

## CHAPTER 4 THE SEA FLOOR AND ITS SEDIMENTS

### *Objectives*

1. To familiarize ourselves with the topography of the sea floor, a surface that most people have never seen.
2. To understand today's modern methods of measuring the depths of the world's oceans and the patterns of depth distribution from shallow shelves to deep trenches.
3. To examine the sediments that cover the bottom of the world's oceans and to discover clues to explain the distribution and abundance of marine sediments.
4. Finally, although we have located, exploited, and depleted much of the high-grade mineral resources on land, we need to be aware of the potential resources that exist in the world's oceans and of the fragile nature of the marine environment as we plan ways to recover them.

### *Key Concepts*

**Major Concept (I)** *Our ability to accurately map the features of the sea floor has been acquired only recently and continues to improve with advancing technology.*

Related or supporting concepts:

- Early mariners, and even scientists, had no idea how deep the oceans are or how rugged their bathymetry is.
- In about 85 B.C. Posidonius, a Greek geographer, used a large rock tied to a rope to measure a depth of 2 km (1.2 mi) in the Mediterranean Sea.
- Soundings, or measures of the depth of the water, continued to rely on weighted lines or ropes for centuries after Posidonius's first measurement.
- Early depth measurements relied on dropping a lead weight over the side and measuring the length of rope it carried with it to the bottom. Wax or tallow on the weight would capture samples of the sediment on the bottom and prove that it had reached the sea floor. At extreme depths, this was a very time-consuming process and the weight of the rope made it difficult to sense when the lead hit the bottom (think of the weight of 8 miles of rope!) so the measurements were seldom very accurate.
- Sounding lines were often marked in fathoms. One fathom is equal to 6 feet.
- Later soundings were made with cannonballs attached to piano wire. This speeded up the process and increased the accuracy because of the relatively small weight of the piano wire compared to the cannonball.
- Today we use very accurate instruments that measure depth by timing the passage of sound waves that are sent out by the ship to reflect off the bottom and return to the surface. These instruments are called echo sounders or precision depth recorders (PDR's). Their accuracy is due to the nearly constant velocity of sound in seawater and the ease of obtaining very precise timing.
- The German research vessel *Meteor* was the first to use an echo sounder extensively on a long voyage in the Atlantic Ocean. It was during this voyage in 1925 that the Mid-Atlantic Ridge was first detected.
- Modern methods map sea floor bathymetry at scales ranging from centimeters to kilometers with impressive accuracy using a variety of different techniques.
- Detailed surveys of small areas are conducted with manned submersibles or remotely operated vehicles (ROVs). Multibeam sonar systems towed by research vessels are used to map large areas of the deep sea floor on scales of tens to hundreds of square kilometers. In shallow regions airborne laser systems can map large regions rapidly.
- We can even measure changes in the height of the sea surface over large areas using satellites. These changes are related to variations in gravity caused by major features on the sea floor such as trenches, ridges, and seamounts. The sea surface may be as much as 25–30 m (80–100 ft) lower over trenches and 5–10 m (16–33 ft) higher over seamounts and ridges.

**Major Concept (II)**      *The land below the sea is as rugged as the land above it. In fact, undersea mountains are longer, the valley floors are wider and flatter, and the canyons are often deeper than those found on land.*

Related or supporting concepts:

- Erosion as we know it on the continents is not as common under the sea except on very steep slopes. As a consequence, it is likely that the appearance of the bathymetric features of the ocean basins and sea floor have remained much the same for millions of years.

**Major Concept (III)**      *The continental margin is made up of the continental shelf, shelf break, slope, and rise (see fig. 4.7).*

Related or supporting concepts:

- There are two types of continental margins; passive, or Atlantic, continental margins and active, or Pacific, continental margins.
- Passive margins:
  - a. are found around the rim of the Atlantic Ocean,
  - b. are not plate boundaries,
  - c. have little or no seismic or volcanic activity, and
  - d. form when a continent rifts apart creating a new ocean basin between the fragments.
- Active continental margins:
  - a. are found around the rim of the Pacific Ocean,
  - b. are plate boundaries,
  - c. are typically seismically and/or volcanically active, and
  - d. tend to be relatively narrow.
- Continental shelves are very flat edges of the continental crust covered by marine waters. The average maximum depth of the shelves is 130 m (427 ft) and their average width is 65 km (40 mi). While these averages will give you some idea of the scales of shelves, you should know that there is a lot of variability in both width and depth. The width can be as great as 1500 km (930 mi) along passive margins and the depth at the outer edge may vary from 20–500 m (65–1640 ft).
- The width of continental shelves is often related to the slope of the adjacent land surface. Narrow shelves are often associated with steep slopes and wide shelves are typically found adjacent to flat continental regions.
- Processes producing continental shelves include the emplacement of structural dams that can trap sediment behind them and erosion due to wave action (see fig. 4.6).
- The surface area and distribution of continental shelves has varied in the past as a result of global changes in sea level produced by large scale melting and freezing of ice sheets.
- The steep slope extending to the ocean basin floor is called the continental slope.
- Submarine canyons cut across the continental margins. In some cases they can be traced from river systems on continents across the shelf and down the slope to open onto the deep sea floor. They provide a pathway for transporting nearshore sediments to the ocean depths.
- Density or turbidity currents are the primary erosional agents for the formation of submarine canyons as they transport large amounts of abrasive sediment through them. Unstable accumulations of sediment at the heads of canyons are periodically triggered by storm or earthquake activity and flow rapidly down through the canyon (see fig. 4.10). When they reach the bottom of the canyon, the reduction in the slope of the sea floor results in a drop in the velocity of the current and the sediment will fall out of suspension to be deposited.
- Turbidity currents can travel at speeds up to 90 km (56 mi) per hour and carry as much as 300 kg of sediment per cubic meter (18.7 lb per cubic foot).

**Major Concept (IV)**      *The deep oceanic basin floor covers more of Earth's surface (30%) than the exposed continental land surface (29%) and is an area that can be just as rugged as the continents. There are a variety of features that rise up above the deep-ocean floor*

*and there are regions that extend to significantly greater depths.*

Related or supporting concepts:

- Features that extend above the deep ocean floor (see fig. 4.12) include:
  - a. abyssal hills less than 1000 meters high,
  - b. seamounts greater than 1000 meters high,
  - c. guyots (flat-topped seamounts),
  - d. islands, and
  - e. vast oceanic ridges and rift valleys extending through the ocean basins.
- Abyssal hills may be the Earth's most common topographic feature. They cover over 50% of the Atlantic sea floor and roughly 80% of the Pacific sea floor.
- When seamounts rise above the sea surface to become islands they are subjected to the erosional power of wind and waves. Some of them have their peaks eroded flat and later sink beneath the surface as a result of sea floor subsidence with time and spreading away from the ridge, as well as the weight of the seamount on the crust. These flat-topped seamounts are called guyots. Further evidence that they were once on the surface is often present in the discovery of coral remains on their tops.
- The tops of guyots are commonly 1000 to 1700 meters (3300–5600 ft) beneath the surface.
- Coral reef structures are often built on islands and seamounts. Darwin first suggested the progression from fringing to barrier reef as islands subside and the coral continues to grow upwards. Finally an atoll forms when the island sinks beneath the surface of the water (see fig. 4.13).
- Ocean trenches are elongate features that extend to great depths beneath the normal deep ocean floor.

### **Major Concept (V)**

*Hidden beneath the sea surface is the most impressive mountain system on our planet. Virtually unknown fifty years ago, this mountain chain extends 65,000 kilometers (40,000 miles) around the globe through every ocean basin. This mountain system is roughly 1000 kilometers (600 miles) wide and is 1000–2000 meters high (3500–7000 feet).*

Related or supporting concepts:

- Where this mountain chain has steep, rugged sides it is called a ridge. Where the sides have less relief and bathymetry they are called rises.
- Fracture zones run perpendicular to the axis of the ocean ridges and rises and break the entire system into smaller segments. The portion of the fracture zone between adjacent segments of the ridge is called a transform fault. One excellent example of a transform fault is the San Andreas fault of California.
- These mountainous regions and other features that rise up above the sea floor break up the ocean floor into isolated basins and sub-basins (see figs. 4.11 and 4.14).
- Basins isolated by tall segments of the ridge system have little mixing of deep water while those that are surrounded by lower segments of the ridge system may still mix significantly.

### **Major Concept (VI)**

*The deepest regions of the world's oceans are not, as one might guess, in the middle of the deep basins but in narrow, steep-sided trenches that extend to depths as great as 11 kilometers (see fig. 4.15).*

Related or supporting concepts:

- Trenches occur either along continental margins or adjacent to arcuate, volcanically active island chains.
- The majority of the world's trenches occur in the Pacific Ocean. Surprisingly the Atlantic Ocean, second largest in size, has only two trenches.
- The deepest spot in the oceans is in a region of the Mariana Trench called the Challenger Deep where the sea floor is 11,020 m (36,150 ft) beneath the surface.
- The longest trench is the Peru-Chile Trench, extending 5900 km (3700 mi) along the western side of South America.

