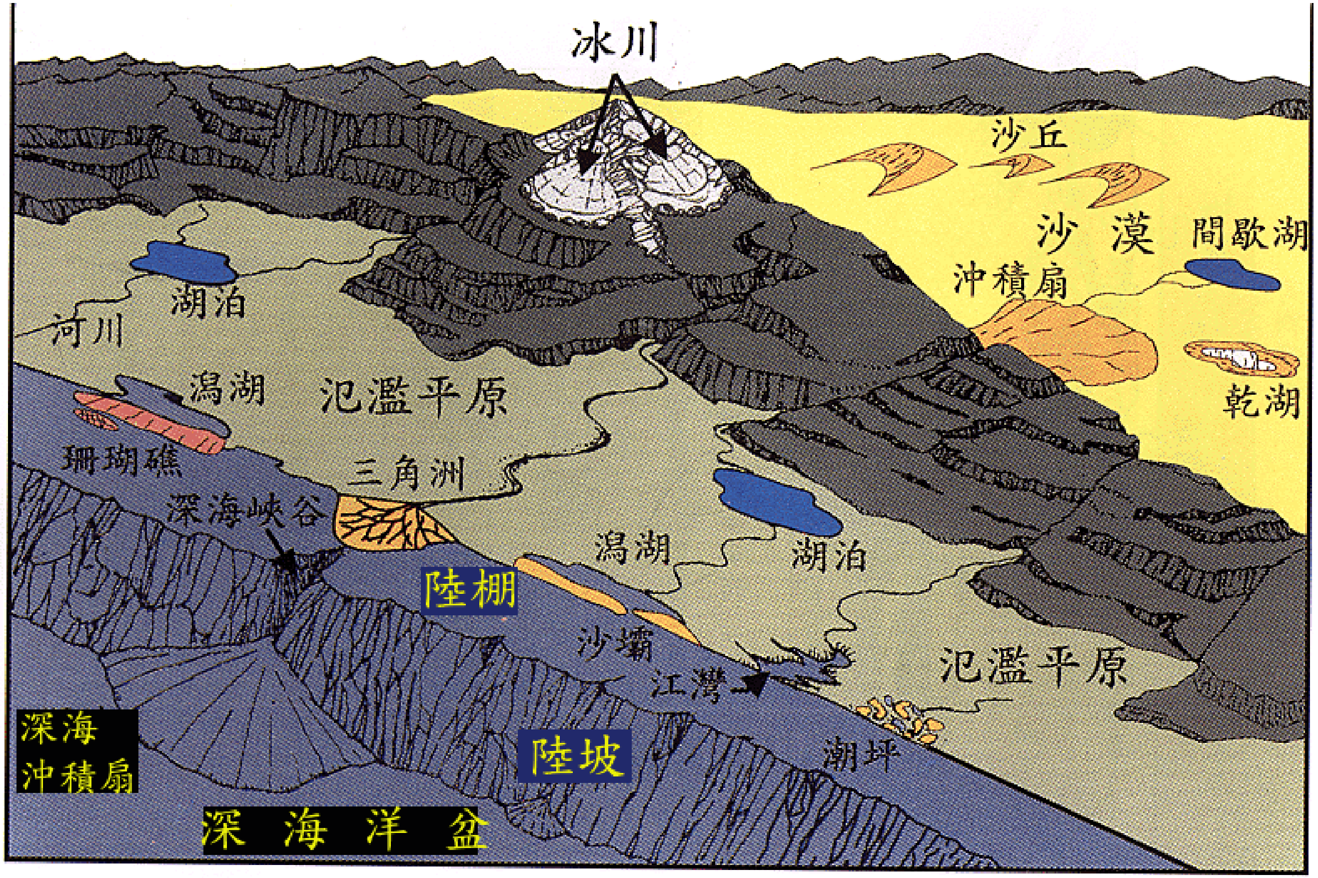
Part IV: Depositional Environments

A depositional environment is a **geomorphic unit** in which deposition takes places. Thus, the study of depositional environment is essentially the study of geomorphology, i.e. **recognition of geomorphic units**. Geomorphic units are recognized by features preserved in ancient sediments.



沈積環境示意圖。陸棚水深200m以內，陸坡深200m至洋盆。注意陸坡坡度只有4-5度，本圖因有垂直放大，使陸坡坡度似達80度。(鄧屬予，1997)

Principles of environmental interpretation and classification

Facies Analysis

1. **Definition:** A **facies** is a body of rock characterized by a particular combination of lithology, texture, suite of sedimentary structures, fossil content, colour, geometry, paleocurrent pattern, etc.

2. **How is a facies formed?** A facies is produced by one or several processes operating in a depositional environment.

3. **Description**: Facies are best referred to objectively in purely descriptive terms, using a few pertinent adjectives; examples could be cross-bedded, coarse sandstone facies or massive pebbly mudstone facies.

4. **Facies association**: Groups of facies genetically related to one another and which have some environmental significance can be designate as a **facies association.** The facies comprising an association are generally deposited in the same broad environment, in which there are several different depositional processes operating.

Facies analysis is to identify geomorphic units in which ancient sediments accumulated.

Sedimentary Environment (Process Element)

Dynamic elements of the environment

- Physical processes: wave and current activity; gravity processes; sea-level changes; tectonism and volcanism
- Chemical processes: solution, precipitation, authigenesis
- Biological processes: biochemical precipitation; biologic reworking of sediment; photosynthesis

Static elements of the environment

- Geomorphology of the depositional site
- Water depth
- Water chemistry
- Depositional materials (sediment supply)
- Climate

→

Sedimentary Facies (Response Element)

Geometry of the deposit

- Blanket, prism, shoestring, etc.

Primary sediment properties

- Physical: bedding and contact relationships; sedimentary textures and structures; color; particle composition
- Chemical: major-element and trace-element composition
- Biological: fossil content (types and abundances of fossils)

Derived sediment properties

- Porosity and permeability
- Accoustical properties (sound transmissibility)
- Electrical conductivity
- Radioactivity

Boggs (2006), p.242

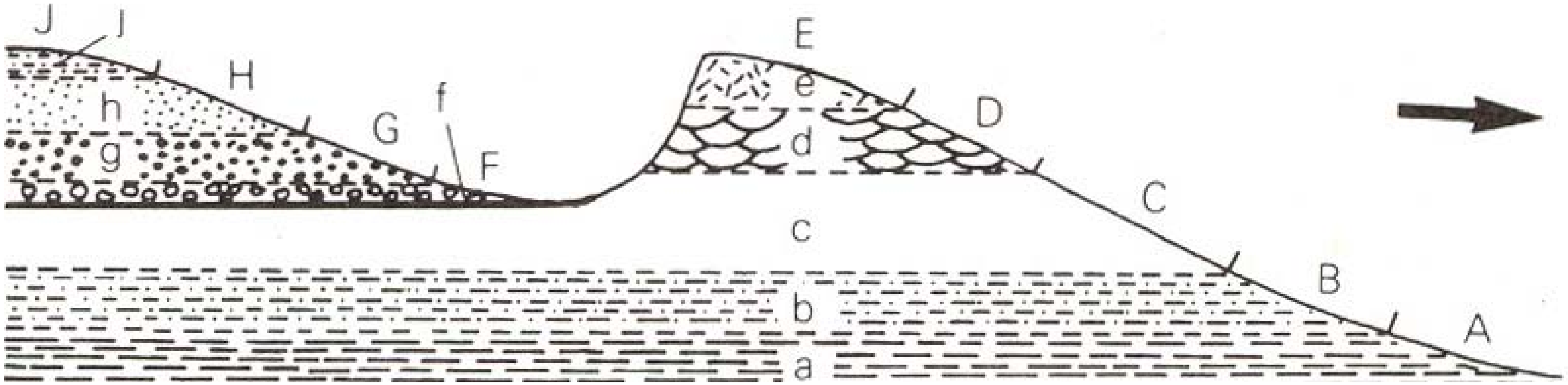
An example on facies classification for fluvial sediments

