10. Siliciclastic Marine Environments

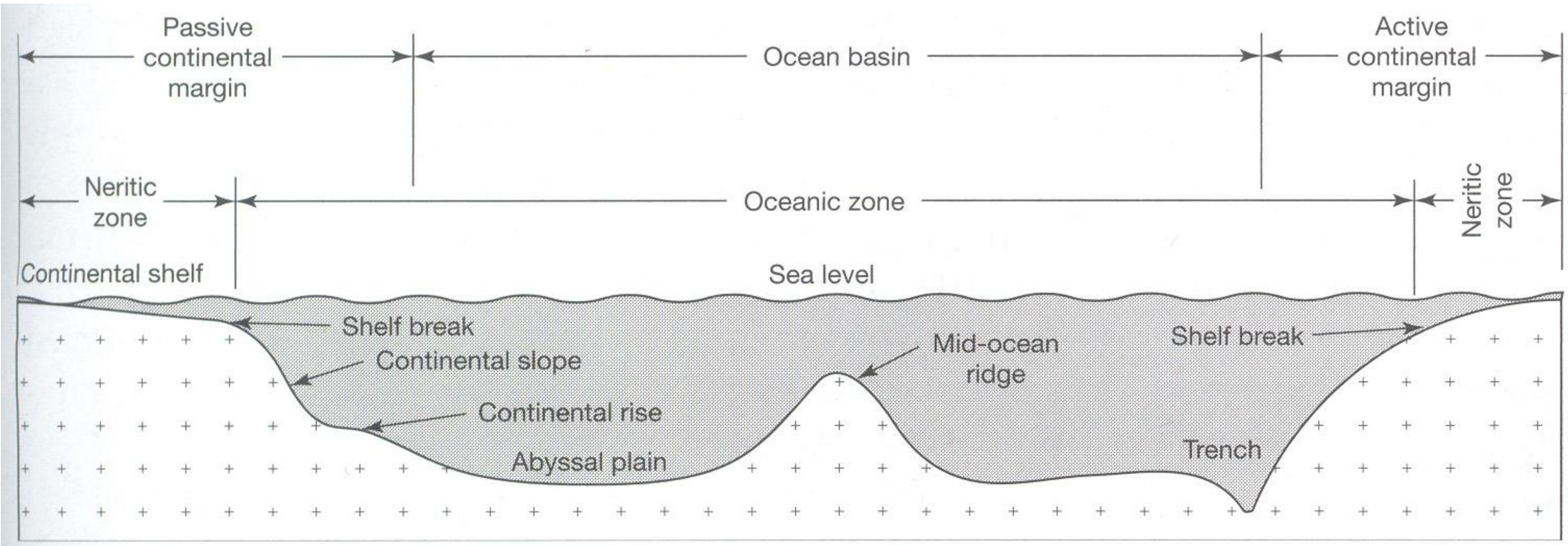


Figure 10.1
Schematic cross-sectional profile of the marine environment. Not to scale.

10. Siliciclastic Marine Environments

10.1 **Introduction**

10.2 **The Shelf Environment**

- Physiography and depositional setting
- Shelf sediment transport and deposition
- Wave- and storm-dominated shelves
  - Fair-weather waves
  - Swells, storm waves, and wind-forced currents
  - Sediment plumes
  - Nepheloid (渾濁) flows
  - Sediment characteristics of storm-dominated shelves
- Tide-dominated shelves
  - Tidal processes
  - Sediments of tide-dominated shelves
- Shelves affected by intruding ocean currents
- Ancient siliciclastic shelf sediments

10.3 The Oceanic (deep-water) Environment

- Depositional setting
  - Continental slope
  - Continental rise and deep ocean basin
- Transport and depositional processes to and within deep water
  - Sediment plumes, wind transport, ice rafting, nepheloid transport
  - Currents in canyons
  - Contour currents
  - Pelagic rain
  - Explosive volcanism
  - Turbidity currents and other mass-transport processes
- Principle kinds of modern deep-sea sediments
  - Terrigenous sediments
    - hemipelagic muds
    - turbidites
    - contourites
    - glacial-marine sediments
    - slump and slide deposits
  - Pelagic sediments
  - Chemical sediments
- Ancient deep-sea sediments

10.2 The Shelf Environment

Physiography and depositional setting

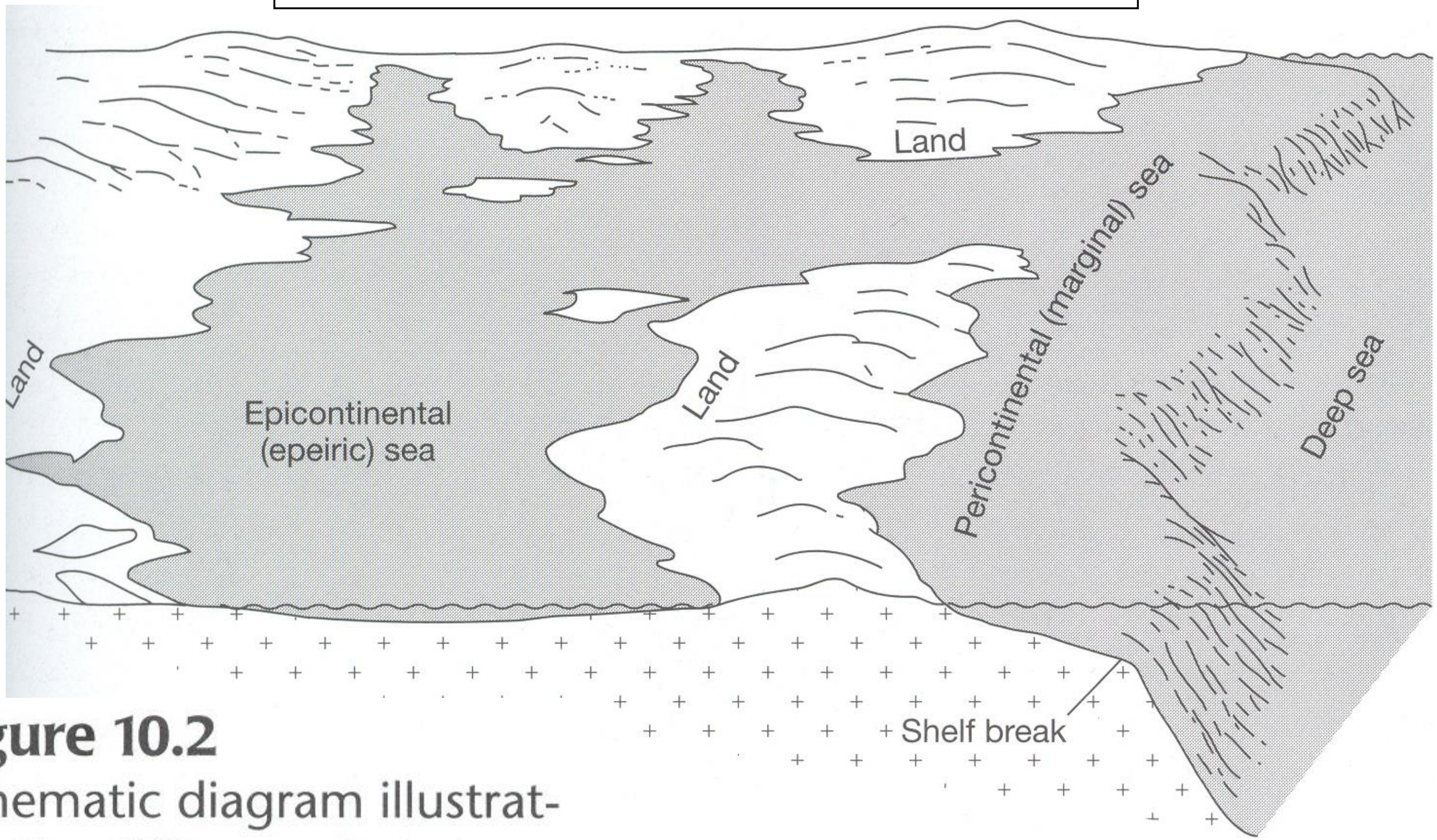
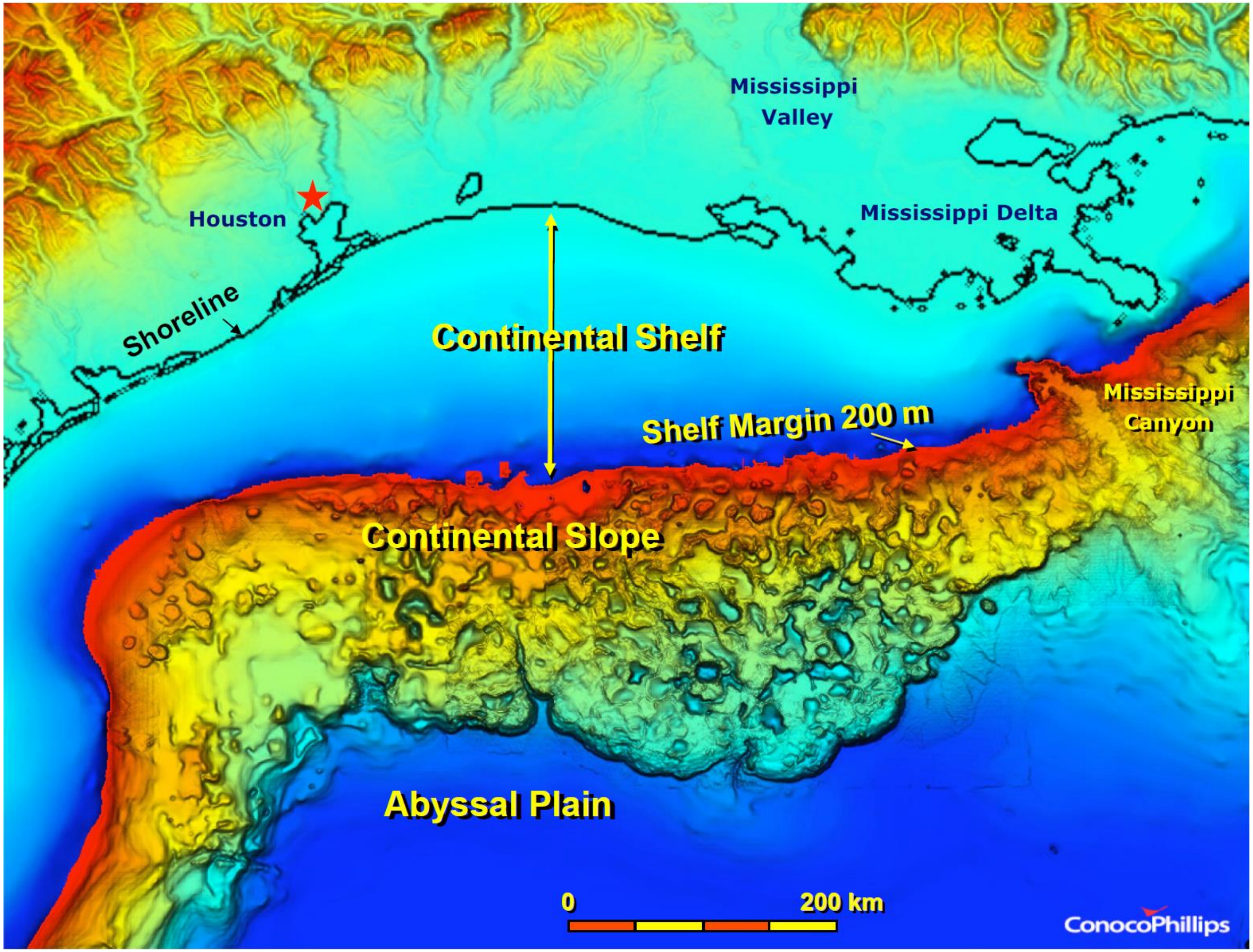


Figure 10.2
Schematic diagram illustrating the difference between pericontinental (continental shelf) and epicontinental shallow-marine environments. [After Heckel, P. H.,

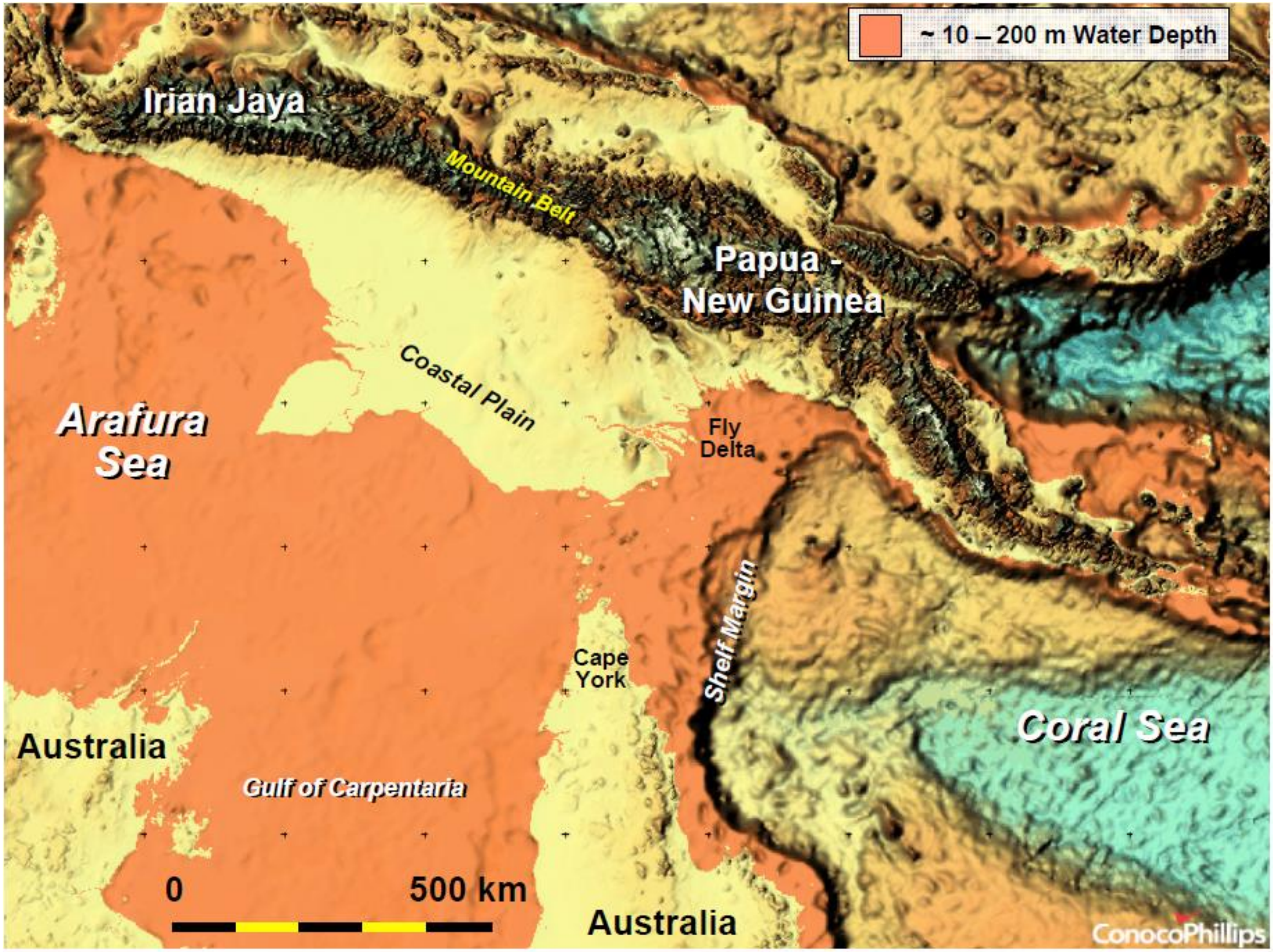
Pericontinental (marginal) sea



The Gulf of Mexico is an excellent example of a submerged continental margin, or pericontinental clastic shelf. Shelves of this kind are the most common today. The continental shelf extends from just seaward of the shoreline to the shelf margin, which lies just landward of the 200 m contour indicated. The rugose topography of the continental slope in this area is the result of extensive salt tectonics.

Posamentier & Walker (2006)

Epicontinental sea



The Arafura Sea between Australia and Papua New Guinea–Irian Jaya is a good modern example of an epicontinental sea. A shelf margin does exist eastward of the Fly Delta and the York Peninsula, but westward a broad, submerged continental platform extends some 1000 km to the Indonesian island arc.

Posamentier & Walker (2006)

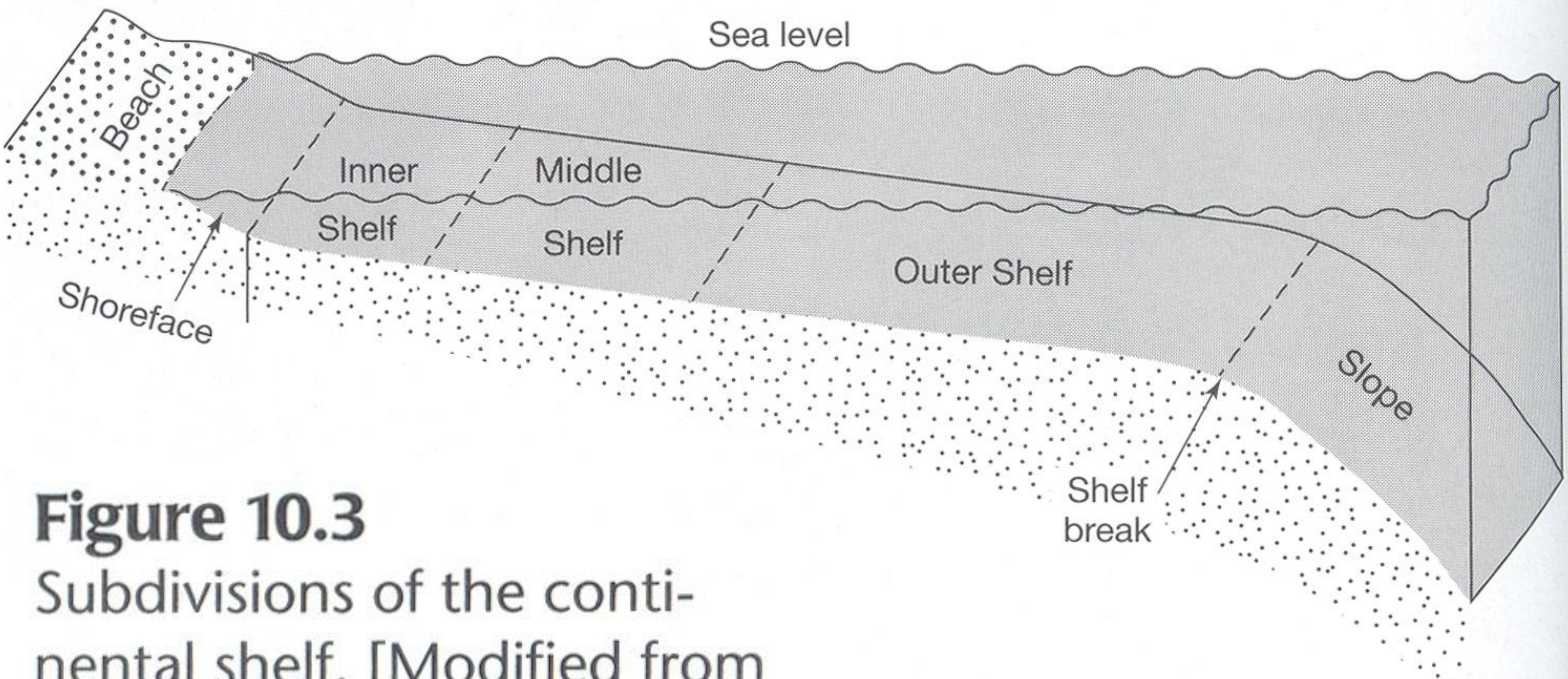


Figure 10.3
Subdivisions of the continental shelf. [Modified from

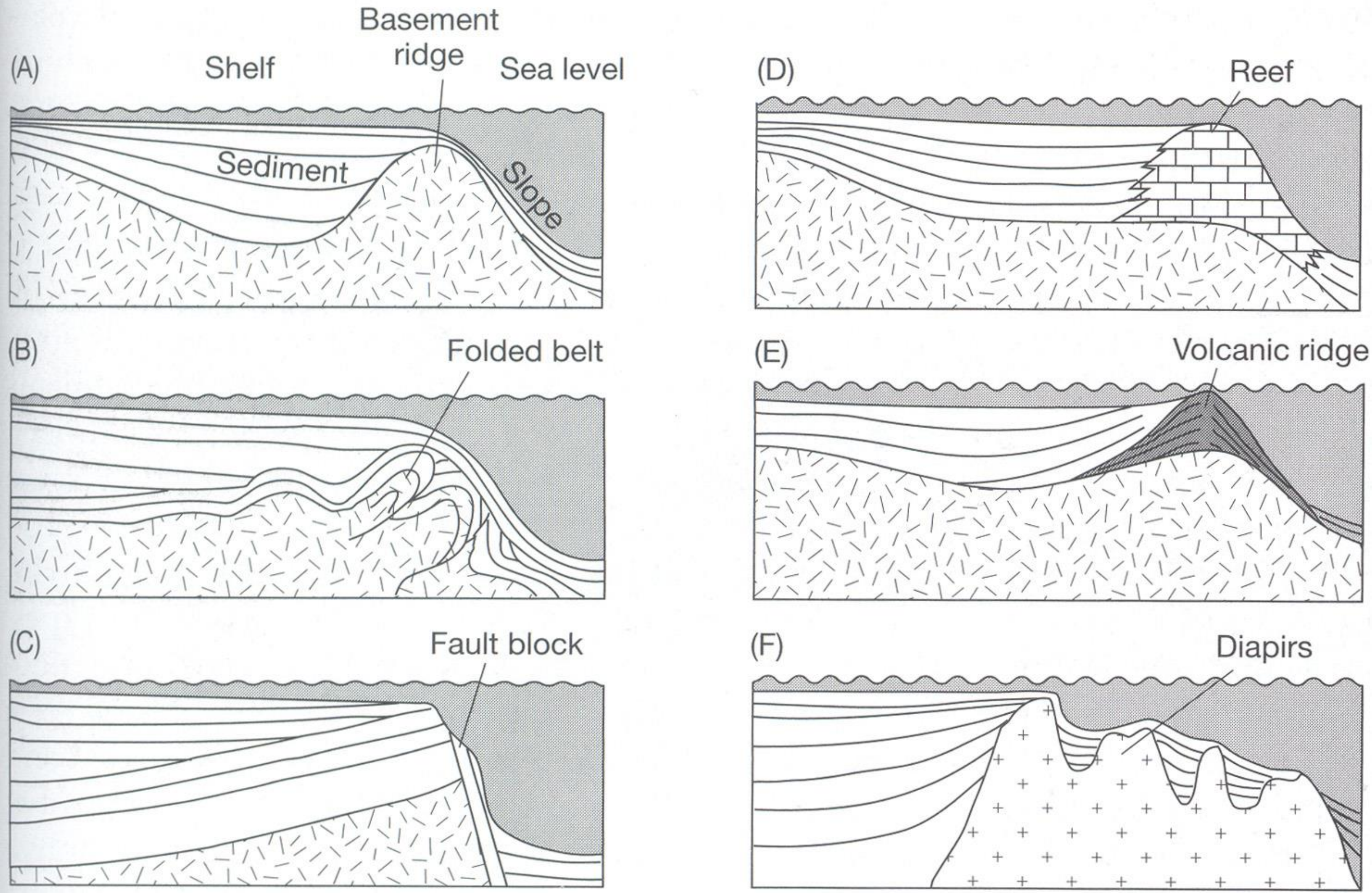


Figure 10.4
Various kinds of structural barriers that form the seaward margins of continenta shelves. [After Hedberg, H.

