tides are unequal in terms of velocity

-*ebb-dominated*: stronger velocities at ebb

-*flood-dominated*: stronger velocities at flood, and shorter duration than idealized 12h 25m period (more common than ebb-dominated)

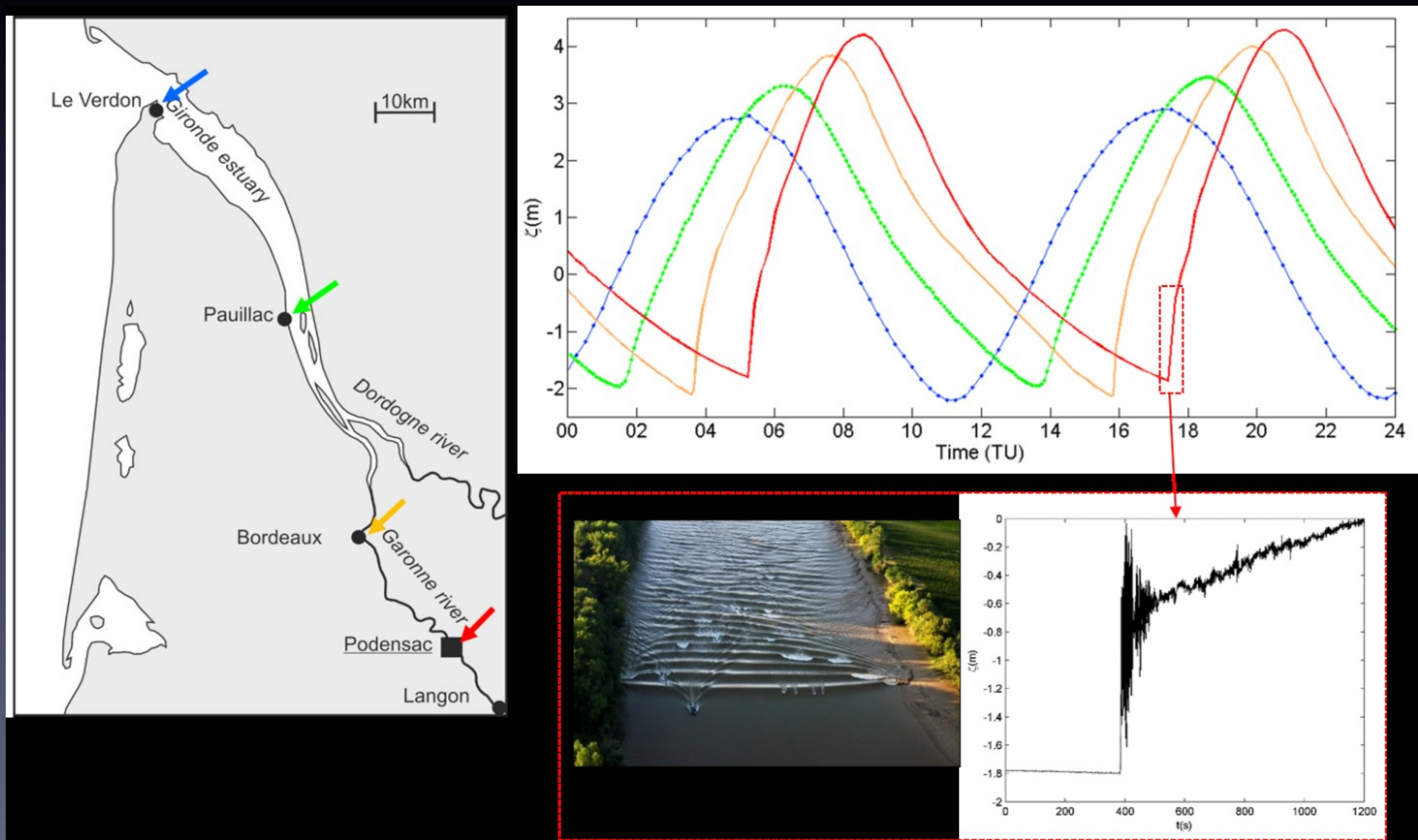
Net sediment transport is usually in the direction of the highest velocities



http://www.coastalwiki.org/wiki/File:HooghlyTidalWaveDeformation.jpg

The distortion of the tide can be so strong that the durations of rising tide and falling tide become very different and that a large difference arises between the peak flow velocities of flood and ebb. Often the duration of rising tide is much shorter than the duration of falling tide.

In the most extreme case, the duration of tidal rise becomes so short that a hydraulic jump develops at the front of the tidal wave. The front of the tidal wave appears as a propagating wall of water, a so-called **TIDAL BORE (it. = mascheretto)**



TIDAL SIGNATURES

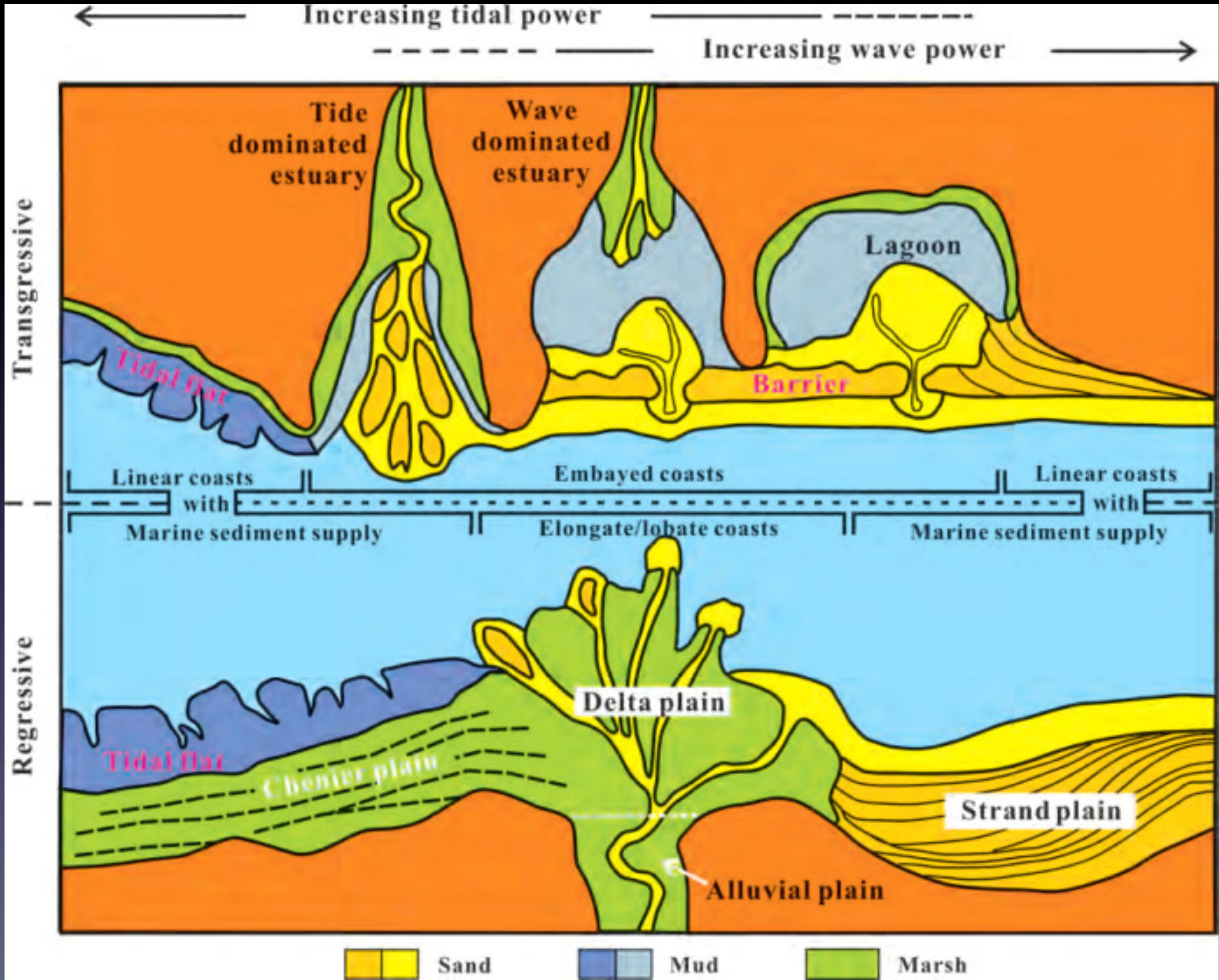
Tidal currents are unique among the processes responsible for sediment transport and deposition because of their regularity, with the speed and direction varying with the frequency of the governing astronomical period (i.e. *Tidal Rhythmites*).

In coastal settings where the shorelines constrain the flow, the landward- (flood) and seaward-directed (ebb) currents typically have directions 180° apart, in a pattern that is termed rectilinear.

A period of little or no current (i.e., *slack-water*) varying in length from a few to several tens of minutes generally accompanies each flow reversal.

As a result, sediment transport is intermittent, with episodes of sand transport (if the currents are sufficiently strong) alternating with periods of mud deposition during the slack-water intervals

TIDAL ENVIRONMENTS



Tidal Flat

Hydro-period

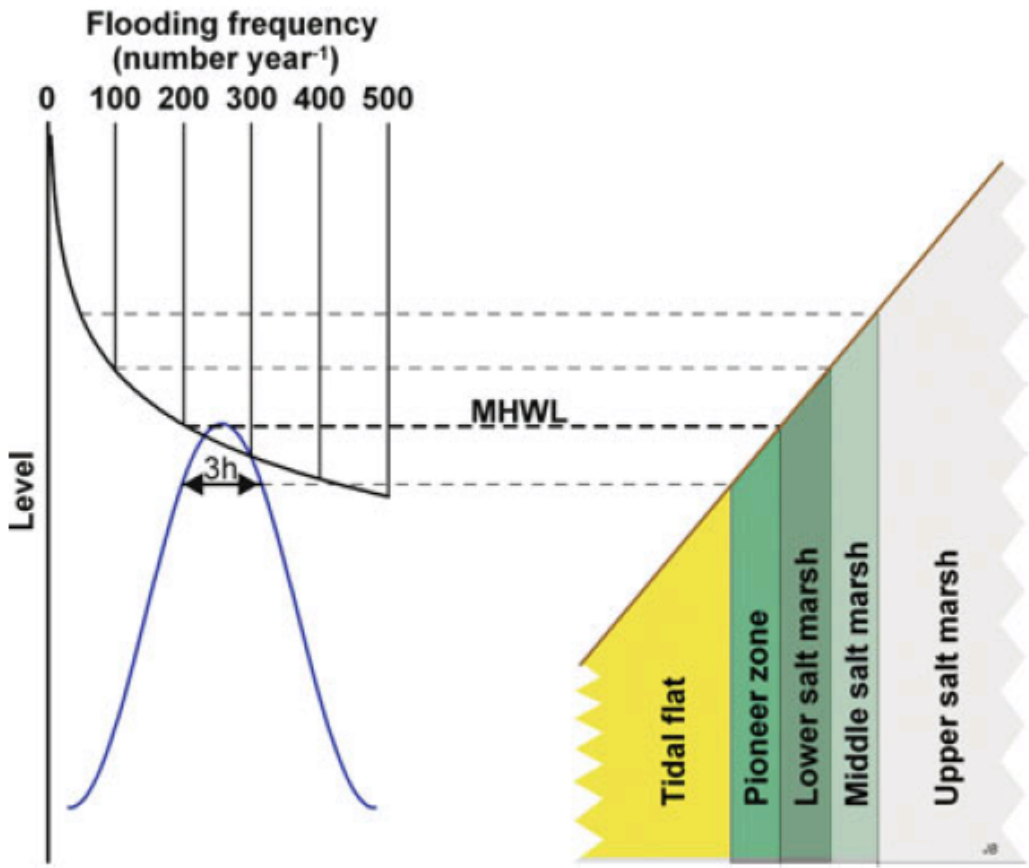


Fig. 8.9 Definition diagram relating zones in the intertidal area to flooding duration and frequency. The *lower zone borders* like the concept are adopted from Coldewey and Erchinger (1992). The flood frequency curve is from the Skallingen peninsula, Denmark

