

SOLUTIONS MANUAL

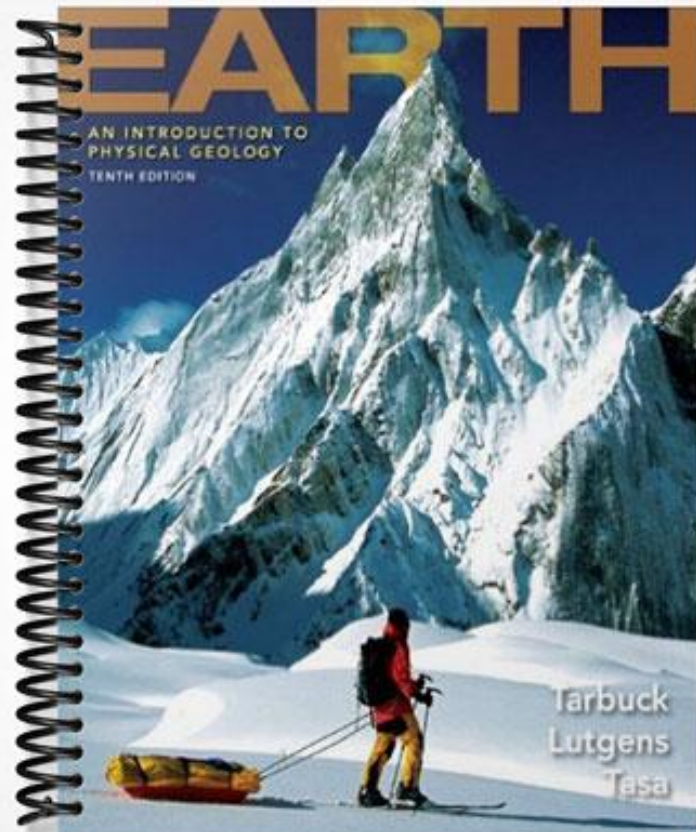


Plate Tectonics: A Scientific Revolution Unfolds

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Plate Tectonics opens by examining the lines of evidence that Alfred Wegener used in the early 1900s to support his continental drift hypothesis. This evidence included matching the outlines of the shorelines of continents that are now separated by vast ocean basins, fossils, rock types and structural similarities between continents, and paleoclimates. Also presented are the main objections to Wegener's ideas.

Following a brief overview, the theory of plate tectonics is discussed in detail. The movement of lithospheric plates and different types of plate boundaries are examined extensively. Paleomagnetism (polar wandering and magnetic reversals), the distribution of earthquakes, ages and distribution of ocean basin sediments, and hot spots are used to provide additional support for plate tectonics. The chapter closes with comments about the driving mechanism for plate motion.

Learning Objectives

After reading, studying, and discussing the chapter, students should be able to:

- Briefly discuss the evidence used by Alfred Wegener to support his theory of continental drift.
- Explain why continental drift was not accepted by most scientists when the theory was originally proposed.
- Explain the theory of polar wandering and how it helped to renew interest in the idea of continental drift.
- Discuss geomagnetic reversals and seafloor spreading, and how each contributed to the development of the theory of plate tectonics in the 1960s.
- Briefly explain the theory of plate tectonics.
- Compare and contrast the distribution and geologic characteristics of tectonic plate boundaries, including divergent, convergent, and transform boundaries.
- Discuss the evidence used to test the plate tectonics model including ocean drilling and hot spots.
- Briefly explain how plate motions are measured.
- Discuss mantle convection and the various mechanisms proposed to explain plate motion.
- Briefly discuss the importance of plate tectonics in providing a unified explanation of Earth's surface features and major processes.

Chapter Outline

- I. Continental drift: an idea before its time
 - A. Alfred Wegener
 - 1. First proposed his continental drift hypothesis in 1915
 - 2. Published *The Origin of Continents and Oceans*

- B. Continental drift hypothesis
 - 1. Supercontinent called Pangaea began breaking apart about 200 million years ago
 - 2. Continents "drifted" to present position