Shelf sediment transport and deposition

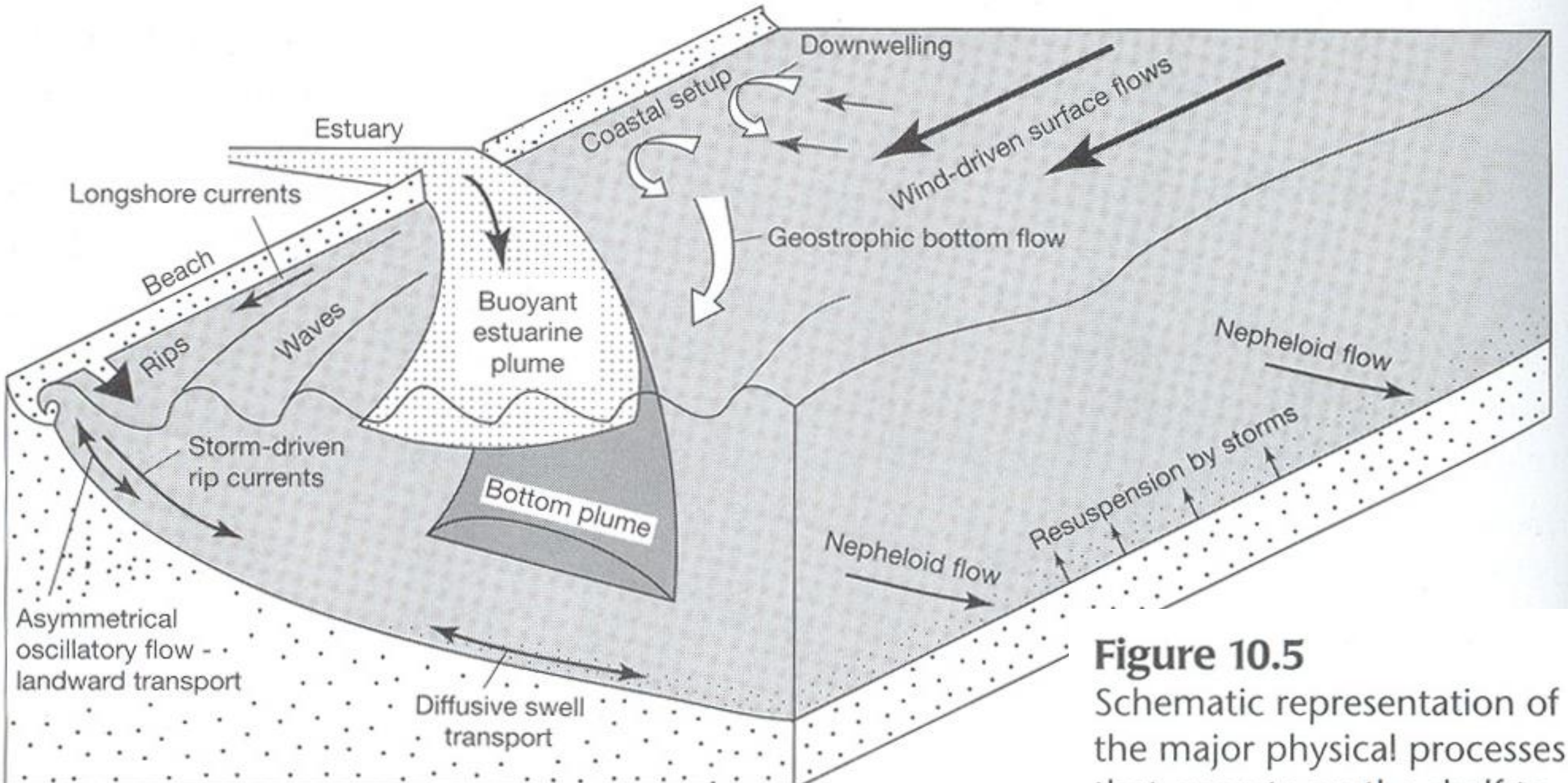
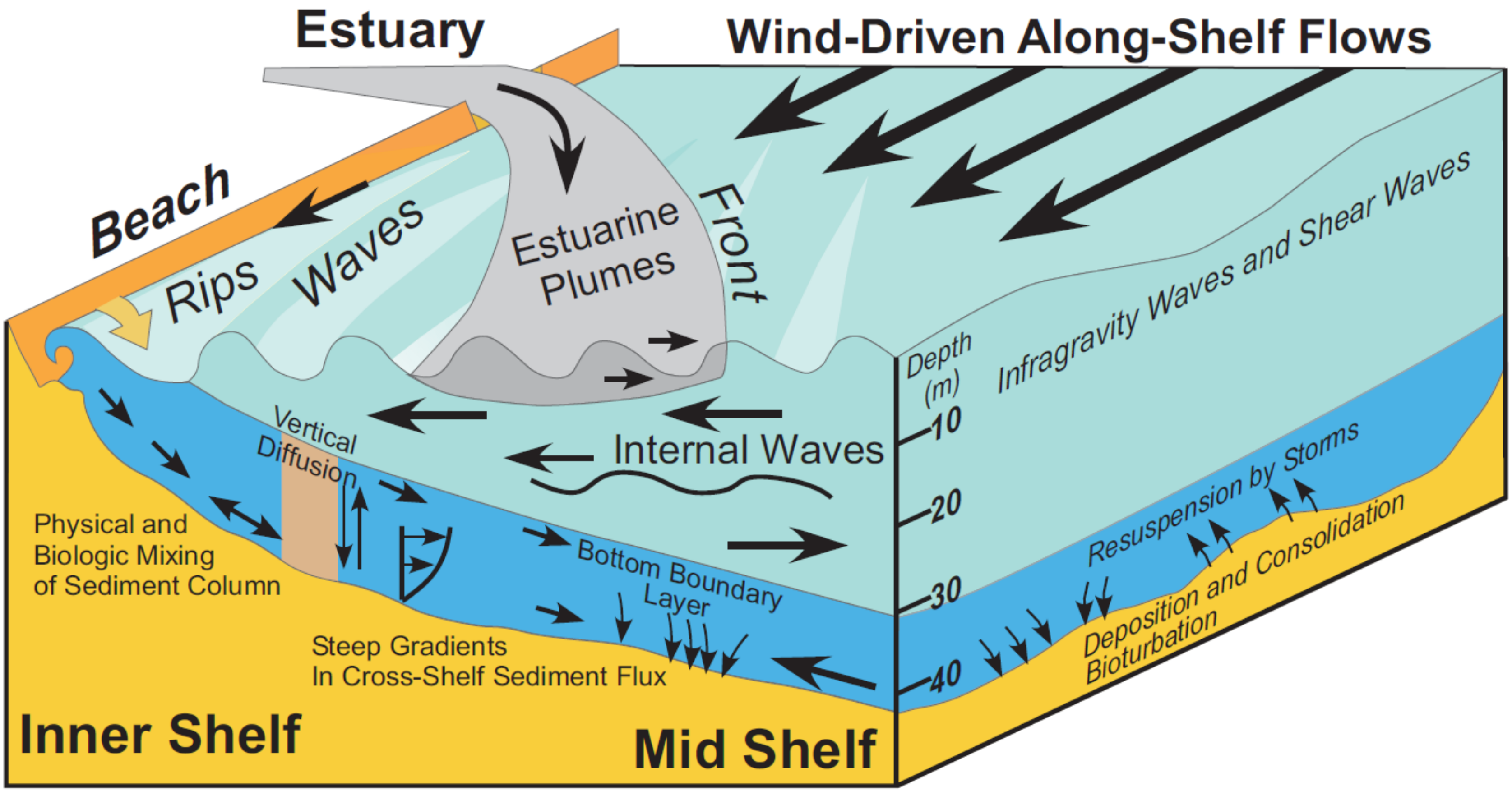


Figure 10.5
Schematic representation of the major physical processes that operate on the shelf to transport sediment. Based on Nittrouer and Wright, 1994; Swift et al., 1986; Swift and Thorne, 1991; and Vincent, 1986.



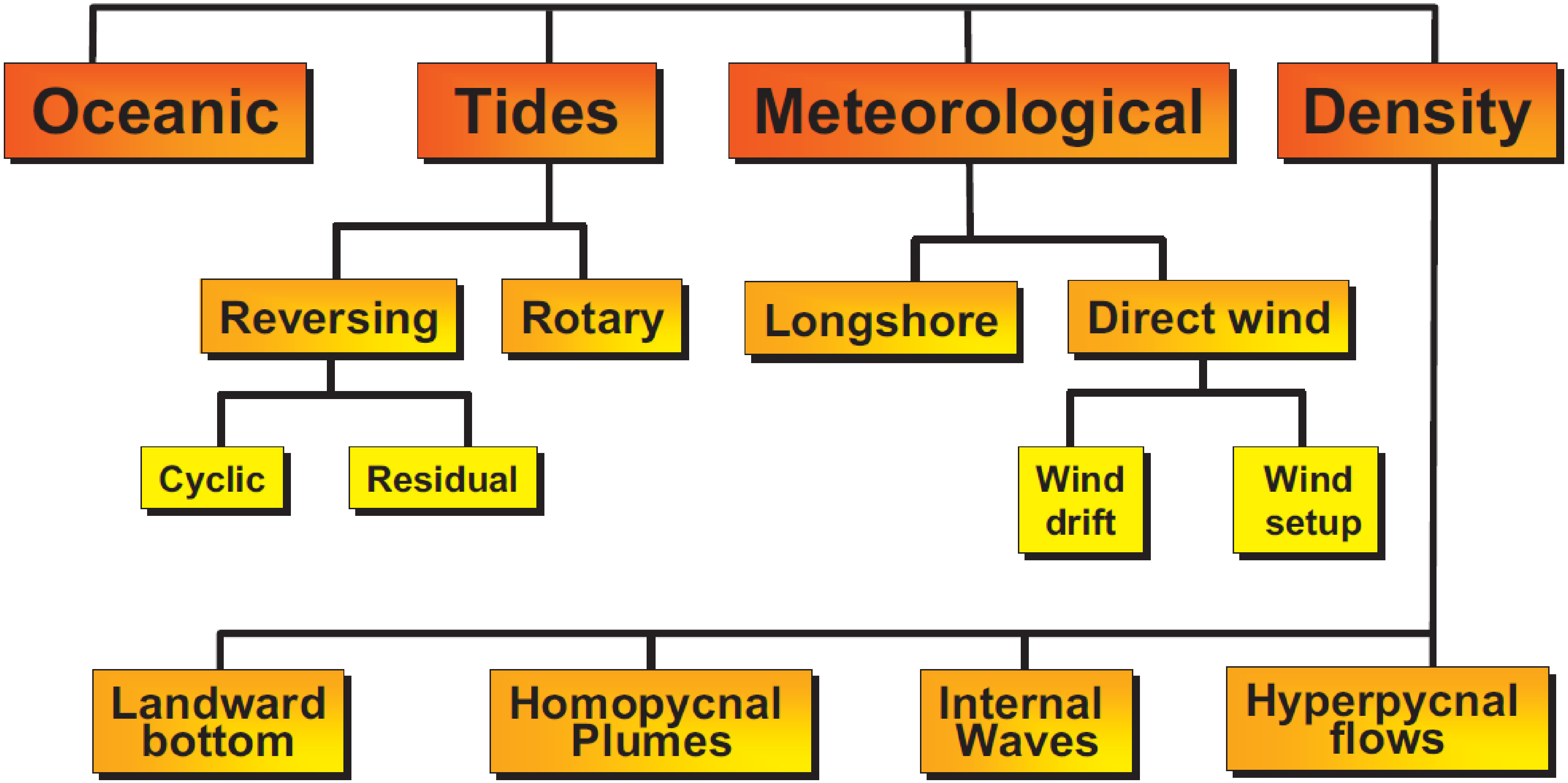
Block diagram illustrating the major physical processes influencing sediment transport and deposition on clastic shelves (redrawn from Nittrouer and Wright, 1994.)

Posamentier & Walker (2006)

Sediment plume from 卑南溪溪口
Note: plume deflected by oceanic currents toward the north and along the shore

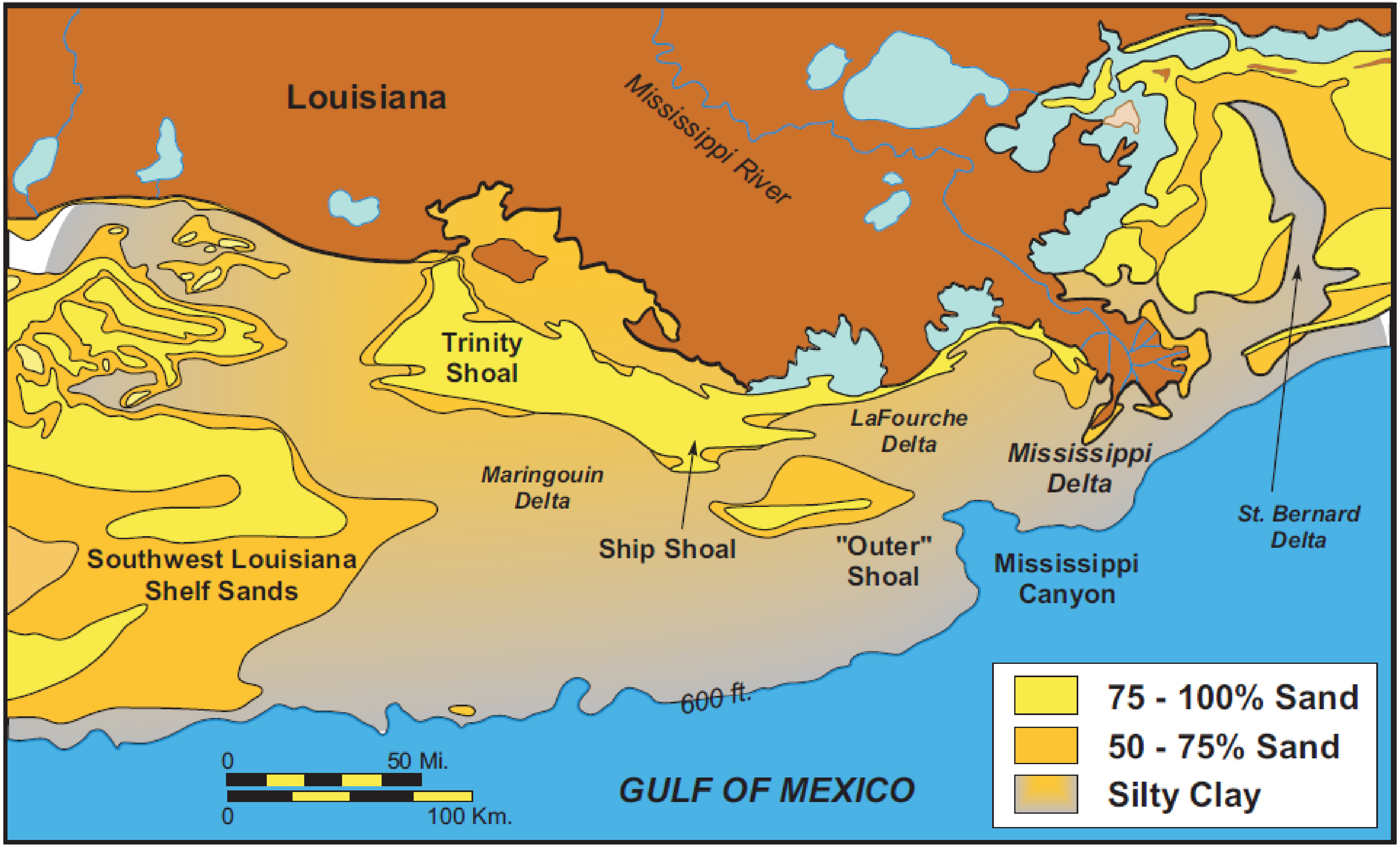
NASA MODIS satellite image , 1 March 2001, of the Mississippi delta and surrounding areas, northern Gulf of Mexico. Buoyant or hypopycnal sediment plumes issue from the deltaic distributaries in both the Balize and Atchafalaya complexes, as well as from several estuaries (e.g., Mobile Bay) along the coast.

Posamentier & Walker (2006)



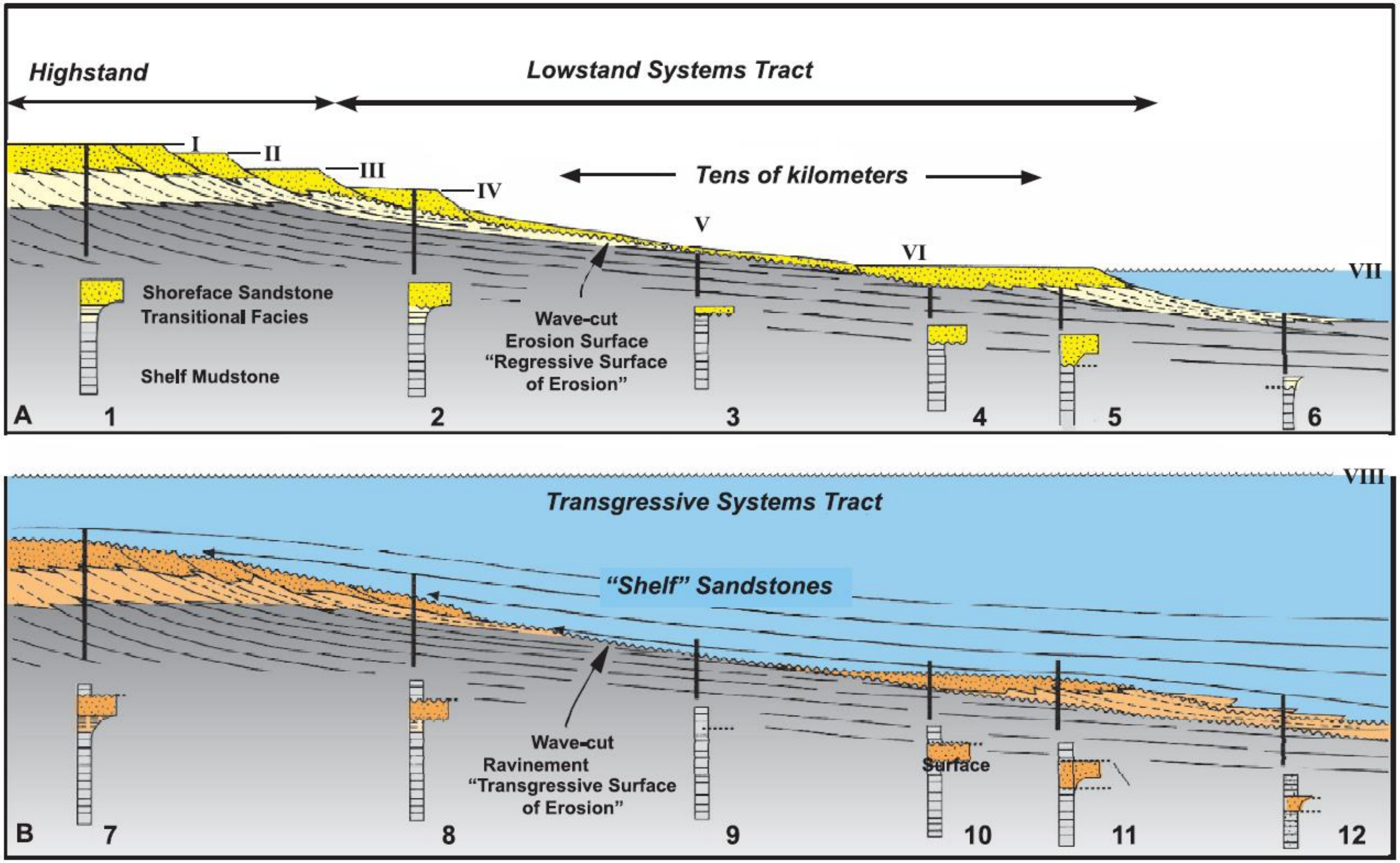
The dynamics of continental shelves can be quite complicated, owing to the interaction of the various components of the current field shown above. Ordinarily a given shelf is dominated by one process or another. All of the currents illustrated above combine with the Coriolis force caused by the earth's rotation to form *geostrophic* "balance of forces" currents

Posamentier & Walker (2006)



Distribution of surficial sediments on the Louisiana continental shelf of the northern Gulf of Mexico. Ship, Trinity, and the "Outer" Shoal are shelf sand bodies related to the transgression of abandoned Maringouin and LaFourche complexes of the Holocene Mississippi. East of the modern Mississippi Delta is another area of shelf sands, related to the transgression of the abandoned St. Bernard complex of the Mississippi Delta. The Southwest Louisiana shelf sands, and their extension into the waters off of East Texas, resulted from transgression of Pleistocene shoreline and coastal-plain deposits during the Holocene sea-level.

Posamentier & Walker (2006)



Generation of shallow marine sandbodies by fluctuations in sea level . **A)** Wavedominated shorelines form as part of a highstand systems tract (sea level I). Subsequent fall in base level causes "forced regression," forming a series of shoreface deposits at successively seaward positions (vertical profiles 2–3), creating "falling stage" and lowstand (profiles 4–6) systems tracts (Sea levels II–VII). At lowstand, a prograding shoreface is reestablished (sea level VII). **B)** Rising base level submerges the exposed coastal plain, expanding the continental shelf. Lowstand and falling-stage deposits are submerged and reworked by shoreface processes. The "ravinement surface" caused by shoreface erosion truncates underlying deposits (vertical profiles 7–12). In places, the transgressive erosion surface can be recognized only by an erosional surface overlain by a thin (centimeter scale) transgressive lag (e.g., thin pebble layer; vertical profile 9). Although not illustrated in this diagram, marine processes, including waves, tides, and currents, continue to rework the shoreline deposits into shelf sand bodies, as will be developed further in this chapter. Given sufficient sediment supply, shelf muds bury the earlier sand deposits.

Posamentier & Walker (2006)

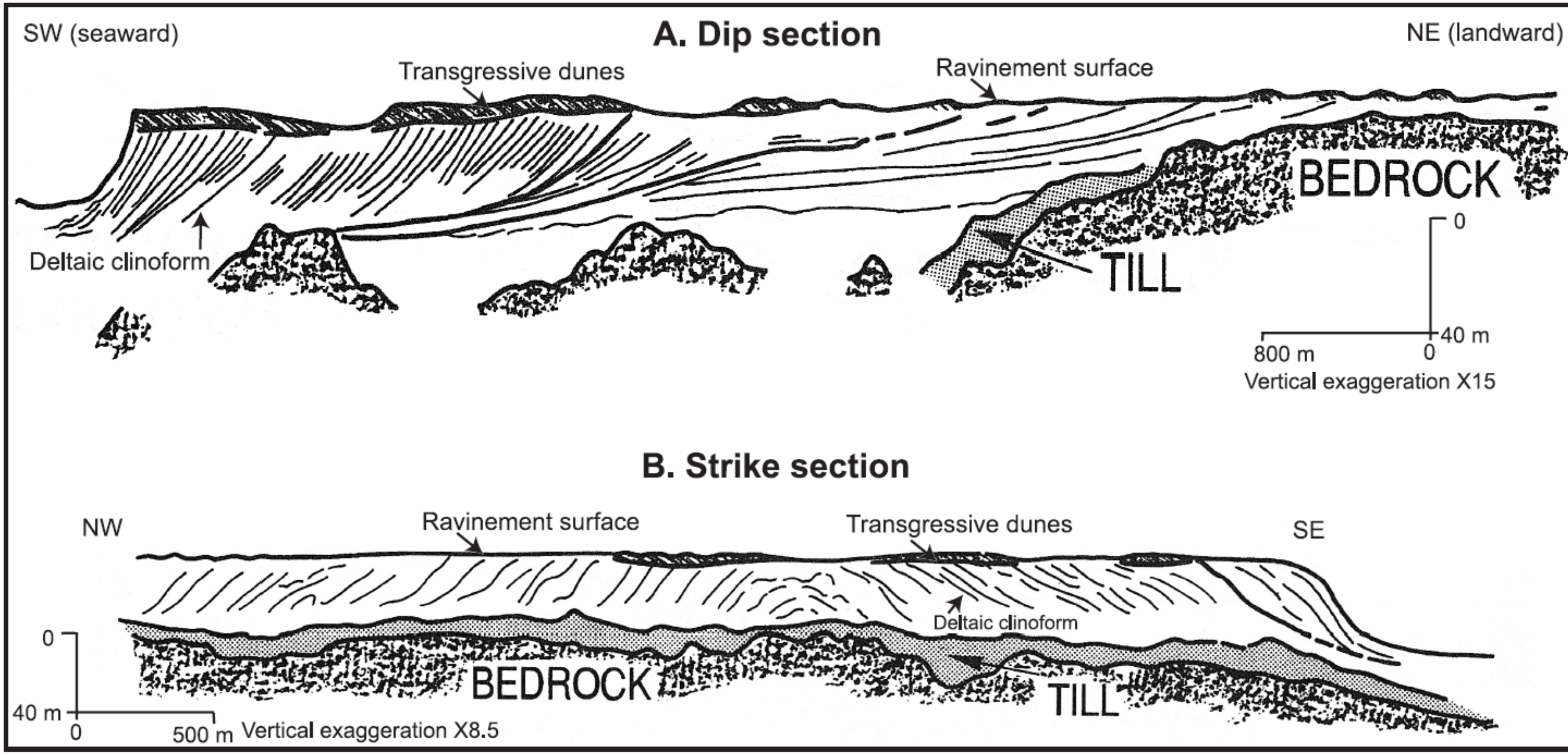
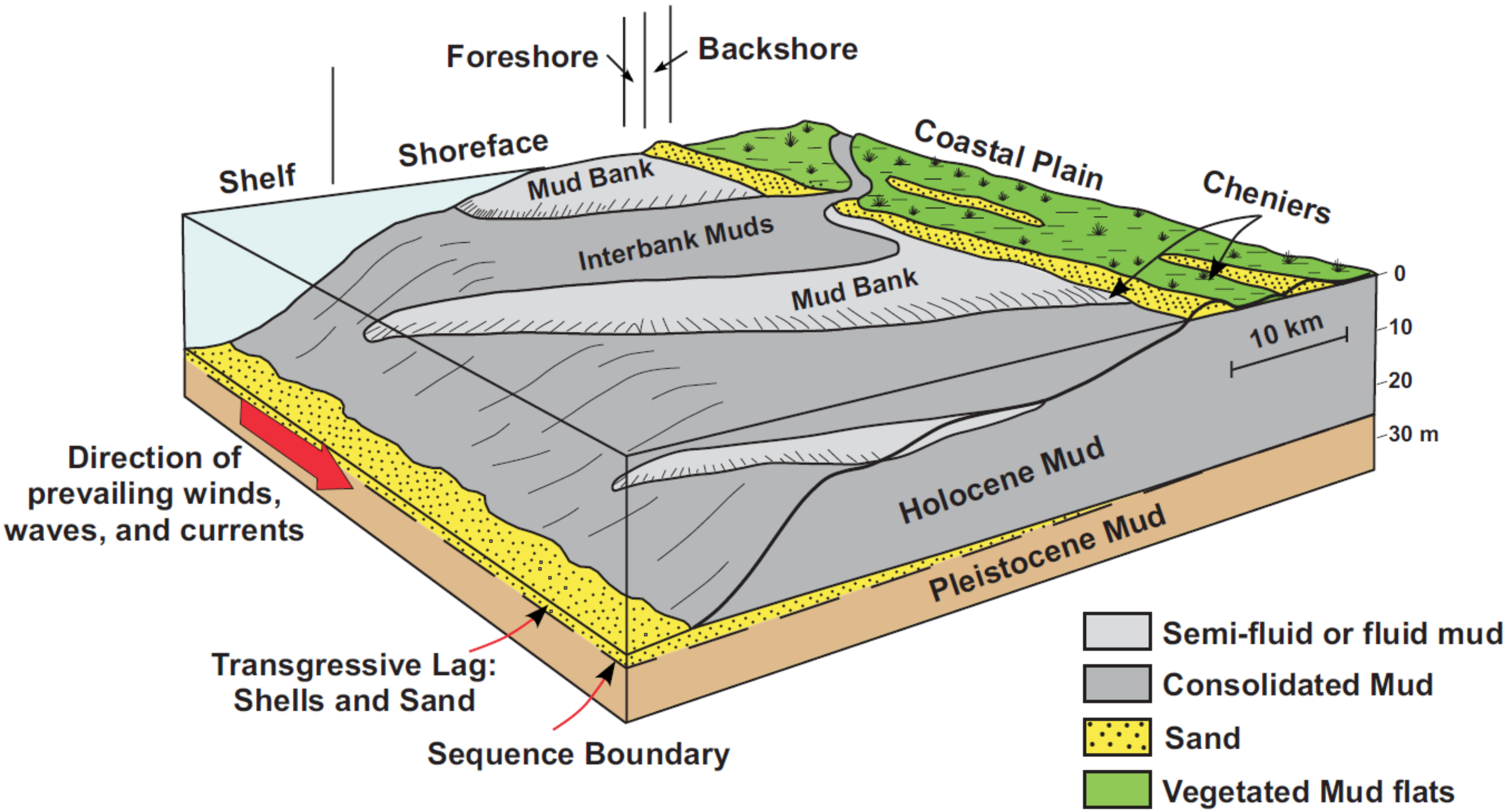


