1 FOCUS

Section Objectives

15.1 **Identify** the units used to express the salinity of ocean water.

15.2 **List** the sources of salt in ocean water.

15.3 **Recognize** the factors that affect the density of ocean water.

15.4 **Compare and contrast** the three main zones of the open ocean.

Reading Focus

Build Vocabulary

L2

Word Parts Before students read this section, ask them to write the meanings of the prefix *thermo- ("temperature")* and the suffix *-cline ("slope")*. Then have students write a definition for what they think the word *thermocline* means. After students read the section, have them examine their definition and discuss whether or not it needs to be changed.

Reading Strategy

L2

a. evaporation, runoff, ice formation, melting of ice

Sample additional questions and answers for **b.** to **g.**: **What are the sources of sea salts?** *(weathered rocks, volcanic eruptions)* **What factors affect seawater temperature?** *(sunlight, depth)* **What factors affect seawater density?** *(salinity, temperature)*

2 INSTRUCT

Salinity

Use Visuals

L1

Figure 1 Have students examine the graph. Ask: **Which of these two types of measures—weight or volume—is used to determine the percentages of salts and water in a sample of seawater?** *(weight)* **What unit of measure is used?** *(grams)* **Why do you suppose salinity is usually expressed as "parts per thousand" instead of "percent" or "parts per hundred"?** *(easier to use in calculations, because fewer decimal places are required)*

Visual

15.1 The Composition of Seawater

Reading Focus

Key Concepts

- What units are used to express the salinity of ocean water?
- What are the sources of salt in ocean water?
- What factors affect the density of ocean water?
- What are the three main zones of the open ocean?

Vocabulary

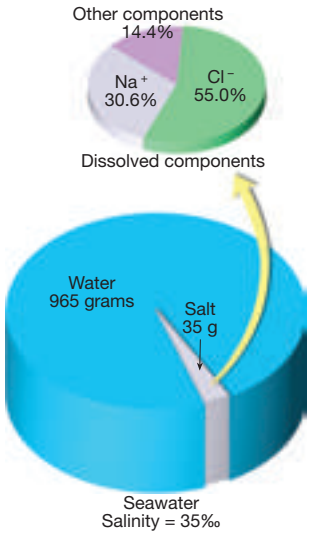
- salinity
- thermocline
- density
- pycnocline
- mixed zone

Reading Strategy

Previewing Copy the table below. Before you read, preview the figures in this section and add three more questions to the table. As you read, write answers to your questions.

Questions About Seawater	Answers
What processes affect seawater salinity?	a. ?
b. ?	c. ?
d. ?	e. ?
f. ?	g. ?

Figure 1 Salts in Seawater This circle graph shows that 1000 grams of seawater with a salinity of 35‰ consists of 965 grams of water and 35 grams of various salts and other solids dissolved in the water.



What is the difference between pure water and seawater? One of the most obvious differences is that seawater contains dissolved substances that give it a salty taste. These dissolved substances include sodium chloride, other salts, metals, and even dissolved gases. In fact, every known naturally occurring element is found dissolved in at least trace amounts in seawater. The salt content of seawater makes it unsuitable for drinking or for irrigating most crops and causes it to be highly corrosive to many materials. However, many parts of the ocean are full of life adapted to this environment.

Water is the major component of nearly every life form on Earth. Our own body fluid chemistry is similar to the chemistry of seawater. Seawater consists of about 3.5 percent dissolved mineral substances that are collectively termed "salts." Although the percentage of dissolved components may seem small, the actual quantity is huge because the ocean is so vast.

Salinity

Salinity (*salinus* = salt) is the total amount of solid material dissolved in water. It is the ratio of the mass of dissolved substances to the mass of the water sample. Many common quantities are expressed in percent (%), which is parts per hundred. **Because the proportion of dissolved substances in seawater is such a small number, oceanographers typically express salinity in parts per thousand (‰).** The average salinity of seawater is 3.5% or 35‰. Figure 1 shows the principal elements that contribute to the ocean's salinity. **Most of the salt in seawater is sodium chloride, common table salt.**

Sources of Sea Salts What are the primary sources of dissolved substances in the ocean? **Chemical weathering of rocks on the continents is one source of elements found in seawater.** These dissolved materials reach oceans through runoff from rivers and streams at an estimated rate of more than 2.3 billion metric tons per year. **The second major source of elements found in seawater is from Earth's interior.** Through volcanic eruptions, large quantities of water vapor and other gases have been emitted into the atmosphere during much of geologic time. Scientists believe that this is the principal source of water in the oceans. About 4 billion years ago, as Earth's temperature cooled, the water vapor condensed and torrential rains filled the ocean basins with water. Certain elements—particularly chlorine, bromine, sulfur, and boron—were emitted along with the water. These elements exist in the ocean in much greater quantities than could be explained by weathering of rocks alone.