- C. Evidence used in support of continental drift hypothesis
1. Fit of the continents
 - a. Wegener used the crude fit of the shorelines of South America and Africa
 - b. Fit using the seaward edges of continental shelves is much better
 2. Fossils evidence
 - a. Existence of identical fossils on widely separated landmasses
 - b. Supported by
 1. *Mesosaurus* – a presumably aquatic, snaggle-toothed reptile
 2. *Glossopteris* – a plant identified by its large seeds
 3. Present day organisms, such as the Australian marsupials
 3. Rock type and structural similarities
 - a. Rock types and ages match on both sides of the Atlantic
 - b. Mountains comparable in age and structure to the Appalachians are found in the British Isles and Scandinavia
 4. Paleoclimatic evidence
 - a. Evidence of late Paleozoic glaciation near the equator
 - b. Fossils from the major coal fields in the eastern United States indicate the past existence of tropical swamps in these regions
- II. The great debate
- A. Objections to the continental drift hypothesis
 1. Inability to provide a mechanism capable of moving continents across the globe
 - a. Wegener proposed that the tidal influence was strong enough to move the continents
 - b. It was pointed out that the magnitude of tidal friction needed to displace continents would stop Earth's rotation
 2. Wegener suggested that continents broke through the ocean crust, much like ice breakers cut through ice
 - B. Continental drift and the scientific method
 1. Wegener's hypothesis was correct in principle, but contained incorrect details
 2. For any scientific viewpoint to gain wide acceptance, supporting evidence from all realms of science must be found
 3. A few scientists considered Wegener's ideas plausible and continued the search
 - III. Continental drift and paleomagnetism
 - A. Initial impetus for the renewed interest in continental drift came from rock magnetism
 - B. Paleomagnetism
 1. Ancient magnetism preserved in rocks at the time of their formation
 2. Magnetized minerals in rocks
 - a. Show the direction to Earth's magnetic poles
 - b. Provide a means of determining their latitude of origin
 3. Polar wandering - The apparent movement of the magnetic poles illustrated in magnetized rocks indicates that the continents have moved
 - a. Shows that Europe was much closer to the equator when coal-producing swamps existed
 - b. Polar wandering curves for North America and Europe have similar paths but are separated by about 24° of longitude
 1. Differences between the paths can be reconciled if the continents are placed next to one another
 2. Shows the separation of the continents

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- IV. A scientific revolution begins
- A. During the 1950s and 1960s technological strides permitted extensive mapping of the ocean floor
 - B. Seafloor spreading hypothesis
 1. Proposed by Harry Hess in the early 1960s
 2. Ocean ridges are located above zones of upwelling in the mantle; as material rises, seafloor is carried in a conveyor-belt fashion away from the ridge
 3. New seafloor forms at the ridges and descends back into the mantle in deep-ocean trenches
 - C. Geomagnetic reversals
 1. Earth's magnetic field periodically reverses polarity – the north magnetic pole becomes the south magnetic pole, and vice versa
 - a. Rocks that exhibit the same magnetism as the present magnetic field are said to possess normal polarity
 - b. Rocks that exhibit opposite magnetism as the present magnetic field are said to possess reverse polarity
 2. Dates when the polarity of Earth's magnetism changed were determined from lava flows
 3. Geomagnetic reversals are recorded in the ocean crust
 4. In 1963 Fred Vine and D. Matthews tied the discovery of magnetic stripes in the ocean crust near ridges to Hess's concept of seafloor spreading
 5. Paleomagnetism (evidence of past magnetism recorded in the rocks) was the most convincing evidence set forth to support the concepts of continental drift and seafloor spreading
- V. Plate tectonics: the new paradigm
- A. Much more encompassing theory than continental drift
 - B. The composite of a variety of ideas that explain the observed motion of Earth's lithosphere through the mechanisms of subduction and seafloor spreading
 - C. Earth's major plates
 1. Associated with Earth's strong, rigid outer layer
 - a. Called the lithosphere
 - b. Consists of
 1. Uppermost mantle
 2. Overlying crust
 - c. Overlies a weaker region in the mantle called the asthenosphere
 2. Seven major lithospheric plates
 - a. North American
 - b. South American
 - c. Pacific
 - d. African
 - e. Eurasian
 - f. Australian
 - g. Antarctic
 3. Plates are
 - a. In motion
 - b. Continually changing in shape
 - c. Continually changing size
 4. Largest plate is the Pacific plate
 5. Several plates include an entire continent plus a large area of seafloor
 6. Plates move relative to each other at a very slow but continuous rate
 - a. Average about 5 centimeters (2 inches) per year
 - b. Ultimately driven by the unequal distribution of heat within Earth
 - c. Cooler, denser slabs of oceanic lithosphere descend into the mantle
 - d. Grinding movements of plates
 1. Generate earthquakes
 2. Create volcanoes
 3. Deform large masses of rock into mountains
 - D. Plate boundaries
 1. All major interactions among individual plates occur along their boundaries
 2. Types of plate boundaries

