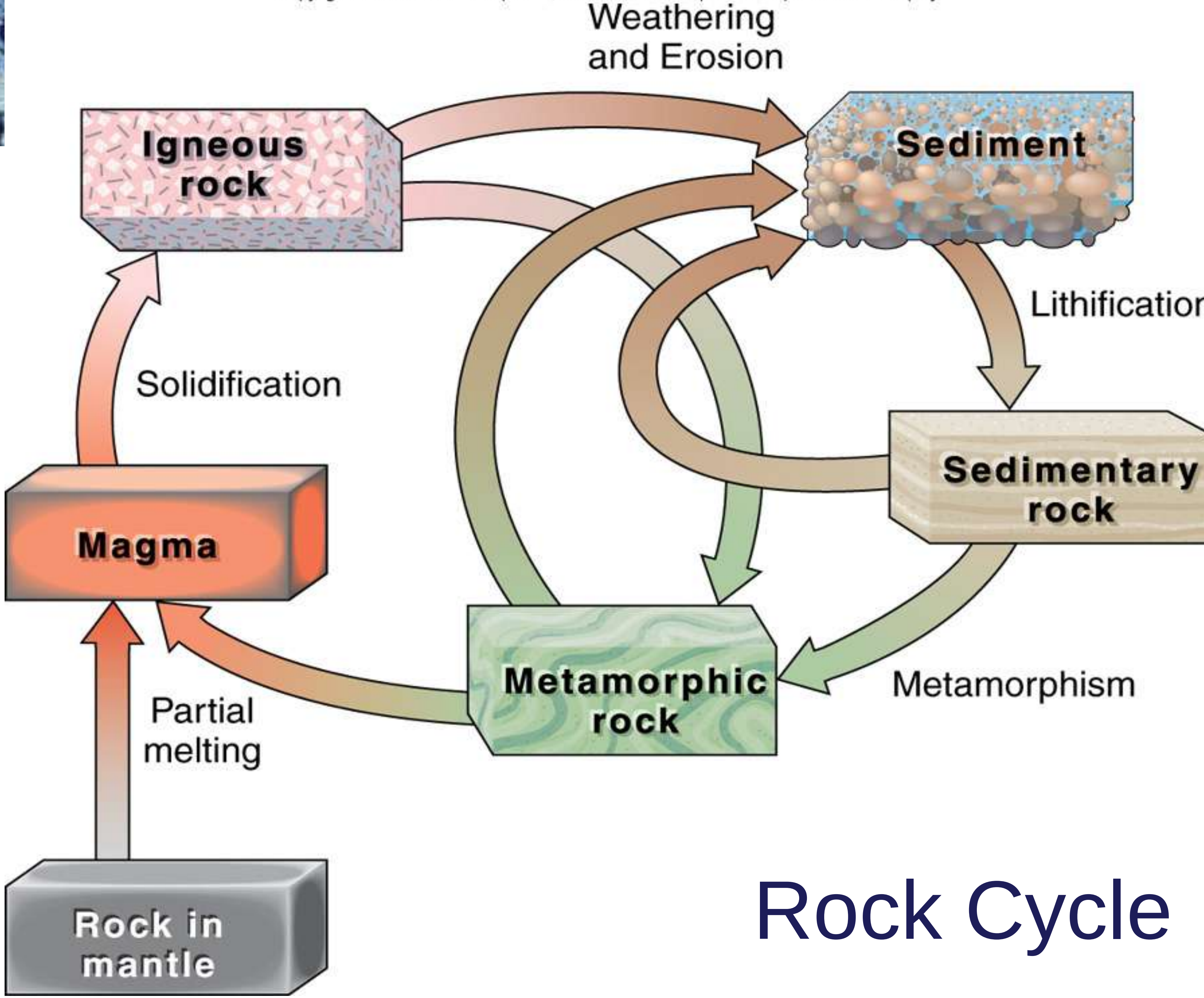
Chapter 6

Sediments and Sedimentary Rocks


Weathering and Erosion
Igneous rock
Sediment
Lithification
Solidification
Sedimentary rock
Magma
Metamorphic rock
Metamorphism
Partial melting
Rock in mantle

Rock Cycle

Sediment

Sediment is the collective term for loose (unconsolidated), solid particles that originate from:

1. wx and erosion of preexisting rocks
2. Chemical precipitation from solution, including secretion by organisms in water.

Sediment

- **Gravel** – all rounded particles coarser than 2mm in diameter (US nickel).
- **Sand** – grains are from 1/16 mm (human hair) to 2mm in diameter.
- **Silt** – grains are from 1/256 to 1/16 mm (too small to see with the naked eye), gritty taste.
- **Clay** – the finest sediment, <1/256mm, smooth taste.

Table 06.01

Table 6.1 Sediment Particles and Clastic Sedimentary Rocks

Diameter (mm)	Sediment		Sedimentary Rock
	Boulder	Gravel	**Breccia** (angular particles) or **Conglomerate** (rounded particles)
256	Cobble		
64	Pebble		
2	Sand		**Sandstone**
1/16	Silt	"Mud"	Siltstone (mostly silt)
1/256	Clay		**Shale** or mudstone (mostly clay)

Sandstone and shale are quite common; the others are relatively rare.

Sediment

Mud – loose term used for wet silt and clay

Clay – clay-sized particle (any mineral <1/256mm) vs. a clay mineral (sheet-silicate mineral)

Character of sediment can be further altered by rounding, sorting , and deposition.

Sediment

Transportation – Rounding, Sorting

- Rounding is the grinding away of sharp edges and corners of rock fragments during transportation.
- Sorting is the process by which sediment grains are selected and separated according to grain size (or shape or specific gravity) by the agents of transportation, especially by running water.

Fig. 06.01

Photo by David McGeary

Sediment

Transportation - Sorting

- Poorly sorted material – glacial sediment (glaciers deposit all sediment sizes in the same place)
- Well-sorted material – river (the sorting of sediment by a river as it flows out of steep mountains onto a gentle plain, where water loses energy and slows down)

Fig. 06.02

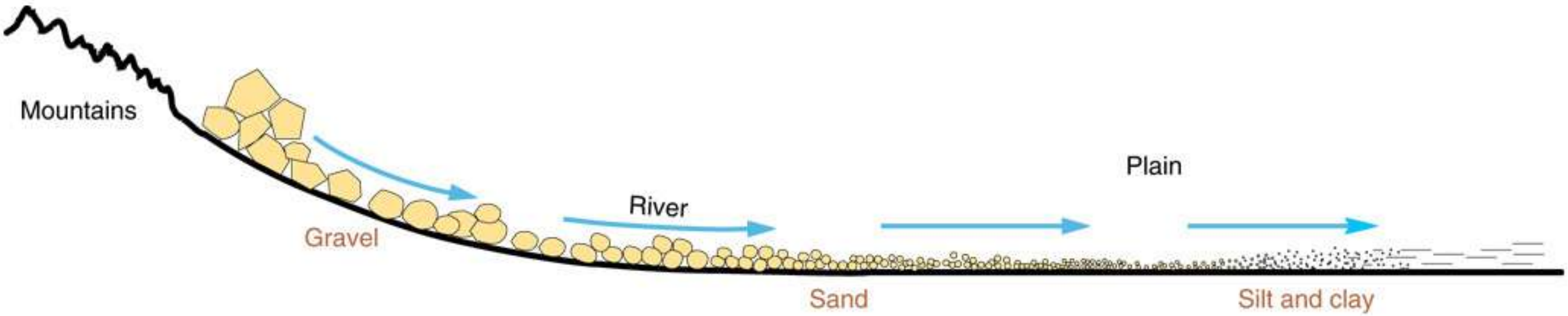


Fig. 06.03

Photo by David McGeary

Fig. 06.04

Photo by David McGeary

Sediment

Deposition

- Deposition occurs when transported material settles or comes to rest. It is the accumulation of clastic, chemical (precipitation) or organic sediment.
- Environment of deposition is the location in which deposition occurs (deep sea floor, river channel, desert valley, lake bottom, coral reef, a beach, or sand dune).

Sediment

Preservation

- Many sediments on land (those well above sea level) are easily eroded and carried away and are not commonly preserved.
- To preserve sediments they need to be covered and buried by later sediments (best place is in a subsiding basin in either continental or marine environments). Sediments on sea floor are the easiest to preserve.

Sediment

Lithification

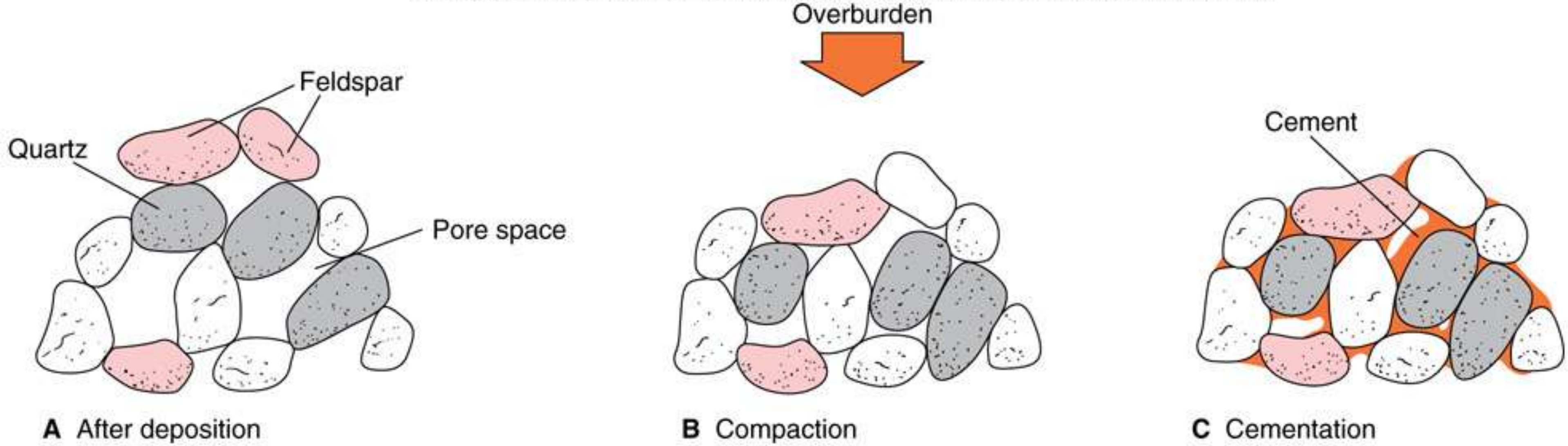
- General term for the processes that convert loose sediment into sedimentary rock.
- Compaction (packing of loose sediment grains) and cementation (precipitation of cement around grains binds them into a firm rock) are these processes.

Sediment

Lithification, cont.

- Crystallization of minerals from solution can also lithify rocks.
- Pore spaces -> overburden -> compaction
- Cement precipitates in the pore spaces as ground water moves through the sediments; as cement partially or completely fills the pores, the total pore space is reduced, and the loose sediment forms a hard sandstone by the process of cementation.

Fig. 06.06


Overburden
Feldspar
Quartz
Pore space
Cement
A After deposition
B Compaction
C Cementation

Sediment

Lithification, cont.

- Silica, iron oxides, and clay minerals can act as cements. But calcite and silica are the most common.
- The ions available for precipitation comes from the chemical wx of feldspar and calcite; and may occur within the sediments being cemented, or at a very distant site.

Sediment

Lithification - texture

- Clastic texture is term given to sedimentary rocks that consist of sediment grains bound by cement into a rigid framework (pore space is still available after cementation).
- Crystallization (crystalline texture) is the term given to sedimentary rocks that develop and grow crystals by precipitation from a solution at or near the earth's surface.