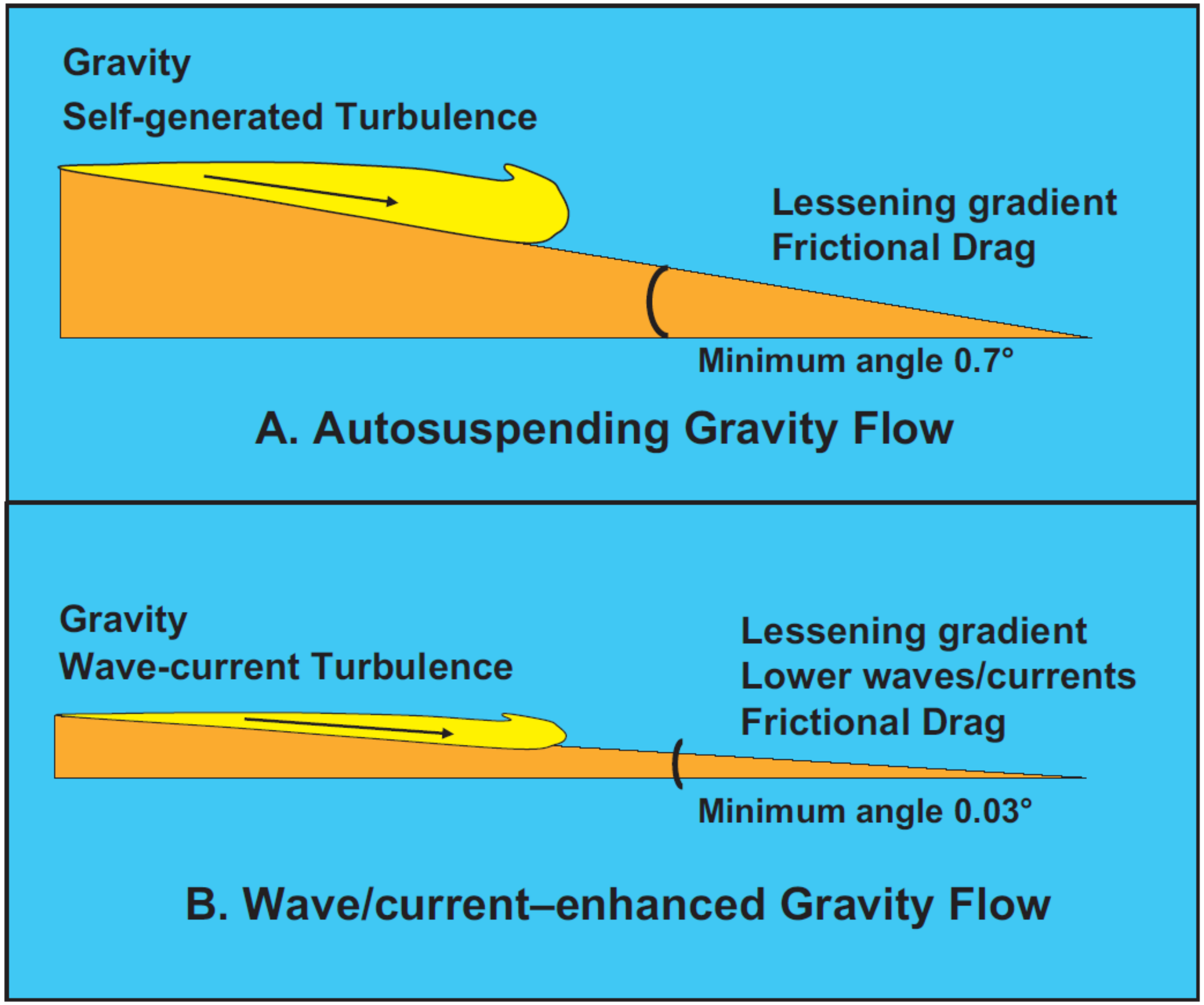
FIG. 43.—**A)** Dip-oriented and **B)** strike-oriented views showing bedding geometry of a top-truncated lowstand delta, based on shallow seismic profiles off the Natashquan River, Gulf of St. Lawrence, Canada (after Hart and Long, 1996). Note reworked sediments on top of deltas.

HART, B.S., AND LONG, B.F., 1996, Forced regressions and lowstand deltas: Holocene Canadian examples: Journal of Sedimentary Research, v. 66, p. 820–829.



Depositional model for accumulation of fluid muds in the shoreface and inner continental. Fluid mud is supplied to the nearshore zone by deltaic and estuarine sources in the form of hypopycnal plumes. Such plumes may reach well out onto the shelf or across the shelf break, depending on their own characteristics, slope of the shelf, and the prevailing shelf winds, waves, and currents. Sediments are deposited as the plume loses momentum into the receiving basin. Individual grains settle out as turbulence decreases, abetted by the process of flocculation. The overall deposit shows oblique to alongshore progradational architecture. Excellent examples of these deposits occur along the coast of northern South America (on which this diagram was based), sourced largely from the Amazon and Orinoco Rivers, and the western coastline of Louisiana, USA, the Chenier.

Posamentier & Walker (2006)



Types of hyperpycnal flows now recognized from river-mouth discharges. **A)** Autosuspended hyperpycnal plumes, with suspension produced by turbulence within the flow— i.e., a "normal" turbidity current. Gravity and turbulence maintain the flow until frictional drag or a decreasing gradient result in deposition. These are believed to be relatively rare on continental shelves because relatively steep gradients are required to produce and maintain the flow. **B)** Wave–current enhanced gravity flow, in which the turbulence associated with waves and/ or currents, abundant sediment supply, and a gradient above 0.03 degrees can produce a gravity flow, creating downslope transport and broad distribution of sediments across a shelf. Deposition results when frictional drag, lowered gradient, and/or decreasing wave–current turbulence decelerate the flow (redrawn from Bentley, 2003).

Wave- and storm-dominated shelves

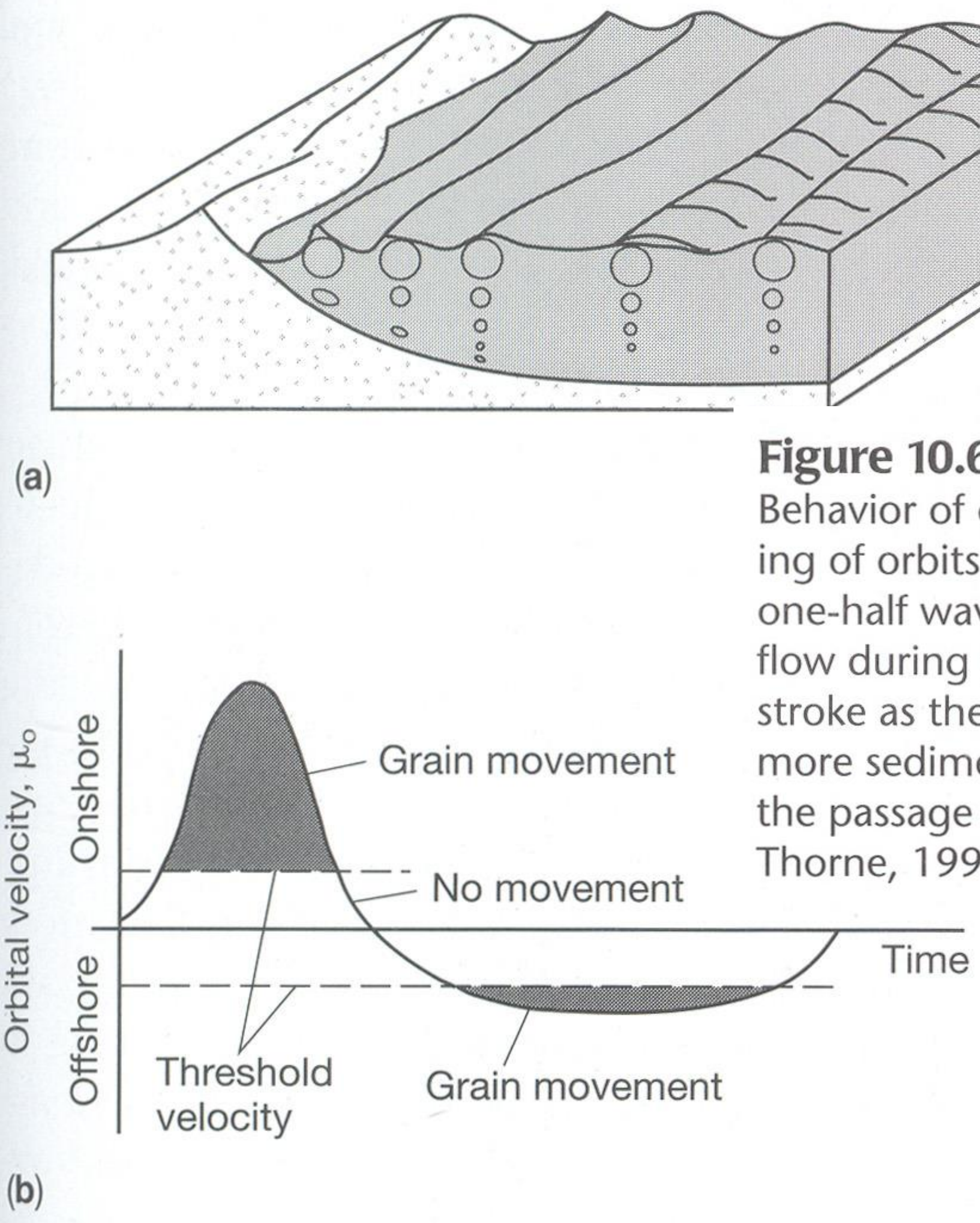
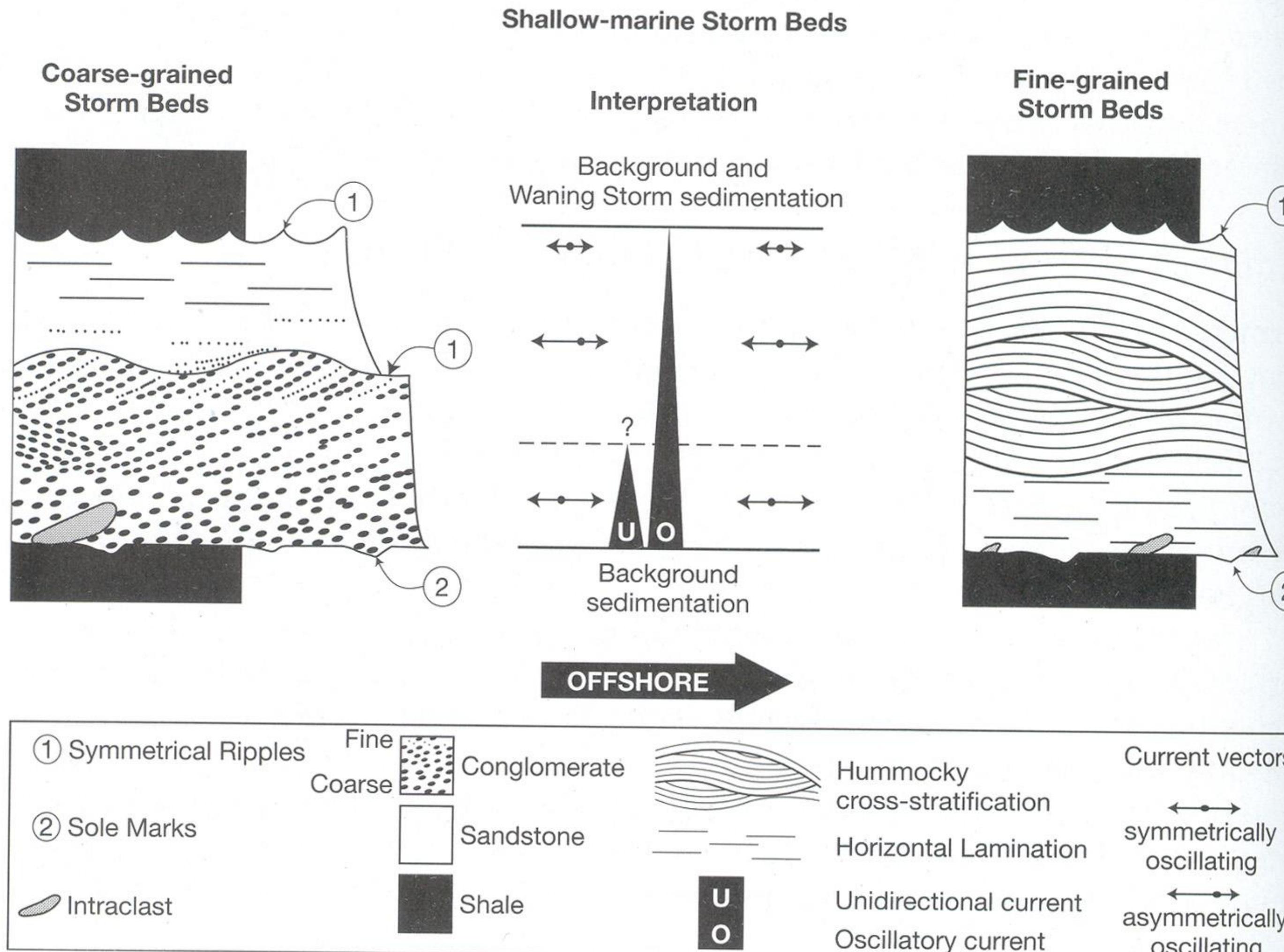


Figure 10.6
Behavior of oscillatory waves in shoaling water. (a) Flattening of orbits as waves enter water shallower than about one-half wave length. (b) Time-velocity record of bottom flow during passage of a shoaling wave. The landward stroke as the crest passes has higher velocity and moves more sediment than does the return stroke associated with the passage of the trough. [After Swift, D. J. P., and J. A. Thorne, 1991, Sedimentation on continental margins, I: a

Figure 10.7

Schematic comparison of idealized coarse-grained storm beds and fine-grained hummocky cross-stratified beds on storm-dominated shelves. The lengths of the current vectors are proportional to the strength of the current in a given direction rather than duration. [From Cheel, R. J., and D. A. Leckie, 1992, Coarse-grained storm beds of the Upper Cretaceous Chungo Member (Wapiabi Formation), southern Alberta, Canada: Jour. Sed. Petrology, v. 62, Fig. 14, p. 943, reproduced by permission of Society of Economic Paleontologists and Mineralogists, Tulsa, Okla.]



Tide-dominated shelves

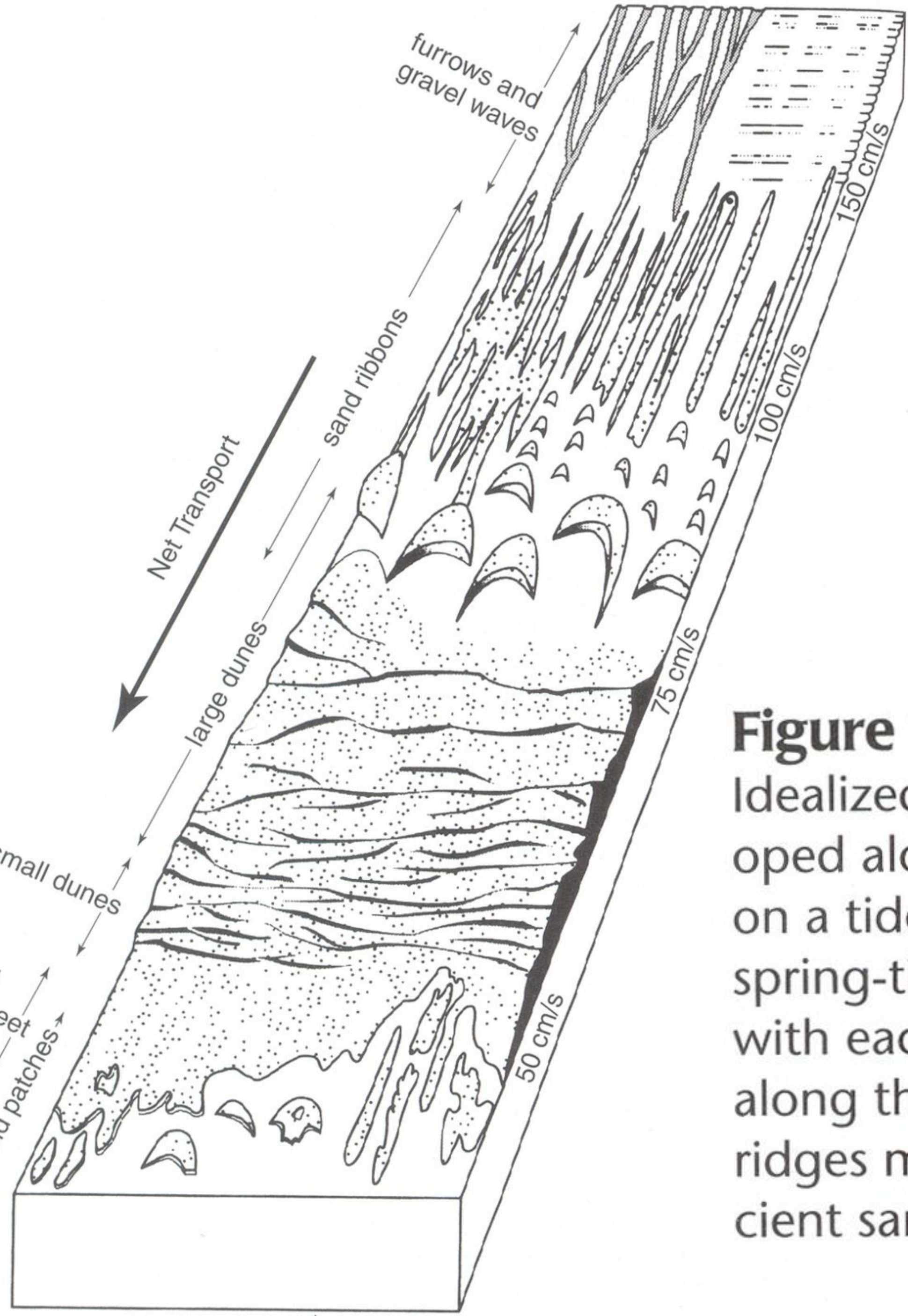


Figure 10.8
Idealized sequence of bedforms developed along a sediment transport path on a tide-dominated shelf. Maximum spring-tide current velocities associated with each bedform type are shown along the edges of the diagram. Sand ridges may form in the dune belt if sufficient sand is present. [After Belderson, R.

Shelves affected by intruding ocean currents

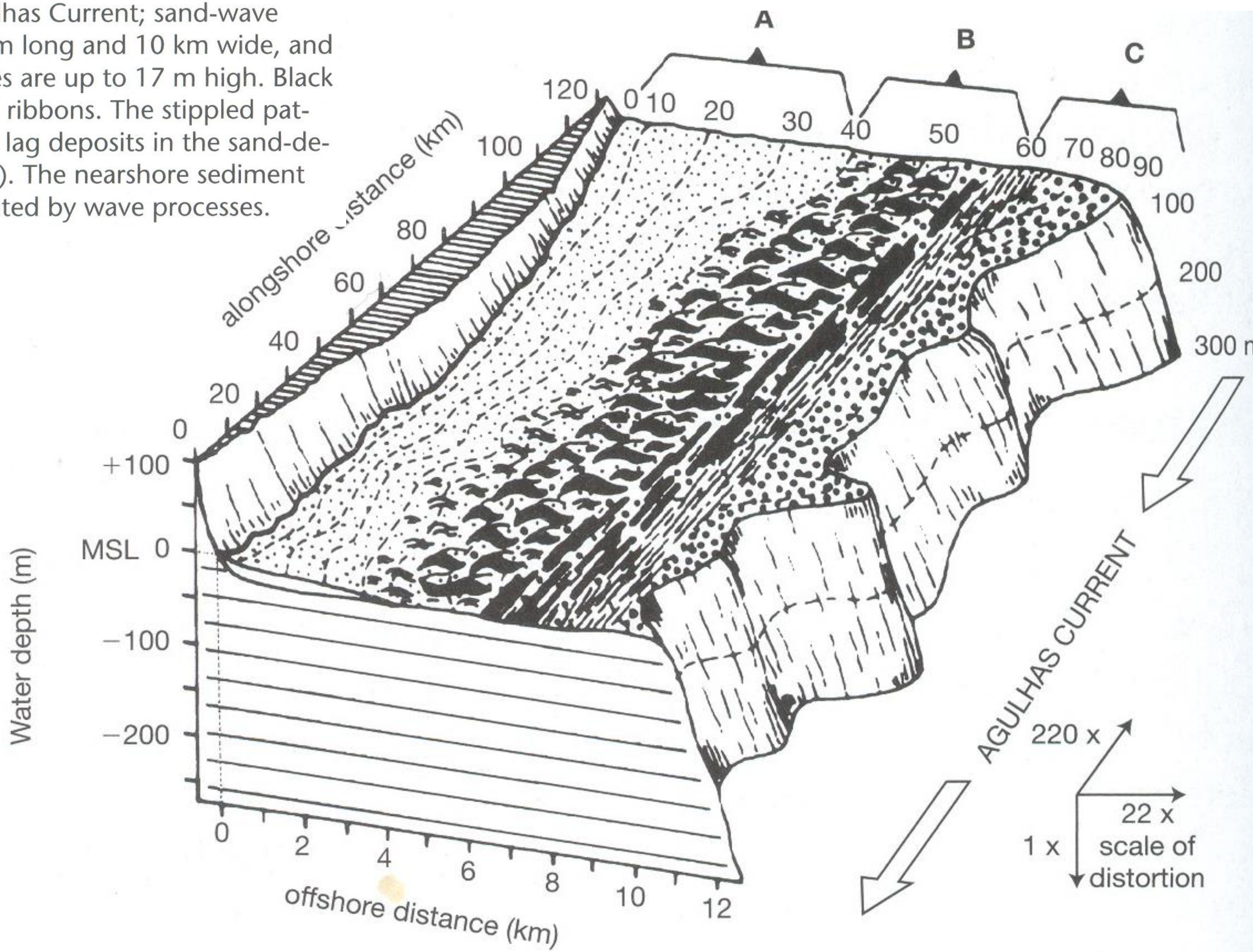


Figure 10.9
Sediment transport by the Agulhas Current off the southeastern tip of Africa. Sand in the current-controlled central shelf (B) migrates under the influence of the Agulhas Current; sand-wave fields are up to 20 km long and 10 km wide, and individual sand waves are up to 17 m high. Black streaks indicate sand ribbons. The stippled pattern indicates coarse lag deposits in the sand-depleted outer shelf (C). The nearshore sediment wedge (A) is dominated by wave processes.