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- a. Divergent plate boundaries (constructive margins)
 1. Two plates move apart
 2. Upwelling of material from the mantle creates new seafloor
 - b. Convergent plate boundaries (destructive margins)
 1. Two plates move together
 2. Possible interactions
 - a. Oceanic lithosphere is thrust beneath an overriding plate, eventually to be reabsorbed into the mantle
 - b. Two continental plates collide to create a mountain system
 - c. Transform fault boundaries (conservative margins)
 1. Two plates grind past each other
 2. No production or destruction of lithosphere
 - 3. Each plate is bounded by a combination of the three types of boundaries
 - 4. New plate boundaries can be created in response to changes in the forces acting on these rigid slabs
- VI. Divergent plate boundaries
- A. Most are located along the crests of oceanic ridges and can be thought of as constructive plate margins
 - B. Oceanic ridges and seafloor spreading
 1. Along well-developed divergent plate boundaries, the seafloor is elevated forming oceanic ridges
 - a. Longest topographic feature on Earth's surface
 - b. Crests commonly 2–3 kilometers higher than the adjacent ocean basins
 - c. Represents 20 percent of Earth's surface
 - d. Winds through all major ocean basins
 - e. 1000–4000 kilometers wide
 - f. Rift valleys, deep down-faulted structures, are found along the axis of some segments
 2. Seafloor spreading occurs along the oceanic ridge system
 - a. Creates new seafloor
 - b. Typical rates of spreading average around 5 centimeters (2 inches) per year
 - c. No ocean floor that has been dated exceeds 180 million years old
 - d. New ocean floor material is added about equally to the two diverging plates
 - C. Spreading rates and ridge topography
 1. Ridge systems exhibit topographic differences
 2. Topographic differences are controlled by spreading rates
 - a. At slow spreading rates (1–5 centimeters per year), a prominent rift valley develops along the ridge crest that is usually:
 1. 30 to 50 kilometers across
 2. 1500 to 3000 meters deep
 3. Rugged
 - b. At intermediate spreading rates (5–9 centimeters per year), rift valleys that develop are:
 1. Shallow
 2. Often less than 200 meters deep
 3. Topographically rather smooth
 - c. At spreading rates greater than 9 centimeters per year no median rift valley develops and these areas are:
 1. Usually narrow (roughly 10 kilometers wide) topographic highs
 2. Extensively faulted
 3. Composed of numerous horsts and grabens

- D. Continental rifts
1. Split landmasses into two or more smaller segments
 2. Examples include the
 - a. East African rift valleys
 - b. Baikal Rift (south central Siberia)
 - c. Rhine Valley (Northern Europe)
 3. Produced by extensional forces acting on the lithospheric plates
 4. Not all rift valleys develop into full-fledged spreading centers (e.g., a failed rift running through the central United States from Lake Superior to Oklahoma)
- VII. Convergent plate boundaries
- A. Older portions of oceanic plates are returned to the mantle in these destructive plate margins
1. Surface expression of the descending plate is an ocean trench which can be
 - a. Thousands of kilometers long
 - b. 8 to 12 kilometers deep
 - c. Between 50 and 100 kilometers wide
 2. Called subduction zones
 3. Average angle at which oceanic lithosphere descends into the mantle is about 45°
- B. Although all have the same basic characteristics, they are highly variable features
- C. Types of convergent boundaries
1. Oceanic-continental convergence
 - a. Denser oceanic slab sinks into the asthenosphere
 - b. Pieces of oceanic crust are plastered against the edge of the overriding continental block and form an accretionary wedge
 - c. As the plate descends, partial melting of mantle rock generates magmas having a basaltic or occasionally andesitic composition
 - d. Mountains produced in part by volcanic activity associated with subduction of oceanic lithosphere
 2. Oceanic-oceanic convergence
 - a. When two oceanic slabs converge, one descends beneath the other
 - b. Often forms volcanoes on the ocean floor
 1. If the volcanoes emerge as islands, a volcanic island arc is formed
 - a. e.g., Aleutian, Mariana, and Tonga islands
 - b. Most are located in the western Pacific
 - c. Only two volcanic island arcs are located in the Atlantic
 1. Lesser Antilles adjacent to the Caribbean Sea
 2. Sandwich islands in the South Atlantic
 2. Often located adjacent to deep-ocean trenches
 3. Young island arcs are simple structures, while older arcs are more complex
 3. Continental-continental convergence
 - a. Continued subduction can bring two continents together
 1. Less dense, buoyant continental lithosphere does not subduct
 2. Result is a collision between two continental blocks
 3. Process can produce mountains
 - a. Himalayas
 - b. Alps
 - c. Appalachians
 - d. Urals
- are called continental volcanic arcs

