

11.3 Mountain Formation



Section 11.3

1 FOCUS

Section Objectives

- 11.8** Identify the type of mountains associated with convergent plate boundaries.
- 11.9** Distinguish between mountains formed by ocean-ocean convergence and mountains formed by ocean-continental convergence.
- 11.10** Identify the type of mountains associated with divergent plate boundaries.
- 11.11** Explain how isostatic adjustment is involved in mountain formation.

Reading Focus

Key Concepts

- What mountains are associated with convergent plate boundaries?
- What mountains are associated with divergent plate boundaries?
- How is isostatic adjustment involved in mountain formation?

Vocabulary

- ◆ accretionary wedge
- ◆ accretion
- ◆ terrane
- ◆ isostasy
- ◆ isostatic adjustment

Reading Strategy

Outlining As you read, make an outline of the important ideas in this section. Use the green topic headings as the main topics and the blue headings as subtopics.

- | | |
|---|-------------------------|
| I. Mountain Formation | |
| A. Mountain Building at Convergent Boundaries | |
| 1. | Ocean-Ocean Convergence |
| 2. | a. _____ ? |
| 3. | b. _____ ? |
| B. Mountain Building at Divergent Boundaries | |

Mountain building still occurs in several places worldwide. For example, the Himalayas began to form 45 million years ago and are still rising. Older mountain ranges, such as the Appalachians in the eastern United States, are deeply eroded, but they have many features found in younger mountains.

Many hypotheses have been proposed to explain mountain formation. One early proposal suggested that mountains are wrinkles in Earth's crust, produced as the planet cooled from its early semi-molten state. People believed that as Earth cooled, it contracted and shrank. In this way, the crust was deformed the way an apple peel wrinkles as it dries out. However, this early hypothesis and many others were not able to withstand careful analysis and had to be discarded.

Figure 11 Young Mountains
The Grand Tetons of Wyoming are an example of relatively young mountains.

Mountain Building at Convergent Boundaries

With the development of the theory of plate tectonics, a widely accepted model for orogenesis became available. **Most mountain building occurs at convergent plate boundaries.** Colliding plates provide the compressional forces that fold, fault, and metamorphose the thick layers of sediments deposited at the edges of landmasses. The partial melting of mantle rock also provides a source of magma that intrudes and further deforms these deposits.



Mountain Building 317

Reading Focus

Build Vocabulary

L2

Paraphrase After students have read the definition of *accretionary wedge* on p. 319, but before they have learned the definition of accretion on p. 321, have them write a short paragraph describing in their own words the process of accretion. After they have read the definition of *accretion*, ask if they would change their definitions.

Reading Strategy

L2

- I. Mountain Formation
 - A. Mountain Building at Convergent Boundaries
 - 1. Ocean-Ocean Convergence
 - 2. Ocean-Continental Convergence
 - 3. Continent-Continent Convergence
 - B. Mountain Building at Divergent Boundaries
 - C. Non-Boundary Mountains
 - D. Continental Accretion
 - 1. Terranes
 - 2. Mountains from Accretion
 - E. Principle of Isostasy
 - 1. Isostatic Adjustment for Mountains

2 INSTRUCT

Mountain Building at Convergent Boundaries

Use Visuals

L1

Figure 12 Have students study the diagrams of ocean-ocean convergence. Ask: **What is the result of the convergence of two oceanic plates?** (formation of a volcanic island arc) **Why does the volume of the crust increase in this type of convergence?** (*Volcanic magma is added to the crust. Sediment that is scraped off the subducting plate accumulates to increase crustal volume.*)

Visual, Logical

Teacher Demo

Partial Melting

L2

Purpose Students observe the process that generates magma during boundary convergence.

Materials can of frozen grape juice concentrate (inexpensive brands work best), can opener, plastic tub, rubber gloves, apron, water, plastic pitcher, paper towels for clean-up

Procedure Allow the grape juice to thaw slightly, but do not let it liquefy. Use a can opener or pull tab to remove one end of the can. Squeeze the juice concentrate out of the can through your hands, letting it fall into the plastic tub. Tell students to look for evidence of partial melting in the concentrate. Be sure to wear an apron and rubber gloves. Use the water, pitcher, and paper towels for cleaning up.

Expected Outcomes The sugary juice has a melting point of about -40°C , whereas the ice crystals in the juice melt at 0°C . If the juice is thawed to a temperature of about -5°C , part of the mixture is liquid, but the ice crystals are still solid. Explain to students that when a plate is subducted, it experiences partial melting. Sometimes the mantle wedge above the subducting plate also can melt when magma coming up from a subducted slab doesn't get all the way to the surface immediately. This melting and migration generates magma and causes the formation of volcanic arcs.