Processes Affecting Salinity Because the ocean is well mixed, the relative concentrations of the major components in seawater are essentially constant, no matter where the ocean is sampled. Surface salinity variation in the open ocean normally ranges from 33‰ to 38‰. Variations in salinity result from changes in the water content of the solution.

Figure 2 shows some of the different processes that affect the amount of water in seawater, thereby affecting salinity. Some processes add large amounts of fresh water to seawater, decreasing salinity. These processes include precipitation, runoff from land, icebergs melting, and sea ice melting.

Q & A

Q *Is the ocean getting saltier?*

A Evidence suggests that the composition of seawater has been relatively stable for millions of years. Material is being removed just as rapidly as it is added by rivers and volcanic activity. Some dissolved components are removed from sea water by organisms as they build hard structures. Other components are lost when they chemically precipitate out of the water as sediment. Still others are exchanged at the oceanic ridge at hydrothermal vents. The net effect is that the overall makeup of seawater has remained relatively constant for a long time.

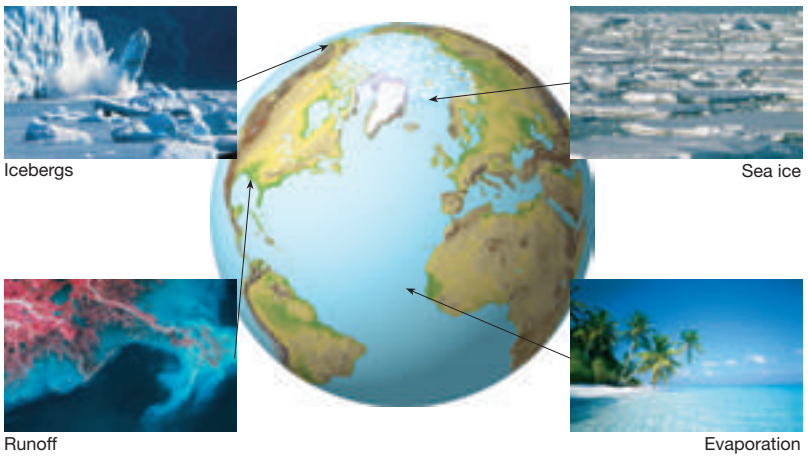


Figure 2 Natural processes affect the salinity of seawater. **Applying Concepts** ***Which processes decrease the salinity of seawater? Which processes increase it?***

Customize for English Language Learners

Explain to students that *pycno* is from the Greek word *pyknos*, which means "dense" or "compact." *Cline* can mean "slope" or "gradient." (*Gradient* means "incline" or "a change in the value of a quantity.") Have students use this information to write the meaning of the term *pycnocline* in their own words. *(Possible answers: density slope or density gradient)* Have students find and look up the meanings of other words that include one of these two word elements. *(Possible answers: pycnometer—device used to measure water density; inclined plane—sloping surface)*

Address Misconceptions L2

Students may think that the salt in ocean water is composed simply of sodium chloride, common table salt. Show students samples of several of the following chemical salts found in ocean water, to give them an idea of the variety of salts in the ocean: sodium chloride (NaCl), magnesium chloride (MgCl), sodium sulfate (Na_2SO_4), calcium chloride ($CaCl_2$), potassium chloride (KCl), sodium bicarbonate ($NaHCO_3$), potassium bromide (KBr), hydrogen borate (H_3BO_3), strontium chloride ($SrCl_2$), sodium fluoride (NaF). Have students make a list of all the elements represented.
Visual, Logical

Teacher Demo

Synthetic Seawater L2

Purpose Students work together as a class to make artificial seawater.

Materials 10 salts listed in the table below, scale, 10 small beakers, 1 large beaker, stirrer

Procedure Assign each of ten groups one salt and have them measure out the grams of that salt according to the table below. After all groups have added their salts to the same container, add enough water to make 1000 g of solution.

Safety Students should wear goggles and take care not to ingest the salts.