- The Sunda-Java Trench in the Indian Ocean runs for 4500 km (2800 mi).

**Major Concept (VII)** *Except for very unusual places or very steep slopes, most of the ocean floor is covered with a blanket of sediments of variable thickness and origin.*

Related or supporting concepts:

- Geological oceanographers classify marine sediments by their:
  - a. source,
  - b. chemistry,
  - c. place of deposit,
  - d. particle size,
  - e. age, and
  - f. color.
- Geological oceanographers study:
  - a. the rate at which marine sediments accumulate,
  - b. the distribution of different kinds of sediment on the sea floor,
  - c. the source and abundance of sediment,
  - d. the chemical composition of sediment, and
  - e. the history recorded in the sediments.

**Major Concept (VIII)** *Sediment particles are classified by size.*

Related or supporting concepts:

- The size classification scheme for sediment particles is given in table 4.1.
- Broad size categories are boulder, sand, and mud from largest to smallest.
- Sediment samples can be sorted by size using a series of sieves with variable mesh size.
- A sample is well-sorted if the particles are nearly all of the same size, and it is poorly-sorted if the particles have many different sizes.
- Particle size and shape influence the distance a particle will travel and the rate at which it will sink. Large particles tend to sink faster than small particles. Spherical particles tend to have comparatively rapid settling rates, angular particles settle more slowly due to turbulence, and flat particles settle relatively slowly (assuming all particles have the same density).
- In general, particle size decreases with increasing distance from the shore.
- There is a close correlation between sediments on the sea floor and sediment particles in surface water directly above.
- Small particles that would ordinarily sink very slowly will sink more rapidly if they clump together to form larger particles. This may happen as a result of electrical attractions between the particles or organisms packaging them in fecal pellets can cause it.
- Clumps of as many as 100,000 skeletal remains of small organisms can be packaged into a single fecal pellet that will sink to the sea floor in 10 to 15 days.

**Major Concept (IX)** *Marine sediment is also classified by the location where it is found.*

Related or supporting concepts:

- Sediment found near the continental margin and adjacent to islands is called neritic sediment.
- Neritic sediments typically have a wide range of sediment particle sizes.
- Most neritic sediments are eroded from rocks on land and transported to the oceans by rivers and streams.
- The largest neritic particles settle out of the water column near shore and the smallest ones are transported furthest offshore across the continental shelf.
- Sediment found on the deep sea floor is called pelagic sediments.
- Pelagic sediments are generally fine-grained.

- The thickness of pelagic sediment is a function of the length of time they have been accumulating, or the age of the seafloor they cover.
- The thickness of pelagic sediment increases with increasing distance from mid-ocean ridges (fig. 3.16).

**Major Concept (X)**      *Marine sediment accumulates at different rates in different areas of the oceans.*

Related or supporting concepts:

- Accumulation rates for neritic sediments are highly variable:
  - a. in river estuaries rates may be as much as 800,000 cm (315,000 in) per 1000 years or 8 m (over 26 ft) per year, and
  - b. in quiet bays the rate may be 500 cm (197 in) per 1000 years.
- The rivers of Asia contribute more than one-quarter of the world's land-derived sediments each year.
- Many of the sediments covering continental shelves were deposited in the past by processes that no longer exist at that location. These are called relict sediments.
- Pelagic sediment accumulates more slowly than neritic sediment.
- Average accumulation rates for pelagic sediments are 0.5–1.0 cm (0.2–0.4 in) per 1000 years.
- The average thickness of pelagic sediment is about 500 to 600 m.

**Major Concept (XI)**      *Sediments derived from pre-existing rocks are called lithogenous, or terrigenous, sediments.*

Related or supporting concepts:

- Roughly 75% of marine sediments are lithogenous in origin and are transported to the marine environment primarily by streams and rivers that run to the seashore. Small particles are easier to transport long distances because it requires very little energy to move them. Conversely, large particles will be deposited rapidly as the velocity of the moving water carrying them decreases. Consequently, there is a clear pattern in the size distribution of lithogenous sediment in the oceans. Nearshore deposits are dominated by coarse particles (gravels and sands) while particle size generally decreases offshore with clays occupying the deep ocean basins.
- Lithogenous sediment that is rich in iron and has been oxidized (that produces a red color) is often small enough to be picked up and transported far out over the oceans by the wind. After it falls to the sea surface it will sink and accumulate very slowly. If there is very little sediment from other sources that falls in the same location, this material will form what is called red clay.
- Abyssal clays are composed of at least 70% by weight clay-sized particles.
- Clays accumulate very slowly, generally less than 0.1 cm (0.04 in) per 1000 years.
- Clay particles are very small and may remain suspended in the water for many years.
- Clay particles are thought to be blown far from land by wind.
- Deep-sea clay, often called red clay, frequently has a reddish or brownish color due to the oxidation of iron.
- Four clay minerals make up the deep-sea clays:
  - a. chlorite,
  - b. illite,
  - c. kaolinite, and
  - d. montmorillonite.
- The four different clays are deposited under different climatic and geologic conditions.
- Chlorite is abundant in deep-sea clays at high latitudes where chemical weathering is less effective because of low temperatures.
- Kaolinite is produced by strong chemical weathering of soils so it is generally found in greater abundance in the tropics.
- Illite is the most widespread of the four. It is found in greater abundance in the Northern Hemisphere (over 50% of the total clay) than in the Southern Hemisphere (20–50% of the total clay). Its abundance depends largely on the degree of dilution by other clay minerals.
- Montmorillonite is the product of the weathering of volcanic material. It is found in regions of low

sedimentation near sources of volcanic ash. It is more abundant in the Pacific and Indian Oceans than in the Atlantic Ocean.

- Lithogenous particles can be transported by water, wind, gravity, and ice.
- Occasionally, very large particles will appear in fine-grained deep-sea clays far away from continental margins. These are actually rafted far out to sea, frozen into glacial ice. This ice breaks off from continents and drifts as icebergs, slowly melting and randomly dropping these unique rocks to the sea floor.

**Major Concept (XII)** *Biogenous sediments are derived from organic sources.*

Related or supporting concepts:

- Deep-sea biogenous sediments are composed almost entirely of the hard remains of single-celled plants and animals. The two most common skeletal materials are calcium carbonate ( $\text{CaCO}_3$ ) and silica ( $\text{SiO}_2$ ). When ocean sediment is composed of over 30% of these skeletal remains, it is called a calcareous or siliceous “ooze,” depending on the chemistry of the remains.
- Calcareous particles are created by single-celled plants called coccolithophorids, small snails called pteropods, and amoebae-like animals called foraminifera.
- Calcareous oozes are the dominant type of pelagic sediment.
- The distribution of biogenous sediment is related to the distribution and density of living organisms, and is also highly dependent on the physical and chemical properties of the surrounding seawater. The most important water properties are depth, temperature, concentration of dissolved gas (particularly  $\text{CO}_2$ ), and the concentrations of calcium carbonate and silica already in solution in the water. Most tropical surface waters are saturated in calcium carbonate but colder water at higher latitudes is not. Almost all of the ocean’s waters are undersaturated in silica.
- Calcium carbonate dissolves more rapidly in cold, deep water, which has a high concentration of  $\text{CO}_2$  and is slightly acidic.
- The depth at which calcareous tests (skeletal material) first begins to dissolve is called the lysocline.
- The depth at which the amount of calcareous material preserved falls below 20% of the total sediment is called the carbonate compensation depth or CCD.
- Calcareous ooze tends to accumulate above the CCD and it is generally absent at depths below the CCD.
- The CCD has an average depth of about 4500 m (14,800 ft), or roughly midway between the crests of ocean ridges and the deepest regions of the abyssal plains.
- In the Pacific Ocean the CCD is generally at a depth of 4200–4500 m (13,800–14,800 ft). It deepens to about 5000 m (16,400 ft) in the equatorial Pacific where there are high rates of biological productivity at the surface generating a large supply of calcareous tests.
- In the North Atlantic and parts of the South Atlantic the CCD is at depths of 5000 m (16,400 ft) or below.
- Calcareous sediments are generally found at temperate and tropical latitudes in relatively shallow regions such as the Caribbean Sea, along the mid-ocean ridge system, and in coastal regions.
- Single-celled plants called diatoms create siliceous ooze in cold and temperate latitudes. A single-celled animal, the radiolarian, produces siliceous sediments in equatorial regions.
- The pattern of dissolution of siliceous material is opposite that of calcareous material.
- Siliceous particles will dissolve at all depths but they dissolve most rapidly in shallow, warm water.
- An estimated 90% of all siliceous tests are dissolved before they can accumulate on the sea floor.
- Diatomaceous siliceous ooze is found at cold and temperate latitudes around Antarctica and in a band across the North Pacific.
- Radiolarian siliceous ooze is found beneath the warm waters of equatorial latitudes.