Kinesthetic, Visual

Ocean-Ocean Convergence

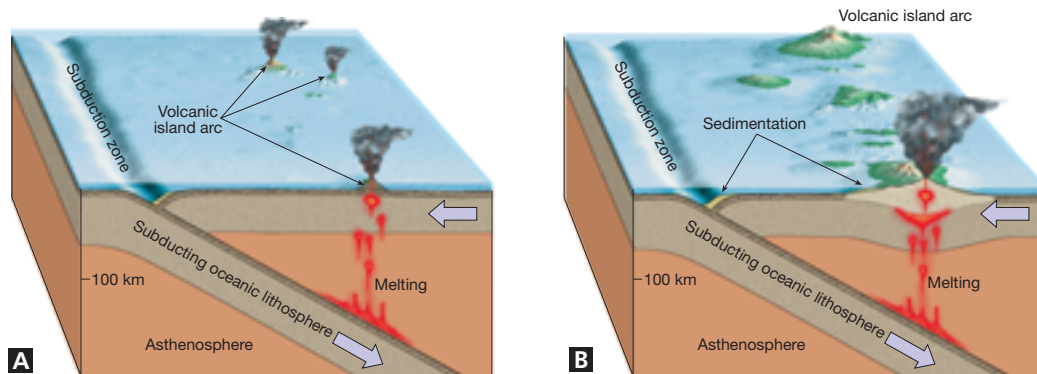


Figure 12 **A** A volcanic island arc develops due to the convergence of two oceanic plates. **B** Continued subduction along this type of convergent boundary results in the development of volcanic mountains.

Ocean-Ocean Convergence Ocean-ocean convergence occurs where two oceanic plates converge and one is subducted beneath the other, as shown in Figure 12. The converging plates result in partial melting of the mantle above the subducting plate and can lead to the growth of a volcanic island arc on the ocean floor. Because they are associated with subducting oceanic lithosphere, island arcs are typically found on the margins of a shrinking ocean basin, such as the Pacific. These features tend to be relatively long-lived. Here, somewhat sporadic volcanic activity, the depth of magma, as well as the accumulation of sediment that is scraped off the subducting plates, increases the volume of the crust. An example of an active island arc is the Aleutian arc, which forms the Aleutian Islands in Alaska. Some volcanic island arcs, such as Japan, appear to have been built up by two or three different periods of subduction. As shown by Japan, the continued development of a volcanic island arc can result in the formation of mountains made up of belts of igneous and metamorphic rocks. 🇯🇵 **Ocean-ocean convergence mainly produces volcanic mountains.**

Ocean-Continental Convergence Mountain building along continental margins involves the convergence of an oceanic plate and a plate whose leading edge contains continental crust. A good example is the west coast of South America. In this area, the Nazca plate is being subducted beneath the South American plate along the Peru-Chile trench. As shown by the Andes Mountains, ocean-continental convergence results in the formation of a continental volcanic arc inland of the continental margin.

Customize for English Language Learners

Have students use a dictionary to look up the origin of the term *isostasy*. (*Iso-* means “equal” and *stasis* means “standing.”) Ask students to brainstorm words that begin with *iso-*. Ask them how the words are similar or different in

meaning. (*Students may know the word isobar [equal air pressure] and isotherm [equal temperature] from meteorology, isotonic [equal concentration] from chemistry, and isometric and isosceles [equal sides] from geometry.*)

Rates of Mountain Building

L2

1. $1 \text{ cm/year} = 0.01 \text{ m/year}$;
 $500 \text{ m} \div 0.01 \text{ m/year} = 50,000 \text{ years}$
 2. $1,000,000 \text{ years} \times 0.01 \text{ m/year} = 10,000 \text{ m}$ or 10 km
 3. the processes of weathering and erosion
 4. Accept all reasonable answers. A possible answer could be as follows: No, the mountains probably can't keep growing taller forever. Erosion would occur at a faster pace than mountain building. In addition, Earth's mantle probably can support only a particular amount of lithospheric thickness. The area of the mountains may begin to spread out or the convergence will stop.
- Logical

For Extra Help

L1

Review conversion factors and dimensional analysis with students. Have students practice making conversions from centimeters to meters and from meters to centimeters by using dimensional analysis. Remind students to label units for each factor and to make sure all unwanted units cancel out to yield a final answer in the desired units.

