Introduction to Earth Science

Answers to Earth System Questions

1. (a) rock: geosphere; (b) people: biosphere; (c) running water: hydrosphere; (d) algae on the rocks: biosphere

2. Geosphere: The earth materials involved in the mudflow are part of the geosphere. 
   Atmosphere: The heavy rains played a key role in this event. 
   Biosphere: The mudflow removed the vegetation from the hillside and also probably affected organisms living on the slope. 
   Hydrosphere: The precipitation is part of the circulation of water in the hydrosphere.

3. Answers will vary for each student.

Answers to “Give It Some Thought”

1. The light switch is broken. The light source (bulbs, tubes, etc.) are “burned out” and no longer working. The electricity to the room is not turned on or has been disconnected.

2. a) hypothesis – it is a tentative explanation; b) observation; c) theory – well tested and widely accepted by the scientific community; d) observation – direct measurement of how far the glacier has moved; e) theory

3. Warmer temperatures would promote melting of glaciers and ice caps, thus reducing the reflection of solar radiation by ice and snow. This would result in a further warming of Earth and the result is a positive feedback mechanism. Increased evaporation would actually put more water vapor into the atmosphere, resulting in an increase in cloud cover. Clouds tend to reflect more sunlight back into space, which diminishes the radiation which reaches the surface of Earth. The result is an increase in global temperatures and this is an example of a negative feedback mechanism.

4. Figures 1.1 B, 1.1A, 1.1B, 1.5 A, 1.5 B

5. At least three and probably four of the main components of the Earth system were involved in the natural disaster at Caraballeda, Venezuela. The atmosphere was most definitely involved with the heavy rains that triggered the massive debris flow as well as the hydrosphere because of the role of water in the disaster. The geosphere played a critical role, both in the types of earth materials in the region and the topographic setting at the mouth of a steep canyon. The disaster also impacted the biosphere in the large loss of human life and the destruction of plants and other animals.

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6. Hydrosphere – atmosphere: Evaporation of surface waters provides the majority of water vapor that is present in the atmosphere. Atmosphere – biosphere: Exchange of gases between living organisms (both plants and animals) is one of the fundamental interactions on our planet. Biosphere – hydrosphere: Absorption of water by plants is one of the key exchanges necessary for life on Earth. Biosphere – geosphere: Death and decay of certain organisms provide the materials necessary to form various rocks (limestone, coal, etc.). Geosphere – atmosphere: Oxidation (some of the oxygen comes from the atmosphere) often results in the breakdown of various rocks and minerals and the formation of new ones. Geosphere – hydrosphere: Erosion by surface waters is a key process in the formation of detrital sedimentary rocks.

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Chapter 2 – Instructor’s Manual

IV. Minerals
A. Properties of minerals
   1. Crystal form
   2. Luster
   3. Color
   4. Streak
   5. Hardness
   6. Cleavage
   7. Fracture
   8. Specific gravity
   9. Other properties
      a. Taste
      b. Smell
      c. Elasticity
      d. Malleability
      e. Feel
      f. Magnetism
      g. Double refraction
      h. Reaction to hydrochloric acid
B. A few dozen minerals are called the rock-forming minerals
   1. The eight elements that compose most rock-forming minerals are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg)
   2. The most abundant atoms in Earth’s crust are
      a. Oxygen (46.6% by weight)
      b. Silicon (27.7% by weight)
C. Mineral groups
   1. Rock-forming silicates
      a. Most common mineral group
b. Contain the silicon–oxygen tetrahedron
   1. Four oxygen atoms surrounding a much smaller silicon atom
   2. The silicon–oxygen tetrahedra join together in a variety of ways
   c. Feldspars are the most plentiful group
   d. Most silicate minerals crystallize from molten rock as it cools
2. Nonsilicate minerals
   a. Major groups
      1. Oxides
      2. Sulfides
      3. Sulfates
      4. Halides
      5. Carbonates
      6. “Native” elements
   b. Carbonates
      1. Major rock-forming group
      2. Found in limestone and marble
   c. Halite and gypsum—found in sedimentary rocks
   d. Many have economic value
D. Mineral resources
   1. Reserves—profitable, identified deposits
   2. Ores—metallic minerals that can be mined at a profit
   3. Economic factors may change

Answers to the Earth System Questions

1. (Answers will vary depending on the mineral commodity selected)

2. (Answers will vary depending on the mineral commodity selected)

Answers to “Give It Some Thought”

1. a) mineral – gold is an example of a mineral classified as a native element; b) seawater is not a mineral – minerals by definition are solids; c) quartz is a mineral; d) cubic zirconia is not a mineral – it is not naturally occurring; e) obsidian is not a mineral because it lacks an internal arrangement of atoms, however, it is an igneous rock; f) ruby is a mineral – it is a gemstone variety of the mineral corundum; g) glacial ice is a mineral as it meets all of the criteria; g) amber is not a mineral since it has an organic origin.

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*Matter and Minerals*

2. a) The element is uranium. b) 92 electrons  c) 146 neutrons

3. Sodium is more likely to form chemical bonds because of its tendency to lose one electron, resulting in an overall +1 charge.

4. Potassium-39 has 19 protons and 20 neutrons; Potassium-40 has 19 protons and 21 neutrons; Potassium-41 has 19 protons and 22 neutrons

5. Specimens A, B, and D have a nonmetallic luster. Specimens C and E have a metallic luster.

6. a) 6  b) 3  c) no

7. 5 gallons of water = 40 lbs. x 20 (specific gravity of gold) = 800 lbs.

8. Answers may vary slightly depending on which websites are utilized by students.

9. Answers will vary.

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Rocks: Materials of the Solid Earth

2. Concentrations of desirable materials are produced by
   a. Igneous processes
   b. Metamorphic processes
3. Most important ore deposits are generated from hydrothermal (hot-water) solutions
   a. Contain metal-rich fluids
   b. Associated with cooling magma bodies
   c. Types of deposits include
      1. Vein deposits in fractures or bedding planes

2. Disseminated deposits distributed throughout the rock

B. Nonmetallic mineral resources
   1. Mined for
      a. Nonmetallic elements they contain
      b. Physical or chemical properties they possess
   2. Two broad groups
      a. Building materials (e.g., limestone, gypsum)
      b. Industrial minerals (e.g., fluorite, corundum, sylomite)

Answers to Earth System Questions

1. The sedimentary rock coquina is a biochemical limestone that consists of loosely cemented shells and shell fragments that have accumulated on the ocean floor. The primary Earth spheres involved in its formation are the biosphere, hydrosphere, and atmosphere (the source of the carbon dioxide for the mineral calcite found in the shells). Shale, a detrital sedimentary rock, is composed primarily of clay, a product of weathering of several different minerals, and possibly some organic matter. The spheres involved in its formation are the biosphere, hydrosphere (where the sediment accumulates), atmosphere (which is involved in the weathering process), and solid earth (which supplied the material to weather into clay).

2. Igneous and metamorphic rocks are associated with Earth’s internal heat. Sedimentary rocks, because they often contain organic matter and form in the sea, where the Sun is the energy source that drives waves and currents, are allied with both solar energy and Earth’s internal heat.

3. 20,000 pounds/year x 75 years = 1,500,000 pounds. If a cubic yard of rock weighs roughly 1700 pounds, the volume of rock that would be mined over 75 years is 1,500,000 pounds / 1700 pounds = 882.4 cubic yards. 1 cubic yard = 27 cubic feet, so 882.4 cubic yards x 27 cubic feet/cubic yard = 23,824 cubic feet. This is the equivalent of a hole approximately 28.5 feet wide, 28.5 feet long, and 28.5 feet deep!

Answers to “Give It Some Thought”

1. The rock cycle supports the fact that sedimentary rocks are most abundant on Earth’s surface because each rock type, once exposed at the surface, is subjected to uplift, weathering, and erosion. The resulting sediment will eventually be transformed into sedimentary rock.

2. No. Crystal size in igneous rocks is a direct function of the rate of cooling and since a given body of magma could experience differential rates as it cools and solidifies, different sizes of crystals in the same rock would be common.
3. A) Rapid rate of cooling resulting in mainly microscopic crystals; B) A very slow rate of cooling followed by a more rapid period of cooling as evidenced by the porphyritic texture; C) Relatively slow, steady rate of cooling resulting in larger crystals of about the same size; D) Extremely rapid rate of cooling as indicated by the glassy texture.