The fining-landward pattern

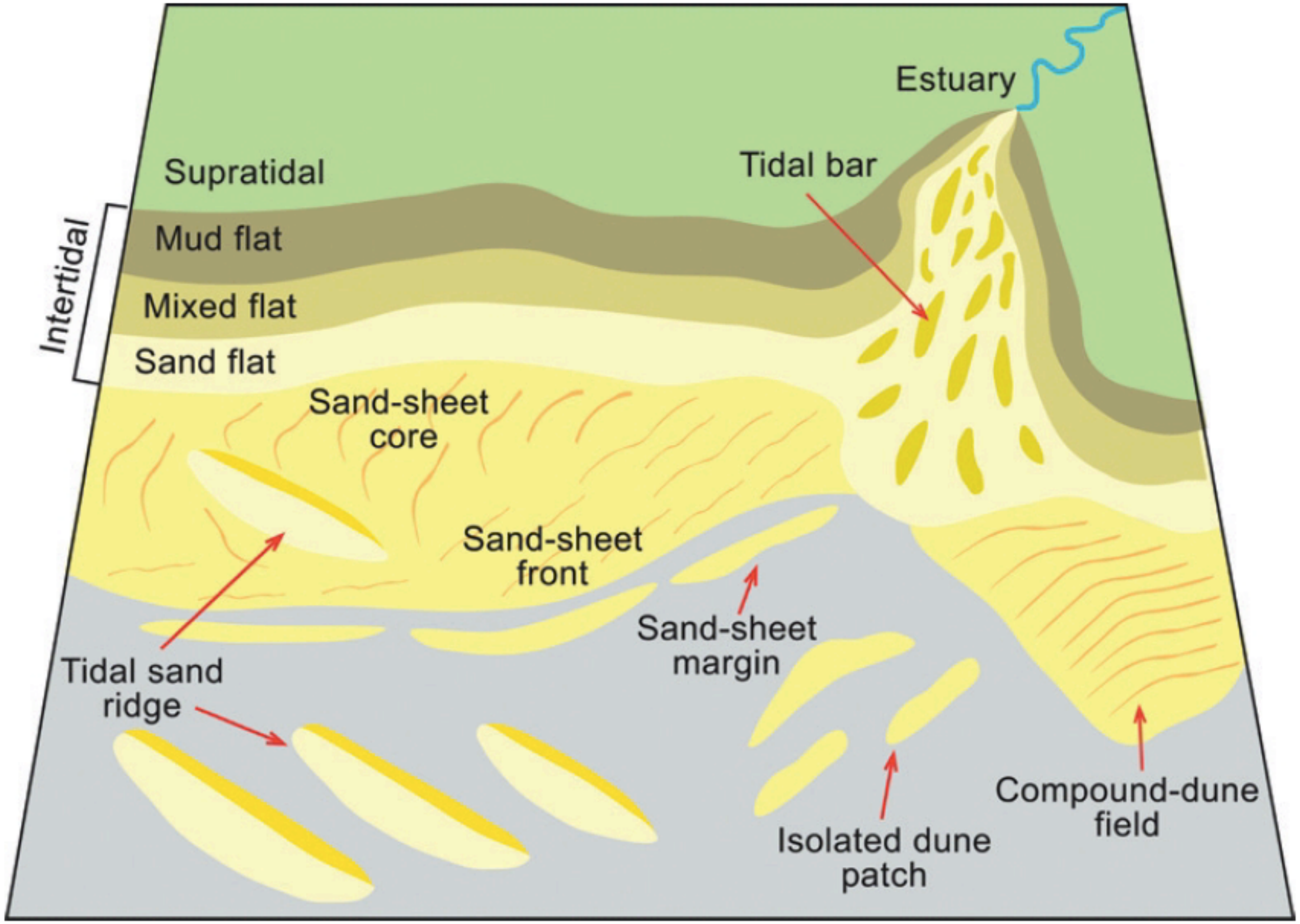
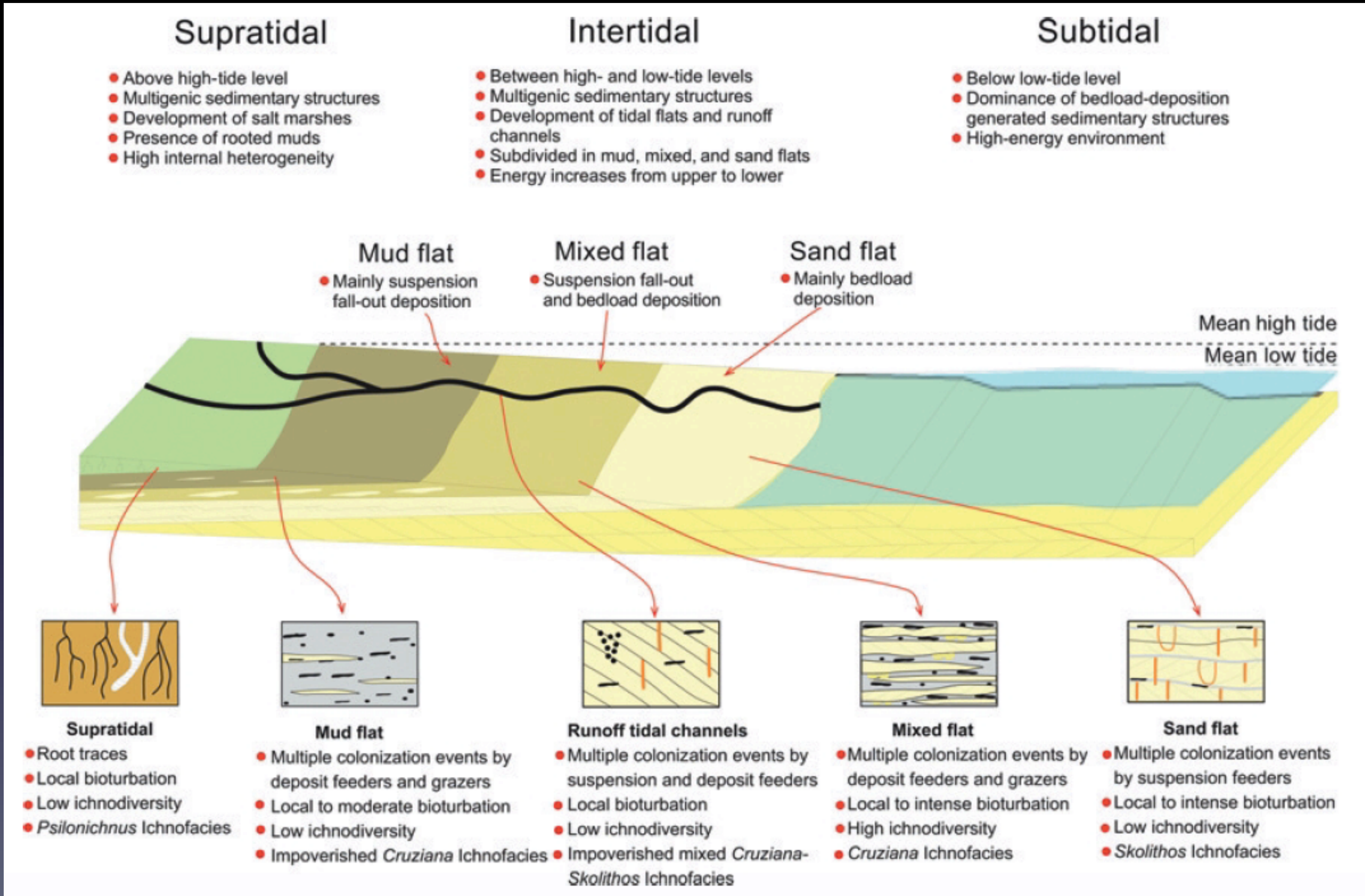


FIGURE 1 Sedimentary environments and sand-body distribution in tide-dominated shallow-marine settings.

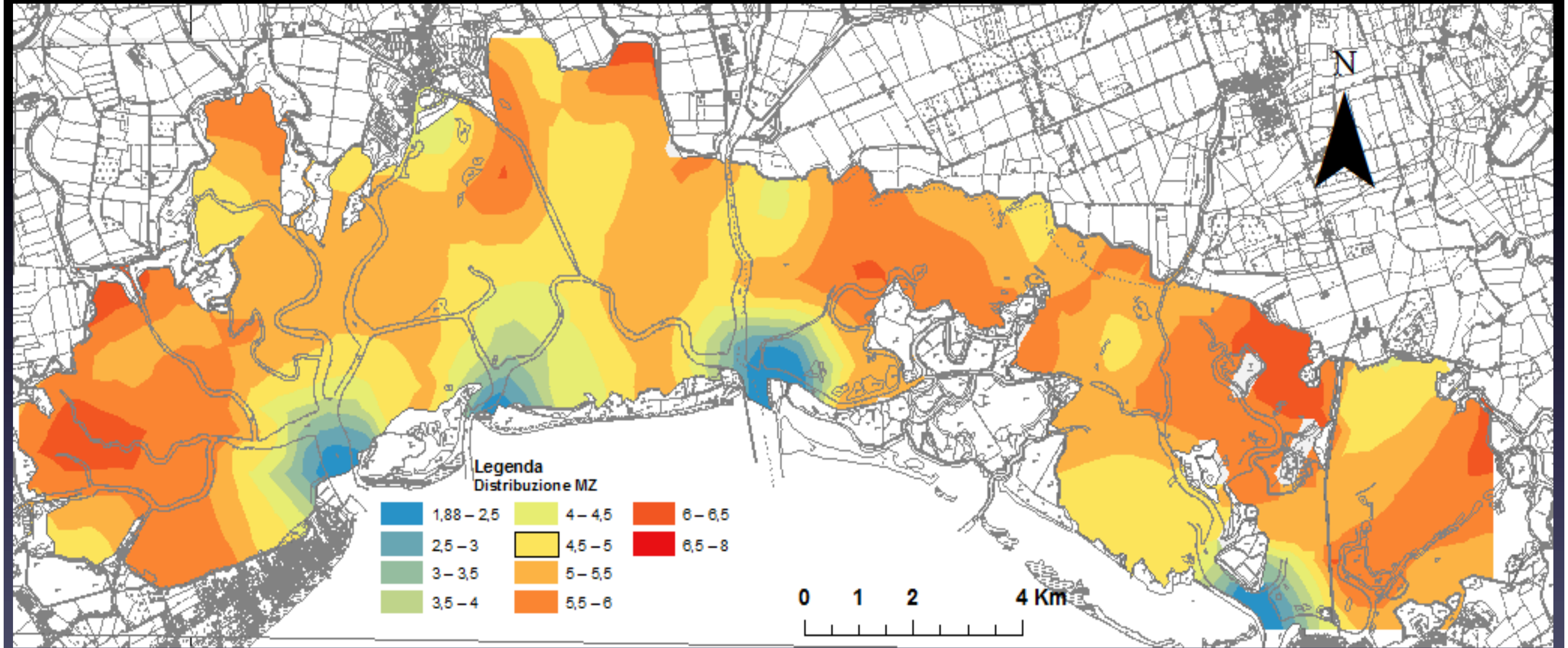
Desjardins et al. (2012) Developments in Sedimentology 64: 529-561