**Major Concept (XIII)** *Hydrogenous sediments are derived from chemical reactions in the water.*

Related or supporting concepts:

- Inorganic chemical processes form hydrogenous sediments either by direct precipitation from the water or by the alteration of preexisting material.
- Hydrogenous sediments include:
  - a. some carbonates,
  - b. phosphorites,
  - c. manganese nodules, and
  - d. sulfides.
- Phosphorites contain phosphorus in the form of phosphate. They are most abundant on the continental shelf and upper continental slope.
- Manganese nodules:
  - a. are enriched in manganese, iron, nickel, cobalt, and copper,
  - b. are black or brown rounded masses generally 1–10 cm (0.5–4 in) in diameter,
  - c. are most commonly found scattered across the sea floor on top of other sediment, and
  - d. grow very slowly at rates of 1–10 mm (0.004–0.04 in) per million years.
  - e. nodules on continental margins have uniquely high growth rates of 0.01–0.1 mm per year, roughly one thousand to one million times faster than deep-sea nodules.
- Manganese nodules from the Pacific Ocean tend to have the highest concentrations of metals with the exception of iron. Atlantic Ocean nodules have the highest iron concentration.

**Major Concept (XIV)** *Sediments derived from space are called cosmogenous sediments.*

Related or supporting concepts:

- We should remember that Earth is not a closed system. There is a constant rain of meteoric dust and particles that enters the atmosphere where some of it burns up and the rest (roughly 10%) penetrates to the surface of the planet.
- This creates a fourth source of oceanic sediment that is of minor importance in terms of the volume of material deposited.
- Cosmogenous sediments are usually recognized in sediment samples as rounded spherules or teardrops of glassy material called tektites.

**Major Concept (XV)** *If sediments become layered on top of one another in thick sequences, the fluids moving through them can cement them together, and the weight of the layers above them will squeeze them into sedimentary rock in a process known as lithification.*

Related or supporting concepts:

- The process known as lithification occurs at temperatures below 200°C and takes relatively long periods of time and thick sequences of sediments.
- Lithification can occur through burial, compaction, recrystallization, and cementation of sediments.
- Chemical changes can also occur in sedimentary particles if they react with seawater. This process is called diagenesis. One example is the gradual change of calcareous ooze to form chalk or limestone.
- If sediments are buried deep enough to be subject to greater temperatures and pressures, yet do not actually melt, they may actually undergo chemical and physical changes leading to what we term metamorphic rock.

**Major Concept (XVI)** *Getting actual samples from the deep sea is critical to our understanding of oceanic processes. Samplers range from those that can retrieve just a surface chunk of sediment or rock to those that can bring back long, relatively undisturbed cores from the deep sea.*

Related or supporting concepts:

- Oceanographers choose samples very carefully, based on exactly what type and quality of samples they

- need to solve a particular problem.
- Sediment samples are collected with a variety of different tools including:
  - a. dredges that are essentially net or wire baskets that can be dragged across the sea floor (see fig. 4.25),
  - b. grab samplers that snap shut when they impact the bottom (see fig. 4.26), and
  - c. corers (see fig. 4.27).

**Major Concept (XVII)** *Marine sediments provide important information about past conditions and processes in the oceans.*

Related or supporting concepts:

- The study of the ocean's history through an analysis of marine sediments is called paleoceanography.
- The chemistry of skeletal parts found in successive layers of sediment can provide information about changes in climate and seawater temperature by analyzing the relative abundance of different oxygen isotopes.
- Seawater contains two main isotopes of oxygen: the common  $^{16}\text{O}$  and the less common  $^{18}\text{O}$ . These isotopes are stable and do not decay radioactively.
- Some marine organisms take oxygen out of the water to construct their skeletons. The relative proportion of the two isotopes in their skeletons ( $^{18}\text{O}$ :  $^{16}\text{O}$ ) reflects the relative abundance of the isotopes in the water when the skeletons were constructed.
- Water molecules containing  $^{16}\text{O}$  are lighter and more easily evaporated from the ocean than water molecules containing  $^{18}\text{O}$ .
- During glacial, or cold, periods  $^{16}\text{O}$  is removed from seawater by evaporation and trapped in ice sheets, thus increasing the ( $^{18}\text{O}$ :  $^{16}\text{O}$ ) ratio in the oceans.
- During interglacial, or warm, periods ice melts and  $^{16}\text{O}$  is returned to seawater, thus decreasing the ( $^{18}\text{O}$ :  $^{16}\text{O}$ ) ratio in the oceans.