Table 2 *Facies classification. From Miall (1978b).*

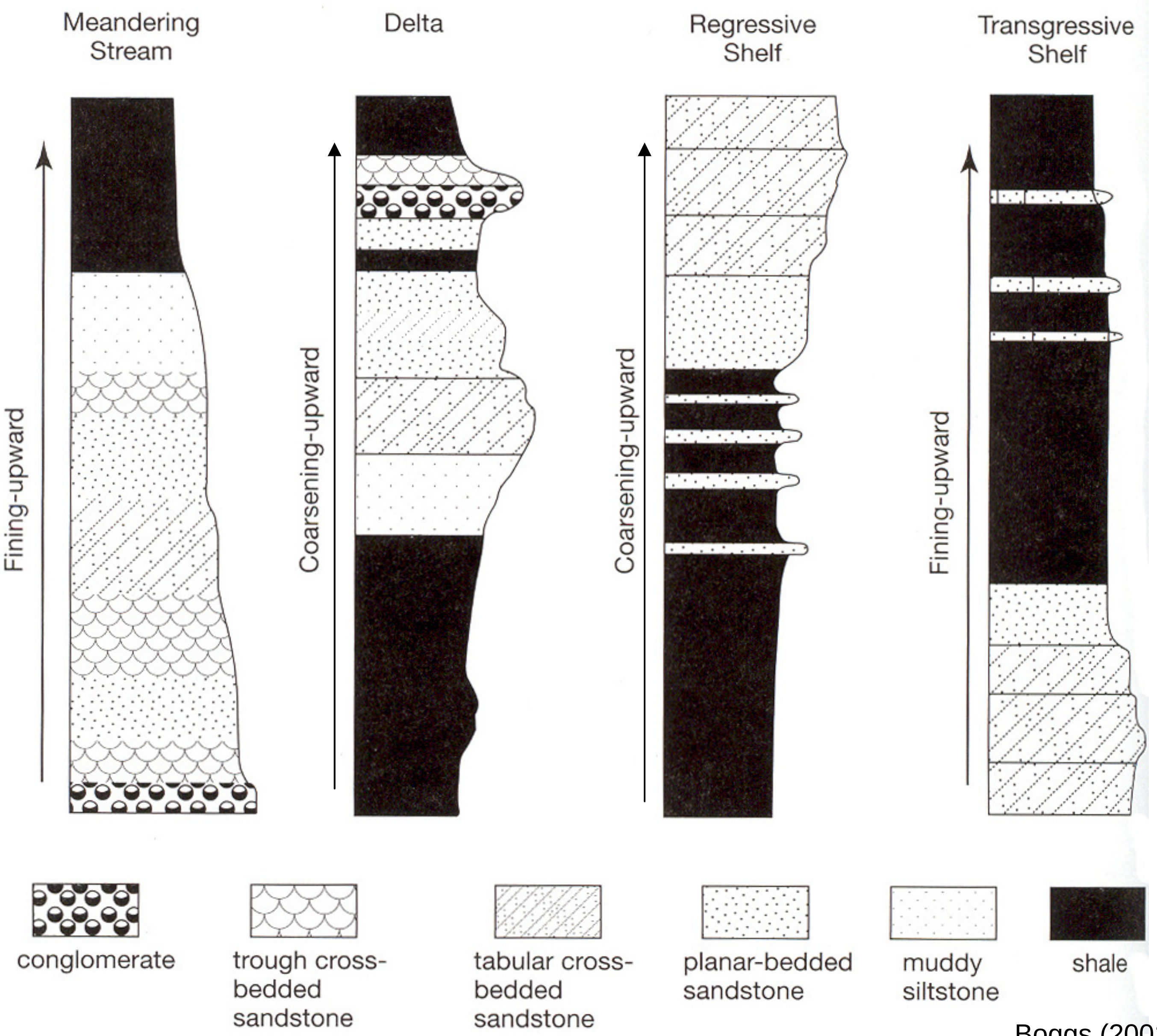
Facies code	Facies	Sedimentary Structures	Interpretation
Gms	massive, matrix supported gravel	grading	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough cross beds	minor channel fills
Gp	gravel, stratified	planer cross beds	longitudinal bars, deltaic growths from older bar remnants
St	sand, medium to very coarse, may be pebbly	solitary or grouped trough cross beds	dunes (lower flow regime)
Sp	sand, medium to very coarse, may be pebbly	solitary or grouped planer cross beds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple cross lamination	ripples (lower flow regime)
Sh	sand, very fine to very coarse may be pebbly	horizontal lamination parting or streaming lineation	planer bed flow (upper flow regime)
Sl	sand, very fine to very coarse may be pebbly	low angle (<10°) cross beds	scour fills, washed-out dunes, antidunes
Se	erosional scours with intraclasts	crude cross bedding	scour fills
Ss	sand, fine to very coarse, may be pebbly	broad, shallow scours	scour fills
Fl	sand, silt, mud deposits	fine lamination, vey small ripples	overbank or waning flood
Fsc	silt, mud	laminated to massive	backswamp deposit
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
C	coal, carbonaceous mud	plant, mud films	swamp deposits
P	carbonate	pedogenic features	paleosol

Facies interpretation is often facilitated by considering the vertical facies succession. Where there is a conformable vertical succession of facies, with no major breaks, the facies are the products of environments which were originally laterally adjacent.

This concept has been appreciated since Johannes Walther expounded his Law of Facies in 1894. **The vertical succession of facies is produced by the lateral migration of one environment over another (e.g. the progradation of a delta or tidal flat). Where there are breaks in the succession, seen as sharp or erosional contacts between facies, then the facies succession need not reflect laterally adjacent envrionments but could well be the products of widely separated environments.**



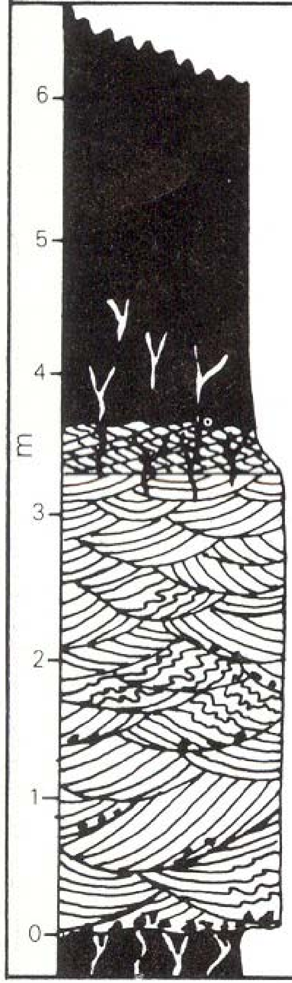
Examples of fining-upward and coarsening-upward facies successions



Boggs (2001), p.260

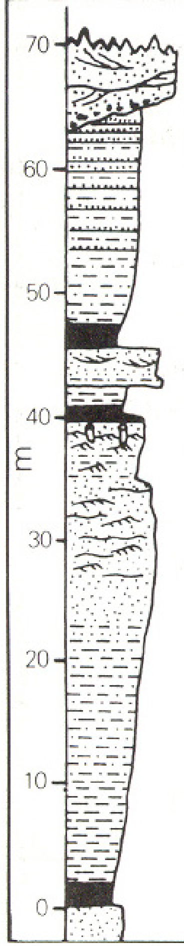
Fluvial example of a fining-upward sequence

(a)



Main facts	Processes	Environment
Coarse, red, structureless siltstone. No body fossils. Sparse concretions of calcium carbonate. Invertebrate burrows in lower part.	Deposition of silt from suspension. Could be from air or water. Post-depositional burrowing and growth of concretions.	Continental, overbank interchannel setting accumulating sediment by vertical accretion. Concretions grow in caliche soil profile.
Fine grained red sandstone. Ripple drift cross laminated. Invertebrate burrows.	Rapid deposition of sand during bedload transport as current ripples. Post-depositional colonisation by animals.	Channel margin/levee?
Fine to medium grained red sandstone. Trough cross bedded with unidirectional palaeocurrents. Siltstone clasts on set bases. Convolute bedding in some sets. Upwards reduction in set size.	Net accumulation of sand during migration of dunes. Post-depositional liquefaction suggests rapid deposition. Erosion taking place nearby.	Laterally migrating channel with deposition on one side; probably a point bar of a meandering stream.
Sharp surface with slight relief. Scoured sole marks. Concentration of siltstone clasts above surface.	Erosion by fluid scour. Winnowing of finer sediment to leave a lag of intraformational clasts.	