The fining-landward pattern

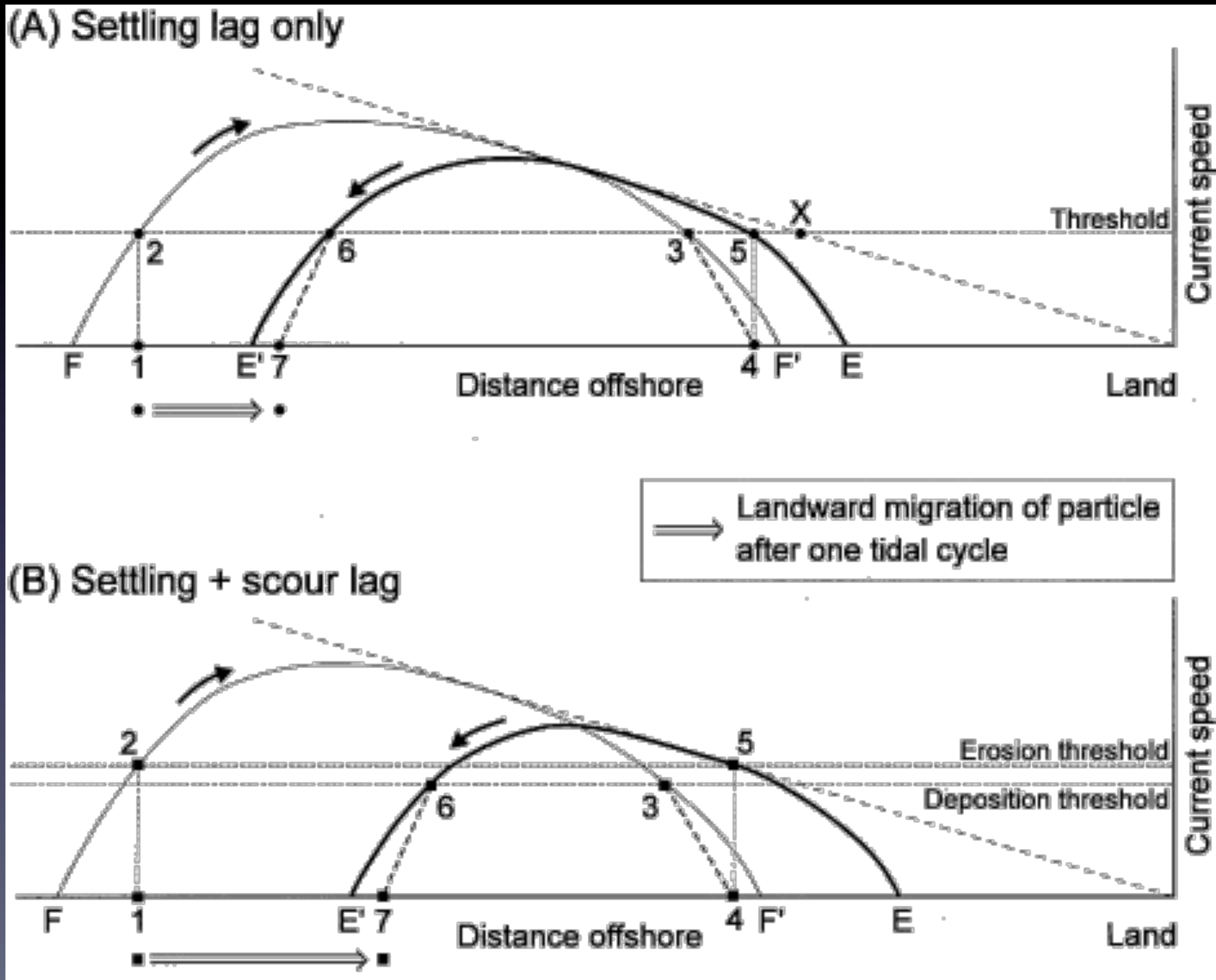


Desjardins et al. (2012) Developments in Sedimentology 64: 529-561

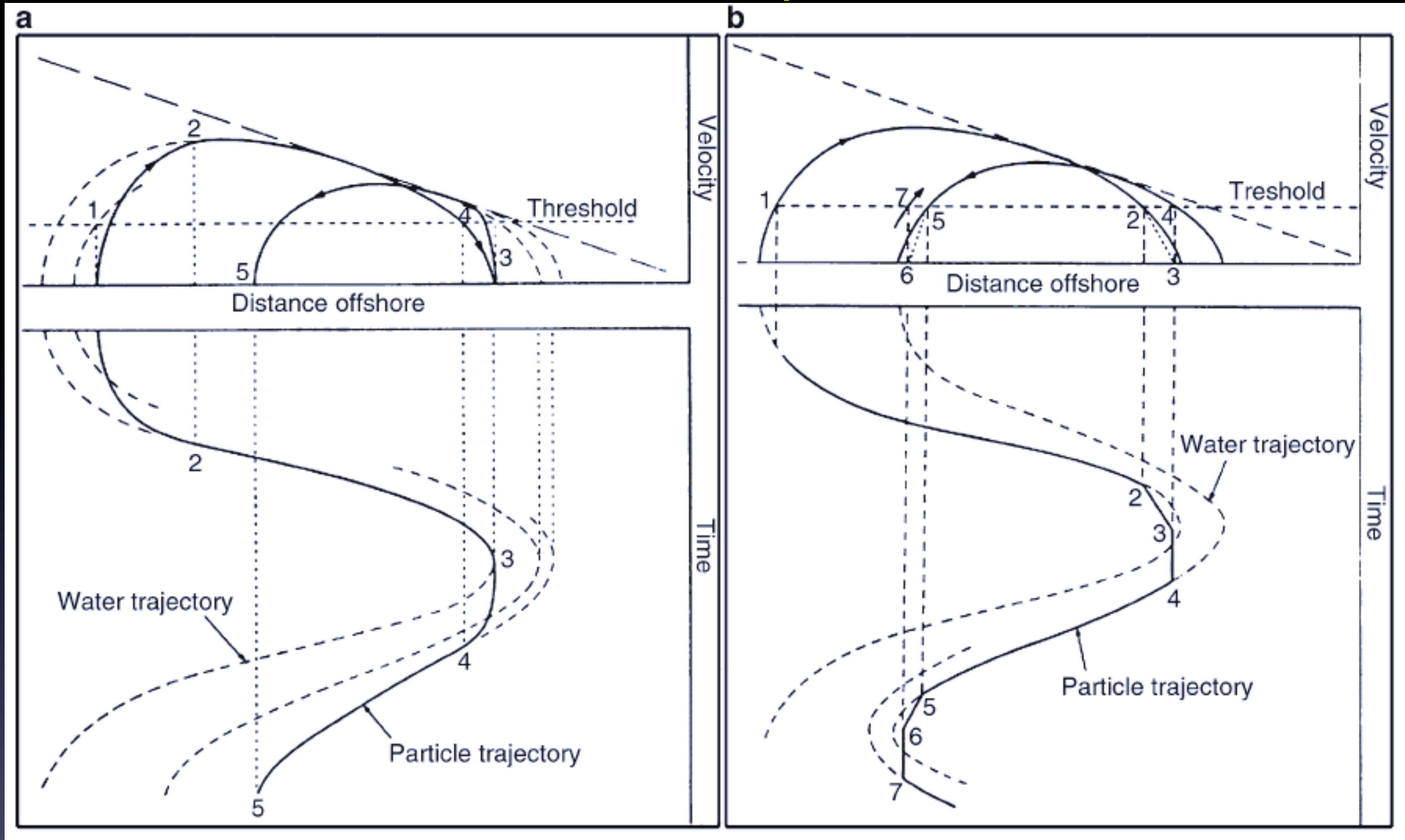
The fining-landward pattern



Sedimentation during tidal cycles: the settling and scour lag effects

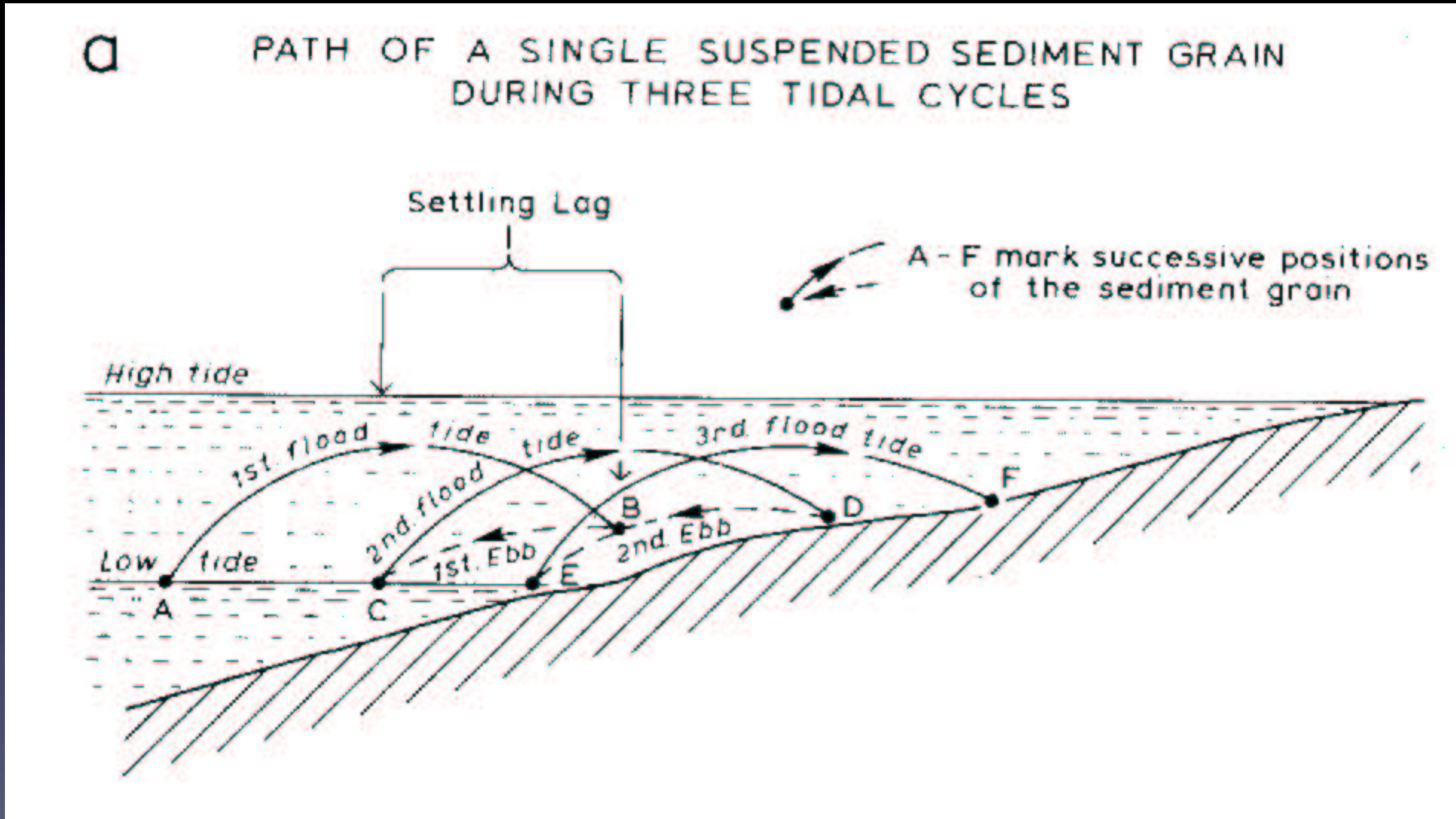


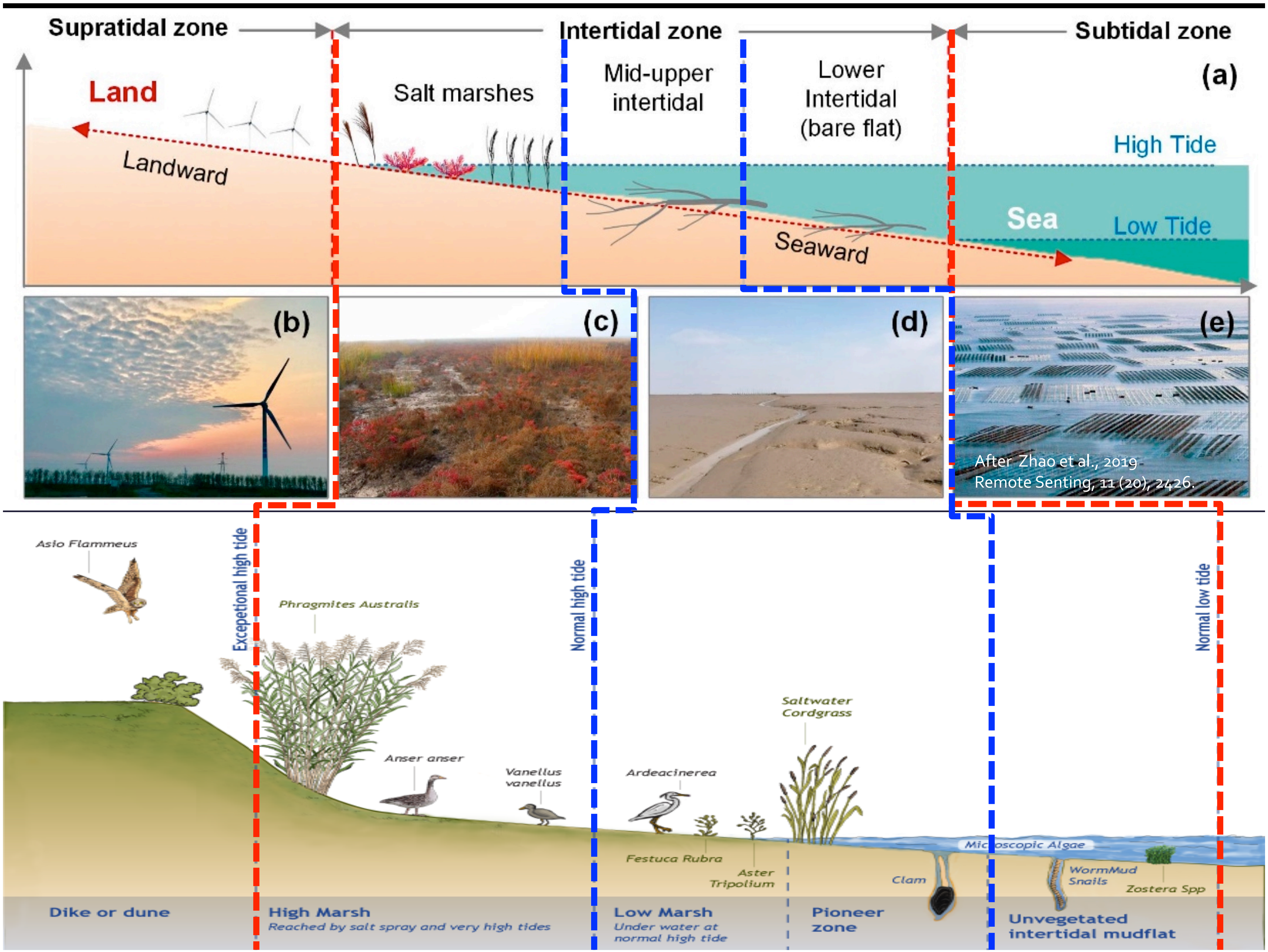
Alternative explanation



Schematics of scour lag (a) and settling lag (b) for fine-grain sediments. (a) Scour lag: a particle on the bed is suspended into the water column when the threshold velocity is exceeded at point 1. It does not, however, achieve the depth averaged velocity till point 2, a relatively seaward position. It then travels with the water trajectory to point 3, where we assume it is instantaneously deposited. On the following ebb tide, the particle is suspended, but again lags the flow till point 4 is reached. It is eventually re-deposited at point 5. Considerable landward movement has occurred during the tidal cycle because of the scour lag. (b) Settling lag: at position 1, the particle is entrained from the bed and travels with water till point 2, where it starts to settle. Because of the settling lag, it reaches the bed at point 3. On the following ebb tide, it is not entrained till later in the tide cycle when the threshold velocity (greater than the velocity for settling) is reached. The deposition at low water is at position 6. Consequently, the particle has moved shoreward due the settling lag (Modified from Dyer 1994).