Fig. 06.07

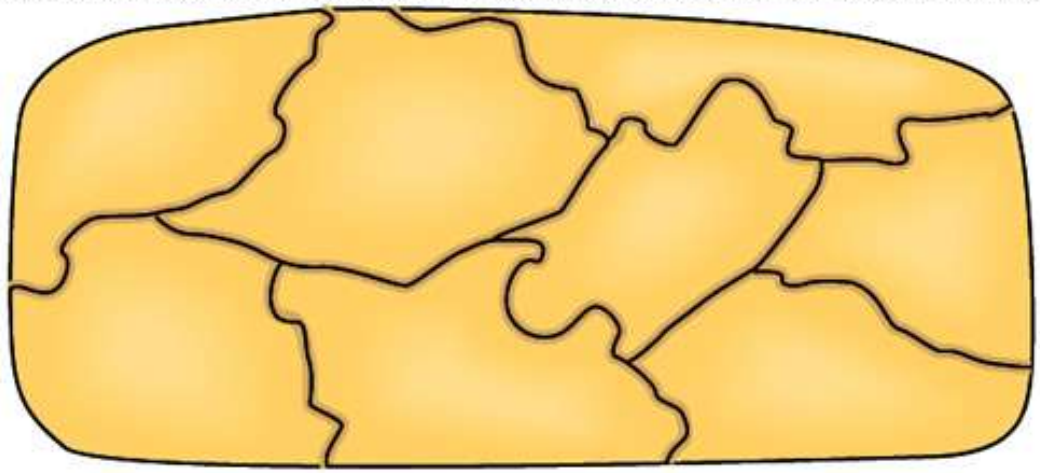


FIGURE 6.7

Crystalline texture. The rock is held together by interlocking crystals, which grew as they precipitated from solution. Such a rock has no cement or pore space.

$$\underbrace{Ca^{++} + 2HCO_3^{-}}_{\text{dissolved ions}} \rightarrow \underbrace{CaCO_3}_{\text{calcite}} + H_2O + CO_2$$

Types of Sedimentary Rocks

- Formed from Lithification of sediment (Clastic), precipitation from solution (Chemical), or consolidation of the remains of plants or animals (Organic).

Types of Sedimentary Rocks

Clastic Rocks

- Breccia and Conglomerate
- Sandstone
- The Fine-Grained Rocks

Non-Clastic Rocks

- Organic
- Chemical
- Limestones

Types of Sedimentary Rocks

Clastic Rocks

- **Breccia** – coarse-grained sed rx formed by the cementation of coarse, angular fragments of rubble

- **Conglomerate** – coarse grained sed rx formed by cementation of rounded gravel

- **Sandstone** – cementation of sand grains
  - Quartz ss – 90% of grains are quartz (clean)
  - Arkose ss – >25% grains are feldspar
  - Graywacke ss - >15% rock volume is a fine-grained matrix due to Turbidity currents (dirty)

Breccia - angular

Photo by David McGeary

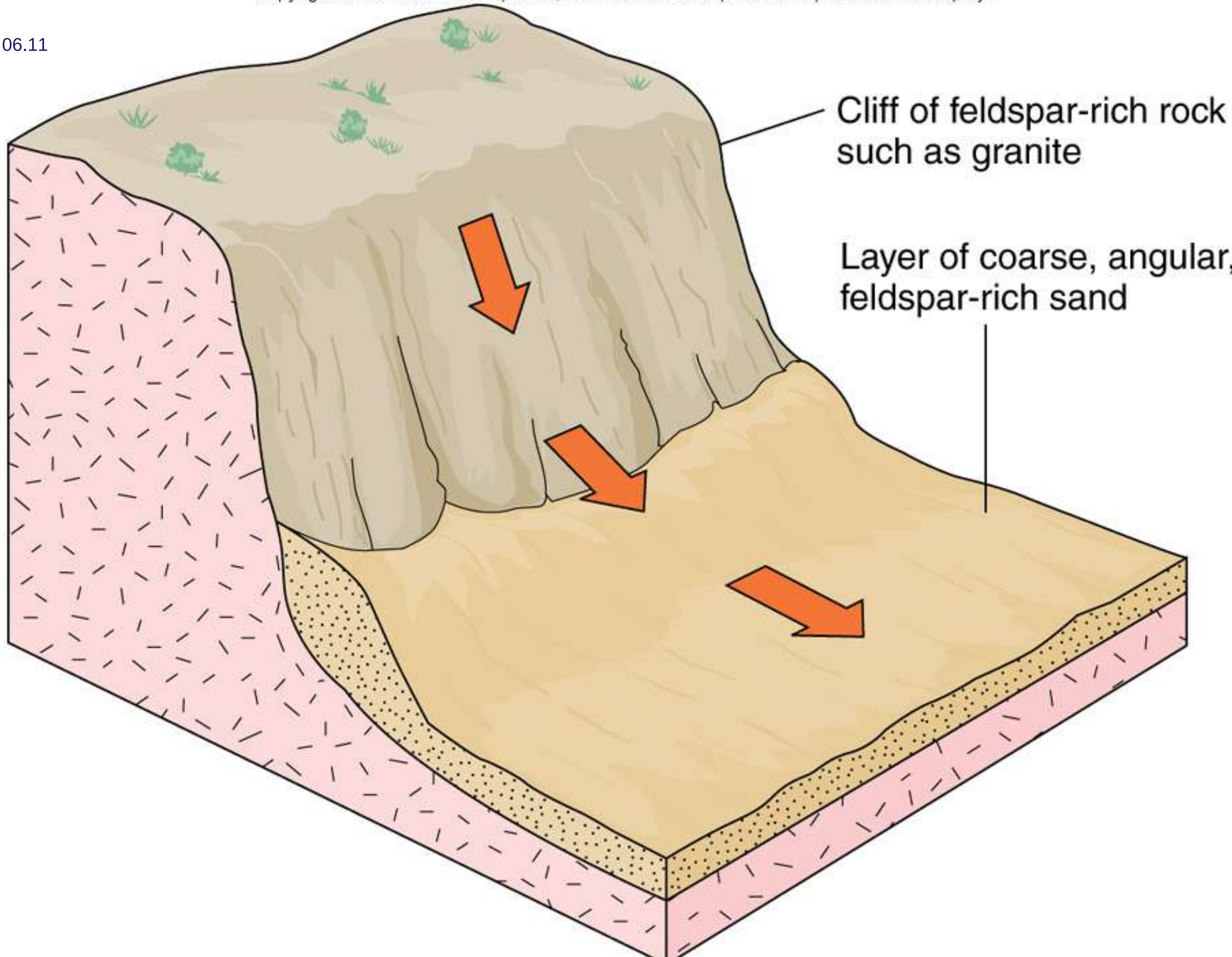
Conglomerate - rounded

Photo by David McGeary

Sandstone – sand sized particles

Sandstone – arkose (>25% feldspar particles)

Fig. 06.11


Cliff of feldspar-rich rock
such as granite
Layer of coarse, angular,
feldspar-rich sand

Sandstone – graywacke (>15% rock fragments and fine grained grey particles)

Due to turbidity currents

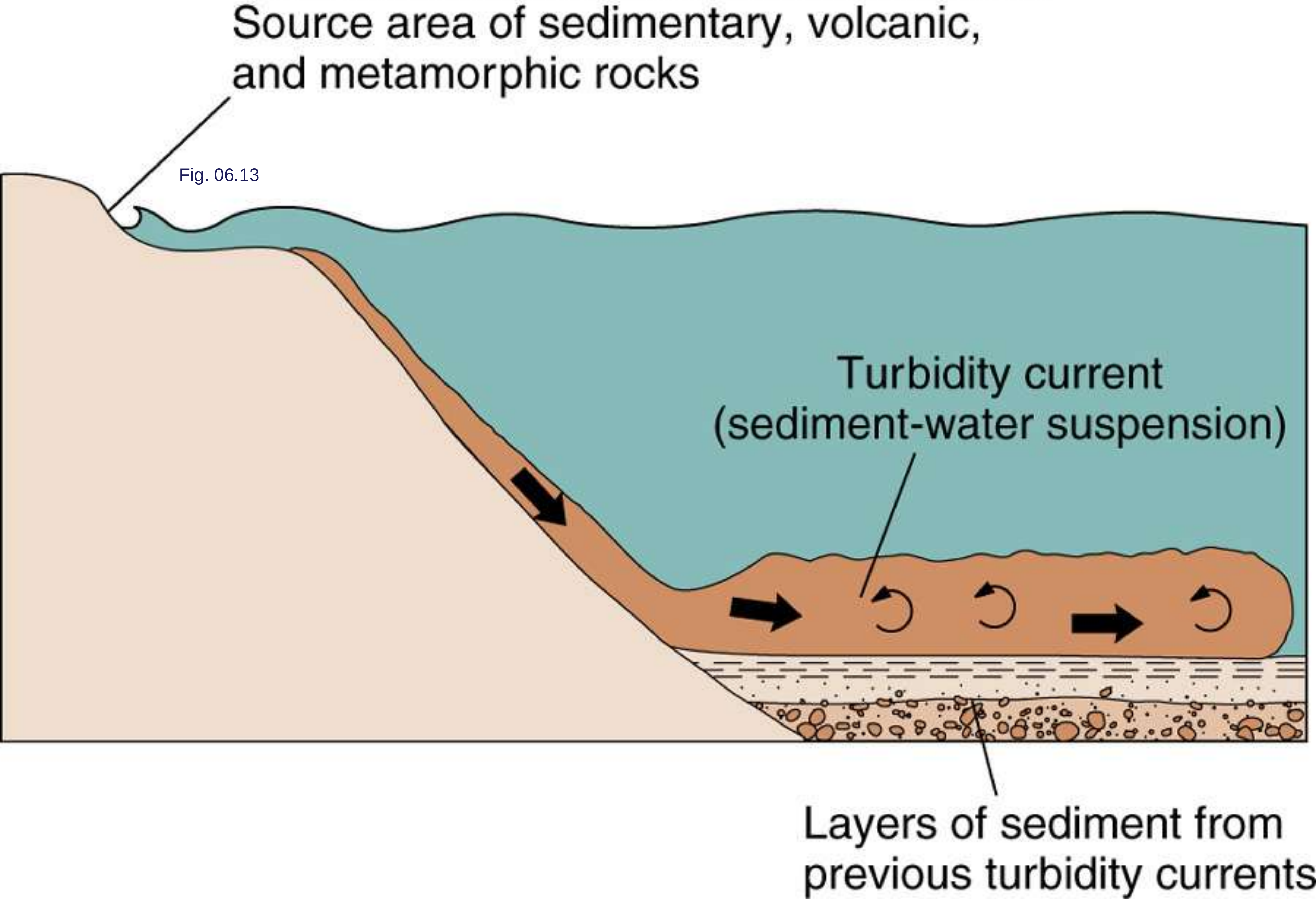
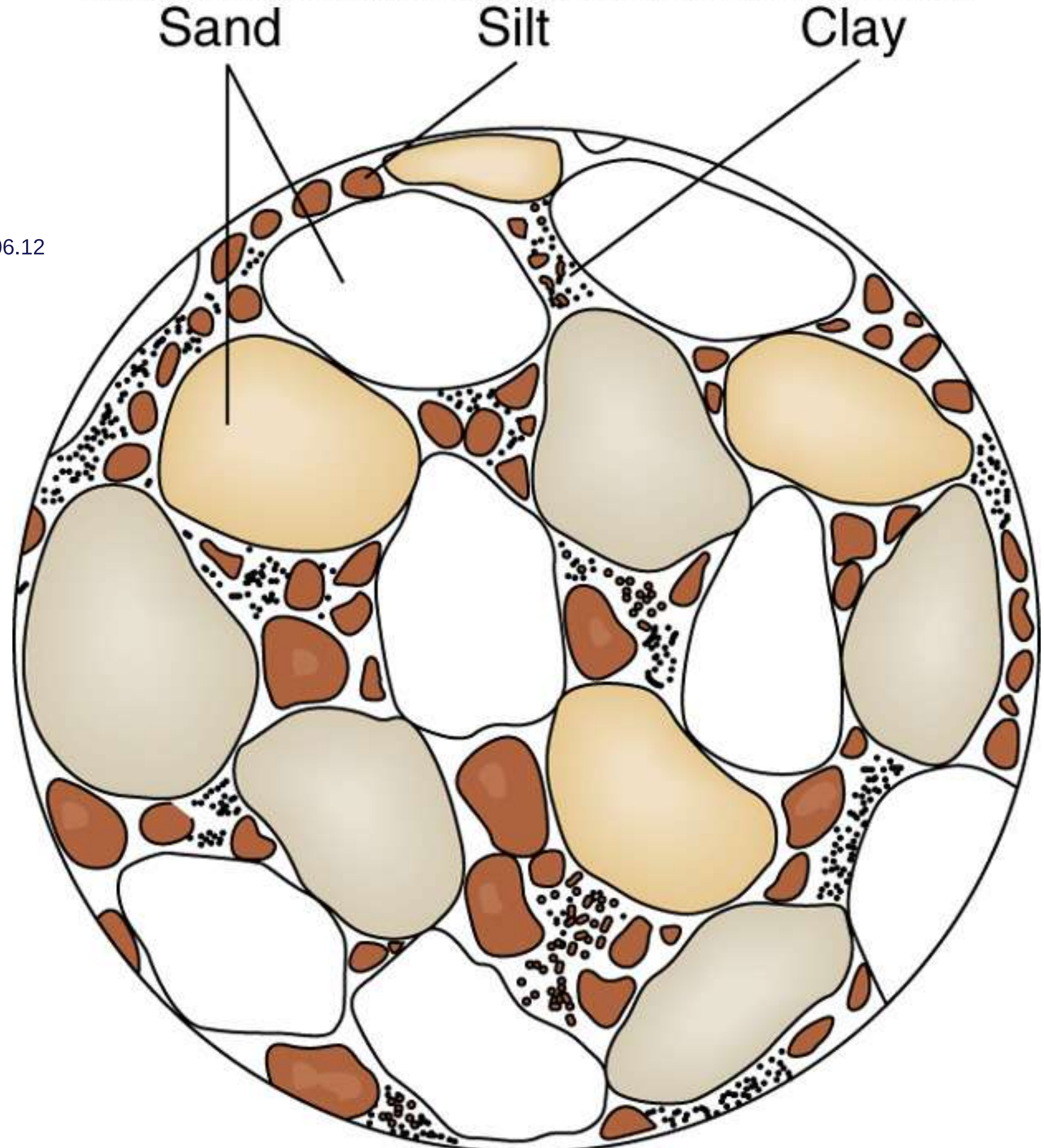