4. Yes, rhyolite and granite are a good example of two rocks with similar compositions. Rapid cooling of lava results in the aphanitic texture typical of rhyolite while granite exhibits large, visible crystals due to slow cooling of magma.

5. Remember that Bowen’s Reaction Series not only predicts the sequence of crystallization for minerals from magmas, but it also provides the order in which those minerals will melt as temperature increases for a given rock. If only partial melting (as opposed to complete melting) occurs, the resulting magma will only contain those chemical elements from the minerals whose melting temperatures have been achieved. Therefore, the magma could have a significantly different chemical composition than the original rock. In addition, varying degrees of partial melting could produce several different magmatic compositions from the original rock.

6. The accumulation of organic debris (leaves, stems, branches, etc.) and physical debris (mud, soil, etc.) around your home and in your yard are other examples of sedimentary processes.

7. One reason why sedimentary rocks are more likely to contain fossils is because sediment accumulates in various environments (oceans, lakes, rivers, beaches, swamps, deserts, etc.) where both plants and animals already exist. As the organisms die, they accumulate with detrital sediments and often become incorporated into the final rock that is formed. Another reason is that the various processes involved in the formation of sedimentary rocks (erosion, deposition, and lithification) are often not so destructive as to obliterate the original form or at least some part of the original organism.

8. The geologic history of the limestone layer would perhaps be the following: 1) formation of marine limestone in a warm, shallow ocean; 2) burial and lithification of limestone over a long period of time; 3) uplift of unit, most likely related to plate tectonic forces at or near a plate boundary; 4) erosion of younger units and exposure of limestone layer at the top of a present-day mountain.

9. Outcrop “B” is composed of metamorphic rock. Photograph “A” shows layers of sediment and coarse layers of gravel typical of sedimentary rocks. Photograph “C” displays an igneous rock with some sort of intrusion cutting through it. Also, photograph “B” shows highly banded rock layers with intense folding and kink banding, typical of metamorphic rocks.

10. a) The Vishnu Schist could have formed from regional metamorphism involving increased temperatures and pressures associated with plate tectonics. This is a very different process from the various steps involved in the formation of the sedimentary rocks above it (weathering, erosion, deposition, and lithification). b) The Grand Canyon obviously had a much different geologic history involving regional metamorphism and perhaps various episodes of mountain building compared the modern erosion of the Colorado River. c) The Vishnu Schist has been exposed at Earth’s surface due to uplift and the erosion of this region by the Colorado River. d) Yes, it is very likely that the Vishnu Schist exists in other areas since such rocks are typically formed by regional metamorphism (which takes place over large regions). It simply has not been exposed in most other areas.

11. a) 20,000 lbs. x 80 years = 1,600,000 lbs. b) 1,600,000 lbs. / 1700 lbs. per cubic yd. = 941.2 cubic yards c) 941.2 cubic yards x 2 = 1883 pickup truck loads
Weathering, Soil, and Mass Wasting

Answers to Earth System Questions

1. The production of carbonic acid (H₂CO₃), which forms when carbon dioxide (CO₂) is dissolved in water (H₂O), is associated with the atmosphere and biosphere, which supply the carbon dioxide, and the hydrosphere, the source of the water.

2. Increasing levels of carbon dioxide should ultimately result in higher levels of carbonic acid. Therefore, chemical weathering, which is primarily accomplished by carbonic acid, should also increase.

3. The burning of fossil fuels like coal and petroleum in power-generating plants, industrial processes such as ore smelting and petroleum refining, and vehicles of all kinds release large quantities of sulfur and nitrogen oxides into the atmosphere each year. Eventually these pollutants are converted into acids that then fall to Earth's surface as rain or snow.

4. Soil is an interface where different parts of the Earth system interact. It forms where the solid Earth, the atmosphere, the hydrosphere, and the biosphere meet. Over time, the material of soil develops in response to complex environmental interactions among the different parts of the Earth system. The solid Earth and biosphere supply the mineral and organic materials of soil; the atmosphere along with the biosphere and hydrosphere furnish the acids and water to weather the material; and the atmosphere, biosphere, and hydrosphere help mix, transport, and sort the materials.

Answers to “Give It Some Thought”

1. Plant roots in search of minerals and water grow into fractures and help to wedge rocks apart. Also, certain plants, fungi, and lichens produce acids or other compounds that aid in the chemical weathering of earth materials. However, the root systems of plants serve to inhibit erosion by binding and helping to hold soils and rocks in place.

2. Chemical weathering would be much more important than mechanical weathering in a hot, wet climate. The moisture and higher temperatures would promote the various reactions involved in chemical weathering. When comparing granite vs. basalt in such an environment, basalt would probably weather more rapidly. Ferromagnesian minerals would be rapidly oxidized and decomposed under these conditions, and basalts have much larger percentages of these minerals than granite.

3. Lunar soil does not meet the definition of soil that we use here on Earth. Soil is defined as being comprised of approximately 25% water, 25% air, 5% organic material, and 45% mineral matter. Of those components, only the mineral matter would be found on the Moon, thus not meeting the geologic definition of soil.

4. Different soils could develop from the same parent material if the rates and types of chemical weathering were dramatically different from one area to another. Such differences would be caused by different climates— for example a hot, wet climate would produce much more intense chemical weathering than a dry, cold climate. For the same reasons, different parent materials could also produce similar soils given the necessary climatic characteristics.

5. The soils adjacent to the Amazon River basin are Oxisols while the American Southwest is characterized by Aridisols. Oxisols develop in tropical climates where leaching predominates, and they are enriched in iron and aluminum oxides. Aridisols are found in arid regions where water is not available to remove soluble materials, and they are enriched in calcium carbonate and salts. The only thing the two soil orders
have in common is that they are both poor soils for agricultural activity.

6. Mass wasting is actively moving rock debris down the steep slopes of the canyon walls. The talus slopes along the base of the canyon wall on the right side of the photograph are evidence that active mass wasting is occurring.

7. Active uplift of a region due to the internal processes of plate tectonics and mountain building could lead to mass wasting events. The uplifted areas could experience earthquakes or oversteepened slopes, both of which could cause mass wasting to occur.

8. Answers will vary significantly. An example of wildfires would be: Wildfires destroy vegetation (biosphere) which removes the anchoring system of a slope and leads to increased mass wasting. The removal of vegetation by wildfires also allows water (hydrosphere) to better infiltrate the rocks and soil (geosphere) of a slope, thus increasing the likelihood of downslope movements.

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Running Water and Groundwater

1. Distribution of groundwater
   a. Belt of soil moisture
   b. Zone of aeration
      1. Unsaturated zone
      2. Pore spaces in the material are filled mainly with air
   c. Zone of saturation
      1. All pore spaces in the material are filled with water
      2. Water within the pores is groundwater
   d. Water table—the upper limit of the zone of saturation

2. Movement of groundwater
   a. Porosity
      1. Percentage of pore spaces
      2. Determines how much groundwater can be stored
   b. Permeability
      1. Ability to transmit water through connected pore spaces
      2. Aquitard—an impermeable layer of material
      3. Aquifer—a permeable layer of material

D. Features associated with groundwater
   a. Hot springs
      1. Water is 6–9°C warmer than the mean air temperature of the locality
      2. Heated by cooling of igneous rock
   b. Geysers
      1. Intermittent hot springs
      2. Water turns to steam and erupts

2. Wells
   a. Pumping can cause a drawdown (lowering) of the water table
   b. Pumping can form a cone of depression in the water table

3. Artesian wells
   a. Water in the well rises higher than the initial groundwater level
   b. Types of artesian wells
      1. Nonflowing
      2. Flowing

E. Environmental problems associated with groundwater
   1. Treating it as a nonrenewable resource
   2. Land subsidence caused by its withdrawal
   3. Contamination

F. Geologic work of groundwater
   1. Groundwater is often mildly acidic
      a. Contains weak carbonic acid
      b. Dissolves calcite in limestone
   2. Caverns
      a. Formed by dissolution of rock beneath Earth’s surface
      b. Formed in the zone of saturation
      c. Features found within caverns
         1. Form in the zone of aeration
         2. Composed of dripstone
            a. Calcite deposited as dripping water evaporates
            b. Common features
               1. Stalacmites hanging from the ceiling
               2. Stalagmites developing on the cave floor
   3. Karst topography
      a. Formed by dissolution of rock at, or near, Earth’s surface
      b. Common features
         1. Sinkholes
            a. Surface depressions
            b. Formed by
               1. Dissolution of bedrock
               2. Cavern collapse
         2. Caves and caverns
            a. Area lacks good surface drainage

Answers to “Give It Some Thought”

1. Zone # 1: a. sediment production; Zone # 2: c. sediment transportation; Zone # 3: b. sediment deposition

2. River # 1: d. alluvial channel (braided); River # 2: b. alluvial channel (meandering); River # 3: c. alluvial channel (non-meandering); River # 4: a. bedrock channel
3. Answers will vary depending on the major river in the region. Base level for the Mississippi River is sea level where it enters the Gulf of Mexico and base level for the Missouri River is the Mississippi River.