Deltaic example of a coarsening-upward sequence



(b) *Main facts*			*Environment*
Cross bedded sandstone. Sharp contact with relief and siltstone clasts.	Dune migration; strong currents. Erosion and winnowing.	prograding delta front	Fluvial distributary channel.
Siltstone with parallel lamination and graded sand beds.	Deposition from suspension. with episodic decelerating flows.		Mouth bar.
Siltstone.	Deposition from suspension.		Delta slope.
Mudstone with marine fossils.	Deposition from suspension; high salinity.		
Coarsening upwards unit.	Increase in energy; shallowing?		Minor readvance of delta?
Mudstone.	Deposition from suspension.		Abandonment of mouth bar.
Siltstone with current ripples, burrows on top.	Mixture of deposition from suspension and from bedload transport by weak currents.		
Cross laminated sandstone with silty partings.	Bedload transport as ripples with quiet interludes.	prograding delta front	Proximal mouth bar.
Silty mudstone with siltstone laminae.	Deposition from siltstone with fluctuating supply.		Delta slope.
Gradationally striped silty mudstone.			
Mudstone with marine fossils.	Deposition from suspension.		Offshore; pro-delta.

Progressive facies successions are commonly terminated by **bounding discontinuities** of some type which generally characterized by abrupt changes in lithology across discontinuities or abrupt changes in facies; these might be erosion surfaces, or surfaces of non-deposition.

Simplified classification of ancient depositional environments

Primary Depositional Setting	Major Environment	Subenvironment
Continental	*Fluvial	*Alluvial fan *Braided stream *Meandering stream
	*Desert	
	Lacustrine	
	*Glacial	
Marginal-marine	*Deltaic	*Delta plain *Delta front *Prodelta
	*Beach/barrier island	
	*Estaurine/lagoonal	
	Tidal flat	
Marine	Neritic	Continental shelf **Organic reef
	Oceanic	Continental slope Deep-ocean floor

*Dominantly siliciclastic deposition

**Dominantly carbonate deposition

Environments not marked by an asterisk(s) may be sites of siliciclastic, carbonate, evaporite, or mixed sediment deposition depending upon conditions.

Boggs (2006), p.243

Table 8–1 Criteria for Recognition of Ancient Sedimentary Environments

Criteria based on primary depositional properties

Mainly physical properties.

- Geometry of facies units—useful only if very distinctive, e.g., ribbon shape of channels; lobate shape of deltaic deposits.
- Gross lithology and mineralogy of strata—a very general environmental indicator; e.g., fossiliferous limestone suggests shallow marine shelf settings; coal indicates swampy environments; the mineral glauconite suggests marine conditions.
- Facies associations (stratigraphic successions)—for example, fining-upward successions are characteristic of meandering-stream deposits; regressive shelf environments (shoreline advancing seaward with time) produce coarsening-upward successions.
- Sedimentary structures.
  - Nondirectional structures—not unique environmental indicators but suggest depositional process; e.g., ripples indicate current flow, graded bedding indicates settling of grains from suspension, mudcracks indicate subaerial exposure.
  - Directional structures (paleocurrent indicators)—paleocurrent patterns may have environmental significance; e.g., bimodal patterns suggest tidal influence; unimodal patterns of high variability suggest meandering-stream environments.
- Sedimentary textures—grain-size data of limited usefulness; grain shape measured by Fourier analysis may be significant; grain orientation (e.g., imbrication) a useful paleocurrent indicator.

Boggs (2001), p.261

Mainly chemical properties

Major-element composition—very limited usefulness.

Trace-element composition—some application in paleosalinity interpretation; e.g., boron more abundant in marine shales than in freshwater shales.

Isotope ratios—carbon and oxygen isotopes may be used to interpret marine vs. nonmarine conditions; oxygen isotopes a possible ocean paleotemperature indicator.

Mainly biologic properties.

Kinds of fossils and their ecologic characteristics—very useful indicators of salinity, temperature, depths, energy, and turbidity of ancient oceans; also an indicator of substrate type (rock, sand, mud).

Types of trace fossils—water depth indicators.

Criteria based on derived sediment properties

Properties measured or interpreted from instrumental well logs.

Properties such as rock resistivity, velocity of sound transmission, and natural radioactivity can be measured in well bores and used, for example, to interpret coarsening- and fining-upward successions in subsurface strata.

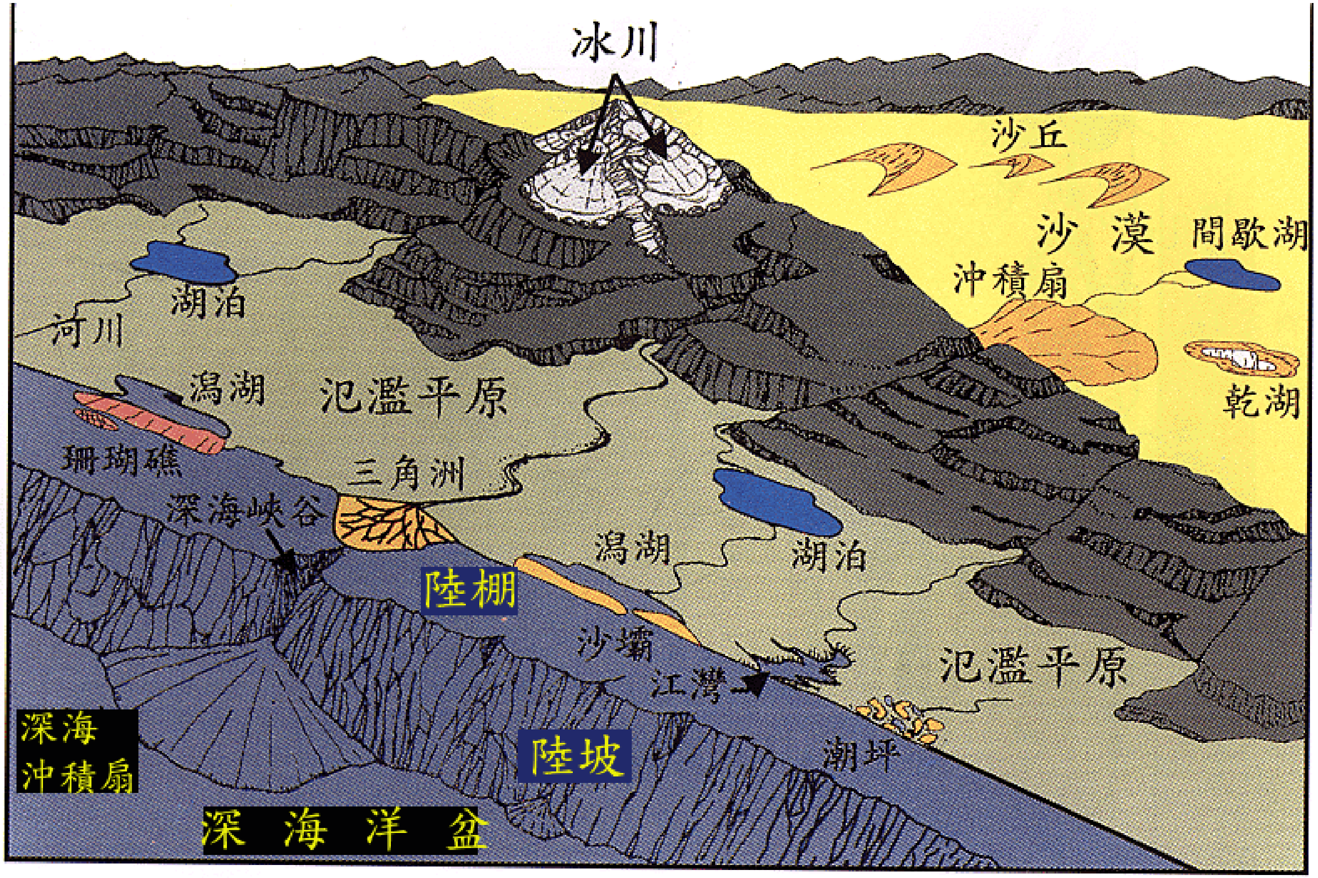
Characteristics interpreted from seismic reflection records.

Sesimic reflection characteristics identified from seismic records indicate features such as inclined bedding, truncations, and pinchouts that have environmental significance.