Expected Outcome Students create a solution of synthetic seawater.
Kinesthetic

Recipe for Artificial Seawater

Salt	Amount (grams)
NaCl	23.48
MgCl	4.98
Na_2SO_4	3.92
$CaCl_2$	1.10
KCl	0.66
$NaHCO_3$	0.192
KBr	0.096
H_3BO_3	0.026
$SrCl_2$	0.024
NaF	0.003

Kinesthetic, Visual

Answer to . . .

Figure 2 *decrease: precipitation, runoff from land, icebergs melting, sea ice melting; increase: evaporation, formation of sea ice*

Ocean Temperature Variation

Build Science Skills

L2

Inferring Ask students to refer to the line graph in Figure 3 and a world map or globe to answer the following questions. Ask: **At which latitude is sea surface salinity the lowest?** *(60°N)* **Where on the globe is this region located?** *(near the Arctic circle)* **During what season(s) of the year were salinity data for latitude 60°N probably taken?** *(spring or summer)* **How do you know?** *(Ice probably was melting, which increases salinity.)* **In what ways can temperature affect salinity?** *(Above-freezing temperatures allow polar ice to melt, adding fresh water to the ocean surface and decreasing salinity. Ice formation in below-freezing temperatures removes fresh water, increasing salinity.)* **Visual, Logical**

Teacher Demo

Solar Incidence Angles

L2

Purpose Students observe the difference in the angle of incidence of the sun's rays at the equator and the poles.

Materials flashlight or slide/filmstrip projector

Procedure Darken the room. Aim the light perpendicular to the ceiling, and have students measure or estimate the area illuminated. Explain to students that this is similar to the angle at which the sun's light reaches equatorial regions of Earth. Next, slant the light so that it covers a much larger area. Encourage students to estimate or measure the illuminated area. Explain to students that this is more like the angle at which the sun's light reaches the polar regions of Earth. Point out to students that, since the energy of the light source is unchanged, a smaller amount of light energy is reaching each unit of illuminated area.

Expected Outcome Students observe that light energy from the sun is more concentrated in equatorial regions, which explains why temperatures are warmer at the equator than at the poles. **Visual, Logical**

Other processes remove large amounts of fresh water from seawater, increasing salinity. These processes include evaporation and the formation of sea ice. High salinities, for example, are found where evaporation rates are high, as is the case in the dry subtropical regions. In areas where large amounts of precipitation dilute ocean waters, as in the mid-latitudes and near the equator, salinity is lower. Both of these examples are shown on the graph in Figure 3.

Surface salinity in polar regions varies seasonally due to the formation and melting of sea ice. When seawater freezes in winter, salts do not become part of the ice. Therefore, the salinity of the remaining seawater increases. In summer when sea ice melts, the addition of relatively fresh water dilutes the solution and salinity decreases.

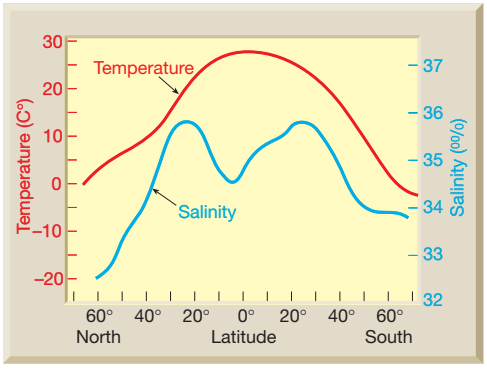


Figure 3 This graph shows the variations in ocean surface temperature (top curve) and surface salinity (lower curve). **Interpreting Diagrams** ***At which latitudes is sea surface temperature highest? Why?***

Ocean Temperature Variation

The ocean's surface water temperature varies with the amount of solar radiation received, which is primarily a function of latitude. The graph in Figure 3 shows this relationship. The intensity of solar radiation in high latitudes is much less than the intensity of solar radiation received in tropical latitudes. Therefore, lower sea surface temperatures are found in high-latitude regions. Higher sea surface temperatures are found in low-latitude regions.

Temperature Variation with Depth

If you lowered a thermometer from the surface of the ocean into deeper water, what temperature pattern do you think you would find? Surface waters are warmed by the sun, so they generally have higher temperatures than deeper waters. However, the observed temperature pattern depends on the latitude.

Figure 4 on page 425 shows two graphs of temperature versus depth: one for low-latitude regions and one for high-latitude regions. The low-latitude curve begins with high temperature at the surface. However, the temperature decreases rapidly with depth because of the inability of the sun's rays to penetrate very far into the ocean. At a depth of about 1000 meters, the temperature remains just a few degrees above freezing and is relatively constant from this level down to the ocean floor. The **thermocline** (*thermo* = heat, *cline* = slope) is the layer of ocean water between about 300 meters and 1000 meters, where there is a rapid change of temperature with depth. The thermocline is a very important structure in the ocean because it creates a vertical barrier to many types of marine life.