4. The flooding occurs at some time after the rainstorm has stopped. Since no time units are given for the graph, it is impossible to know how much time has elapsed before the flood waters peaked, but they definitely were after the storm had passed.

5. Graph “B” would most likely represent a rural area. In Graph A, the flooding peaks shortly after the rainstorm and has a higher discharge, but it occurs over a shorter period of time. This is typical of urban areas where paving and construction decrease infiltration and rapidly increase runoff, resulting in intense floods of shorter duration. Graph B indicates flooding longer after the rainstorm (slower rate of runoff and more infiltration) that doesn’t have as high a discharge as Graph A, but it lasts much longer. Such floods are more common in rural areas where infiltration is greater and runoff is slower.

6. Sedimentary rocks have the greater likelihood of being a good aquifer because they generally have higher porosities and permeabilities than do igneous or metamorphic rocks.

7. I would explain to my friend that neither one has “better” water—springs occur where the water table intersects Earth’s surface while artesian systems represent wells where the water rises above the level where it was first encountered. Also, I would explain to them that in some instances artesian springs occur, which is a combination of the two phenomena explained above.

8. The main difference between an intermittent stream and one that flows all of the time, even during extended dry periods, is the level of the water table. The intermittent stream has a much lower water table that doesn’t always intersect the stream channel.

**Answers to Earth System Questions**

1. (a) evaporation; (b) precipitation; (c) transpiration and evaporation; (d) runoff and infiltration

2. Sea level does not drop because water is also being added to the sea via runoff and infiltration.

3. Among the many answers are the following: (1) the cutting of forests, which lessens the amount of transpired water added to the atmosphere and interferes with the balance between runoff and infiltration; (2) the removal of groundwater for agricultural or other uses, which may lower the water table; and (3) ocean oil spills, which interfere with the ocean–atmosphere interface and retard evaporation and the oxygen–carbon dioxide exchange.

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Glaciers, Deserts, and Wind

B. Basin and range: the evolution of a desert landscape
   1. Uplifted crustal blocks
   2. Interior drainage into basins produces
      a. Alluvial fans and bajadas
      b. Playas and playa lakes
   3. Erosion of mountain mass causes local relief to continually diminish
   4. Eventually, mountains are reduced to a few large bedrock knobs called
      inselbergs projecting above a sediment-filled basin

C. Wind erosion
   1. By deflation
      a. Lifting of loose material
      b. Producyes
         1. Blowouts
         2. Desert pavement
   2. By abrasion

D. Types of wind deposits
   1. Loess

a. Deposits of windblown silt
b. Extensive blanket deposits
c. Primary sources
   1. Deserts
   2. Glacial stratified drift
2. Sand dunes
   a. Mounds and ridges of sand formed from the wind’s bed load
   b. Characteristic features
      1. Slip face—the leeward slope of the dune
      2. Cross beds—sloping layers of sand in the dune
   c. Types of sand dunes
      1. Barchan dunes
      2. Transverse dunes
      3. Longitudinal dunes
      4. Parabolic dunes
      5. Star dunes

Answers to “Give It Some Thought”

1. a) 920 meters / 8 years = 115 meters per year. b) 115 meters / 365 days = 0.32 meters or 32 centimeters per day. c) 320 meters / 8 years = 40 meters per year or 40 meters / 365 days = 11 centimeters per day.
   d) The center of the glacier moved faster due to the frictional drag along the sides of the valley.

2. a) 1600 kilometers / 50 meters per year = 32,000 years. b) 1600 kilometers / 320 meters per year = 5,000 years.

3. You would expect to find a moraine due to the melting of ice at the terminus of the glacier. If ablation begins to exceed accumulation, the glacier would begin to retreat. Ground moraines would form under the glacier as it retreats along with recessional moraines depending on the nature of the retreat. Also, various deposits of stratified drift would form in response to the melting ice.

4. Some evidence that the glacier in Figure 6.1 is really moving include the fractured and broken surface of the ice due to brittle deformation caused by movement, the trail of sediment extending through the center of the photograph where the two glaciers come together, the sediment at the terminus of the glacier that has been deposited by the moving ice, and the dark sediment along the margins of the glacier picked up along the walls of the valley.

5. Statement “A” is true—wind is more effective in arid regions as compared to humid areas. The loose, dry particles in arid regions are more influenced by wind than arc particles in humid places where the moisture serves to make the sediment more cohesive and also heavier. However, statement “B” is not true—water is actually the most important agent of erosion in arid regions.

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6. Barchanoid dunes. The prevailing winds are blowing from the top of the photo towards the bottom. The dunes are asymmetric and the wind direction can be determined by examining the gentle slopes of the windward side and the much steeper slopes on the slip faces.

7. Sediment deposited by streams is generally well-sorted as a function of increasing or decreasing stream velocity. Particles are rounded despite the variety of sizes transported by running water. Wind tends to transport only very fine sediment—silt or sand-sized at best and the particles are often angular and have a frosted appearance. Glacial deposits are the most poorly sorted due to the indiscriminate nature of ice as a transporting medium—boulders and mud may be moved together in the same part of a glacier. The particles show a large disparity of sizes and they are often polished and scratched by the ice. Wind deposits would have the most uniform grain sizes (due to the limited ability to move larger particles) while glacial deposits are the most poorly sorted.

Answers to Earth System Questions

1. Answers will vary for different instructors.

2. (Answers will vary) Because glaciers are water, and they also erode, transport, and deposit sediment, and eventually melt, they can be considered part of the hydrosphere. However, they are also solid and behave as many rocks do and therefore may also be included in the solid Earth.

3. With reference to the obvious problem addressed in question 1, many Earth scientists include a fifth sphere in Earth’s spheres—the cryosphere, which includes the various types of glaciers. Such an idea has merit in that it solves the dilemma of where to place ice.

4. The expansion of mechanized agriculture along with prolonged drought left the unprotected farm fields vulnerable to severe wind erosion. The result was soil loss, crop failures, and economic hardship.

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2. Older are at a distance from the ridge
c. Ocean basins are geologically young
4. Hot spots
   a. Rising plumes of mantle material
   b. Volcanoes can form over them
      1. Example: Hawaiian Island chain
      2. Chains of volcanoes mark plate movement
F. Measuring plate motion
   1. By using hot spot “tracks” like those of the Hawaiian Island–Emperor Seamount chain
   2. Using space-age technology to directly measure the relative motion of plates
      a. Very Long Baseline Interferometry (VLBI)
      b. Global Positioning System (GPS)
G. Driving mechanism of plate tectonics

Answers to “Give It Some Thought”

1. a) The puzzle-like fit of the coastal outlines of South America and Africa, b) Wegener gathered several pieces of evidence to support his continental drift hypothesis including matching fossils (plants and animals) on different continents, matching bodies of rocks and mountain belts on different continents, and matching paleoclimates on different continents. c) The continental drift hypothesis was rejected by the scientific community because Wegener lacked a credible mechanism to explain why the continents were moving or drifting. Also, he incorrectly proposed that the continents broke through the thinner oceanic crust although no evidence existed to support this idea. d) Yes, overall Wegener followed the basic principles of scientific inquiry. He proposed evidence to support his various explanations although not all of his evidence supported his conclusions.

2. a) A = ocean to continent convergence, B = ocean to ocean convergence, C = continent to continent convergence; b) oceanic crust; c) Volcanoes are absent at continent to continent convergent boundaries because there is no subduction and therefore no mechanism to produce partial melting of mantle rocks. d) Ocean to ocean convergent boundaries are different from ocean to continent convergent boundaries in that the resulting volcanism occurs on the ocean floor rather than on land and the composition of the volcanoes between the two would be somewhat different due to the interaction of continental rather than oceanic crust. They are similar in that both of them produce volcanism, they both involve subduction zones, and both are characterized by earthquakes.