Boggs (2001), p.261

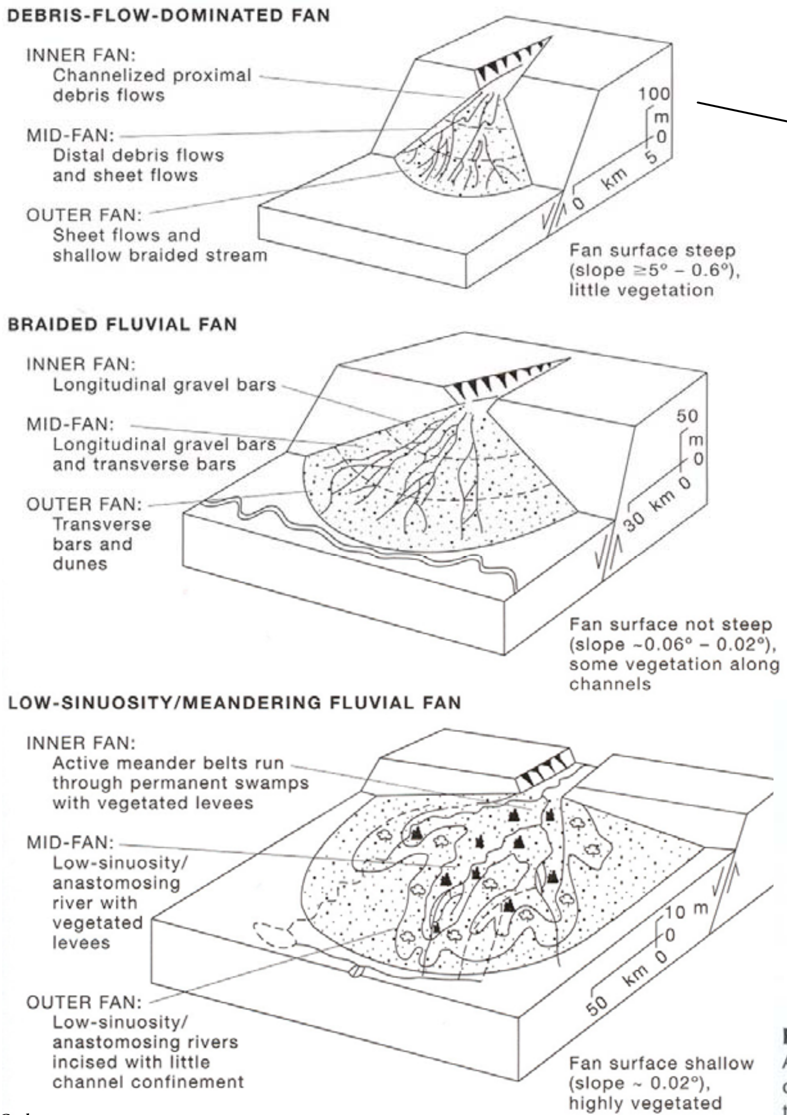
8. Continental Environments

In the **continental environment**, most sediment transport is accomplished by flows that move in response to the gravity field from positions of greater to lesser potential energy except wind-blown sediment. Where the flow paths of wind flows are determined by the local barometric gradient rather than the earth's gravity field.



沈積環境示意圖。陸棚水深200m以內，陸坡深200m至洋盆。注意陸坡坡度只有4-5度，本圖因有垂直放大，使陸坡坡度似達80度。(鄧屬予，1997)

8.1 Alluvial Fans (沖積扇)



Stanistreet & McCarthy (1993)

Alluvial fans are deposits with gross shapes approximating a segment of a cone and exhibiting a convex-up transverse profile.

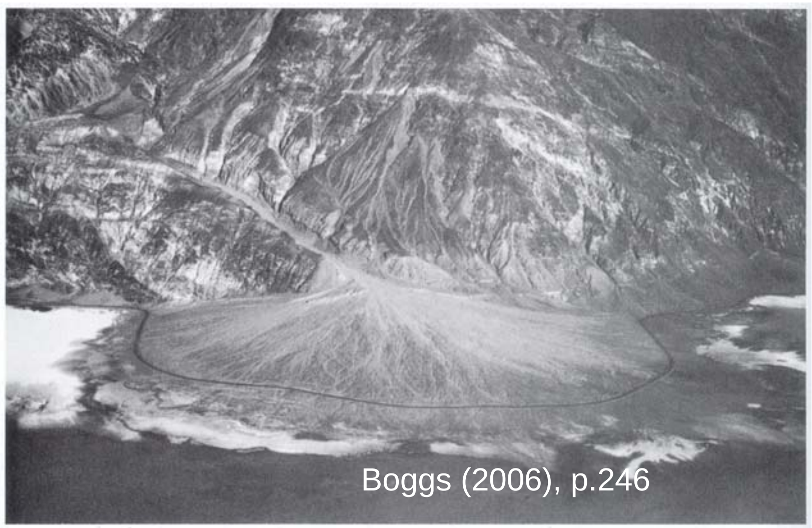
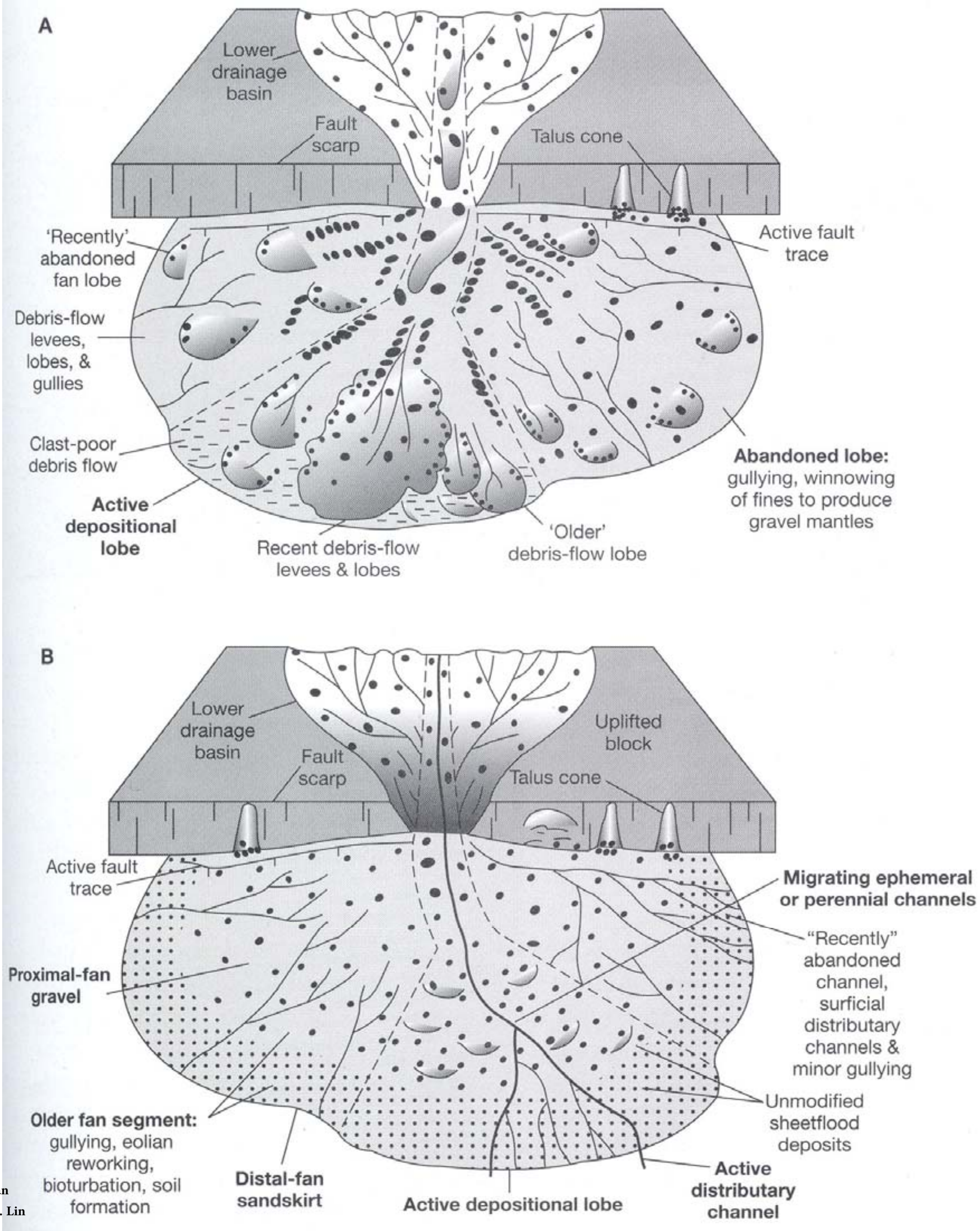


Figure 8.1
Aerial view of a debris-flow-dominated alluvial fan at the mouth of a canyon in the steep east wall of Death Valley, California. The highway gives the scale. [Photograph by John Shelton.]