Source area of sedimentary, volcanic, and metamorphic rocks
Turbidity current (sediment-water suspension)
Layers of sediment from previous turbidity currents

Fig. 06.13

Fig. 06.12



Types of Sedimentary Rocks

Clastic Rocks, cont.

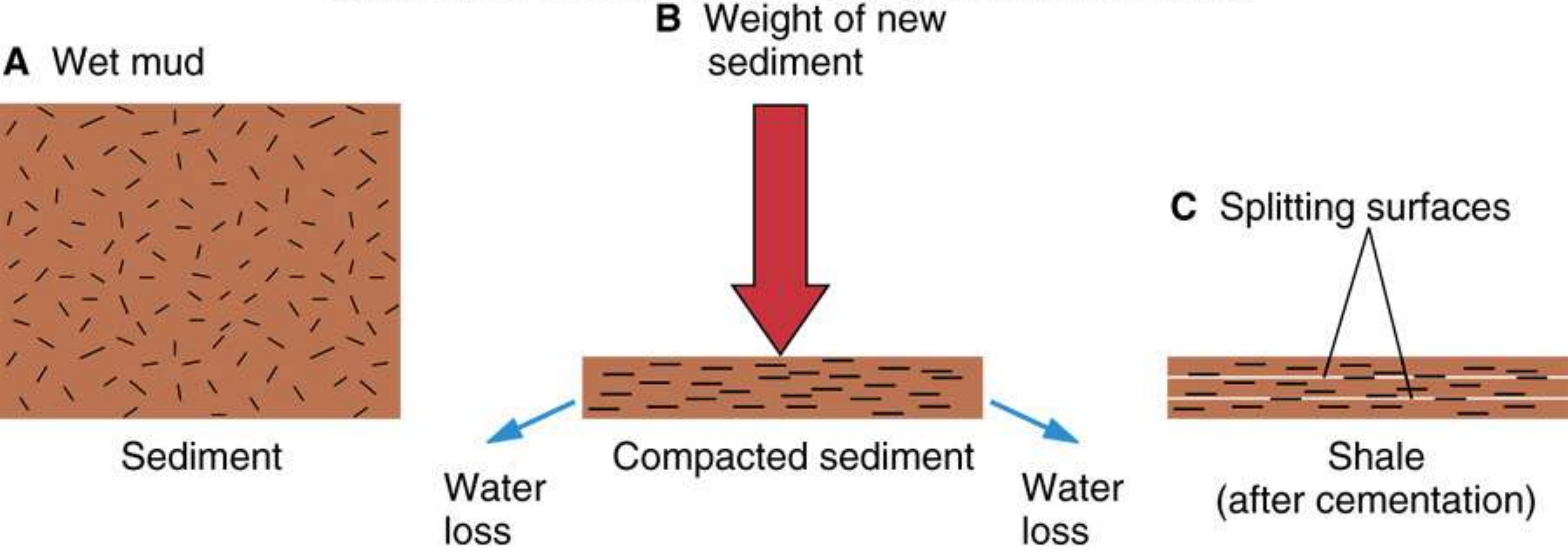
The Fine-grained Rocks (vary on ratio of silt to clay)

- **Siltstone** (mostly silt grains)
- **Mudstone** (1/3 silt sized quartz, 2/3 clay-sized clay minerals) - vs. **Shale** (shale is essentially a mudstone w/same content, but fissile and laminated)
- **Claystone** (mostly clay-sized particles)

Shale

Shale – splits into very thin layers

Fig. 06.15


A Wet mud
B Weight of new sediment
C Splitting surfaces
Sediment
Water loss
Compacted sediment
Water loss
Shale (after cementation)

Chemical Sedimentary Rocks

- Carbonate Rocks ($CaCO_3$)
- Chert (SiO_2)
- Evaporites (miscellaneous)

Chemical Sedimentary Rocks

Precipitated from an aqueous environment, directly by inorganic processes or by the actions of organisms (include carbonates, chert, and evaporates)

Chemical Sedimentary Rocks

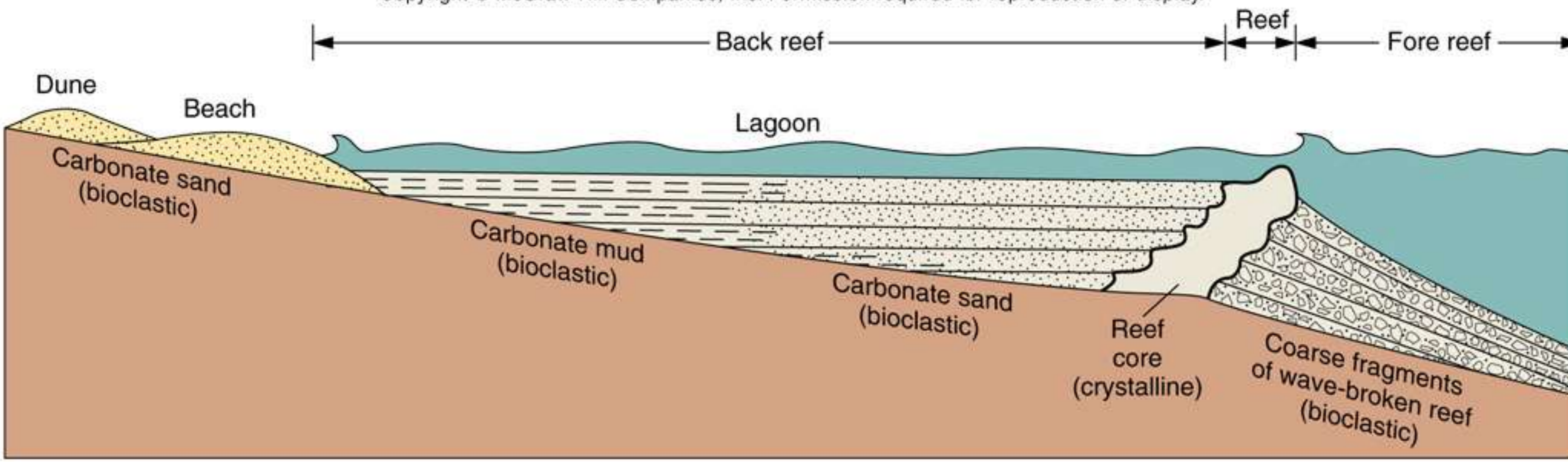
Carbonate Rocks

- **Limestone** – mostly consists of calcite ($CaCO_3$); precipitated by either organisms or directly as result of inorganic processes -> biochemical or inorganic limestone.
- Biochemical limestone formed on continental shelves in warm, shallow water. Can precipitate directly by coral reefs or by small shell forming organisms. Texture is crystalline with fossil remains preserved.

Fig. 06.16

Photo by David McGeary

Fig. 06.17


Back reef
Reef
Fore reef
Dune
Beach
Lagoon
Carbonate sand
(bioclastic)
Carbonate mud
(bioclastic)
Carbonate sand
(bioclastic)
Reef
core
(crystalline)
Coarse fragments
of wave-broken reef
(bioclastic)

Bioclastic limestones – fossiliferous limestone , and micrite

Photo by David McGeary

Algae producing fine-grained carbonate mud – Bahama Banks

Chemical Sedimentary Rocks

Carbonate Rocks, **Biochemical Limestones**

- Majority of limestones are biochemical limestones formed by wave-broken fragments of algae, corals, and shells. Fragments can be any size, but are often sorted and rounded as they are rolled around and transported on ocean floor, giving a clastic texture.

  Coquina – fossil hash, coarse grained

  Chalk – light colored, porous, very fine-grained bioclastic limestone forms from sea-floor accumulation of microscopic marine organisms.