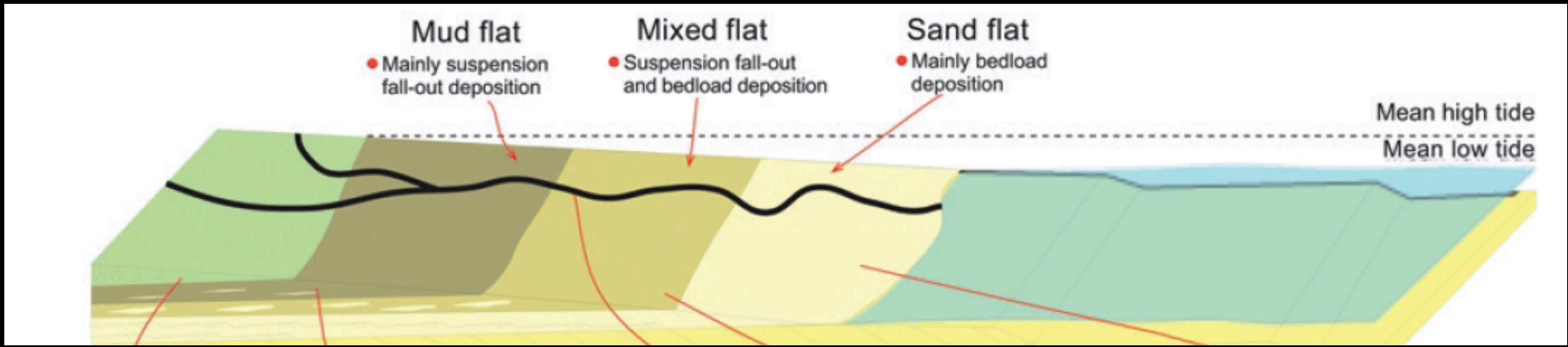
Settling lag (more tidal cycles)

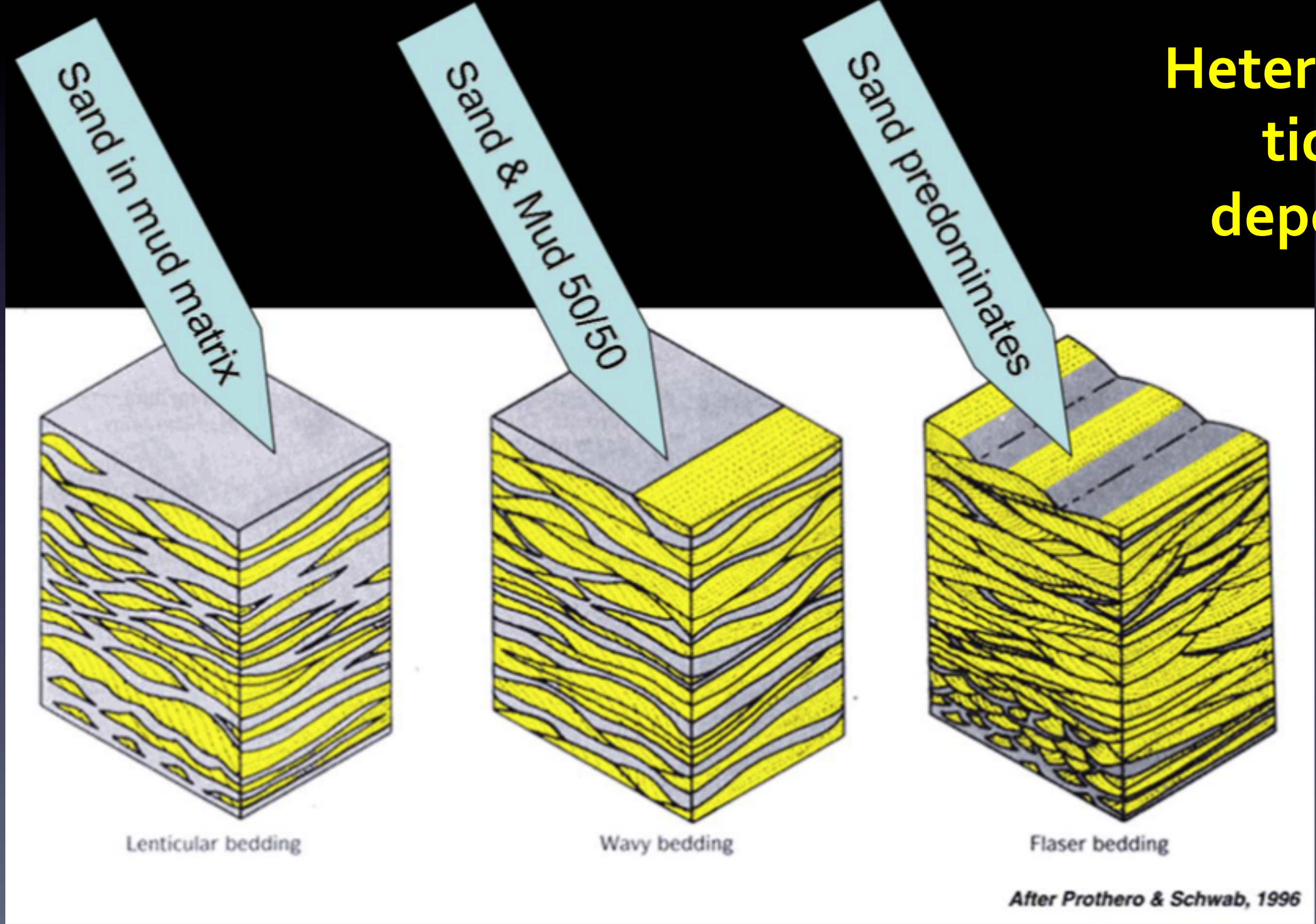




Supratidal zone
Intertidal zone
Subtidal zone
Land
Salt marshes
Mid-upper intertidal
Lower Intertidal (bare flat)
(a)
High Tide
Landward
Sea
Low Tide
Seaward
(b)
(c)
(d)
(e)
After Zhao et al., 2019
Remote Senting, 11 (20), 2426.
Asio Flammeus
Exceptional high tide
Phragmites Australis
Normal high tide
Normal low tide
Saltwater Cordgrass
Anser anser
Vanellus vanellus
Ardeacinerea
Festuca Rubra
Aster Tripolium
Microscopic Algae
Clam
WormMud Snails
Zostera Spp
Dike or dune
High Marsh
Reached by salt spray and very high tides
Low Marsh
Under water at normal high tide
Pioneer zone
Unvegetated intertidal mudflat