Boggs (2006), p.246

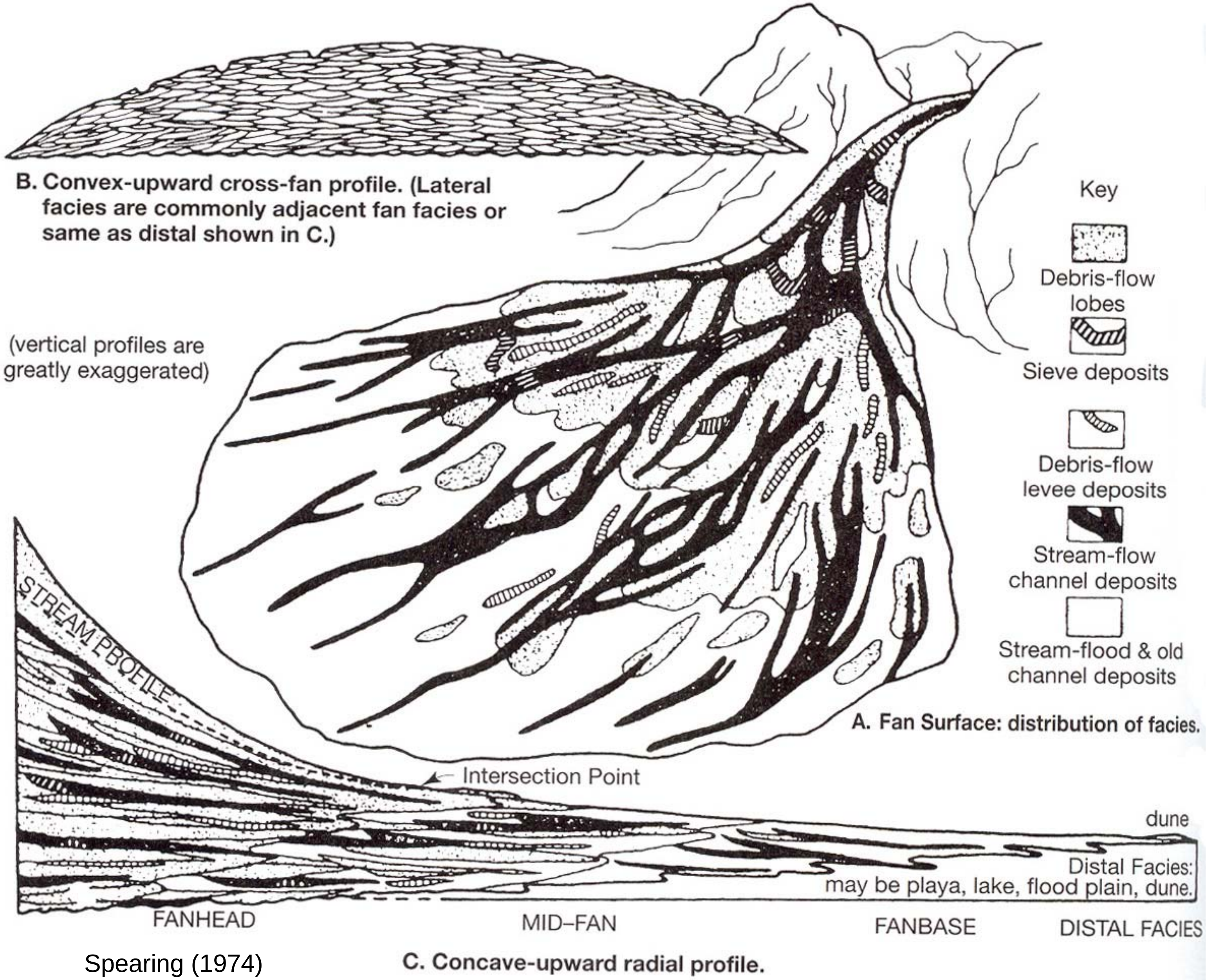
Debris-flow versus stream-flow-dominated alluvial fans



Boggs (2006), p.247

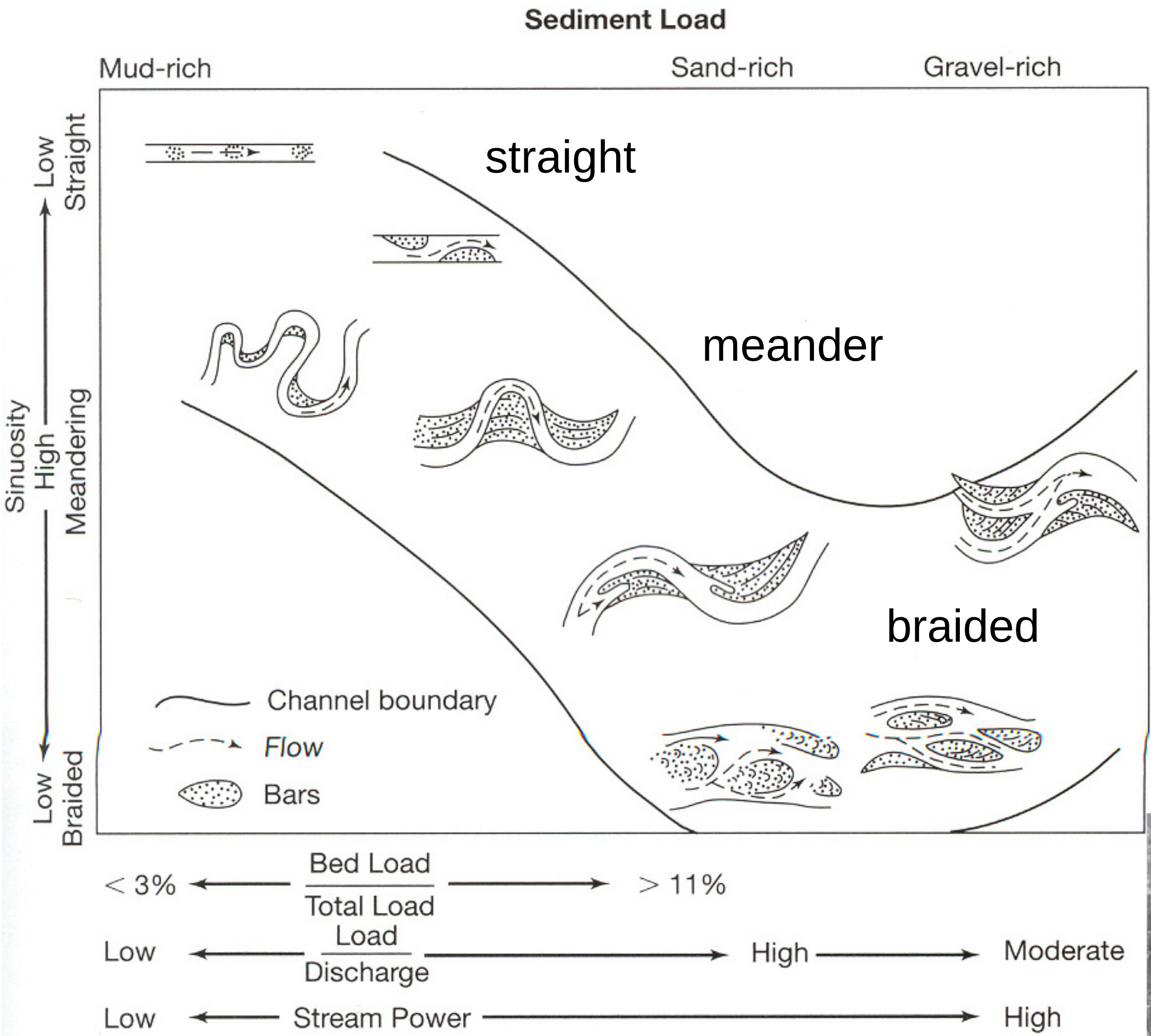
Figure 8.2
Schematic diagrams illustrating the depositional features of (A) debris-flow and (B) stream-flow-dominated alluvial fans adjacent to active normal faults. [Modified from Blair and McPherson, 1994, Alluvial fans and their natural distinction from rivers based on morphology, hydraulic process, sedimentary processes, and facies assemblages: Jour. Sedimentary Research, v. A34, Fig. 1, p. 455, reproduced by permission of the Society for Sedimentary Geology.]