Facts and Figures

The salinity of seawater is about four times greater than the salinity of body fluids. If seawater enters the digestive system, it causes internal membranes to lose water through osmosis, which transports water molecules from higher concentrations to lower concentrations. Drinking seawater would cause water from one's body fluids to move into the digestive tract and eventually be expelled from the body, causing dehydration. This can be a problem if seawater is consumed in large amounts, but an occasional swallow when swimming or snorkeling is nothing to worry about.

The high-latitude curve in Figure 4 shows a very different pattern from the low-latitude curve. Surface water temperatures in high latitudes are much cooler than in low latitudes, so the curve begins at the surface with a low temperature. Deeper in the ocean, the temperature of the water is similar to that at the surface, so the curve remains vertical. There is no rapid change of temperature with depth. A thermocline is not present in high latitudes. Instead, the water column is isothermal (*iso* = same, *thermo* = heat).

Reading Checkpoint *What is the thermocline?*

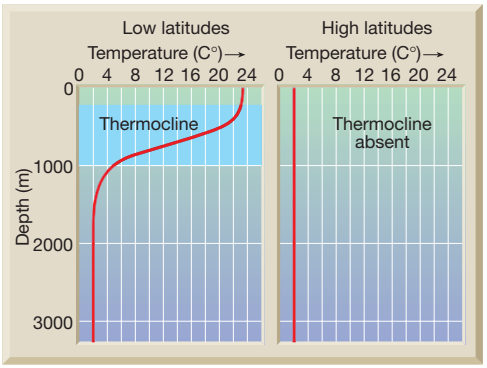


Figure 4 These graphs show the variations in ocean water temperature with depth for low-latitude and high-latitude regions. **Applying Concepts** ***Why is the thermocline absent in the high latitudes?***

Ocean Density Variation

Density is defined as mass per unit volume. It can be thought of as a measure of how heavy something is for its size. For example, an object that has low density is lightweight for its size, such as a dry sponge, foam packing, or a surfboard. An object that has high density is heavy for its size, such as cement, most metals, or a large container full of water.

Density is an important property of ocean water because it determines the water's vertical position in the ocean. Density differences cause large areas of ocean water to sink or float. When high-density seawater is added to low-density fresh water, the denser seawater sinks below the fresh water.

Factors Affecting Seawater Density

Seawater density is influenced by two main factors: salinity and temperature. An increase in salinity adds dissolved substances and results in an increase in seawater density. An increase in temperature results in a decrease in seawater density. Temperature has the greatest influence on surface seawater density because variations in surface seawater temperature are greater than salinity variations. In fact, only in the extreme polar areas of the ocean—where temperatures are low and remain relatively constant—does salinity significantly affect density. Cold water that also has high salinity is some of the highest-density water in the world.

Facts and Figures

Seawater has unique thermal properties that make it resistant to changes in temperature. Many marine species cannot withstand rapid temperature changes. Researchers have concluded that the ocean's stability as a habitat has been instrumental in the development of life on Earth. Scientists who study the effects of global warming indicate that atmospheric warming would eventually be transferred to the ocean, potentially affecting marine organisms. A research project conducted by scientists at the Scripps Institute of Oceanography in the 1990s used sound waves transmitted across an ocean basin to measure ocean temperature. The speed of sound in seawater increases as the water temperature increases, so in the future, if the oceans are getting warmer, the sound would take less time to travel the same distance.

Ocean Density Variation

Build Reading Literacy L1

Refer to **p. 420D**, which provides the guidelines for this preview strategy.

Predict Have students preview the remainder of this section by looking over the headings, figures, figure captions, and boldfaced terms. Ask students to write their predictions of how seawater density is affected by salinity and by temperature. After students have read the section, have them evaluate their predictions and make changes, if necessary.
Verbal, Logical

Integrate Physics L2

Weight and Density Remind students that the weight of a given volume of material increases as its density increases. Ask: **What physical force causes water of a higher density to sink below water of a lower density?** *(gravity)*
Logical

Use Visuals L1

Figure 4 Have students examine the two graphs. Ask: **What is the temperature range within the thermocline at low latitudes?** *(approximately 24°C to 4°C)* **What is the lowest water temperature shown on the graph?** *(approximately 2°C)* **What is the range of depths at which water of this temperature is found at low latitudes?** *(from approximately 1500 m to below 3000 m)* **At high latitudes?** *(from the surface to below 3000 m)*
Visual, Verbal

Answer to . . .