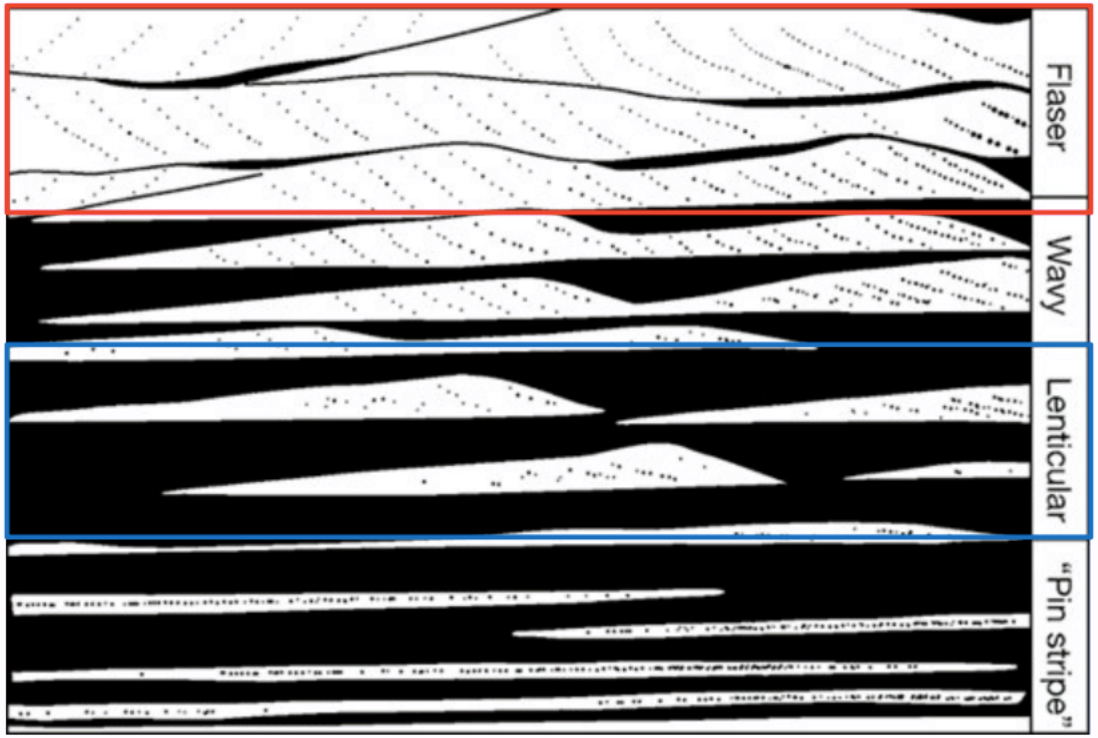
Heterolithic tidal deposits



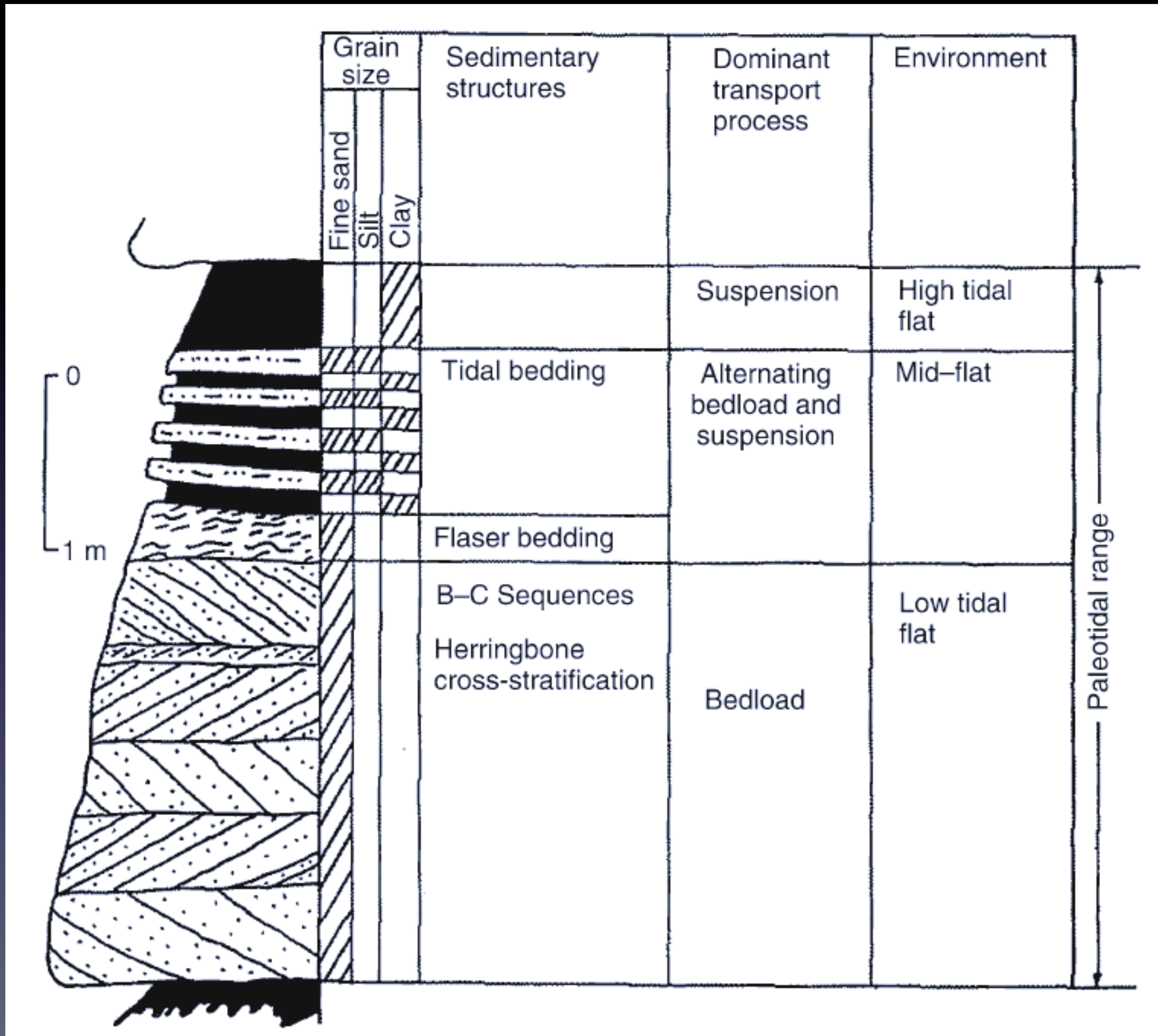


Heterolithic tidal deposits

Gradation from flaser bedding (rippled sand with mud drapes) to lenticular bedding (isolated sand ripples in mud) as grain size fines and energy decreases

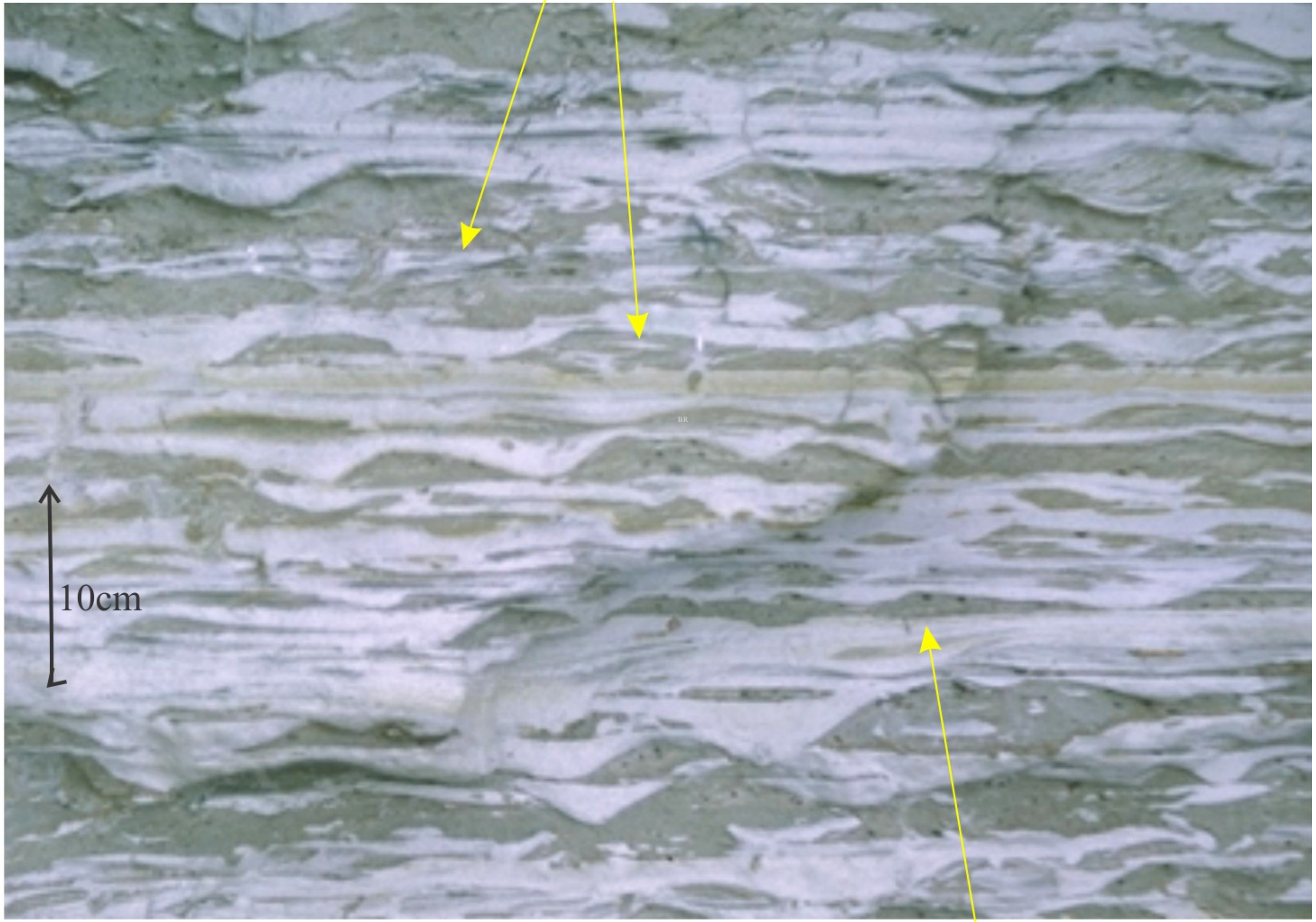


General scheme



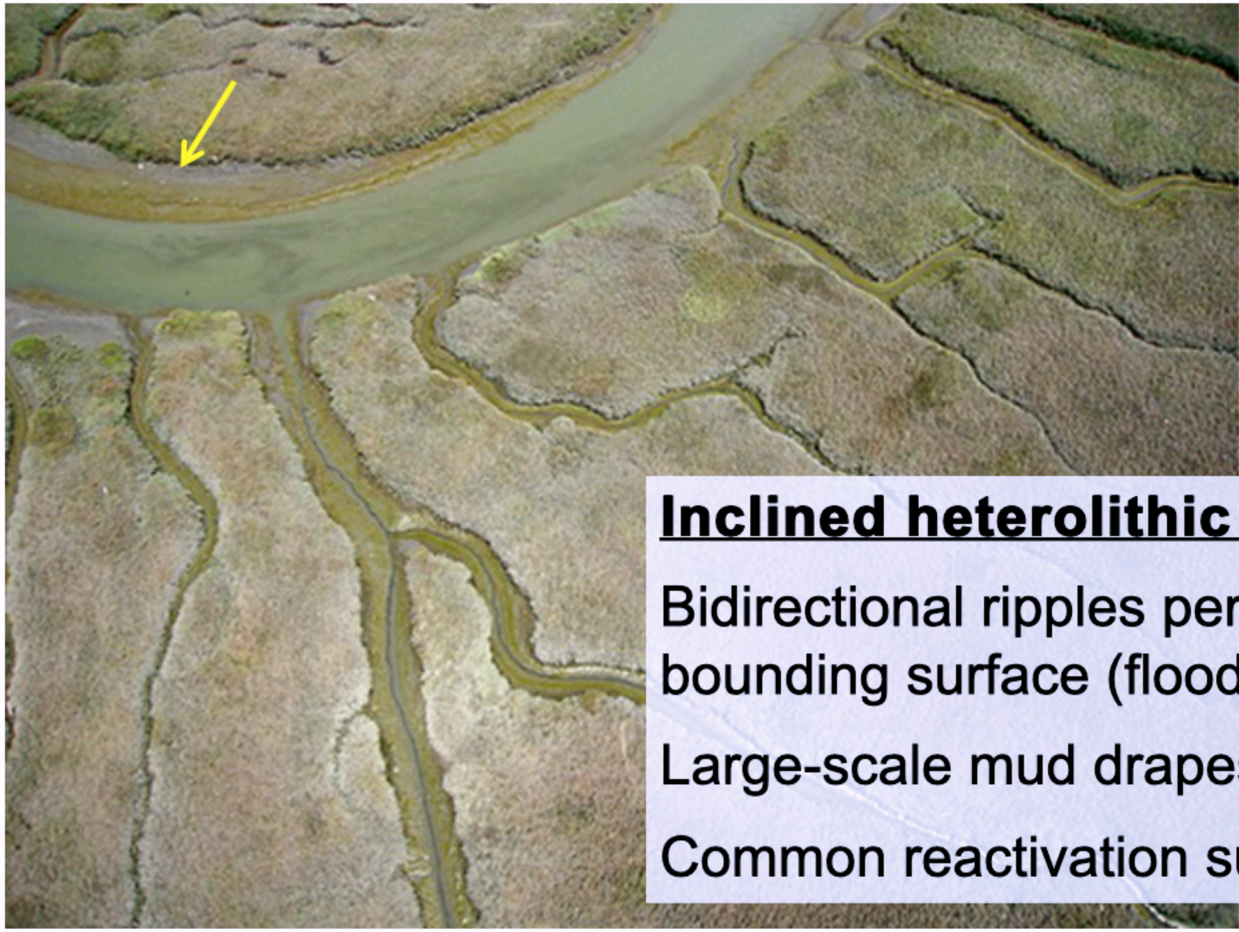
Lenticular and flaser bedding, commonly structures indicative of tidal flat and shallow subtidal environments. Dark colours are sand; light greys mud. Pleistocene, Ihumatao, New Zealand.

Flaser bedding, commonly manifested as mud drapes over sand ripples



Lenticular bedding - sand ripples, commonly isolated within mudstone host

Tidal channels have point bars with lateral accretion similar to meandering f



Inclined heterolithic stratification (IHS):

Bidirectional ripples perpendicular to bounding surface (flood and/or ebb stage)

Large-scale mud drapes (slack-water stage)

Common reactivation surfaces

Inclined heterolithic stratification (IHS)