- b. Subduction initiates partial melting in the overlying mantle rocks, which, in turn, results in the growth of a volcanic arc
- c. After continents collide, the subducted ocean plate may separate from the continental block and continue its downward movement

VIII. Transform fault boundaries

- A. The third type of plate boundary
- B. Plates slide past one another and no new lithosphere is created or destroyed
- C. Transform faults
 - 1. Most join two segments of a mid-ocean ridge as parts of prominent linear breaks in the oceanic crust known as fracture zones
 - 2. Provide the means by which the oceanic crust created at ridge crests can be transported to the deep-ocean trenches
 - 3. A few (the San Andreas fault and the Alpine fault of New Zealand) cut through continental crust

IX. Testing the plate tectonics model

- A. Evidence from ocean drilling
 - 1. Some of the most convincing evidence confirming seafloor spreading has come from drilling directly into ocean-floor sediment
 - a. Deep Sea Drilling Project (ship: *Glomar Challenger*)
 - b. Age of deepest sediments
 - 1. Youngest sediments are near the ridges
 - 2. Older sediments are at the greatest distance from the ridge
 - 3. Confirms seafloor-spreading hypothesis
 - 4. Ages illustrate that the ocean basins are geologically young

- a. Thickness of ocean-floor sediments verifies seafloor spreading
 - 1. Sediments are almost entirely absent on the ridge crest
 - 2. Sediment thickens with increasing distance from the ridge
- 2. The Ocean Drilling Project has succeeded the Deep Sea Drilling Project with the more advanced drilling ship, the *JOIDES Resolution*

C. Hot spots

- 1. Caused by rising plumes of mantle material
- 2. Volcanoes can form over them
 - a. e.g., Hawaiian Island chain
 - b. Chains of volcanoes mark plate movement
- 3. Most mantle plumes are long-lived structures and at least some originate at great depth, perhaps at the mantle-core boundary

X. Measuring plate motion

- A. A number of methods have been employed to establish the direction and rate of plate motion
 - 1. Volcanic chains
 - 2. Paleomagnetism
 - 3. *Very Long Baseline Interferometry* (VLBI)
 - 4. *Global Positioning System* (GPS)
- B. Calculations show that
 - 1. Hawaii is moving in a northwesterly direction and approaching Japan at 8.3 centimeters per year
 - 2. A site located in Maryland is retreating from one in England at a rate of about 1.7 centimeters per year

XI. The driving mechanism

- A. No one driving mechanism accounts for all major facets of plate tectonics

- B. Researchers agree that
1. Convective flow in the rocky 2900-kilometer-thick mantle is the basic driving force of plate tectonics
 2. Mantle convection and plate tectonics are part of the same system
 3. The slow motion of the plates and mantle are driven by the unequal distribution of heat within Earth's interior
- C. Several mechanisms generate forces that contribute to plate motion
1. Slab-pull
 - a. Cool, dense oceanic crust sinks into the asthenosphere and "pulls" the trailing lithosphere along
 - b. The primary downward arm of the convective flow operating in the mantle
 2. Ridge-push
 - a. The elevated position of the oceanic ridge system causes the oceanic lithosphere to gravitationally slide down the flanks of the ridge
 - b. Less important than slab-pull
 3. Most models suggest that hot, buoyant plumes of rock are the upward flowing arms in the convective mechanism at work in the mantle
- D. Models of plate-mantle convection
1. Any model describing mantle convection must explain why basalts that erupt along the oceanic ridge
 - a. Are fairly homogeneous in composition and
 - b. Depleted in certain trace elements
 2. Models
 - a. Layering at 660 kilometers
 1. Two zones of convection
 - a. Above 660 kilometers – provides mid-ocean ridge basalts
 - b. Below 660 kilometers – the source of the mantle plume that feeds the Hawaiian volcanoes
 2. Subducting lithosphere mixes the upper and lower layers together and the layered mantle structure is lost
 - b. Whole-mantle convection
 1. Slabs of lithosphere descend into the lower mantle providing the downward arm of convective flow
 2. Hot mantle plumes originating near the mantle-core boundary transport heat toward the surface
 - c. Deep-layer model
 1. Two layers of convection within the mantle without substantial mixing
 2. A small amount of material from the lower layer can flow upward as a mantle plume
 3. Model provides two chemically different mantle sources for basalt