Address Misconceptions

L2

Ask students if Mount Everest will always be the highest mountain on Earth. If they say yes, they may think that mountain-building processes are no longer taking place and that mountains will remain the same size as they are now. Because the Indian and Eurasian plates continue to push against each other—at a rate of about 2 cm a year—the Himalayas are continuing to grow. According to data from recent GPS experiments, the Himalayas are growing at a rate of 5 mm a year. Ask: **What process could prevent the Himalayas from growing?** (*erosion*) **What would happen if the Indian and Eurasian plates stop moving?** (*The Himalayas will stop growing and will decrease in height due to erosion.*)

Logical

Answer to . . .

Figure 13 volcanic mountains

The convergence of the continental block and the subduction of the oceanic plate leads to deformation and metamorphism of the continental margin. Partial melting of mantle rock above the subducting slab generates magma that migrates upward. This melting and fluid migration occurs once the oceanic plate moves down to about 100 kilometers. During the development of this continental volcanic arc, sediment derived from the land and scraped from the subducting plate is stuck against the landward side of the trench. This accumulation of different sedimentary and metamorphic rocks with some scraps of ocean crust is called an **accretionary wedge**. A long period of subduction can build an accretionary wedge of rock that is large enough to stand above sea level, as shown in Figure 13.

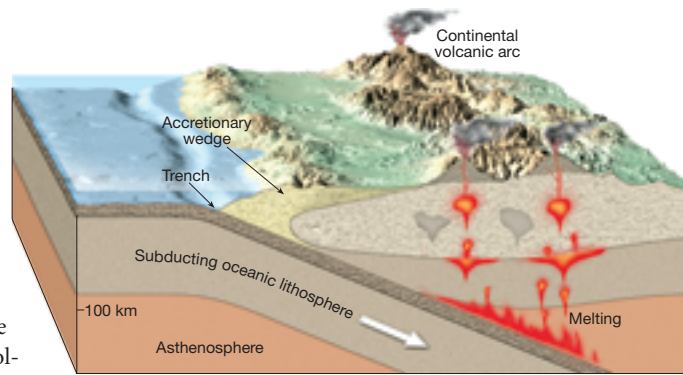


Figure 13 Ocean-Continental Convergence Plate convergence generates a subduction zone, and partial melting produces a continental volcanic arc. Continued convergence and igneous activity further deforms the crust and forms a roughly parallel folded mountain belt. **Observing** What type of mountains result from the partial melting?

Ocean-continent convergence produces mountain ranges composed of two roughly parallel belts. The continental volcanic arc develops on the continental block. The arc consists of volcanoes and large intrusive bodies mixed with high-temperature metamorphic rocks. The seaward belt is the accretionary wedge. It consists of folded, faulted sedimentary and metamorphic rocks. 🌍 **The types of mountains formed by ocean-continent convergence are volcanic mountains and folded mountains.**

Problem-Solving Activity

Rates of Mountain Building

The mighty Himalayas between India and Tibet are the tallest mountains on Earth, rising to more than 8 kilometers. These mountains are still rising at about 1 centimeter per year. Mount Everest is the tallest peak with an elevation of 8848 meters above sea level. The Himalayas formed as a result of India colliding with the Eurasian plate.

1. **Calculating** If you assume that the Himalayas will continue to be uplifted at the current rate of 1 centimeter per year, how long will it take the mountains to rise another 500 meters?
2. **Calculating** Assuming a rate of uplift of 1 centimeter per year, how much higher could the Himalayas be in one million years?
3. **Applying Concepts** If the convergence of tectonic plates is causing the Himalayas to rise in elevation, what common surface processes are working to decrease their elevations?
4. **Inferring** Do you think it is reasonable for the Himalayas to continue to rise in elevation indefinitely? Explain your answer.

Mountain Building 319

Facts and Figures

For years, scientists thought that the elevation of Mount Everest was 8848 m above sea level. A number of attempts over several years were made to set up Global Position System (GPS) equipment so the mountain could be measured using satellite-based technology. A team of seven climbers successfully measured the

mountain from the summit on May 5, 1999. The data were collected from various GPS satellite receivers, one of which had to be placed in bedrock, at the top of Mount Everest. Using GPS technology, Mount Everest finally was re-measured and was found to be 8850 m above sea level.

Section 11.3 (continued)

Use Visuals

L1

Figure 14 Have students examine the diagram of continent-continent convergence. Ask: **Why are there sedimentary rocks and oceanic crust high above sea level in the Himalayas?** (They come from sediment and bits of crust that were scraped off an oceanic slab as it subducted under India. When India and Asia collided, this material was uplifted.) **What caused the formation of a continental volcanic arc in the Himalayas?** (partial melting of the overlying mantle rocks triggered by the subducting oceanic slab)

Visual, Logical

Build Science Skills

L2

Inferring Have students infer how a mountain range can occur far inland. (Two continental plates must have collided sometime in the past.)