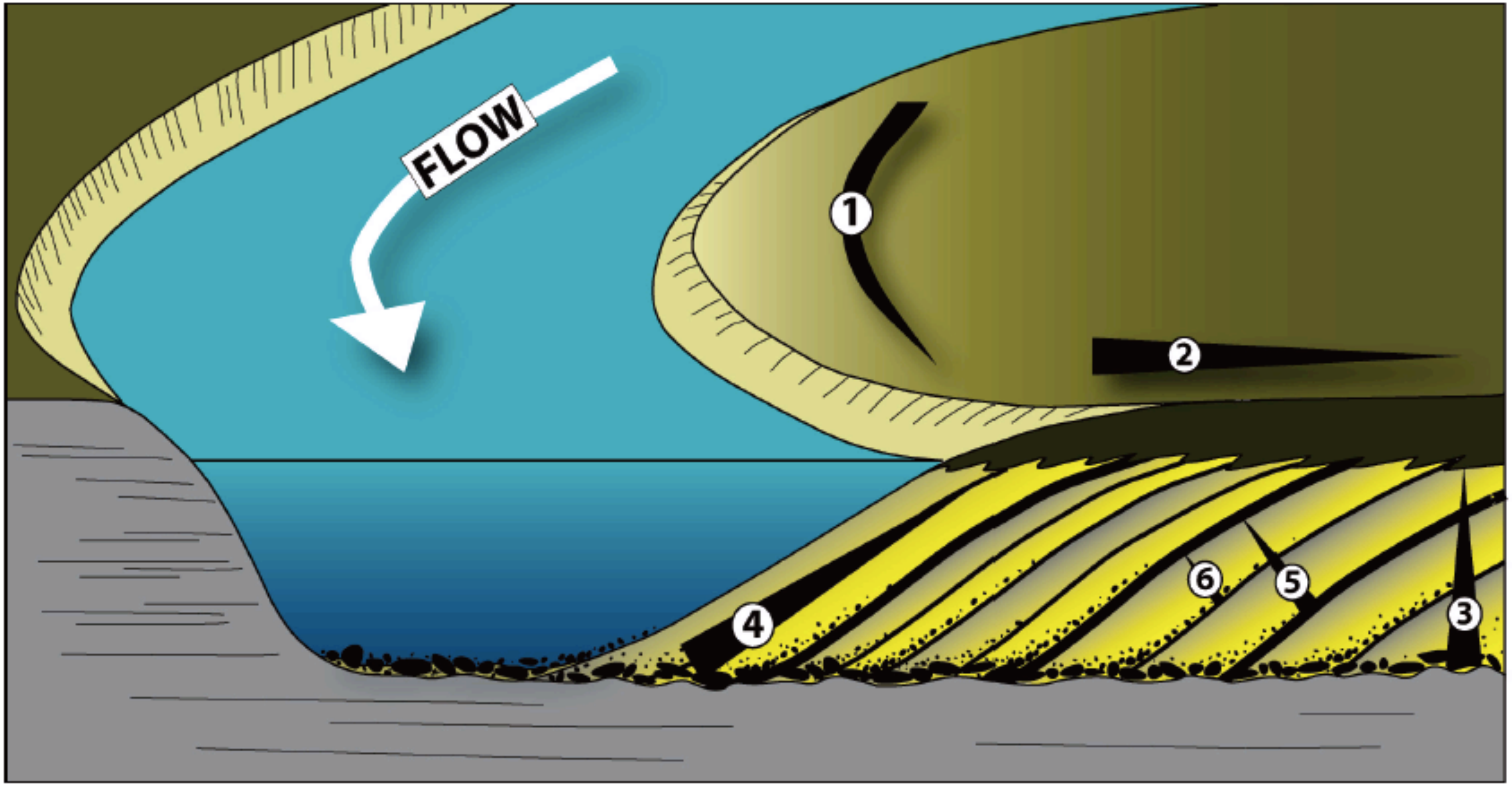
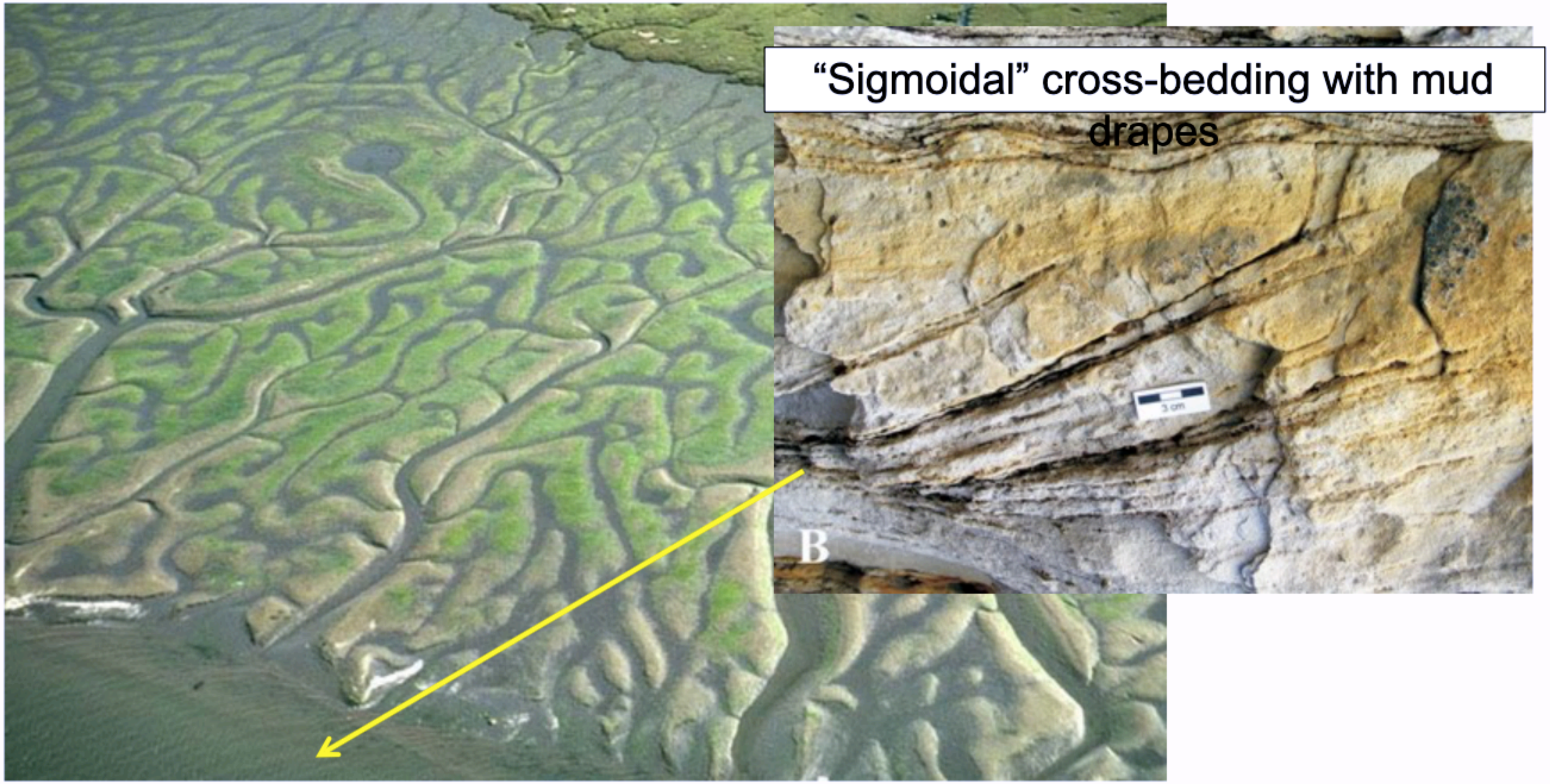


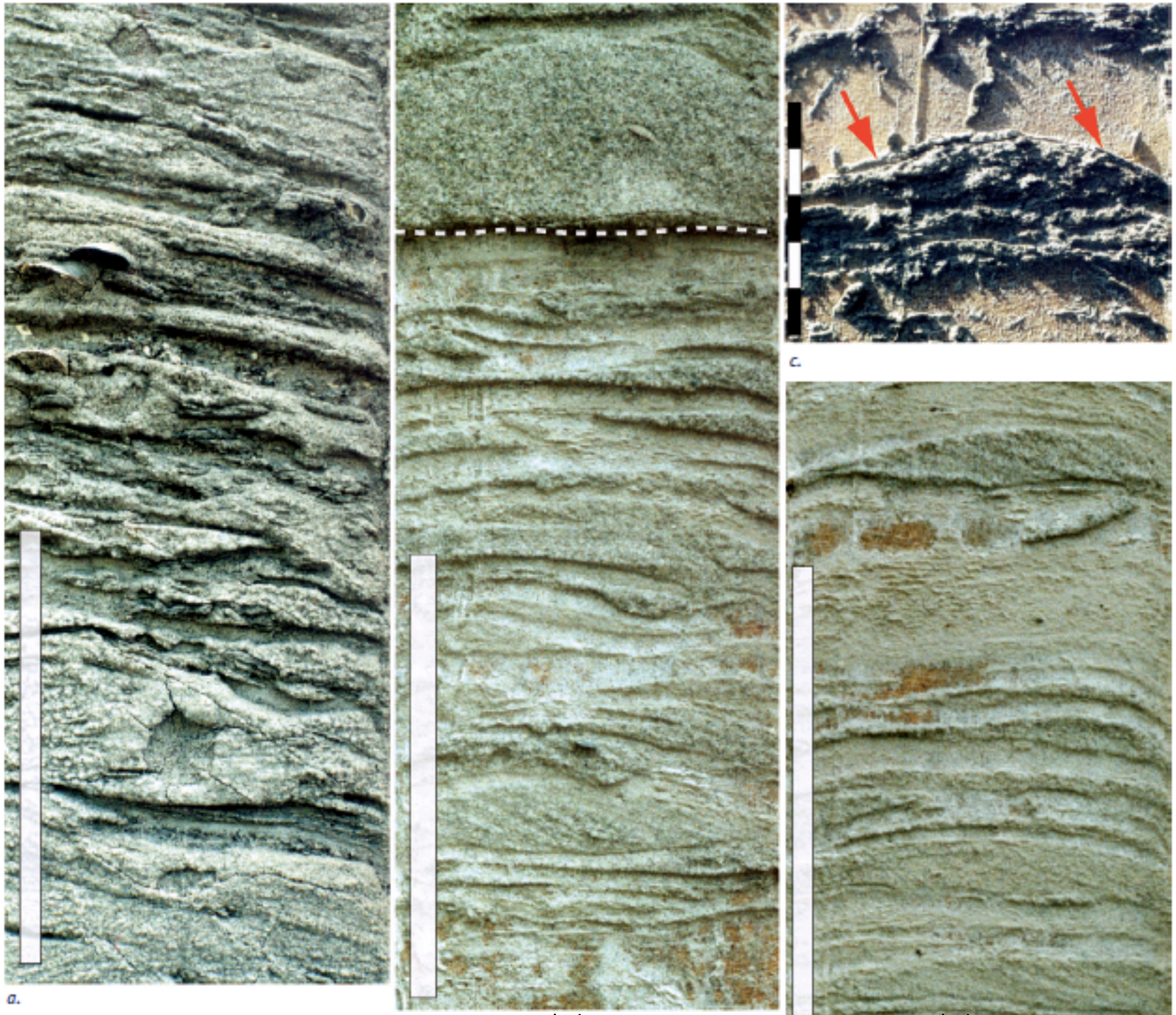
Figure 1.4 Schematic illustration of a hypothetical point bar showing six possible grain-size fining trends associated with IHS deposits. **1)** Along-strike (down-flow) proximal-to-distal fining; **2)** Lateral fining (away from channel) into an overbank sequence; **3)** Overall vertical fining upward; **4)** Up-dip fining within individual inclined beds; **5)** Fining of coarse-grained beds of successive inclined units, perpendicular to inclined bounding surfaces; **6)** Fining perpendicular to inclined bounding surfaces within individual beds. Modified by Stephen Hubbard after Thomas et al. (1987).

[redacted]

Higher-energy in subtidal channels leads to larger dune cross-bedding (but still bidirectional or frequently containing mud drapes)