3. California will not necessarily sink into the ocean, but the continued motion of the Pacific plate will separate a portion of California from the North American plate along the San Andreas Fault system. The broken segment will then move with the Pacific plate as a large island since it is composed of continental crust rather than oceanic.

4. a) five; b) Continents A, B, and C are moving away from each other because of the divergent boundary that occurs between all three of them; c) Active volcanoes are found on both A and B because each of them has an oceanic plate that is subducting underneath the continental plate; d) Continent C does not
Plate Tectonics: A Scientific Revolution Unfolds

have volcanoes because it does not have a plate boundary involving subduction or rifting. Hot spot activity or continental rift could perhaps produce volcanoes in the future.

5. The extremely large volcanoes on Mars suggests that either the tectonic plates were moving really slowly when the volcanism occurred or perhaps Mars was lacking tectonic plates and the large volcanoes resulted from hot, stationary plumes inside of Mars.

6. Along the first ridge, the plate movements were apparently steady and relatively fast (as evidenced by the narrow magnetic stripes). On the second ridge, the movements are relatively slower over the most recent geologic times, but the plates were apparently moving faster at some point further back in time.

7. The break-up of Pangaea some 200 million years ago allowed for the separation of once-joined landmasses and the isolation of common organisms to undergo a long period of evolutionary development. The resulting organisms today share a common ancestry because of their common origins on Pangaea, but the long period of time has allowed for distantly related groups to develop their own unique characteristics.

8. Eurasia.

9. Density or density differences in plate tectonics play a key role in 1) the subduction of more dense oceanic crust underneath continental crust; 2) the rising of hotter mantle material at divergent boundaries and the sinking of colder lithospheric plates at subduction zones, thus creating the “conveyor belt” model that somehow drives the plate tectonics engine; and 3) the collision and uplift of continental crust at continent to continent convergent boundaries due to lower densities of continental rocks.


Answers to Earth System Questions

1. The changing positions of the continents and the redistribution of land and water over Earth’s surface have had a significant impact on Earth’s atmosphere, hydrosphere, and biosphere through time. Atmospheric and oceanic circulations are interrelated systems driven by heat energy from the Sun. As continents moved about, the distribution of heat energy over Earth’s surface varied, which, in turn, caused changes in global wind patterns and ocean circulation. Different atmospheric and oceanic circulation patterns produced changes in temperature, precipitation, storm tracks, and global climates in general. Furthermore, when the continents were assembled into large landmasses, their size and location produced climates much different from today.

Life on Earth was greatly affected by the distribution of landmasses and the resulting climates. At times landmasses may have been arid and may have promoted the evolution of certain adaptable species. Then, as a consequence of plate tectonics, the landmass may have split and/or changed global position and become tropical, forcing extinctions and/or adaptations. A good example of the impact of plate tectonics on life is found in the unique species that currently inhabit Australia.

2. Seattle, WA: Seattle would be much closer to the equator, warmer, and perhaps subtropical. Without the breakup of Pangaea, plate tectonics, and the collision of the North American and Juan de Fuca plates, the volcanic Cascade Range would not exist.
Earthquakes and Earth's Interior

c. Earth’s overall density is also best explained by an iron core

Answers to “Give It Some Thought”

1. The concept of elastic rebound explains that earthquakes are caused by excess elastic strain energy being suddenly (catastrophically) released as the highly overstrained rocks snapped back (rebounded) to a state of much lower strain. Cool lithospheric rocks have elastic limits large enough to support earthquake-causing elastic strains. Hence, most earthquakes originate in the lithosphere. Because they are much warmer, asthenospheric rocks begin deforming by flowage (plastic deformation) at much lower stress magnitudes. Therefore, any stored elastic strain energies in the asthenosphere are too small in magnitude to produce a strong earthquake. Other than the idea of a rubber band, a plastic or wooden ruler would illustrate the same concept by bending it and allowing it to snap back or “rebound” to its original shape.

2. Most earthquakes occur at convergent plate boundaries.

3. a) P waves, b) 6 minutes, c) about 3000 miles or 4800 kilometers, d) surface waves

4. The water that fills your footprints is located between the grains of sands or in the pore spaces. This is a good analogy to liquefaction that occurs in water-saturated soils during an earthquake.

5. As the tsunami waves begin to “feel bottom” and the water begins to pile up, the result of the building surge or wave is a rapid withdraw of water from the beaches prior to the wave coming ashore. This “piling up” effect of the waves pulls the water away from the beach, thus signaling the approach of the main surge.

6. It is possible to issue a tsunami warning because they are possible after an earthquake has occurred. In other words, they result from the earthquake event. However, we cannot issue earthquake warnings because there are no precursors or signs that signal an impending quake.

7. a) The southernmost section has not produced an earthquake in over 300 years, so it has the best chance of a major earthquake in the foreseeable future. b) central segment, c) around 2050 to 2060, d) Los Angeles, because it is located close to both the segment that produced the 1857 quake and the southernmost segment, which is way overdue according to the idea that major quakes occur approximately every 200 years.

8. Earth’s internal layers are defined based on their composition and their physical properties or behavior (mechanical).

9. The outer core of the Earth does not transmit S waves and the reason for this behavior is thought to be because this region is composed of a dense liquid, probably liquid iron.

10. In general, interior or body waves (mainly P waves) would travel fastest in the inner core because the highest densities are thought to occur there. The slowest interior waves would occur in the outer core or perhaps in the asthenosphere where a limited amount of partial melting is thought to occur.

11. Answers will vary depending upon the websites utilized by students.

Answers to Earth System Questions
Answers to “Give It Some Thought”

1. a) convergent plate boundary  b) intraplate volcanism  c) convergent plate boundary  d) divergent plate boundary  e) intraplate volcanism  f) convergent plate boundary  g) intraplate volcanism  h) convergent plate boundary

2. a) It is a composite or stratovolcano. The shape is the best indication as to the type of volcano although the size is also consistent with a composite volcano. b) This type of volcano is characterized by explosive eruptions due to the highly viscous magmas/lavas associated with them. Typically they are rhyolitic or andesitic in composition. c) Composite volcanoes are found mainly at convergent plate boundaries. d) Seattle, Mexico City, Mexico, Tokyo, Japan, and Naples, Italy are all cities that could be impacted by future eruptions of composite volcanoes.

3. a) Basaltic lavas at divergent boundaries are generated by partial melting in the upper mantle. b) Melting occurs due to decompression melting as the tectonic plates pull apart. c) A divergent boundary, such as the East African Rift, could have lavas other than basalt associated with it. The melting here could produce a composition of andesite or perhaps rhyolite because of the partial melting of continental crust.

4. Volcanism occurs at areas other than plate boundaries (known as intraplate volcanism) due to a rising mass of hotter than normal mantle material that ascends towards the surface. The result is a localized region of volcanism called a hot spot.

5. a) convergent plate boundary with a continental volcanic arc; b) divergent plate boundary involving oceanic plates; c) divergent plate boundary in a continental plate (continental rifting); d) intraplate volcanism in an oceanic plate; The convergent plate boundary will produce the most explosive volcanism while the divergent plate boundary and intraplate volcanism are both characterized by outpourings of fluid basaltic lava.

6. Possible indications that magma is moving through the crust beneath a volcano include changes in the pattern of volcanic earthquakes, surface inflation of the volcano, changes in the amount and/or composition of gases released from the volcano, and an increase in ground temperatures due to the emplacement of new magma.

7. The primary criteria would be the selection of actively explosive volcanoes that are located near densely populated regions or major cities. Other criteria would include choosing volcanoes that are exhibiting signs of erupting in the near future and volcanoes that have documented histories of major eruptions. Some potential sites to consider based on the above criteria include major cities such as Tokyo, Seattle, or Mexico City, and other areas of active volcanism such as Mt. Etna in Italy or densely populated areas in the Philippines and Indonesia.

8. A major eruption of Mt. Rainier, similar to the one that occurred at Mt. St. Helens, would be considerably more destructive because of the close proximity to the densely populated region in and around Seattle, Washington. Much of the human development near Seattle is located on recent volcanic deposits from earlier explosive eruptions. Any future, major eruptions of Mt. Rainier would certainly impact those areas.

9. a) laccolith; b) dike; c) batholith; d) sill

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Volcanoes and Other Igneous Activity

10. The presence of vesicles near the top of the basalt unit suggests that it was extruded onto the surface as a lava flow. Afterwards, the area was submerged and the shale unit was deposited. Inspection of the contact between the shale and basalt units for no evidence of contact metamorphism could further strengthen the argument that the unit is a lava flow.