Typical surface features and cross-sectional profiles of alluvial fans

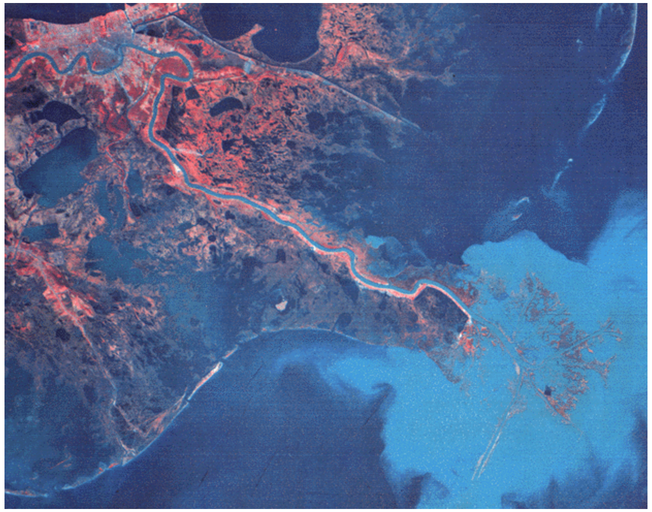


Spearing (1974)

8.2 River Systems



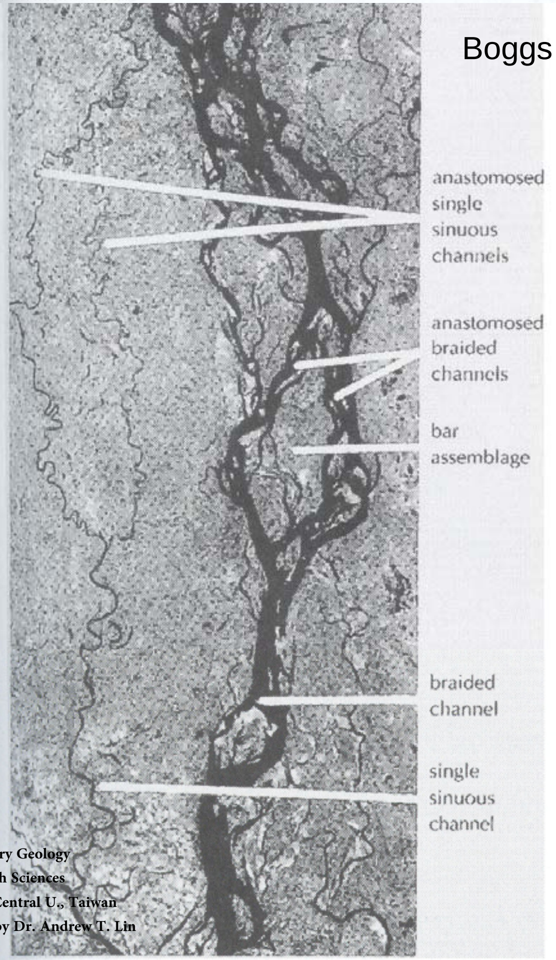
Galloway & Hobday (1996)



Braided Rivers

Figure 8.6
Braid bars in a braided lower reach of the Kongakut River, Arctic National Wildlife Refuge, northeastern Alaska.

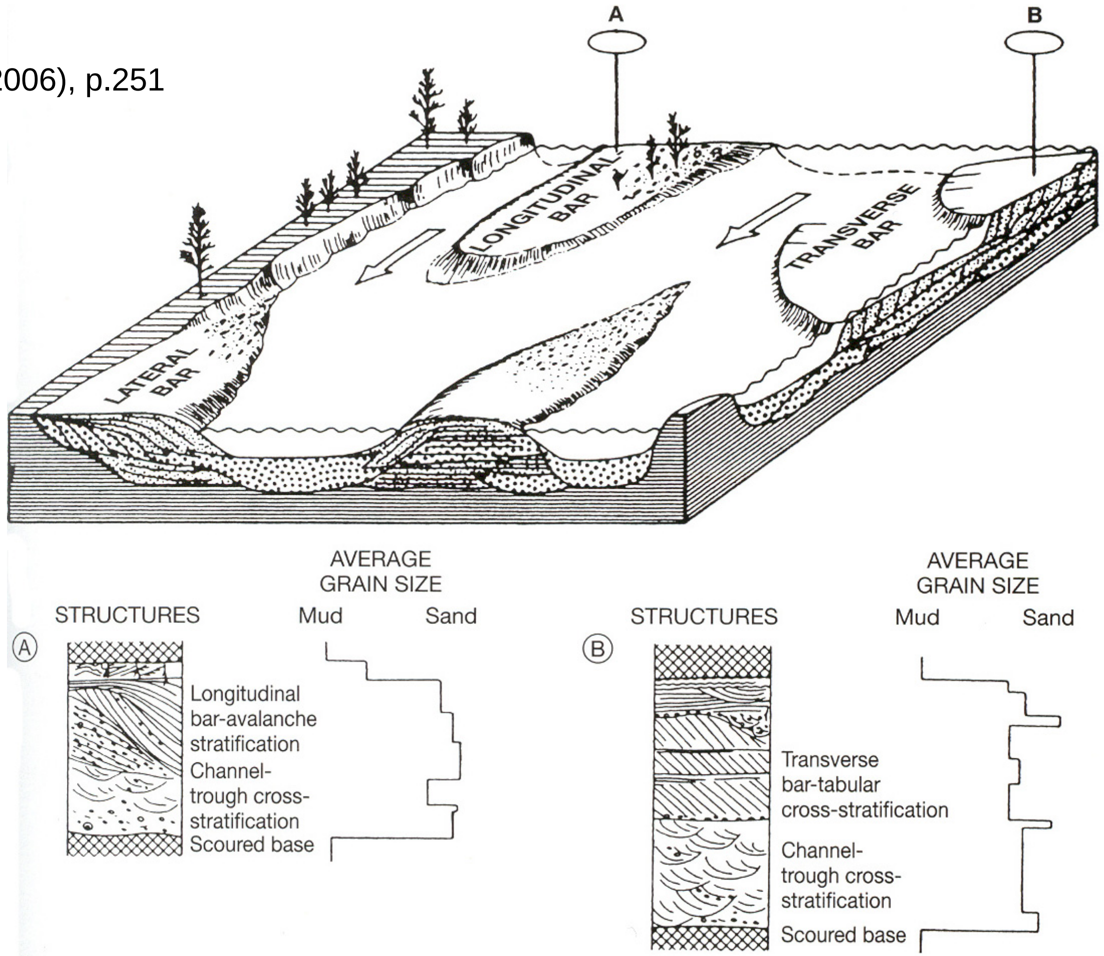
Boggs (2006), p.251



Boggs (2006), p.253

Figure 8.7
Landsat photograph of the Bramaputra River immediately north of its confluence with the Ganges, showing anastomosing, single-channel, and braided channel patterns. [From Bridge, J. S., 1993, The interaction between channel geometry, water flow, sediment transport and deposition in braided rivers, *in* Best, J. L., and C. S. Bristow (eds.), Braided rivers, Geological Society London Special Publication No. 75, Fig. 4, p. 21, reproduced by permission.]