Sand-dominated heterolithic deposits

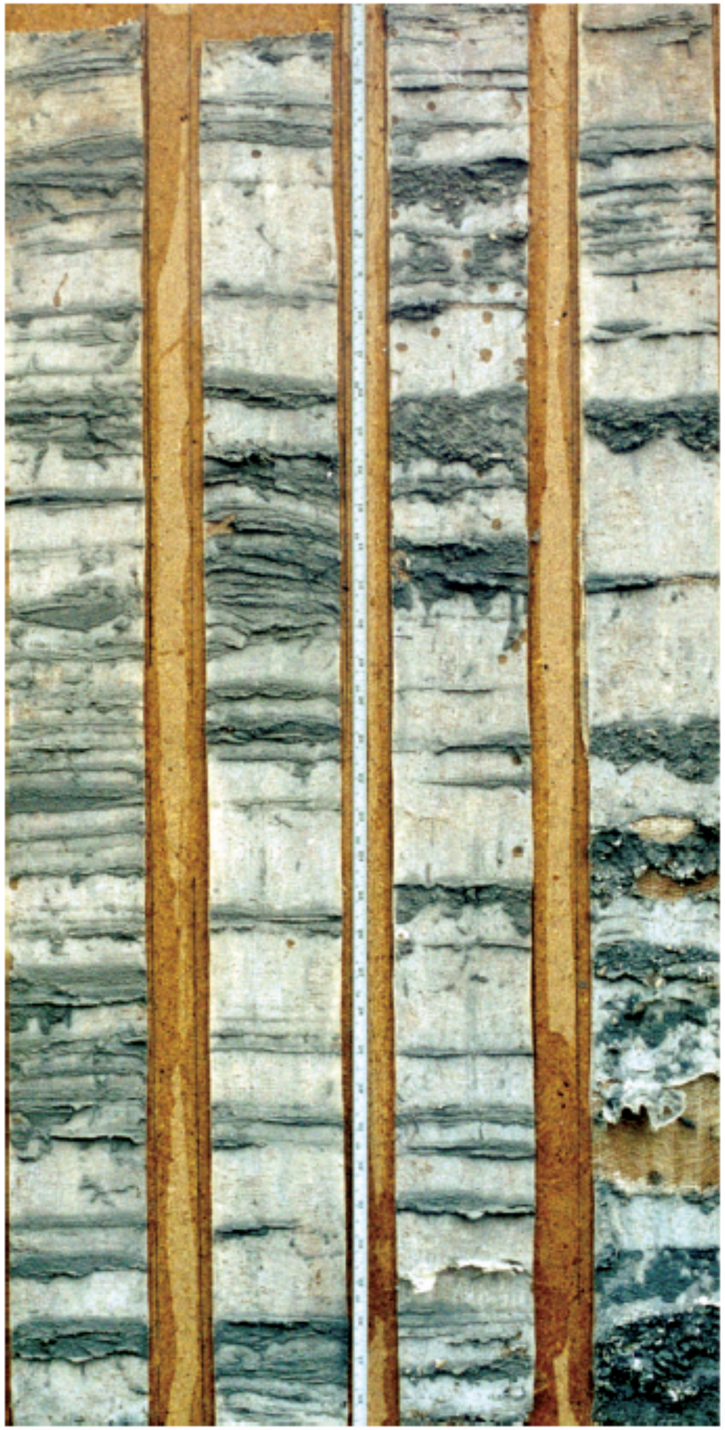


Scale bar 10 cm

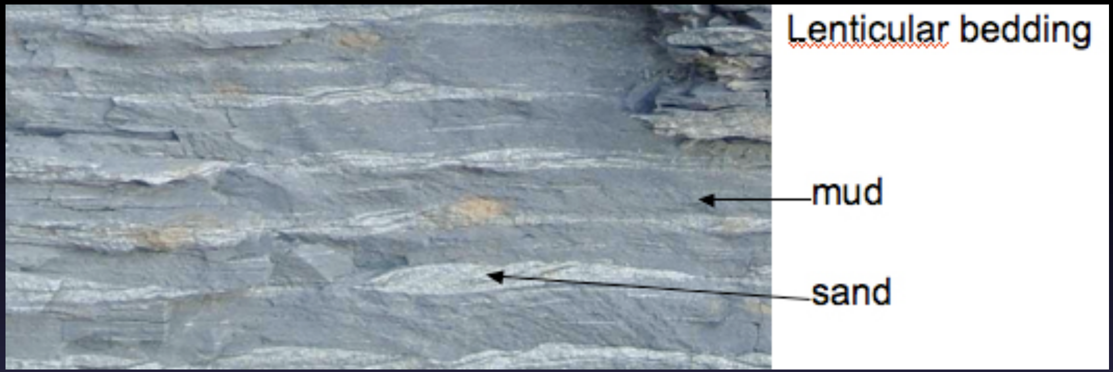
Scale bar 10 cm

Scale bar 5 cm

Donselaar & Geel (2007) Geologie en Mijnbouw 86 – 4: 389 – 402

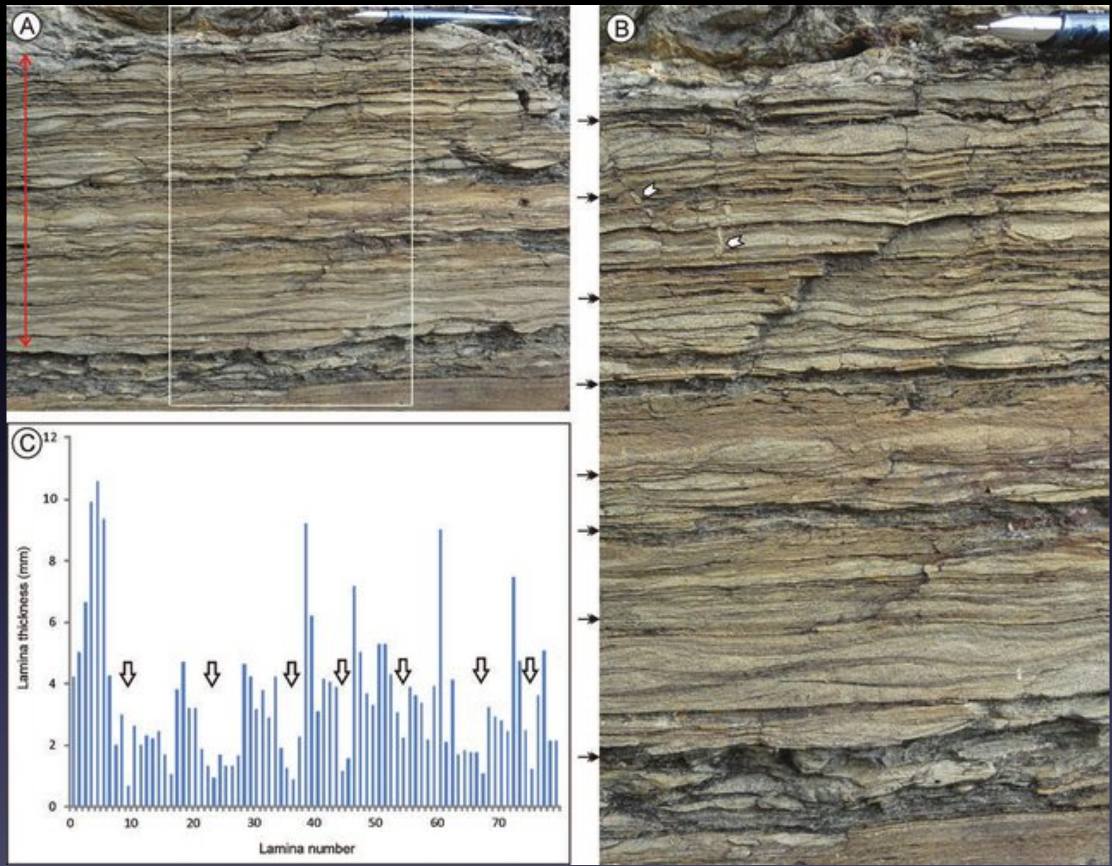


Mud-dominated heterolithic deposits



Donselaar & Geel (2007) Geologie en Mijnbouw 86 – 4: 389 – 402

Tidal cyclicity

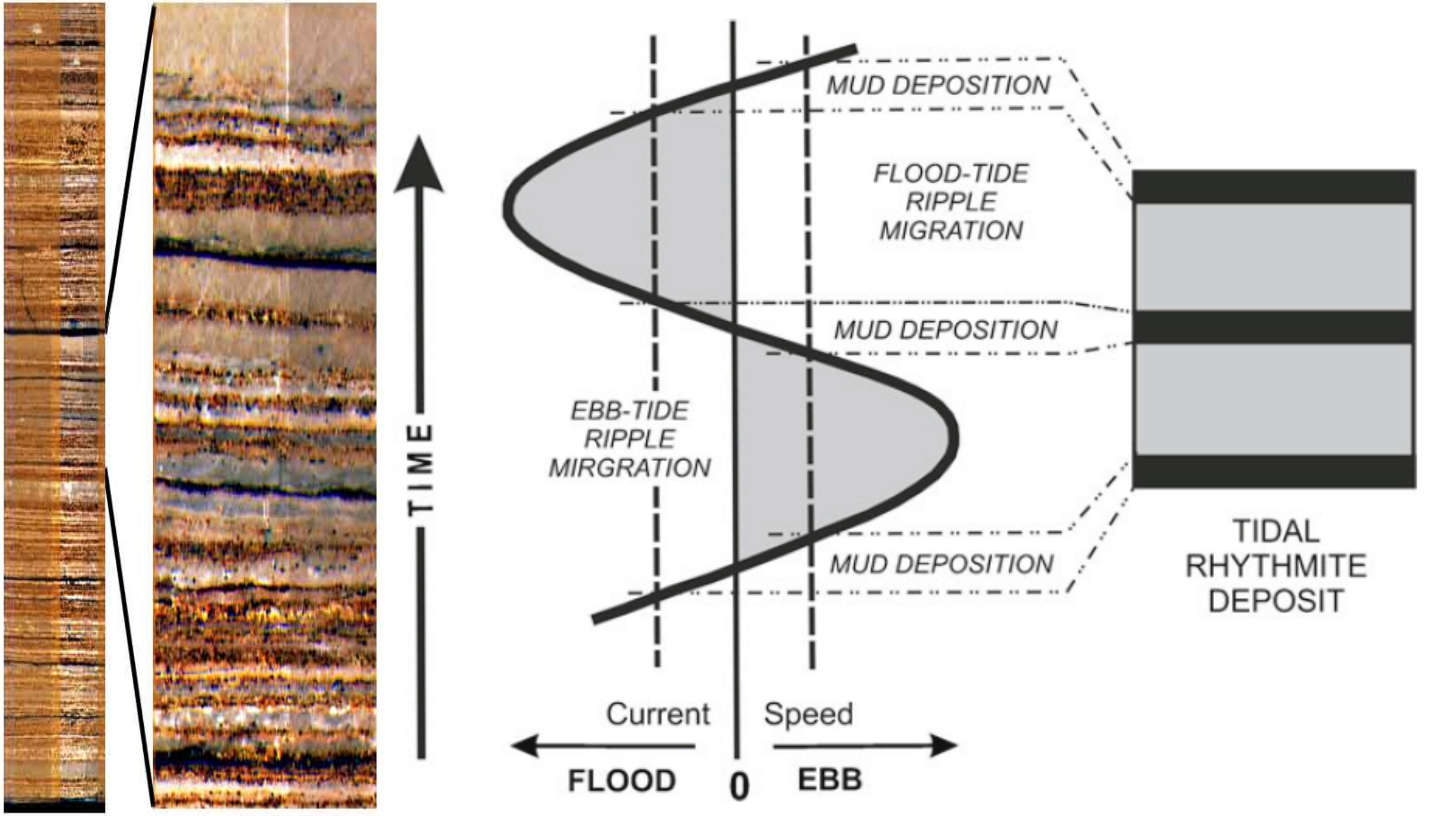


A) Flaser, wavy and lenticular bedding within IHS. Note the rhythmic variations in type of bedding and thicknesses of sandstone -mudstone couplets. The ripple cross stratification indicates palaeocurrents directions towards the left.

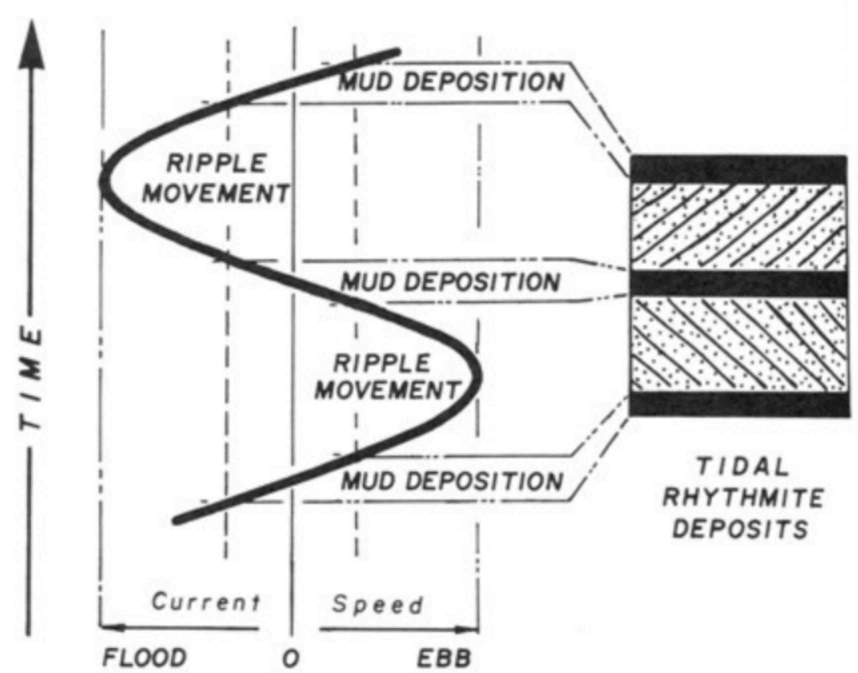
B) Detail of sandstone-mudstone couplets shown in A. The black arrows point to the thinner couplets

(C) Plot of thicknesses of the couplets in A and B. Note the rhythmic variations, interpreted as probable tidal cyclicities. Arrows indicate probable neap-stage couplets.