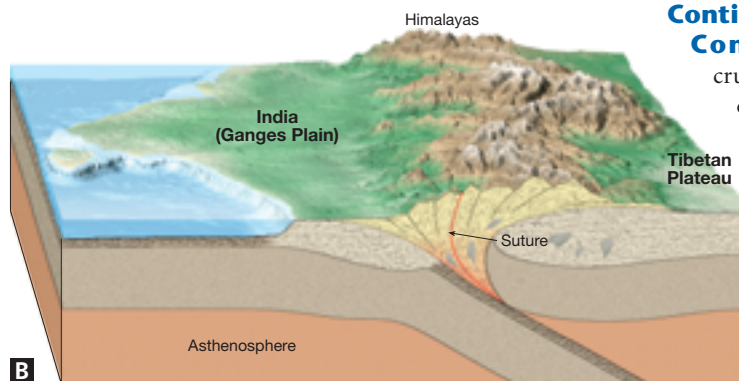
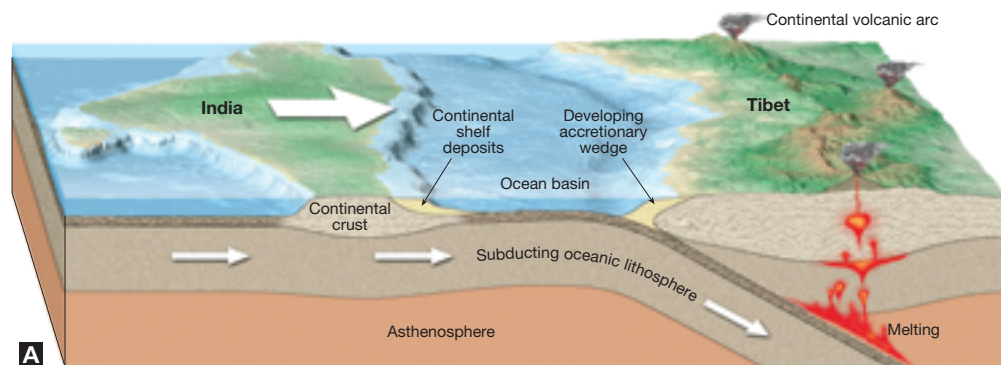
Logical

Use Community Resources


L2

Invite a civil engineer to your class, and have students interview him or her to find out what a civil engineer needs to know about local landforms when planning new roads. Have students prepare questions for the guest speaker in advance of his or her visit.

Verbal



Continent-Continent Convergence

Continental crust floats too much to be subducted.  At a convergent boundary between two plates carrying continental crust, a collision between the continental fragments will result and form folded mountains.

An example of such a collision began about 45 million years ago when India collided with the

Figure 14 Continental-Continental Convergence The ongoing collision of India and Asia started about 45 million years ago and produced the majestic Himalayas. **A** Converging plates generated a subduction zone, producing a continental volcanic arc. **B** Eventually the two landmasses collided, which deformed and elevated the mountain range.

Eurasian plate, as shown in Figure 14. Before this event, India was once part of Antarctica, and it had split from that continent over the course of millions of years. It slowly moved a few thousand kilometers due north. The result of the collision was the formation of the spectacular Himalaya Mountains and the Tibetan Plateau. Most of the oceanic crust that separated these landmasses before the collision was subducted, but some was caught up in the collision zone, along with the sediment along the shoreline. Today these sedimentary rocks and slivers of oceanic crust are elevated high above sea level.

A similar but much older collision is believed to have taken place when the European continent collided with the Asian continent to produce the Ural Mountains in Russia. Before the theory of plate tectonics, geologists had difficulty explaining mountain ranges such as the Urals, which are located far within continents.



Why can't continental crust be subducted?

Facts and Figures

Numerous earthquakes recorded off the southern coast of India indicate that a new subduction zone may be forming. If formed, it would provide a subduction site for the floor of the Indian Ocean, which is continually

being produced at a spreading center located to the southwest. Should this occur, India's northward journey, relative to Asia, would come to an end, and the growth of the Himalayas would cease.