Ancient siliciclastic shelf sediments

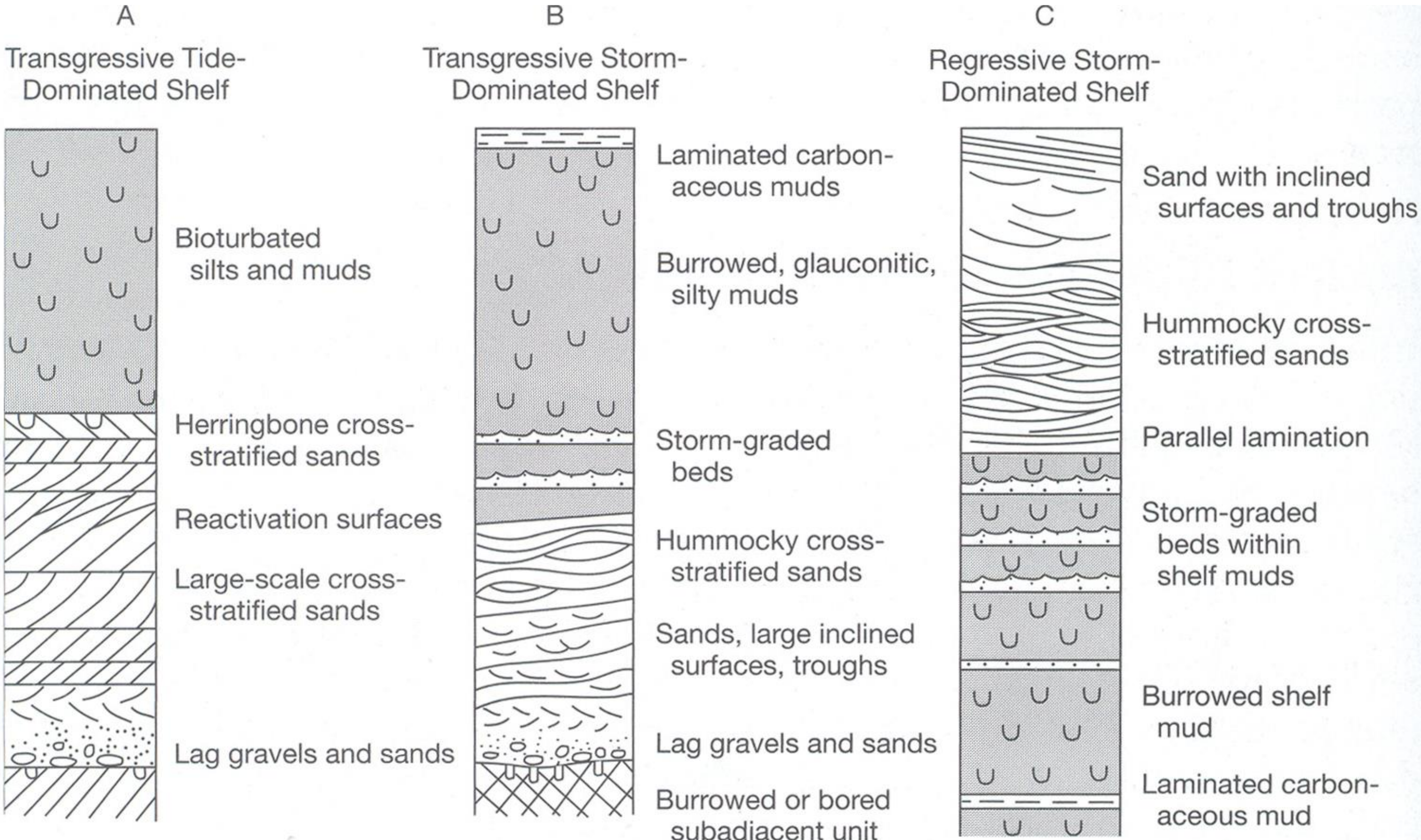


Figure 10.10
Idealized diagrams illustrating typical fining-upward transgressive shelf successions on (A) a tide-dominated shelf and (B) a storm-dominated shelf, and a coarsening-upward regressive shelf succession (C) on a storm-dominated shelf.

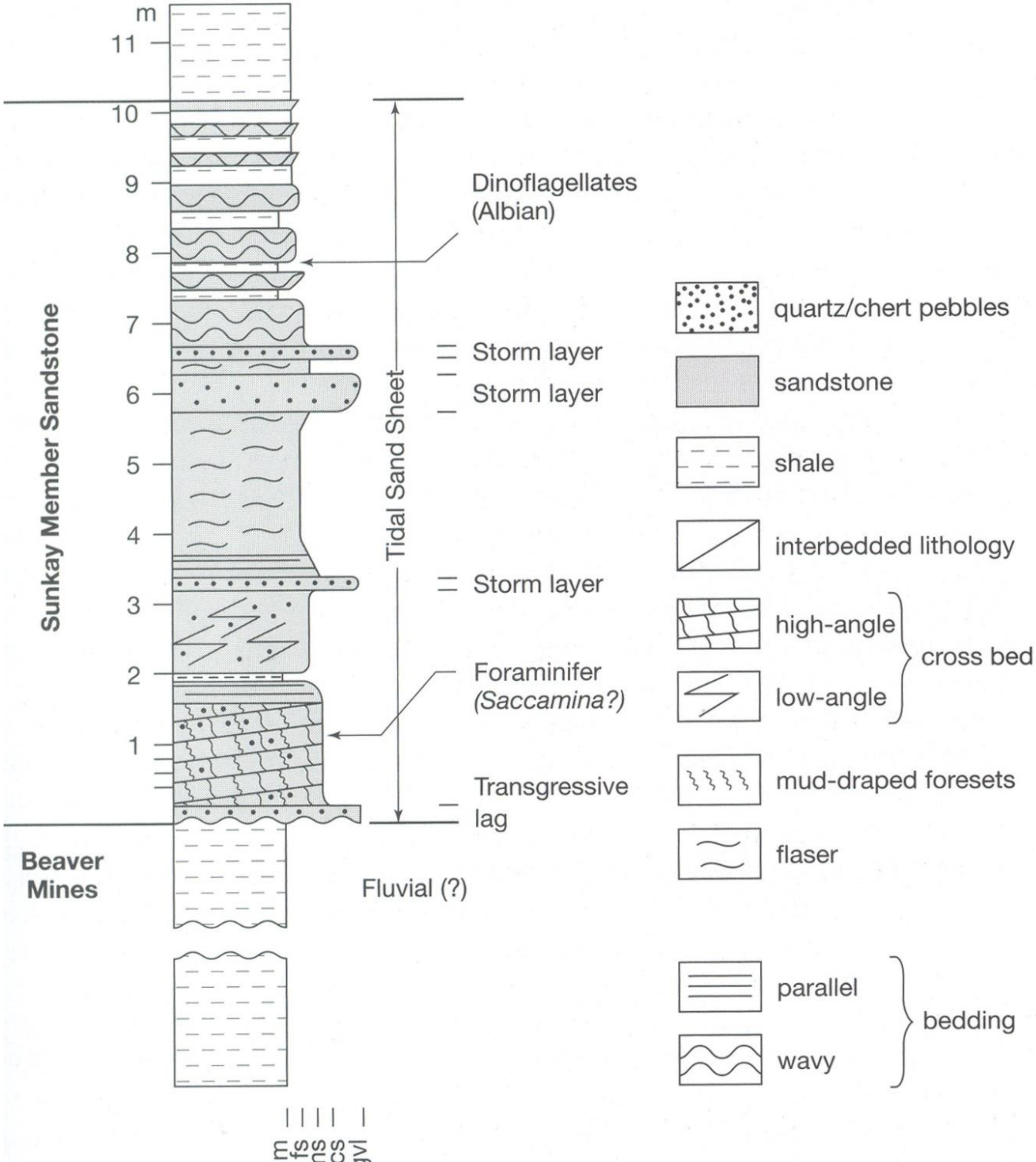


Figure 10.11
Vertical succession of sandy tidal shelf deposits in the Sunkay Sandstone Member of the Lower Cretaceous Alberta Group, southern Alberta, Canada. Symbols in the grain-size scale are gvl = gravel, cs = coarse sand, ms = medium sand, fs = fine sand, and m = mud (silt-clay). [After Banerjee, I.,

10.3 The Oceanic (deep-water) Environment

Depositional setting

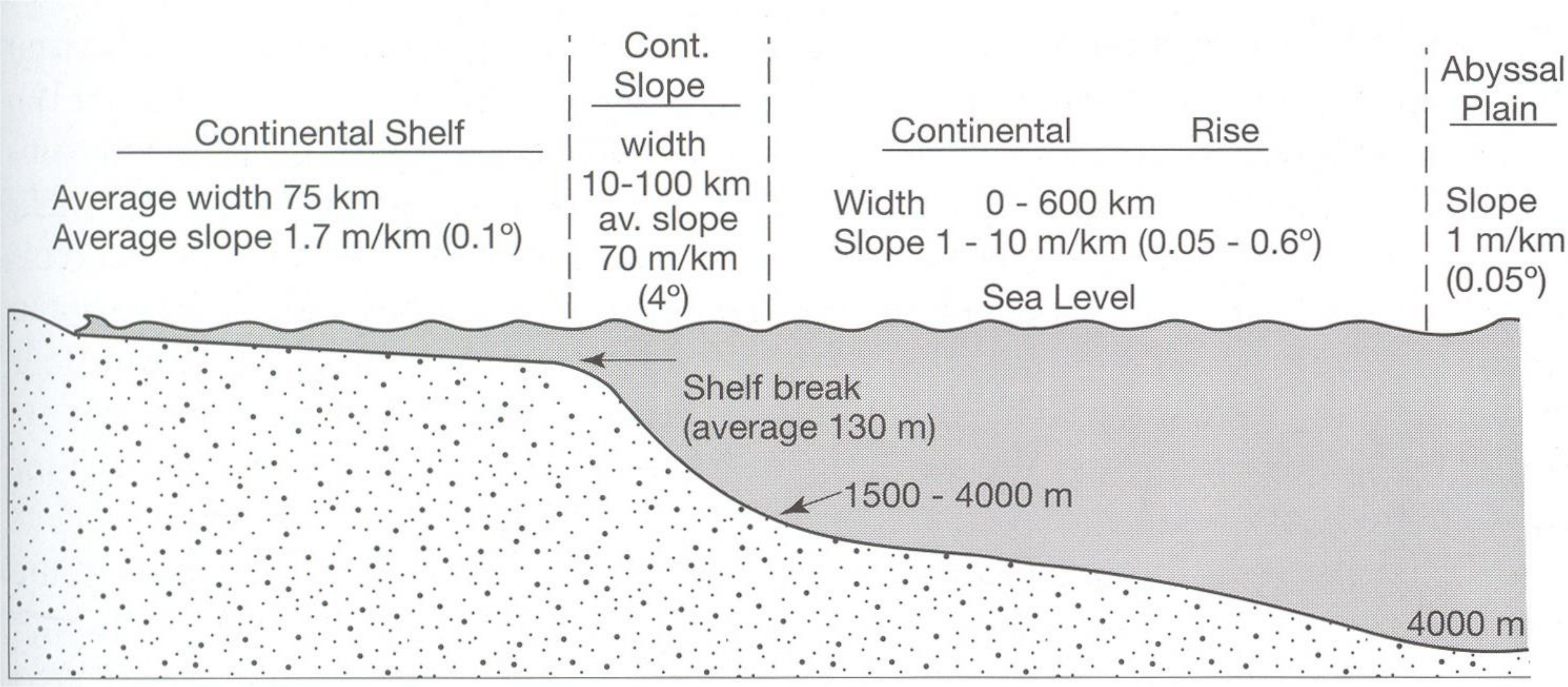


Figure 10.12

Principal elements of the continental margin. [After

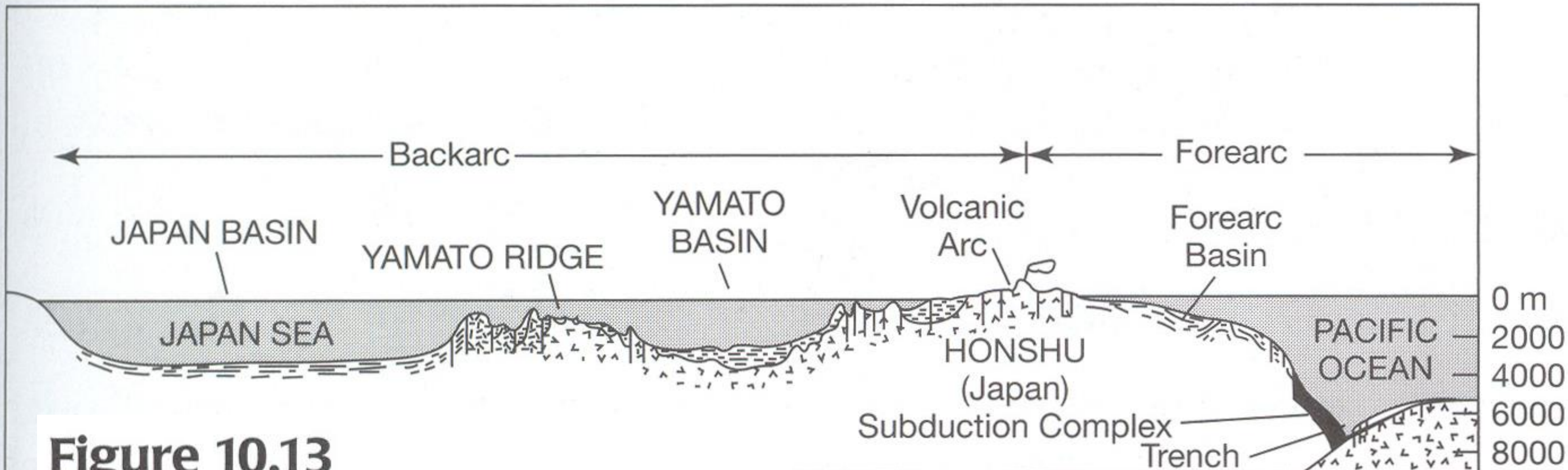
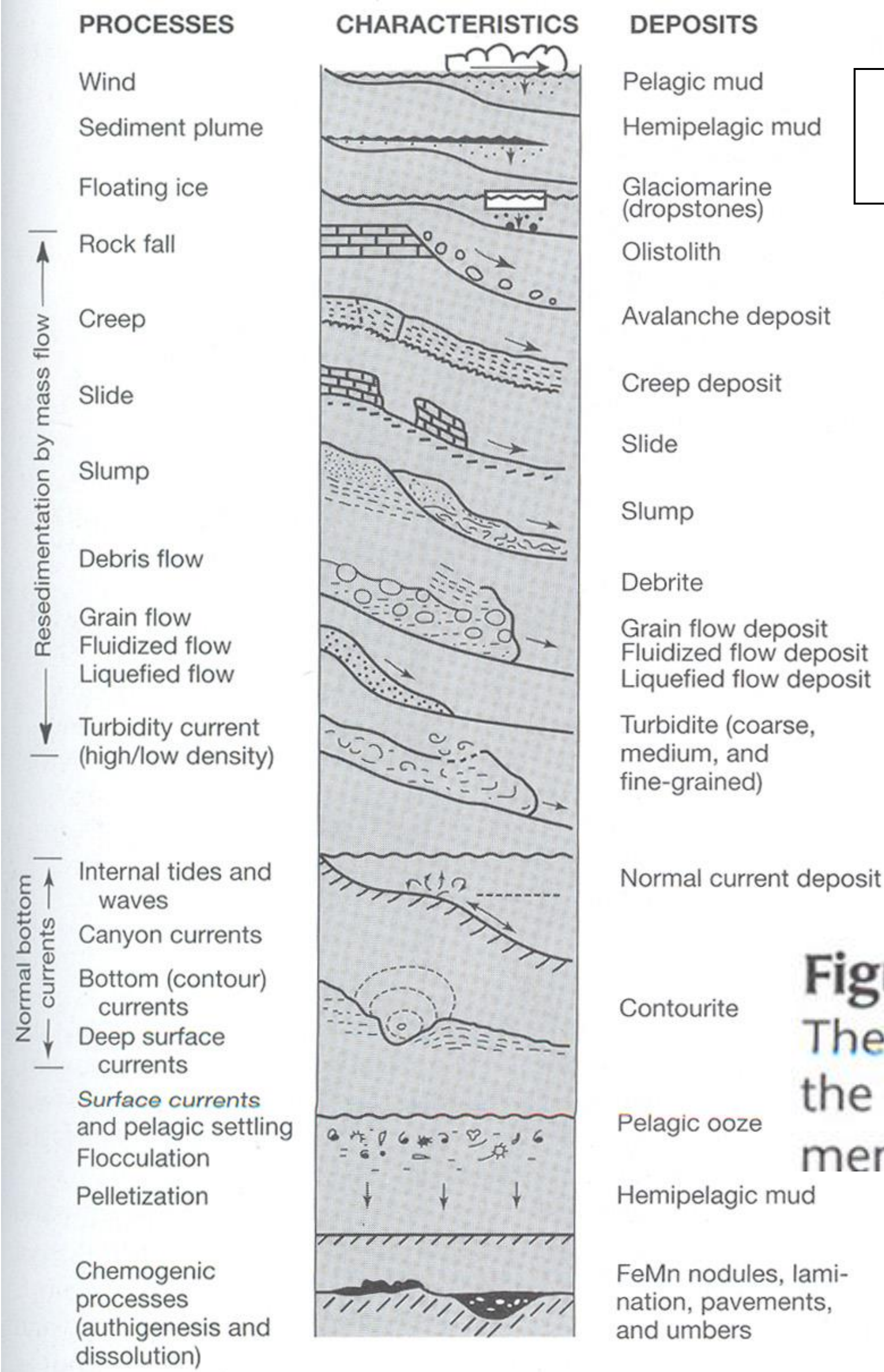


Figure 10.13
Schematic representation of an active continental margin (Japan), showing both the fore-arc and back-arc characteristics of the margin. [From Boggs, S., Jr., 1984,

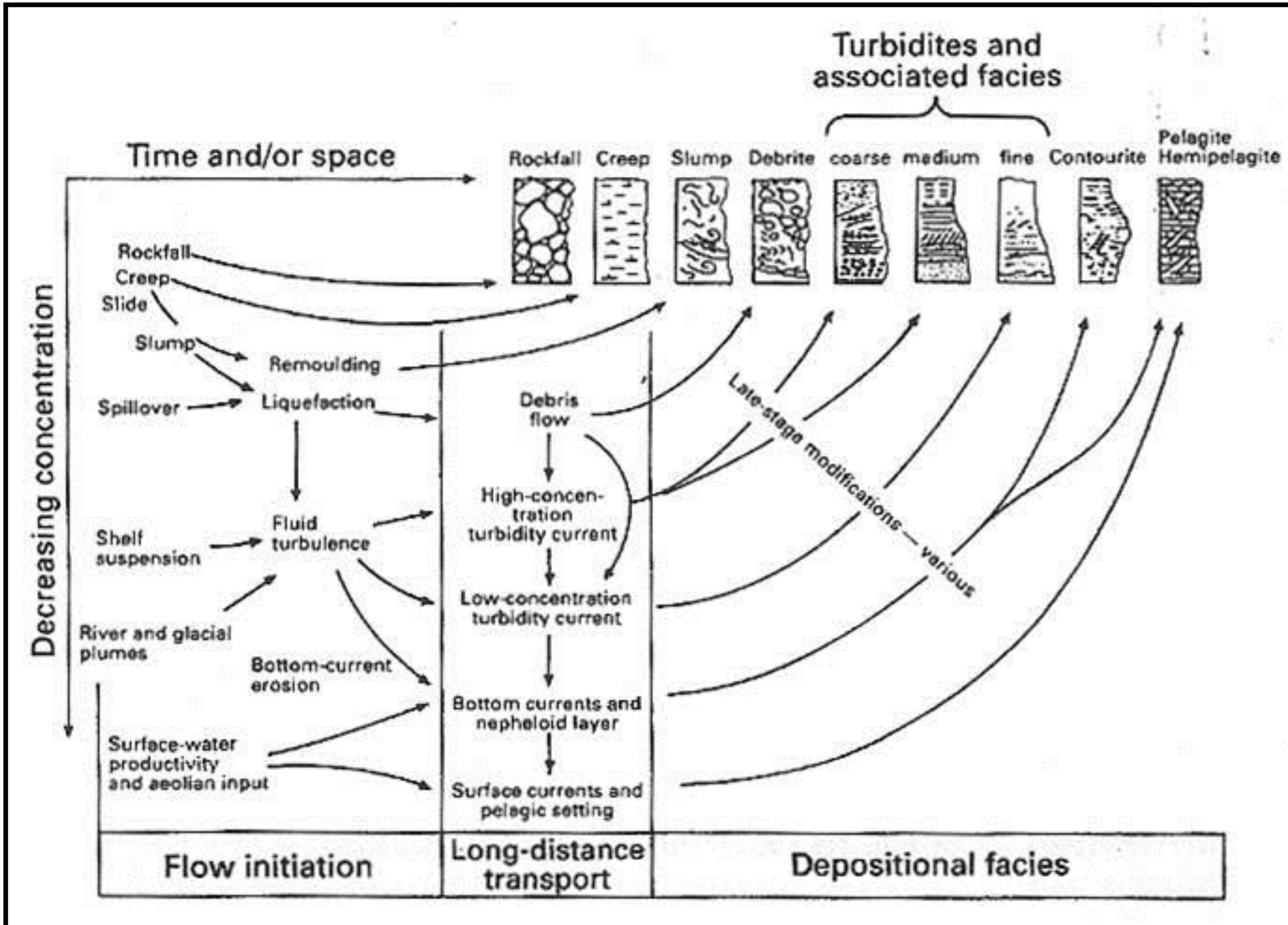
Transport and depositional processes
to and within deep water



- Sediment plumes, wind transport, ic
  nepheloid transport
- Currents in canyons
- Contour currents
- Pelagic rain
- Explosive volcanism
- Turbidity currents and other
  mass-transport processes

Figure 10.14
The various kinds of processes that operate in the deep sea to transport and deposit sediments. [After Stow, D. A. V., 1994. Deep sea