Structure of bars and vertical sequences in braided rivers

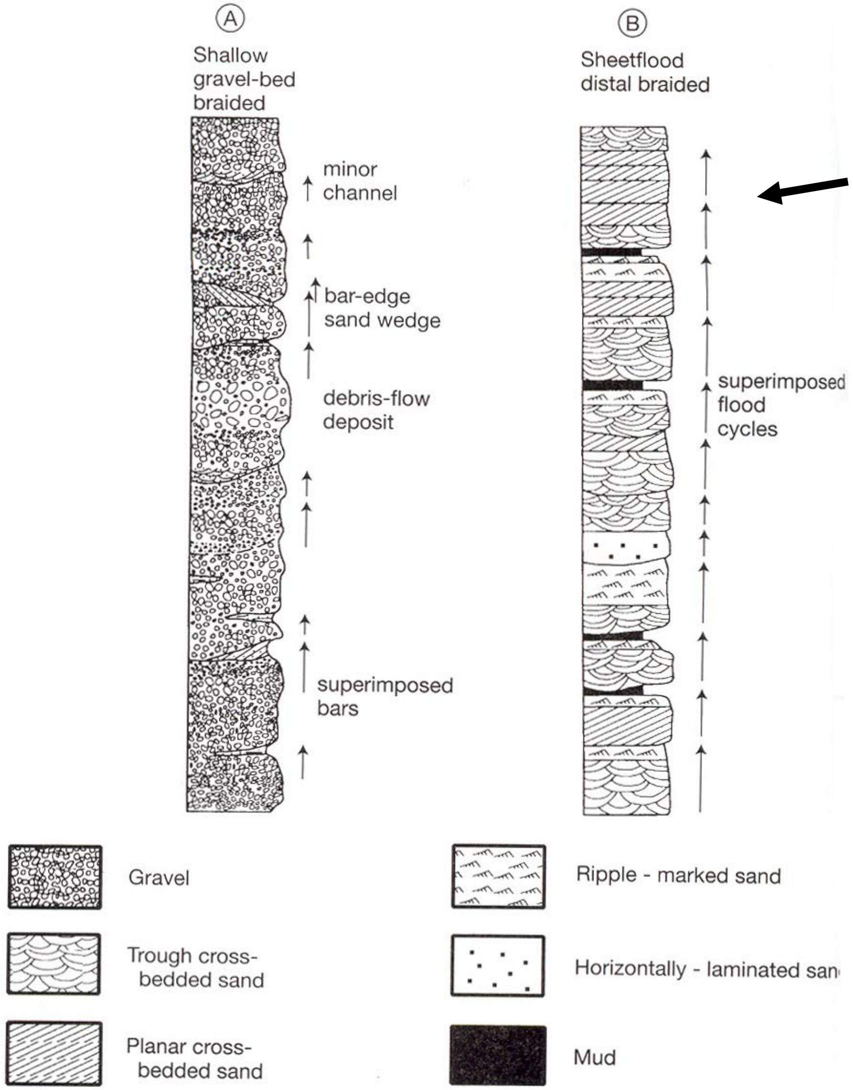


Galloway & Hobday (1983)

Typical facies and vertical profiles of braided rivers:

(A)shallow, gravel-bed braided river;

(B) sheetflood distal braided river



Fluvial architecture of braided-river deposits

Boggs (2006), p.256

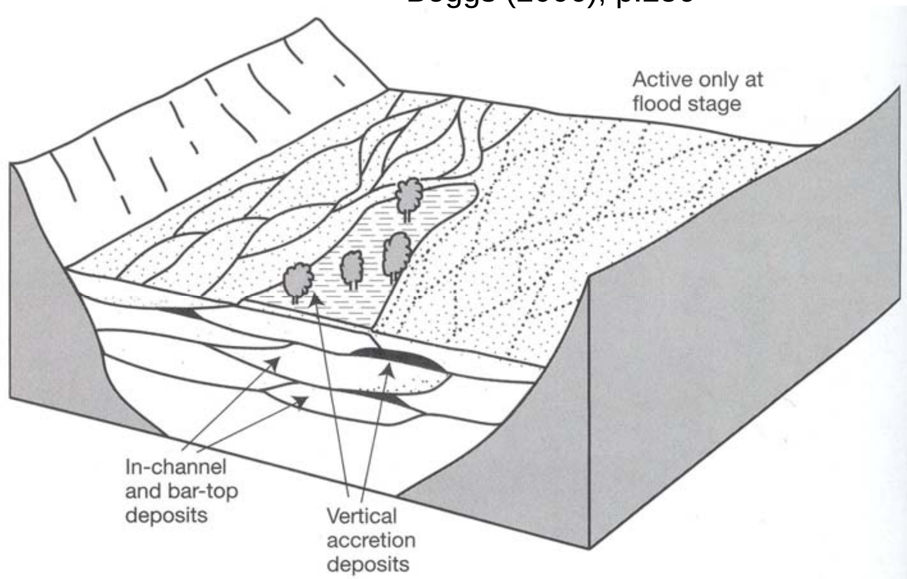


Figure 8.11
Schematic representation of the fluvial architecture of braided-river deposits. [After Walker, R. G., and D. J. Cant, 1984, Sandy fluvial systems, *in* R. G. Walker (ed.), Facies models: Geoscience Canada Reprint Ser. 1, Fig. 9, p. 77, reprinted by permission of Geological Association of Canada.]

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Gravelly braided-river deposits

Sharp erosional contact

Sandy braided-river deposits

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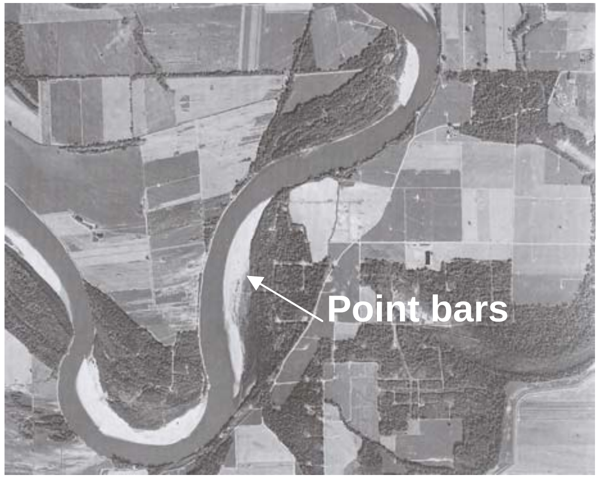
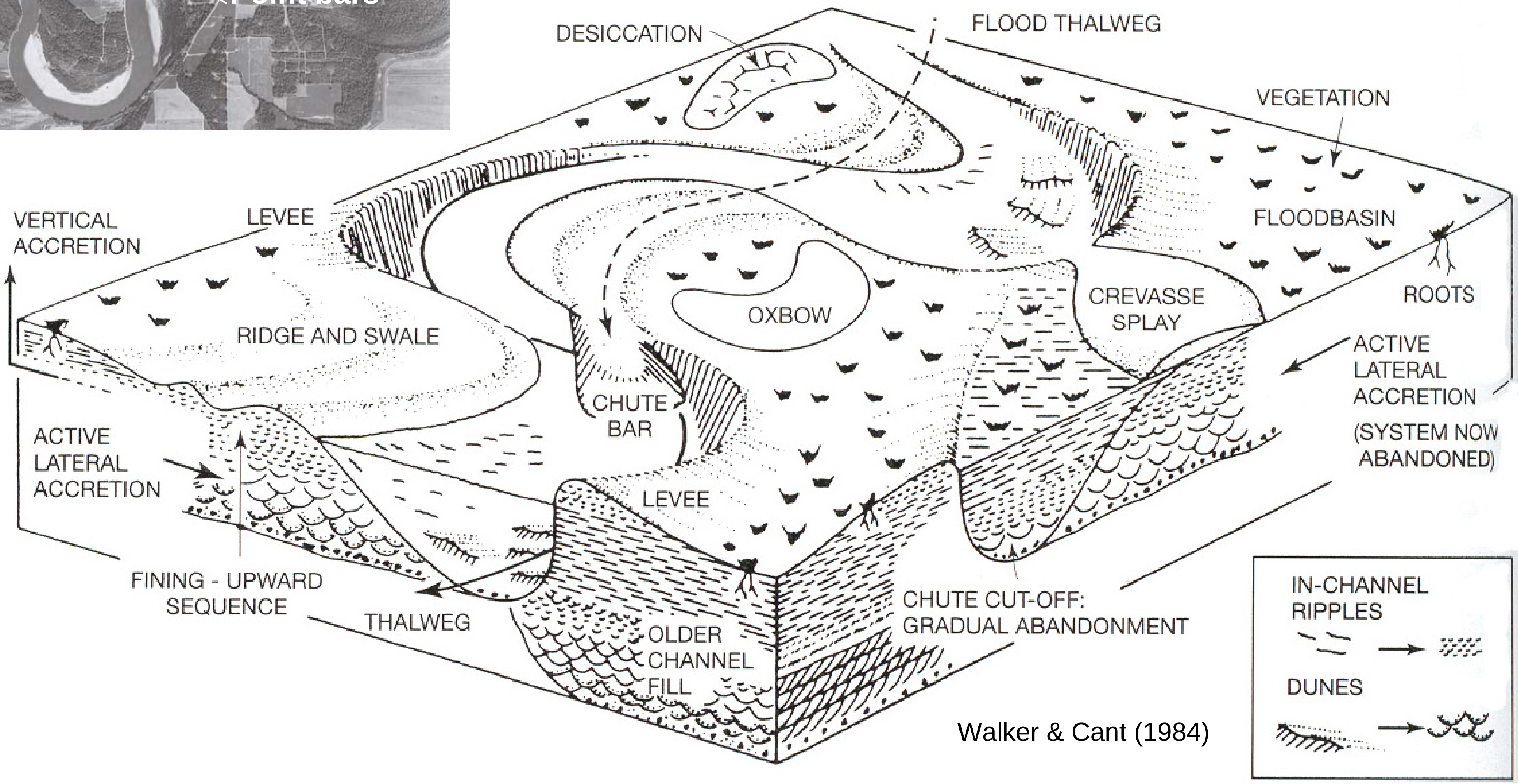