Mountain Building by Continental Accretion

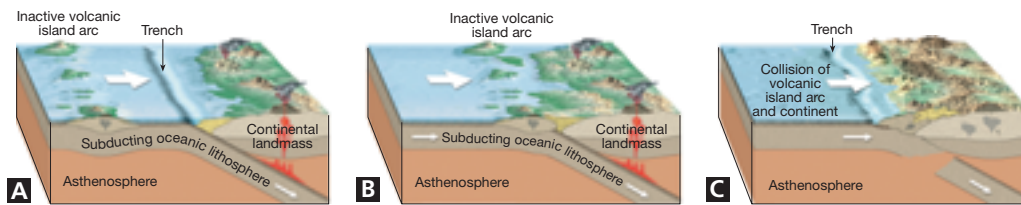


Figure 15 This sequence illustrates the collision of an inactive volcanic island arc with the margin of a continental plate. The island arc becomes embedded or accreted onto the continental plate.

Mountain Building at Divergent Boundaries

Most mountains are formed at convergent boundaries, but some are formed at divergent boundaries, usually on the ocean floor. These mountains form a chain that curves along the ocean floor at the ocean ridges. This mountain chain is over 65,000 kilometers long and rises to 2000 to 3000 meters above the ocean floor. 🔄 **The mountains that form along ocean ridges at divergent plate boundaries are fault-block type mountains.** The mountain chain that makes up the Mid-Atlantic Ridge is an example.

Non-Boundary Mountains

Even though most mountains are formed at plate boundaries, some are found far from any boundaries. Some upwarped mountains, fault-block mountains, and volcanic mountains are not formed at plate boundaries. Volcanic mountains such as the Hawaiian Islands are formed at a hot spot, far from any plate boundary. Many fault-block mountains occur in areas that are undergoing regional extension or stretching. These areas may possibly become a plate boundary if the plate rifts apart.



Where is the longest mountain range?

Continental Accretion

Plate tectonics theory originally suggested two major mechanisms for orogenesis at convergent boundaries: continental collisions and subduction of oceanic lithosphere to form volcanic arcs. Further studies have led to another mechanism in which smaller crustal fragments collide and merge with continental margins. When the fragments collide with a continental plate they become stuck to or embedded into the continent in a process called **accretion**. Many of the mountainous regions rimming the Pacific have been produced through the process of collision and accretion.



For: Links on mountain building

Visit: www.SciLinks.org

Web Code: cjn-3113

Mountain Building 321

Mountain Building at Divergent Boundaries

Build Science Skills

L2

Problem Solving Have students describe a process whereby mountains can form at divergent boundaries. Students should draw a series of diagrams showing the formation of an ocean ridge and describe what is happening in each diagram.

Visual

Non-Boundary Mountains

Build Reading Literacy

L1

Refer to p. 124D in Chapter 5, which provides the guidelines for summarizing.

Summarize Have students reread the description in Chapter 9 of how hot spots cause the formation of volcanic mountain arcs. Students should write a short summary of the process. Then they should write a paragraph about how the formation of hot spots relates to this section.

Verbal

Continental Accretion

Use Visuals

L1

Figure 15 Have students examine the diagram of continental accretion. Ask: **What is the crustal fragment in these diagrams?** (*the volcanic island arc*) **Will the mountains that are formed by this process be as large as mountains formed by converging continental plates?** (*No, there is much less crustal material in the fragment.*)

Visual, Logical



Download a worksheet on mountain building for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .



It is too buoyant.



the Mid-Atlantic Ridge on the Atlantic Ocean floor

Section 11.3 (continued)

Address Misconceptions

L2

Students often confuse a *terrane* with a *terrain*. The term *terrane* is used to designate a distinct and recognizable series of rock formations that has been transported by plate tectonic processes. Since geologists who mapped these rocks were unsure where they came from, these rocks were sometimes called “exotic,” “suspect,” “accreted,” or “foreign” terranes. The term *terrain* describes the shape of the surface topography or “lay of the land.” Have students use the two terms in sentences so that their meanings are clear.

Verbal

Use Visuals

L1

Figure 16 Have students examine the map showing terranes added to western North America. Ask: **What mechanism of plate tectonics might have caused the addition of so many terranes to the West Coast?** (The North American plate could have moved westward, overriding the Pacific Basin and picking up crustal fragments as it moved.) **What was the origin of the Baja Peninsula?** (It was originally an island arc.) **What does this map imply about the number of times crustal material has been added to the West Coast?** (Based on the many sources of crustal material, it is likely that material has been added many times.)

Visual, Logical



Figure 16 Accretion in Western North America These terranes are thought to have been added to western North America during the past 200 million years.

Interpreting Maps What do the areas in blue represent?



What is a terrane?