Sediment transport agents and products



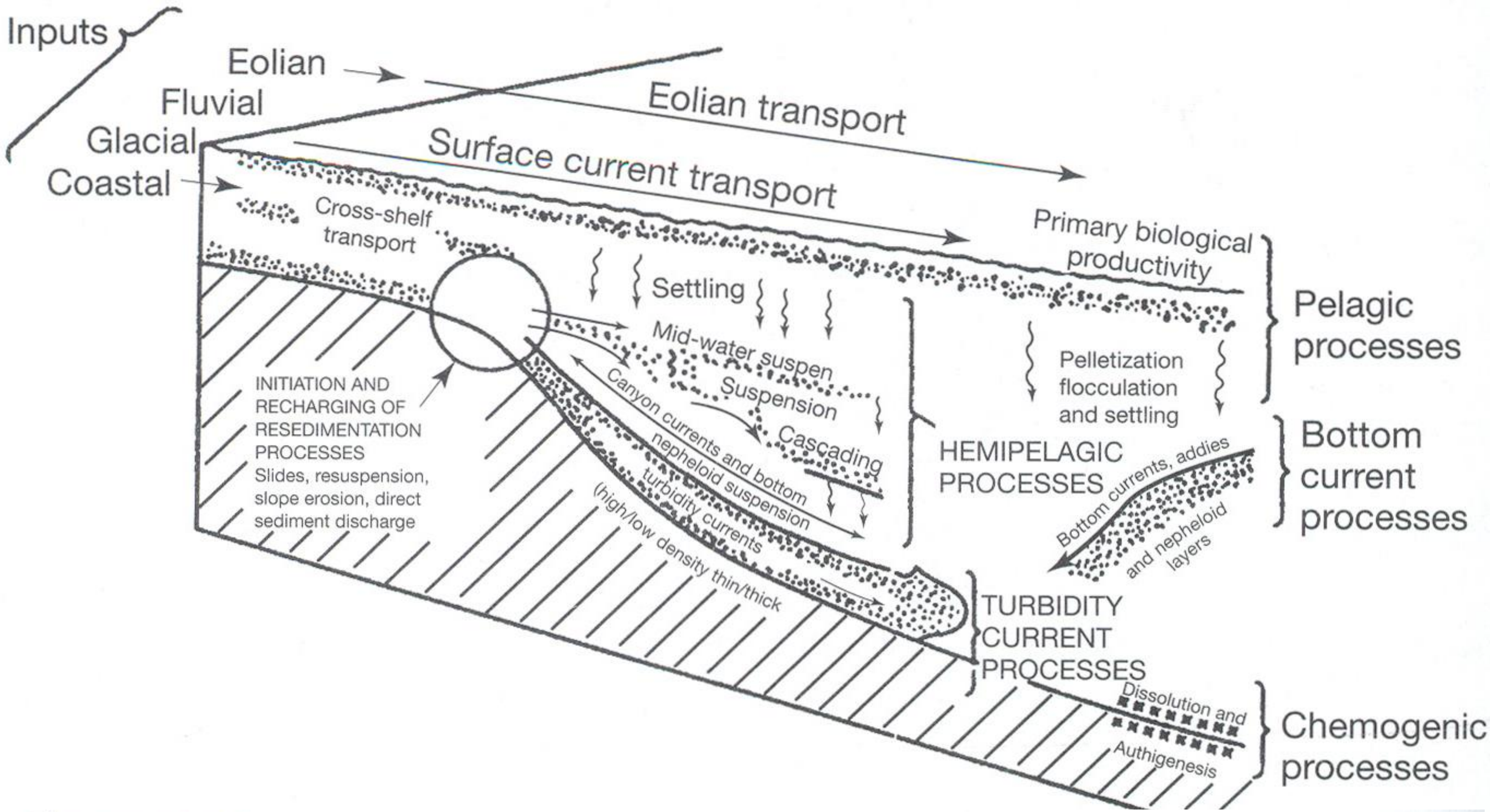


Figure 10.15

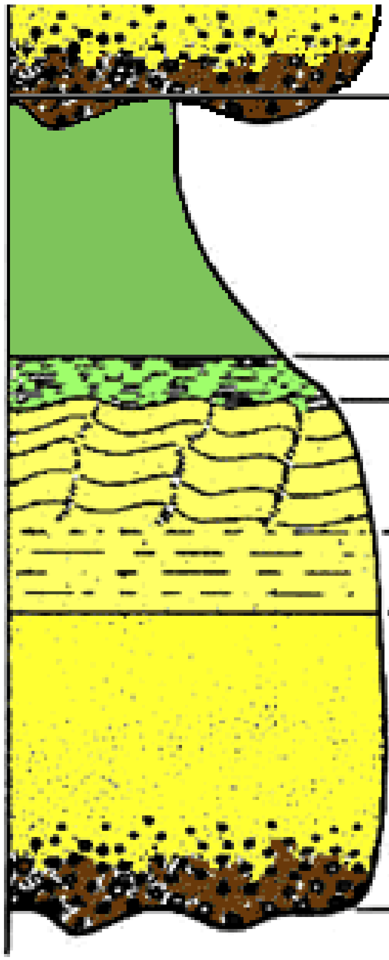
Schematic representation of principal processes responsible for transport and deposition of sediments to the deep ocean. Note that most of the processes deposit fine sediment; however, glacial (floating ice), turbidity current, and resedimentation processes can move both coarse and fine sediment. Chemogenic refers to minor processes that are largely chemical in nature. [After Stow, D. A. V., H. G. Reading, and J. D. Collinson, 1996. Deep

Table 10.1 Principal kinds of deep-sea sediments

Terrigenous siliciclastic deposits
Hemipelagic mud—mixtures of terrigenous mud and biogenic remains; deposited from nepheloid plumes and by suspension settling and pelagic rain-out
Turbidites—graded gravel/sand/mud; deposited by turbidity currents
Contourites—sandy or muddy sediments deposited and/or reworked by contour currents
Glacial-marine sediments—Gravel, sand, and mud deposited by ice rafting
Slump and slide deposits—Terrigenous or pelagic deposits emplaced downslope by mass-wasting processes
Pelagic deposits
Pelagic clay— >2/3 siliciclastic clay; deposited by suspension settling and authigenic formation of clay minerals
Oozes— >2/3 planktonic biogenic remains; deposited by pelagic rain-out
Calcareous—dominantly C_4CO_3 biogenic remains
Siliceous—dominantly SiO_2 biogenic remains
Allochthonous deep-sea carbonates
Shallow-water carbonates emplaced downslope by storms or sediment gravity flows

Turbidity Currents → Turbidites

CLASSICAL TURBIDITE



Grain Size		Bouma (1962) Divisions	Interpretation
Mud	T_{ep}	Pelite	Pelagic sedimentation
	T_{et}	Massive or graded Turbidite	fine grained, low density turbidity current deposition
	T_d	Upper parallel laminae	? ? ?
Sand–Silt	T_c	Ripples, wavy or convoluted laminae	Lower part of Lower Flow Regime
	T_b	Plane parallel laminae	Upper Flow Regime Plane Bed
Sand (to granule at base)	T_a	Massive, graded	? Upper Flow Regime Rapid deposition and Quick bed (?)

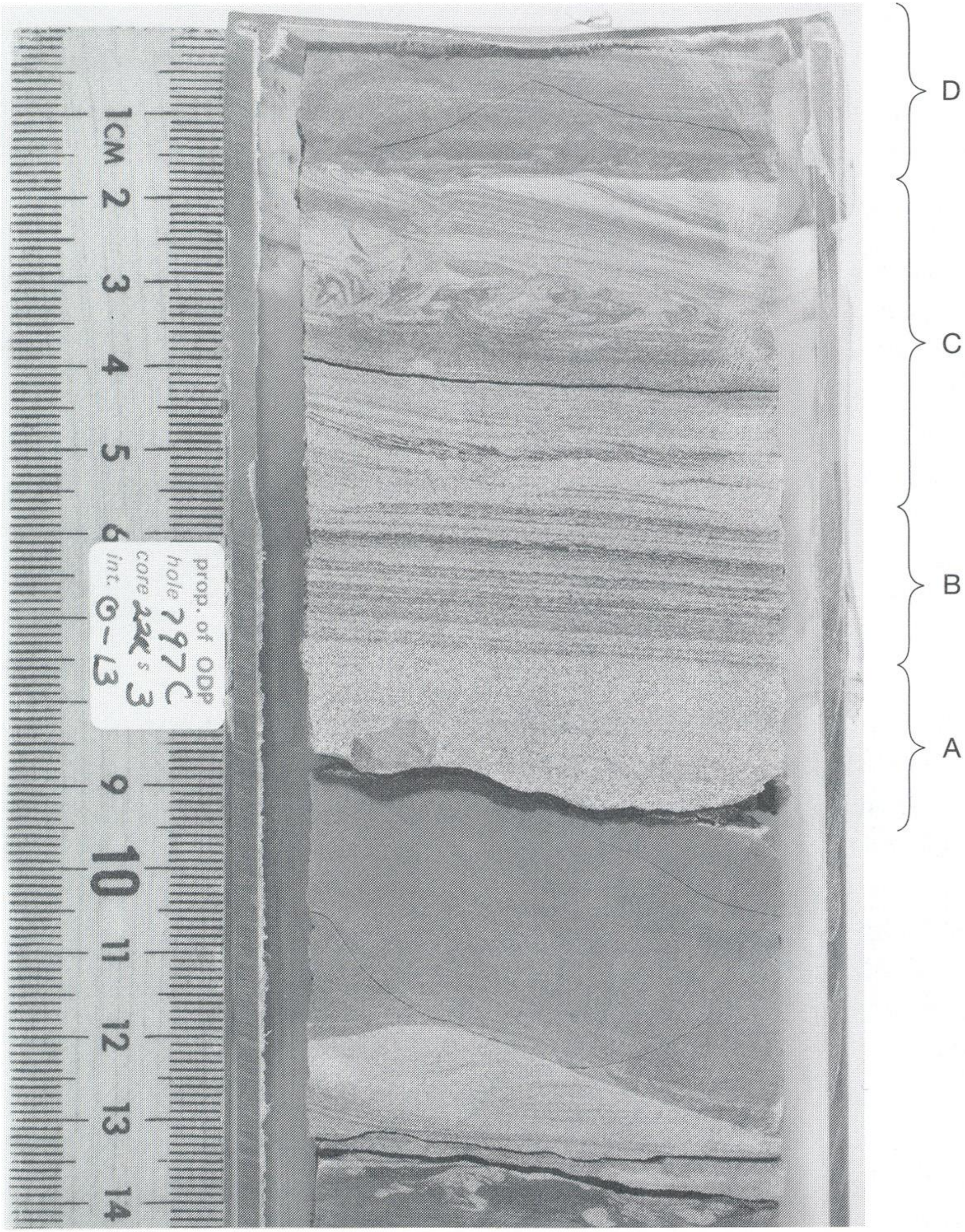


Figure 10.17
Graded volcaniclastic turbidite with Bouma divisions marked, from an Ocean Drilling Program (ODP) Leg 127 core of Miocene sediments in the Japan Sea back-arc basin.

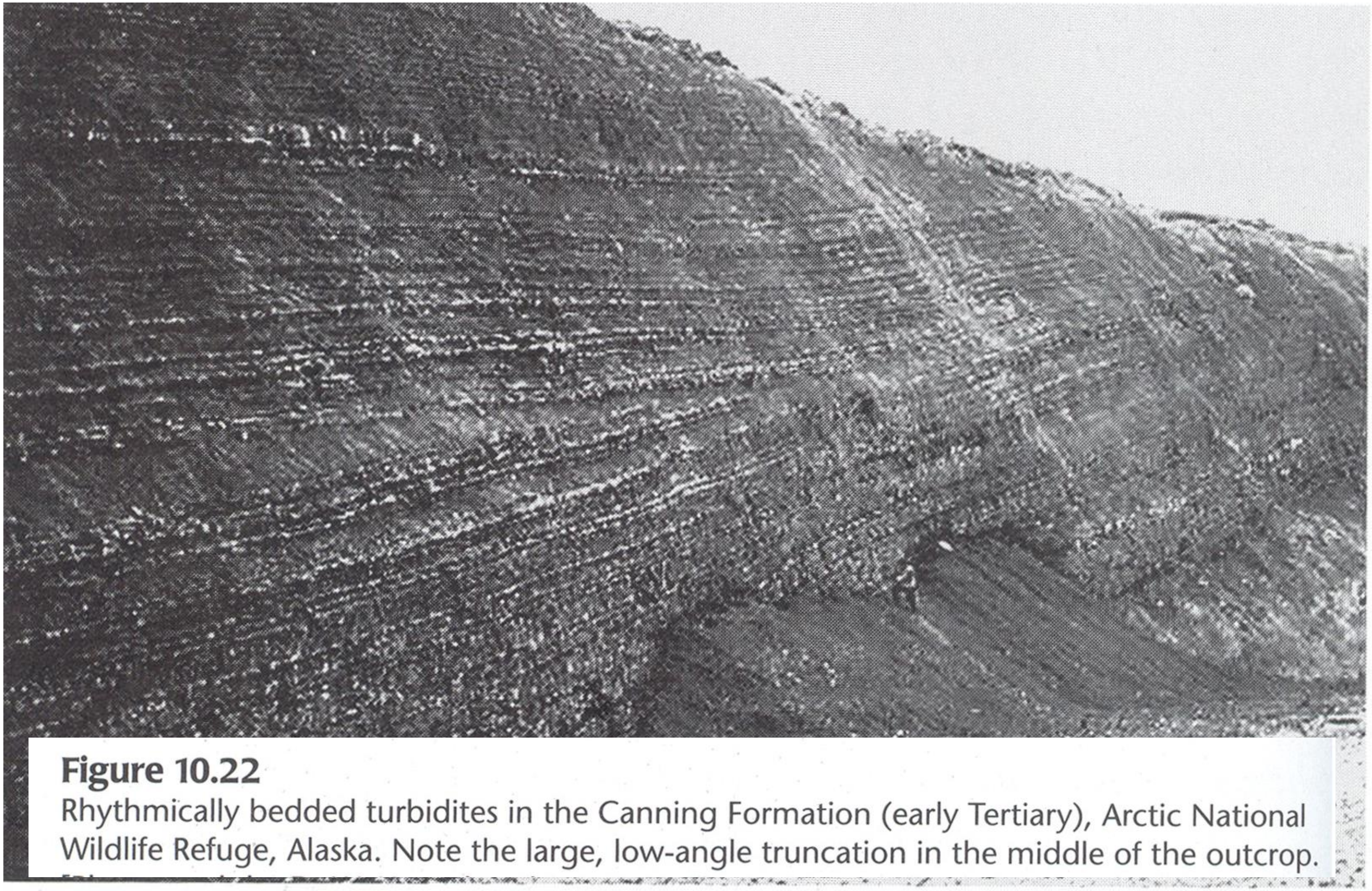
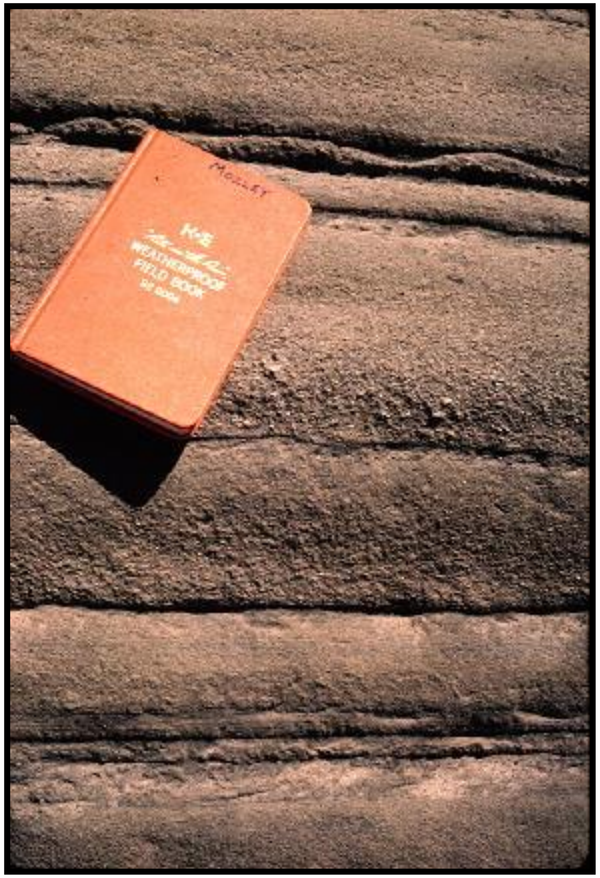
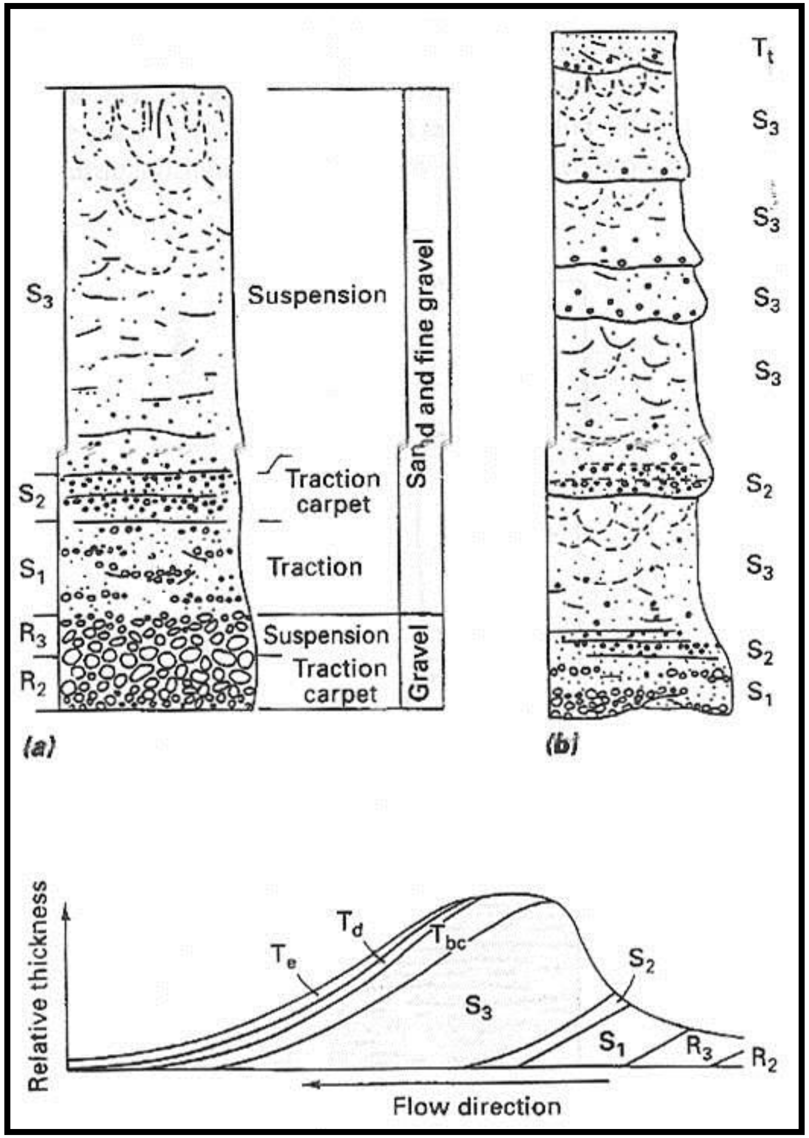


Figure 10.22
Rhythmically bedded turbidites in the Canning Formation (early Tertiary), Arctic National Wildlife Refuge, Alaska. Note the large, low-angle truncation in the middle of the outcrop.

Coarse-grained Turbidites





Contourites

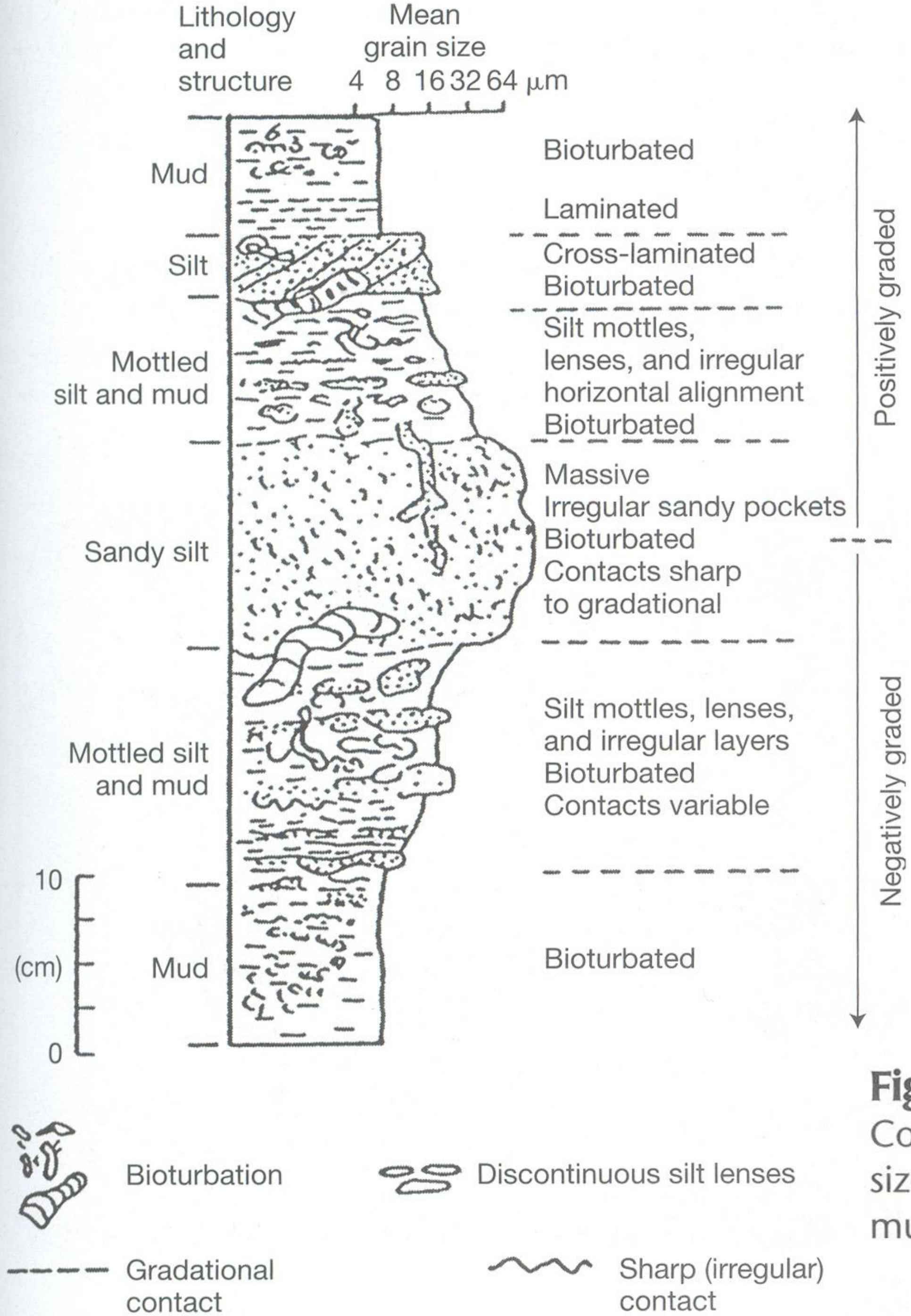
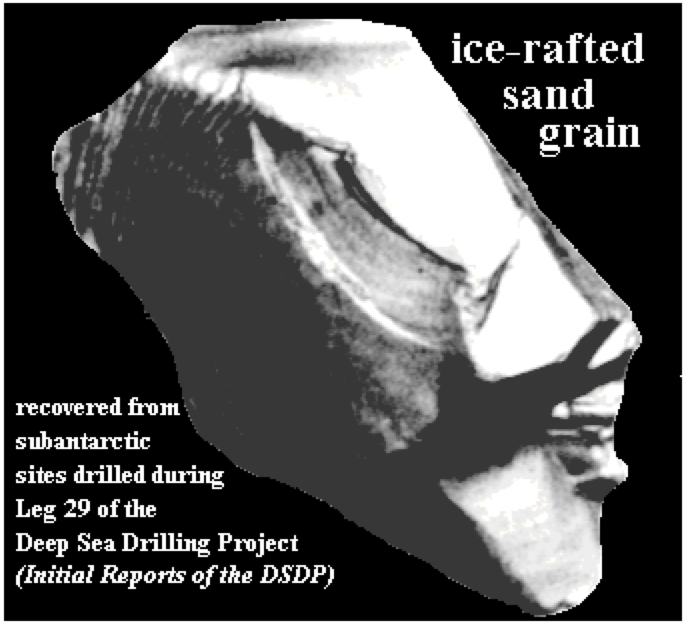
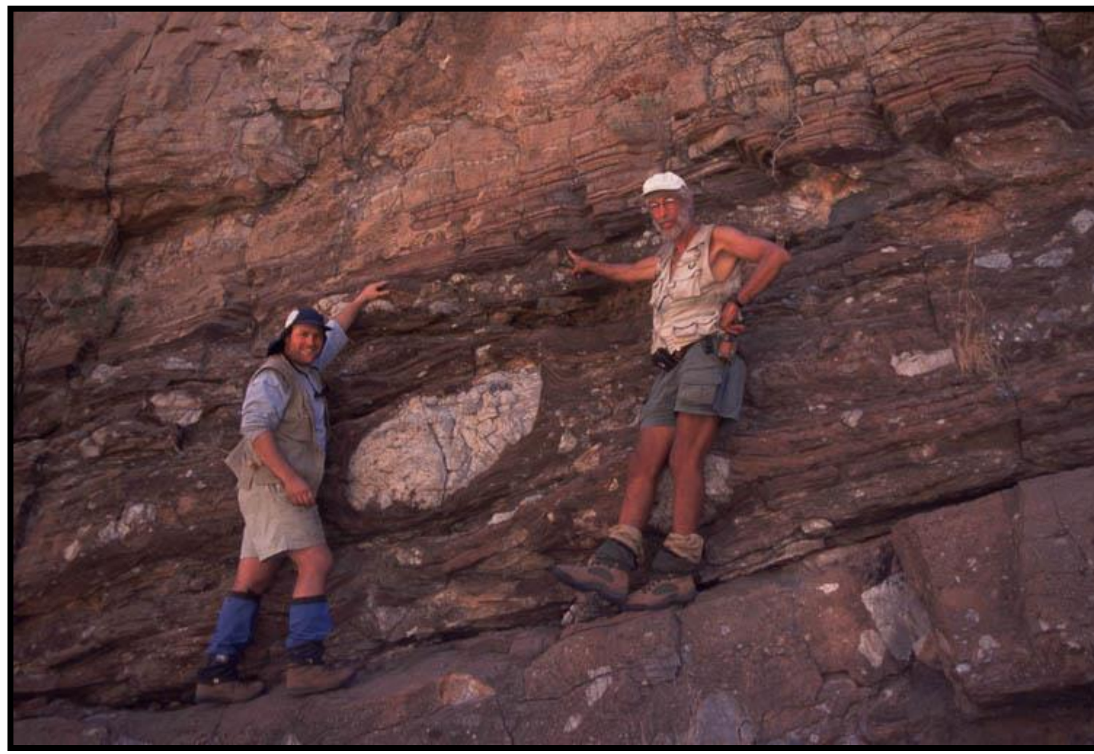