Answers to Earth System Questions

1. A great and prolonged increase in volcanic activity will add substantial amounts of volcanic dust to the atmosphere, block sunlight, cause a global lowering of temperatures, and alter the general pattern of atmospheric and oceanic circulation. The reduction in both sunlight and temperature will have a substantial impact on the biosphere, perhaps resulting in mass extinctions. Lowering temperatures will result in increased cloud cover and precipitation. Consequently, erosion will be more pronounced, and additional sediment and water will be added to the oceans.

2. Volcanic regions, especially those such as the Hawaiian Islands and the Philippines that are located in tropical regions, often offer rich, fertile, and productive soils along with majestic scenery.

Lecture outline, art-only, and animation PowerPoint presentations for each chapter of Earth Science, 13e are available on the IRC DVD (ISBN 0321720253).
Crustal Deformation and Mountain Building

1. One of the largest regions of fault-block mountains on Earth
2. Tilting of these faulted structures has produced nearly parallel mountain ranges that average 80 kilometers in length
3. Extension beginning 20 million years ago has stretched the crust to twice its original width
4. High heat flow and several episodes of volcanism provide evidence that mantle upwelling caused doming of the crust and subsequent extension

VIII. Buoyancy and the principle of isostasy
A. Evidence for crustal uplift includes wave-cut platforms high above sea level
B. Reasons for crustal uplift
   1. Not so easy to determine
   2. Isostasy
      a. Concept of a floating crust in gravitational balance
      b. When weight is removed from the crust, crustal uplifting occurs
         1. Called isostatic adjustment
         2. Crustal buoyancy can account for considerable vertical movement

Answers to “Give It Some Thought”

1. Ductile deformation describes material failure by internal flowage; recrystallization is usually involved, especially at elevated temperatures. Ductile deformation is enhanced both by elevated temperatures and increased confining pressures such as exist at depth inside the Earth. Brittle deformation describes material failure by cracking and rupture. Brittle deformation is favored by shallow depths, low rock temperatures, and massive rigid rocks.

2. Mica schist is much more likely to flow or fold when subjected to differential stress because the foliation in metamorphic rocks imparts an internal weakness that is susceptible to ductile deformation.

3. Diagram 1 is a reverse fault and it is caused by compressional stress. Diagram 2 is a normal fault and it is caused by tensional stress. Diagram 1 = “a” and Diagram 2 = “b”.

4. The Galapagos Rise is more likely to be accreted because it is attached to the oceanic plate that is subducting underneath the South American plate. In the future, it could probably be recognized as an accreted terrane because the composition of the rocks (mainly basalt and other mafic rocks) is significantly different than the rocks that comprise the continental crust.

5. The Ural Mountains, a north-south range in west-central Russia, mark the closure site of an ancient marine basin that once existed between the European and Siberian parts of the Eurasian plate. As the two continents converged and joined, the sediments in the former marine basin were lithified, crumpled, and uplifted into a mountain range. Hence, they are now located in the interior of a massive landmass.

6. Although the Appalachians and Urals share a similar origin (collision of continental plates), they are located in different parts of their respective continents. In North America, when Pangaea begin to break apart, it split just to the east of the modern Appalachians so that they are now located near the margin of the continent. However, when they formed, the Appalachians would have been located more in the center of the massive landmass of Pangaea.
7. The final stage in the evolutionary history of the Appalachian orogen was energized by the continental collision between North Africa (then part of Gondwanaland) and North America in Pennsylvanian time. The northern Cordillera evolved over a long-lasting interval of plate convergence starting in early to mid-Mesozoic time. Along most of the North American Pacific margin, convergence was replaced by transform faulting beginning in mid-Cenozoic time. Terrane accretion, volcanism and plutonism, folding, thrust faulting, and horizontal shortening and crustal thickening characterized its evolution, but compressive deformation occurred without continental collision. This was the major difference in the tectonic evolution of the two orogens. However, prior to closure of the proto-Atlantic Ocean basin, the evolutionary history of the Appalachian orogen was very similar to that of the northern Cordillera, where the active continental margin faced a subducting oceanic plate carrying an island arc or two, numerous seamounts and other accreted blocks.

8. The uplift and subsequent erosion of major mountain belts would also lead to isostatic adjustment of crustal rocks. As erosion lowers the summits of mountains, the crust rises in response to the reduced load. These processes will continue until the crust reaches a balanced thickness.

9. Gravitational collapse is another process that would eventually lower a mountain range. Ductile spreading at depth is accompanied by normal faulting and subsidence in the upper, brittle portion of the crust.

10. a) 10 meters would be above sea level.  b) 5 meters  c) Overall icebergs are good examples of isostasy. The density of ice is about 10% less than that of water, which is similar to the density difference between continental and oceanic crust. d) Although melting of icebergs does reduce overall mass, similar to the erosion of mountains, it is a much faster process than erosion and therefore isostatic adjustment is much more rapid.

11. 1) 600 million years ago – accretion of microcontinents against the eastern margin of North America, 2) 450–500 million years ago – development of the Piedmont and Blue Ridge regions as North America and Africa continued to move towards one another; ancestral Atlantic ocean was being consumed, 3) 400 million years ago – development of the Carolina Slate belt and eastern Piedmont with an ocean to continent collision of the ancestral Atlantic underneath North America, 4) 250–300 million years ago – collision of Africa and North America with extensive folding / thrust faulting and the development of the Valley and Ridge Province.

Answers to Earth System Questions

1. Seattle, located on the western, or windward, side of the Cascades receives more than twice as much annual precipitation as Spokane, about 360 kilometers to the east. Compared with Spokane, Seattle has warmer winters and cooler summers and a smaller annual range of temperature. The mountains act as a barrier to the flow of moist air from the Pacific. As the air crosses the mountains, it loses much of its moisture and is relatively dry when it reaches Spokane. Furthermore, the moderation of Seattle’s temperatures by the Pacific Ocean accounts for the less extreme conditions and smaller annual range. The greater continental influence and higher elevation of Spokane also affect its temperatures.

2. As a consequence of geographic position, Seattle, with its moderate temperature and greater annual precipitation, has lush forest areas of large trees, primarily of the needle-leaf type. In the drier highland area of Spokane, vegetation is less dense, primarily grasslands, and more suited to the semiarid conditions.

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Chapter 11 – Instructor’s Manual

Answers to “Give It Some Thought”

1. a) Fault A cuts the sandstone layer so the fault is younger. b) Dike A also crosscuts the sandstone layer so the dike is younger. c) Fault A stops at the base of the conglomerate; thus the conglomerate layer truncates the fault and is younger than the fault. d) The conglomerate is cut and displaced by fault B; thus fault B is younger. e) The faults do not cross, but the relationship between the faults and the conglomerate proves that fault A is older than fault B. f) Dike A does not cut the batholith so other relationships must be used. Dike B clearly cuts the batholith; the sill fed by dike B is crosscut by dike A, proving that dike A is younger than dike B and younger than the batholith.

2. A depositional contact or unconformity would be proven if detrital rock and mineral grains from the granite were found in the sandstone. Also the granite just below the contact might show reddish discoloration or other evidences of having been weathered before the sandstone was deposited. Bedding in the sandstone will be parallel or nearly parallel to the contact; there will be no evidence for contact metamorphism in the sandstone; and the sandstone will not be cut by the granitic dikes.

If the contact is intrusive, the sandstone may be cut by granitic dikes and may show contact metamorphism. Rock and mineral grains in the sandstone will not show any direct correlation to the granite, and bedding in the sandstone will probably not be parallel to the contact.

3. Each time beta decay occurs, the atomic number rises by one and does not affect the mass number. Each alpha decay decreases the atomic number by 2 and the mass number by 4. Thus, for 6 alpha decays and 4 betas, the atomic number of the daughter would be \((90 - (6 \times 2) + 4) = 82\), which is the atomic number of lead. The mass number of the daughter would be \((232 - (6 \times 4)) = 208\). The stable daughter is lead-208.

4. A ratio of 1:1 would be produced in 10,000 years (one half-life). After two half-lives, 25 percent of the
original parent would be left and 75 percent of the daughter would have formed. The ratio (25 : 75) is 1:3, so the sample is 20,000 years old (2 half-lives x 10,000 years in one half-life = 20,000 years).