Terranes Geologists refer to accreted crustal blocks as terranes. A **terrane** is any crustal fragment that has a geologic history distinct from that of the adjoining terranes. Terranes come in many shapes and sizes. Some are no larger than volcanic islands, while others are immense, such as the one making up the entire Indian subcontinent. Before their accretion to a continental block, some of the fragments may have been microcontinents similar to the present-day island of Madagascar, located in the Indian Ocean east of Africa. Many others were island arcs like Japan and the Philippines.

As oceanic plates move, they carry the embedded volcanic island arcs and microcontinents along with them. Eventually a collision between the crustal fragment and the continent occurs. Relatively small crustal pieces are peeled from the oceanic plate at a subduction zone, and thin sheets of the crustal fragment are thrust onto the continental block. This newly added material increases the width and thickness of the continental crust. The material may later be displaced farther inland by the addition of other fragments.

Mountains from Accretion The accretion of larger crustal fragments, such as a mature island arc, may result in a mountain range. These mountain ranges are much smaller than the ones that result from a continent–continent collision. Because of its buoyancy, or ability to float, an island arc will not subduct beneath the continental plate. Instead, it will plow into the continent and deform both blocks.

The idea that mountain building occurs in connection with the accretion of crustal fragments to a continental mass came mainly from studies

in western North America. See Figure 16. Areas in the mountains of Alaska and western Canada were found to contain rocks, fossils, and structures that were different from those in surrounding areas. These areas have been accreted to the western margin of North America.

Facts and Figures

Imagine 45-million-year-old tree stumps of 50-m-tall trees existing next to glaciers. These trees resemble the remains of a redwood forest that once grew in northern California. Fossils of palm trees and tropical rain forest plants have all been found in Alaska within 800 km of the North Pole. Not only is the present climate too cold to support life of these organisms, but they would not be able to live in a region

that has limited sunlight five months of the year. Either the climate of Earth was different when the palms grew 45 million years ago or else the rocks in which the fossils occur moved in from someplace else. Most paleontologists think the rocks were once part of terranes that were added to the Pacific coast of North America.

Principle of Isostasy

In addition to the horizontal movements of lithospheric plates, gradual up-and-down motions of the crust are seen at many locations around the globe. Although much of this vertical movement occurs along plate margins and is linked to mountain building, some of it is not. The up-and-down motions also occur in the interiors of continents far from plate boundaries.

Earth's crust floats on top of the denser and more flexible rocks of the mantle. The concept of a floating crust in gravitational balance is called **isostasy** (*iso* = equal and *stasis* = standing). One way to understand the concept of isostasy is to think about a series of wooden blocks of different heights floating in water, as shown in Figure 17. Note that the thicker wooden blocks float higher than the thinner blocks. In a similar way, many mountain belts stand high above the surface because they have buoyant (less dense) crustal "roots" that extend deep into the denser mantle. The denser mantle supports the mountains from below.

What would happen if another small block of wood were placed on top of one of the blocks in Figure 17? The combined block would sink until a new isostatic balance was reached. However, the top of the combined block would actually be higher than before, and the bottom would be lower. This process of establishing a new level of gravitational equilibrium is called **isostatic adjustment**.

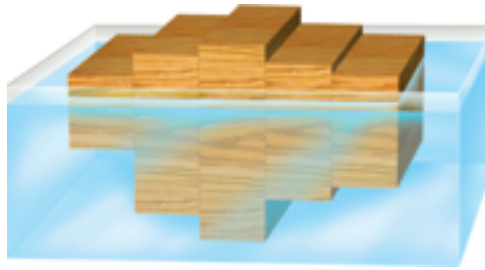
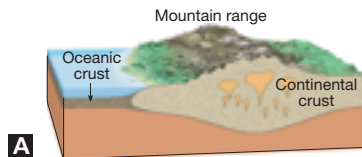
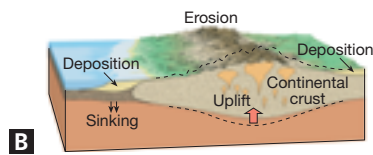


Figure 17 Isostatic Adjustment This drawing illustrates how wooden blocks of different thicknesses float in water. In a similar manner, thick sections of crustal material float higher than thinner crustal slabs. **Inferring** Would a denser wooden block float at a higher or lower level?

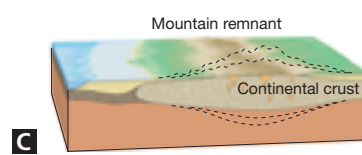
Isostatic Adjustment in Mountains



A When mountains are young, the continental crust is thickest.



B As erosion lowers the mountains, the crust rises in response to the reduced load.



C Erosion and uplift continue until the mountains reach "normal" crustal thickness.