Morphological elements of a meandering-river system



Walker & Cant (1984)

Note: A thalweg is a line connecting the deepest points along a stream channel; it is commonly the line of maximum current velocity.

Helical flow in a meander bend

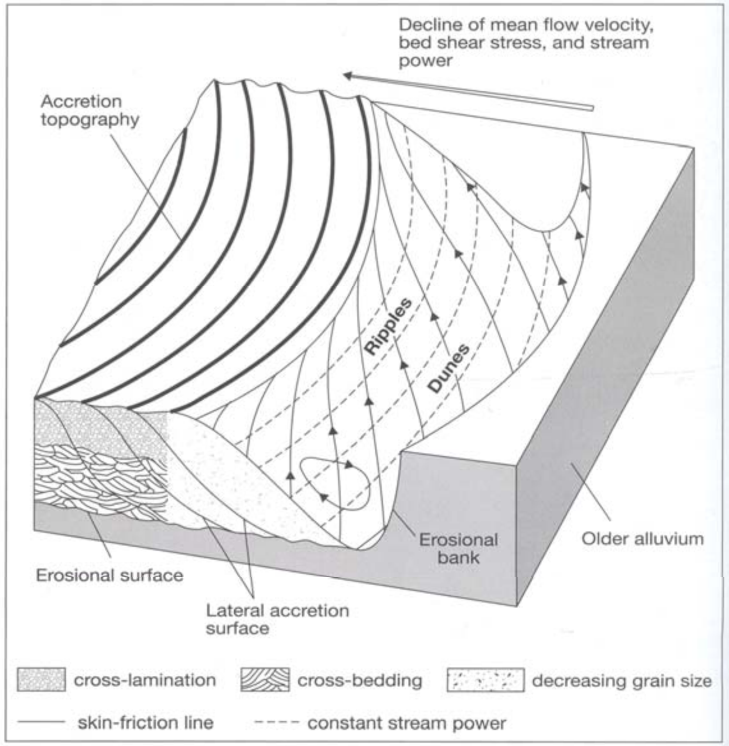
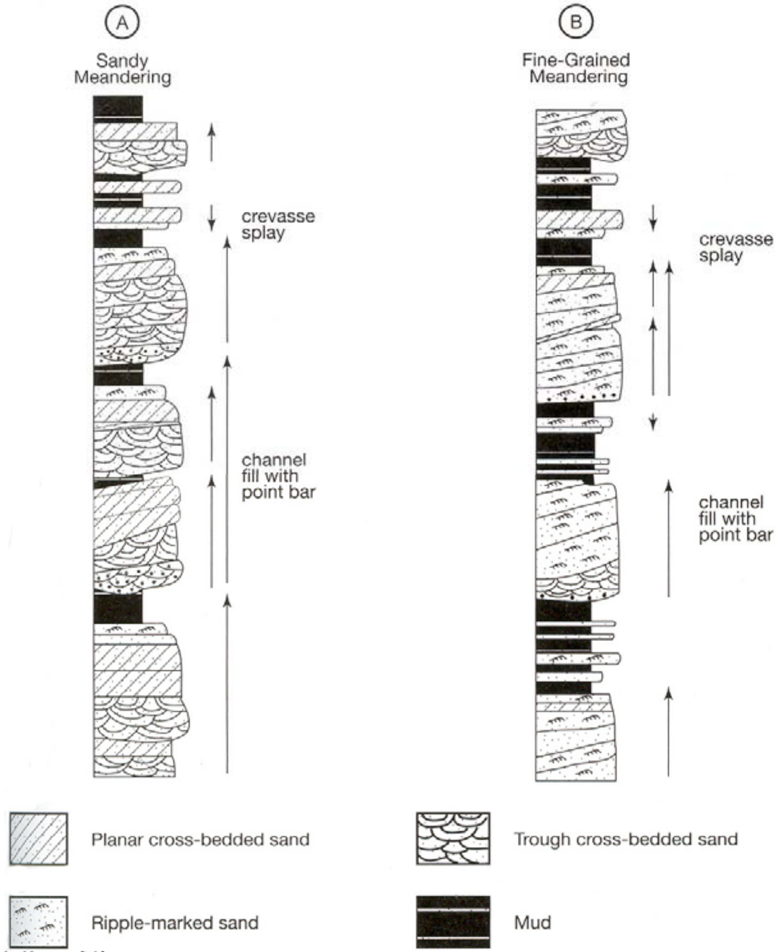


Figure 8.8
Helical flow in a meander bend, leading to lateral accretion of cross-bedded, fining-upward deposits. [From Leeder, M., 1999, Sedimentology and sedimentary basins, Fig. B17.1, p. 313. Reproduced by permission of Blackwell Science Ltd.]

Typical lithofacies and vertical profiles
(A) Sandy meandering river;
(B) fine-grained meandering river



Miall (1996)

Fluvial architecture of meandering-river deposits

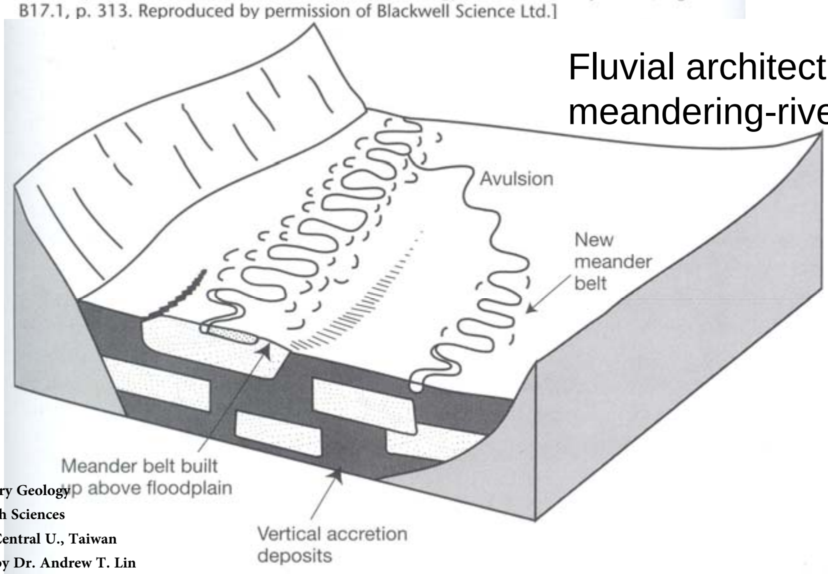


Figure 8.12
Schematic representation of the fluvial architecture of meandering-river deposits. [After Walker, R. G., and D. J. Cant, 1984, Sandy fluvial systems, *in* R. G. Walker (ed.), Facies models: Geoscience Canada Reprint Ser. 1, Fig. 9, p. 77, reprinted by permission of Geological Association of Canada.]

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