**Major Concept (XVIII)** *Man has lived in intimate connection with the geological riches of the sea well back into pre-history, yet we are just now realizing that economic deposits of energy sources, building materials, fertilizers, sulphide ores, and scarce manganese and nickel alloys are present in distinct geologic locations on the sea floor.*

Related or supporting concepts:

- Oil and natural gas presently dominate the “mineral” resources being removed from the world's oceans.
- Oil and gas represent more than 95% of the mineral value presently taken from the sea.
- Most oil and gas reserves are found in marine sedimentary rocks roughly 85–180 million years old.
- Factors controlling the development of viable deep-sea mining ventures include the legal aspects of ownership and control of these resources in a global market.
- In actual practice in the United States, only sand and gravel are mined in any real quantities in our offshore waters.
- Annual world production of sand and gravel is about 1.2 billion metric tons.
- Phosphorite is mined to produce phosphates for fertilizer.
- The world's ocean reserve of phosphorite is estimated to be about 50 billion tons.
- There is no commercial mining of phosphorite in the oceans at this time.
- While we do not presently mine sulfur from the oceans, millions of tons of sulfur reserves are known to exist in the Gulf of Mexico and the Mediterranean Sea.
- There has been an increasing interest in gas hydrates in recent years. Gas hydrates are a combination of natural gas (primarily methane) and water that form a solid, ice-like structure under pressure at low temperatures.
- Gas hydrates are a subject of intense interest because they:
  - a. are a potential source of energy,
  - b. they may contribute to slumping along continental margins. and

- c. they may play a role in climate change.
- Mining manganese nodules has not proven to be economically viable because of the depressed international market in minerals and the complex problem of ownership of pelagic mineral deposits.

### *Matching Key Terms with Major Concepts*

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–XVIII) of the appropriate major concept identified in this section:

sounding	echo sounder	precision depth recorder
fathom	submarine canyon	continental shelf
turbidite	continental slope	guyot
rift valley	abyssal plain	trench
ridge and rise system	subsidence	seamount
abyssal hill	neritic sediment	pelagic sediments
boulder	sand	mud
carbonate	lithogenous	hydrogenous
cosmogenous	biogenous	terrigenous
ooze	radiolarian	diatom
foraminifera	pteropod	coccolithophorid
red clay	chlorite	illite
kaolinite	montmorillonite	manganese nodule
lithification	metamorphic	dredge
core	grab sampler	paleoceanography
relict sediment	lysocline	CCD

### *Test Your Recall*

#### **Answer the following questions to test your understanding**

##### FILL IN THE BLANK

1. The sea floor is covered nearly everywhere with \_\_\_\_\_.
2. The continental \_\_\_\_\_ is made up of the shelf, shelf-break, slope, and rise.
3. The \_\_\_\_\_ of the slope is often related to the slope of the adjacent land.
4. A \_\_\_\_\_ may be steep sided and V-shaped, with tributaries similar to those of river-cut canyons on land.
5. \_\_\_\_\_ currents are fast moving avalanches of mud, sand, and water that flow down the slope, eroding and picking up sediment as they gain speed.
6. Steep-sided volcanic \_\_\_\_\_ sometimes rise up from the ocean floor and ‘pierce’ the sea surface to be seen as islands.
7. Flat-topped seamounts are termed \_\_\_\_\_.
8. A \_\_\_\_\_ is a volcanically active canyon or valley bordered by rugged rift mountains.
9. Originally, a \_\_\_\_\_ was the length between a sailor’s outstretched hands.
10. \_\_\_\_\_ sediment is the term used for deep sea deposits, removed from the direct influence of land.

11. \_\_\_\_\_ sediments are derived from living organisms.
12. Sediments composed primarily of particles of one size are called \_\_\_\_\_ sediments.
13. Icebergs can carry large rocks out to sea in a process called \_\_\_\_\_.
14. Oceanic sediments are laid down in \_\_\_\_\_.
15. \_\_\_\_\_ is a particle whose size (diameter) can vary between 2 and .0625 mm.
16. A \_\_\_\_\_ is essentially a hollow pipe with a sharp cutting end.
17. The continental shelf and the continental slope are separated by the shelf \_\_\_\_\_.
18. Rift valleys along mid-ocean ridges are \_\_\_\_\_ active.
19. The process of obtaining a measure of water depth is sometimes called a \_\_\_\_\_.
20. \_\_\_\_\_ sediment is produced by the accumulation of particles from space.