5. To make calculations easier, let us round the age of Earth to 5 billion years.
   
a) What fraction of geologic time is represented by recorded history (assume 5000 years for the length of recorded history)? The percentage is \(5 \times 10^9\) yrs divided by \(5 \times 10^9\) yrs x 100% which equals \(1 \times 10^{-1}\) % or 0.0001 %.

b) What fraction of geologic time is represented by the presence of hominids on Earth? (assume 5,000,000 years) The percentage is \(5 \times 10^9\) yrs divided by \(5 \times 10^9\) yrs x 100% which equals \(1 \times 10^{-2}\) % or 0.1 %.

c) The first abundant fossil evidence does not appear until the beginning of the Cambrian period (540 million years ago). What percentage of geologic time is represented by abundant fossil evidence? The percentage is \(6 \times 10^9\) yrs divided by \(5 \times 10^9\) yrs x 100% = 1.2 x 10% or 12%.


Answers to Earth System Questions

1. The once-living tree was petrified ("turned into stone") as the small internal cavities of the original wood were filled with precipitated mineral matter deposited by groundwater moving through the pores. The tree was originally a part of the biosphere and then it was buried by volcanic ash from magma that came from within the solid Earth. The atmosphere was not only the medium that carried the ash but also provided the precipitation that removed minerals from the ash once it settled to Earth. As groundwater, a part of the hydrosphere, moved through the cavities of the wood, the dissolved minerals were deposited in voids within the wood and the tree was petrified.

2. To produce the unconformity, sediment was originally deposited horizontally, tilted by crustal disturbance, uplifted, and eroded by wave action or running water. The area was then submerged, and new horizontal sediment was deposited on top of the inclined layers.

   Yes, all the spheres of the Earth system could have been involved. For example, the solid Earth provided the forces to tilt the sedimentary layers, the atmosphere supplied the water, the hydrosphere was associated with deposition of the sediment and subsequent wave erosion, and the biosphere could have supplied some of the sediment in the form of seashells.

   Earth’s internal heat source provided the energy to deform the sedimentary layers during mountain building. The Sun, the external heat source, furnished the energy for the ocean’s waves, tides, and currents that are responsible for the movement, deposition, and erosion of the sediments.

Lecture outline, art-only, and animation PowerPoint presentations for each chapter of *Earth Science, 13e* are available on the IRC DVD (ISBN 0321720253).
1. \(a = \text{weather}, \ b = \text{climate}, \ c = \text{climate}, \ d = \text{weather}, \ e = \text{weather}, \ f = \text{climate}, \ g = \text{weather \ and \ climate}, \ \text{and} \ h = \text{weather.}\)

2. Following a major volcanic eruption that sends huge volumes of debris and gases into the atmosphere, global temperatures tend to decrease over a period of several months to perhaps a year or two. The volcanic debris and aerosols (primarily droplets of sulfuric acid) serve to block and reflect a portion of the incoming solar radiation, thus reducing the amount of heat energy that reaches Earth's surface.

3. a) It would take a little over three breaths at the top of Mt. Everest to equal the same amount of air your lungs would receive with one breath at sea level. b) At an altitude of 12 kilometers, approximately 80% of the air's mass is below you.

4. Since the layers of the atmosphere are defined by temperature, the most useful instrument would be a thermometer. A barometer would also be somewhat useful since the layers roughly correspond to approximate altitudes. However, temperatures (and their corresponding altitudes) will vary seasonally, so temperature is the only definitive method for accurately locating each layer.

5. 24,900 miles / 24 hours = 1038 miles/hour. If Earth's rotational speed were to slow down, daytime high temperatures would be higher and nighttime low temperatures would be lower.

6. The Earth would be tilted at an angle of 40°. If this were the actual tilt of the Earth's axis, seasonal variations would be more extreme than they are now—warmer summers and colder winters in both hemispheres.

7. Despite the long period of solar radiation continually reaching the North Pole, the temperatures never get very warm because the sun angle is quite low and never gets above 23 1/2° during this entire time, thus the intensity of solar radiation is always low as well.


9. An increase in total albedo to 50% would undoubtedly lead to lower surface temperatures. The additional 20% would result in less radiation available to heat the surface and resulting lower temperatures.

10. The red line represents Urbana, Illinois, whereas the blue line is San Francisco. Urbana, located in the interior of the continent, would experience a much greater range of temperatures since sun angle is the primary determining factor. San Francisco, located along the coast, would receive the same amount of solar radiation as Urbana, but the effect of being located next to the ocean would result in a much lower temperature range.

11. Clear skies during both the day and night would produce the greatest temperature range. Cloudy skies during both the day and night would produce the smallest temperature range.

12. The differential heating of land and water would produce a milder climate since the location is along the coast. Water requires more heat energy to raise the temperature of water and it also takes much longer to cool down, hence locations along the coast experience a moderating effect. The latitude appears to be a tropical or subtropical location, so the sun angle would be higher year-round with more heating at the Earth's surface. Altitude would have no effect on climate since the location is at sea level.

Answers to Earth System Questions
b. Layers of freezing rain are caught in up- and downdrafts in the cloud

c. Pellets fall to the ground when they become too heavy

d. Rime
   1. Forms on cold surfaces
   2. Freezing of
      a. Supercooled fog or
      b. Cloud droplets

D. Measuring precipitation

1. Rain
   a. Easiest form to measure
   b. Measuring instruments
   1. Standard rain gauge

2. Snow
   a. Depth
   b. Water equivalent
      1. General ratio is 10 snow units to 1 water unit
      2. Varies widely
      3. Radar is also used to measure the rate of rainfall

Answers to “Give It Some Thought”

1. a) liquid  b) water vapor  c) water vapor  d) hexagon or hexagonal shape

2. The steam is actually in the liquid state. Water is evaporating out of the coffee cup and as it rises it cools and condensation into tiny liquid droplets occurs—hence the steam is actually tiny liquid droplets.

3. a) Perspiration cools our skin by evaporation. As the liquid evaporates, it absorbs heat energy from our body surface, which it turns cools our bodies down. b) Phoenix. The much lower dew point temperature allows for a much greater rate of evaporation, so it would be easier to stay cooler by perspiring.

4. Evaporation of the liquid in the cup will slow the warming process as it requires heat energy.

5. 45 grams of water vapor per kilogram of air.

6. a) Bismarck  b) Phoenix  c) Bismarck  d) Phoenix

7. Around 5:00 to 6:00 a.m.

8. a) B: temp = 17°, dew point = 17°; C: temp = 12°, dew point = 12°; D: temp = 7°, dew point = 7°; E: temp = 17°, dew point = 7°; F: temp = 27°, dew point = 7°; G: temp = 37°, dew point = 7°  b) 1 km. c) Temperatures are warmer on the leeward side due to the air warming at the dry adiabatic rate as it descends. d) The water vapor content decreased as the air ascended over the mountain as moisture was lost due to condensation. e) Lush vegetation on the windward side and dry, desert conditions on the leeward side. f) Cascade Range of the Pacific Northwest or the Sierra Nevada mountains in California.

9. 12000 m x 8000 m x 8000 m = (7.68 x 10^{11} m^3) x 0.5 = 3.84 x 10^{11}/3785 = 101,453,104 gallons.

10. Cloud droplets become the size of raindrops by the Bergeron and the collision-coalescence processes.
Moisture, Clouds, and Precipitation

11. Radiation fog forms mainly on nights because the lack of clouds allows for more cooling of surface air (due to radiational cooling). Consequently air temperatures are more likely to reach the dew point, resulting in fog.

12. The storm traveling through Nebraska, Iowa, and Illinois will likely produce a deeper snowfall. The air temperature of 26° would contain more water vapor than the same storm as 16° and therefore more snowfall would occur.

13. 1.3 inches / hour x 2.5 hours = 3.25 inches.

14. Rain gauges have the advantage in that they do not require any instrumentation or electrical components and they are much less expensive. The disadvantages are that errors can occur if the rain gauge is improperly placed and also they are not very accurate in windy conditions.

Answers to Earth System Questions

1. Although only a few hundred kilometers from the Pacific, the Great Basin desert of the western United States is situated on the eastern side of the imposing Sierra Nevada range, which acts as a moisture barrier for the region. Without the geologic evolution of the mountains to the west, the Great Basin region would not be located in a rainshadow and hence would have a much different climate.

Because precipitation is scanty, drainage is essentially interior, infiltration rates are often high, and the region has high evaporation, no major rivers have their source in the Great Basin.