Figure 3 *Sea surface temperature is highest at the equator and low latitudes because these areas receive the most solar radiation at the highest angle of incidence.*

Figure 4 *The thermocline is absent in the high latitudes because the temperature of surface water is closer to the temperature of deeper water.*

Reading Checkpoint *The thermocline is the layer of ocean water between about 300 m and 1000 m, where there is a rapid change of temperature with depth.*

Build Science Skills

L2

Compare and Contrast Have students compare the graph showing a thermocline in Figure 4 with the graph showing a pycnocline in Figure 5. Ask: **In what way are the data plot lines in these two graphs similar?** *(Both show variations that occur from the ocean surface down to depths of close to 1000 m.)* **In what way are the data plot lines in these two graphs different?** *(Temperature decreases within the thermocline; density increases within the pycnocline.)*
Visual, Logical

Build Science Skills

L2

Inferring Have students examine the two graphs shown in Figure 5. Ask: **What can you infer about temperature by looking at these two graphs? Why?** *(Since the density of ocean water is affected more by temperature than by salinity, it follows that the density gradient shown in the low latitude graph reflects variations in temperature with changes in depth, and the lack of a density gradient in the high latitude graph reflects little or no variation in temperature with changes in depth.)* **Under what circumstances might a pycnocline occur in high latitude waters?** *(During warmer seasons of the year, ice melt could add fresh water to the upper layer of seawater, creating a variation in density with respect to water at greater depths.)*
Visual, Logical

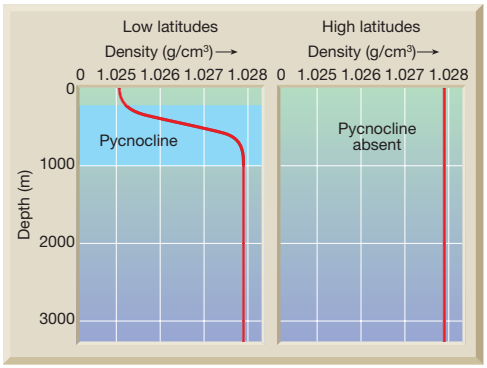


Figure 5 The graphs show variations in ocean water density with depth for low-latitude and high-latitude regions.
Interpreting Diagrams
What is the difference between the low-latitude graph and the high-latitude graph? Why does this difference occur?

Density Variation with Depth

By sampling ocean waters, oceanographers have learned that temperature and salinity—and the water's resulting density—vary with depth. Figure 5 shows two graphs of density versus depth. One graph shows the density for low-latitude regions and the other for high-latitude regions. Compare the density curves in Figure 5 to the temperature curves in Figure 4. They are similar. This similarity demonstrates that temperature is the most important factor affecting seawater density. It also shows that temperature is inversely proportional to density. When two quantities are inversely proportional, they can be multiplied together to equal a constant. Therefore, if the value of one quantity increases, the value of the other quantity decreases proportionately. When water temperature increases, its density decreases.

Reading Checkpoint

How does temperature affect the density of seawater?

The **pycnocline** (*pycno* = density, *cline* = slope) is the layer of ocean water between about 300 meters and 1000 meters where there is a rapid change of density with depth. A pycnocline presents a significant barrier to mixing between low-density water above and high-density water below. A pycnocline is not present in high latitudes; instead, the water column is about the same density throughout.

Ocean Layering

The ocean, like Earth's interior, is layered according to density. Low-density water exists near the surface, and higher-density water occurs below. Except for some shallow inland seas with a high rate of evaporation, the highest-density water is found at the greatest ocean depths. **Oceanographers generally recognize a three-layered structure in most parts of the open ocean: a shallow surface mixed zone, a transition zone, and a deep zone.** These zones are shown in Figure 6.

Surface Zone

Because solar energy is received at the ocean surface, it is here that water temperatures are warmest. The **mixed zone** is the area of the surface created by the mixing of water by waves, currents, and tides. The mixed zone has nearly uniform temperatures. The depth and temperature of this layer vary, depending on latitude and season. The zone usually extends to about 300 meters, but it may extend to a depth of 450 meters. The surface mixed zone accounts for only about 2 percent of ocean water.