Figure 10.20
Composite contourite facies model showing grain-size variations and sedimentary structures through a mud-silt-sand contourite succession. [From Stow

Glacial-marine sediments



Dropstones



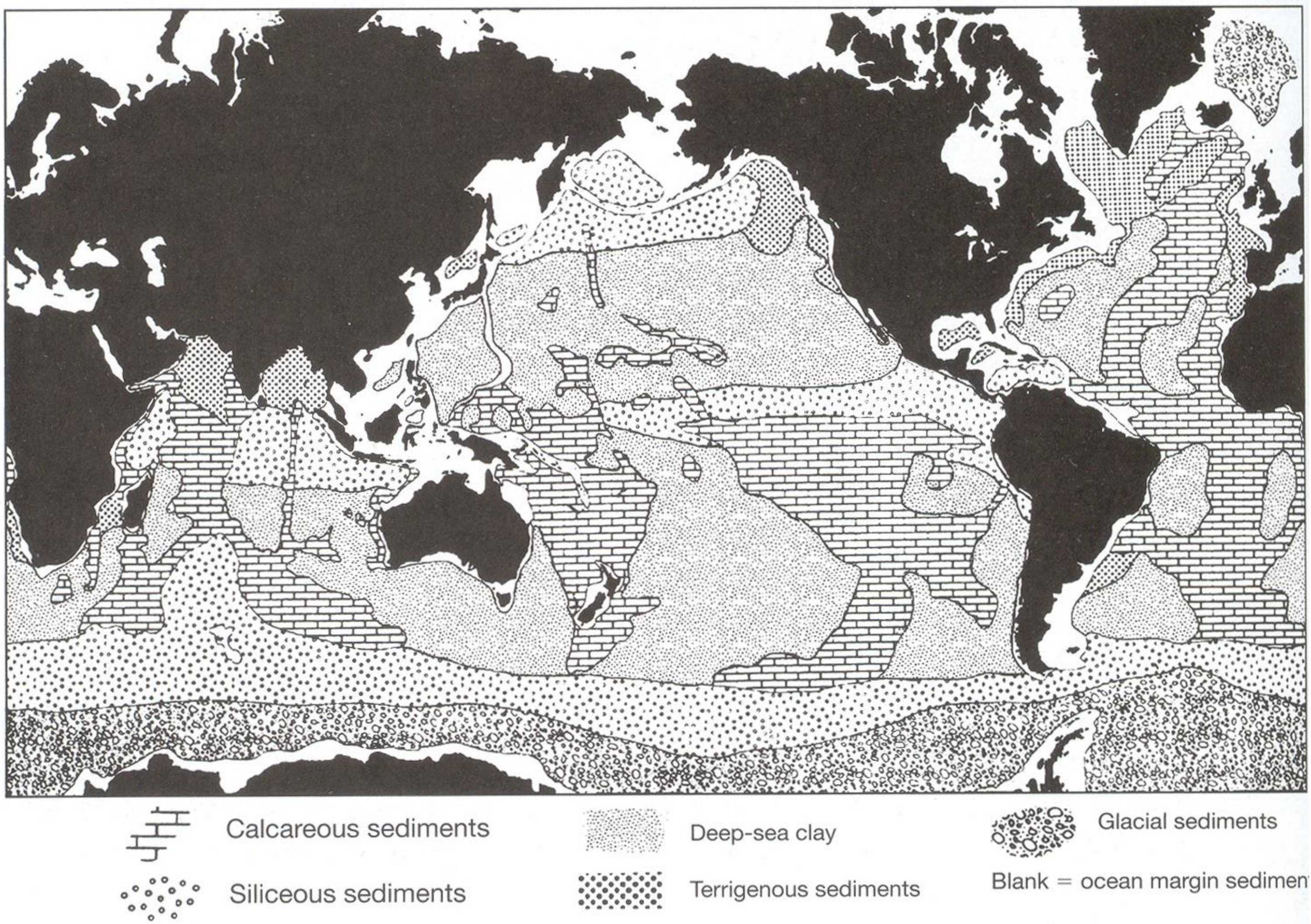


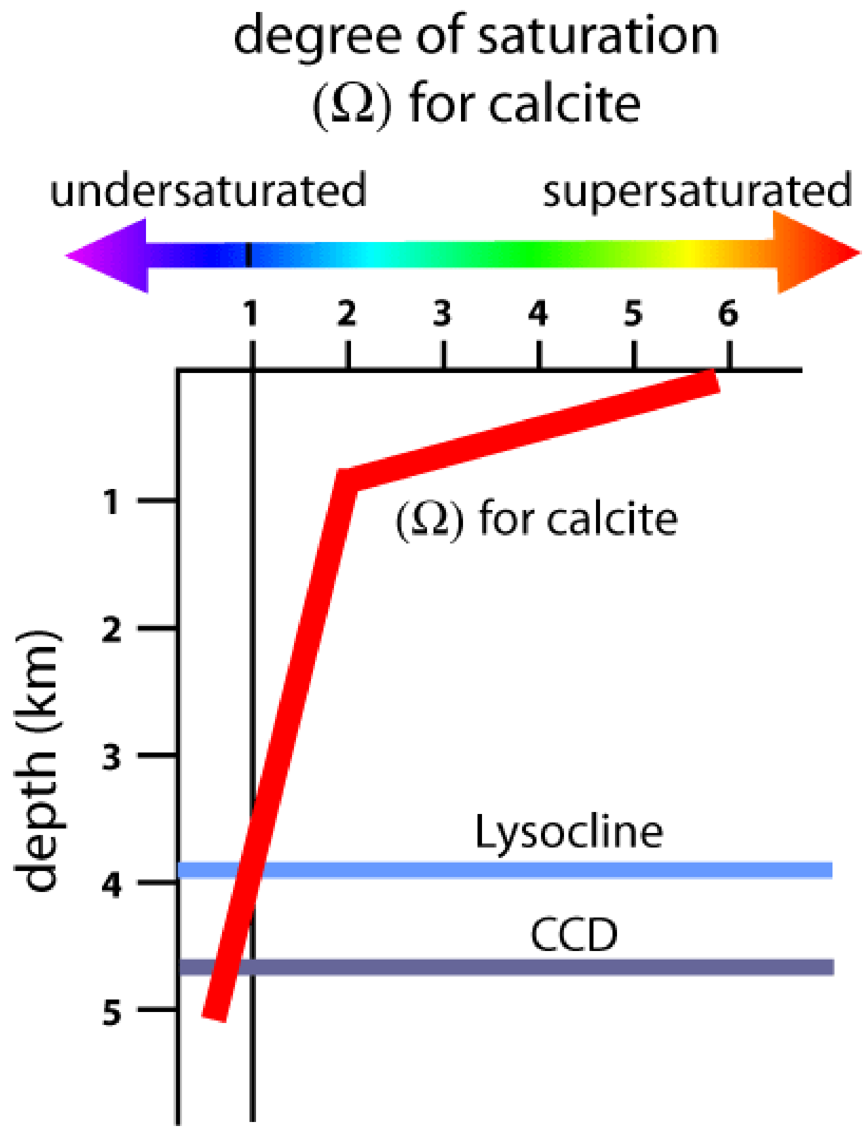
Figure 10.21
Distribution and dominant types of deep-sea sediments in the modern ocean. [From

CCD

CCD: 碳酸鈣補償深度
Calcium carbonate compensation depth @4500 m (3500~5500 m):

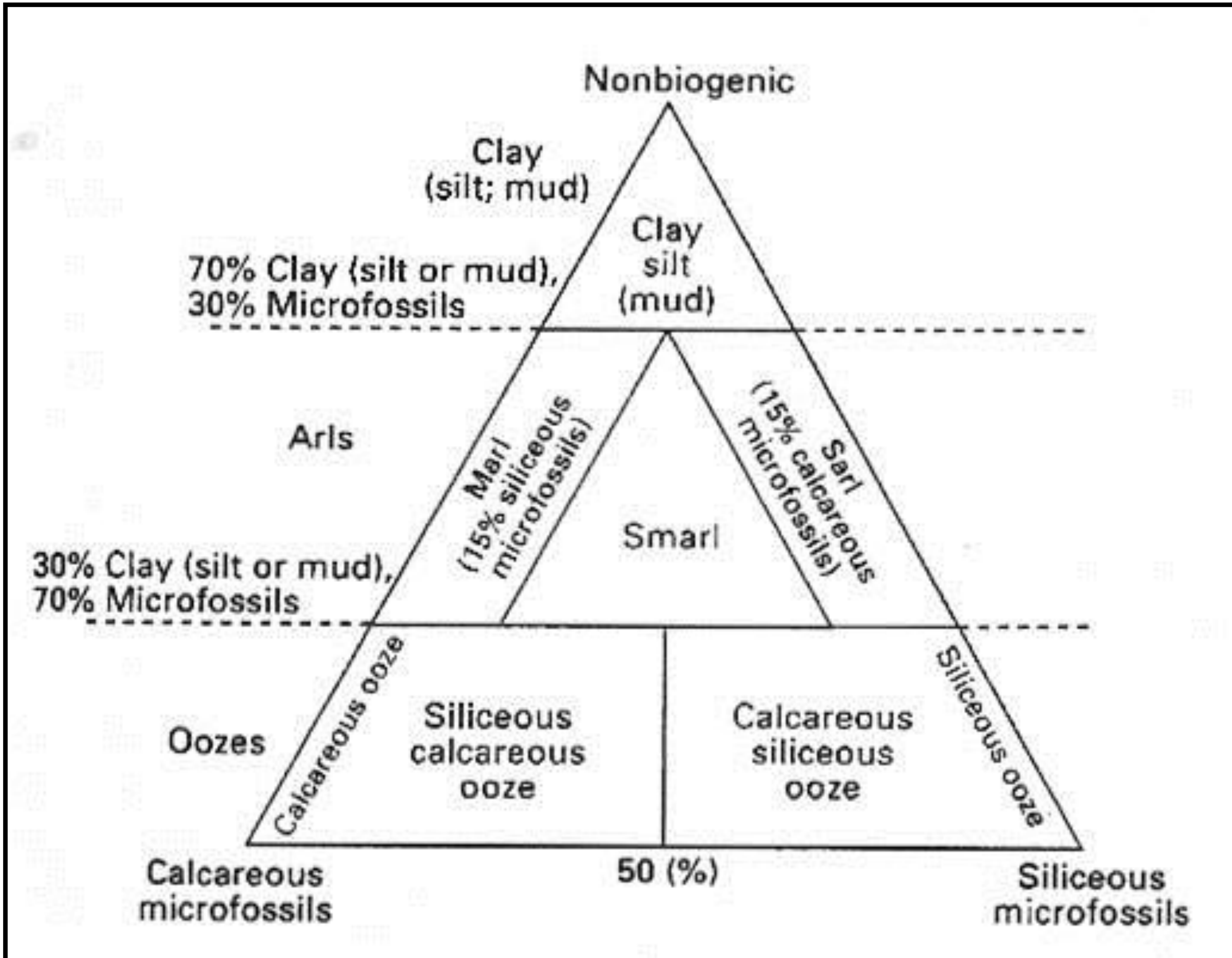
The particular depth at which the rate of dissolution of calcium carbonate equals the rate of supply of calcium carbonate to the seafloor, so that no net accumulation of carbonate takes places.

Lysocline: 碳酸鹽速溶深度

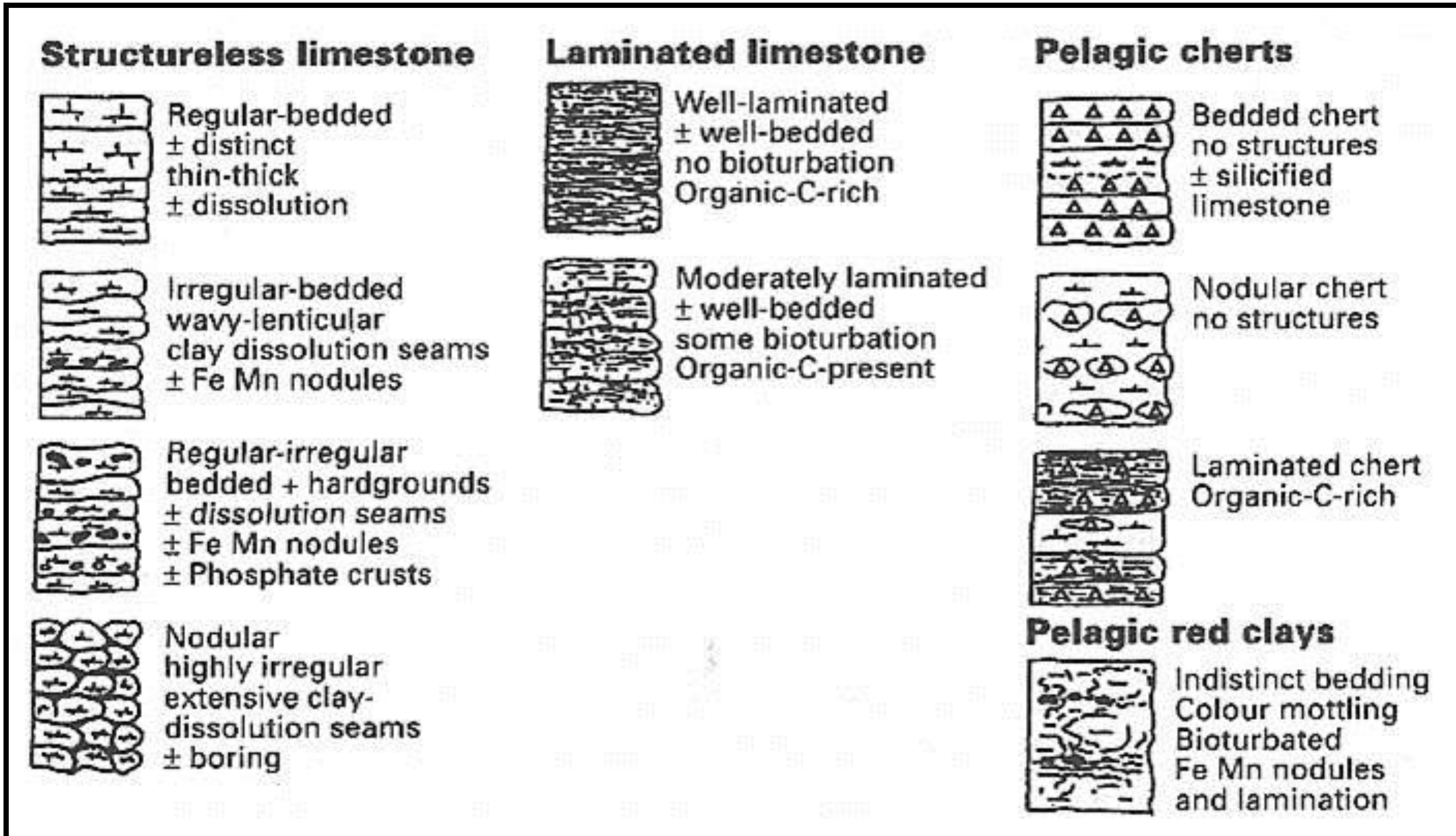


Degree of saturation versus depth.

Pelagic Sediments

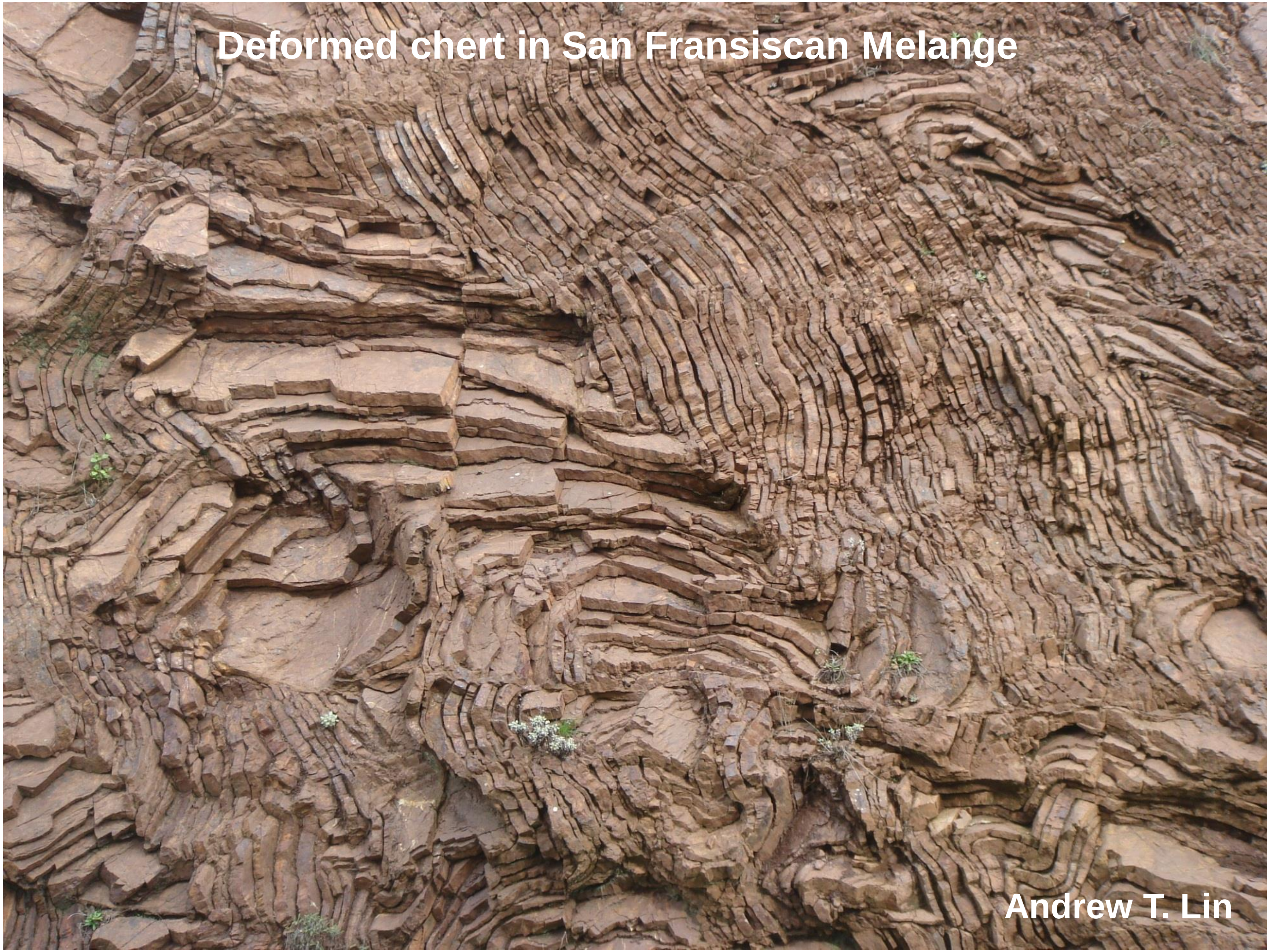


Pelagic Sediments

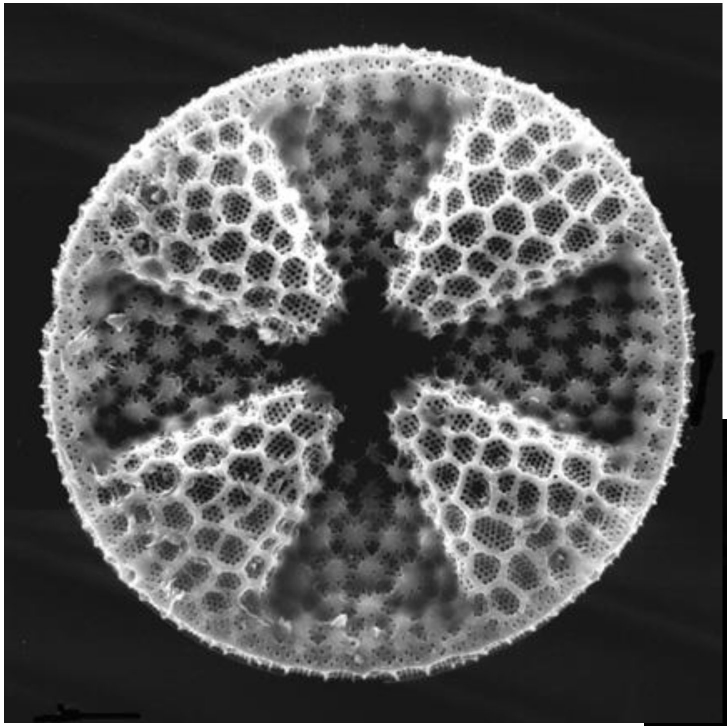


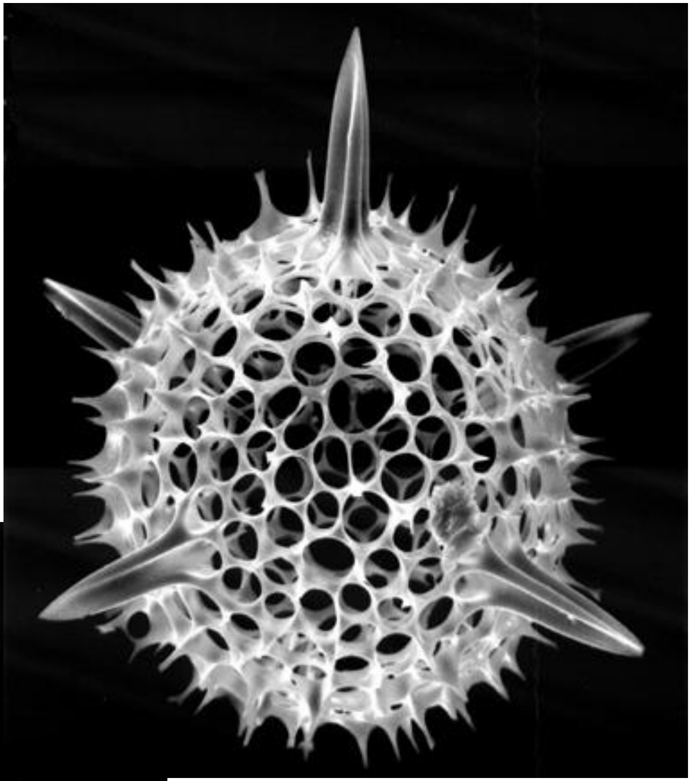
Calcareous Microfossils

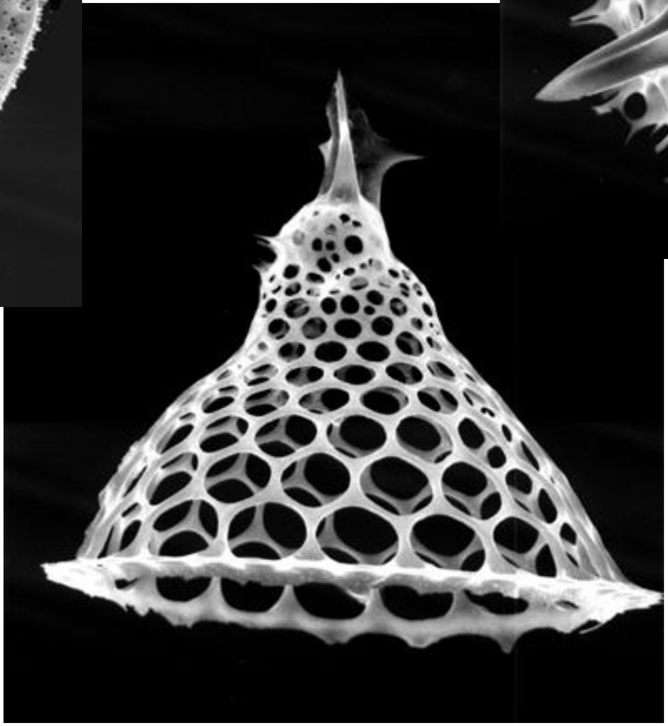
Siliceous Microfossils → Chert


Deformed chert in San Fransiscan Melange
Andrew T. Lin

Siliceous Microfossils







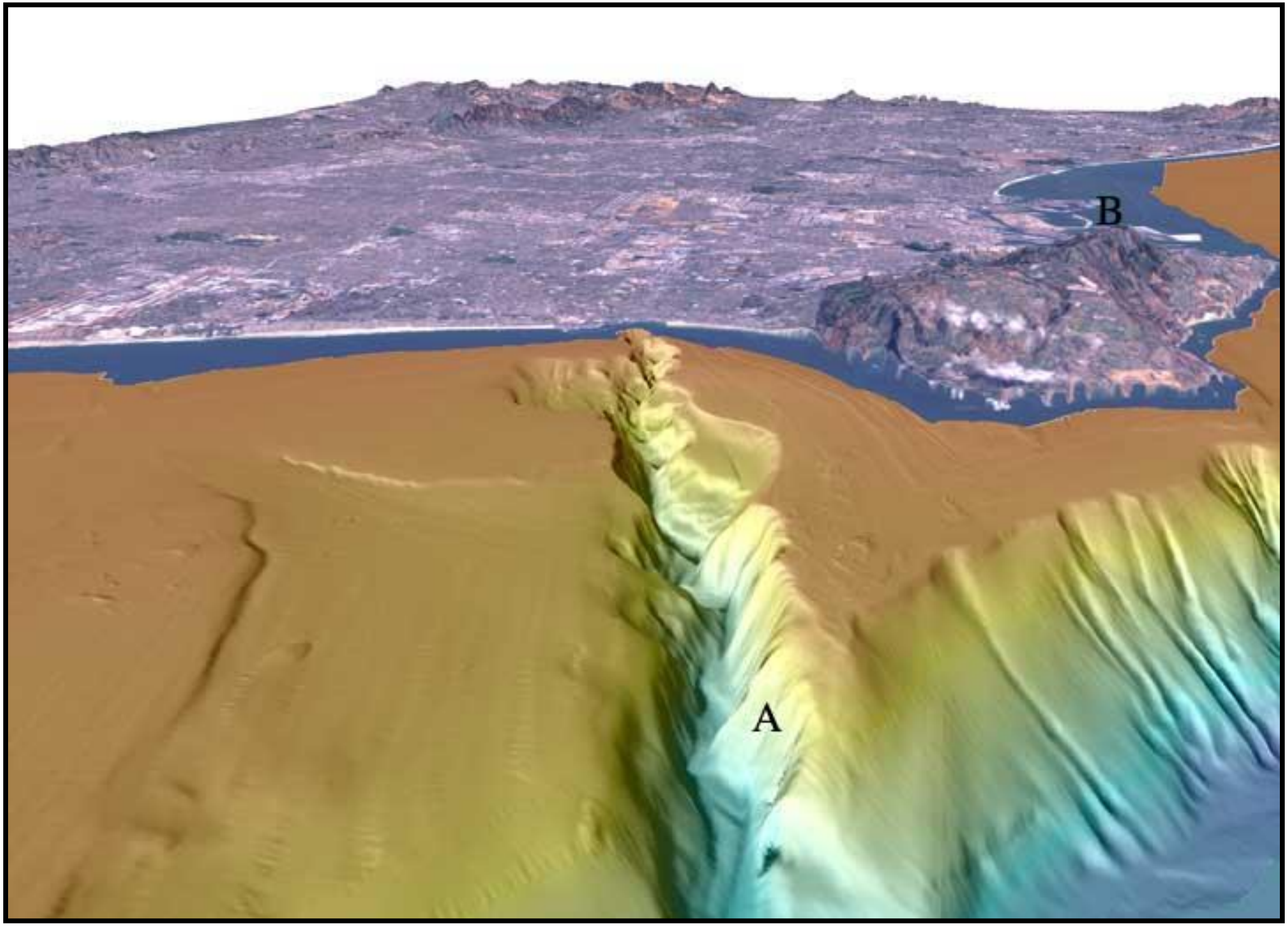
Deep Sea Fan Depositional Systems

- Form in the moderate to deep ocean, down-dip of submarine canyons and often deltas
- Large sediment flux, high sedimentation rate, large area
- Gravity flow transport and deposition
  - turbidity currents
  - subaqueous debris flows
  - suspension fall-out
- Lobes and lobe-switching important
- Both coarse and fine grained sediment
- Often well-sorted and normally graded