- XII. Importance of plate tectonics
- A. Theory provides a unified explanation of Earth's major surface processes
 - B. Within the framework of plate tectonics, geologists have found explanations for the geologic distribution of
 1. Earthquakes
 2. Volcanoes, and
 3. Mountains
 - C. Plate tectonics also provides explanations for
 1. Past distributions of plants and animals and
 2. The occurrence of economically significant mineral deposits
 - D. Although not completely understood, the theory of plate tectonics is nonetheless an evolving model of Earth's dynamic processes

Answers to the Review Questions

1. Alfred Wegener is credited with developing the continental drift hypothesis in the early 1900s.
2. Speculations about the apparent “nice fit” between the west coast of Africa and the east coast of South America date from the sixteenth century, when the first reasonably accurate maps of the Americas were compiled. This observation led some scientists to suspect that the continents had once been joined together based on their similar coastlines.
3. Pangaea was the supercontinent that existed in late Paleozoic time when Gondwanaland (the Southern Hemisphere landmass composed of Africa, India, South America, Australia, India, and Antarctica) collided with North America to form one, super-large landmass. Pangaea was a relatively short-lived continent as it began breaking up during the Triassic period.
4. If the continents were once together, they must have drifted apart. Thus Wegener had to prove that now widely separated continents and/or pieces of continents were once close together or contiguous. The evidence he used to support continental drift included apparent, geometrical fits between edges of continents; similar, late Paleozoic and early Mesozoic stratigraphic, geologic, and paleoclimatic records from different continents; and organisms, identified by their fossil remains, that would have had serious trouble migrating from one continent to another across oceans the size of those today. These latter organisms include land-dwelling amphibians and reptiles and numerous species of plants.
5. If *Mesosaurus* was able to swim well enough to cross the vast ocean currently separating Africa and South America, its remains should also be found on other continents. Since this is not the case, we conclude that South America and Africa were joined during the time period that these animals existed.
6. Animals were thought to have migrated from continent to continent using island chains as stepping stones, floating on logs, crossing on temporary continental links such as today’s isthmus of Panama, or swimming. Plants (seeds and spores) floated on currents or were rafted by the wind. In retrospect, these mechanisms were not satisfactory, and oceanographic studies had pretty much debunked them by the early 1950s. For example, *Mesosaurus*, an early Permian, aquatic reptile known only from South Africa and Brazil, lived in freshwater and coastal, salt water habitats, much like those of the modern crocodile or salt water crocodile. Such animals would have had great difficulty migrating between continents if the Atlantic Ocean was the same size in early Permian time as it is today. It seems more sensible to believe that the land areas were once together and have since drifted apart as the ocean opened and widened.
7. Wegener accounted for glaciers in southern landmasses with his supercontinent of Pangaea. The large landmass would provide the necessary conditions to generate large expanses of glacial ice over much of the Southern Hemisphere. This same geography would also place today’s northern landmasses nearer the equator and account for their vast coal deposits.
8. One of the main objections to Wegener’s hypothesis stemmed from his inability to identify a credible mechanism for continental drift. He also incorrectly proposed that the larger continents broke or “plowed” through the thinner oceanic crust, despite a lack of evidence.