Coquina – bioclastic limetsone formed by the cementation of coarse shells

Fig. 06.21

Photo by David McGeary

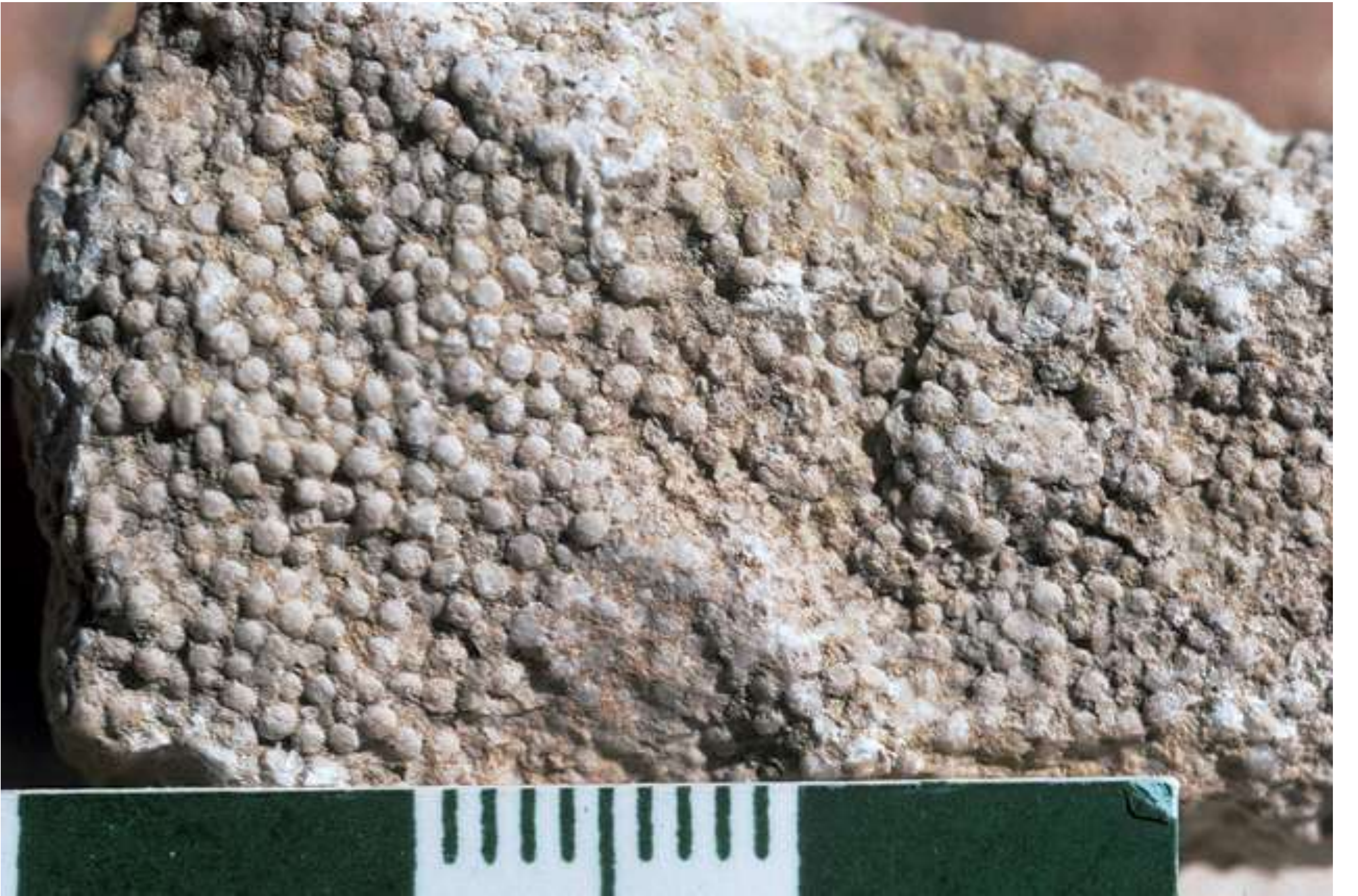
Chemical Sedimentary Rocks

Carbonate Rocks, **Inorganic limestones**

- Oolitic limestone
- Tufa
- Travertine
- Recrystallization

Aerial photo of underwater dunes of ooids that are chemically precipitated from seawater on the shallow Bahama Banks. Tidal currents move the dunes.

Oolitic limestone formed by the precipitation of concentric layers of calcium carbonate on the underwater dunes or tidal currents.



Chemical Sedimentary Rocks

Carbonate Rocks, **Dolomite**

- Both a sedimentary rock and the mineral that makes it up: $CaMg(CO_3)_2$.
- Dolomite forms from limestone as the *calcium* in calcite is partially replaced by *magnesium*, usually as water solutions move through the limestone (as magnesium-rich brines created by solar evaporation of seawater trickle through existing layers of limestone).
- $Mg^{++} + 2CaCO_3 \rightarrow CaMg(CO_3)_2 + Ca^{++}$

Chemical Sedimentary Rocks

Chert

- A hard, compact, fine-grained sed rx formed almost entirely of silica.
- Forms as nodules (by precipitation through replacement) or layered by the accumulation of hard, shell-like parts of microscopic marine organism on the sea floor: radiolarians.

Chert nodules in limestone

Bedded chert, coast ranges, California

Chemical Sedimentary Rocks

Evaporites

- Rock that forms from crystals that precipitate during evaporation of water (seawater, or saline lake).
- Rock gypsum, rock salt, borates, potassium salts, and magnesium salts. All have a crystalline texture.

Fig. 06.24

Photo by David McGeary

Organic Sedimentary Rocks

Coal

- Forms from compaction of plant material that has not completely decayed (Peat → Coal).

Fig. 06.25

Photo by David McGeary

Table 06.02

Table 6.2 Chemical Sedimentary Rocks

Inorganic Sedimentary Rocks

Rock	Composition	Texture	Origin
Limestone	$CaCO_3$	Crystalline	May be precipitated directly from seawater. Cementation of oolites (ooids) precipitated chemically from warm shallow seawater (*oolitic limestone*). Also forms in caves as *travertine* and in springs, lakes, or percolating ground water as *tufa*.
Dolomite	$CaMg(CO_3)_2$	Crystalline	Alteration of limestone by Mg-rich solutions (usually)
Evaporites			Evaporation of seawater or a saline lake.
Rock salt	NaCl	Crystalline	
Rock gypsum	$CaSO_4 \cdot 2H_2O$	Crystalline	

Biochemical Sedimentary Rocks

Rock	Composition	Texture	Origin
Limestone	$CaCO_3$ (calcite)	Clastic or crystalline	Cementation of fragments of shells, corals, and coralline algae (*bioclastic limestone* such as coquina and chalk). Also precipitated directly by organisms in reefs.
Chert	SiO_2 (silica)	Crystalline (usually)	Cementation of microscopic marine organisms; rock usually recrystallized.

Sedimentary Structures

- Found within sedimentary rx, formed during deposition, determine environment of deposition.
- Principle of Original Horizontality
- Principle of Superposition

Sedimentary Structures

- Bedding – series of visible layers in rock.
- Bedding plane – a nearly flat surface of deposition separating two layers of rock.

Sedimentary Structures

- Cross-bedding

    - A type of bedding consisting of a series of thin, inclined layers within a larger bed of rock.

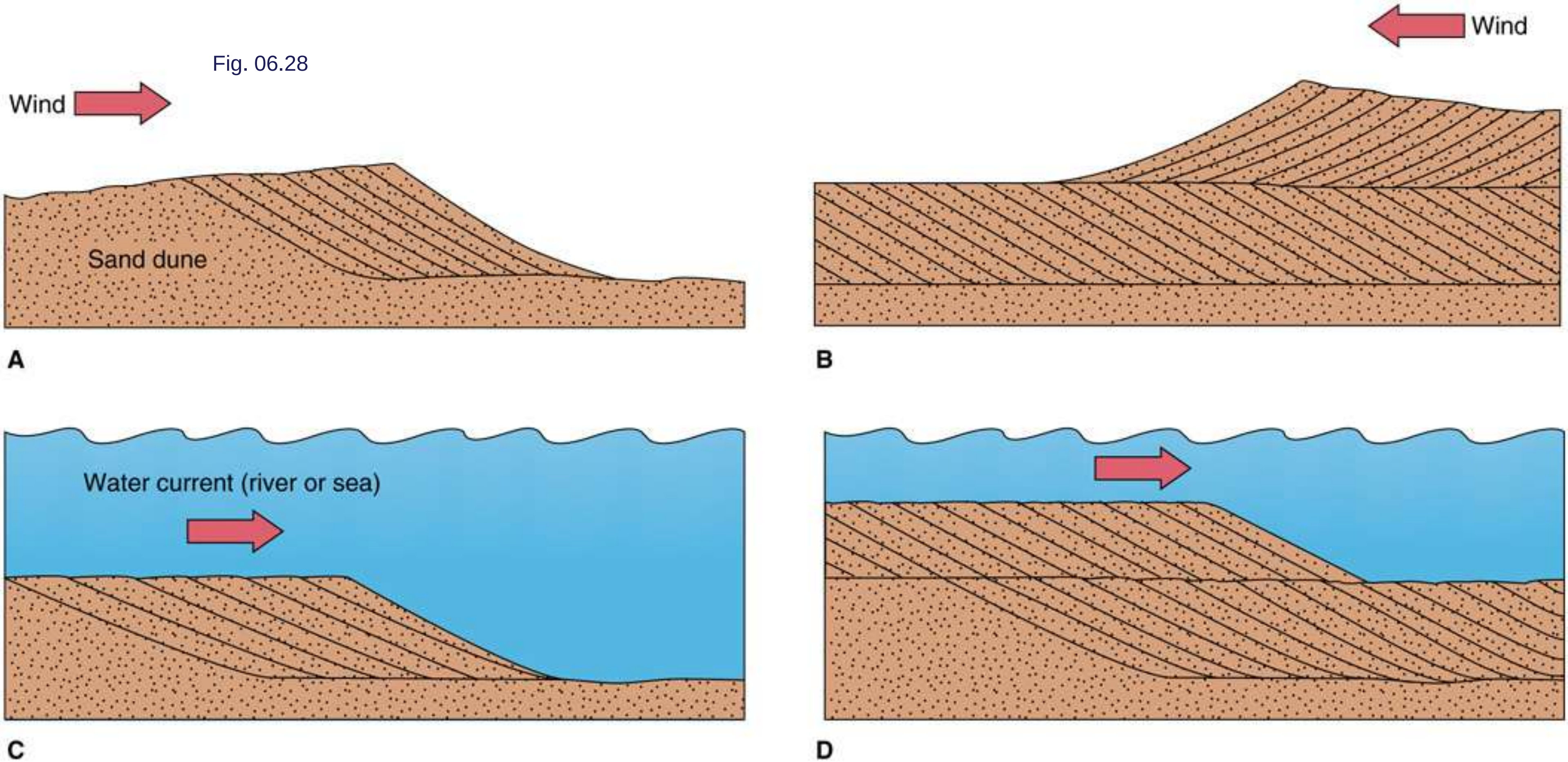
    - Most often found in sandstone.

    - Forms in wind blown sand dunes, sand ridges on ocean floor, sediment bars and dunes from rivers, deltas.