Figure 18 This sequence illustrates how the combined effect of erosion and isostatic adjustment results in a thinning of the crust in mountainous regions.

Mountain Building 323

Principle of Isostasy

Teacher Demo

Modeling Isostasy

L2

Purpose Students model the principle of isostasy by measuring how high blocks of varying density float in water.

Materials large plastic container, water, balance, metric ruler, several blocks of varying sizes and kinds of wood

Procedure Wear apron and goggles. Fill a large plastic container approximately half full with water. Determine the mass and volume of each of the wooden blocks. Calculate the density of each. Place each block in the water. Use a ruler to measure how much of each block is supported above the water. Stack two or more blocks on top of the other blocks in the water. Measure how much of the blocks are supported above the water.

Expected Outcomes The thicker blocks floated higher than the thinner blocks. The blocks that had lower densities also floated higher than the denser blocks.

Visual, Kinesthetic

Facts and Figures

Archimedes, born in Sicily in 287 B.C., is credited with discovering the principle of buoyancy. He was ordered by King Hiero to determine whether a crown was pure gold or whether the goldsmith who had made it had replaced some of the gold with cheaper silver. Archimedes realized while taking a bath that he could solve the puzzle using water displacement. After determining the volume of water displaced by the crown, a piece of pure gold

could easily be made to match the volume of the displaced water, and thus the volume of the crown. In theory, if the volume of the crown and the volume of the gold block are the same, they should also have the same mass. The only reason they would not have the same mass is if one of them was not pure gold. Archimedes tested the crown and found that it, indeed, weighed less than the block of gold. The goldsmith confessed.

Answer to . . .

Figure 16 ancient ocean floor deposits

Figure 17 at a lower level



A terrane is an area that has a different geologic history from surrounding areas.

Section 11.3 (continued)

Build Science Skills

L2

Predicting When you place a block of wood in a pail of water, the block displaces some of the water, and the water level rises. Ask: **If you could measure the mass of the water that the block displaces, what would you find?** (*The mass of the water equals the mass of the block.*) **If 1 million kg of ice were added to a land mass, how much mantle would be displaced?** (*1 million kg*)
Logical

3 ASSESS

Evaluate Understanding

L2

Ask students to describe two events that would cause crust to subside. (*Accept any event that increases the mass of the crust, such as formation of large ice sheets, accumulation of large amounts of sediments, or formation of volcanic mountains.*)

Reteach

L1

Have students design an experiment that models the formation of an uplifted mountain. Students may use a bicycle pump, balloon, fabric, and any other materials they choose when designing their model.

Writing In Science

Students' descriptions will vary. Be sure they correctly describe the volcanic arc and another mountain range inland of the continental margin.

Answer to . . .



The weight of added ice causes crust to subside.

When ice melts, and weight is removed, crust rebounds.

Isostatic Adjustment for Mountains Applying the concept of isostasy, we should expect that when weight is added to the crust, the crust responds by subsiding. Also when weight is removed, the crust will rebound. Evidence of crustal subsidence followed by crustal rebound is provided by the continental ice sheets that covered parts of North America during the Pleistocene epoch. The added weight of a 3-kilometer-thick mass of ice depressed Earth's crust by hundreds of meters. In the 8000 years since the last ice sheet melted, uplift of as much as 330 meters has occurred in Canada's Hudson Bay region, where the ice was thickest.



How are ice sheets related to isostatic adjustment?

Crustal buoyancy can account for considerable vertical movement. Most mountain building causes the crust to shorten and thicken. **Because of isostasy, deformed and thickened crust will undergo regional uplift both during mountain building and for a long period afterward.** As the crust rises, the processes of erosion increase, and the deformed rock layers are carved into a mountainous landscape.

As erosion lowers the summits of mountains, the crust will rise in response to the reduced load, as shown in Figure 18 on page 323. The processes of uplifting and erosion will continue until the mountain block reaches "normal" crustal thickness. When this occurs, the mountains will be eroded to near sea level, and the once deeply buried interior of the mountain will be exposed at the surface.

Section 11.3 Assessment

Reviewing Concepts

1. What types of mountains are associated with convergent plate boundaries?
2. What mountains are associated with divergent plate boundaries?
3. How is isostatic adjustment involved in mountain building?
4. How is accretion involved in mountain formation?

Critical Thinking

5. **Comparing and Contrasting** Compare mountain building along an ocean-continent convergent boundary and a continent-continent convergent boundary.

6. **Drawing Conclusions** How does the theory of plate tectonics help explain the existence of marine fossils in sedimentary rocks on top of the Himalayas?
7. **Applying Concepts** How would the accretion of a large microcontinent affect the isostatic adjustment of the region around a mountain range?