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9. Seafloor spreading is the divergent movement of two oceanic plates away from a mid-ocean ridge, accompanied by addition of new basalt to the trailing edges of the diverging plates. Partial melting of a rising, mantle-peridotite plume supplies the basaltic magma. Professor Harry Hess of Princeton University laid out the basic idea early in the 1960s using new topographic data on the ocean floor acquired during and after World War II. Sea-floor spreading occurs today along the oceanic ridges.
 10. By the early 1970s, age-dating and paleomagnetic studies of basaltic lavas had produced a detailed chronology of Earth's magnetic field from the late Tertiary to the present and had conclusively documented several intervals of reversed polarity. Vine and Matthews recognized two fundamental characteristics of the stripe-like, seafloor magnetic patterns: they were symmetrically arranged about mid-oceanic ridges; and the ages, lateral positions with respect to the ridge axis, and remnant magnetic polarities of the seafloor basalts conformed to the polarities and time intervals evident in the newly developed, paleomagnetic time scale. They concluded that the magnetic patterns were acquired when the basalts were erupted along the axis of the mid-ocean ridge. As new magma was erupted, the older basalts split, forming roughly equal-sized strips attached to the trailing edges of diverging, lithospheric plates. These strips retained the rock's original magnetic polarity, accounting for the rough, lateral symmetry observed in the magnetic patterns on both sides of the ridge axis.
 11. The lithosphere, which consists of the uppermost mantle, along with the overlying crust, behaves as a strong, rigid layer. This is the zone or portion of the Earth that is broken into a series of segments or plates. Underlying the lithosphere is a weak region in the mantle known as the Asthenosphere. Here the temperatures and pressures are such that the rocks there are very near their melting temperatures and, hence, respond to stress by flowing.
 12. **Divergent boundaries** occur at regions where two plates move apart, resulting in upwelling of hot material from the mantle to create new seafloor. **Convergent boundaries** are characterized by two plates moving together or colliding, resulting in oceanic lithosphere descending beneath an overriding plate, eventually to be reabsorbed into the mantle, or possibly in the collision of two continental blocks to create a mountain system. **Transform fault boundaries** are formed where two plates grind past each other without the production or destruction of lithosphere.
 13. New, oceanic lithosphere is formed at the mid-ocean ridges and an equivalent area of old lithosphere sinks into the mantle along a subduction zone. Most geologists believe that Earth's radius and the area of lithosphere have been constant over geologic time; thus the production and subduction rates of lithosphere have to be roughly equal over time.
 14. Continental rifting occurs where opposing forces stretch and pull the lithosphere apart in the interior of a continent. The initial stage is characterized by mantle upwelling that is associated with broad upward warping of the overlying lithosphere. As the tectonic forces pull the crust apart, the crustal blocks sink, forming an elongated depression called a continental rift. A good example of a modern continental rift is the East Africa Rift.
 15. A continental volcanic arc is a mountain chain, such as the Andes or Cascades, comprised of volcanoes that are the result of an oceanic-continental convergent plate boundary. A volcanic island arc consists of a chain of volcanic islands, like the Aleutians or Tonga Islands that form at an oceanic-oceanic convergent plate boundary.

16. Oceanic lithosphere, being composed of basalt (rich in Fe- and Mg-rich minerals), is dense and readily sinks into the mantle at subduction zones. However, continental lithosphere (andesitic to granitic in composition) is not dense enough to sink into the mantle and be subducted. In some instances, small pieces or chips of continents may be subducted if they are carried down with unusually old, dense, oceanic lithosphere.
17. The Himalaya Mountains formed when the subcontinent of India collided into Asia approximately 40 million years ago. During this continental-continental collision, the crust buckled, fractured, and was generally shortened and thickened, resulting in the highest mountains on Earth today.
18. Transform boundaries are long, vertical, deep faults along which two plates move in opposite directions horizontally and parallel to the boundary. Plate motions at divergent and convergent plate boundaries have their major components of motion perpendicular to the boundary. Volcanism is prominent along convergent and divergent plate boundaries but is generally absent along transform fault boundaries.
19. No, California is not sinking into the ocean. The sliver of California west of the San Andreas fault is slowly moving northwest as part of the Pacific plate and the movement is essentially horizontal. Far in the geologic future, the sliver may eventually arrive in Alaska or the Aleutian Islands.
20. Himalayas – These have formed along a convergent, continent-continent, collisional boundary between the Indian subcontinent and Eurasia.

Aleutian Islands – These islands are the oceanward part of a volcanic island arc situated on the northwestern margin of the North American plate; the volcanoes lie above the subducting Pacific plate.

Red Sea – The Red Sea occupies a major rift zone and a very young seafloor spreading center that has opened between Africa and the Arabian block.