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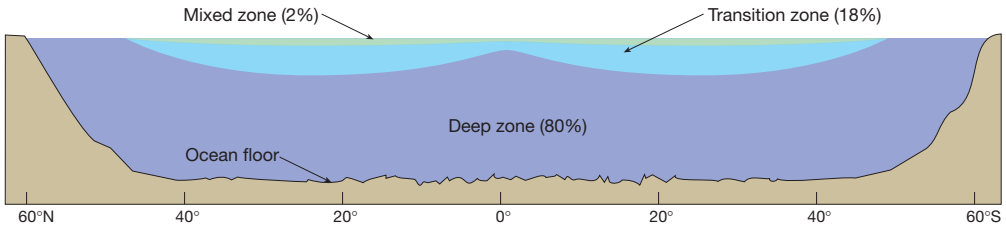

Figure 6 Ocean Zones Oceanographers recognize three main zones of the ocean based on water density, which varies with temperature and salinity.

Transition Zone Below the sun-warmed zone of mixing, the temperature falls abruptly with depth as was seen in Figure 4. Here, a distinct layer called the transition zone exists between the warm surface layer above and the deep zone of cold water below. The transition zone includes a thermocline and associated pycnocline. This zone accounts for about 18 percent of ocean water.

Deep Zone Below the transition zone is the deep zone. Sunlight never reaches this zone, and water temperatures are just a few degrees above freezing. As a result, water density remains constant and high. The deep zone includes about 80 percent of ocean water.

In high latitudes, this three-layered structure of the open ocean does not exist as seen in Figure 6. The three layers do not exist because there is no rapid change in temperature or density with depth. Therefore, good vertical mixing between surface and deep waters can occur in high-latitude regions. Here, cold high-density water forms at the surface, sinks, and initiates deep-ocean currents, which are discussed in Chapter 16.

Section 15.1 Assessment

Reviewing Concepts

1. What is salinity? What units are used to express the salinity of ocean water?
2. What are the six most abundant elements in seawater?
3. What are the sources of salt in ocean water?
4. Explain the relationship between latitude and sea surface temperature.
5. What factors affect the density of ocean water?
6. What are the three main zones of the open ocean?

Critical Thinking

7. **Inferring** Why does the salinity of seawater remain relatively constant over time?
8. **Summarizing** Explain the general pattern of temperature variation with depth in low-latitude oceans.

Writing in Science

Descriptive Paragraph Write a paragraph that describes the different characteristics of the three zones of the open ocean. Include an explanation of why polar regions do not exhibit the same pattern of water stratification.

Ocean Layering

Use Visuals

L1

Figure 5 After students have read the description of the transition zone, have them look back at Figure 5. Ask: **What is the depth range of the transition zone as shown in this graph?** *(region of most abrupt temperature change, from about 500–1000 m)*
Visual

3 ASSESS

Evaluate Understanding

L2

To assess students' understanding of section content, present them with an unlabeled diagram showing an ocean profile similar to the one shown in Figure 5. Have students label the three ocean zones, or layers, and use arrows to indicate the direction in which water temperature increases at lower latitudes, and the direction in which density increases at lower latitudes.

Reteach

L1

Have students work in pairs to create a set of flash cards for all the vocabulary terms in this section. Have students use the flash cards to quiz each other on the definitions.

Writing in Science

The surface mixed zone has the warmest temperatures and the most light. Water is well mixed by waves, currents, and tides. The water temperature is nearly uniform. The transition zone includes the thermocline and pycnocline in which both temperature and density change rapidly with depth. Sunlight does not reach the deep zone where water is near freezing in temperature. This pattern does not exist at polar latitudes because water is isothermal and of uniform density, so there is good vertical mixing in the water column.

Section 15.1 Assessment

1. Salinity is the total amount of solid material dissolved in water; parts per thousand
2. sodium, chlorine, sulfur, oxygen, magnesium, calcium
3. chemical weathering of rocks on continents; Earth's interior
4. Sea surface temperature is higher at the equator and low latitudes. Sea surface temperature decreases as latitude increases.
5. temperature and salinity
6. surface mixed zone, transition zone, deep zone
7. Dissolved components are being removed as rapidly as they are being added.
8. Temperature decreases with increasing depth; a thermocline is present between 300 m and 1000 m.

Answer to . . .

Figure 5 *Pycnocline is not present in high latitude waters. This occurs because density and temperature do not vary with depth.*

Reading Checkpoint *As the temperature of seawater decreases, its density increases.*