Fig. 06.27

Photo by David McGeary

Fig. 06.28



Sedimentary Structures

- Graded bedding

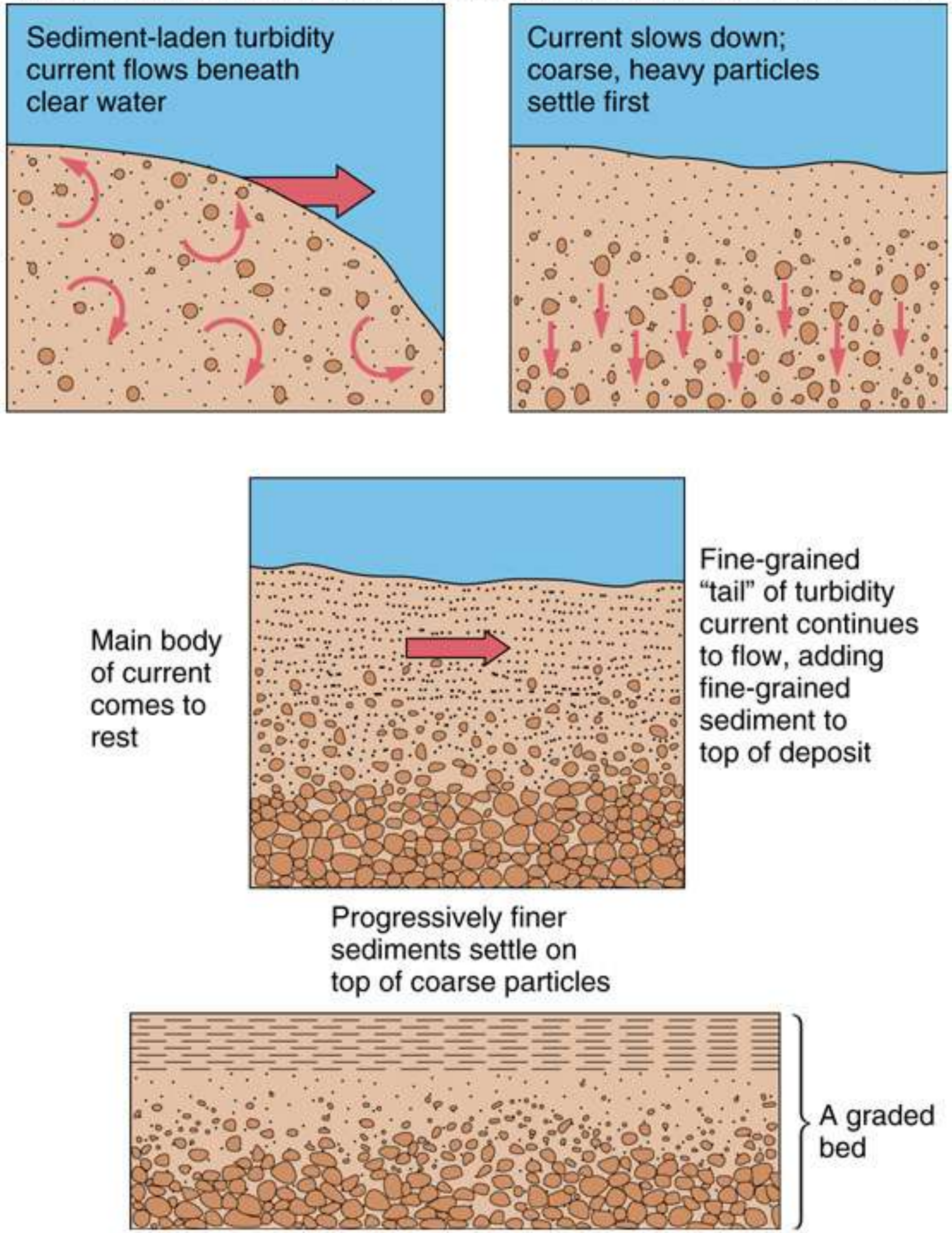
  - A layer with a vertical change in particle size, usually from coarser grains at the bottom of the bed to progressively finer grains toward the top.

  - Turbidity currents

Graded Bedding

Photo by David McGeary

Fig. 06.30

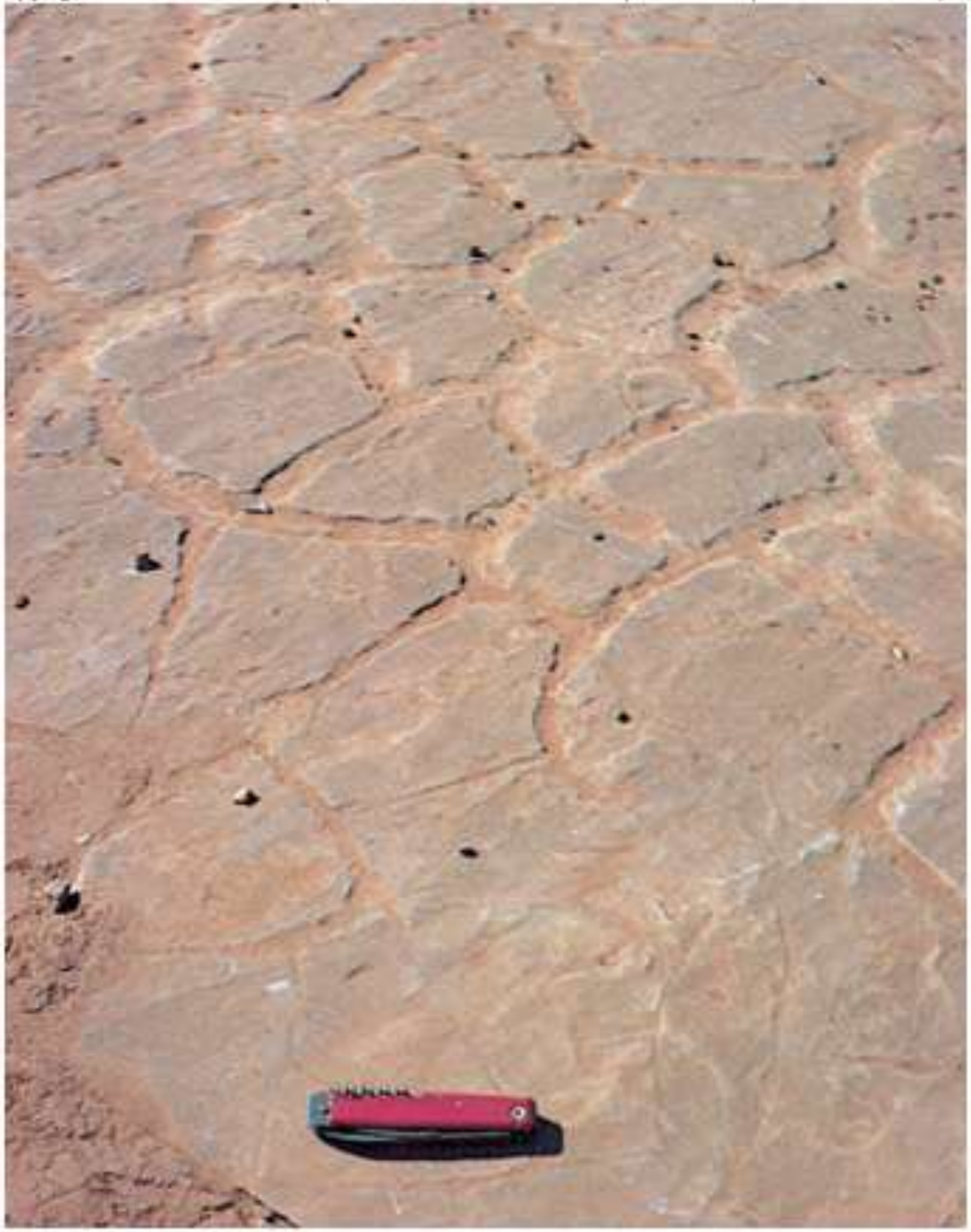

Sediment-laden turbidity current flows beneath clear water
Current slows down; coarse, heavy particles settle first
Main body of current comes to rest
Fine-grained "tail" of turbidity current continues to flow, adding fine-grained sediment to top of deposit
Progressively finer sediments settle on top of coarse particles
A graded bed

Sedimentary Structures

- Mud cracks

  polygonal pattern of cracks formed in very fine-grained sediment as it dries.

Fig. 06.31b



B

Photo by David McGeary

Sedimentary Structures

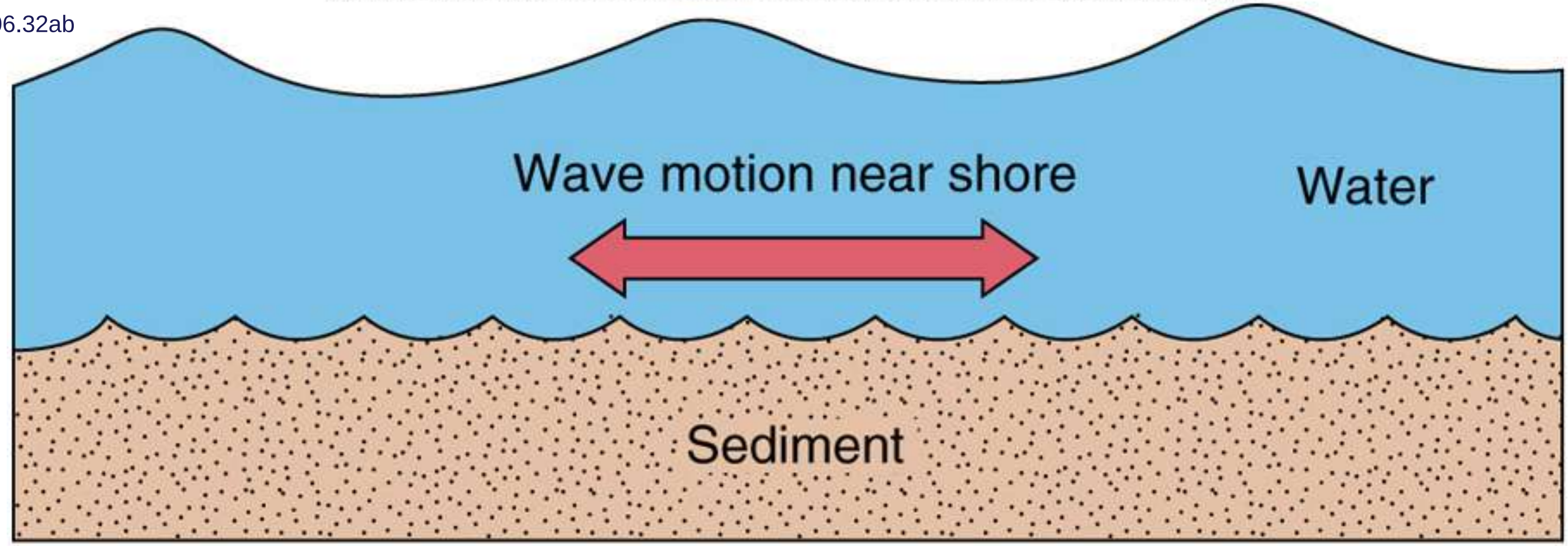
- Ripple marks

  - Small ridges formed on the surface of a sediment layer by moving wind or water.

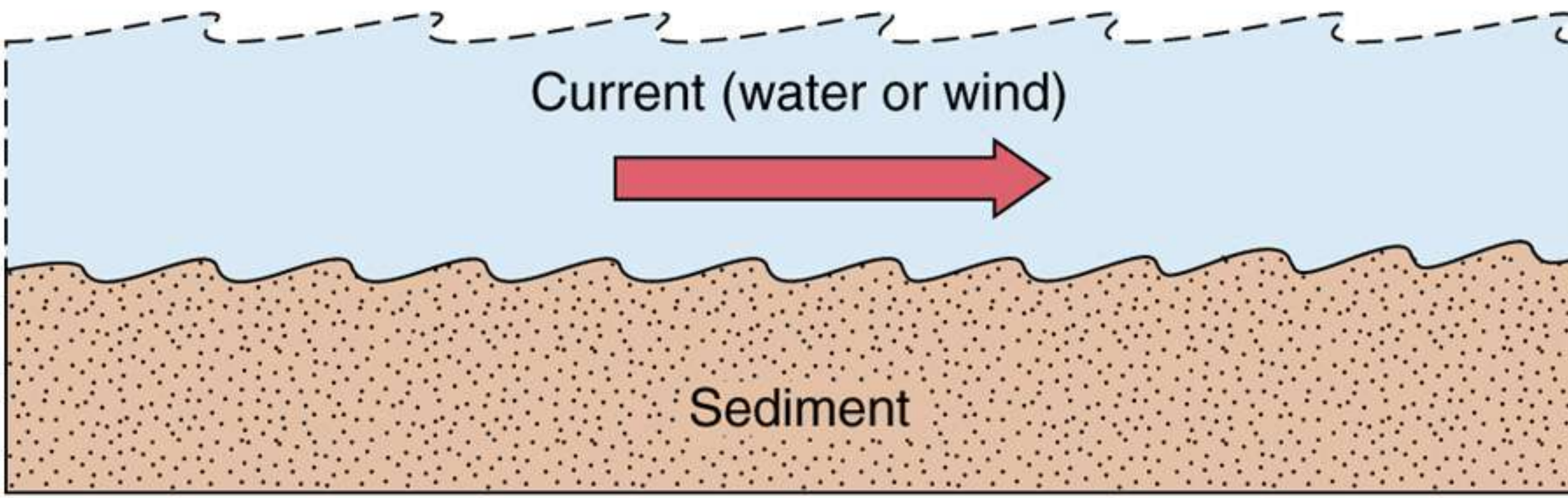
  - Wave-caused are usually *symmetrical*.