Tidal rhythmites



Bidirectional paleocurrent indicators (especially cross-stratification) are diagnostic of tidal deposition

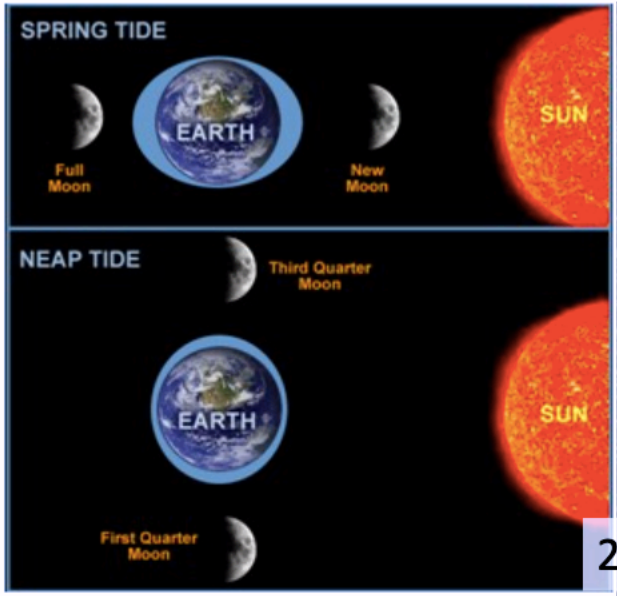


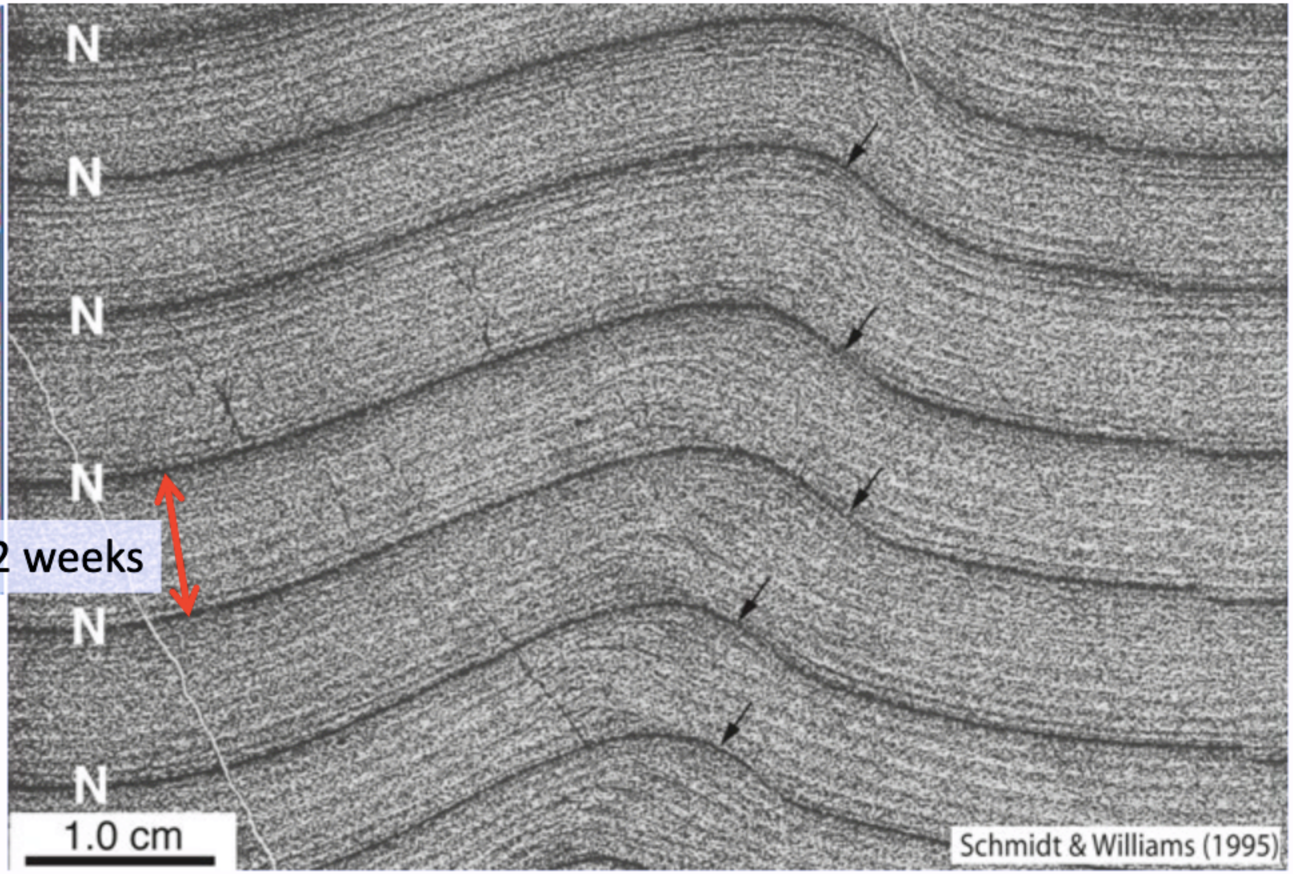
Herringbone cross-stratification

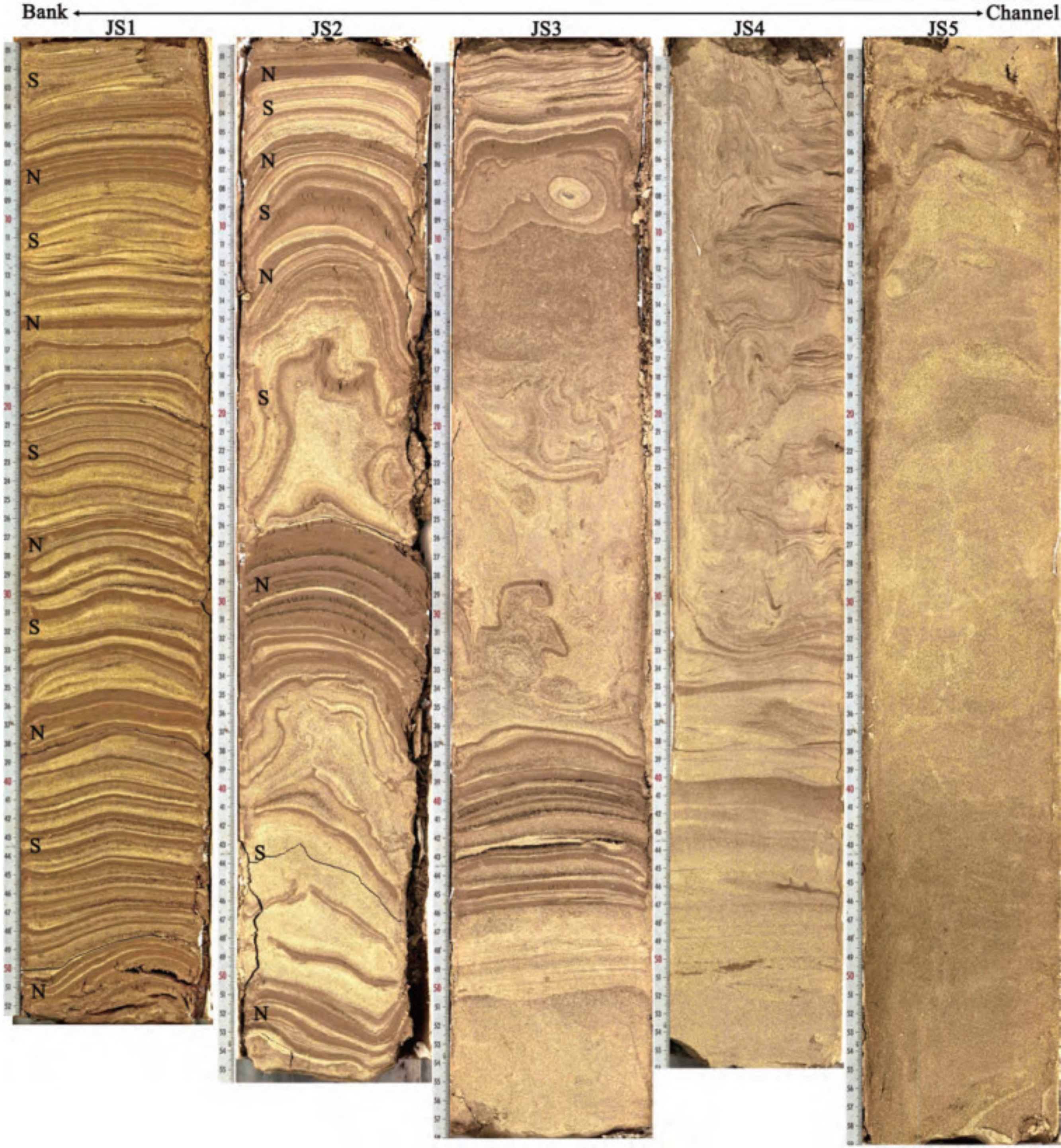
Flood current: tide going in
Ebb current: tide going out

Spring-neap cyclicity

Tidal rhythmites showing spring / neap cyclicity (Ediacaran,



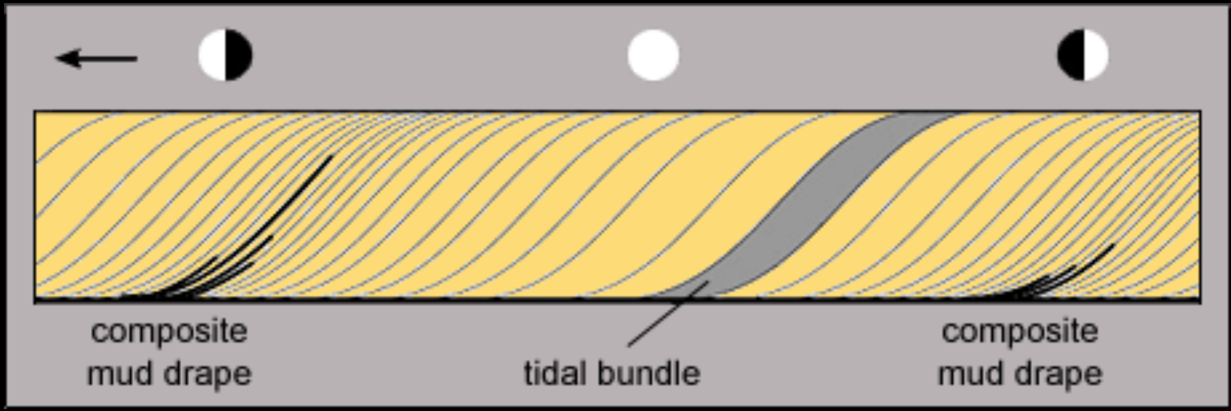


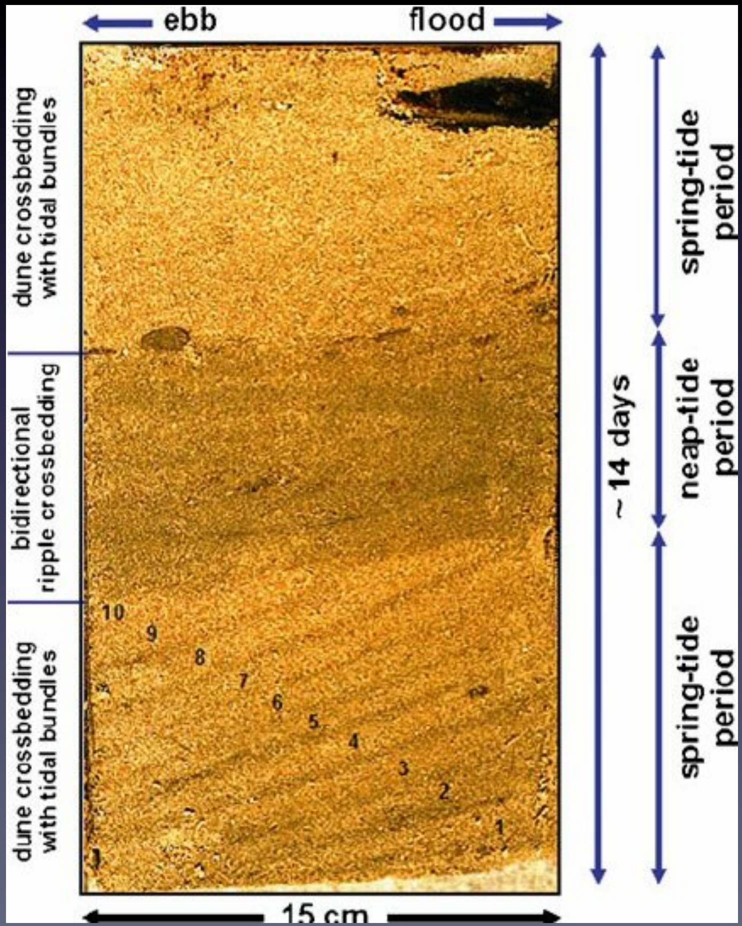


Series of photos of short cores collected from Jianshan tidal-flats along the north bank of the Qiantang Estuary showing cross-shore change in cyclic tidal rhythmites at the higher intertidal flats to massive tidal-bore deposits at the lower intertidal flats (N: neap tide, S: spring tide).

After Daidu (2013) J. of Paleogeography, 2(1): 66-80.

Tidal bundle





A tidal bundle sequence can be seen as a variation in bed thickness with a periodicity of 14 days (diurnal) or 28 days (semidiurnal).

During the neap tide, when the tidal current strength is weakest, smaller quantities of finer grains are deposited.

As the tidal variation grows larger, towards the spring tide, larger quantities of coarser material will be deposited which results in an increasing bed thickness.

Bed thickness will be greatest at the spring tide and then decreases as the tidal variation grows smaller, towards the neap tide again and the thinnest beds.

Tidal bundle