Andes Mountains – The Andes are a volcanic and plutonic arc resting on the western margin of the South American plate; they lie above subducting, oceanic lithosphere of the Nazca and Antarctic plates.

San Andreas fault – This is a transform fault that forms the boundary between the North American and Pacific plates. The crustal sliver composed of westernmost California and the Baja California peninsula on the eastern edge of the Pacific plate is moving northwestward with respect to North America.

Iceland – Iceland and nearby smaller islands comprise a major zone of basaltic volcanism that probably overlies a mantle hot spot located directly beneath the Mid-Atlantic Ridge, the divergent boundary between the Eurasian and North American plates.

Japan – The Japanese Islands lie on the eastern margin of the Eurasian plate, above subducting parts of the Pacific and Philippine oceanic plates.

Mount St. Helens – This is a very young stratovolcano in the state of Washington; it is part of the Cascade Range, a continental-margin, volcanic arc extending from the Canadian border to northern California.

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21. The age of the oldest sediments recovered by deep-ocean drilling is about 180 million years. These sediments are geologically quite young when compared to the oldest continental crust, which has been dated at 3.9 billion years.
 22. The Emperor Seamounts are aligned roughly north-south and are older to the north, proving that when they formed, the Pacific plate was moving northward with respect to a stationary hot spot. The Hawaiian Islands are oriented west-northwest and east-southeast and are youngest to the southeast; thus the plate was moving west-northwest over the same hot spot when the Hawaiian Seamounts were growing. Loihi, a rapidly growing seamount off the southern coast of Hawaii, is the newest active volcano to develop over the hot spot. Its location supports continuing northwest movement of the Pacific plate.
 23. Slabs of cold, dense lithosphere that subduct or sink into the asthenosphere drag or “pull” the trailing plate with them. This phenomenon is known as slab pull. Another important driving force for plate motion is gravity pushing the slabs of lithosphere down the subduction zone from the elevated position of the oceanic ridges. This process, called ridge push, appears to contribute much less to overall plate motions than does slab pull.
 24. Mantle plumes serve to transport heated material from deep inside the Earth towards the surface, thus providing thermal convection that ultimately drives plate motions.
 25. The two models proposed to explain mantle convection are a shallower, two-layer convective model and a whole mantle convective model. The shallow, two-layer model envisions a thin convective layer above 660 kilometers and a deeper layer below. The whole mantle model proposes a single convective cell where rising, hot mantle plumes originate near the core-mantle boundary and subducted lithosphere descends into the lower mantle. None of the models fit all of the available data, thus the exact nature of the convective flow in the mantle remains unknown.

Lecture outline, art-only, and animation PowerPoint presentations for each chapter of *Earth, 10e* are available on the Instructor’s Resource Center DVD (0321676793).

Classroom Demonstration

Mantle Plume Model

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Materials:

- 50 mL beakers or baby-food jars
- 250 mL or larger beaker
- Hot plate
- Corn syrup
- Water
- Red food dye
- Eye dropper
- Table spoon or glass rod to stir warm syrup

Preparation Time: 10 minutes, just before demonstration. Place about 100 mL of corn syrup into the 250 mL beaker, add several drops of red food dye, stir, and heat until the corn syrup is hot but not boiling.

Demonstration Time: 10–15 minutes (depending on time for brief writing and/or discussion)

Procedures

1. Have students review illustrations in their textbook of hypothetical mantle plumes and models of how they may be related to hot spots.
2. Have each group of 2–4 students pour about 4 cm of corn syrup into a 50 mL beaker (to represent Earth's mantle) and immediately cover it with a layer of about 1 cm of water (to represent Earth's crust).
3. Have one student from each group obtain an eyedropper full of the hot red corn syrup from the 250 mL beaker. The student should place the dropper into his/her beaker and squeeze out a pool of the red hot corn starch onto the bottom of the cool corn starch layer in the 50 mL beaker.
4. Remove the dropper and observe the behavior of the red hot syrup over the next 5 minutes. Encourage students from one group to also view the results of adjacent groups. They should observe a plume that rises as a linear plume until it reaches the water-crust layer, whereupon it forms a pool of red syrup just beneath the water-crust.
5. Have students again review illustrations in their textbook of hypothetical mantle plumes. How are they the same? Different?