  - Current-caused are usually *asymmetrical* (steeper sides in the down-current direction).

Fig. 06.32ab



A



B

Fig. 06.32c

C

Photo by David McGeary

Fig. 06.32d

D

Photo by Frank M. Hanna

Sedimentary Structures

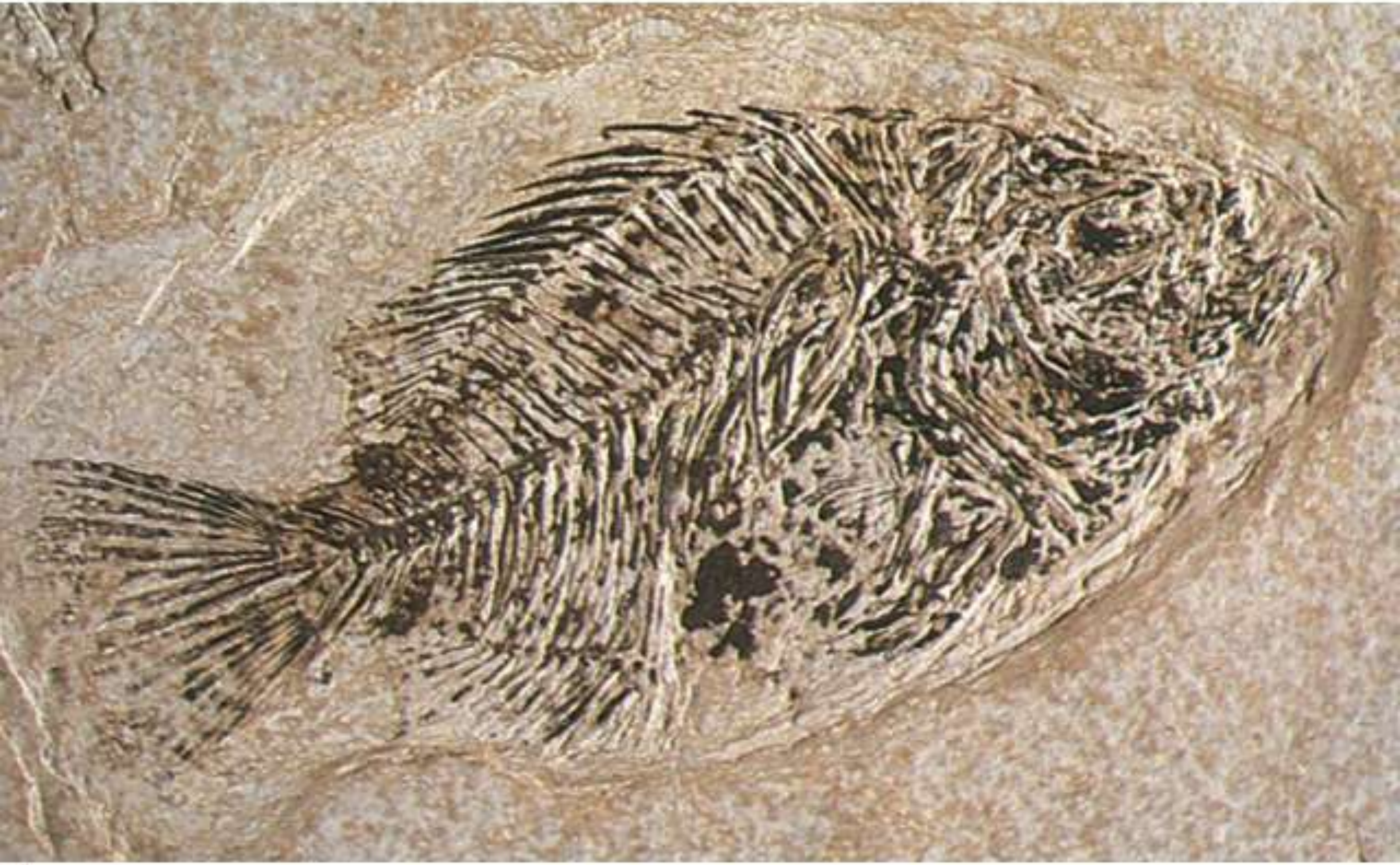
- Fossils

  - Bone or shell preserved if covered.
  - Calcite or silica may fill the pore spaces or completely replace original material.
  - Molds and casts.
  - Flat fossils of fish or leaves.
  - Tracks, trails, and burrows.
  - Fossil fuels.

Fig. 06.33

Photo by David McGeary

Fig. 06.34a



A

Photo by U.S. Geological Survey

Fig. 06.34b

B

Photo by David McGeary

Formations

Source Area

Fig. 06.35

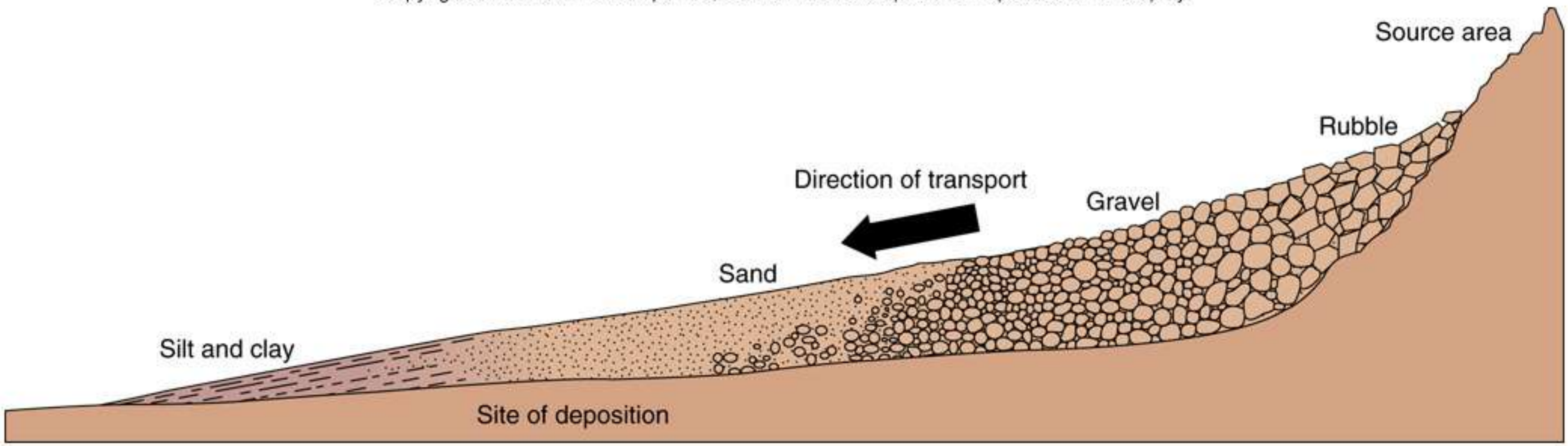
Photo by David McGeary

Interpretation of Sedimentary Rocks

- Source Area

  - Sediment tells about the locality that eroded and provided the sediment; the rock type, location and distance.

Fig. 06.36


Source area
Rubble
Direction of transport
Gravel
Sand
Silt and clay
Site of deposition