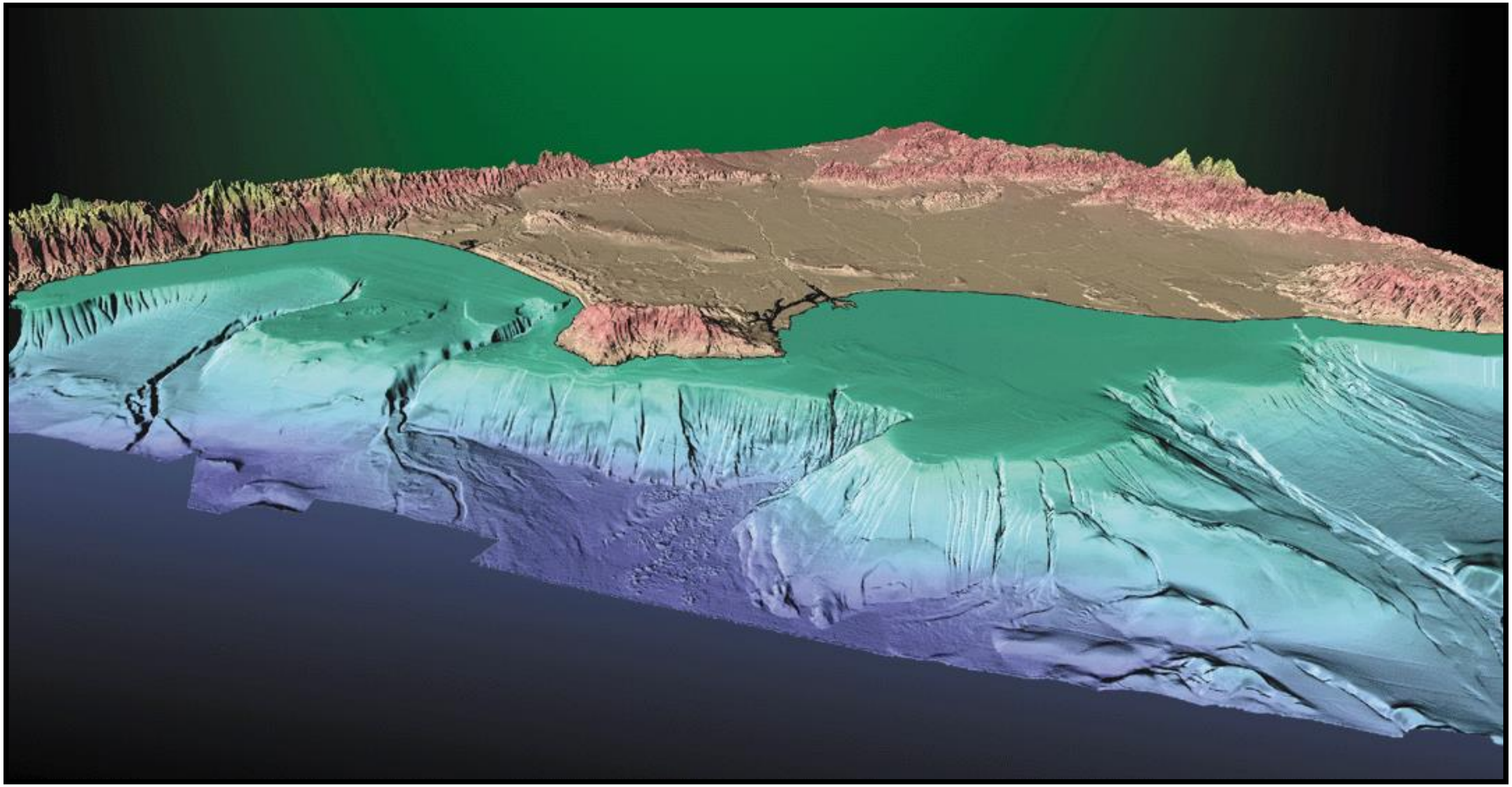
Characteristics of Deepwater Systems

- Sediments fine upward from marine fans
- Sand bodies form lobes perpendicular to basin margin
- Formed by a mix of fluvial input, and turbidite currents
- Facies
  - Subdivided erosion surfaces formed during
    - Migrating fan lobe fill
    - Dropping in base level
      - Local channels
    - Rising in base level
  - Poor to well sorted litharenites common
  - Sedimentary structures
    - Fining upward cycles that coarsen up as depo-center of lobes migrate
    - Up dip channel cut and fill
    - Gently seaward dipping thin parallel lobate sheets
  - Geometries
    - Confined incised channels
    - Open lobate sheets perpendicular and occasionally parallel to shore
  - Fauna & flora
    - Restricted Marine fauna often in over bank shales

Submarine Canyons



Submarine Canyons and Deep Sea Fans



Submarine Fan Types

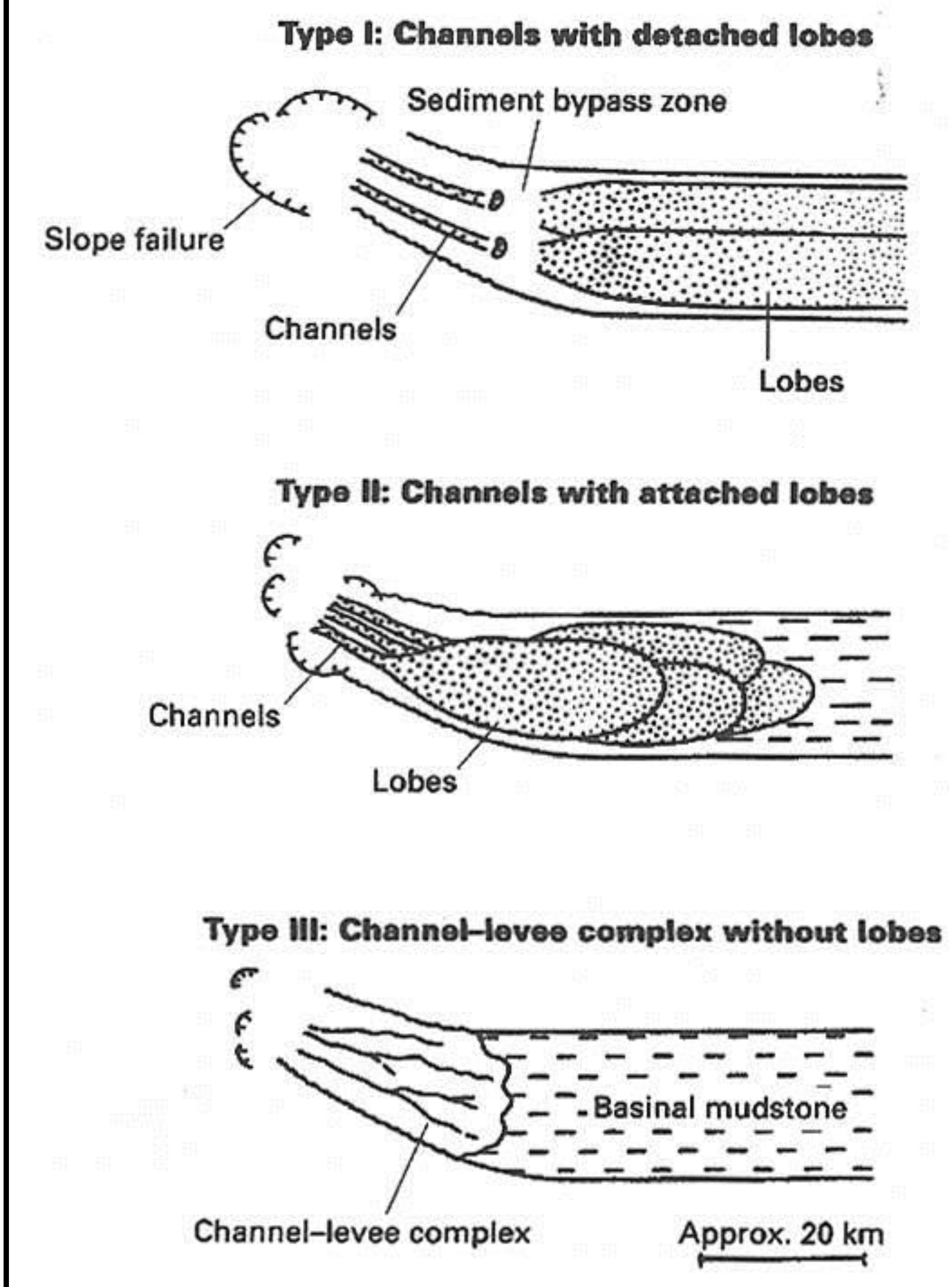
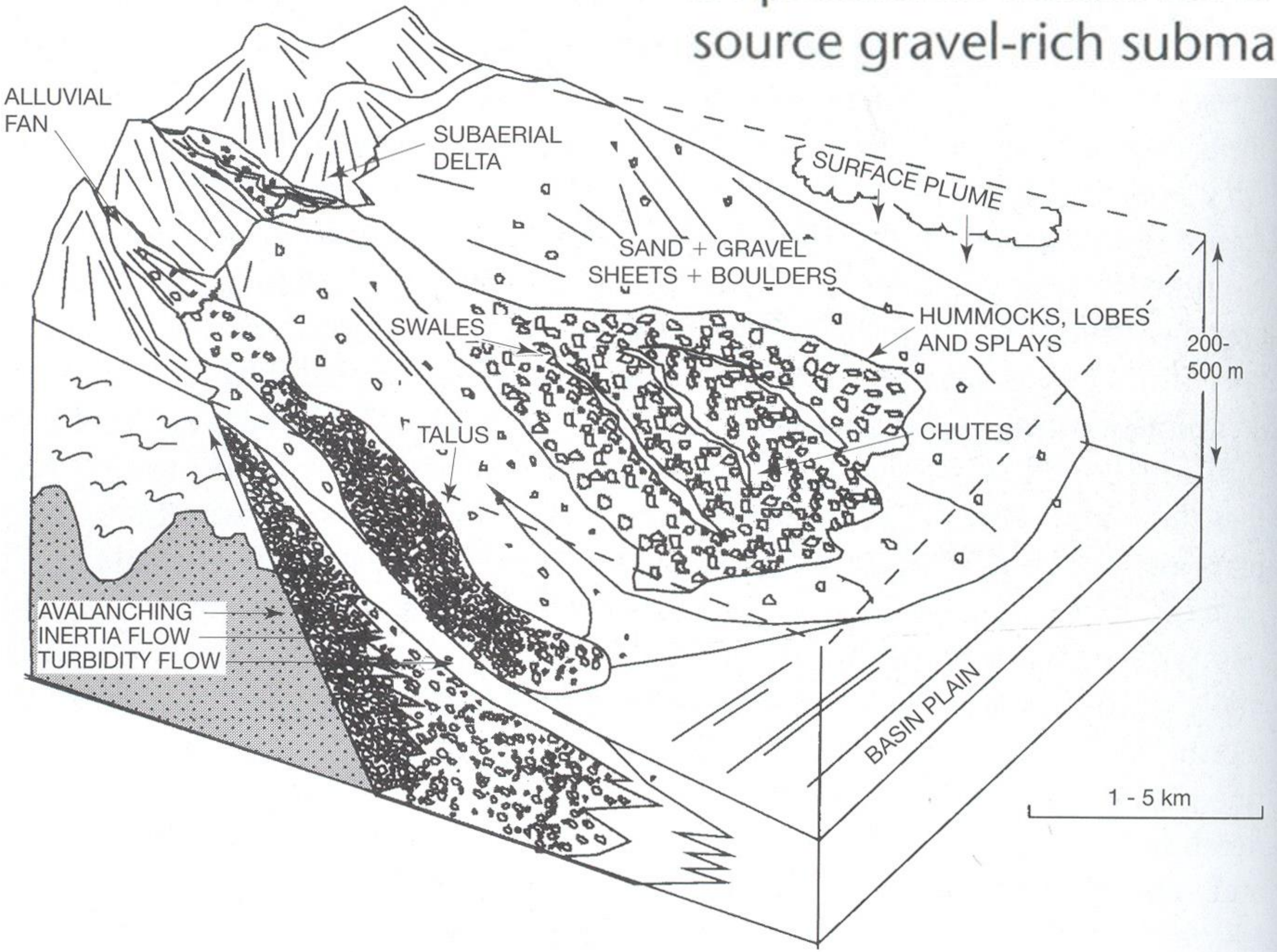


Figure 10.18

Depositional model for a point-source gravel-rich submarine fan.



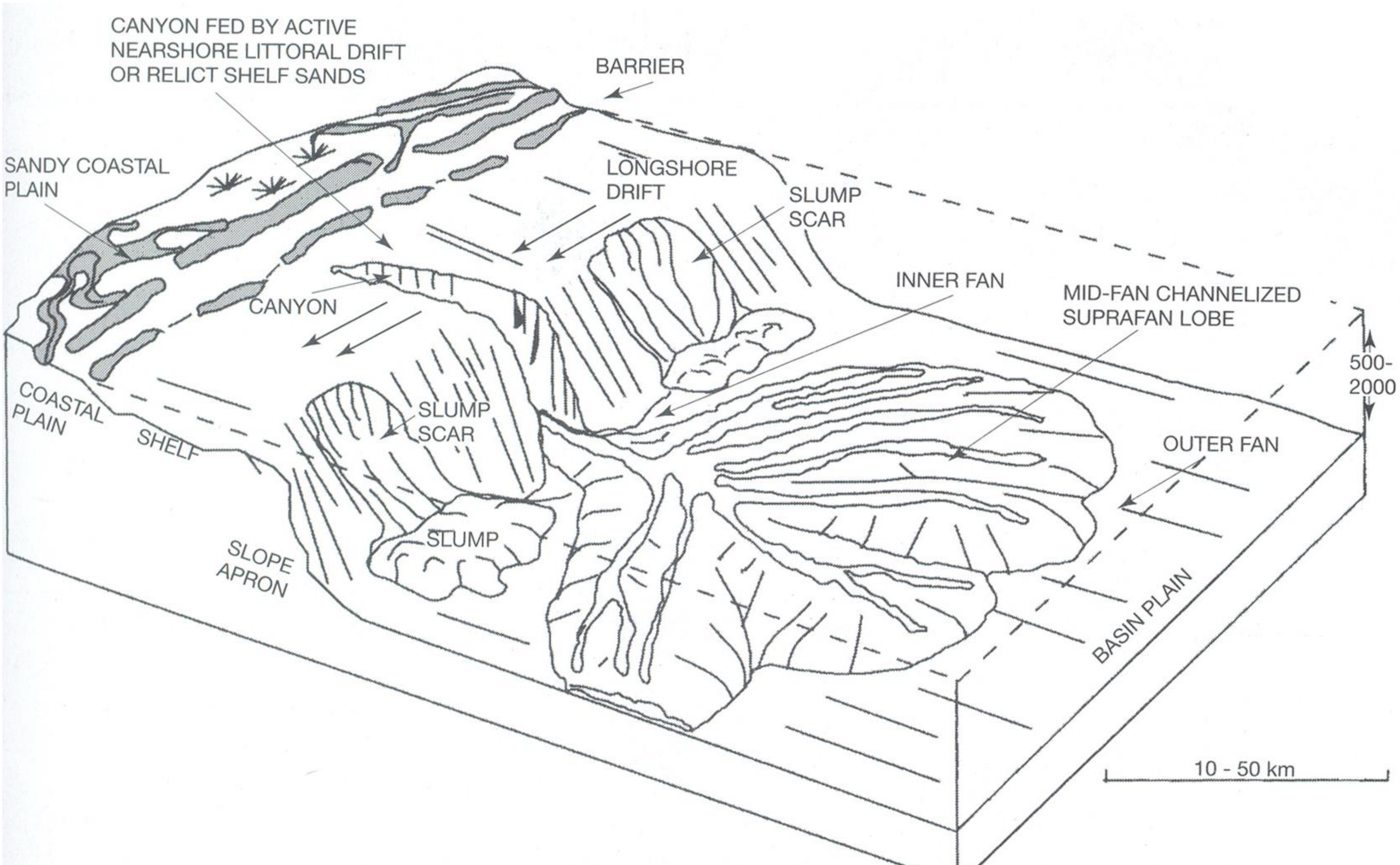


Figure 10.16

Depositional model for a point-source sand-rich submarine fan.

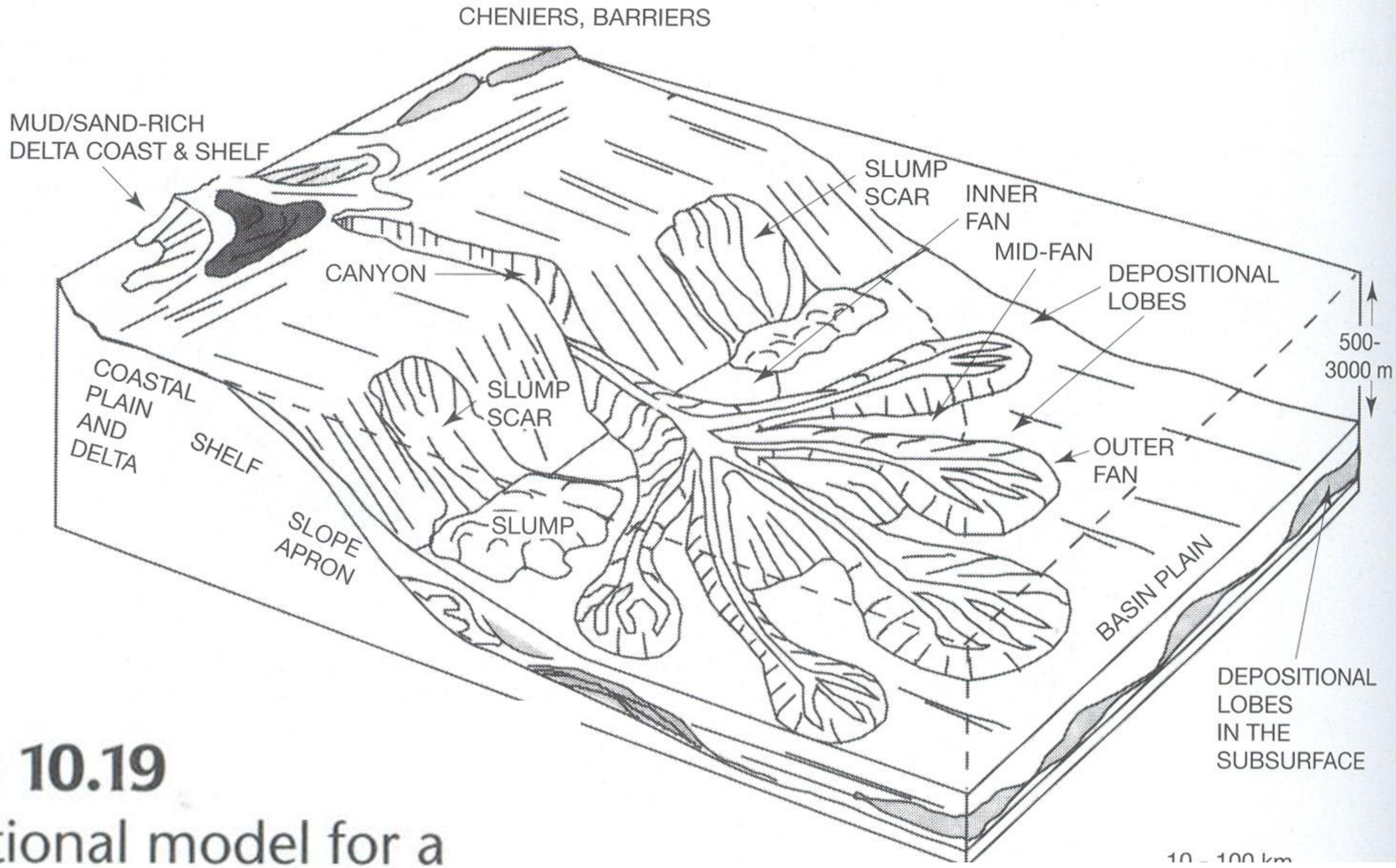
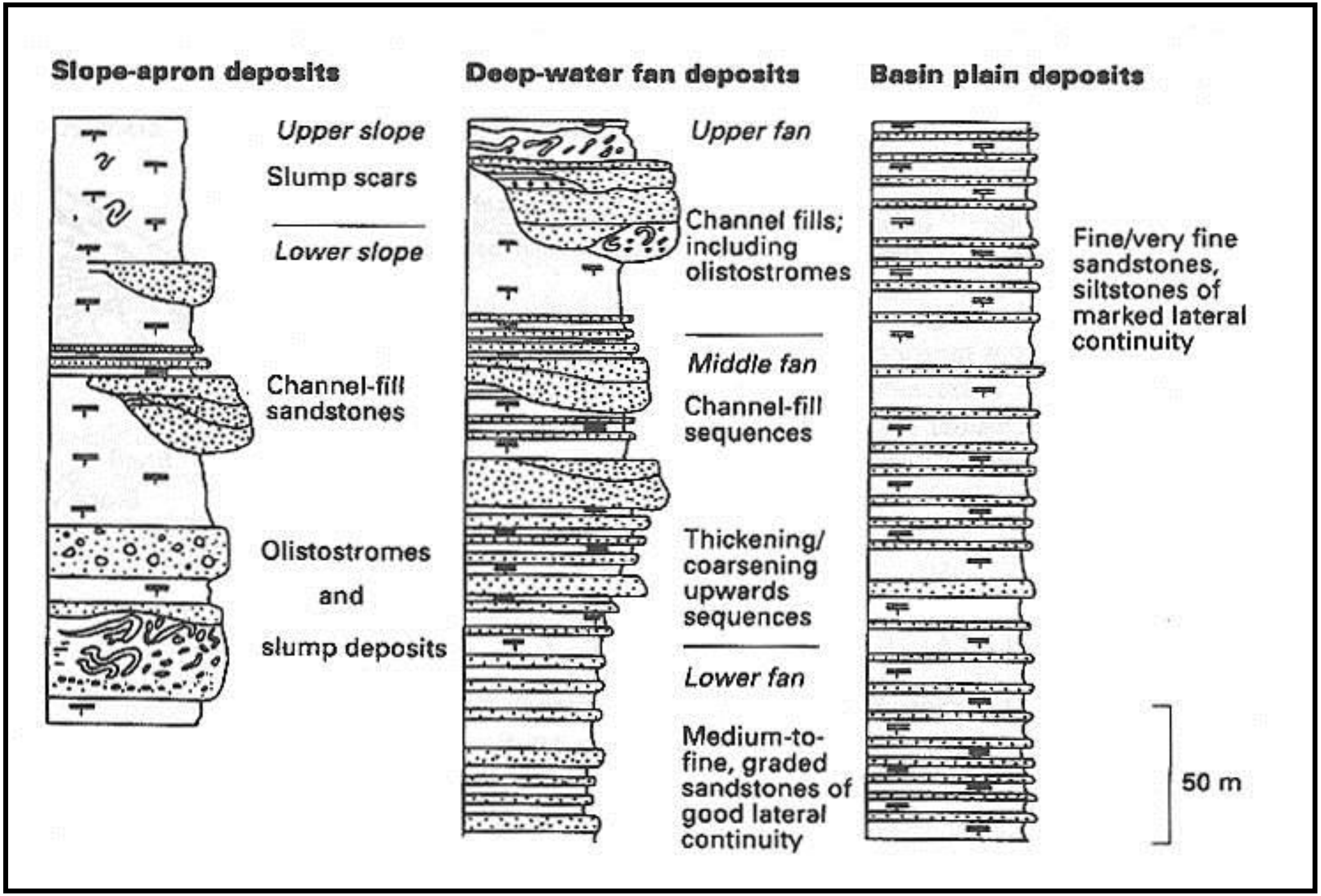
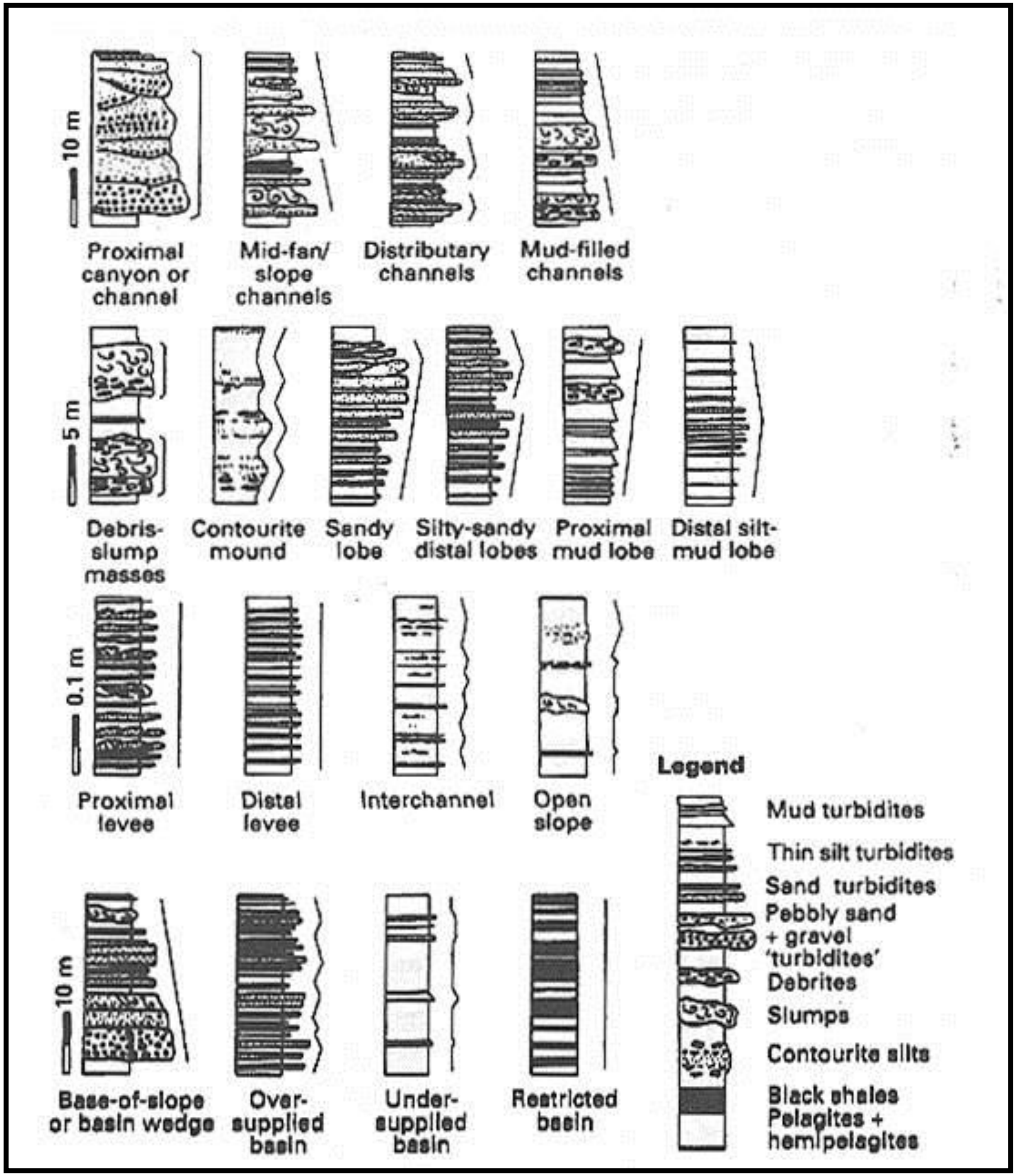