#### TRUE-FALSE

1. It was not until the 1950s that we were truly able to sample the sea floor with ease.
2. The profile of topography of the sea floor across the Atlantic shows more relief than a similar profile drawn anywhere across North America.
3. The continental shelves are underlain by oceanic crust, and are not geologically similar to the continents.
4. Submarine canyons are never related to existing river systems on land.
5. In terms of the percent of Earth's total surface area covered, abyssal hills are Earth's most common feature.
6. Mid-ocean ridges can effectively separate deep ocean water in one basin from another, and can control the flow of bottom currents.
7. Continental shelves are often narrow along mountainous coasts.
8. Modern instruments that measure ocean depth use pulses of sound.
9. Neritic sediments are deposited far from land.
10. The majority of oceanic trenches are associated with volcanic island arcs or chains of land volcanoes.
11. By far, the largest volume of terrigenous or lithogenous sediments are deposited on the continental margins.
12. Manganese nodules develop very rapidly on the deep sea floor, growing 1–10 mm per year.
13. Coarse sediments are usually found far offshore from high-energy river mouths and beaches.
14. Calcite is more soluble in cold water than in warm.
15. Seabed resources do not have to be competitive with onshore markets and other sources.
16. Rift valleys along mid-ocean ridges may be as much as 1500 m deep.
17. The deep oceans can be divided into about 20 separate basins by bathymetric features.
18. Hydrogenous sediments are the most plentiful sediment type in the oceans.
19. Tektites are produced by organisms in cold, deep water.
20. Calcite solubility depends on temperature.

#### MULTIPLE CHOICE

1. The steepest part of the continental margin is the
  - a. shelf.
  - b. beach.
  - c. rise.
  - d. slope.
  - e. break.
2. The continental rise is often absent along Pacific margins because
  - a. there are fewer submarine canyons.
  - b. there are many deep trenches.
  - c. less sediment is eroded from the continents.
  - d. intense earthquake activity prevents its formation.
  - e. sea floor spreading rates are generally faster in the Pacific.
3. Submarine canyons

- a. provide pathways for terrigenous sediment to reach the deep sea floor.
  - b. are eroded by turbidity currents.
  - c. may be as large as the Grand Canyon of Arizona.
  - d. cut across the continental margin.
  - e. all of the above.
4. Abyssal hills are less than \_\_\_\_\_ meters high.
- a. 1000
  - b. 500
  - c. 2500
  - d. 3000
  - e. 1500
5. The abyssal plain is extremely flat because
- a. there is no sediment on it to form abyssal hills.
  - b. the oceanic crust is very smooth because it forms from molten rock.
  - c. sediment covers the irregular sea floor beneath it.
  - d. there is no faulting or folding of the rocks.
  - e. none of the above.
6. Which of the following describes a sediment composed of particles that have been eroded from pre-existing rocks?
- a. ooze
  - b. biogenous
  - c. hydrogenous
  - d. nodules
  - e. lithogenous
7. If oceanic sediment is composed of more than \_\_\_\_\_ % biogenous material by weight, it is called an ooze.
- a. 30
  - b. 60
  - c. 25
  - d. 15
  - e. 5
8. Which of the following is an animal?
- a. radiolarian
  - b. foraminifera
  - c. pteropods
  - d. all of the above
  - e. none of the above
9. The smallest sediment particles are called
- a. very fine sands.
  - b. granules.
  - c. clays.
  - d. silts.
  - e. muds.
10. Sediments that have been laid down on the continental shelf by processes that no longer exist at that location are called
- a. neritic.
  - b. pelagic.
  - c. hydrogenous.
  - d. terrigenous.
  - e. relict.
11. Continental shelves are
- a. deep ocean canyons.
  - b. flat plateaus in deep-ocean basins the size of continents.
  - c. flatland borders at the edge of continents.
  - d. volcanic seamounts.
  - e. none of the above.