2. Although the pattern of monthly temperature changes for each place is similar, Flagstaff, at the higher elevation, has cooler temperatures and more precipitation owing to orographic lifting. As a consequence of these differences, vegetation surrounding Phoenix is typical of a dry desert, whereas that in Flagstaff is characteristic of the Colorado Plateau, with vegetation of broadleaf evergreen and dwarf shrub variety.

3. (a) An increase in elevation often brings more precipitation, especially on windward slopes.

(b) A decrease in the area covered by forests and other types of vegetation would reduce precipitation because less moisture would be added to the atmosphere from plants.

(c) The immediate response to lowering ocean-surface temperatures would be an increase in precipitation as global temperatures fell. However, eventually, the lower water temperatures would result in less evaporation of water to the air and a drop in precipitation.

(d) Winds blowing more frequently from an adjacent body of water would increase the amount of precipitation as more moisture was brought to the area.

(e) A major long-lasting episode of global volcanism would at first produce more precipitation as the atmosphere cooled. Eventually, less precipitation would fall owing to lower evaporation rates as a consequence of cooler temperatures.

Lecture outline, art-only, and animation PowerPoint presentations for each chapter of Earth Science, 13e are available on the IRC DVD (ISBN 0321720253).
Air Pressure and Wind

Answers to “Give It Some Thought”

1. 29.92 inches x 13.5 = 404 inches high.

2. Kansas would have the highest wind speeds because the pressure gradient force is greatest there (closest spacing of isobars).

3. A strong pressure gradient. A higher pressure gradient would produce higher wind speeds on average as the air is rushing more quickly from areas of higher pressure into areas of lower pressure.

4. The sailboat would move due south. Without a rotating Earth and the resulting Coriolis effect, the only factor affecting the wind would be the pressure gradient force. Higher pressure at the colder North Pole would move towards the lower pressures at the equator in a north to south direction.

5. Southern Hemisphere. The hurricane is rotating in a clockwise direction, which indicates a low-pressure system in the Southern Hemisphere.

6. Winds are likely to get stronger. As divergence aloft exceeds the air converging at the surface, the air is pulled into the low-pressure system faster, resulting in faster wind speeds.

7. The “inches” refer to the level of mercury in a barometer, an instrument for measuring air pressure. The level of the mercury rises or falls, depending on the weight of the air present in the atmosphere (i.e., higher levels = a greater weight of air present). The fact that the mercury level is increasing indicates higher pressures in the atmosphere. Higher pressure is caused by sinking or stable air, and this creates conditions of lower relative humidity and clear skies.

8. Directly west of a cyclone in the Northern Hemisphere would be characterized by north winds due to the counterclockwise rotation around the low. Directly west of an anticyclone would have just the opposite situation—south winds.

9. It is most likely a cool breeze blowing from the water onto the land. Differential heating of the land and water throughout the day produces rising air over the hotter land and sinking air over the cooler water. The result is a local pressure gradient with low pressure over land and high pressure over water; hence the winds blow from the water onto the land.

10. The prevailing winds are blowing from the northeast and east, therefore the runways should be oriented southwest to northeast if at all possible. You might find a wind rose like this in Hawaii or perhaps the Caribbean as both locations are located in the belt of northeasterly trade winds.

11. Map A is July and map B is January. Higher rainfall would occur associated with low pressure, which is more prevalent during the summer over land in the Northern Hemisphere (map A) and during summer over land in the Southern Hemisphere (map B).
Weather Patterns and Severe Storms

1. Strength of storm (the most important factor)
2. Size and population density of the area affected
3. Shape of the ocean bottom near the shore
   a. Saffir–Simpson scale ranks the relative intensities of hurricanes
   b. Categories of hurricane damage

1. Storm surge — large dome of water 65 to 80 kilometers (40 to 50 miles) wide sweeps across the coast where eye makes landfall
2. Wind damage
3. Inland flooding from torrential rains

Answers to “Give It Some Thought”

1. a) In the late autumn and early winter, the cP air from Canada blows across Lake Superior and picks up a considerable amount of moisture from the warmer lake waters. The saturated air cools when it hits the leeward shore (where Marquette is located) and falls as snow in the areas south and east of Lake Superior. Thunder Bay, located on the windward shore, received much less snow for this reason. b) The band of heavy snows east of Pittsburgh and Charleston are caused by lifting of air onto the higher Appalachian Mountains. The moist air rises and cools to the dew point as it is forced upward, resulting in increased snowfall in the higher elevations.

2. A wintertime cP air mass would be colder than a wintertime mP air mass. The differential heating/cooling of land and water is such that land cools off much more than does water. Therefore, in the winter, the air that originates over land in polar regions is going to be much colder than the air over water at higher latitudes.

3. “Rain long foretold, long last” refers to a warm front. Warm fronts move quite slowly compared to cold fronts and long before the warm air arrives it is preceded by a long period of increasing cloud cover that is followed by a long period of rain, hence the rain long foretold, long last comment. “Short notice, soon past” refers to a cold front. Cold fronts move much faster and the clouds arrive shortly before or with the intense, short-lived rainfall—the clouds give short notice and the rain will soon be past.

4. Not necessarily. The term cyclone refers to a low-pressure region and it can refer to a relatively weak storm system, a much stronger storm system, a tropical storm or even hurricane, and even a tornado. So using the phrase “cyclone” requires much more information to decide whether or not seeking shelter is necessary.

5. a) City A = northwest, City B = southwest, City C = east-southeastern. b) City A and C = cP, City B = mT. c) cold front = lower left line, warm front = lower right line, occluded = upper line. d) City A = rising barometer, City C = dropping or falling barometer. e) City A is coldest, City C is warmest.

6. The higher number of tornadoes in the 1990s and 2000s is probably the result of more amateur storm spotters watching the skies and also perhaps to the improved technology of Doppler radar.

7. a) four, b) Tropical depression, tropical storm, hurricane. Gaston received its name when it became a tropical storm. c) No, the greatest storm surge and highest wind speeds will occur on the eastern side of the hurricane, due to the counterclockwise rotation and the direction of movement. d) The greatest threat to life and property in Dallas would be flooding from heavy rainfall and wind damage, perhaps even from tornadoes.
8. a) Wind speeds would have been higher on Thursday because the barometric pressure was much lower, hence the pressure gradient would have been greater. b) Approximately 400 miles. The speed would have been 350 miles/24 hours = 14.6 mph.

Answers to Earth System Questions

1. High snowfalls on the leeward shores of the lakes occur when the atmosphere, hydrosphere (the Great Lakes), and solid Earth interact. This lake-effect snow develops during autumn and winter as cold eP air travels over the warm lakes, acquires large quantities of moisture from the water, and becomes humid and unstable. The result is often heavy snow showers over the cooler land on the downwind shores of the Great Lakes.

2. The most devastating damage from a hurricane is caused by the storm surge. As the water moves over low-lying land, loss of life, destruction of buildings, and severe erosion are possible. Wind damage can affect a much larger area than the storm surge, often uprooting trees and destroying buildings. Heavy rains may also cause extensive flooding and severe erosion hundreds of kilometers from the coast. Following a hurricane, it may take years for the eroded land, disrupted drainage network, and destroyed natural vegetation to reestablish or be repaired.

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World Climates and Global Climate Change

1. Mean temperature of the warmest month is below 10°C
2. Enduring cold
3. Meager precipitation
4. Two types of polar climates
   a. Tundra climate (ET)
      1. Treeless climate
      2. Almost exclusively in the Northern Hemisphere
      3. Severe winters, cool summers
      4. High annual temperature range
   b. Ice cap climate (EF)
      1. No monthly mean above 0°C
      2. Permanent ice and snow

F. Highland climates
1. Usually cooler and wetter than adjacent lowlands
2. Great diversity of climatic conditions
3. Best described by the terms variety and changeability

V. Human impact on global climate
A. Humans have been modifying the environment over extensive areas for thousands of years
   1. By using fire
   2. By overgrazing of marginal lands
B. Most hypotheses of climatic change are to some degree controversial
C. Global warming
   1. Water vapor and carbon dioxide absorb heat and are largely responsible for the greenhouse effect of the atmosphere
   2. Burning fossil fuels has added great quantities of carbon dioxide to the atmosphere
D. Response of the atmosphere
   1. Global temperatures have increased
   a. Balance of evidence suggests a human influence on global climate
   b. Globally averaged surface temperature is projected to increase by 1.4° to 5.8° by the year 2100

2. The role of trace gases
   a. Atmospheric trace gases
      1. Methane
      2. Nitrous oxide
      3. Certain chlorofluorocarbons
   b. Absorb wavelengths of outgoing Earth radiation
   c. Taken together, their warming effects may be nearly as great as that of carbon dioxide

VI. Climate feedback mechanisms
   A. Possible outcomes of altering the climate system
   B. Two types
      1. Positive-feedback mechanisms reinforce the initial change
      2. Negative-feedback mechanisms produce results that are the opposite of the initial change and tend to offset it

VII. Some possible consequences of global warming
   A. Altered distribution of the world’s water resources and the effect on the productivity of agricultural regions
   B. Rise in global mean sea level
   C. Changing weather patterns
      1. Higher frequency and intensity of hurricanes
      2. Shifts in the paths of large-scale cyclonic storms
      3. Changes in frequency and intensity of heat waves and droughts

Answers to “Give It Some Thought”

1. Answers will vary depending on which components are chosen. Also, more than one type of interaction is possible with various components.