Interpretation of Sedimentary Rocks

Source Area

- Salt Wash member of the Morrison Formation

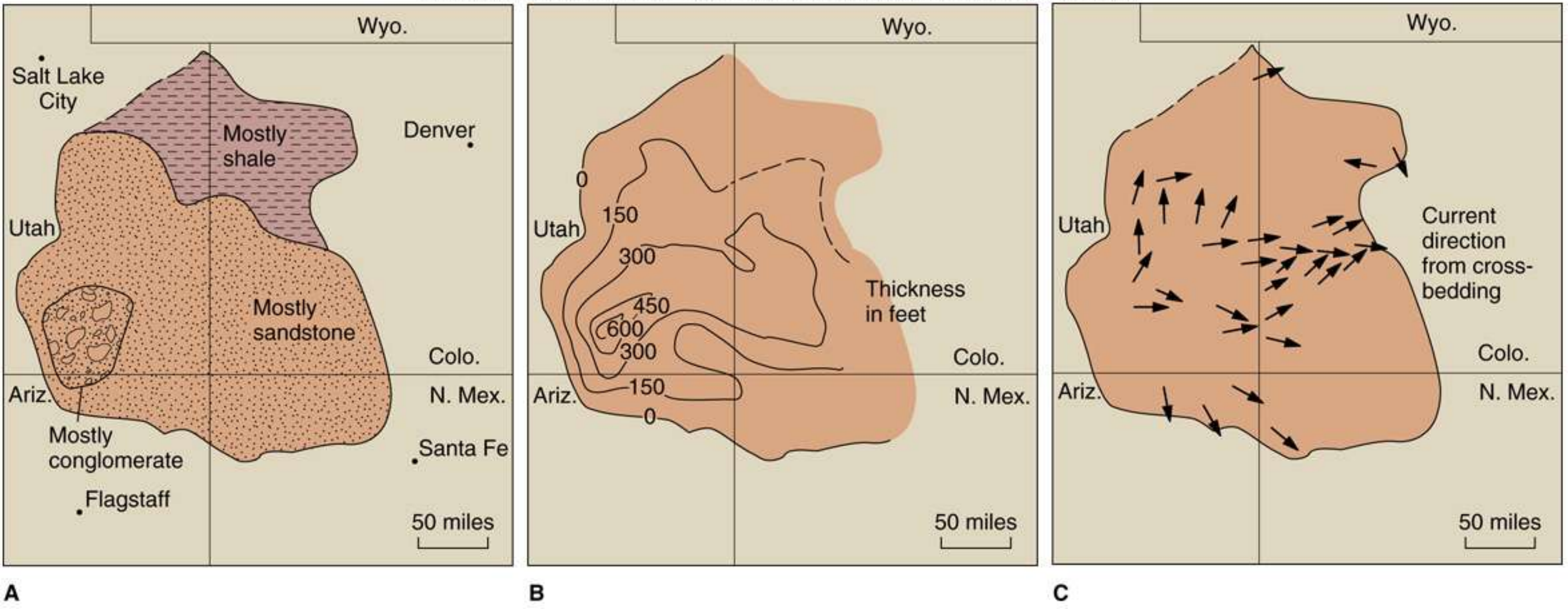
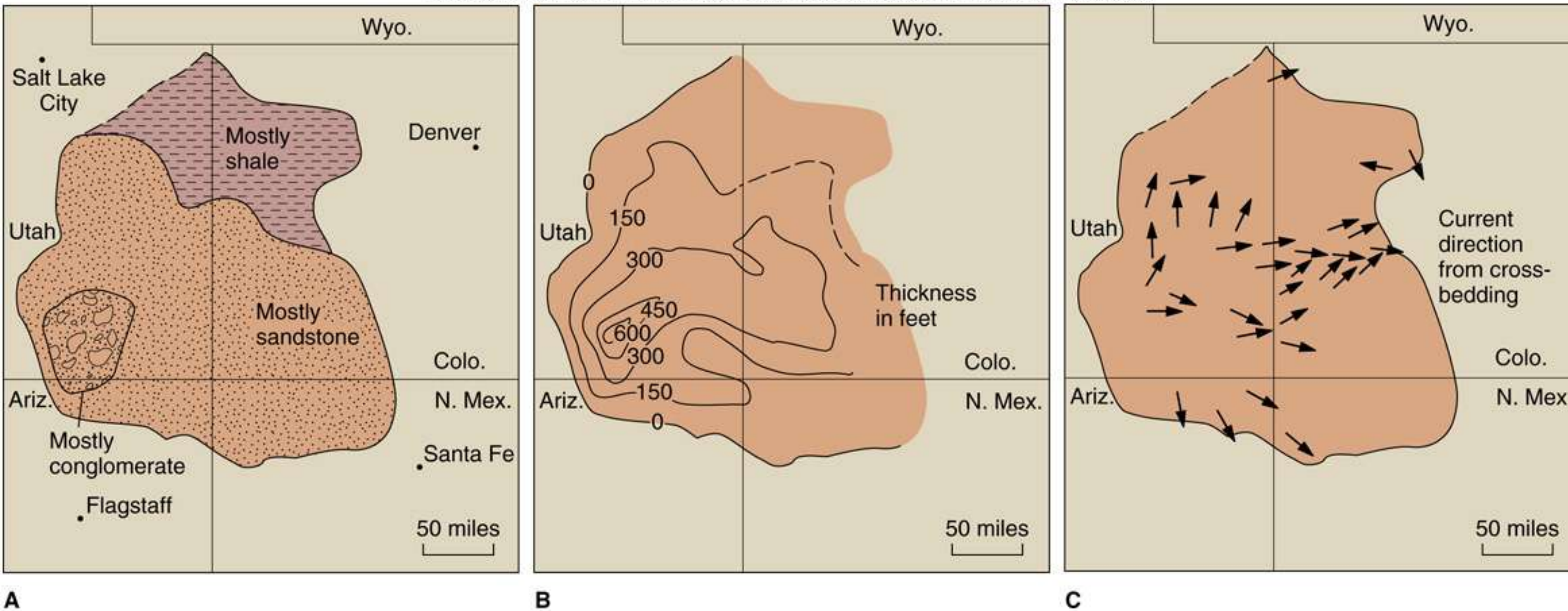
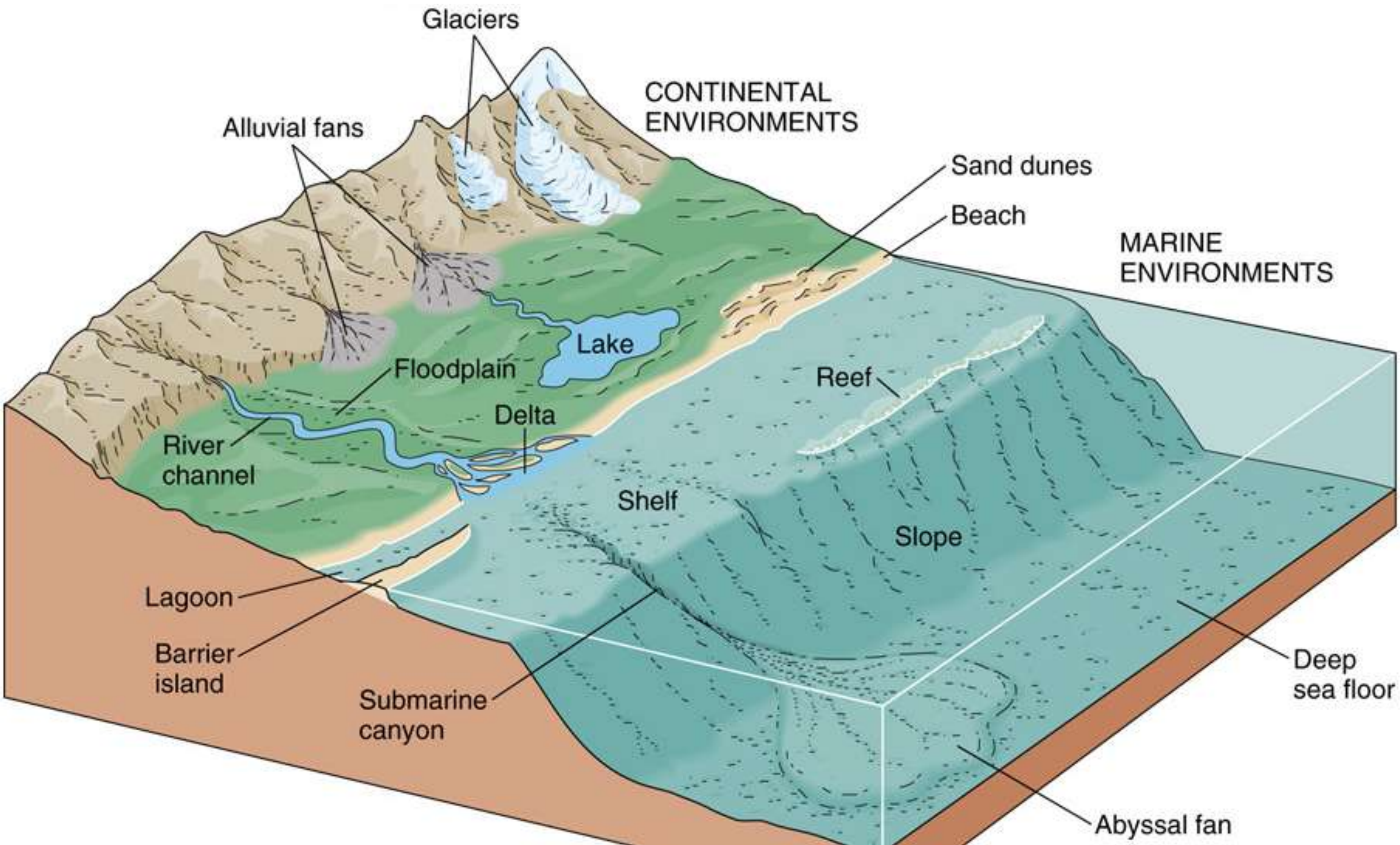


Fig. 06.37


Wyo.
Salt Lake City
Denver
Mostly shale
Utah
Mostly sandstone
Colo.
Ariz.
N. Mex.
Mostly conglomerate
Santa Fe
Flagstaff
50 miles
A
Wyo.
Utah
0
150
300
450
600
300
150
0
Thickness in feet
Colo.
Ariz.
N. Mex.
50 miles
B
Wyo.
Utah
Current direction from cross-bedding
Colo.
Ariz.
N. Mex.
50 miles
C

Interpretation of Sedimentary Rocks

- Environment of Deposition



Interpretation of Sedimentary Rocks

- Environment of Deposition

  - **Glacial**: till of unsorted mix of unweathered boulders, gravel, sand, silt, and clay.

Interpretation of Sedimentary Rocks

- Environment of Deposition

  - **Alluvial fan**: broad, fan-shaped piles of sediment including conglomerates and arkosic sandstones, cross-bedding and lens-like channel deposits are common.

Fig. 06.39

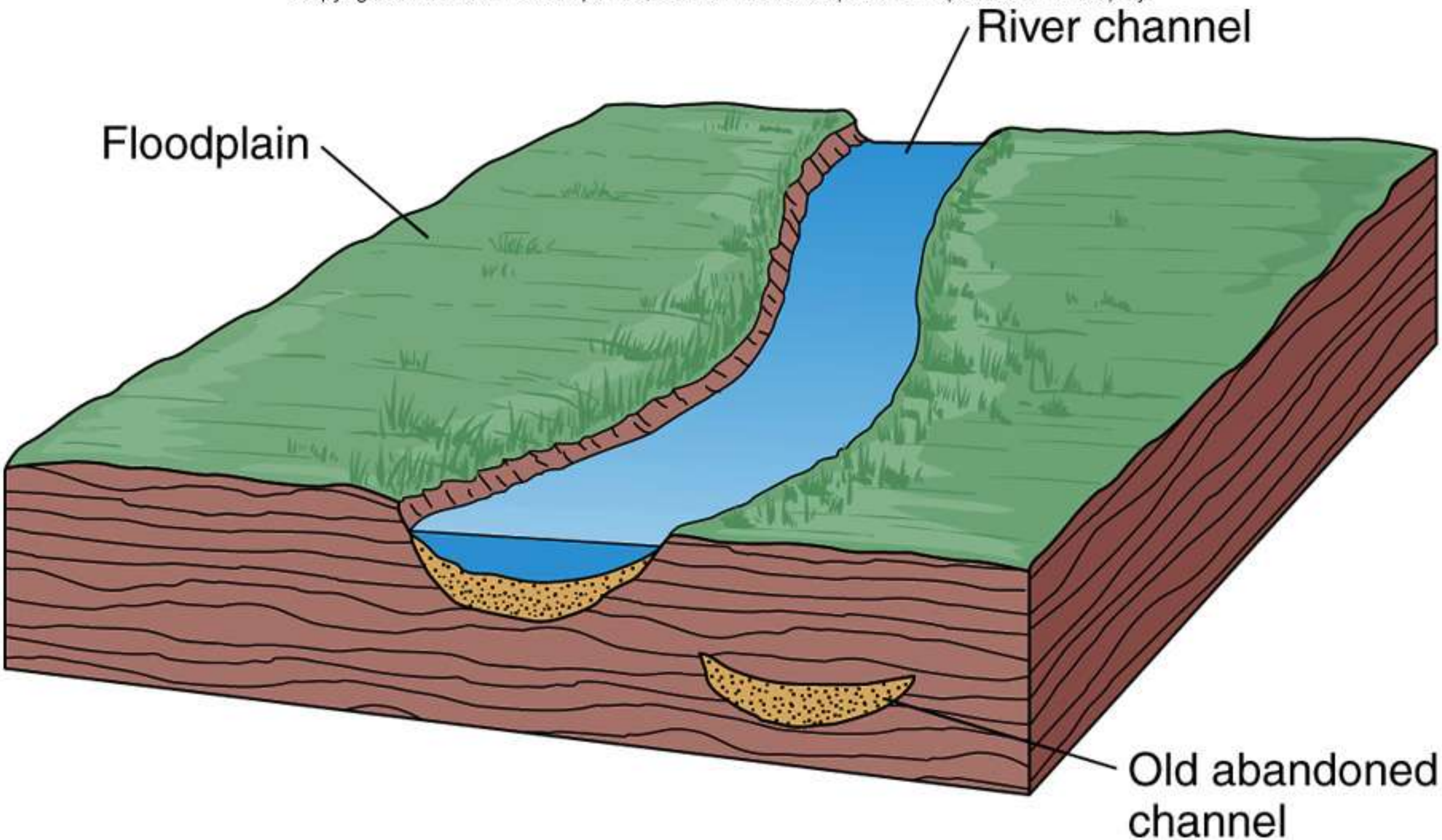
Photo by David McGeary

Interpretation of Sedimentary Rocks

- Environment of Deposition

  - **River channel and floodplain**: elongate lenses of conglomerate or sandstones (arkose), to fine-grained rx. River deposits may contain cross-beds and ripple marks. Floodplains may contain mud cracks, fossil footprints.

Fig. 06.40



Interpretation of Sedimentary Rocks

- Environment of Deposition

  - **Lake**: thin bedded shales, may have fish fossils. If frequent drying up occurs, may form mud cracks and/or interbedded evaporites.

  - **Delta**: thick sequences of siltstone and shale, low-angle cross-bedding, cut by coarser channel deposits. May contain marine fossils, or even beds of peat or coal.