12. Turbidity currents may be caused or triggered by
  - a. high velocity winds.
  - b. earthquakes.
  - c. overloading of sediments on steep slopes.
  - d. b and c above.
  - e. none of the above.
13. Guyots are
  - a. French bicycle racers.
  - b. oceanic volcanic islands.
  - c. coral reef pinnacles.
  - d. flat-topped submarine volcanoes.
  - e. none of the above.
14. The mid-ocean ridge system extends for
  - a. 25,000 km.
  - b. 35,000 km.
  - c. 45,000 km.
  - d. 55,000 km.
  - e. 65,000 km.
15. The deepest oceanic trench, the Mariana, is
  - a. 1 km deep.
  - b. 5 km deep.
  - c. 8 km deep.
  - d. 11 km deep.
  - e. none of the above.
16. Sediments that precipitate directly from seawater are called
  - a. lithogenous.
  - b. hydrogenous.
  - c. biogenous.
  - d. anthropogenous.
  - e. pelagic.
17. In the Atlantic Ocean, water is saturated with respect to calcite to depths of
  - a. 1000 m.
  - b. 2000 m.
  - c. 3000 m.
  - d. 4000 m.
  - e. 5000 m.
18. Layers in oceanic sediment are recognized by
  - a. color.
  - b. particle size.
  - c. kind or composition of particles.
  - d. all of the above.
  - e. none of the above.
19. Ridge systems are about \_\_\_\_\_ km wide.
  - a. 1000
  - b. 500
  - c. 100
  - d. 50
  - e. 10
20. Sedimentary particles are transported by
  - a. wind.
  - b. ice.
  - c. moving water.
  - d. gravity.
  - e. all of the above.

### Visual Aids: Test Your Understanding of the Figures

1. How does figure 4.24 show that a dramatic change in wind direction occurs across the North African continent between winter and summer? What would you guess the wind direction to be in summer?
2. Which ocean has only two oceanic trenches; which one has only one? (see fig. 4.15).
3. Study figure 4.13 carefully. Now close your book, and on a piece of scrap paper, quickly sketch the three steps in the formation of an atoll. How did you do?

### Study Problems

1. If water is 3658 meters deep, what is its depth in fathoms?
2. If the average deep-sea sediment thickness is 550 meters and the average age of the sea floor is 57 million years, calculate the average deep-sea sedimentation rate in cm/1000 years.
3. A typical piston core may recover a sediment core 20 feet long. At a reasonable deep-sea sedimentation rate of 0.5 centimeters per 1000 years, how far back in time are you looking with a core of this length?

### Answer Key for Key Terms and Test Your Recall

#### KEY TERMS

sounding (I)	echo sounder (I)	precision depth recorder (I)
fathom (I)	submarine canyon (III)	continental shelf (III)
turbidite (III)	continental slope (III)	guyot (IV)
rift valley (IV, V)	abyssal plain (IV)	trench (IV, VI)
ridge and rise system (IV, V)	subsidence (IV)	seamount (IV)
abyssal hill (IV)	neritic sediment (IX)	pelagic sediments (IX)
boulder (VIII)	sand (VIII)	mud (VIII)
carbonate (VII)	lithogenous (XI)	hydrogenous (XI)
cosmogenous (XI)	biogenous (VII)	terrigenous (XI)
ooze (XII)	radiolarian (XII)	diatom (XII)
foraminifera (XII)	pteropod (XII)	coccolithophorid (XII)
red clay (XI)	chlorite (XI)	illite (XI)
kaolinite (XI)	montmorillonite (XI)	manganese nodule (XIII)
lithification (XV)	metamorphic (XV)	dredge (XVI)
core (XVI)	grab sampler (XVI)	paleoceanography (XVII)
relict sediment (X)	lysocline (XII)	CCD (XII)

#### FILL IN THE BLANK

- |                     |                 |                  |
|---------------------|-----------------|------------------|
| 1. sediments        | 2. margin       | 3. width         |
| 4. submarine canyon | 5. turbidity    | 6. seamounts     |
| 7. guyots           | 8. rift valley  | 9. fathom        |
| 10. pelagic         | 11. biogenous   | 12. well-sorted  |
| 13. rafting         | 14. layers      | 15. sand         |
| 16. corer           | 17. break       | 18. volcanically |
| 19. sounding        | 20. cosmogenous |                  |

#### TRUE - FALSE

1.T 2.T 3.F 4.F 5.T 6.T 7.T 8.T 9.F 10.T 11.T 12.F 13.F 14.T 15.F 16.T 17.F 18.F 19.F 20.T

#### MULTIPLE CHOICE

1.d 2.b 3.e 4.a 5.c 6.e 7.a 8.d 9.c 10.e 11.c 12.d 13.d 14.e 15.d 16.b 17.d 18.d 19.a 20.e

#### STUDY PROBLEMS

1. 2000 fathoms
2. 0.96 cm/1000 years
3. 1,219,200 years