2. a) Changes in the biosphere, such as deforestation on a global scale, are capable of producing changes in the climate system. Removal of significant amounts of vegetation will increase the amount of carbon dioxide in the atmosphere, thus contributing to the greenhouse effect. b) Changes in global temperatures
will significantly impact weather patterns and the resulting droughts would affect vegetation. c) The biosphere records changes in the climate system with proxy data such as fossil pollen, corals, and tree-growth rings.

3. 1 = City B, 2 = City A, 3 = City C. Matching the cities to the rainfall data can be done by realizing that City 1 has summer in the Northern Hemisphere and City 3 has summer in the Southern Hemisphere. Figure 18.25 and the diagram from question #11 in Chapter 18 will be helpful in answering this question.

4. These land-controlled climates are found along the margins of the North Atlantic and North Pacific oceans because of the large continental landmasses in the Northern Hemisphere. Despite their proximity to the ocean basins, they are more influenced by the large, continental landmasses.

5. a) The polar and subarctic climates are classified as humid (even though they have low precipitation totals) because the colder air holds less water vapor and is therefore easily saturated.

b) Despite the long periods of perpetual sunshine, temperatures remain cold in polar regions because the sun angles are low, thus the amount of heat energy reaching Earth’s surface is low.

6. The greenhouse effect refers to the heating of the lower atmosphere by the absorption of terrestrial radiation by carbon dioxide and water vapor. These gases act much like the glass in a greenhouse in that they allow shorter wavelengths to pass through them while absorbing longer wavelengths. This effect is not the same as global warming—global warming may have many contributing factors and certainly an increase in the greenhouse effect could contribute to an increase in global temperatures. However, the natural heating of the lower atmosphere by various gases does not necessarily cause global warming.

7. The climatic patterns over a relatively short time period (a few years) are certainly not indicative of global warming or cooling. Natural climatic variability can bring about changes over several years that appear to be outside the “normal” patterns that people come to expect. In order to accurately determine if such changes are real, and even perhaps caused by other factors (including human activity), climatic data over a longer period of hundreds or thousands of years should be studied and evaluated.

Answers to Earth System Questions

1. Af: The wet tropics are characterized by constantly high temperatures and year-round precipitation. The most luxuriant vegetation found in any climatic region, the tropical rain forest, is located in this climate.

   Bwh: In this arid or desert climate, yearly precipitation is not as great as the potential loss of water by evaporation. Vegetation is sparse and adjusted to the low and infrequent rainfall.

   Dfc: In the subarctic climate, precipitation totals are low, with a maximum occurring during the warmer summer months. Although scrawny, the spruce, fir, larch, and birch trees in the taiga represent the largest stretch of continuous forest on the surface of Earth.

   ET: The tundra climate is a treeless climate found almost exclusively in the Northern Hemisphere. The amount of water vapor in the air is low, and precipitation, most abundant during the summer months, is scanty.

2. The burning of fossil fuels adds great quantities of carbon dioxide to the atmosphere. Carbon dioxide absorbs heat. Therefore, increasing levels of carbon dioxide in the atmosphere will result in warmer global temperatures. Global warming will result in a rise in sea level and a higher frequency and greater
a. Types of meteorites classified by their composition
   1. Irons
      a. Mostly iron
      b. 5–20 percent nickel
   2. Stony
      a. Silicate minerals with
      b. Inclusions of other minerals
   3. Stony irons—mixtures
   4. Carbonaceous chondrites
      a. Rare
      b. Composition
         1. Simple amino acids
         2. Other organic material
      c. May suggest composition of Earth’s core
      d. Give an indication of the age of the solar system

D. Dwarf planets

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1. Pluto is not visible with the unaided eye
   a. Discovered in 1930
   b. Long considered to be one of the “classical” 9 planets
   c. Much smaller than the terrestrial planets
   d. Planetary status was questioned in 1992 when another icy body was discovered beyond Neptune
2. New class of planets added to our solar system in 2006 called dwarf planets
3. By definition, dwarf planets
   a. Orbit the Sun
   b. Are round due to their self-gravity
   c. Not the only object to occupy their area of space

Answers to “Give It Some Thought”

1. Planet 1 – terrestrial because of size and density. Planet 2 – Jovian because of size and density. Planet 3 – neither because of distance and orbital eccentricity.

2. a) 3.7 Moons. b) 768,798 km/2 = 384399/12756 = 30 c) 109 Earths d) 150,000,000 km/1,390,000 = 108 Suns.


4. Crater C is oldest, then crater D, then crater A, then crater B is the youngest.

5. The removal of Ophelia would allow for the Epsilon ring to fall apart and the particles that comprise the ring system would begin to scatter outward.

6. a) 1) one tail – pointing up and to the right. 2) two tails – both pointing towards the left. 3) 1, maybe 2 tails pointing towards the lower left. b) If the Sun’s output were to increase significantly, the tails would become longer and perhaps the two tails at position 2 might merge into a single entity. c) If the solar wind ceased, the tails would decrease in size significantly, but the light from the Sun would still cause a tail to form. The comet would continue to exhibit a coma as it came close to the Sun.

7. 100,000,000,000/100,000,000 = 1,000 x 76 years = 76,000 years remaining.
Touring Our Solar System

8. Although the planets are quite small, they are orbiting in the region of the solar system that is occupied by the terrestrial planets. Mercury, the smallest terrestrial planet, is not much larger than our Moon so I would agree with the argument that the new bodies are actually planets because of their location. It would be difficult to classify the bodies as dwarf planets since Pluto and the other dwarf planets orbit well beyond the orbit of Neptune. It would be helpful to know the density of the new bodies to see if they are similar to that of the terrestrial planets (since Pluto is thought to have a low density), but the argument of them being planets makes more sense.

Answers to Earth System Questions

1. Of the four spheres, the atmosphere, hydrosphere, and biosphere are absent, or nearly absent (there is some indication of frozen water on the Moon), on the Moon. Because the Moon lacks these spheres, processes such as chemical weathering; erosion by wind, water, and ice; soil formation; weather in general; and sedimentation and lithification are all absent.

2. No water, in any state, has been detected on Mercury. Only scant water vapor has been detected in the Venusian atmosphere. The Martian atmosphere contains small amounts of water vapor, and the polar caps are made of water ice.

   If Earth’s orbit were inside the orbit of Venus, the liquid water currently found on Earth would be vaporized by the much higher temperatures and perhaps be driven away from the planet. Ice would not exist; and condensation, cloud formation, and precipitation would not likely take place. Without precipitation, runoff and infiltration would not occur.

   If Earth’s orbit were outside the orbit of Mars, the extreme cold would freeze all water, and only ice would exist. With only frozen water, there would be no precipitation, runoff, or infiltration. In essence, the hydrologic cycle would not exist.

3. If a large meteorite were to strike Earth, the results could be disastrous. A large impact would add great amounts of dust to the upper atmosphere and significantly reduce the sunlight reaching the surface. If the condition persisted, global temperatures would fall, precipitation patterns would be altered, and climate in general would be significantly changed. The eventual effect on the biosphere would be to cause large-scale extinctions, such as those that occurred in conjunction with the extinction of the dinosaurs about 65 million years ago.

Lecture outline, art-only, and animation PowerPoint presentations for each chapter of Earth Science, 13e are available on the IRC DVD (ISBN 0321720253).