Figure 10.19
Depositional model for a point-source mud/sand-rich submarine fan. [From Read-

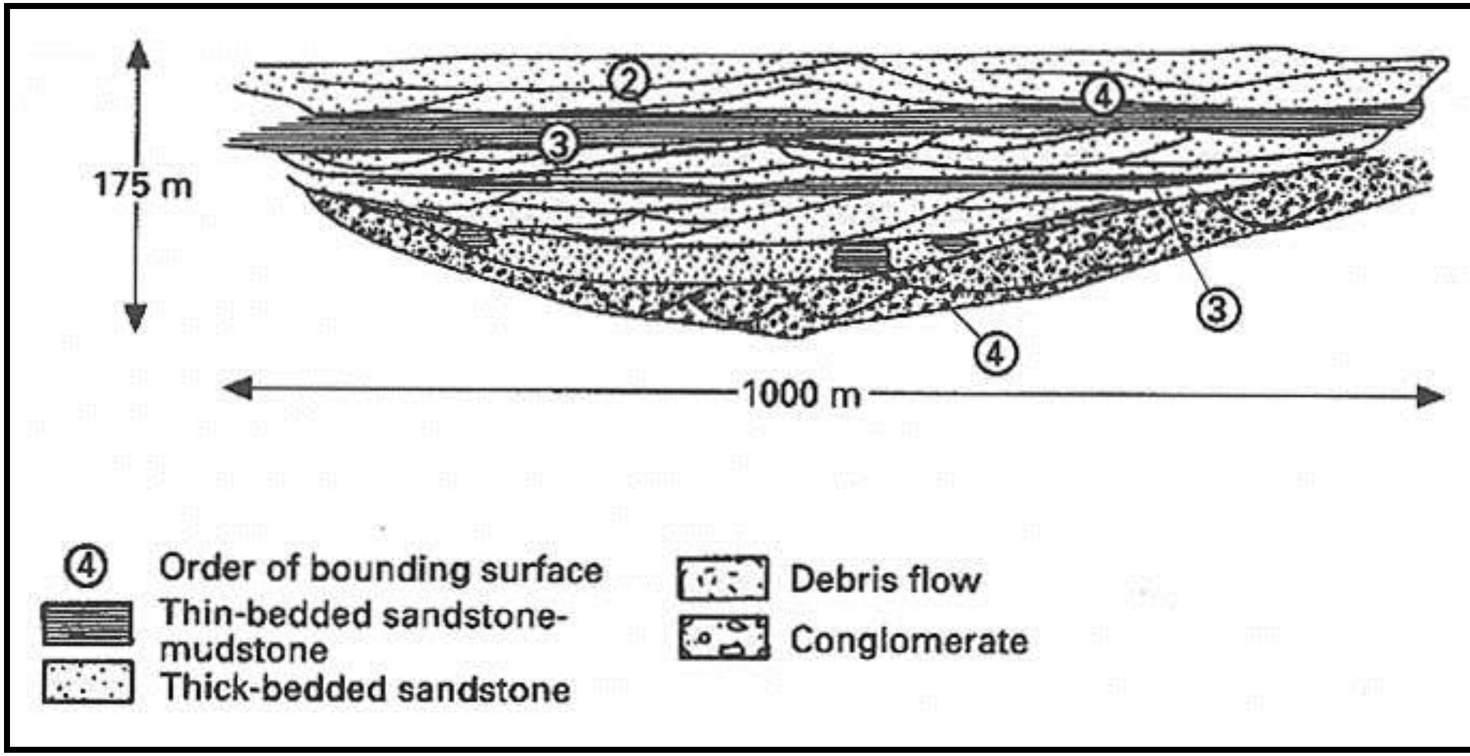
Deep Water Fan Deposits



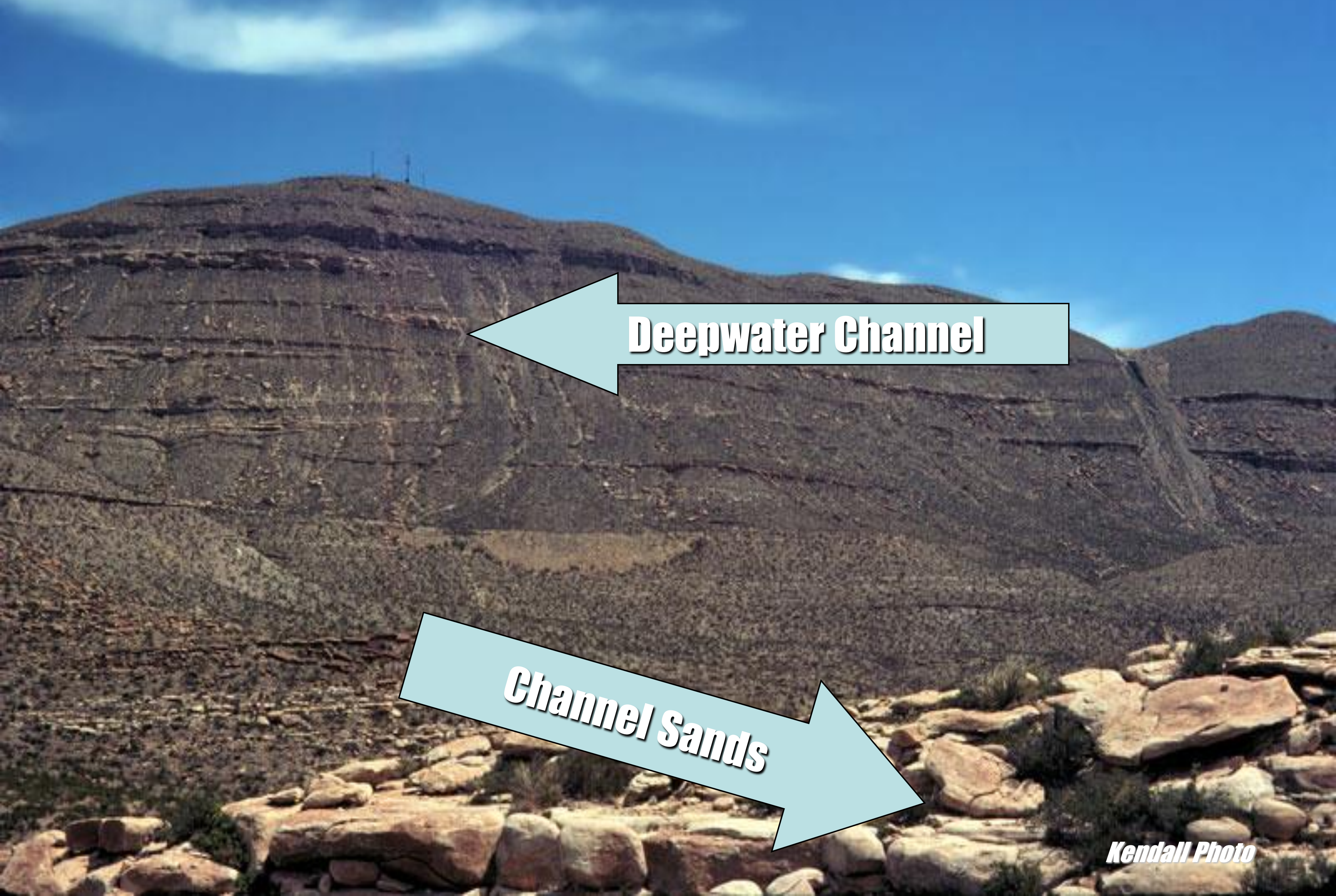
Deep Water Fan Deposits



Submarine Channels



Delaware Mountains – Basin Fans



Brushy Canyon Group - Base of Slope Permian Basin

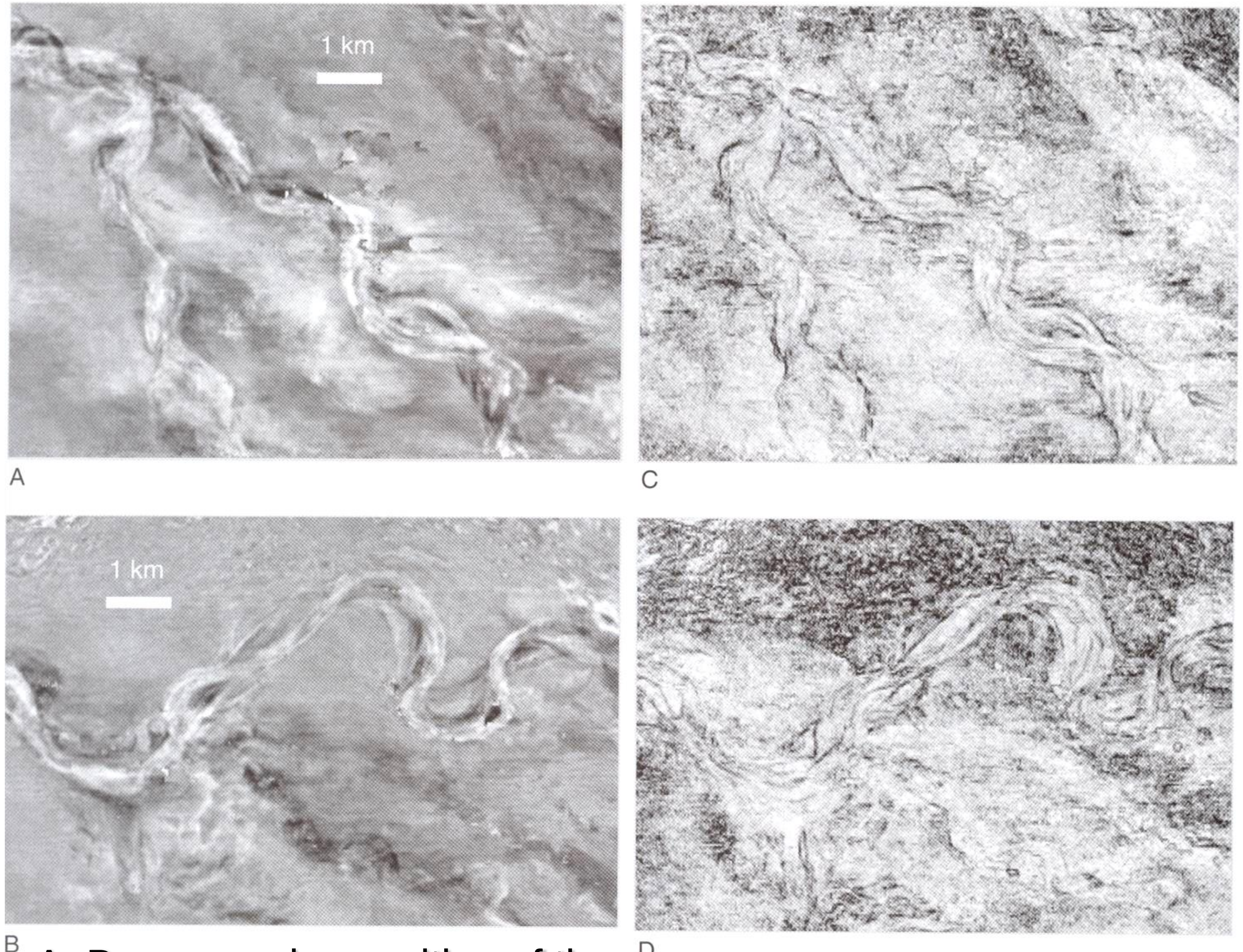
Deep-water Plio-Pleistocene channel system in the eastern Gulf of Mexico

A. Coherence is a volume attribute that emphasizes the correlation of seismic traces.

B. Light color: seismic traces correlate

Dark color: lack of correlation of seismic traces

C. Coherence highlights seismic edges: i.e., edge of depositional elements.

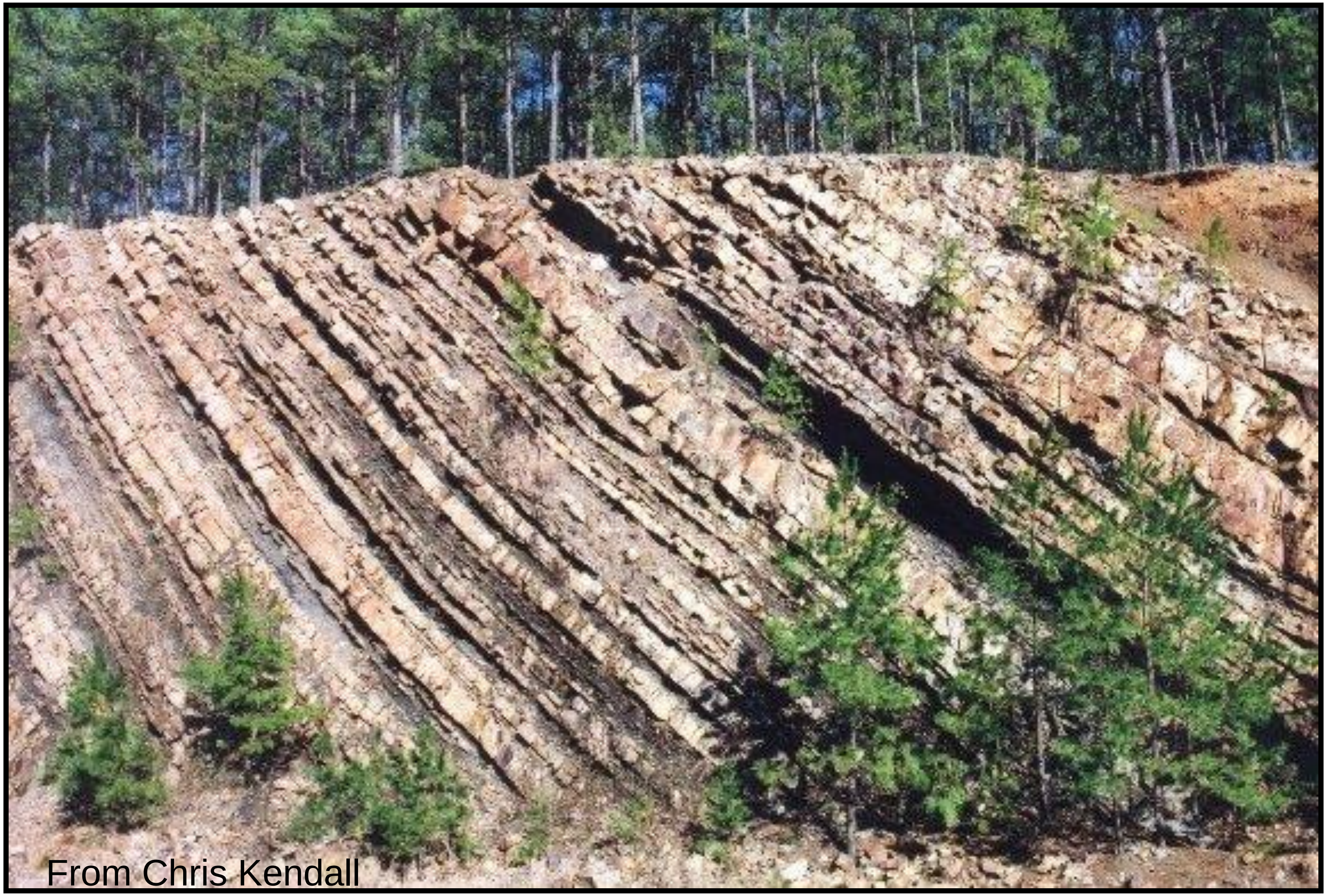


A, B: successive position of the channel thalweg and episodes of channel avulsion.

C, D: Coherence slice of A, B.

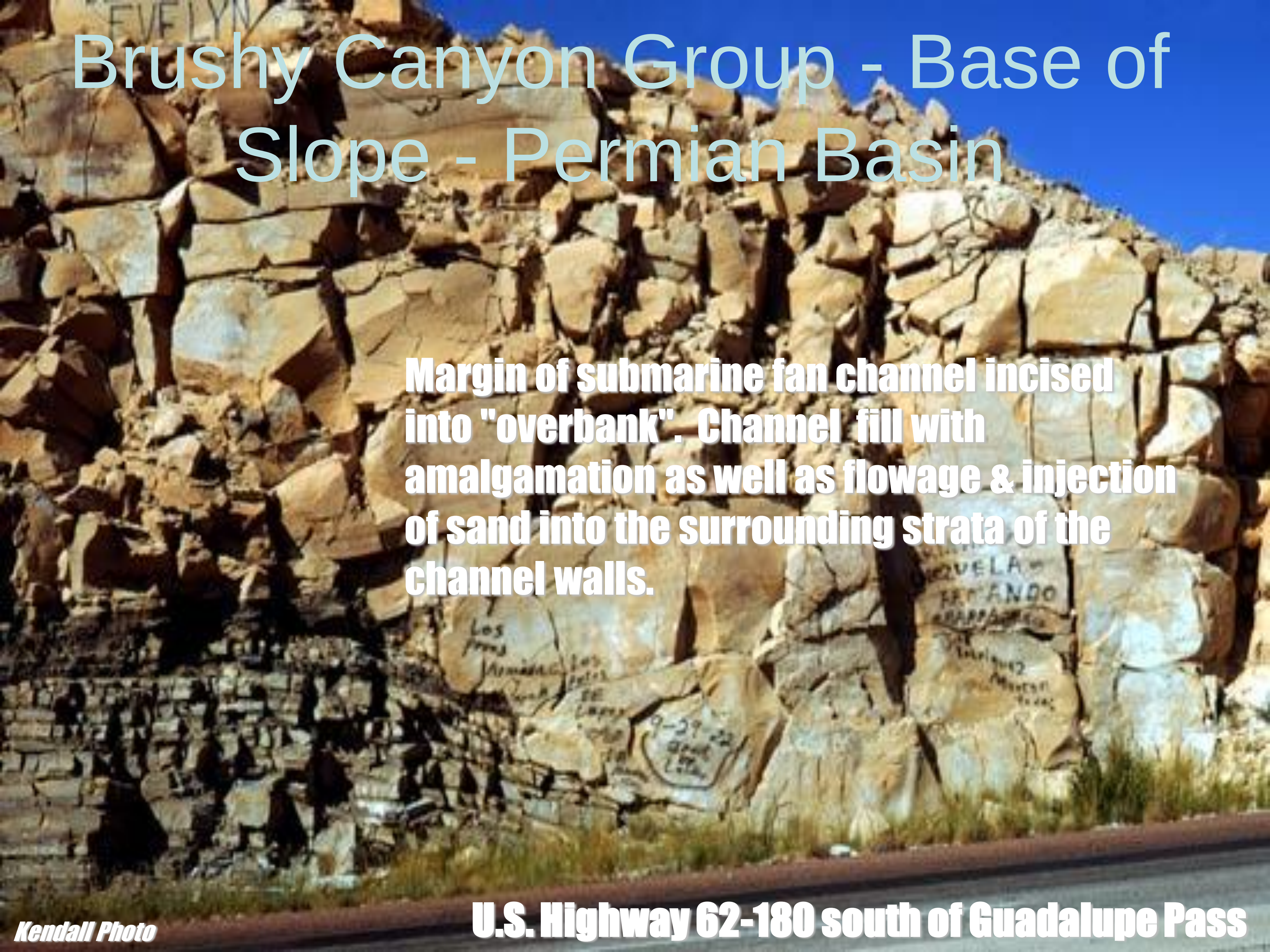
Catuneanu (2006)

Proximal Turbidites



Distal Turbidites

Brushy Canyon Group - Base of Slope - Permian Basin



Margin of submarine fan channel incised into "overbank". Channel fill with amalgamation as well as flowage & injection of sand into the surrounding strata of the channel walls.

Kendall Photo

U.S. Highway 62-180 south of Guadalupe Pass