Writing In Science

Creative Writing Describe a trip through a mountain range like the Andes that has formed at an ocean-continent convergent boundary.

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Section 11.3 Assessment

1. mainly volcanic mountains
2. Fault-block mountains at ocean ridges are associated with divergent boundaries.
3. As the crust is thickened due to mountain building, the lithosphere will sink deeper into the mantle. But the lithosphere is less dense than the mantle, so the lithosphere will stand higher. To balance the added thickness, the crust will rise as a new level of gravitational equilibrium is reached.

4. At a subduction zone, if an oceanic plate is carrying any island arcs or small continental fragments, they will be stuck to or embedded into the margin of the continental plate. This process of accretion deforms the continental plate and can form mountains.
5. Ocean-continent convergent boundary: subduction of oceanic crust beneath continental crust, development of a continental volcanic arc, and formation of folded mountains as accretionary wedge is deformed and folded. Continent-continent convergent boundary: no subduction because the conti-

6. The ocean basin between India and the Eurasia was subducted before the collision of India with the Eurasian plate. The sedimentary rocks on the ocean floor and along the shoreline were scraped off and uplifted and folded up into the mountains.
7. The addition or accretion of a large fragment onto a mountain range would load the crust and cause the crust to subside.

The San Andreas Fault System

The San Andreas, the largest fault system in North America, first attracted attention after the 1906 San Francisco earthquake. But this dramatic event is just

one of many thousands of earthquakes that have resulted from movements along the San Andreas over the last 29 million years.

The San Andreas fault system, as shown in the map, trends in a northwesterly direction for nearly 1300 kilometers through much of western California. In many places, a linear trough marks the trace of the San Andreas fault. From the air, linear scars, offset stream channels, and elongated ponds mark the location of the fault. On the ground, however, evidence of the fault is harder to find. Some of the most distinctive landforms include long, straight cliffs, narrow ridges, and sag ponds formed by the settling of blocks within the fault zone.

Transform Boundary Mountains

The San Andreas fault is a transform fault boundary separating two crustal plates that move very slowly. The Pacific plate, located to the west, moves northwestward in relation to the North American plate.

Some large blocks of crust within the fault zone are pushed up forming hills or mountains of various sizes. Other blocks are forced down and form depressions called sag ponds. The fault trace is not straight. It has many bends along its length. In one of these major bends, the force of the two sides of the fault moving past one another has caused the uplift of the San Gabriel Mountains north of Los Angeles.

Fault System

Different segments of the San Andreas behave differently. Some portions creep slowly with little noticeable seismic activity. Other segments regularly



slip, producing small earthquakes. Still other segments seem to store elastic energy for hundreds of years and rupture in great earthquakes.

Because of the great length and complexity of the San Andreas fault, it is more appropriately referred to as a "fault system." This major fault system consists primarily of the San Andreas fault and several major branches, including the Hayward and Calaveras faults of central California and the San Jacinto and Elsinore faults. By matching rock units across the fault, geologists have determined that the total displacement from earthquakes and creep along the San Andreas is greater than 560 kilometers.

Mountain Building 325

The San Andreas Fault System

L2

Background

The 1906 San Francisco earthquake resulted from a 5-m displacement along the San Andreas Fault. The earthquake had a magnitude of 8.25, one of the two largest along this fault. The other 8.25-magnitude earthquake occurred in 1857 in Fort Tejon, near Los Angeles. As much as 80 percent of the damage in the San Francisco earthquake was caused by fire.

Teaching Tips

- Use an overhead projector to project the map of California. Use blocks of wood or rigid plastic foam to demonstrate the movement of the fault. Emphasize that the Pacific plate, along with the California coast, is moving northwest in relation to the North American plate.
- Have students think about what will eventually happen to southwestern California if present movements continue. Examining a globe and the map on this page will help them make predictions. Refer to Address Misconceptions on p. 313 about California's coast sliding into the Pacific Ocean. (*Los Angeles will move northward and become close to San Francisco. Eventually, the Baja Peninsula may become an island off the coast of Oregon or Washington.*)
- Tell students that each segment of the San Andreas Fault exhibits somewhat different behavior. Some portions exhibit a slow creep with little noticeable seismic activity. Other segments regularly slip, producing small earthquakes. Still other segments seem to store elastic energy for hundreds of years and then rupture in great earthquakes. Have students research how various segments of the fault system behave. Ask them to make predictions for future seismic activity around Los Angeles and San Francisco.

Verbal, Visual