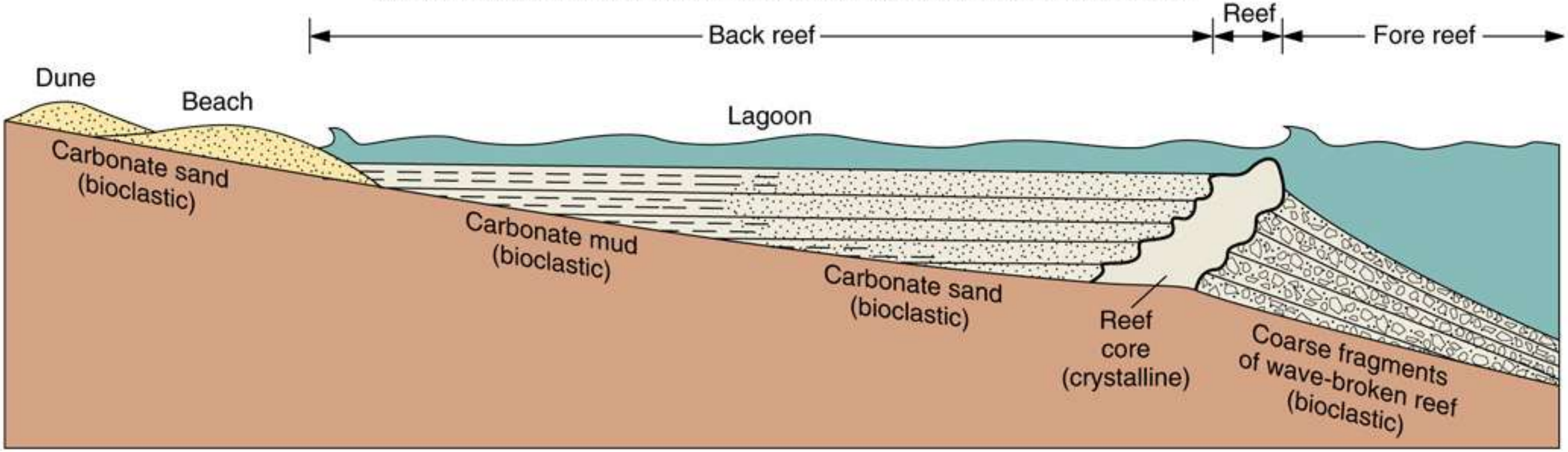
Interpretation of Sedimentary Rocks

- Environment of Deposition

  - **Beach, Barrier Island, Dune**: an elongate bar of sand built by wave action. Well-sorted, well-rounded quartz sandstones may contain cross-bedding (low-angle) and rarely marine fossils.

  - **Lagoon**: semi-closed, quiet body of water between a barrier island and mainland. Shales cut by channels, may contain fossil oysters and other marine fossils.

Fig. 06.17


Back reef
Reef
Fore reef
Dune
Beach
Lagoon
Carbonate sand (bioclastic)
Carbonate mud (bioclastic)
Carbonate sand (bioclastic)
Reef core (crystalline)
Coarse fragments of wave-broken reef (bioclastic)

Interpretation of Sedimentary Rocks

- Environment of Deposition

  - **Shallow Marine Shelves**: can contain ss, siltstone, sh. Coarser may contain symmetrical ripple marks, cross-beds, and marine fossils like clams and snails; mud cracks may be preserved in shales formed in near shore tidal flats.

  - **Reefs**: massive ls beds in reef cores, ls breccias forming seaward, and finer materials forming landward.

Interpretation of Sedimentary Rocks

- Environment of Deposition
  - **Deep marine environments**: shale and graywacke.

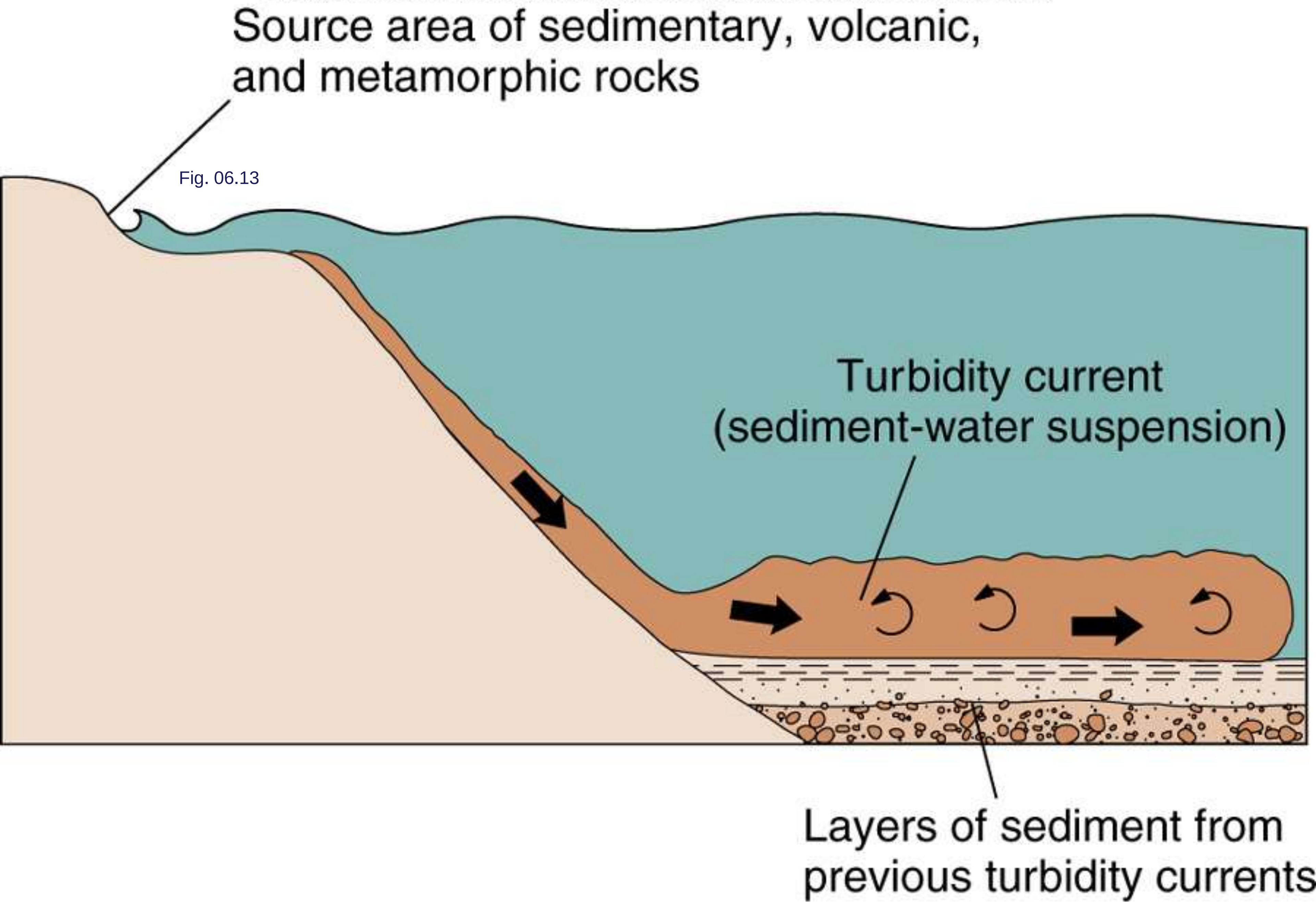
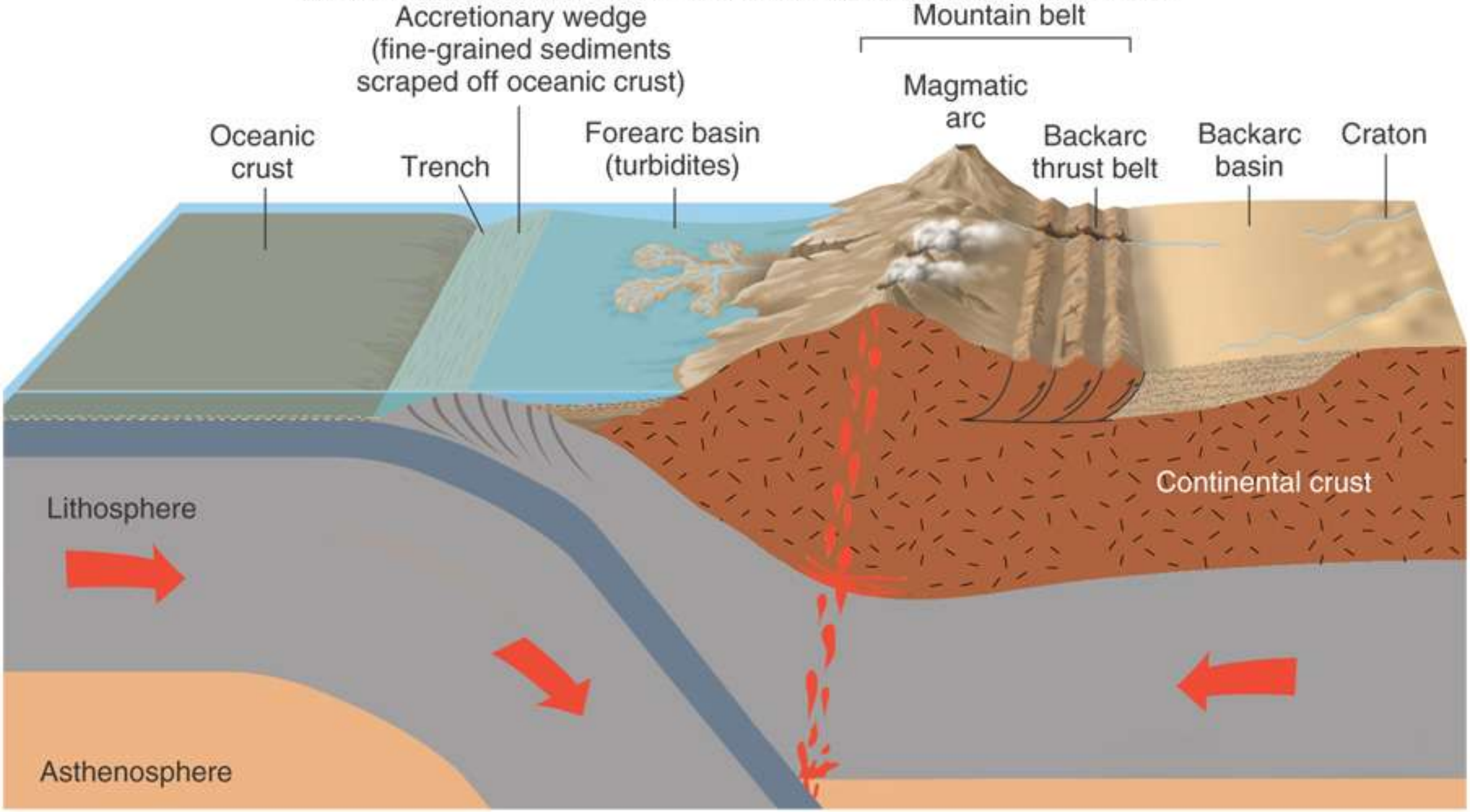

Source area of sedimentary, volcanic, and metamorphic rocks
Turbidity current
(sediment-water suspension)
Layers of sediment from previous turbidity currents

Fig. 06.13

Interpretation of Sedimentary Rocks

- Plate Tectonics and Sedimentary Rocks

Fig. 06.41



Accretionary wedge
(fine-grained sediments
scraped off oceanic crust)
Mountain belt
Magmatic
arc
Oceanic
crust
Trench
Forearc basin
(turbidites)
Backarc
thrust belt
Backarc
basin
Craton
Continental crust
Lithosphere
Asthenosphere

Fig. 06.42